OSMOSE

OPTIMAL SYSTEM-MIX OF FLEXIBILITY SOLUTIONS FOR EUROPEAN ELECTRICITY

Test results of the Flexibility Scheduler

D7.4

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Author(s)	Rui Pestana, Rui Pinto (REN), Ricardo Pastor, João Saragoça, Gonçalo Glória (R&D NESTER), José Simões, Paulo Viegas (EFACEC),
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Table of content

List of figures

List of tables

Abbreviations

Abbreviation	Meaning
aFRR	Automatic Frequency Restoration Reserve
AS	Ancillary Services
AVR	Automatic Voltage Regulation
BRP	Balance Responsible Party
CCGT	Combined Cycle Gas Turbine
DER	Distributed Energy Resource
DSR	Demand-side Response
DMS	Distribution Management System
DFR	Distributed Flexibility Resource
DSO	Distribution System Operator
EPES	Electrical Power and Energy System
EPSO	Evolutionary Particle Swarm Optimization
FCR	Frequency Containment Reserve
FS	Flexibility Scheduler
GUI	Graphic User Interface
mFRR	Manual Frequency Restoration Reserve
OPF	Optimal Power Flow
PCC	Point of Common Coupling
RES	Renewable Energy Source
RR	Replacement Reserve
SCADA	Supervisory Control and Data Acquisition
ScateX#	EFACEC's SCADA/DMS solution for electrical power utilities
ScOPF	Sequence-constrained Optimal Power Flow
SUC	System Use Case

TCL	Thermostatically Controlled Loads
TSO	Transmission System Operator
RTPSS	Real-time Power System Simulator

Executive Summary

This deliverable is the result of the activities of task 7.2 from Work Package 7 “Scaling up and replication” of OSMOSE project. This report compiles the work done in each one of the sub-tasks, namely, sub-task 7.2.1 “Specification of Flexibility Coordination”, sub-task 7.2.2 “Development of a Flexibility Scheduler” and sub-task 7.2.3 ”Lab Testing of the Flexibility Scheduler”.

Firstly, this report provides an analysis on the flexibility sources available in the power system, as well as on how the TSOs and DSOs should be coordinated to allow a joint and smooth exploitation of flexibility resources, focused on reactive power management in the TSO-DSO interface (i.e. coordinated voltage control and congestion management). For this last objective, several schemes for joint TSO-DSO coordination and activation of flexibility resources are presented.

The processes for joint coordination of flexibilities between TSOs and DSOs, the development of a flexibility marketplace and regulation are actually some of the main challenges that the system is facing. The innovative schemes for coordination between TSOs and DSOs and in terms of ancillary services (AS) market model for the exploitation of flexibilities at the interface between transmission and distribution networks are explored in this report. The analysis of the major benefits arising from adequate TSO-DSO coordination in the exploitation of flexibilities is also performed.

The Distributed Flexibility Resources (DFRs) are assuming an important weight in the secure and stable operation of the network with the undergoing changes in the power system. The activation rules for flexibility assets connected to the distribution network in the TSO-DSO interface should be clearly specified in order to guarantee an efficient and productive use of DFRs with the definition of the data that should be exchanged for the purpose. Therefore, the processes for flexibility activation in a jointly manner between TSO and DSO, depending on different time horizons and technical challenges, are explored in detail. The improvements related with the exchange of information between operators are a key element for the optimization of the control of the distribution-connected flexibilities, as for example information about the observability area.

Additionally, a set of requirements for flexibility activation and coordination at the operational planning stage for TSOs and DSOs is defined. These requirements are the base for the development of the innovative Flexible Scheduler (FS) tool. This tool aims to help the DSOs on exploiting DFRs taking into consideration the constraints and needs from the transmission grid side. Therefore, it is possible to benefit from a closer and systematic collaboration between operators, reducing technical losses and optimizing the usage of the flexibility sources available.

This report also describes in detail the overall architecture design of the Flexibility Scheduler tool, which is based on a Sequence-constrained Optimal Power Flow, as well as the description of the user interface used for the Flexibility Scheduler testing environment. The Flexibility Scheduler takes into consideration the operational network plan for the distribution network

and the observability area of the transmission network, optimising the losses and/or reactive power dispatch costs for the area under analysis.

The operational scenarios considered and network models from both FS tool and Real-Time Power System Simulator (RTPSS) are presented and described. Furthermore, the use case description and sequence diagram of the validation process, including the exchange of information between the TSO and DSO, are defined and explained in detail according to the standard IEC 62559-2. In the use case, multiple test cases considering a network model of a distribution network connected to two transmission substations are analysed. This model takes into account multiple topological scenarios, as well as distributed energy resources (i.e. wind, solar and hydropower) and different network assets (e.g. power transformers, capacitor banks) that will be the target of optimisation. The laboratorial test setup used to demonstrate and validate the FS tool is presented and decribed in detail.

The results from the simualtions performed for the 16 test cases considered in the validation process are presented and discussed. The outcomes from each test case are analysed and debated.

Table 1 presents a resume of the simulation results' validation in both platforms (FS tool and RTPSS).

Table 1 – Resume of simulation results

Test Case	FS tool – Voltage within the limits at the TSO-DSO interface	Losses (FS tool)	Objective function fitness (FS tool)	RTPSS – Voltage within the limits at the TSO-DSO interface – validation of FS tool results
1	YES	↗	↘	YES
2	YES	↘	↘	YES
3	YES	↘	↘	YES
4	YES	↘	↘	YES
5	YES	↘	↘	YES
6	YES	↘	↘	YES
7	NO*	↘	↘	YES
8	YES	↘	↘	YES
9	YES	↘	↘	YES
10	YES	↘	↘	YES
11	YES	↘	↘	YES
12	YES	↘	↘	YES
13	YES	↘	↘	YES
14	YES	↘	↘	YES
15	YES	↘	↘	YES
16	YES	↘	↘	YES

* Although the voltage limit was not respected, the values are marginally away from the minimum value (deviation <0,05kV).

The results show that the TSO-DSO coordination combined with the optimisation strategy from the Flexibility Scheduler is able reduce, in most of the cases, the overall losses in the distribution network, at the time that minimizes the flexibility activation costs for all cases. The solutions found by the Flexibility Scheduler include the redschedule of capacitor banks at both transmission and distribution substations as well as tap positions of distribution power transformers and generator's reactive redispatch. In average, the reactive losses reduction for the 16 test cases was around 8,5 Mvar. Similarly, the reactive activation cost were reduced in 1/3 in average.

Thus, this work contribute for the improvement of TSO/DSO coordination for the systematized and collaborative reactive power control, taking into consideration the benefits from mutual observability areas. The dissemination of this work will contribute for the promotion and design of innovative collaborative solutions between TSOs and DSOs, which allows a more efficient and integrated exploitation of their respective systems.

Additionaly, potential expansions for the Flexibility scheduler tool were identified for future development and implementation, that would allow to further exploit the developments done in this project.

1 Introduction

1.1 Background

This deliverable aims at addressing the problem of reactive power optimisation of the distribution network taking into consideration flexibility assets that are available at transmission level, exploring how they can be used for the joint optimisation of the TSO-DSO interface in a useful, secure and economical way. This delivebrale is focused on the activities of task 7.2 from Work Package 7 (WP7) “Scaling up and replication” from project OSMOSE.

The main objectives of task 7.2 are as follows:

- Identify the flexibility sources in the power system and specify their functionalities (T7.2.1);
- Describe innovative coordination methods for flexibilities at TSO-DSO interface;
- Define the main flexibility activation processes and rules;
- Set the requirements for the operations management systems of TSOs and DSOs;
- Develop and implement the Flexibility Scheduler (FS) overall architecture (T7.2.2);
- Demonstration, test and validation the FS tool in a laboratorial environment (i.e. RTPSS) (T7.2.3).

The distributed generation that is increasingly being connected to the distribution side, the mix generation that is becoming more volatile and non-dispatchable and consequently affects the security and operation of the network are some of the main reasons for studying a systematic and closer TSO-DSO cooperation for efficient exploitation of flexibility assets. These tasks want to focus on the key elements to a consolidated TSO-DSO coordination and an optimal jointly use of the flexibilities services, showing the benefits at operational planning time-frame for voltage control and congestion management purposes.

This deliverable intends to be a useful base of work for the following sub-tasks of task 7.2, once the specifications for the Flexibility Scheduler, that will be implemented, are already stated taking into consideration not only technical, but also technological aspects looking ahead for the needs of laboratory implementation and demonstration.

1.2 Report Structure

The deliverable addresses the following main topics:

- the characterization of the flexibility sources and specification of the requirements for flexibility activation and coordination between system operators;
- the description of the Flexibility Scheduler (FS) tool architecture;
- the explanation of the RTPSS laboratorial setup designed to validate the FS tool’s results, and;
- the presentation and discussion of the simulation results from the validation process of the FS tool.

In addition, it includes two dedicated chapters, with the introduction to the topic and the main conclusions from the developed work. Hereupon, this deliverable is organized as follows:

Chapter **one** introduces the deliverable, containing a background analysis of the topics addressed and their context according to the project timeline and execution plan, and the description of the report structure.

Chapter **two** introduces the characterisation of the flexibility sources that are available in the power system at different voltage levels. It introduces some innovative strategies for improvement of coordination between TSOs and DSOs mainly for flexibility purposes. The joint exploitation of the flexibility assets is addressed in this chapter as well as the auxiliary services market models that can fit for the flexibility coordination at TSO-DSO interface. It introduces the processes for flexibility activation at the TSO-DSO interface. It describes the main characteristics that the market and coordination between transmission and distribution operators should follow in order to ensure that the joint activation of flexibility sources occurs without considerable drawbacks. An analysis of the set of requirements for the coordination and activation of flexibility services between TSOs and DSOs is performed. The requirements for the flexibility scheduler tool are also presented as they were issued for implementation in the task 7.2.2.

Chapter **three** introduces the review of the FS tool fundamental requirements, including the general task requirements – identified as G(requirement number) –, the tool input requirements – identified as I(requirement number) –, the control variables requirements – identified as C(requirement number) –, and the output requirements – identified as O(requirement number). A specific section addressing the purpose of the FS tool for congestion management is also included. The ScOPF application is also addressed and includes the mathematical formulation of the presented ScOPF, and overview of the sequential approach of the methodology developed, and the main inputs and outputs of the ScOPF tool. The definition and explanation of the integration process of the FS tool in the ScateX#, the industrial solution that EFACEC developed for SCADA systems applications in the Electrical Power and Energy System (EPES) is also discussed. The FS GUI and comprehensive description over the main features and processes involved, such as the FS control window, the FS tool results, and the proposed actions execution are presented.

Chapter **four** describes the laboratorial setup for both FS tool and RTPSS, including the Python interface (i.e. script) developed to automatically configure and exchange information between patforms. It also describe in detail the use case and sequence diagram of the validation process.

Chapter **five** presents and discuss the simulation performed in the validation process, comparing the results achieved with both patforms (FS tool and RTPSS) for all the 16 test cases considered.

Lastly, chapter **six** shows the main conclusions and key takeaways from this deliverable.

2 Specification of Flexibility Coordination

This section aims at identifying the flexibility assets that are available in the energy system and explore how they can be used by both distribution and transmission operators in a useful, secure and economical way. This section is focused on the activities delevelped within sub-task 7.2.1 from OSMOSE Work Package 7 (WP7) “Scaling up and replication”.

The main objectives of sub-task 7.2.1 are as follows:

- Identify the flexibility sources in the power system and specify their functionalities;
- Describe innovative coordination methods for flexibilities at TSO-DSO interface;
- Define the main flexibility activation processes and rules;
- Set the requirements for the operations management systems of TSOs and DSOs;
- Define the prerequisites for the subsequent sub-task 7.2.2 and 7.2.3 for the Flexibility Scheduler tool development and demonstration

The distributed generation that is increasingly being connected to the distribution side, the mix generation that is becoming more volatile and non-dispatchable and consequently affects the security and operation of the network are some of the main reasons for studying a systematic and closer TSO-DSO cooperation for efficient exploitation of flexibility assets. These tasks want to focus on the key elements to a consolidated TSO-DSO coordination and an optimal jointly use of the flexibilities services, showing the benefits at operational planning time-frame for voltage control and congestion management purposes.

2.1 Assessment of Flexibility Sources in the Power System

2.1.1 Characterisation of Flexibility Sources

The flexibility is the capability to react to an external signal generating a change in the consumption or production as a service provided to the energy system. Thus, the large scale of controllable resources available at different voltage levels will play an important role in operating the network in a more flexible manner. These ‘flexibility resources’ are to be used to overcome constraints and increase network reliability and security.

In this chapter, the flexibility energy resources available in the power system was collected and characterized in terms of the flexibility services that they can provide.

2.1.1.1 Electricity generation

The base-load power, peak-load power, reserve power and regulation power described the use of power plants. Nevertheless, because of the evolution of the electric markets due to the liberalization and the massive increment of the DERs, the three first terms have lost their official roles. However, the mode of production in power system varies in electricity markets of different countries. For example, in some countries, the thermal power plant is used often for peak-load power production whereas in others it is used for base-load power production.

- **Base-load power***:* Base-load power means production capacity which is, almost, always available and the production amount of electricity is well programmable.

Examples of base-load capacity include hydropower, combined heat and power (CHP) and nuclear power.

- **Peak-load power***:* The annual operating time of peak-load power is normally short and it is used for load levelling for the purpose of reducing peak demand. Peak-load power can be supplied from hydropower plants or generated by gas turbines.
- **Reserve power***.* The reserve power replaces the base-load power during maintenance or failure of the power plant. The same power plant may be used for both the reserve or peak-load purposes.
- **Regulation power***.* The regulation power refers to production capacity in electricity markets or other flexible production by which the controllable electricity generation adapts to the variability of renewable electricity generation (wind, solar etc.) and consumption. The regulation capacity is used for hourly, daily or weekly regulation.
- **Minimum power***.* The regulation capabilities of a power plant will depend on the minimum power it can be operated, on the time it needs to start (starting time), and on its ramping power. Gas turbines and motors are the quickest to start. The speed of power change is clearly the highest for motors and their minimum power is low. Also steam and CHP plants can be utilised relatively quickly to increase the electricity production if they are already running and operating under the nominal power production. Slower power changes are possible also with nuclear power but they cannot be carried out continuously.

Hydropower

The regulation characteristics of hydropower are superior in comparison to other electricity generation technologies, particularly for high-speed regulation. Hydropower is the most profitable alternative in the hour time frame and quicker regulation. In addition, the main part of the daily power balancing is also carried out by hydropower. Exploiting the hydro capacity for high-speed regulation of the power system needs effective short-term water regulation and sufficient water stores.

The regulation capability depends on the adequacy of water, season, water system and type of turbine. The regulation causes changes in the water level downstream of the water system. The requirements of the licence also influence on the possibilities of regulation by setting restrictions to the water level changes and water flow rate. River hydropower can be exploited in power system regulation but its regulation characteristics are not as good as the ones of reservoir type hydropower. The regulation characteristics of the river hydropower can be improved by optimizing the utilization of the whole water system. Typical hydropower size and connection to grid are shown in Table 2.1.

Table 2.1 – Hydropower typical characteristics

Characteristic	Value
Typical unit size (for Italy)	20 units P > 200 MW 2000 units 200 MW>P>10 MW
Connecting grid level	P >10 MW connected to HV and smaller to MV.
Availability of control functions	For P> 10MW, frequency and voltage regulation
Efficiency	
old	87 %
new	92%
Starting times	
cold start-up	n/a
warm start-up	1-2 min
hot start-up	1-2 s
Minimum power	15-20 %
Speed of power change	high

Largest plants are between 200 MW - 500 MW. Plants with P >10 MW are connected to the HV network (Italy [1]) and smaller capacities are connected to the MV network. In each country there are also many small-scale hydropower plants connected to medium or low voltage networks.
Power plants have remote communication and control capability by fibre or wired connection for large and medium size plants and wireless connection for smaller plants. The parameters are possible to change via remote connections by service and mode control, but set points can be changed also locally. Smaller generators have usually fixed control.
Hydropower plants have usually continuous availability and simultaneous provisions for both voltage and frequency control. Local voltage and frequency control schemes are normally used. For the synchronous and asynchronous generators the voltage regulation is executed by excitation (Voltage Control and Excitation System), and frequency regulation by rotating speed of turbine (Governor).
The output power controllability for upwards regulation is 20%->100% and for downward regulation 100%->20% of nominal power (Italy). The constraints for regulation action are the minimum power of 15-20 %, size of water reservoirs and the regulation time (varying from 1-2 min as warm start to 1-2 sec as hot-start). The duration of control can range from minutes to some hours depending on water reservoirs.

Thermal power

Typical thermal power plants are condensing, combined heat and power, gas turbine, motor and nuclear power plants.

Thermal power plant

The starting time of thermal power plant depends on the time when the plant was last time in operation (cold start or warm start). The start-up of warm plant takes about two hours while the start-up of a cold plant takes more than 10 hours. If the maintenance of the start readiness of the power plant is neglected, the return to production may take months. Recent technological developments try to reduce the minimum power to around 20%, while also improving the ramping capabilities (allowing higher speed of the temperature rise) and reducing the starting time (by maintaining components' temperature during shutdown). Frequency and voltage control can be provided at the same time, given that the working point of the synchronous machine and of the prime mover are within the capability limits.

Combined heat and power (CHP)

The exact values for the speed of power change are difficult to give for CHP used for cogeneration of district heating or cogeneration of industry. The increase of the electricity power decreases the heat power or vice versa, in the case, the fuel efficiency remains constant. An advantage of using the cogeneration in the power system control is the long and continuous power regulation possibility, because the CHP plants are in operation due to the heat production. On the other hand, the control possibilities of the CHP plants for district heating vary according to the season and temperature. The cogeneration power plant for district heating is normally run according to the heat demand. Therefore, the possibilities to participate regulation power markets are low during the peak demand of heat power. In addition, during the summer time the cogeneration may be too expensive due to the low heat demand. It is possible to increase the flexibility of the cogeneration by heat storages, and in this way to decrease the dependence between electricity and heat production. The energy efficiency of the heat storages is over 90% in short term usage. The main driver of the cogeneration in industry is the heat production whereas the electricity is only the secondary product. However, it is possible to increase the flexibility and electricity generation of the industry and its value on the electricity market. Depending on the profitability of the industrial production, flexibility can be achieved by increasing the electricity generation at peak demand, when the price of electricity is high, at the expense of heat production to industrial processes.

Gas Turbine

Gas turbine power plants are available for control continuously. Frequency and voltage control can be provided at the same time, given that the working points of the synchronous machine and of the prime mover are within the capability limits. Concerning the output power controllability, gas-fired power plants are able of proving upwards and downwards regulation within 40% ->100% of nominal power. The technical minimum is 20-50% of nominal power and the starting phase takes (typical) 2-15 minutes. For the power factor controllability, the cosφ limits are 0,7-0,95 ind/cap. The other constraints are:

- excitation limits: field heating limit (max provision of reactive inductive power);
- under excitation limit (max consumption of reactive inductive power);
- armature heating limit (constraints with max active power output).

The duration of control may be from minutes to hours. Response time of control is 1-2 sec, using rotating DC exciter machine, and 0,15 - 0,3 s for static exciter.

Engine power plant

The technical control characteristics of the engine power plants are insurmountable in comparison to the other thermal power plants. The high maintenance charges of the motor power plants remain reasonable in the regulation power projects in the case the operation time is below 50.000 hours during the lifetime of the application. Engine power plants and gas turbines are normally used as system reserves.

Nuclear power plants

Nuclear power plants are normally run in full power because the capital costs are high but the operating costs are low due to the low fuel cost. Accordingly, downward power regulation provision is its main market. The need for downward regulation is most plausible during low demand. The regulation of the nuclear power plant succeeds best when the time and reduction of demand are foreseeable. Multiple changes of power production lead to non-optimal use of fuel. Any change of the operation state increases the risk of the failure occurrence and may lead to an unwanted shutdown. The generated power can be controlled by affecting to the nuclear reactivity, also known as to the number of nuclear fissions. The reactivity of the pressurised water reactor (PWR) is regulated by control rods and by the boron concentration of the reactor water. The reactivity of the cooling water reactor (CWR) is regulated by control rods and by the pumps recycling the reactor water. The technical characteristics of the fission reactors restrict the ability to regulate the nuclear power plant. The restricting factor for the speed of changes so called “xenon poisoning” affects to the stability of the power distribution in the nuclear core. The xenon stability after the power change is possible to achieve in about 40 hours. This restricts the possibilities for the power changes especially in the end of refuelling interval.

Control characteristic of the thermal power plants are shown in following Table 2.2.

Table 2.2 – Thermal power plants typical characteristics

Characteristic	Thermal power plant	Combined power plant (CHP)	Gas turbine	Engine	Nuclear
Typical unit size (Europe) MWe	600-900	60-400	10-300	1-20	1000-1600
Connecting grid level	HV/MV				
Availability of control functions	Frequency, voltage control, power balancing				
Efficiency					
old	40%	50%	32%	45%	33%
new (max)	47%	61%	38%	48%	37%
Starting time					
cold start-up	5-10 h	2-3 h	20 min	15 min	2 days
warm start-up	3-5 h	1-1,5 h	10 min	15 min	1 day 8-16 h, 60-100%
hot start-up	1,3-2,5 h	0,5-1 h	10 min	5 min	2-4 h
Minimum power	40%	40-50%	50%**	30%**	(15-)30%
Speed of power change	3-6 %/min	4-6 %/min	5-10 %/min	25%/min	

Wind power

Wind power, besides the sun power, is increasing most quickly in the world in these years. The modern wind power plants are able to active and reactive power control. The power of wind turbine is possible to control in three different ways: Pitch Controlled Wind Turbines, Stall Controlled Wind Turbines and Active Stall Controlled Wind Turbines.

- On a pitch controlled wind turbine the turbine's electronic controller checks the power output of the turbine several times per second. When the power output becomes too high, it sends an order to the blade pitch mechanism, which immediately pitches (turns) the rotor blades slightly out of the wind. Conversely, the blades are turned back into the wind whenever the wind drops again. During normal operation the blades will pitch a fraction of a degree at a time - and the rotor will be turning at the same time.

- (Passive) stall controlled wind turbines have the rotor blades bolted onto the hub at a fixed angle. However, the geometry of the rotor blade profile has been aerodynamically designed to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade which is not facing the wind. This stall prevents the lifting force of the rotor blade from acting on the rotor. Around two thirds of the wind turbines currently being installed in the world are stall controlled machines.
- Active stall wind turbine. Technically the active stall machines resemble pitch controlled machines, since they have pitchable blades. In order to get a reasonably large torque (turning force) at low wind speeds, the machines will usually be programmed to pitch their blades much like a pitch controlled machine at low wind speeds. When the machine reaches its rated power, however, you will notice an important difference from the pitch controlled machines: if the generator is about to be overloaded, the machine will pitch its blades in the opposite direction from what a pitch controlled machine does. In other words, it will increase the angle of attack of the rotor blades in order to make the blades go into a deeper stall, thus wasting the excess energy in the wind [15].

In addition of downward control also the upward control is possible to a certain extent, if the wind generation is first curtailed. Upward regulation requires stable wind conditions. The second option for upward regulation is to exploit momentarily the kinetic energy stored in the inertia of the rotor. This way the wind power plants can momentarily support the system frequency. The grid operators have given some requirements to wind turbines:

- The wind turbine has to be able to control the upper limit of its active power generation. By the controllable upper limit it is possible to ensure if needed that the active power production will not exceed the predefined level.
- The rising speed of the active power production has to be able to restrict so that the speed of power change is possible to the speed of 10 %/min of the nominal power.
- The active power generation downward has to be able from 100% -> 20 % of nominal power in 5 s.

Table 2.3 – Wind power plants typical characteristics

Characteristic	Value
Typical unit size	1 MW, 3 MW and 5 MW units and wind parks in scale of 200 MW.
Connecting grid level	P >10 MW connected to HV and smaller to MV.
Availability of control functions	For P> 10MW, frequency and voltage regulation
Output power controllability [MW] or % of nominal	For upwards regulation: possible only if the farm is operating below the available power output. For downwards regulation: possible (over-frequency regulation). Can be realized both at wind turbine and farm level (i.e. reducing the output of the wind turbine or shutting down one or more wind turbines in order to reduce the overall farm output
Constraints of controllability	Wind availability (for upward)
Rate of change [MW/s]:	Any for downward; limited to the wind available for upward
Response time	Within seconds
Power factor controllability [cosϕ limits]	0,95 cap –0,95 ind.
Duration of control	Continuous

Solar power

Solar-sourced electricity can be generated either directly using photovoltaic (PV) cells or indirectly by collecting and concentrating the solar power to produce steam, which is then used to drive a turbine to provide the electric power (CSP).

Photovoltaic (PV)

PVs are heavily subsidized today and thus cannot be used for balancing purposes. At least until the present supporting schemes continues. PV plants are available for voltage control so far but also frequency control is possible in the future. Voltage control is normally implemented locally by reactive/active power droop control, Q(U), P(U), cosφ(P), constant cosφ. No fixed, local or centralized frequency control schemes are applied for the time being but 50,2 Hz control and islanding detection are implemented. Flexibility for control scheme and parameter changes is locally possible and also the possibility of simultaneous provision of these functions.

The availability for output power and power factor control is continuous, but depends on solar radiation.

Output power controllability:

- For downwards regulation: 100-0%
- For upwards regulation: in case of upfront curtailment 0-100% possible.
- Duration of control [min]: continuous, depending on solar radiation
- Rate of change [MW/s]: ~10%/s
- Response time [s or min]: s

Power factor controllability [cosφ limits]: 0,9 - 0,9. (cap/ind).

- Constraints of controllability: 0,9 for plants <13,8 kVA and 0,95 for smaller plants
- Duration of control [min]: continuous, depending on solar radiation

PVs are subject to high changes depending on sun conditions. Therefore, it requires balancing power what affects balancing power market and to some extent electricity markets. PV plants have potential for aggregation to virtual power plant and participation in markets as for example balancing markets [2].

Concentrated Solar Plant (CSP)

The main control problems with concentrated solar plants are related to sun tracking and control of the thermal variables. Although control of the sun-tracking mechanisms is typically done in an open-loop mode, control of the thermal variables is mainly done in closed loop. Solar plants exhibit changing dynamics, nonlinearities, and uncertainties, characteristics that result in detuned performance with classical PID control. Advanced control strategies that can cope with these issues are needed for better performance and for decreasing the cost per kilowatt-hour generated.

2.1.1.2 Energy Storage

Electricity storage

Today we are witnessing an ever-increasing development of the electricity storage market. In fact, storage systems can provide a great help to the frequency and voltage control. The frequency of the grid may be altered by short-term, random fluctuations in demand or power provision, which requires either power or loads adjustment for recovering the load-generation balancing. This is a short-term service, primary frequency control (FCR) acting within seconds and with a minimum duration of 15 minutes. Charging and discharging of the storage system at the right moments (response within milli-seconds to seconds) can help to preserve the balance between consumption and generation [3]. Storages can also provide secondary (aFRR) and tertiary frequency control (mFRR and RR). In the figure below was classified the different storage categories for the power system.

The grid applications for storage technologies can be loosely divided into power applications and energy management applications, which are differentiated based on storage discharge duration. Figure 2-2 shown below, presents power ratings and discharge times required for different types of network services [4].

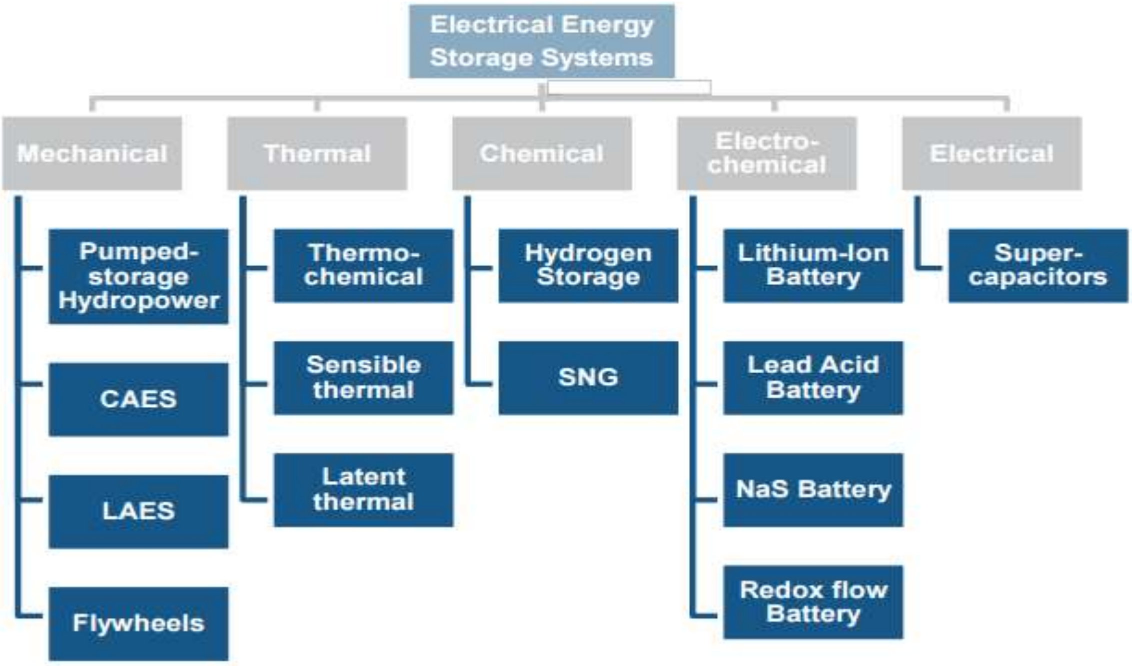


Figure 2-1 – Storage: different categories (FLEXNET)

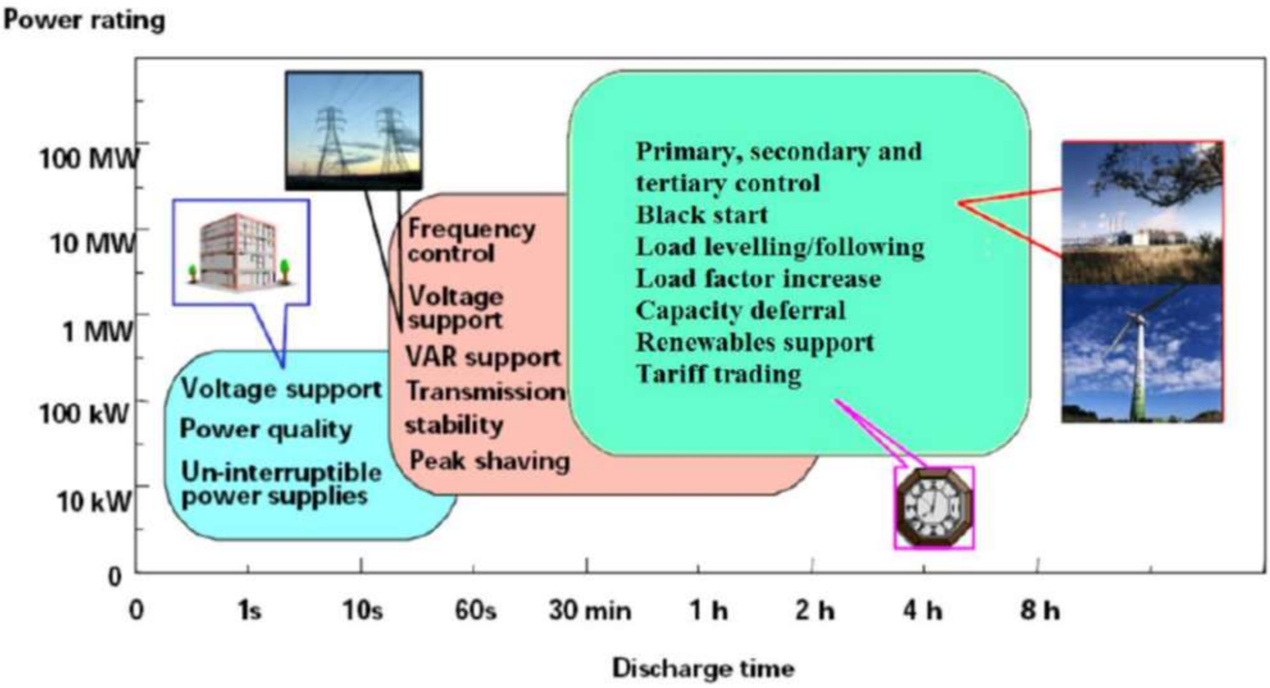


Figure 2-2 – Power ratings and discharge times required for different types of network services.

Batteries

Conventional battery categories today include the most technologically and commercially mature technologies, i.e. Lithium-ion, Lead Acid batteries (PbA) and nickel based batteries, including Nickel Cadmium (NiCd) and Nickel Metal Hydride (NiMH) batteries. All conventional batteries are commercially available on the market. High recyclability improves usability. Rechargeable type conventional batteries, which could be used in smart grids, are Lithium-ion, PbA, NiMH and NiCd type batteries. They are already used widely in end-user systems and in other grid applications. Batteries are providing energy storage for decentralized grids including renewables. They are essential to a vast range of applications from protecting control and switching systems and supporting UPS (Uninterruptable Power Supply) installations. Batteries are used to improve grid stability by acting as a buffer to compensate for the intermittent nature of renewable energy resources.

The main application areas for these batteries are:

- Photovoltaic energy systems
- Solar & wind hybrid systems
- Telecommunication networks
- Emergency power back-up and generator starting applications
- UPS

Lithium-ion batteries
Lithium-ion batteries are expected to contribute to the energy storage in grids due to fast charging, light weight, and high energy density in comparison to their counterparts. Lithium-ion batteries are becoming the energy storage of choice for future electric mobility applications. Foreseen prospects for Lithium-ion technology in larger applications are significantly growing with respect to other electrochemical storage systems and, particularly, in combination with more innovative integration of electricity grids within the transport sector.

Sulphur Sodium (NaS)
NaS battery systems provide solutions for energy management (peak shaving), reliability (outage) and power quality issues. These applications increase asset utilization, provide alternatives to meet peak demand and improve quality of service. Italy has two NaS battery applications with two 12 MW units and one 10,8 MW unit connected to HV grid. They are used for voltage and frequency control scheme with local and also centralized control. Output power controllability is 0%-100% in charge and 100%-0% in discharge mode and rate of change is 100%/s. In the power factor control, the duration and response time is up to 1 second. They are used in the balancing power market.

Vanadium Redox flow batteries
These are particularly suitable for large-scale utility applications such as peak shaving, back-up systems and applications coupled with renewables, such as large-scale photovoltaic fields. Vanadium redox batteries also have a short response time and good power density that makes them suitable for Power Quality applications.

Supercapacitors
Can offer advantages over other forms of energy storage. These include long cycle life, high charge/discharge rates, no overcharge, high cycle efficiency, low maintenance costs, reliability, and a rated voltage independent of the cell chemistry. Supercapacitors are in contrast quite sensitive to overcharging and present a very low energy density. Supercapacitors can perform various functions in electric grids for example: transmission line stability, spinning reserve, phase correction, harmonics suppression, area and frequency control. The characteristics of supercapacitors are the fast response time in milliseconds, high-energy efficiency (more than 95%), high power density and long shelf and cycle life.

Flywheels

Have high steady inertia and they can support ancillary services like frequency response, provide short time support for spinning reserves and standby reserves. One module is typically 2 kW - 250 kW. Low speed type flywheels have been used in industrial applications in Poland and their power size has been in the range from 120 kW to 2 MW. They are typically connected to low voltage and medium voltage networks and used for voltage control. Flywheels have the potential for effectively supporting Flexible Alternating Current Transmission Systems (FACTS) devices to maintain grid stability and reliability but main applications of flywheels in the smaller distributed power systems are for UPS systems. Flywheels in UPS applications typically provide power for 15 - 30 seconds that covers most power quality events and short power shortages. Flywheel systems can work as ride-through power sources with generators and can be used with batteries to cover short-duration events and save batteries that work for longer outages. Flywheel systems with power conversion electronics can serve customers as a controllable and automatic demand-side management option that can provide premium services, including power quality for sags or surges lasting less than 5 seconds, uninterruptible power supply for outages lasting about 10 minutes, and peak demand reduction to reduce electricity bills. For output power control, the response time is very short and the rate of change is for example 100 kW / 20 s.

Pumped hydro storages (PHS)

Pumped hydroelectric storage (PHS) can be pure PHS or pump-back PHS. Pure PHS plants rely entirely on water that is pumped to an upper reservoir from a lower reservoir, while pump-back PHS use a combination of pumped water and natural inflow to produce [5].

PHS plants are characterized by long asset life, typically more than 50 years, round-trip efficiencies of 70–85%, fast response time, usually in orders of seconds or minutes. Generally storage system requires less than 10 minutes to get to full capacity, or 10 to 30 seconds within 1 minute if it runs on standby. The discharge time can attain in some installations as much as 24 hours. Pumping and generating can follow a daily cycle, or weekly or even seasonal cycling in larger PHS plant. During long holding times, there are almost no losses in the storing process, which enables long-time scale storage. The storage capacity can attain several gigawatt hours. The storage power is dependent on the reservoir capacity and the head. As well known the hydraulic power available is proportional with flow and head. The average plant size in the EU-27 is about 270 MW, with the largest pumped-storage facilities being Grand' Maison plant located in Isère in France and the Dinowig power station in Wales, United Kingdom, developing each about 1800 MW.

Response time is dependent on mainly two time constants, the inertial time constants of rotational masses and the time constant for the hydraulic inertia. The first one is dominated by the generator and is usually of the order of 6 seconds. The hydraulic inertia is approximate 1 second, which is more or less a design criterion. The result is that the hydropower plants will stabilize at approximately 10 s. In normal operation Dinorwig pumped storage plant in UK, Wales can regulate 100 MW in 6.5 seconds, which equals 923 MW/min. The emergency response equals 2250 MW/min, while traditional hydropower plants will have trouble with meeting 200 MW/min.

PHS plants offer a significant technology base for regulation and can accommodate variable electricity generation. The main applications for hydropower storage are wholesale arbitrage and peak power capacity, energy balancing, the provision of tertiary and secondary reserves, forecast hedging, transmission curtailment, time shifting, load following etc. PHS can provide both up and down regulation and can assist with frequency regulation and voltage control. Due to quick start capabilities, PHS can provide black starts and provision of spinning and standing reserves. They are most suitable for transmission application rather than distribution. PHS plants are also used for seasonal fluctuations, being capable of providing hundreds of megawatts for many hours at a time. With regard to the future trends, the technical potential of new pumped hydro plants in Europe is very low, due to the high potential impact on the environment and to the necessity of an adequate altitude profile and geology. It is estimated that about 75% of the total potential for hydropower has already been developed in Europe. By 2030 more than 50% of the present installed capacity of hydro storage in Europe will have to be refurbished in any case due to aging. The capacity of hydro reservoirs in Europe is estimated to be approximately 180 TWh, of which, the Norwegian hydro reservoir capacity accounts for about 50% (84.3 TWh). The large hydropower capacity of Norway already supports the need for flexibility and storage of its neighbouring countries. The large deployment of wind power in the North Sea drives to the exploitation the Norwegian hydropower potential.

2.1.1.3 Demand response

Industrial loads

Processes where the electricity consumption can be modulated are suitable for demand response in industry. Typically modulation is subject to constraints as buffer management, throughput, production numbers. This type of flexibility is suitable for continuous operation. Examples of processes are many industrial installations e.g. electrolysis, reduce speed of a rolling mill installation, pulp and paper processes, extruder operation, etc. The typical unit size offered to markets varies from 100 kW to several MW. The minimum size for participation in reserves varies from 1 MW to 10 MW and for real time disconnection 20 MW in some countries. Industrial loads are normally connected to MV, HV or EHV network and the communication channel used is phone call, relay-connected, automated or manual dis-connectable loads. They are available for balancing, voltage control at feeder level and frequency support functions. Frequency control scheme can be local and also centralized by phone call or signal from the TSO for real time disconnection. Power controllability for upwards regulation depends strongly on the conditions, but it is typically limited. Downwards regulation is more suitable for fixed power agreed. The control is subject to constraints. Duration of power control may be from minutes to hours and response time can be from milliseconds to minutes. In the power factor controllability the cosφ limits varies typically 0,7–0,95 (cap/ind) and the duration of control may be from minutes to hours and response time is in the range of seconds. Affecting market mechanisms are reserve markets including frequency containment reserves, balancing, day ahead market, Balance Responsible Party (BRP) portfolio management, and having also potential for aggregation. Industrial loads are continuously available for control as far as the industrial process is running. An activation may result in an opposite reaction of the unit for some time but it depends on the industrial process.

Electric Vehicles

Electric vehicles (EVs) are commonly recognized as smart grid assets in addition to their environmental benefits due to their flexible charging time.

They can be utilized to balance power fluctuations caused by the high penetration of intermittent renewable energy sources in the transmission system level. The studies performed in US, UK and Denmark are summarized in the following three paragraphs, [6].

In [7] was analysed the potential profits of vehicle to grid (V2G) support by comparing it to existing ancillary services and found that participating regulation power market appears to be most promising and offers a substantial earning potential to EV owners. This is because: (a) it has the highest market value for V2G among the different forms of electric power (much higher than peak power, for example), (b) it minimally stresses the vehicle power storage system, and (c) battery-electric vehicles are especially well suited to provide regulation services. The electric vehicles can participate in the regulation services individually or by joining a fleet, the communication can be facilitated by power line and wireless control connections. It is advocated that fleets are more easily accommodated within existing electric market rules, which typically require power blocks of 1 MW. To fulfil the concept of V2G, each vehicle must have three required elements: (a) a connection to the grid for electrical energy flow, (b) control or logical connection necessary for communication with the grid operator, and (c) controls and metering on-board the vehicle. By predefining the wanted driving distance and the comfortable buffer, the electric vehicles can be connected to the grid and then participate the regulation service market. It is also learned that important variables for the V2G market are: (a) the value of ancillary services in the area, (b) the power capacity of the electrical connections and wiring, and (c) the kWh capacity of the vehicle battery. The amount of time the vehicles were on the road or discharged did not turn out to be a major variable. The results showed that battery electric vehicles fleets have significant potential revenue streams from vehicle to grid.

Other results and literature [8] indicate that it is feasible to participate in the electricity market and provide ancillary service to the gird. It is summarized and concluded from the literature that a new business entity, namely the EV fleet operator (FO) has been widely proposed capturing the new business opportunities arising from the variety of services EVs can provide, while contributing to the challenges solving of power system operator. Alternatively, names for an EV FO are used such as EV virtual power plant, EV aggregator, EV charging service provider or EV service provider (EVSP).

However, a large-scale application of EVs also means new loads to electric utilities, and undesirable peaks may exist in the distribution network when recharging the battery. Research has indicated that uncoordinated charging or price responsive charging bring congestion and voltage violation problems to the distribution system operators. The price responsive charging means the EVs may react to the wholesale/regulating power market prices in a correlated way since they react to the same electricity price. For example, when EVs postpone charging until the electricity price is at lowest, they will create a peak demand at that moment. To address the congestion problems introduced by the uncoordinated charging or price responsive charging, much research has been done to coordinate the interests of different actors such as optimize the charging cost of electric vehicles as well as respecting the hard constraints imposed by the distribution system operator. The proposed solutions include centralized control strategies [9], dynamic tariff based approach and market based control or transactive energy approach. All the proposals use the charging flexibility of electric vehicles.

In summary, it is safe to conclude that EVs can be used to provide services to various actors in a smart grid environment. However, it will mostly bring localized distribution problems. Therefore, knowing where those loads will occur, having the data and tools to analyse their impacts, and providing incentives for network-friendly charging patterns will be the key to both consumers and utilities realizing the potential of electric vehicles. Furthermore, how to handle the 'controller conflict' is also an important issue such as the activation requested from the TSO might introduce the congestion problem to the DSO level.

Household appliance and Thermostatically Controlled Load (TCL)

This category gathers all loads controlled by thermostat: e.g. Heating Ventilation and Air-Conditioning (HVAC), electric boiler, heat pumps, air conditioning, cooling. Various TCLs and household appliance can participates in demand response if the device is scheduled for operation with a due time and for example, the device has a fixed load profile like dishwashers, washing machines, tumble dryers, fridges, water heaters, space heating etc. It is expected a growing share of heat pumps applied for space heating and cooling. Several countries prohibited use of heavy fuel-based heating at households since 2017 (Norway, Denmark +) and support installation of heat pumps for space heating purposes. Heat pumps represent a great resource for DR schemes.

Their typical sizes of household appliances and TCLs are from 100 W to 2 kW and they are connected to low voltage network. Communication channel may be, for example, via smart meters using automated direct control of on/off switching or indirect with price signal (market based control) or manual (dis)connection. Household devices can be aggregated for voltage control at feeder level and also for frequency support. Frequency control scheme may be fixed or centralized control through directly sending external control signals to frequency-responsive household appliances. Fixed control means automated on/off switching of the device based on predetermined threshold frequency. The control scheme can be switched to consumer-based scheme that involves active participation from the demand side and consumers managing their household appliances on the basis of their own preferences. Direct load control and consumer-based scheme have a high possibility to be issued to consumers at the same time. Household appliances can be applied for power control of downwards regulation 100% of nominal power (switch off). In the case of fridges, the temperature of the fridge room may case constraints of controllability. The load profile and the "due time" are predefined. The starting time of the load can be chosen freely, but in some cases started load can be interrupted. Duration of the control may be from minutes to hours, but for fridges it depends on the thermal constant of the fridge and also on the amount of food located inside. Rate of power change is high (100 % power on/off) and the response time is in seconds including delays which may be determined by communication latencies. With regard to market mechanisms there are no business cases without aggregation and they depend strongly on business model. Participation is possible in the reserve, balancing and day ahead markets.

Control of household equipment may be available at discrete times, depending on the customers scheduling. An activation of control may result in an unwanted reaction of the unit for some time, which is known as rebound effect. For example, uncoordinated control may lead to synchronization of the fridges dynamics determining a correlated on/off cycles. In addition, load will be delayed, no extra consumption on an individual basis. On an aggregated level, however, a major activation/delay may result in a concentrated activity of the loads afterwards. Demand response activations may influence the overall annual energy consumption of the unit depending on consumers' energy consumption patterns and preferences.

With regard to the general trends until 2030, scheduled load is not used in any commercial demand response program yet. Now, direct load control and price-incentive scheme could achieve an average 8%-15% demand reduction during peak time durations for residential loads. With the active participation from the demand side, (or combined with direct load control/price-incentive scheme), the potential demand reduction would be hard to estimate [10] [11].

2.1.1.4 Other flexibility resources available for network operators

FACTS

FACTS (Flexible AC Transmission Systems) are power-electronics-based devices that are able to influence such parameters of AC system as impedances (shunt and series), current, voltage, phase angle and power flow. They are very effective in power flow control, voltage control, oscillation damping on various frequencies, voltage and transient stability improvement, etc.

Depending on the technology used in a particular device, both static and dynamic properties will be different. For the two most popular solutions, i.e. SVC and STATCOM, differences in static characteristic mean different achievable operational range in QV plane, wider and less dependent on Point of Common Coupling (PCC) voltage for STATCOM. Also in terms of dynamic performance, i.e. time response and stability of control STATCOM is superior to that offered by SVC, being approximately three times faster and more robust against system condition changes. In fact, the performance of both of these static compensators is highly dependent on system impedance, which continuously varies, and thus worst case response time is typically in the range of 30 – 80 ms. Typical rated power of a FACTS device can be as high as a few hundred Mvar, with almost symmetrical division into capacitive and inductive range. Usually, they have been installed in the HV transmission networks, but nowadays more and more often they are also present in the distribution systems, since (distributed) generation is also there and due to its volatile nature it needs support from flexible resources.

With great flexibility boost in the power system comes considerable cost of a FACTS device, thus a lot of attention has to be placed into the optimal location search for such a device. The selected location can often be optimal only for a set of the most critical or the most frequent grid conditions and contingencies, but not for all.

Static compensators (STATCOM)

Currently there are quite a few static shunt compensation devices operating in EHV and HV grid (both capacitive and reactive). The source of reactive power is either a reactor or capacitor. The typical unit size is around 15 Mvar, whereas max is 50 Mvar. Typically, they are connected to tertiary winding of 220 or 400 kV/110 kV transformers, and operating at MV level. Some of them are also connected to 110 kV and 220 kV voltage level. Their main goal is to maintain desired voltage level by feeding the grid with necessary reactive power. They are controlled by switch, so they can operate either at their nominal power, or switched off. The control signals come either from local station SCADA system, or from TSO/DSO dispatching centre. Control functions are maintained by station group voltage regulation system that controls both transformer tap changes and static compensation devices.

A direction of evolution for static compensation devices would be shift from mechanically-controlled (switch) to electronically-switched (thyristor) devices. This change will enable them to not only regulate the voltage level but also dynamically respond to grid operating state. The main advantage of thyristor switched devices over simple mechanically-switched is their near-instantaneous response to changes in the system voltage. Most of the currently installed devices (both reactors and capacitors) can be updated to thyristor switched ones and thus create either TCR - Thyristor Controlled Reactor or TSC - Thyristor Switched Capacitor.

The only present drawback of TCR and TSR is that they are more expensive than mechanically switched compensation devices. A combination of the two technologies (even in the same installation) can be utilized. In this case static VAR compensators are used to provide support for fast changes and the mechanically switched ones are used to provide steady-state reactive power compensation, however a lot of attention has to be put into optimal selection of device’s location to be upgraded to TCR or TSR.

Synchronous condensers

Synchronous condensers have already been known and used in the power system for more than a hundred years and after a few decades of reduced interest in favour of their power electronics counterparts, namely SVC and STATCOM, they now regain the attention, primarily as dynamic reactive power devices, and additionally due to synchronous inertia and short circuit power provision. Unit size can extend from a few tens of Mvar for industrial applications to several hundreds of Mvar in power system use, both as new dedicated units and conversions of synchronous generators of the phased-out nuclear power plants.

The main reason for synchronous condenser installation is reactive power output and/or voltage stabilisation. For conditions or contingencies including low voltage, SVC will perform much worse, as its reactive power output decreases in square with voltage. Synchronous condenser and STATCOM have better performance in this respect since reactive power decreases proportionally to voltage. The distinguishing feature of a synchronous condenser is its overloading capability allowing to keep the reactive power output constant for a few seconds when the voltage drops down. Another difference is that like any rotating machine, synchronous condensers inherently and constantly provide inertia support, which is of special importance in smaller (islanded) systems with high RES penetration. On the other hand, STATCOMs can also be controlled in a way that virtual synchronous inertia is obtained, but this is subject to time and magnitude limits.

Tap changing transformers

Tap changing transformers provide a means of voltage control, typically in the range of ±10%. It enables transformer linking networks at different voltage levels to keep the voltage in the required range, during undesirable voltage fluctuation usually caused by system load changes. Ratio adjustment is performed by changing the number of windings turns in the transformer either on the primary or the secondary winding. Number of turns is stepwise changed through the taps. This gives a step regulation of the transformer.

From point of view of tap changing facilities transformers can be divided into two groups:

- *On-load tap changing* transformers (OLTC), which allows the taps to be changed whilst the transformer is energised – under load without interruption.
- *Off-load tap changing* transformers (*No-Load Tap Changer* - NLTC, *off-circuit tap changer*, or *De-Energized Tap Changer* - DETC) – the tap changer requires to be de-energised whilst tap changing takes place.

A transformer may include a tap changer on each winding, for example, in distribution networks, a large step-down transformer may have an off-load tap changer on the primary winding and an on-load automatic tap changer on the secondary winding or windings. In practice, mainly for economic reason, changing the number of turns is performed on one side of the transformer. Because of lower current, the taps are usually situated on the high voltage side of the transformer and near the neutral end of the winding, where voltage with respect to ground is the least. In autotransformers, taps are also on the high voltage side but near common part of the winding.

Off-load tap changing transformers are commonly used in distribution MV network, where tap is usually changed manually and seasonally (e.g. twice year).

The OLTC transformers operating in EHV and HV substation are supervised by substation transformer control system within the scope of:

- maintaining the set (reference) voltage level at transformer substation busbars,
- maintaining the set value of reactive power flow through a transformer,
- turn-ratio control of a transformer.

The tap selection in under load tap changing transformers is automatic and controlled by assigned an individual regulator that typically can operate according to one of the following four regulation modes:

- voltage control on switching substation busbars at higher-voltage side of a transformer,
- voltage control on switching substation busbars at lower-voltage side of a transformer,
- control of reactive power flow through a transformer,
- turn-ratio control of a transformer.

The OLTC can be classified as mechanical, electronically assisted, or fully electronic. The tap selection in mechanical under load tap changing transformers operate by motors. The mechanical tap changer physically makes the new connection before releasing the old one using selector switches. To avoid creating high circulating currents a diverter switch to temporarily place a large diverter impedance in series with the short-circuited turns is used. Such motor-based OLTCs are characterized by a slow time response (tens of seconds) and low operating speed, short lifetime and heavy size. In order to improve these properties, two technologies are used: electronically assisted and solid-state OLTCs. Both technologies are inherently faster than the motor-based one. However, the differences in the model are mainly in the low-level logic of the electronic switches. These solutions prevents problems with open or short-circuit turns.

Electronically assisted tap changers are based on thyristors, which take the on-load current while the main contacts changeover from one tap to the next. This prevents arcing on the main contacts and lengthen lifetime and period between service and maintenance activities. This solution is more complex and requires a low voltage power supply for the thyristor circuits.

For the time being, no alternative to regulating transformers is expected. What is more, a possible way of controlling the voltage in LV distribution grids is by means of on load tap changer of a MV/LV transformer (OLTC MV/LV) in a similar way of how it is currently done for MV grids with HV/MV OLTC will be developing. The tap-changer will therefore continue to play an essential part in the optimum operation of electrical networks and industrial processes in the foreseeable future.

Phase shifting transformer

Phase shifting transformers are specially designed transformers for the purpose of changing voltage angle. When installed in series with a line or a transformer they can effectively control power flow in this element by changing voltage phase angle on one of the ends and thus changes.

$$P = \frac{U_1 U_2}{X} sin\ \delta \tag{2.1}$$

For this reason they are often installed in cross-border AC connections allowing for line overloading reduction and stability improvement. PSTs are installed on borders between Germany and Belgium, Germany and the Netherlands, Italy and Slovenia and are under construction between Germany and Poland.

With respect to PSTs' controllability, maximum phase shift $\pm\alpha_{max}$ is the main parameter characterising available control range. α_{max} is typically in the range of 20º – 40º. Resulting power flow change depends on network voltage level (EHV/HV) and the present power flow conditions in the power system; for instance, it can be in the level of 10 – 30 MW/deg for 400 kV network. The objective of the PST operation is to control the power flow in the tie lines in the medium-to-long term operation so the time regime for tap-changing operation is rather low. It takes 30 – 60 sec. for a tap to change and the following power change is immediate.

2.1.2 Flexibilities in Different Time Horizons

A qualitative characterization of the flexibility resources can be based on the effectiveness of the power generation in a specified time horizon as these factors determine the type of service they can provide. Note that the effectiveness is strongly related with the dispatchability of the flexible resource.

Three types of grid operations can be defined:

1. **Real time operation**. These are operations that act in real time, with horizon times ranging from tenths of a second to a few minutes, including services such as primary and secondary frequency control, related to the network stability.
2. **Operational Planning** have a time horizon ranging from a few minutes to hours. The services involved refer to restoring the power reserves of the real time services, and some examples are the tertiary frequency regulation and the day-ahead dispatching schedule.

3. **Long term Planning** are those activities of programming of the resources to be supplied to the electric network that can be programmed in terms of days and more, as are the schedule start-up of the power plants.

Table 2.4 – Flexible resources, time horizon performances vs. grid operations

Flexible resource		Real-time operation	Operational planning	Long-term planning
Electricity generation	Hydropower			
	Thermal power			
	Wind power	Up - Unsuitable Down - Suitabe		
	Photovoltaic	Up - Unsuitable Down - Suitabe		
Energy storage	Lithium-ion batteries			
	Sulphur Sodium			
	Vanadium Redox flow batteries			
	Supercapacitors			
	Flywheels			
	Pumped hydro storages			
Demand side response	Industrial loads			
	Electric Vehicles			
	Household appliance			
Other flexibility resources	STATCOM and FACTS			
	Synchronous condensers			
	Tap changing transformers			
	Phase shifting transformer			

	Indicates **very suitable** horizon time performances
	Indicates **suitable** horizon time performances
	Indicates **satisfactory** horizon time performances
	Indicates **unsatisfactory** horizon time performances
	Indicates **unsuitable** horizon time performances

In general, for the Electricity Generation resources, Hydropower and Thermal power are well suited for all the grid operational activities, but less effective are the Wind and Solar sources, due to their intermittent generation. For the Energy Storage resources, batteries are very well suited for the real time operations. The Demand-Side Response (DSR) devices, due to their latency, are not suited for the real time operations. More details about the Ancillary Services (AS) provision versus flexibility resources can be found in the following section.

2.1.3 Flexibilities in Addressing Different Technical Challenges

An interesting assessment about the capability to provide different Ancillary Services for DERs and for advanced power technologies was done in SmartNet project [12].

As it is shown in Figure 2-3, the best resources to provide frequency ancillary services are the storage systems, which have high performances and fewer constraints with respect to other resources. CHPs and industrial shiftable loads show high performances, due to the thermal storage system (CHPs) and the good monitoring and control (industrial processes). Wind turbines, Photovoltaic, EVs and curtailable loads have lower performance for long-duration ancillary services due to lower predictability. On the contrary, the shiftable loads (wet appliances) are more suitable for long time horizon due to the latency of the response. Regarding Thermostatically Controlled Loads (TCL), they can provide quite good capabilities from fast AS (FCR) to longer duration AS (FRR and even RR in some cases), which is linked to their thermal inertial of the TCL. More generally, loads are not well suited for voltage control services as they do not provide the mechanisms to change their reactive power output.

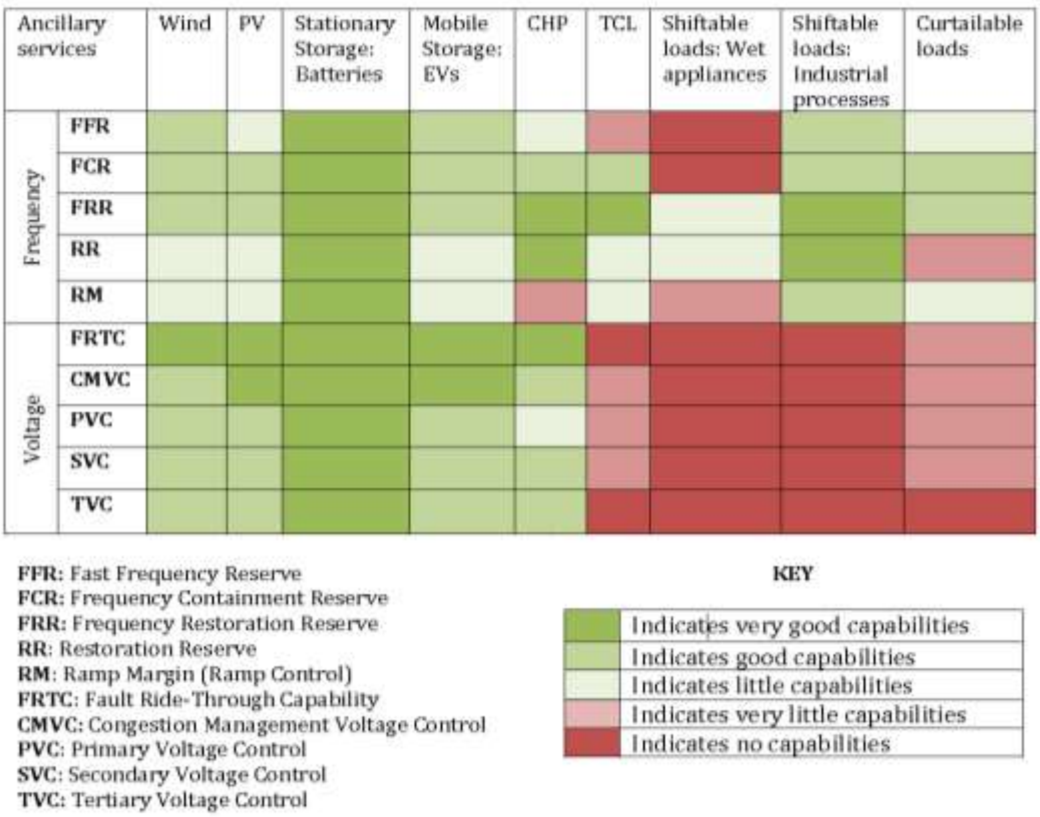


Figure 2-3 – Capability of DFRs to provide future ancillary services (SmartNet)

Advanced power technologies allow a better management of MV networks but also HV networks and is foreseen that in the future (Figure 2-4) can contribute more. Direct support for active power AS is provided only by MV-DC networks and Synchronous Converters. In fact, the use of DC networks allows a better management of the active power production and absorption from local resources. Besides, the use of one single power electronic interface allows a better flexibility and control with respect to multiple small converters.

From the point of view of indirect support, every FACTS can contribute to AS support. Indeed, they can be used for voltage management of MV networks, allowing a better exploitation of other resources providing ancillary services. The performance of this mechanism is strictly dependent on the characteristics of the distribution network so the impact is difficult to evaluate. However, from the point of view of voltage management all the resources which have power converters can support directly voltage (with different performances depending on the services for which they are designed). MV/LV OLTC and STS (Static Transfer Switch) are only able to provide indirect support as they are not able to exchange reactive power and they can only support the management of resources. In general, the flexibility provided by the power inverters guarantees high performances for all the voltage ancillary services.

In conclusion, FACTS devices can be used to sustain MV networks or to substitute aging devices with lower performances (e.g. D-STATCOM with respect capacitor banks). However, other benefits have to be taken into account during their installation. In fact, these devices can increase the active power flexibility from local resources and support directly the voltage of transmission system. Considering the increasing need of voltage flexibility in transmission system, due to the substitution of centralized and transmission grid connected generators by distributed ones, the potential flexibility from power electronic devices can be envisioned to support voltage.

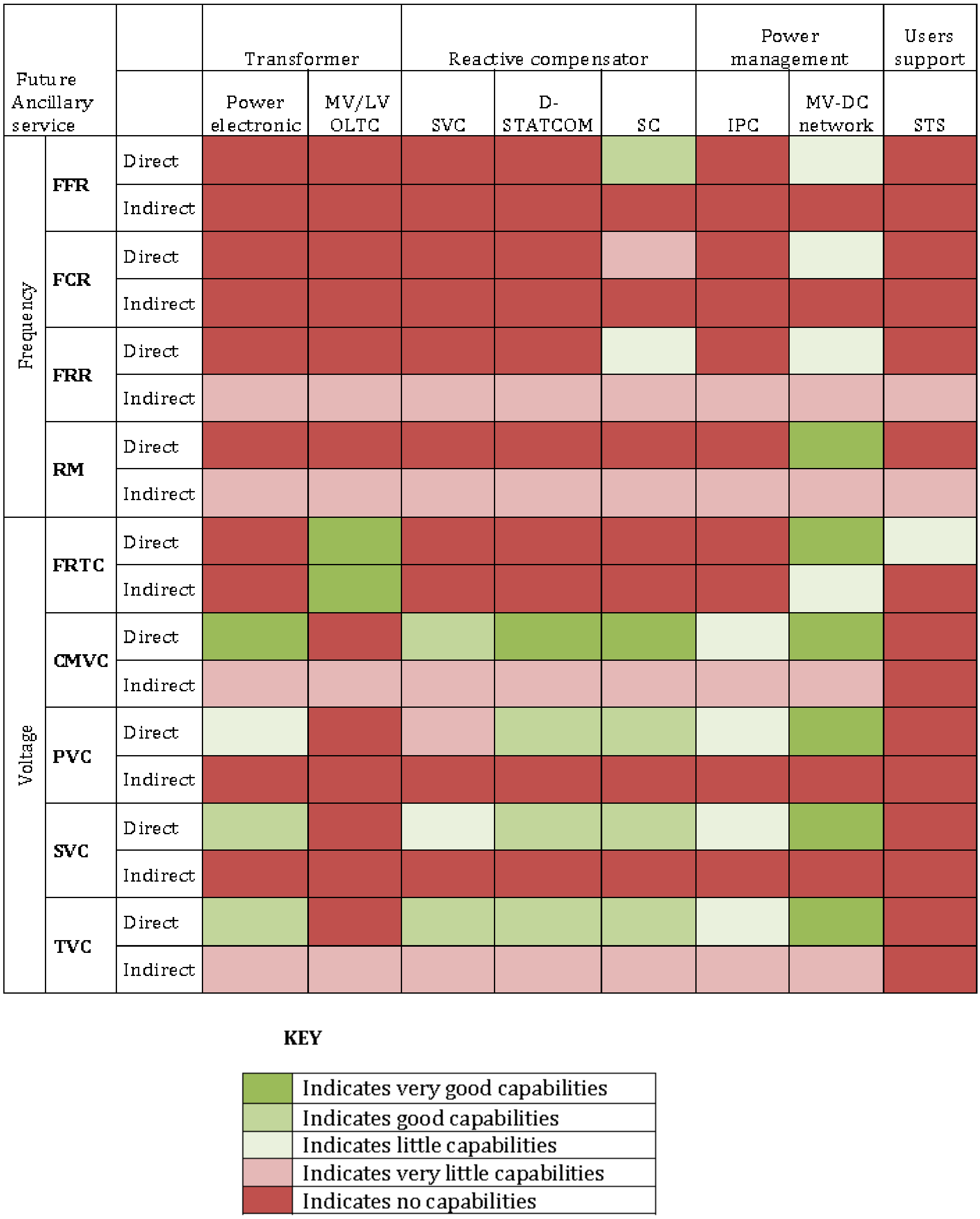


Figure 2-4 – Capabilities of Advanced power technologies to provide future ancillary services (SmartNet)

2.2 Innovative Coordination of Flexibilities at TSO-DSO Interface

2.2.1 TSO-DSO Joint Coordination of Flexibilities and Its Challenges

An evaluation of the benefit of the DSO-TSO cooperation was covered in the EvolvDSO project [13].

The transition of distribution networks towards a smart system which supports the successful integration of distributed renewable energy sources (DRES) and demand participation in the electricity system, requires an evolution of the role of DSOs with respect to the operation and management of the grid, as well as new tools to support these potential new roles.

EvolvDSO has investigated a limited number of services perceived as being particularly relevant in the near future by describing the associated business processes and their requirements using the use case methodology. Ten priority business processes designed to implement the key services associated have been identified.

Starting from the definition of the business use cases, mapped in each domain of a smart grid conceptual model, the innovative functions supporting the business processes, as well as their associated functional and non-functional requirements have been described in system use cases.

In particular, in the domain of the "DSO-TSO Cooperation" the correspondent business use case was identified as necessity of pushing to "Manage TSO request at different time horizons" from the network development activities and the Operational planning, to the real time operation. This business case was detailed with a certain number of System Use Cases (SUCs) (Figure 2-5), namely:

1. Forecasting functions of load and generation for MV distribution grids
2. Grid optimization to deliver active and reactive power profile to TSO
3. Estimate flexibility range of primary substation
4. Maintain primary substations profiles in real time operation and define emergency procedure actions under TSO request.

Once the list was finalized, the EvolvDSO project developed a set of innovative tools that implement the system use cases.

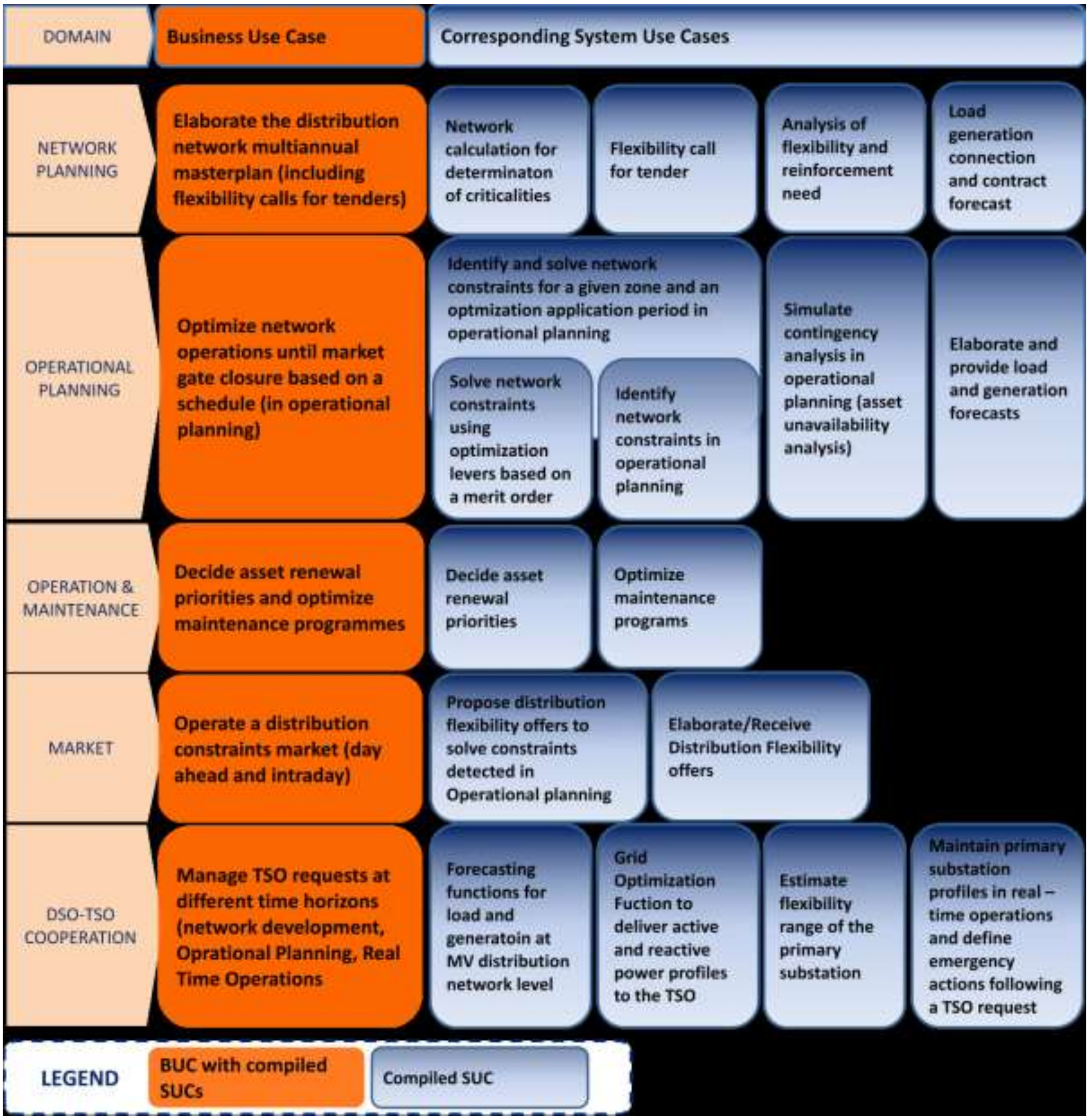


Figure 2-5 – Business and System use cases (EvolvDSO)

In this topic, following the EvolvDSO concepts, the project SmartNet[1] has addressed the theme of the possible ancillary services that the DSOs could provide. In fact, today, the resources from the distribution grid are starting to participate in the TSO ancillary services (AS) markets. However, the participation is still limited and there is a wide variety in products and rules across countries. DSOs use rarely flexible resources to solve local network problems. In case the TSO uses resources from the distribution grid, this service is mainly organized without any involvement of the DSO, which could potentially lead to problems in case of increasing volumes of distributed RES. The need for increased cooperation between system operators is

[1] SmartNet- "Basic schemes for TSO-DSO coordination and ancillary services provision – D1.3"

recognized by several stakeholders and the EU regulation (Network Codes) provides a first basic framework to develop further collaboration structures.

2.2.2 Innovative Schemes for Flexibility Coordination at TSO-DSO Interface

In SmartNet five coordination schemes are discussed that present different ways of organizing the coordination between system operators [14].

2.2.2.1 Centralized AS market model

The Centralized AS market model is the actual, most diffused, market scheme: TSO operates a market for both resources connected at transmission and distribution level, without extensive involvement of the DSO.

Characteristics	
Market design	There is one common market for ancillary services, operated by the TSO, for both resources connected at transmission and distribution level. There is no separate local market.
TSO role	The TSO is responsible for the operation of its own market for ancillary services. The TSO does not take DSO constraints actively into account. A separate process (system prequalification) could be installed to guarantee that the activation of resources from the distribution grid by the TSO does not cause additional constraints at the DSO-grid (e.g. congestion).
DSO role	The DSO is not involved in the procurement and activation process of AS by the TSO, except in the case that a process of system prequalification[13] is installed to guarantee that the activation of resources from the distribution grid by the TSO does not cause additional constraints at the DSO-grid (e.g. congestion). The DSO is not procuring local flexibilities in real-time or near to real-time.

Figure 2-6 – Centralised AS market model (SmartNet)

In summary, this scheme limits the involvement of the DSO to a possible role in the system prequalification process. To note that in exceptional cases, the DSO might want to include DSO grid constraints in the TSO market clearing process. Consequently, the DSO will need to provide the necessary data to the TSO or the TSO should have full observability of the DSO-grid.

2.2.2.2 Local AS market model

In Local AS market model, the DSO organizes a local market for resources connected at the DSO-grid and, after solved local grid constraints, aggregates and offers the remaining bids to the TSO.

Characteristics	
Market design	There is a separate local market managed by the DSO. Resources from the DSO grid can only be offered to the TSO via the DSO/local market and after the DSO has selected resources needed to solve local congestion. The DSO aggregates and transfers bids to the AS market, operated by the TSO. The DSO assures that only bids respecting the DSO grid constraints can take part in the AS market.
Role of TSO	The TSO is responsible for the operation of its own market for ancillary services, where both resources from the transmission grid and resources from the distribution grid (after aggregation by the DSO) can take part.
Role of the DSO	The DSO is the operator of a local market for flexibility. The DSO clears the market, selects the necessary bids for local use and aggregates and transfers the remaining bids to the TSO-market. The DSO has priority to use the flexible resources from the local grid.

Figure 2-7 – Local AS market model (SmartNet)

In sum, the Local AS market model deviates from the Centralized AS market model by promoting a local market. The implementation of such a market shifts priorities towards the DSO. All flexibility not needed/procured at the local market (where the DSO is the market operator) is sent to the central market (where the TSO acts as the market operator) in an aggregated form, taking into account that the distribution network constraints are respected (e.g. some local market bids could possibly not be transferred to the TSO if that would jeopardize the distribution grid operation). In this scheme, the DSO contracts and aggregates (already) aggregated bids.

2.2.2.3 Shared balancing responsibility model

In the Shared balancing responsibility model, balancing responsibilities are divided between TSO and DSO according to a predefined schedule. The DSO organizes a local market to respect the schedule agreed with the TSO while the TSO has no access to resources connected at the distribution grid.

Characteristics	
Market design	There is an AS market for resources connected at the TSO-grid, managed by the TSO. There is a separate local market for resources connected at the DSO-grid, managed by the DSO. Resources from the DSO-grid cannot be offered to the TSO-grid. DSO constraints are integrated in the market clearing process of the local market.
Role of TSO	The TSO is the operator of the AS market, limited to resources connected at the transmission level. The TSO is responsible for the balancing of the transmission grid.
Role of the DSO	The DSO is the operator of a local market. The DSO contracts local flexibility for both local congestion management and balancing of the DSO-grid. The DSO is responsible for the balancing of the DSO-grid, i.e. respecting the pre-defined schedule.

Figure 2-8 – Shared balancing responsibility model (SmartNet)

The Shared balancing responsibility model is the only coordination scheme where the TSO has no access to resources connected at the distribution grid. Flexibility from the distribution grid is reserved exclusively for the DSO, in order to fulfil its responsibilities with respect to local grid constraints and local grid balancing.

2.2.2.4 Common TSO-DSO AS market model

In the Common TSO-DSO AS market model, the TSO and the DSO have a common objective to decrease costs to satisfy both the need for resources by the TSO and the DSO. This common objective could be realized by the joint operation of a common market (centralized variant) or the dynamic integration of a local market, operated by the DSO, and a central market, operated by the TSO (decentralized variant).

Characteristics	
Market design	There is a common market for flexibilities for both TSO and DSO with both resources connected at transmission level and connected at distribution level. TSO and DSO are both responsible for the organization and operation of the market. DSO constraints are integrated in the market clearing process. Two alternatives are considered: (1) all constraints are integrated in one only optimization process that encompasses both TSO and DSO grid constraints (centralized variant), (2) a separate local DSO market for local grid constraints runs first (without commitment to the market participants) and communicates with an AS market operated by a TSO with transmission grid connected resources. The outcome of the second market communicates back to the first market to find the optimal solution to be communicated to the market participants (decentralized variant).
Role of TSO	The TSO and DSOs are jointly responsible for the market operation of the common TSO-DSO market (centralized variant) while they are jointly responsible for the final outcome of the two separate market runs (decentralized variant). The TSO is contracting AS services from both transmission and distribution. In practice, in the centralized variant, the joint responsibility could be organized by allocating the responsibility to a third party, under guidance of both TSOs and DSOs.
Role of the DSO	The TSO and DSOs are jointly responsible for the market operation of the common TSO-DSO market (centralized variant) while they are jointly responsible for the final outcome of the two separate market runs (decentralized variant). The DSO uses
	flexible resources from the distribution grid in cooperation and interaction with the TSO.

Figure 2-9 – Common TSO-DSO market model

In summary, the Common TSO-DSO AS market model could be seen as an extension of the Centralized AS market model (for the centralized variant) and the Local AS market model (for the decentralized variant). In the centralized variant, the optimization is still organized by aggregating both resources connected at transmission grid and distribution grid, but in this scheme, not only TSO grid constraints are integrated but also DSO grid constraints and possible local needs for flexibility are part of the common market. The decentralized variant differs from the Local AS market model in such a way that the DSO has no priority to use flexible resources from the distribution grid. The choice of which resources to be used by the DSO to solve local constraints will depend on the combined optimization of both needs for flexibility at distribution level and needs for flexibility at transmission level.

2.2.2.5 Integrated flexibility market model

In the Integrated flexibility market model, the market is open for both regulated (TSOs, DSOs) and non-regulated market parties (BRPs, CMPs), which requires the introduction of an independent market operator to guarantee neutrality. The Integrated flexibility market model promotes the introduction of a market where regulated (TSO and DSO) and commercial market parties (CMPs) procure flexibilities in a common market.

Characteristics	
Market design	The common market for flexibilities is organized according to a number of discrete auctions and is operated by an independent/neutral market operator. There is no priority for TSO, DSO or CMP. Resources are allocated to the party with the highest willingness to pay. There is no separate local market. DSO constraints are integrated in the market clearing process.
Role of TSO	TSOs are contracting AS services in a common market. TSOs can sell previously contracted DER to the other market participants.
Role of the DSO	DSOs are contracting flexibilities for local purposes in a common market. DSOs can sell previously contracted DER to the other market participants.

Figure 2-10 – Integrated flexibilities market model (SmartNet)

In sum, the Integrated flexibility market model proposes a market mechanism where available flexibility can be procured by system operators and commercial market parties under the same conditions. There is no distinction between regulated and liberalized actors. Market forces dictate how flexibility will be allocated. This allocation, however, will respect grid constraints at all voltage levels.

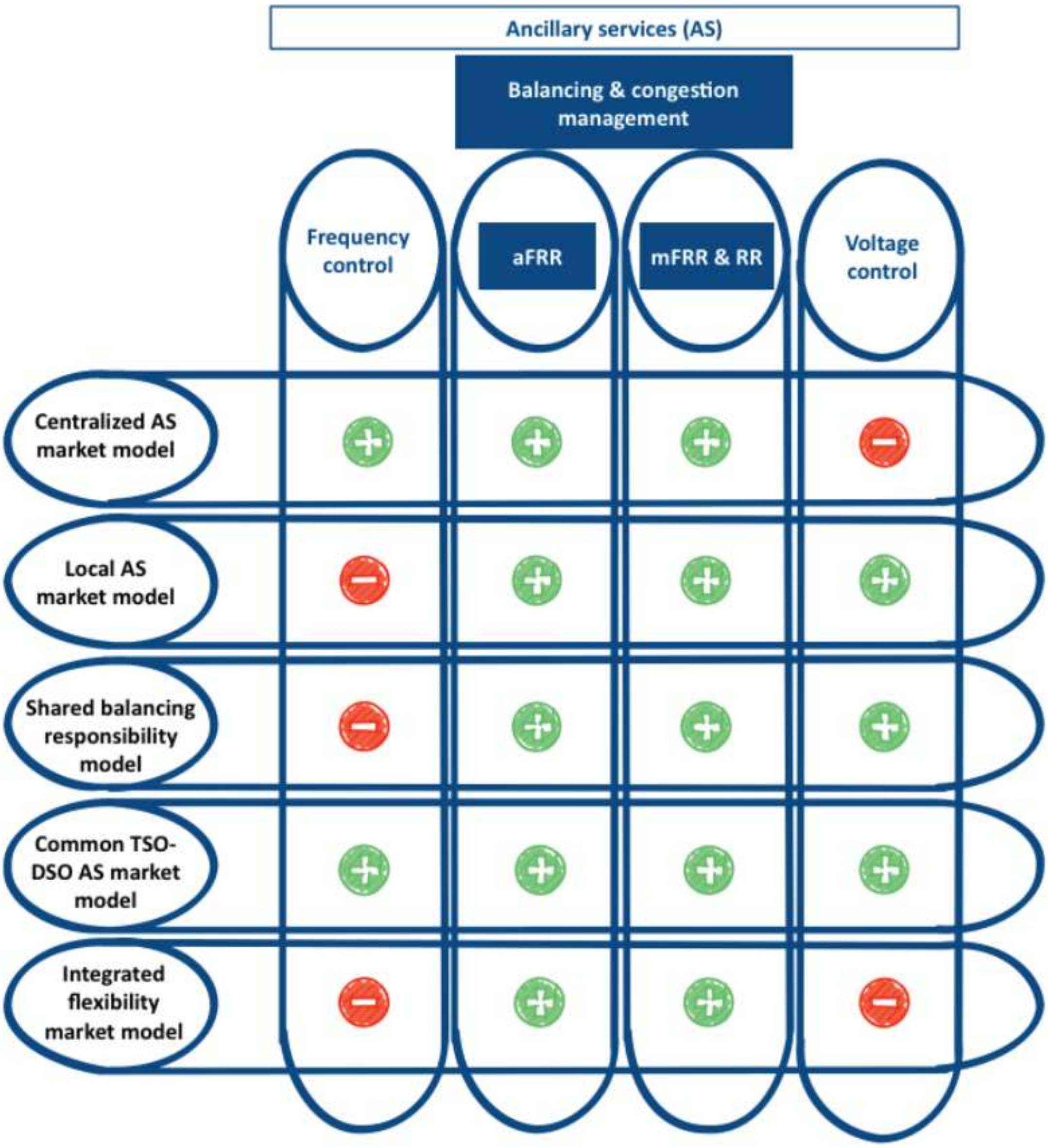


Figure 2-11 – Mapping of ancillary services and coordination schemes (SmartNet)

2.3 Activation of Flexibilities at TSO-DSO Interface

2.3.1 Processes for Flexibilities Activation

As seen before the flexibility in a power system represents the active management of a certain asset that could be managed with impact in the system balance or grid power flows in time horizons on a short-term basis that can be from day-ahead to the real time. The activation of flexibility resources is triggered by an external signal in order to provide a service within the energy system. The focus of the services related to flexibilities activation are:

- Electricity balancing from Frequency Restoration Reserves (aFRR and mFRR) and Replacement Reserves (RR);
- Congestion management on transmission and distribution networks;
- Voltage control;
- Frequency control;
- Balance responsible parties (BRP) portfolio (energy) balancing.

The mechanisms of flexibility activation are different for the diverse time horizons (e.g. day-ahead and real-time) and they depend on the intended use. This means that for balancing, voltage control or congestion management purposes different processes arouse. It is important to highlight that the balancing refers to a situation where the electricity markets are already closed and where the TSO has to ensure the inexistence of imbalances between the supply and demand, for the close to real time period. The ancillary services as the range of services that can be used/contracted to guarantee the security of the system can provide a wide range of different products with different proposes, what allow the operator to make efficient decisions.

According to the Network Code about the ancillary services, for each of the operational planning timeframes should guarantee the availability of ancillary services to ensure the operational security of the transmission network. The TSO is responsible to design, set up and manage the procurement of ancillary services, ensuring operational security. In terms of reactive power ancillary services, in addition, to ensure the operational security of his grid, the TSOs should monitor the available reactive power capacities of facilities in transmission network and reactive power capacities of the DSOs.

Until now, most of the flexibility assets were sourced from the supply side mainly associated with large power plants. However, with the decentralization of the generation and the increase of others distributed flexibility resources (DFRs) connected to the distribution grid, the focus of enabling flexibility is increasingly shifting to the demand side. Therefore, the flexibility assets can be connected to the TSOs or the DSOs grids, so it is important to look up to the interaction of those flexibilities in the TSO-DSO interfaces. With the intensification of DFRs available, it is imperative to define properly the best practices for integration of them in the balancing and congestion management processes. As seen, the SOs may need some flexibility to deal with grid constraints in timeframes close to the real time, so some practices should be followed to guarantee efficient and transparent processes between operators.

Firstly, the DSOs should identify what are the needs for DFR in their network (amount of DFR needed, activation time, number of activations, etc.). Then this should be compared with the foreseeable capacities of the potential providers. The share of these needs with the TSOs may be valuable once it can be possible to find synergies between operators. Another ensuing key step is the definition of the suitable flexibility products by TSOs and DSOs taking into account the interests of all the stakeholders involved, before the NRA (National Regulatory Authorities) approval. All this consideration about the definition of the flexibility products should have in mind that is important to minimize the influence on the liquidity for markets. Bearing in mind the Guideline on System Operation in the EU legislation, the TSOs and DSOs shall be able to set limitations or to activate flexibility to solve congestions in coordination. These restrictions to avoid security issues on the grids can be defined by the operators during prequalification or before the activation [15].

The activation of flexibility services require a well-coordinated process between all the stakeholders (DSOs, TSOs, BRPs, marketplace, aggregators, etc.). It should be used with an efficiently economical and technical care because it will influence grid operation and balancing of the system. The coordination between TSOs and DSOs is a key point to avoid system disturbances due to the activation of flexibility assets in the transmission or distribution grids. Another point is that the activation of one bid related with a certain product, e.g. aFRR, ought not to generate a new need of congestion management in the network. The coordination between operators shall assure that one DFR bid is not activated twice for different processes (balancing and congestion management). In fact, about the DFRs is important to the TSOs possess transparency about them. For prequalification or procurement of balancing capacities the TSOs should take into account the available DFRs without distortion.

As seen in the previous section, the definition of a future market for AS purposes can be supported in diverse schematization of collaboration between the parties involved in the market and different architecture of the marketplace design. The neutrality, confidentiality, transparency and liquidity are some of the most important characteristics of any marketplace. The liquidity for balancing and congestion management resources in AS market is a key factor, because it assures that the DSOs and TSOs are able to deal with its respective operational cost with a lower cost. Therefore, the market mechanisms should be able to generate enough liquidity to procure all ancillary services [16]. Some of the best practises to increase the liquidity of a flexibilities services market are:

- Increasing the number of flexibility providers/suppliers;
- Increasing the volume of offers;
- Ensure that one DFR could participate on bids for balancing or congestion management purposes if it is fit for;
- Utilization of aggregators pooling resources (e.g. smaller distributed flexibilities);
- A level-playing field for all sources of flexibility;
- Avoid cascading principle;
- Implementation of a single flexibility marketplace for balancing and TSOs and DSOs congestion management processes.

Currently, there is no available marketplace platform for the provision of flexibilities products. An ideal flexibility marketplace is one that establishes also an appropriate mean of communication between the different system users, market parties and grid operators. Since there are different market designs, technical characteristics of grids and technical specifications in Europe, it does not exist a one-model-fits-all for the successful integration of DFRs in the flexibility market. Before a market model can be planned or adapted to introduce the DFRs services properly, is important to identify his potential services, conflicts and interests. In addition, the coordination between day-ahead and intra-day markets is fundamental to safeguard suitably amount of supply at all timeframes without compromise the security of the system.

As introduced before in the activation of flexibilities, the TSO-DSO coordination is fundamental. It is important to check how the different uses of flexibilities products by TSO and DSO can affect each other and the system stability. A flexibility bid should only be activated if its activation does not affect negatively the transmission and/or distribution grids, or any other player like aggregator, prosumers, consumers, etc. That is one of the main reasons why the existence of a clear data exchange framework is a must to have in the future flexibilities market design. With that, all the parties involved in the processes can have access to relevant data to assess the impact of the activation of balancing or congestion management services, namely the DSOs with the DFR assets. From the available flexibility, the TSOs and DSOs should be able to activate and deactivate the flexibility that they want being sure that the activation of the procured flexibility does not harm any other part of the network. This could be set by defining blocking on active bids, for example. Another perspective where the coordination between TSOs and DSOs is expected is on the interest for activation of a resource, because both could be interested in the activation of an asset for different purposes, what could arise conflicts. In this case, the priority should be brought to the DSO if the final objective is to overcome a local physical constraint. So it is important recognize that the activation of a flexible service can have impact on system parameters governed by other services. As well is of the utmost importance to guarantee that these possible conflicts are taken into consideration in the regulation of a flexibilities market to assure, for example, that causing imbalances doesn't develops financial gains.

For preventing major problems in the system and to define the way that should be followed when conflicts for requesting flexibilities arise, it useful to state the prioritization of the needs as a method to efficiently take decision. The order list suggested could be [17]:

1. Emergency situations – Include actions needed to avoid blackouts or instabilities in the system;
2. Local constraints – Include actions needed to solve local constraints that has smaller amount of DFRs than a global constraint, so it has priority.
3. Global constraints – Include actions needed to solve global constraints. These includes services for maintenance of the security of the system and issues on the transmission grid that are not urgent.
4. Planning and financial processes – These are processes that do not affect directly a more secure system, usually non-technical.

For example, the activation of a flexibility service by the DSO to solve a local constraint might develop imbalances. To avoid this the TSOs should be noticed of the activation of such flexibility service by the other operator in order to guarantee that the TSOs are prepared to do corrective actions to restore the balance of the system, if needed. One problem that can also occur is related with the activation or exclusion of assets from aggregated flexibility portfolios, which were initially designed for use on the transmission network. For example, the balance responsible parties (BRP) build up a set of flexibility assets that can be activated to solve global constraints, however the local activation of this assets will influence negatively the portfolio of this agent.

When the topic is the DFRs, the coordination is therefore essential once the flexibility providers are able to set their flexible assets either in balancing or congestion management processes. According to ENTSO-E, pricing rules need to avoid inconsistent activation orders, settlement prices and perverse incentives to DFR providers, DSOs and TSOs [15]:

- Before the balancing capacity gate closure time (GCT) is from the balancing service providers (BSPs) responsibility to manage DFRs to coordinate updating in the processes where the GCT has not been reached.
- Between the balancing capacity and the balancing energy, the bids that are contracted in the GCT need to be coordinated by the BSPs or the TSOs and DSOs depending on the market design.
- After the GCT, according to the Guidelines for energy balancing, different merit order lists (MOLs) will run in parallel for the diverse processes. Coordination between processes is needed to assure the elimination of risk of DFRs being activated in opposite directions by different bid processes. Such coordination allow the TSOs and DSOs to define limits on DFRs activation bids for congestion management issues.

The marketplace collects the bids for the balancing and congestion management proposes. The TSO and DSO interacts with the marketplace to receive the energy and capacity bids to be used in the different processes and sets the necessary limitations to their networks. Then, the TSOs and DSOs send activations orders to the providers of the flexibilities and the information on the activated bids is updated and the processes are coordinated. The TSOs and DSOs are responsible for their processes and they manage their respective MOLs according the necessities. On the other hand, the activation of the flexibility bids can be done directly from the system operators to the flexibility service providers.

In the figure bellow is possible to identify the main actors, services and provision streams of the flexibility [18].

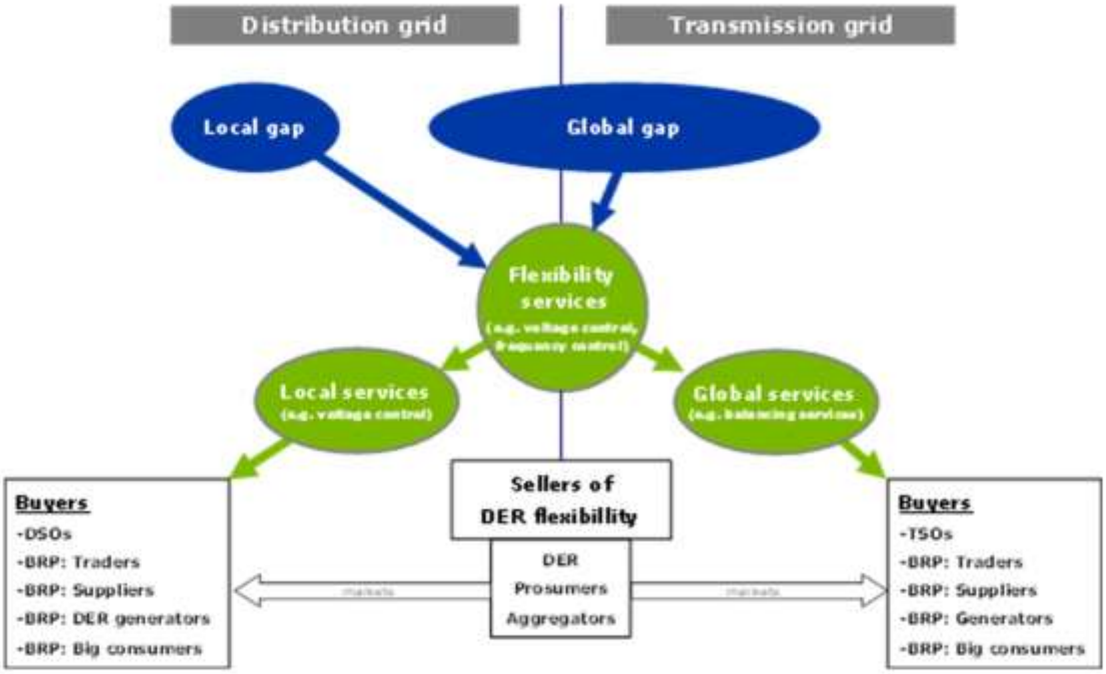


Figure 2-12 – Main actors, services and provision of flexibility [18]

As it is possible to see, the DFR can provide flexibilities services to the DSOs, TSOs and BRPs to solve either local or global constraints. At local level, the geographical location of the asset that provide the flexibility matters. The DSOs look for flexibilities services in order to address grid issues related to local flexibility gap, as voltage control or congestion management.

For the activation of the flexibility in the distribution network, there are three actors involved: the provider, the aggregator and the buyer or end-user (DSO or TSO). The providers of flexibility are likely to be remunerated by a capacity payment and additionally could have a fee for activation. With this change of paradigm of increasingly transfer generation to the distribution side, new challenges arose like the necessity of implementation of communication infrastructure or DSO regulation. Actually, the DFR flexibilities are already being used in some countries to support DSO grid management as demand flexibility by way of an alternative for grid reinforcements, as distributed generation used to address grid management constraints and as distributed storage for help with capacity constraints or with the volatility of DFR.

At system level, the activation of flexibilities is desirable for purposes of balancing and congestion management. The balancing services are responsible to safeguard that the balance between demand and generation is secured. The balancing services can either act in the generation or demand side and with either downward or upward regulation. They can be detached into two types:

- The non-energy products, mainly covered by the primary reserve also called frequency control reserve (FCR). The FCR service is called in order to guarantee that the frequency is kept inside a certain pre-defined band of allowed temporary frequency. The provision of this reserve is, in most cases, a non- remunerated and mandatory service supplied by generators that is automatically activated by system control.
- The energy products encompass the frequency restoration reserve (FRR) and restoration reserve (RR), that are products that can result in energy volume after

activation. FRR are related with operational reserves that can be used to re-establish the system frequency. RR are the reserves that can be used to replace the reserves that are activated, in order to have available reserves in the system. These products usually are remunerated to the provider in two parcels one related with the capacity and the other with the activation of it.

The different balancing services also vary in terms of time response requirements, which means that some type of flexibility sources are more suitable than others for a certain service. FCR requires fast response times, less than a few seconds. aFRR reserve is an automatic service provided normally through market mechanisms, where the physical units that are able to respect the technical requirements to provide the service are obliged to present offers. The time response is slower than the primary reserve, between 30 seconds and 15 minutes. Finally, mFRR and RR (with time response up to hours) it is the only balancing service that is not activated automatically, so it is usually activated manually under TSOs request to resolve congestion problems or imbalances in the control area. By this diversity of requirements presented, it is obvious that the different DFR features matters for providing proficiently each services. For example, the batteries and flywheels are DFRs that have a fast-ramping response, which is appropriate to deal with the frequency control. The balancing services once they require a reduction or increase of production or demand, the demand side management could be a proficient solution to solve imbalances also. Increasingly, the transmission operators are considering the use of DFR for congestion management purposes related to remedial actions after the allocation capacity. The demand side management, which consists in the adjustment of the load level, is also a possible measure that can be used by the operators for short-term congestion management. From the TSO side this traditionally is overcome by re-dispatch actions, but from the DSO side, the same role could be taken. Through the load adjustment is possible to satisfy the imbalance and solve the congestions from the demand side. At a global level, the DFR can be very useful for optimization of the portfolio of BRPs.

As seen before, the use of DFRs will increasingly be used for the provision of flexibility and for that reason the market design and regulation should be revised and adjusted in accordance to the different needs of the participants and to the new challenges. The requirements for a DFR to provide a flexibility service should be defined by the TSOs and DSOs in the relevant markets for the different time horizons (day-ahead, intraday and balancing market). For the balancing market, only the TSOs and DSOs are in conditions to operate them once it occurs in the imbalance settlement period and the activation of flexibility sources will not affect the balance of BRPs as the activation can be adjusted posteriorly. The DSO has to assure that the appropriate DFR capacity is available. For the activation of the balancing product, the coordination between the TSO and DSO is crucial, as also when products are activated by the DSO. In the case of the intra-day and day-ahead market, the need of coordination for DFR services provision is bigger once more actors are involved and can be affected by imbalances in portfolios and therefore in the settlement period. Depending on the application and time horizon different actors should be informed in order to guarantee the coordination between parties. The market activation rules should also be cared about the ease of participation in the demand side response by avoiding long activation periods or high frequency needs.

In practical, it is important to define in a standardized way, which are the characteristics of each flexibility product in order to be clear for the operators (end-users) specifications.

Accordingly, for each of the flexibility products, the provider should specify respectively the following data if applicable for the purpose of the product:

- The type of flexibility;
- Point of connection;
- Capacity [MVA];
- Response time;
- Availability period;
- Ramping rate [MW/min];

In the process of the activating flexibility, it is crucial to avoid uncoordinated access and use of resources and the DSO role as distribution network technical validator is also essential. The activation of DFRs for balancing and congestion management purposes requires a proficient communication and cooperation between operators in order to avoid conflicting of interests.

2.3.2 TSO-DSO Joint Flexibilities Activation

In the past, the production was incontestably associated to the centralized and dispatchable power plants connected to the transmission networks, where the flow of flexibility was necessarily from the generation (TSO) to the consumption side (DSO). With this new paradigm of DFR and the growth of an energy system less dispatchable and predictable, the need of flexibility services also increases. However, this gives to the system some new features that can be used to surpass some challenges generated by the actual energy system structure. Nowadays the demand side is more elastic and the flow of flexibility is no longer unidirectional from the production to the demand side, with the distribution assets being able to contribute to the overall flexibility of the electric system.

Many of the needs that DSOs and TSOs have in their networks can be solved by services provided by DFRs. In general, the system needs different types of flexibility products because of the different kinds of needs and technical requirements. Some of the system needs are local and other global, and they can also differ in respect to the time-frame of usage. Following table presents the main needs of the each of the agents involved in the flexibility market.

Table 2.5 – DFRs available services for different players

TSO	DSO	BRP
Frequency control	Peak shaving	Imbalance problems
Voltage control	Power quality	Portfolio
Congestion management	Voltage control	

The flexibility products can be offered to the TSOs and DSOs by different sources to be used in multiple benefits. Conventional power plants, reversible pump storage hydro-power plants and interconnections capacity are mainly the flexibility sources that the TSOs have at his disposal for power balancing, frequency control and congestion management. From the DSOs side they have the distributed flexibility providers connected to the distribution grid as batteries, supercapacitors, RESs and DFRs, which can be useful assets for flexibility purposes, like congestion management, voltage control or as portfolio for BRP. The technical features of each of the different flexibility provider technology should be assess in order to be adequate for a certain flexibility usage in terms of capacity and time of response, for example. Since the distribution flexibility providers can offer services for the TSOs, the challenge now is to coordinate efficiently these actions taking care of the technical, regulatory and economical aspect.

A strengthened TSO-DSO coordination is the key requirement for an optimal and secure sharing of the flexibility services. Nowadays, the need for active power management is increasingly shifting for the demand side with the growth of the control of generation units, storage units and demand response, coordinated with the transmission operators to minimize the impacts on the transmission grid. For the reactive power management the same coordination is expected, since the voltage constraints and control of reactive power have mainly a local characteristic, therefore, some local actions should be coordinated between operators in order to maintain the voltage levels inside the acceptable limits. In the cases where distribution assets like batteries, reactors or capacitors devices are activated or their taps changed the transmission network could be affected, coordination between TSO-DSO should be efficient in order to prevent it. In fact, some actions can have a negative cross-network effect. For instance, TSO use of distributed resources for balancing purposes has the potential to exacerbate DSO constraints. Equally, whilst DSO use of innovative solutions, such as active network management, can deliver benefits to customers, if not managed properly, in some cases they may counteract actions taken by the TSO [19].

As already discussed, one potential problems related with the utilization of DFRs is the conflict of interests that could arise between players of the system. The criteria to rank the priorities of the usage of a certain distributed flexibility product should be well defined because different stakeholders could be interested at the same time in the utilization of the same asset. Another important conflict that can ascend is the negative impact of the activation of a certain asset in the others agents of the system. An activation of a certain flexibility service from request of any of the operators shouldn’t cause any kind of congestions, so ex-ante network analysis must be done. For that reason, the coordination between all the agents that can be potential affected is crucial for an efficient operation of the system. In the previous sub-chapter 2.2 a way to prioritize the needs of the different operators was proposed in order to guarantee coordination and prevent conflict of interests between operators for the same flexibilities products. On the other hand, to ensure that a flexibility activation can only be made if it does not provoke problems in adjacent networks it is needed to have a coherent data exchange framework. In particular, with this approach all the parties that could be affected with the activation should have access to the essential data to assess the impact of the activation and be aware of the potential constraints. For TSO-DSO joint flexibility activation is important to define some of the data that should be exchanged. For example:

- The DSO should provide the DFRs energy measurements and the aggregated generation forecast by point of connection in the observability area to the TSO;
- Final DFR schedules must be provided;
- The activation of a DFR service should be communicated;

According to ENTSO-E these are some of the key TSO-DSO coordination characteristics that should be addressed [20]:

- Clear specifications of TSO and DSO observability needs
- TSO overseeing of any active power action with impact on balancing or on the transmission grid constraints.
- Operational planning and before RT TSO-DSO coordination, definition of DFR controllability procedures to identify mutual impact of TSO and DSO flexibility activations in emergency situations, and development of system operation agreements under these emergency situations.
- TSO-DSO coordination for efficient and non-discriminatory usage of DFR flexibility.
- Structural data exchanges (demand forecasts, generation forecasts, dynamic data models, single line diagrams of planned network, etc) for planning purposes

About this last point, in the European project TDX-ASSIST, the Portuguese partners have developed System Use Cases (SUCs) that address the exchange between the DSO and TSO of the disaggregated forecast of generation and load by node of the observability area. Keeping the system up and running in the future requires a more collaborative approach between the TSOs and DSOs that can be supported by innovative ICT tools that facilitate the data exchange between operators. In the TDX-ASSIST project, one of the main objectives is to define the designing of different type of information from operation planning to real time actions and the implementing of the exchange of this data.

An important concept for a feasible coordination between TSO-DSO is the definition of the observability area. The observability that the DSOs and TSOs have on each other's networks is fundamental to the definition of the information that shall be exchanged. Nowadays the need of the operators to improve the observability is growing, mainly in the TSO-DSO interface where the action of each operator can affect negatively the other ones. Typically, the DSOs don't have any visibility for the transmission network and sometimes they do not even have acquaintance about the TSOs' actions. From the TSOs point of view, normally, the lack of information about the distributed generation and demand facilities is the major handicap for his tasks, because it can affect the operation of the transmission networks. So, for both of the operators, the improvement of the observability is seen as essential to fulfil their roles [21]. The improvement of the controllability over distributed energy resources is also a challenge for both of the operators.

The concept of observability for each system operator can be briefly described as the portion of a grid operator's grid that affects flows in another operator's grid. This concept is related to the meshed grid as grids connected radially only affect the connecting grid on the border. Grids connected in a meshed way or with large-scale deployments of RES may affect connecting grid at more points [16]. Although the TSO-DSO physical interface varies according to different EU countries, the concept of observability area is described in the following figure, showing also the aggregation of generation and load at nodal level of the common observability area.

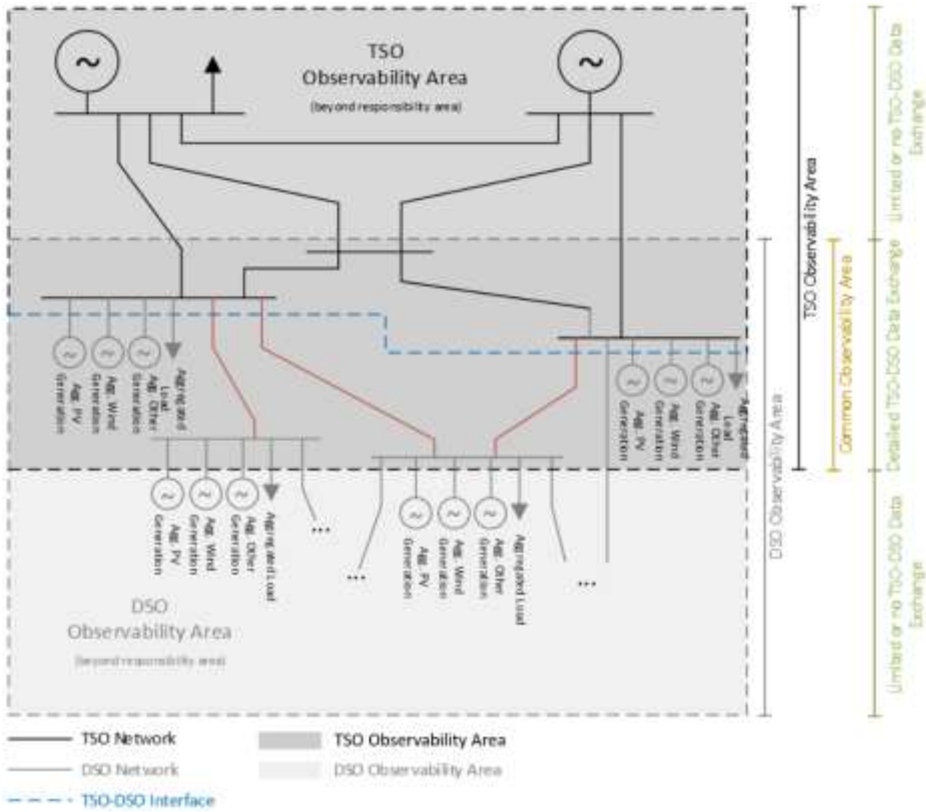


Figure 2-13 – The concept of observability area. Adapted from [22]

The collaboration between TSOs and DSOs requires the exchange of important data that sometimes is seen as confidential so the information exchange has to be carefully handled. For the definition of the observability area both operators should look for their needs trying to find technical methodology to describe the observability area over the others operator networks and specify the data that they need from each other. For that, it is important to define standard formats and models that should be followed for TSO-DSO data exchange and also a transparent platform as mean of communication. The security, privacy, standardization and quality of data are some of the most important factors to guarantee an efficient exchange of information between relevant players (DSOs, TSOs, stakeholders, etc.).

2.4 Set of Requirements for Flexibility Activation and Coordination

2.4.1 Requirements for Flexibility Activation and Coordination at the Operational Planning Stage

For operational planning proposes is important to define the set of requirements for flexibility activation and coordination that should be implemented in order to guarantee the safe and efficient operation of the system.

With the intention of assuring that the TSO knows for the next hours the range of flexibility in each primary substation node at the observability area that came from the distribution grid side, the DSOs need to perform a power flow analysis. The DSOs need to estimate and provide the information to the transmission operator about what are the DFRs that are feasible to be used and what is the cost of activation. By this way, the TSOs and DSOs are capable to study the cost-benefit of the available products and also manage the technical part behind the flexibility activation. The economic and technical analysis that should be accomplished by the DSOs shall assess the active and reactive resources and identify what are the optimal actions among the possible choices towards the constraints imposed by the system.

The main purpose of the Flexibility Scheduler, developed in Task 7.2 of OSMOSE project, is to be a tool that can help the DSOs to exploit distribution level flexibilities, whilst taking into account transmission-level constraints. The tool is mainly an Optimal Power Flow (OPF) that indicates the optimized control of distribution-connected flexibilities. Once this tool takes into account the needs of the TSOs in terms of reactive power it can optimize the exploitation of assets of flexibility connected to the distribution grid that can be used by the transmission operator in a coordinated manner.

The focus of this software is on the management of reactive power. Consequently, it will allow to not only overcome possible voltage violations but also to minimize losses in the grid, hence promoting an efficient usage of the grid.

The Flexibility Scheduler can be characterized as a Predictive Management instrument: it should suggest actions to be taken at several instants, typically in a day-ahead time horizon. That is, the Flexibility Scheduler runs at a given instant and the result comprises several sets of proposed actions. Each set of actions is intended to be executed at a different instant of the day-ahead time horizon. Since a control action at a given period may have an impact in further decisions, the optimization algorithm behind the Flexibility Scheduler must consider the **inter-temporal constraints** in its formulation. In other words, when performing each OPF for the optimization horizon, it should be taken into account control actions established for previous periods. This feature is paramount and the optimization algorithm will be hereinafter referred to as **Sequence-constrained Optimal Power Flow (ScOPF). Using the OPF acronym will then refer to only one of the optimization periods**.

In practice, this means that a run of the Flexibility Scheduler does not consist in running a grid analysis multiple times. Instead, the ScOPF considers the problem as a whole, considering the grid conditions expected at a given time instant, along with the inter-temporal constraints.

The results of the Flexibility Scheduler will allow the user to know in anticipation the flexibilities that should be activated/deactivated at each instant. In addition, the detailed results could present the optimal global solution at each node of the observability area and could also present its time evolution during the considered operation planning period.

The Flexibility Scheduler is intended to be **executed manually, on user request**. Each execution consists in running the ScOPF using the most updated information available, including production and load forecasts. Normally, these predictions evolve over time and become more accurate as the forecast time approaches the operation time. This means that the Flexibility Scheduler execution can be repeated along the time to improve accuracy of the computed solution and to improve the effectiveness of the corresponding proposed actions on the grid. As illustrated in Figure 2-14, if one runs the Flexibility Scheduler frequently, we may think on its results as a **sliding time window**.

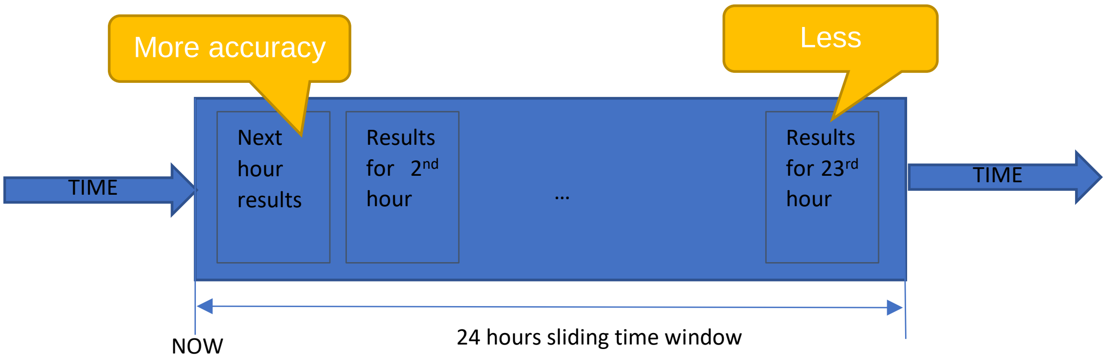


Figure 2-14 – Sliding window concept of a preventive management

As stated above, a call to the Flexibility Scheduler triggers the ScOPF and multiple output sets will be obtained, one for each period considered in the day-ahead time-frame. For each period, the ScOPF should consider the following inputs:

- **The RES and Loads forecast for the considered instant**
  Nevertheless, the calculation of such forecasts is outside of the scope of the Flexibility Scheduler. As an alternative, it is assumed that this information is somehow available to the Scheduler (in a real system it should be provided by external modules, but in simulation it is enough to provide, for example, sample of historical data).
- **The needs of reactive power to/from the TSO grid**
  The congestion management or the voltage control from the TSO side can define need of reactive power injection from the DSO side, or the consumption of reactive power by the DSO side. In general, these needs corresponds to definition of a range of reactive power in the TSO/DSO interface nodes. This coordination is fundamental to the operation of the power system as a global system as it is.
- **The constraints of the TSO grid**
  These constraints usually consist of voltage and current static limits. Besides, the optimization must also consider the time constraints associated with the allocation of flexibility resources. These time constraints may arise from technological restrictions specific to each asset, but may also be imposed by regulatory rules. For instance, it is

common the existence of limits to the frequency of activation/deactivation of capacitor banks (e.g. not possible to activate a capacitor bank within the next 2 hours after it has been switched off), as well as limits to the frequency of status change of a switching device.

The following grid flexibilities shall be considered as control variables during the optimization:

- **RES with reactive power control**
  In Section 2.1.1.1 which covers the Electricity Generation, it is referred that some types of power plants provide reactive power control. In what concerns TSO-DSO flexibility coordination, the most relevant are those related with the use of renewable resources. For example, and as aforementioned in section 2.1.1.1, the modern wind and solar power plants are able to provide some control over its reactive power output. In this section, we refer to plants with this capability as “RES reactive power”.
- **Tap changing transformers**
  This type of flexibility sources is covered in section 2.1.1.4 Tap changing transformers provide a means of voltage control by changing the number of windings turns, which gives a step regulation of the transformer. OLTC – *On-load tap changing* transformers – shall be considered in the scope of the Flexibility Scheduler. In this section, we generally refer to these assets as “Transformer taps”.
- **Static Compensators (STATCOM)**
  This type of flexibility sources is covered in section 2.1.1.4. The source of reactive power is either a reactor or capacitor, but, in this section, we generally refer to these assets as “Capacitor banks”.
- **Grid switches**
  Devices capable of changing the network topology by changing its status (0 – closed, 1 – opened).

The above sources of flexibility are the most relevant for reactive power management, which is the main goal of the Flexibility Scheduler. For this reason, the other sources of flexibility identified in section 2.1 will not be considered in the Flexibility Scheduler.

The results for each time instant considered in the Flexibility Scheduler, will be:

- The set-points for the flexibility sources that ensure optimized operation at that instant.
- The metrics for the grid before and after the optimization, allowing the Operator to evaluate the benefits of using the proposed set-points at that instant.
- The resulting metrics should include the reactive power costs, before and after optimization, to effectively help the Operator to evaluate the economic benefits of the proposed actions.

Besides presenting overall results like costs, the Flexibility Scheduler should also present detailed information, i.e. aggregated P and Q values, for each node of the observability area.

The results computed for each instant should be presented in the Flexibility Scheduler in a manner that helps the Operator to easily understand its evolution during the considered operation planning period.

There are also requirements related to the ability of configuring parameters of the tool. It should be possible to:

- Define the optimization mode:
  - Congestion management
  - Voltage control
- Define the network limits within which the OPF solutions are feasible. This includes:
  - The maximum and minimum voltage values in any node of the observability area
  - The maximum capacity that should be considered for lines and transformers
  - The maximum and minimum values for $tan(\phi)$ at TSO/DSO interface nodes
- Choose which types of flexibility sources should be considered by the ScOPF[2]. The user should be able to select one or many of the following types:
  - RES reactive power
  - Transformer taps
  - Capacitor bank taps
  - Grid switches
- Define time related parameters for the Scheduler. This includes:
  - The “Time Horizon” that should be considered during a single run of the tool (for example “24 hours” allows a day-ahead predictive management)
  - The discrete time instants that should be considered during that time horizon: for each of these instants, each OPF will run considering the grid conditions predicted for that instant and will present the optimized solution for that instant.
    - The Flexibility Scheduler configuration will allow the user to define the time interval between these instants. For example “every 30 min” means that the Flexibility Scheduler will suggest actions to be executed at 13:00, 13:30, 14:00, etc.
- Define sources for RES production forecast and for Load forecast (assuming that there are different sources available at the TSO or DSO). As stated before, for simulation purposes it is enough to prepare datasheets containing historic data for RES production and Loads, and supply these datasheets to Scheduler instead of providing forecast values.

[2] The tool will only use the resources that are modelled in the system. For example, if a producer doesn’t support reactive power control then it should be modelled without that capacity, and consequently no such resource will be considered by the tool in that producer

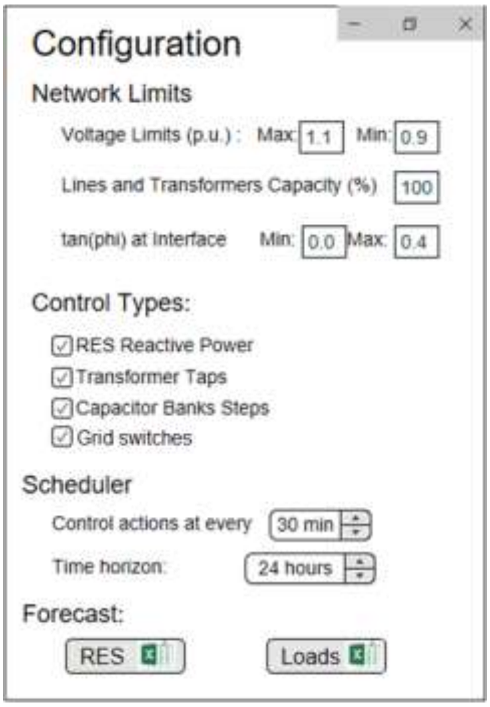


Figure 2-15 – Proposed GUI for "Configuration of the Flexibility Scheduler tool"

In what concerns the presentation of the results, the requirements are:

- Present a list of the suggested actions concerning the activation/deactivation of available sources of flexibility for each time instant in the defined time horizon.

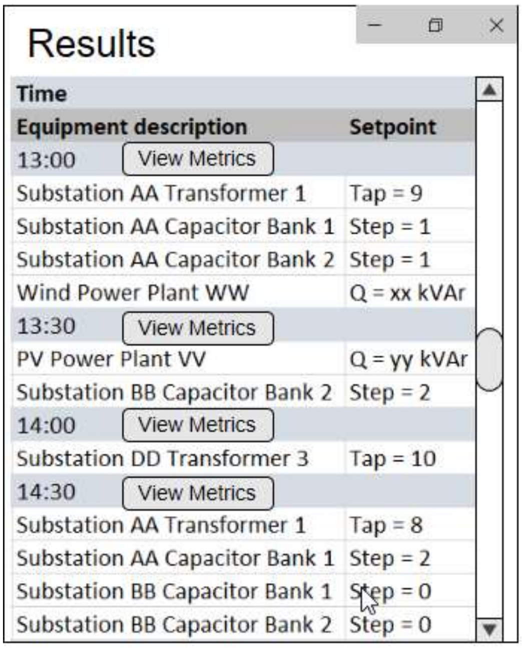


Figure 2-16 – Proposed GUI for "Overall Results of a run of the Flexibility Scheduler tool"

Naturally, the set point actions presented in the results will reflect the "Control Types" chosen in the Configuration. For example, a set point like "Q=300 kvar" will be suggested only if the "RES Reactive Power" flexibility source type has been selected in the Configuration.

- For each time instant considered above, present the global computed metrics for the grid
  - In the initial operation point at that instant (“Initial global values” in the figure below)
  - and in the operation point resulting from executing the block of proposed actions at that instant (“Optimized global values” in the figure below)

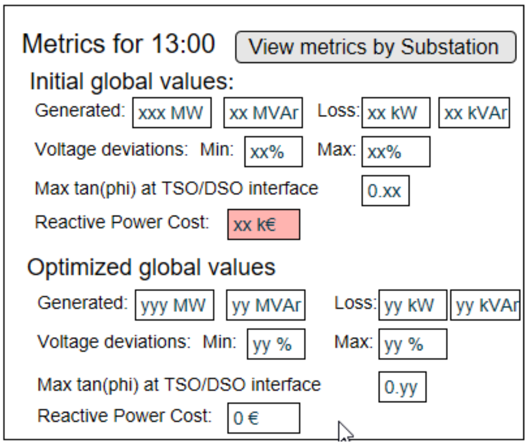
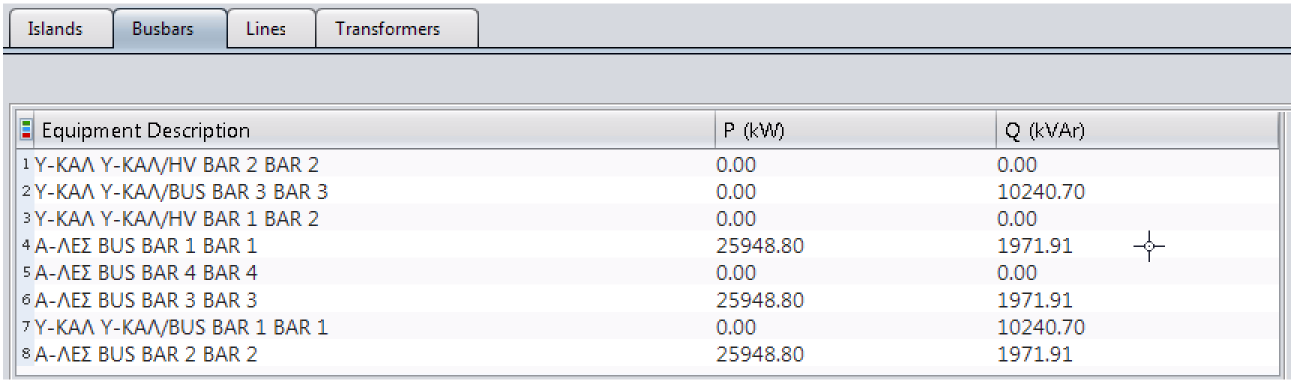


Figure 2-17 – Proposed GUI for “Metrics before and after optimization at an instant”

- For each time instant considered above, it should also be possible to view the computed metrics for each substation in the TSO/DSO interface (“View metrics by Substation” in the figure above)
- These metrics (global or by substation, initial or optimized) should include:
  - Generated Active and Reactive Power
  - Active and Reactive Power losses
  - Maximum and Minimum Voltage deviations
  - Maximum $tan(\phi)$ at TSO/DSO interface
  - Reactive Power Cost (in €) associated with the value of $tan(\phi)$
- For each time instant considered above, it should be possible to present the aggregated P and Q values of the optimal solution for each node of the observability area.



	Equipment Description	P (kW)	Q (kVAr)
1	Y-ΚΑΛ Y-ΚΑΛ/HV BAR 2 BAR 2	0.00	0.00
2	Y-ΚΑΛ Y-ΚΑΛ/BUS BAR 3 BAR 3	0.00	10240.70
3	Y-ΚΑΛ Y-ΚΑΛ/HV BAR 1 BAR 2	0.00	0.00
4	Α-ΛΕΣ BUS BAR 1 BAR 1	25948.80	1971.91
5	Α-ΛΕΣ BUS BAR 4 BAR 4	0.00	0.00
6	Α-ΛΕΣ BUS BAR 3 BAR 3	25948.80	1971.91
7	Y-ΚΑΛ Y-ΚΑΛ/BUS BAR 1 BAR 1	0.00	10240.70
8	Α-ΛΕΣ BUS BAR 2 BAR 2	25948.80	1971.91

Figure 2-18 – Proposed GUI for “Aggregated values for each node at an instant”

2.4.1.1 Congestion Management Purposes

In this mode of operation, the ScOPF searches for an optimal reconfiguration of the network, constrained not only by the network technical limits for voltage and power flows, but also by limits for the frequency of change of switching devices. Feasible solutions are evaluated performing power flow studies.

2.4.1.2 Voltage Control Purposes

For voltage control purposes, the tool should run multiple optimizations that minimize the costs, while respecting the constraints, for the next 24 hours. Before the activation of any DFR, product and grid prequalification should be performed. The product prequalification is related to the study that identifies if the features of a certain asset are enough to satisfy the needs to solve the constraint in cause. The grid prequalification is a classic power flow analysis and system security analysis that assesses if no negatives impacts arise on the grid.

By controlling and balancing the voltage magnitudes of the network nodes, the flows of energy are reduced thus reducing losses.

2.4.2 Specific Flexibility Scheduler Requirements

In terms of the requirements for the flexibility scheduler, it is important to define properly the set of requirements not only technical but also technological, having in mind the needs for the laboratory implementation and for execution of the demos.

In the following figure describes the expected architecture to be implemented in the Real-Time Power System Simulator (RTPSS) Laboratory at R&D Nester.

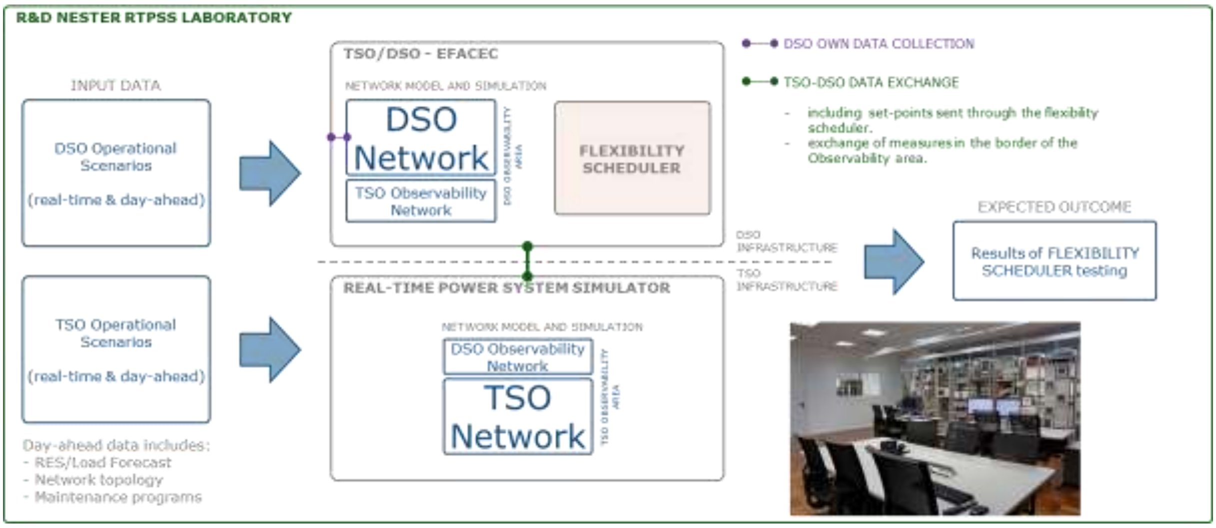


Figure 2-19 – Architecture to be implemented in the R&D Nester RTPSS Laboratory for the sub-task 7.2.3

The course of action for simulation purposes that will be tested has two processes that should run in parallel, one allied to the DSO infrastructure and other with the TSO infrastructure. For both of the processes being carried out as *sine qua non* condition both of the simulations done in each infrastructure (DSO and TSO) has the stretches of one and another's network in order to assure that the simulations will run with the entire observability area for both. With the topology and network data, it is possible to develop models that will be the base for the running of the power flow simulations. Each of the infrastructure sides should define the machines and software to run the simulations, however, is up to each one the choice of them because no impact is supposed on the other side, so no special requirements should be imposed.

As input for the flexibility scheduler tool, it is the responsibility of the TSO to provide to the DSO what are the needs for reactive power in the transmission network. This means that, for interface TSO/DSO nodes, the tool will provide the injection or consumption from the DSO side, according to the needs of the TSO network. The TSO should also supply the information about the constraints of his own grid because they will be used as input for the ScOPF to find the optimal solution for voltage control or congestion management purposes.

From TSO side, for the real time power system simulation the operational scenarios for the TSO observability area network will be implemented in OPAL-RT technologies that provide a complete range of real-time and control prototyping for power grids systems. With these systems is possible to perform power systems simulations with different applications and with typical time steps for network solution from 10 to 100µs. The power system simulation can communicate via communication protocol IEC60870-5-104 with the TSO SCADA. This normative is a standard for power system monitoring, control and communication for electric power systems that defines an open TCP/IP (Transmission Control Protocol/Internet Protocol) interface to a network to have connectivity to the LAN and routers which include different WAN-types might be connected through a common TCP/IP-LAN-interface. The specifications of this standard present a combination of the application layer of IEC 60870-5-101 and the transport functions provided by a TCP/IP [23].

As depicted in Figure 2-19, for the purpose of the testing an emulated TSO SCADA system could communicate with the simulator via IEC60870-5-104 and “translate” information that should be provided/received to the DSO SCADA (ScateX#) via another protocol (ICCP).

The communication channel between the TSO and DSO side, it is recommended the use of standardized approaches to information and data exchange. Thus, the communication link that will follow a standard communication protocol that enables the exchange of information objects based on defined rules is the Inter-control Center Communication Protocol (ICCP). This protocol is proper for real-time data exchange and when used between TSOs and DSOs represents a good path to exchange information about the operation of the system which can provide to the operators a greater awareness about the neighbouring networks. As it happens in the actual Portuguese electric system where the DSO and TSO SCADAs are connected via ICCP, on R&D Nester laboratory the same protocol can be used to connect the DSO SCADA EFACEC to the emulated TSO SCADA. For the purposes of this laboratory implementation and demonstration, the link should be used to provide the following data:

- Share data in order to expand the visibility of DSOs and TSOs on each other networks consequently expanding the observability area of both;
- Exchange the information about the set points of transformer, capacitors and other assets at the TSO-DSO interface through the flexibility scheduler;
- Exchange other relevant real-time data as measurements of bays or topological information as state of breakers. This information is only applicable for the observability area agreed between transmission and distribution system operators.

As expected outcome of this RTPSS laboratory demonstration, we have the assessment of the impact of the optimization actions suggested by the flexibility scheduler tool through real-time simulations that try to reproduce real operation conditions and scenarios. The reactive power set-points, power factor ranges, and voltage set-points for voltage control at the connection point between the TSOs and DSOs will reflect a joint assessment of the network state. Ultimately, this demonstration will be useful to find out how the coordinated exploitation of DFRs can improve the flexibility of the global system and to prepare DSOs and TSOs with coordination steps and rules that should be followed for an efficient operation.

2.5 Summary on Flexibility Coordination

A characterization and discription of the flexibilities sources available in the energy system and the innovative coordination processes for joint operation of DFRs are provided in this document.

The flexibility assets are key to manage network constraints and increase its reliability and security. However, their different technical features make them more suitable to some services than others, depending on the capacity, response time or the ramping rate, for example. The diverse flexibility sources are appropriate for different time-horizons from real-time to operational planning what makes fundamental an analysis to the technical performance to ensure a successful choice for the ancillary service intended to provide.

The decentralization of the generation and the participation of the demand in the electricity system bring up new challenges but also opportunities to the system. In this chapter, five schemes for flexibility coordination between TSO-DSO interface were explored, where the market design for ancillary services and the TSO and DSO roles are described for each one. The results from the projects EvolvDSO and SmartNet supplied the basis for this analysis.

The majority of the requirements that are presented, concerning the harmonization and efficiency of the coordination between TSOs and DSOs, are stated in the report. The transparency of communication and the effort to find synergies between operators are key elements. Nontheless, it is also crucial to guarantee that the best practices are followed in order to ensure the liquidity of the flexibility markets.

In the activation of flexibility services, the coordination between stakeholders is paramount as this could generate a negative impact on the grid operation. With a clear data exchange framework, the operators are able to examine if the activation of a flexibility asset does not harm up any part of the grid, as for example, provoking imbalances in the neighbourhood's grid. When the flexibility resource is connected to the distribution network, conflicts of interests may arise, as referred in this chapter. For that reason, it is important to specify a list that defines the prioritization order according with the application of the flexibility service, looking from an all system benefit perspective.

ENTSO-E and other organizations already provided some guidelines and recommendations to help designing a strengthened TSO-DSO coordination. In addition, some European projects as TDX-ASSIST are mentioned as a reference in this subject.

The set of requirements for flexibility activation and coordination at the operational planning stage are stated in this deliverable. The Flexibility Scheduler tool should implement these requirements. The FS tool is mainly a ScOPF that indicates the optimized control of DFRs taking into consideration the needs and constraints of the transmission side. As result, the tool provides to the user the flexibilities that should be activated as well as their set-points, for each time interval for the next 24 hours. Having in mind the needs for the real-time power system simulation (RTPSS) laboratory implementation and for execution of the demonstration, the main requirements are described in this chapter.

3 Flexibility Scheduler overall architecture design

This section is structured in four main chapters, from a review over the fundamental requirements of the Flexibility Scheduler tool, through the Sequence-constrained Optimal Power Flow tool characterisation, to the user interface used for the Flexibility Scheduler testing environment, and the further developments.

3.1 Flexibility Scheduler Tool Requirements

The previous chapter, "Specification of Flexibility Coordination", identified a set of requirements for flexibility activation and coordination at the operational planning stage for TSOs and DSOs. These requirements – described in section 2.4 of the previous chapter - defined the base for the innovative FS tool.

3.1.1 Requirements review

This section presents the FS tool requirements, formatted as a list, and organized by functions. Some requirements have been simply transcribed from the previous section, but others have been further explored and detailed mainly during the EFACEC, REN and R&D NESTER meeting that took place in REN premises on 2019.01.22.

3.1.1.1 General

Table 3.1 – General task requirements.

ID	Requirement
G1	The main purpose of the FS is to be a tool that can help the DSOs to exploit distribution level flexibilities, whilst considering transmission-level constraints.
G2	The tool is mainly an Optimal Power Flow that indicates the optimized control of distribution-connected flexibilities.
G3	The focus of this software is on the management of reactive power. Consequently, it will allow to not only overcome possible voltage violations, but also to minimize losses in the grid.
G4	The FS can be characterized as a predictive management instrument that should suggest actions to be taken at several instants, typically in a day-ahead time horizon.
G5	Since a control action at a given period may have an impact in further decisions, the optimization algorithm behind the FS must consider the inter-temporal constraints in its formulation. When performing each OPF for the optimization horizon, the control actions established for previous periods should be considered.
G6	The FS is intended to be manually executed, on user request.
G7	The FS tool is to be used for the day-ahead (next 24 hours), with a time resolution of 1 hour (same as the market).
G8	A single run of the FS will result in multiple output sets, one for each period considered in the day-ahead time-frame.
G9	The results of the FS will allow the user to know in anticipation the flexibilities that should be activated/deactivated at each instant.
G10	The detailed results should present the optimal global solution at each node of the observability area and should also present its time evolution during the considered operation planning period.

3.1.1.2 Inputs

Table 3.2 – Input requirements.

ID	Requirement
I1	The FS Tool requires the network model of the DSO and the observability area in the TSO network.
I2	It should be possible to define the network topology for each time period. In practice, this corresponds to define the state of each switch of the grid, for each period.
I3	The tool should be aware of maintenance plans existing in the grid. In practice, any equipment is put in maintenance by isolating it, i.e., manoeuvring switches in order to isolate it. This means that this requirement is equivalent to the above one – the maintenance plans can be expressed in terms of switch states for each time period.
I4	The tool should consider load forecasts for the DSO network (day-ahead).
I5	The tool should consider the Renewable Energy Sources (RES) production forecasts for the DSO network (day-ahead).
I6	It should consider the following network limits: • The maximum and minimum voltage values in any node of the modelled grid; • The maximum capacity that should be considered for lines and transformers.
I7	It should consider the following time constraints: • Number of manoeuvres per time period; The optimization criteria should minimize the number of manoeuvres per period. A cost could be associated to each manoeuvre (being possible to have different costs for different resources);
I8	There are some parameters that are different in the transmission and distribution network levels (e.g., tan(Φ) margins), which are especially relevant for distributed generation connected to each network. Therefore, the tool should allow the definition of different tan(Φ) ranges for renewable generators directly connected to the transmission grid and for renewable generators connected to the distribution grid. For example, in Portugal, transmission system connected generators operate in range {-0,2;+0,2} and distribution system connected generators operate in range {0;+0,3}. (Note: it should also be possible to define an exact value for tan(Φ) – in this case the FS should not suggest control set points for these generators.)
I9	In the TSO/DSO interface nodes the FS should guarantee that the DSO should not operate above tan(Φ)=+0,4 (configurable), during the full and peak hours, and should not inject reactive power during off-peak load periods (operate below tan(Φ)=0). The tool should support the definition of the allowed tan(Φ) interval for different time periods. If no solution can be found within the configured tan(Φ) limits, then the tool should calculate the reactive power penalty costs (as result of violation of the regulated limits).
I10	The tool should be capable of defining different voltage limits for each interconnection node. (Note: normally the rule for REN – Portuguese TSO – is to deliver 63kV ± 3%, but the DSO may require narrow limits at some interconnection nodes).

3.1.1.3 Control Variables

Table 3.3- Control variable requirements.

ID	Requirement
C1	The following grid flexibility parameters shall be considered as control variables during the optimization: • RES with reactive power control (tan(Φ)); • Tap changing transformers; • Capacitor banks with steps.
C2	Being a tool mostly developed for the DSO, it should be demonstrated the added value of performing optimization using both TSO's and DSO's assets. Two approaches should be possible: 1) simulate with TSO+DSO assets; 2) simulate with only DSO assets. In practice, the FS tool should allow to choose one or many of the following control assets: ○ DSO RES tan(Φ); ○ DSO Transformer; ○ DSO Capacitor bank; ○ TSO RES tan(Φ); ○ TSO Capacitor bank; ○ TSO Transformer. (Note: Automatic Voltage Regulation (AVR) systems in place in REN for the control of power transformers' taps are normally in "automatic control mode", which means that the "TSO Transformer" option will not be used to analyse real REN scenarios).
C3	If a producer doesn't support reactive power control, then it should be modelled without that capacity, and consequently no such resource will be considered by the tool in that producer.

3.1.1.4 Outputs

Table 3.4 – Output requirements.

ID	Requirement
O1	Multiple output sets will be obtained, one for each period considered in the day-ahead time-frame.
O2	The results for each time instant considered in the FS, will be: • The set-points for the flexibility sources that ensure optimized operation at that instant; • The metrics for the grid before and after the optimization, allowing the operator to evaluate the benefits of using the proposed set points at that instant.
O3	The resulting global metrics should include: • Network losses (€ or MWh); • Max/Min tan(Φ) at TSO/DSO interface; • Reactive power penalty costs (as result of violation of the regulated limits).
O4	The FS should also present detailed information, i.e. aggregated P and Q values, for each node of the observability area.
O5	It would be very valuable to highlight the results in the TSO/DSO observability area. The global results tables should present values in TSO assets with a different colour.

3.1.2 Flexibility Scheduler for Congestion Management Purposes

The FS tool could be used to **help in the active power management, namely for resolving congestion problems**.

In this case, the sequence-constrained OPF algorithm would be used to search for an optimal reconfiguration of the network. That would be constrained not only by the network technical limits for voltage and power flows, but also by limits for the frequency of change of switching devices (e.g. a switch cannot change its state more than N times during the next 24 hours, capacitor bank switching on/off restrictions, etc). The feasible solutions would be evaluated performing power flow studies.

This optimal reconfiguration of the network would resolve congestion problems in the grid, or at least would identify the configuration that, at each period, minimizes those issues.

However, **for TSO, the reactive power management is much more important/relevant than active power congestion management**:

- Typically, the congestion problems in TSO grid are not frequent and are normally associated with planned events (transformers maintenance, etc).
- However, voltage limits problems are a constant concern.

This motivates to **keep the focus on reactive power management**, as it has been done since the OSMOSE project proposal.

Furthermore, the implementation of active power management in the FS is out of the scope of the project. However, as referred above, this possibility is technically feasible, and as such, there is the potential of developing this capability in a future expansion of the FS tool.

3.2 Sequence-constrained Optimal Power Flow (ScOPF)

The Flexibility Scheduler tool is mainly developed to be used by the DSO for the day-ahead (next 24 hours) optimization of reactive power flows and network losses at distribution level, with a typical time resolution of 1 hour (same as the market).

In its back-end, the FS uses a Sequence-constrained Optimal Power Flow (ScOPF) algorithm to solve the optimization problem. The optimization function aims to minimize losses (and number of manoeuvres and other "costs") while keeping technical constraints.

It suggests actions to be taken at several instants, typically in a day-ahead time horizon. Thus, the FS runs at a given instant and the result comprises several sets of proposed actions. Each set of actions is intended to be executed at a different instant of the day-ahead time horizon. Since a control action at a given period may have an impact in further decisions, the optimization algorithm behind the FS must consider the inter-temporal constraints in its formulation. In other words, when performing each OPF for the optimization horizon, control actions established for previous periods should be considered. This feature is crucial, and the optimization algorithm will be hereinafter referred to as ScOPF.

The proposed ScOPF is a tool capable of deriving a set of control actions that keep the active and reactive power flow within pre-agreed limits at the primary substation level. Additionally, it is capable of increasing the efficiency of the network by optimizing reactive power flows, thus reducing losses. The main innovative features of this software are the following:

a) Integration of different types of flexibility (e.g., demand response, flexible generation, capacitors banks, OLTCs and switching devices).
b) Its integration with the Flexibility Scheduler presents a framework to fully tackle the problem of managing the active and reactive power flows in the TSO-DSO boundary.

Moreover, this approach also distinguishes itself from other OPFs by considering consecutive periods of analysis using a slide window methodology that takes into account inter-temporal constraints as stated in the previous part. The tool should support the configuration of this type of constraints, typically by defining a set of rules. For example, one should be able to define that it is not allowed to activate a capacitor bank within the next 2 hours after it has been switched off.

This is a NP-hard (Non-deterministic Polynomial) problem (see section 3.2) that brings the necessity to use an evolutionary optimization algorithm or other meta-heuristic. Since exact methods have an exponential running time as the number of branches and buses of a network increases, the use of a meta-heuristics generally provides a good solution in a very reasonable time.

In general, the objective is to reduce the flexibility operational costs, assuring the proper functioning of the network within a defined timeframe. The tool will define the state of the contracted flexible resources and the resources owned by the DSO for each time interval during the desired operational planning period, aiming to guarantee to the TSO an agreed active and reactive power domains or limited profiles at primary substations.

The ScOPF tool is used to define a series of control actions that comprehend for each defined time frame the optimal suitable mode of operation, i.e. the one that minimizes the operating cost (e.g., cost of activating flexibility) and respects the pre-agreed PQ profiles at the TSO-DSO interface. The control actions may be composed of updated set-points that alter the characteristics of operation of determined grid equipment (i.e. transformer taps, generation unit, power storage unit, etc.) or activated flexibility offers/contracts.

Concerning Inputs and Outputs, as illustrated later in Figure 3-5, the ScOPF will provide the power profile at each substation and the values for all the control variables. To accomplish this, the module needs information about all the network assets, in terms of their technical characteristics and settings. Then, in order to perform the optimization considering consecutive timeframes, the tool receives, for each period, forecasted data for all the power injection points and the corresponding flexibility.

In practice, this means that a run of the Flexibility Scheduler does not consist in running a grid analysis multiple times. Instead, the ScOPF considers the problem as a whole, considering the grid conditions expected at a given time instant, along with the inter-temporal constraints, as depicted in Figure 3-1.

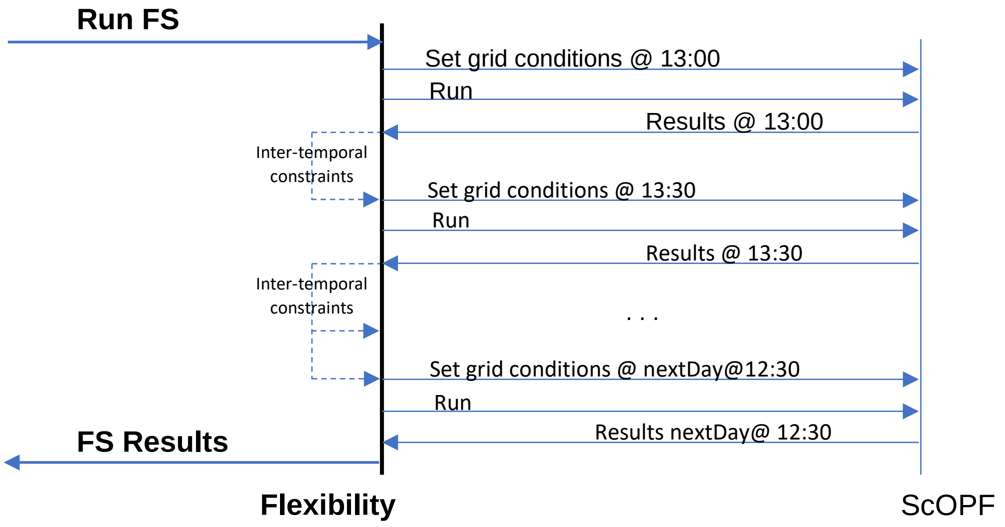


Figure 3-1 – Back-end of the Flexibility Scheduler.

ScOPF is a tool capable of deriving a set of control actions that keep the active and reactive power flows within pre-agreed limits at the primary substation level. Additionally, it can increase the efficiency of the network by optimizing reactive power flows, thus reducing losses. The main innovative features of this software are the following:

a) Integration of different types of flexibility (e.g., flexible generation, capacitors banks and On-Load Tap Changers – OLTCs).
b) Its integration with the FS presents a framework to fully tackle the problem of managing the reactive power flows in the TSO-DSO boundary.

Moreover, this approach also distinguishes itself from other OPFs by considering consecutive periods of analysis using a slide window methodology that considers inter-temporal constraints. This is a NP-hard (Non-deterministic Polynomial) problem that brings the necessity to use an evolutionary optimization algorithm or other meta-heuristic. Since exact methods have an exponential running time as the number of branches and buses of a network increases, the use of a meta-heuristics generally provides a good solution in a very reasonable time.

In general, the objective is to reduce the flexibility operational costs, assuring the proper functioning of the network within a defined timeframe. The tool will define the state of the contracted flexible resources and the resources owned by the DSO for each time interval during the desired operational planning period, aiming to guarantee to the TSO the agreed reactive power and voltage ranges at primary substations.

A high-level integration of the ScOPF in a monitoring and control framework is illustrated in Figure 3-2.

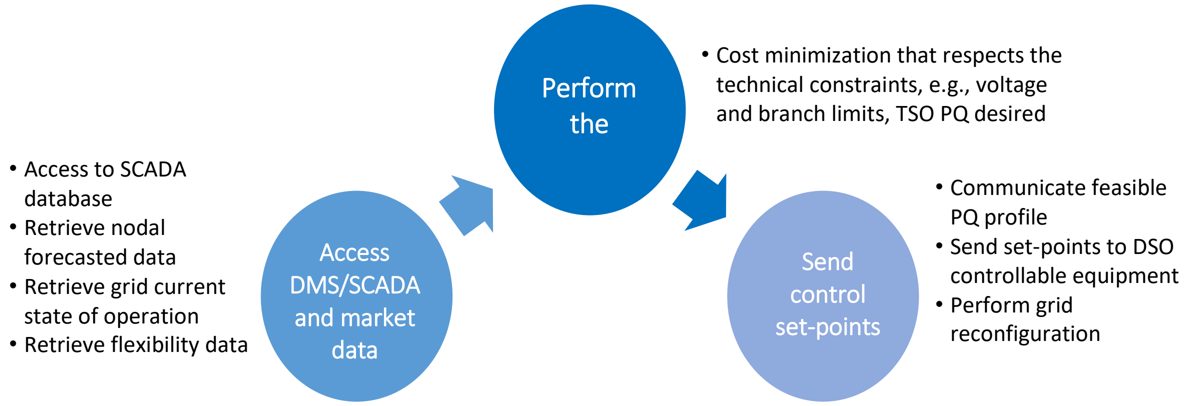


Figure 3-2 – High-level integration of the ScOPF in a monitoring and control infrastructure.

The ScOPF tool is used to define a series of control actions that comprehend, for each defined time frame, the optimal suitable mode of operation, i.e. the one that minimizes the operating cost (e.g., cost of activating flexibility), and respects the pre-agreed PQ profiles at the TSO-DSO interface. The control actions may be composed of updated set points that change the characteristics of operation of specific grid equipment (i.e. transformer taps, generation unit, etc.).

3.2.1 Mathematical Formulation of the ScOPF

The objective of the algorithm is to find a solution with smaller operation costs associated to the activation of flexibility resources and penalties for violating active and reactive power limits at TSO/DSO boundary.

Objective function:

$$\min\left(\sum_{p}\left(\sum_{i} C_{i,p}.P_{i,p}^{FG}+\sum_{j} C_{i,p}.P_{i,p}^{FL}+\sum_{k} C_{P_{k,p}}.F_{P_{k,p}}+C_{losses,p}^{total}.P_{losses,p}^{total}\right)\right) \quad (3.1)$$

Subject to:

Permanent constraints during the simulation:

- Technical limits of branches power flows:

$$S_{ij}^{min} \leq S_{ij}(V_i, \theta_i, V_j, \theta_j) \leq S_{ij}^{max} \tag{3.2}$$

- Technical limits of node voltages:

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{3.3}$$

- All consumers (loads L) should be supplied:

$$S_L^{total} = S_L^{initial} \tag{3.4}$$

$$real(S_L^{total}) = \sum_i P_i^L \tag{3.5}$$

$$imag(S_L^{total}) = \sum_i Q_i^L \tag{3.6}$$

- Maximum and minimum limits of generated (G) power:

$$S_{Gi}^{min} \leq S_{Gi} \leq S_{Gi}^{max} \tag{3.7}$$

- Maximum and minimum limits of flexible generated (FG) power:

$$S_{FGi}^{min} \leq S_{FGi,p} \leq S_{FGi}^{max} \tag{3.8}$$

- Maximum and minimum limits of flexible load (FL) power:

$$S_{FLi}^{min} \leq S_{FLi,p} \leq S_{FLi}^{max} \tag{3.9}$$

- Limits of transformers taps:

$$t_f^1 \leq t_{f,p} \leq t_f^{k_f} \tag{3.10}$$

- Limits of capacitor banks taps:

$$e_c^1 \leq e_{c,p} \leq e_c^{k_c} \tag{3.11}$$

- Network power balance:

$$S_{L,p}^{total} + S_{losses,p}^{total} = S_{G,p}^{total} \tag{3.12}$$

$$real(S_{G,p}^{total}) = \sum_i (P_{i,p}^G + P_{i,p}^{FG}) \tag{3.13}$$

$$imag(S_{G,p}^{total}) = \sum_i (Q_{i,p}^G + Q_{i,p}^{FG}) \tag{3.14}$$

$$real(S_{losses,p}^{total}) = P_{losses,p}^{total} \tag{3.15}$$

$$imag(S_{losses,p}^{total}) = \sum_{ij} B_{ij}(y_{ij,p})(V_i^2 + V_j^2 - 2V_iV_j\cos(\theta_i - \theta_j)) \tag{3.16}$$

- Equations of active power flow on branches and null balance:

$$P_{i,p}^G + P_{i,p}^{FG} - P_{i,p}^L - P_{i,p}^{FL} = V_i \sum_j V_j(G_{ij}(y_{ij,p})\cos(\theta_i - \theta_j) + B_{ij}(y_{ij,p})\sin(\theta_i - \theta_j)) \tag{3.17}$$

- Equations of reactive power on branches and null balance:

$$Q_{i,p}^G + Q_{i,p}^{FG} - Q_{i,p}^L - Q_{i,p}^{FL} = V_i \sum_j V_j(G_{ij}(y_{ij,p})\sin(\theta_i - \theta_j) - B_{ij}(y_{ij,p})\cos(\theta_i - \theta_j)) \tag{3.18}$$

$$G_{ij}(y_{ij,p}) = \begin{cases} G_{ij}, & if\ y_{ij,p} = 1 \\ 0, & if\ y_{ij,p} = 0 \end{cases} \tag{3.19}$$

$$B_{ij}(y_{ij}) = \begin{cases} B_{ij}, & if\ y_{ij,p} = 1 \\ 0, & if\ y_{ij,p} = 0 \end{cases} \tag{3.20}$$

- Inter-temporal constraints:

$$\alpha_{C,i,p}.C_{tap,i,p} = \alpha_{C,i,p}.C_{tap,i,p-1} \tag{3.21}$$

$$\alpha_{T,i,p}.T_{tap,i,p} = \alpha_{T,i,p}.T_{tap,i,p-1} \tag{3.22}$$

- Radiality constraints (guarantees that the number of lines out of service in the beginning of the process is equal in the end of the process):

$$\sum_{ij}(1 - y_{ij,1}) = N_{open}^{inic} \tag{3.23}$$

Decision Variables:

- $y_{ij,p}$ – Topological state of branch ij (1-branch ij in service, 0- branch ij out of service) at period p;
- $t_{f,p}$ – Integer decision variable associated to tap of transformer f at period p;
- $e_{c,p}$– Integer decision variable associated to tap of capacitor bank c at period p;
- $P_{i,p}^{FG}$ – Active power activated by flexible resource i at period p;
- $P_{i,p}^{FL}$ – Active power activated by flexible load i at period p.

Where:

$C_{i,p}$ – Cost of activation of flexibility *i* at period *p* per activated unit;

CPk,p – Penalization cost on substation k by exceeding the active or reactive power limits at period p per exceeded unit;

$C_{losses,p}^{total}$ *– Penalization cost for losses at period p;*

FPk,p – Active or reactive injected power value on substation k that is outside the bounds at period p;

$S_{FGi,p}$ *– Apparent power of flexible generator (FG) i at period p;*

$S_{FLi,p}$ *– Apparent power of flexible load (FL) i at period p;*

S_{G}^{total} *– Total apparent power generated;*

S_{L}^{total} *– Total apparent power consumed;*

S_{ij}^{min} *– Minimum apparent power on branch ij;*

S_{ij}^{max} *– Maximum apparent power on branch ij;*

V_{i}^{min} *– Minimum value for voltage at node I;*

V_{i}^{max} *– Maximum value for voltage at node I;*

N_{open}^{inic} *– Number of lines out of service in the initial configuration;*

S_{Gj}^{min} *– Minimum apparent power of generator i;*

S_{Gj}^{max} *– Maximum apparent power of generator i;*

t_f^1 *e* $t_f^{k_f}$ *– tap 1 (the lower value of taps) and tap kf (the largest value of taps) of transformer f with kf taps;*

e_c^1 *e* $e_c^{k_c}$ *– tap 1 (the lower value of taps) and tap kc (the largest value of taps) of capacitor bank c with kc sections;*

V_i *– Voltage at node i;*

θ_i *– Voltage phase at node i;*

G_{ij} *– Element of nodal admittance matrix (real part);*

B_{ij} *– Element of nodal admittance matrix (imaginary part);*

$P_{i,p}^G$ *– Active power generated at node i at period p;*

$P_{i,p}^{FG}$ *– Active power generated by flexible resources at node i at period p;*

$Q_{i,p}^G$ *– Reactive power generated at node i at period p;*

$Q_{i,p}^{FG}$ *– Reactive power generated by flexible resources at node i at period p;*

$P_{i,p}^L$ *– Active power consumed at node i at period p;*

$P_{i,p}^{FL}$ *– Active power consumed by flexible resources at node i at period p;*

$Q_{i,p}^L$ *– Reactive power consumed at node i at period p;*

$Q_{i,p}^{FL}$ *– Reactive power consumed by flexible resources at node i at period p;*

$S_L^{initial}$ *– Active power generated at node i at period p;*

$\alpha_{C,i,p}$ *– Binary variable which decides if the current tap/position of the Capacitor i is under restriction at period p;*

$\alpha_{T,i,p}$ *– Binary variable which decides if the current tap/position of the Transformer i is under restriction at period p;*

$C_{tap,i,p}$ *– Tap/position of Capacitor i at period p;*

$T_{tap,i,p}$ *– Tap/position of the Transformer i at period p;*

S_{FGj}^{min} *– Minimum apparent power of flexible generator (G) i;*

S_{FGj}^{max} *– Maximum apparent power of flexible generator (G) i;*

S_{FLj}^{min} *– Minimum apparent power of flexible load i;*

S_{FLj}^{max} *– Maximum apparent power of flexible load i;*

As the first equation shows, the objective of this optimization problem is to minimize the operational costs of the flexibilities activated, plus penalty costs for violating the limits on primary substations. For that, the algorithm searches all possible values for the decision variables of the problem, which corresponds to changing the winding turns ratio of a transformer, changing the amount of reactive power injected by capacitor banks and changing the amount of flexible energy that is activated by flexible resources.

The algorithm chosen to solve this problem is the Evolutionary Particle Swarm Optimization (EPSO), along with a heuristic that uses the correlation between decision variables and constraints to favour feasible solutions. This process is depicted in Figure 3-3.

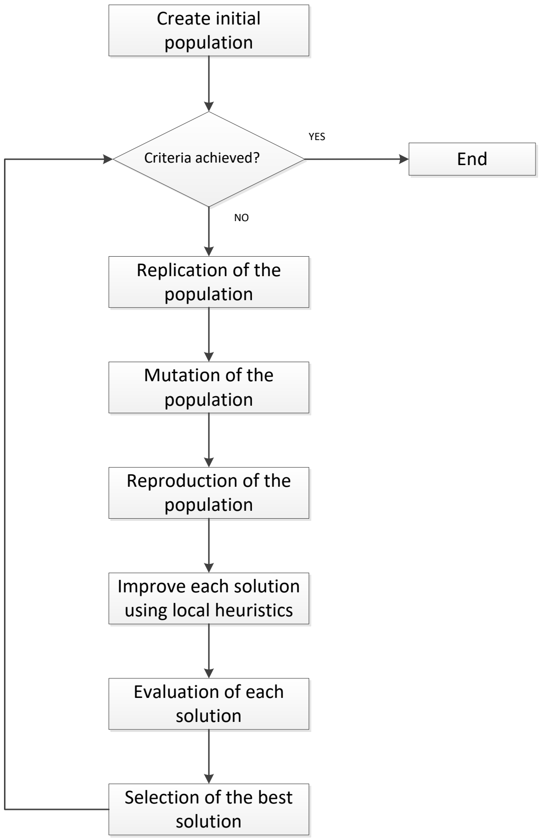


Figure 3-3 – Heuristic methodology to solve the ScOPF.

These steps are repeated until the stop criterion is satisfied. The stop criterion is based on the evolution of the fitness function value of the EPSO method. If the following equation is true the process proceeds, otherwise it returns to the point where it searches for the optimal configuration.

$$\begin{gathered}(\mathrm{fit}_1 - \mathrm{fit}_2) < \varepsilon \\ or \\ iteration > \mathrm{n}_{\max}\end{gathered} \tag{3.24}$$

EPSO is a strategy based on population that creates a set of solutions denominated particles. The particles move in the space of solutions according to their respective positions. Their past positions and the best-found position of the particles set (swarm) until that moment, defines how the particles move. The operator of movement, which is responsible to move each particle, has three terms: inertia – related with past positions of particle, memory – related with the best past position of particle, and cooperation – related with best position found by the swarm. Each of these three terms has different weights that are optimized by EPSO algorithm using the mutation evolutionary algorithms logic.

Concerning voltage constraints, the taps of the transformers and capacitor banks are adjusted in case of violation of voltage limits or branch limits. In distribution networks, the voltage control is typically achieved through transformers and capacitor banks. These types of equipment have taps that can be adjusted in order to maintain the voltage magnitude, at a control node, on a specified discrete value.

3.2.2 Overview of the sequential approach of the methodology

The global simulation can be performed for just one or several periods using a moving window approach. The tool minimizes the losses of the network by optimizing reactive power flows, naturally considering the costs of activation of flexibility.

Between periods, inter-temporal constraints are activated to guarantee that the correct status of an equipment is properly considered since it may have been changed by previous corrective actions in previous periods. Figure 3-4 illustrates the ScOPF tool global idea.

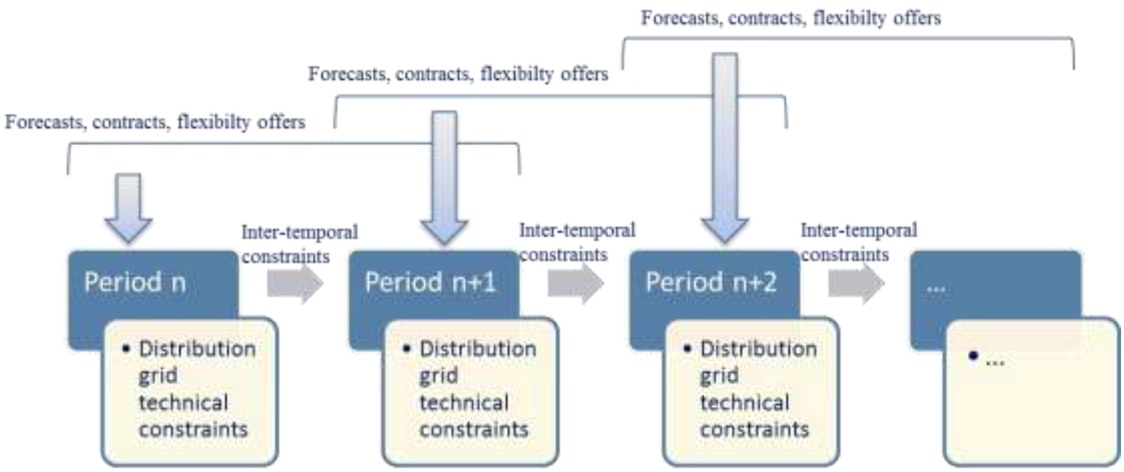


Figure 3-4 – Sequence-constrained OPF (ScOPF) using a moving window approach.

For every period subsequent to the first one, the input data is updated with its respective load power, the relevant information about flexibilities, and the variables related to the inter-temporal constraints. The final solution should be feasible, where all loads are supplied, and the technical limits of the system components are met.

3.2.3 Inputs and Outputs

As illustrated in Figure 3-5, the ScOPF will provide the power profile at each substation and the values for all the control variables. To accomplish this, the module needs information about all the network assets, in terms of their technical characteristics and settings. Then, in order to perform the optimization considering consecutive timeframes, the tool receives, for each period, forecasted data for all the power injection points and the corresponding flexibility.

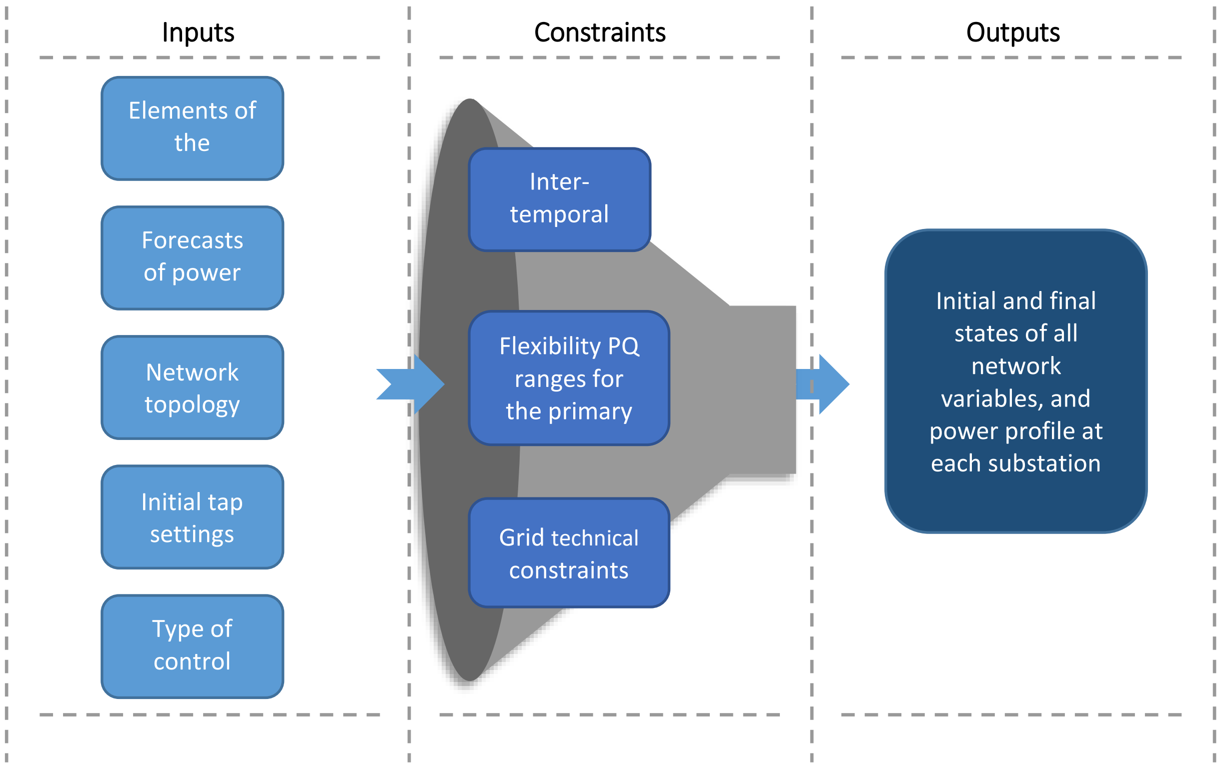


Figure 3-5 – Inputs and outputs of the ScOPF tool.

For voltage control purposes, the tool should run multiple optimizations in order to minimize the costs, while respecting the constraints, for the following 24 hours. Before the activation of any distributed flexible resource, an asset and a grid prequalification should be performed. The asset prequalification is related to the study that identifies if the features of a certain asset are enough to satisfy the needs to solve the constraint in cause. The grid prequalification is a classic power flow analysis and system security analysis that assesses if no negative impacts arise on the grid.

By controlling and balancing the voltage magnitudes of the network nodes, the energy flows are reduced, and thus reducing losses.

3.3 Flexibility Scheduler User Interface

The FS tool software can be used via an interface that processes input data from ASCII text files. In terms of editing, Excel should be used to edit these files to ensure tab-separated values.

The input files are the following:

- Configuration file
- Network file
- Forecast file

- Flexibility file
- Limits file
- Maintenance file

The details of the input files listed above are described in Annex E – Flexibility Scheduler User Interface Details.

3.4 Further developments

The integration within ScateX# was not fully finalized in the OSMOSE timeframe due to the time spent on the development and testing of the algorithm and the non-negligible impact of the COVID19 pandemic context.

Nevertheless, the following chapters present the integration of Flexibility scheduler within ScateX# defined within the OSMOSE project.

Although it was not possible to make the complete integration of FS in the ScateX# product, the main objective of the project was achieved with the development of the algorithm and with the fully test environment, as presented in the previous section.

Considering the constraints presented above we will proceed with the integration of these features in the ScateX# product, outside the OSMOSE project, but in line with the ScateX# roadmap.

3.4.1 Flexibility Scheduler integration within ScateX#

The FS tool will be implemented as a module of EFACEC's ScateX# Supervisory Control and Data Acquisition / Distribution Management System (SCADA/DMS).

The ScateX# system is an open, modular and distributed system for the control and management of a power system. It was designed to provide modularity as a priority. This enables flexible deployment schemes – as single SCADA, single DMS, single Outage Management System (OMS) or as a fully Advanced Distribution Management System (ADMS) either for high voltage, medium voltage or low voltage, safeguarding the client investment in future evolutions of the system.

ScateX# is built upon a real-time cybersecure infrastructure and includes many innovative features that provide quick and easy access to real-time information, improving situational awareness and readily providing enhanced decision support. The set of network, power and outage management applications further leads to efficient operation and network optimization. Featuring openness, flexibility, expandability and performance, ScateX# can scale to meet the needs of large networks and infrastructures, enabling customers to leverage stepwise investment strategies.

The workstation has a fully integrated user interface for the operator. It includes bi-directional navigational and highlighting mechanisms between tabular applications and any kind of diagram. The system provides SCADA and DMS functions based on diagrams, trending, tagging, colouring, tracing and advanced analytical functions constantly monitoring the network.

ScateX# also offers a suite of power applications that are fully integrated with the other SCADA/DMS applications and functions. The power applications, in common with the other ScateX# applications, can be used in two different environments:

- In the “Real-World” environment, over the present network model and state, enhancing the SCADA information available to the operator during network operations;
- On “Study” environments, based on alternative network models that allow studies and simulations to be performed without affecting the Real-World operations, model and power network. The study network models are created from an actual network, current or historical. The network state, formed of the switching state, tagging, network loading, voltage and network flow values, can also be based on Real-World values, current or historical. The user may edit the model and apply these changes within the study, alter switching states, apply and remove tags and adjust loads, flows and voltage values and use values calculated by these power applications. The study environment for a workstation is typically not shared and chosen from a pool of available studies.

The new FS tool will integrate ScateX#’s power applications suite. The figure, below, shows the relevant overall architecture in what concerns power applications:

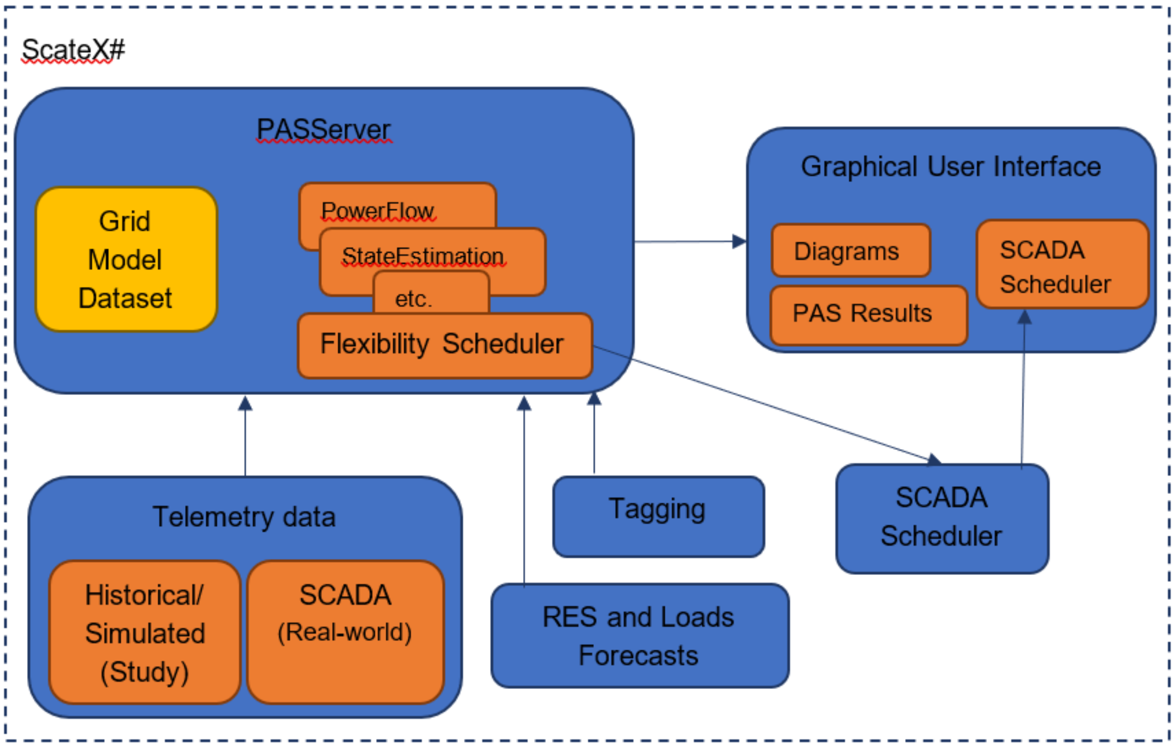


Figure 3-6 – Power applications architecture.

The PASServer is a container that runs power application function modules like “Power Flow” or “State Estimation”, and that will now run the new “Flexibility Scheduler” module. The PASServer provides a running environment to these functions, supplying a grid model and a framework to communicate with client Graphic User Interfaces (GUIs) and telemetered/simulated data and Tagging[3].

[3] Tagging allows to capture manual operations like opening and closing non-telemetered switches.

The grid model, i.e. the topology and electrical characteristics of the grid, exist in a dataset that is shared by all applications running in the PASServer container. This model is generally populated using the ScateX# network editor, although there are some model aspects specific to FS (including FS time constraints) that may be defined elsewhere – the next section will detail these exceptions. The Renewable Energy Sources (RES) and loads forecasts will also be provided to the FS through that dataset, being the forecast files loaded into the dataset, and the FS tool will access this information from the dataset.

The results of the PASServer calculations are displayed in diagrams (typically using labels), but the details are more conveniently presented in the PASResults tabular lists. The FS results include also the list of computed set point actions, which can be scheduled for automatic execution. The Scheduler is a new component that will be added to the ScateX# framework and that will be responsible for the automatic execution of the set points. This scheduler component is not specific for the FS tool, and instead should be able to provide the scheduled execution framework for any SCADA control. This SCADA Scheduler requires a new GUI where the user can manage the planned actions.

There is a PASServer instance running in real-world environment and another PASServer instance running in each study environment. Each one communicates with the data providers and GUIs appropriate for each environment.

3.4.2 Flexibility Scheduler Graphic User Interface design

Similarly to the other ScateX# power applications, the Flexibility Scheduler Graphic User Interface (GUI) should be composed by a control window where the user defines parameters to control each run, and by a user interface showing several lists with the computed results.

This section describes all these GUIs and illustrates them using mock-up pictures. The purpose of these pictures is simply to better understand the GUI description, and not to really present the front-end display of the GUI. Thus, after implementation, it is possible that the GUIs will look differently or have different fields or button names.

3.4.3 Flexibility Scheduler Control window

The FS control window will integrate the already existing PASParameters component that is responsible for showing the “Configuration of energy applications” window.

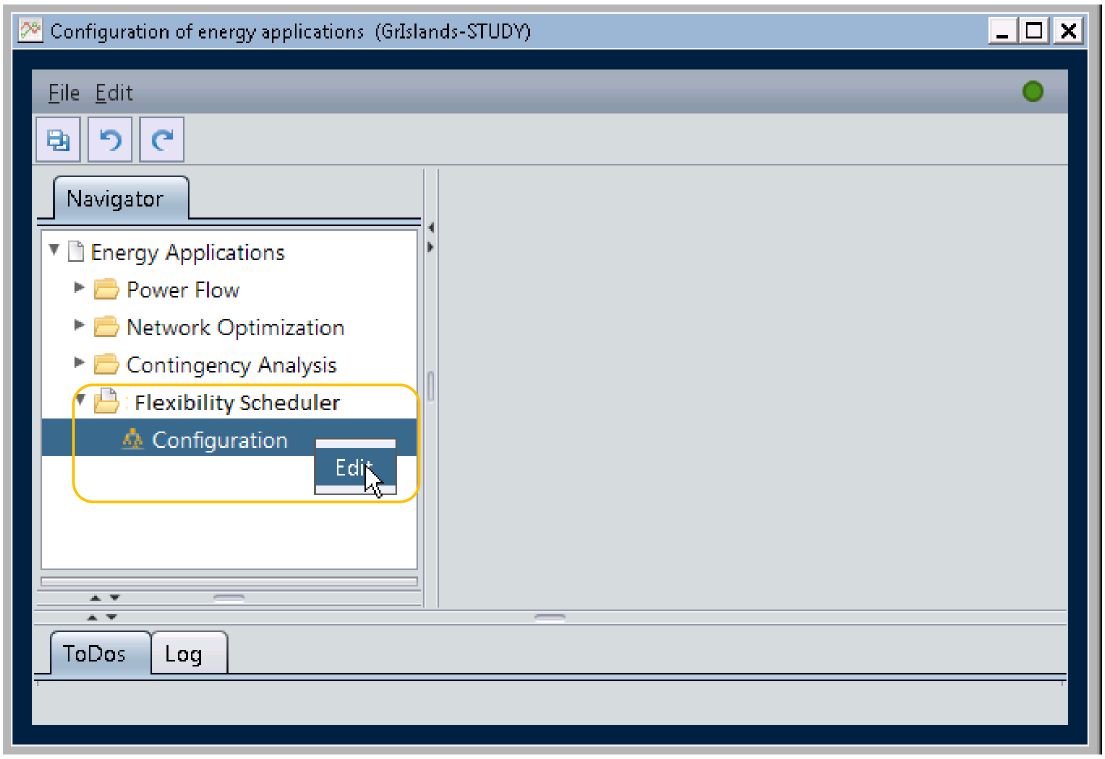


Figure 3-7 – "Configuration of energy applications" window.

The "Edit" option will allow the user to configure all relevant parameters of the FS. These parameters are similar in real world and in study environments, and are presented in the mock-up picture below:

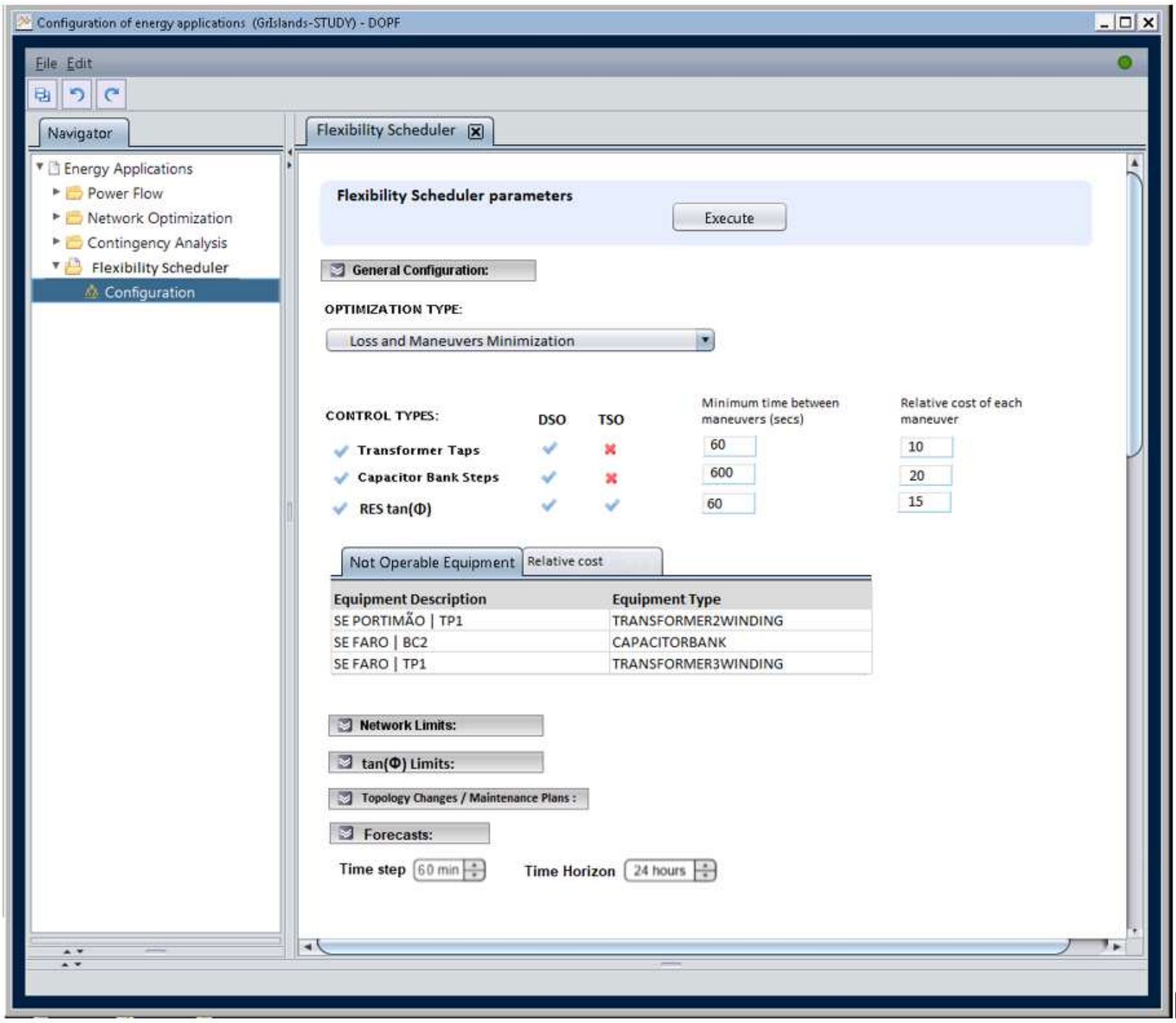


Figure 3-8 – "Flexibility Scheduler" control window.

This window shows the FS main control parameters directly in the GUI, and offers collapsible areas where, after expansion, the user may define other aspects.

Main control parameters:

<u>Optimization type:</u>

Selects the optimization function to be used by the Optimal Power Flow (OPF).

In the scope of the OSMOSE project, this drop-down will only offer the "Loss and Manoeuvres Minimization" option, meaning that the optimization function will try to minimize both grid losses and the costs of the manoeuvres. The rationale is that each manoeuvre has a relative cost, which can be defined in this window – see below.

In the future, other options may be available in this drop-down menu.

Control types:

This area allows the user to define which flexibility sources should be considered during the next FS run. Consequently, the FS results may only include set points for types of controls that have been selected ✓ by the user.

According to requirements C1 and C2, the user may select one or many of the 6 control types:

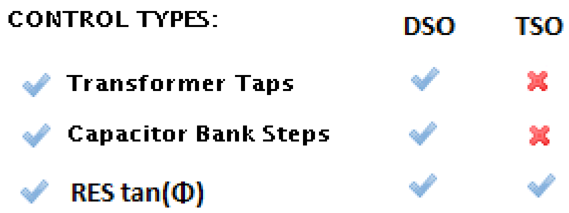


Figure 3-9 – "Control Types" area.

In the figure above, each checkbox on the left controls the corresponding two checkboxes DSO and TSO. That is, if the user toggles the checkbox on the left, then this affects both checkboxes on the right.

Note that the separation between DSO and TSO is an artificial segmentation of the resources, that have interest for OSMOSE simulations, but doesn't seem to reflect properly the DSO's reality[4]. It can contribute to the automation of the distribution network optimization process, considering the existing and available resources at the TSO/DSO frontier after the results of OSMOSE have been fully integrated in the ScateX# product for commercial exploitation.

In addition, the user may define that some of the individual resources should not be considered by the FS tool, meaning that the FS tool will not propose any set points for these resources (requirement C3). This can be done adding the corresponding equipment to the "Non-operable equipment" table, using ScateX#'s "pick and drop" paradigm (select the "Go To" tool, apply it on any equipment representation and then again on the table).

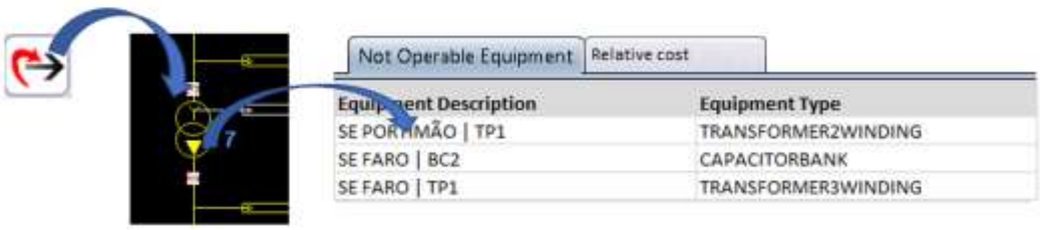


Figure 3-10 – "Non-operable equipment" table.

In this area the user may also define, for each control type, the "Relative Cost of Each Manoeuvre". The ScOPF will assign a cost to each manoeuvre, based on the defined "Relative

[4] Which according to Requirement G1 is the target of this function.

Cost”. As explained above, the optimization function will try to minimize the sum of the relative costs of all proposed actions.

These parameters can be defined globally but can also be defined for each individual resource. A global value is only used if no individual definition exists for a given resource.

In the case of the relative cost definition, the individual definition can be done adding the corresponding equipment to the “Relative cost” table, using the ScateX#’s “pick and drop” paradigm, and then manually entering a value for the “Relative cost” in that table:

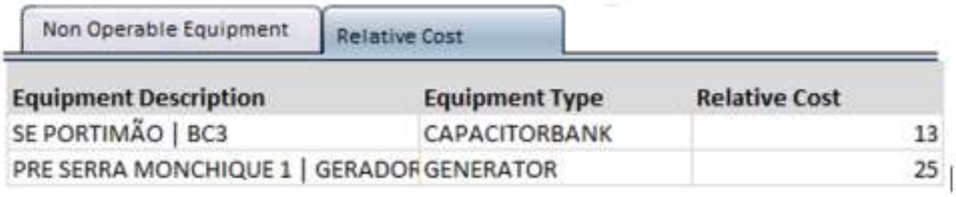


Figure 3-11 – "Relative Cost" table.

In this table, the columns “Equipment Description” and “Equipment Type” are automatically filled (and not editable). The “Relative cost” column is editable.

The rest of this section describes the collapsible areas available at the bottom of the GUI (Figure 3-8).

General configuration:

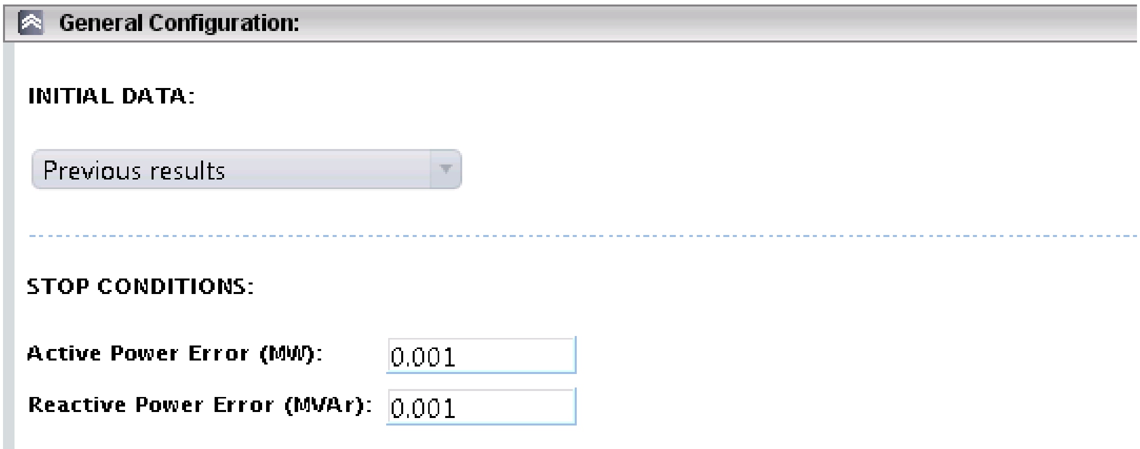


Figure 3-12 – "General Configuration" area.

This area allows the user to define some aspects related with the numeric calculation of the ScOPF algorithm.

Initial data: the drop-down menu will offer only the “Previous results” option, meaning that the iterative algorithm will start from the previous results dataset;

Stop conditions: the user may define here the numerical errors to be used as stop conditions of the iterative algorithm.

Network limits:

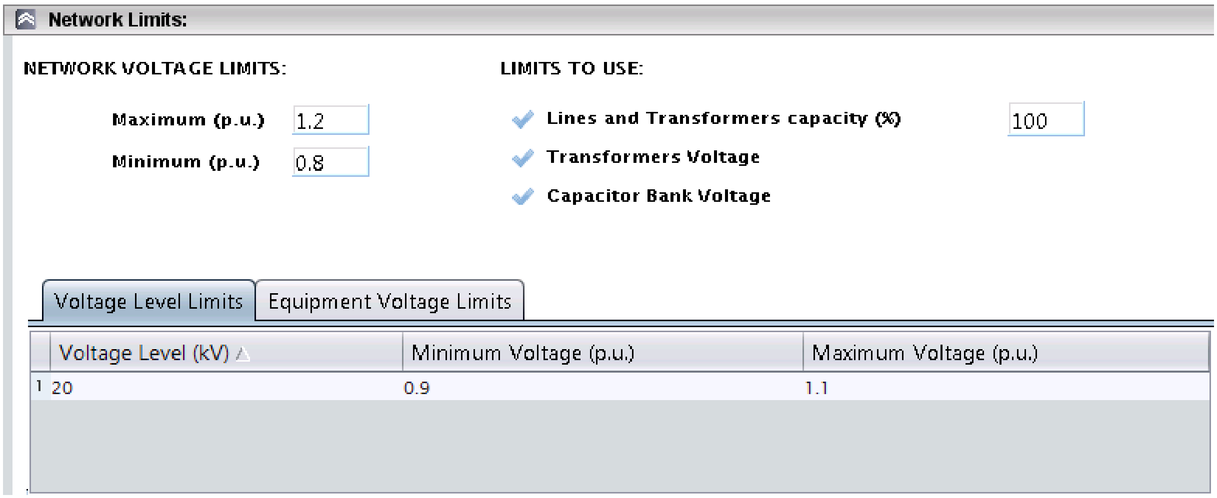


Figure 3-13 – "Network Limits" area.

In this area, the user may define the network limits, referred in requirement I6, that should be respected by the OPF function:

- The maximum and minimum voltage values in any node of the modelled grid;
- The maximum capacity that should be considered for lines and transformers.

In addition, the user may define exceptions to these limits, by defining specific limits for certain equipment, and by choosing to ignore the limits validation on some types of equipment. The details on how to do this are presented next.

<u>Network voltage limits:</u>

The user may define globally the maximum and minimum voltage limits for any node.

The user may also define different voltage limits for certain voltage levels: the user creates a new line in the "Voltage Level Limits" table, manually enters its "Voltage Level (kV)" and then defines the acceptable maximum and minimum voltage limits for given voltage levels (as illustrated in Figure 3-13).

The user may also define different voltage limits for specific equipment (requirement I10), by creating the corresponding entry in the "Equipment Voltage Limits" table:

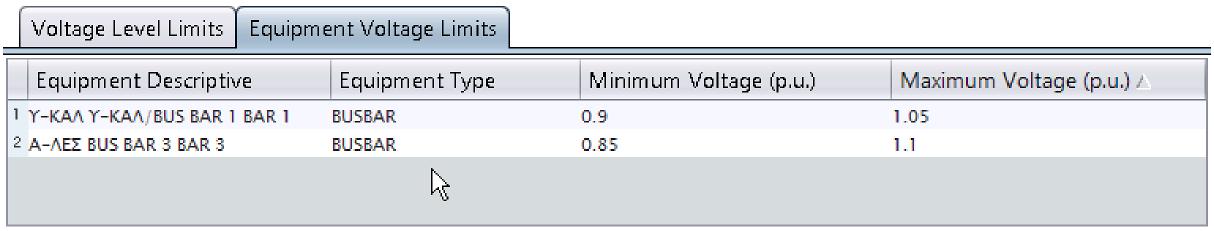


Figure 3-14 – "Equipment and Voltage Limits" table.

To create a new entry in this table the user should use the "Pick and Drop" feature (select the "Go To" tool, apply it on any equipment representation and then again on the table). After creating a new entry, the “Equipment Description” and “Equipment Type” columns are automatically filled (and are nor editable) with the characteristics of the picked equipment. Then the user manually fills the minimum and maximum voltage limits for that equipment.

In conclusion, the voltage limits for an equipment are defined as follows:

1. If there is an entry for that equipment in the “Equipment Voltage Limits” table then the tool uses these limits;
2. Else, if there is an entry in the “Voltage Level Limits” table for the voltage level of that equipment then it uses those limits;
3. Else it uses the voltage limits globally defined.

<u>Limits to use:</u>

The user may define which limits should be validated by the tool. The user may activate ( ) or deactivate ( ) the validation of the following types of limits:

- Ensure that the maximum capacity of lines and transformers is not exceeded;
- Validate/don’t validate voltage limits in transformers;
- Validate/don’t validate voltage limits in capacitor banks.

tan(Φ) limits:

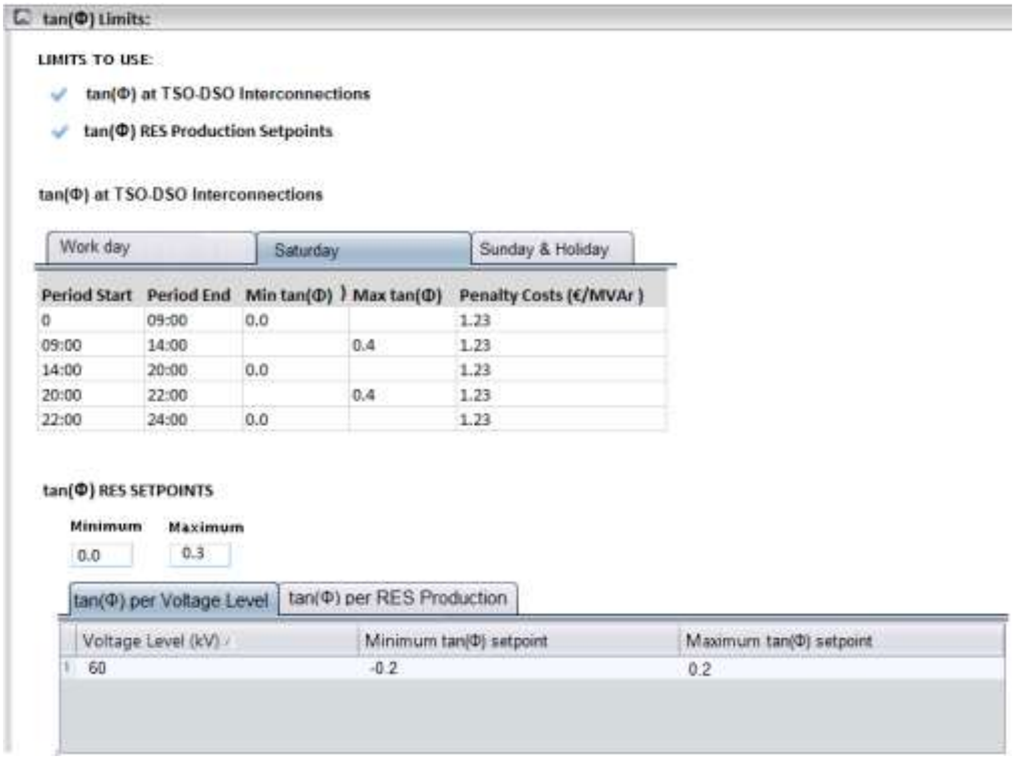


Figure 3-15 – "tan(Φ) Limits" area.

In this area the user may define the tan(Φ) limits, referred in requirements I8 and I9, that should be respected by the OPF function:

The user may activate (✔) or deactivate (✖) the enforcement of the following types of limits:

- tan(Φ) limits at TSO-DSO interconnections;
- tan(Φ) limits in Renewable Energy Sources (RES) production set points.

tan(Φ) limits at TSO-DSO interconnections:

If this option is activated, then the ScOPF will try to set the operation point in the TSO/DSO interface nodes within specified limits. These limits may change, depending on the time period. If no solution can be found within the defined tan(Φ) limits, then the tool should calculate the reactive power penalty costs (as result of violation of the regulated limits).

The user may define different tan(Φ) limits for different periods by filling the time tables for "Work Day", "Saturday" and for "Sunday & Holiday". In each time table the user must split the day into different periods, by specifying a "Period Start" and a "Period End". The application must ensure that the 24 hours of the day are fully, uniquely, covered in the time table. For each period the user may define the minimum and/or maximum tan(Φ) limits for that period. The user must also define the reactive power penalty cost for each period (in € / Mvar) to be used by the algorithm to calculate penalty costs when no appropriate solution is found (i.e. the optimal solution found violates some tan(Φ) limits).

tan(Φ) limits in RES production set points:

This option allows the user to define limits to the tan(Φ) set points sent to renewable generators. If this option is not active, then the ScOPF will be free to propose set points in any range.

Note that this option is meaningful only if the "RES tan(Φ)" control is active. The main control "RES tan(Φ)" was already described above (see the Main control parameters section above), and it allows the user to choose if the set points should be calculated only for renewable generators directly connected to the distribution grid, only for those directly connected to the transmission grid, or for any renewable generator. In addition, the "Non-operable equipment" table described above allows the user to individually identify the renewable generators for which no set point should be calculated.

The tan(Φ) limits for the ScOPF proposed set points can be globally defined using the "Minimum" and "Maximum" fields illustrated in Figure above.

The user may also define different tan(Φ) set point limits for certain voltage levels: the user creates a new line in the "tan(Φ) per Voltage Level" table, manually enters the "Voltage Level (kV)", and then defines the acceptable maximum and minimum tan(Φ) set point limits for the generators at this voltage level. This feature will allow the user to define different limits for generators directly connected to the transmission grid and for renewable generators connected to the distribution grid, because in practice these generators will have different voltage levels (this corresponds to requirement I8).

The user may also define different tan(Φ) set point limits for specific generators, by creating the corresponding entry in the "tan(Φ) per RES Production" table:

tan(Φ) per Voltage Level | tan(Φ) per RES Prodution

	Producer Description	Producer Type	Minimum tan(Φ) setpoint	Maximum tan(Φ) setpoint
1	XPTO 1	WIND	0.1	0.3
2	XPTO 2	P.V.	-0.1	0.2

Figure 3-16 – “tan(Φ) per RES **Production**” table.

To create a new entry in this table the user should use the “Pick and Drop” feature already described. After creating a new entry, the “Producer Description” and “Producer Type” columns are automatically filled (and are nor editable) with the characteristics of the picked equipment. Then the user manually fills the minimum and maximum tan(Φ) limits for the generator(s) of that producer.

Topology Changes / Maintenance Plans:

Topology Changes / Maintenance Plans

Topology Changes

	Switch Description	Switch Type	State	Time
1	Y-KAΛ Y-KAΛ	BREAKER	OPEN	13:00
2	A-ΛΕΣ	SECTIONALIZER	CLOSE	15:00

Figure 3-17 – "Topology Changes" area.

The state of the switches is modelled in ScateX# with “tags” that can be applied over the switches normal state (the normal state being defined in the editor) – if the switch is in its normal state, then no tag is applied. Therefore, “tagging” is ScateX#’s strategy to handle abnormal conditions, and this applies to every aspect of the grid, not only to the state of the switches.

These tags are managed by ScateX# to reflect the reported or wanted state. For example, tags may reflect telemetry live data (in real world mode only), telemetry historic data (in study mode only) or manually operated equipment state (real world and study modes).

In general, the FS tool will consider the current network configuration, i.e., it will consider the tags that are present at the time the tool runs. However, the tool should also be aware of the planned topology changes for the near future that could affect ScOPF results. These topology changes may also be motivated by maintenance plans whose purpose is to isolate some equipment.

These planned topology changes correspond to planned tags, and it is noticeable that there is a close relationship between these tags and the corresponding planned tags created in the scope of the ScateX# switching orders function. However, ScateX# switching orders model should be reviewed, allowing for a more flexible interface with FS concerning the planned topological changes.

For this reason, within OSMOSE, the FS tool control window will offer a “Topology Changes” table, independent of the switching orders function, where the user can enter the planned switch state changes for the day-ahead timeframe.

To create a new entry in this table the user should use the “Pick and Drop” feature already described, to capture switches. After having created a new switch entry, the “Switch Description” and “Switch Type” columns are automatically filled (and are nor editable) with the characteristics of the picked switch. Then the user manually fills the new planned switch state (toggling between OPEN/CLOSE) and the planned time for that change. The user only needs to fill “hour:minutes” because it is implicit that this time is within the day-ahead timeframe.

Forecasts:

The FS tool considers the loads and the renewable production forecasts for the day-ahead timeframe,

Within the OSMOSE project no real forecasts will be used and instead simulated data (based on historic real data) will be used. For this reason, the “Forecasts” area of the FS control window will let the user enter data manually, either by introducing data, record by record, or by importing a ASCII file with such data. Later, outside OSMOSE scope, the ScateX# product should offer a way to import equivalent data from an external provider.

The user starts by defining time related parameters for the scheduler in the “Main Control Parameters” area:

- The “Time Horizon” that should be considered during a single run of the tool (for example “24 hours” allows a day-ahead predictive management);
- The “Time Step” which results in the discrete time instants that should be considered during that time horizon. For each of these instants, each OPF will run considering the grid conditions predicted for that instant and will present the optimized solution for that instant.

Figure 3-18 – "Time Settings" related fields.

After filling these values, it is not possible to modify them unless the forecasts tables are empty (see below).

The “Loads Forecast” table should define the active power forecast values for all loads at all time step instants within the defined time horizon. The interaction with the table illustrated in figure below aims to satisfy this purpose.

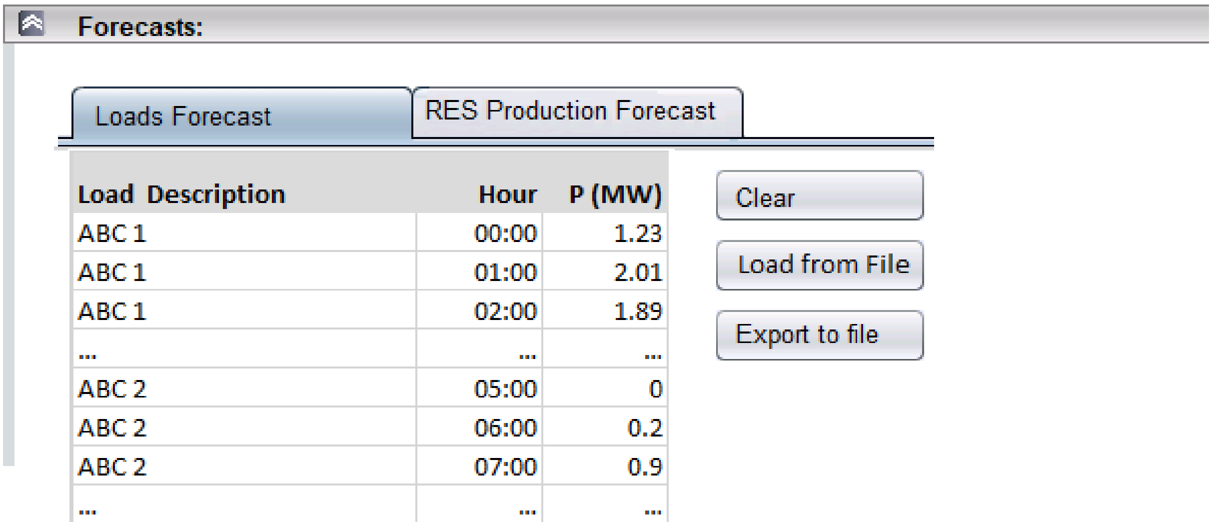


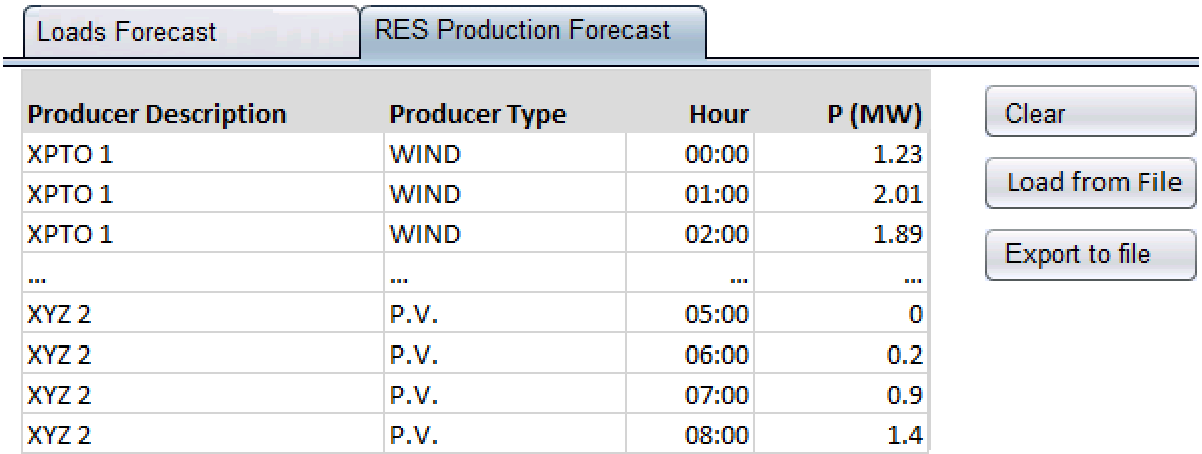
Figure 3-19 – "Loads Forecast" table.

The button “Clear” destroys the previous contents of the table and creates a new table with *L*T* lines, where *L* is the number of loads modelled in the system and *T* is the number of time steps during the time horizon (thus, there will be *T* lines for each load). The “Load Description” and the “Hour” columns are automatically filled for all lines and cannot be edited by the user. The “Clear” action leaves the active power *P* values unset.

The user may now manually fill *P* values for all loads at all time instants. However, instead of doing that manually, the user can do the following steps:

- The user presses the “Export to File” button. This creates a Comma Separated Values (CSV) file with the current content of the table, including an additional column: the ScateX# internal ID of the load.
  (Note that at this time – after having cleared the table – the CSV file will have no values for *P*.)
- Then the user opens the file in an application like Excel to fill the *P* values for all lines. The user will typically use some Excel operations to merge forecasted *P* values (existing probably in other datasheets) into the CSV file. These merging operations should be based on the “Load Description” column. Besides filling the *P* column, no other operation should be made on the CSV file;
- Then the user presses the “Load From File” button and supplies the CSV file produced above. The GUI imports this file using the load internal ID + hour as the key of each line. The result is that the *P* values are now displayed in the “Loads Forecast” table (Note that the internal ID is used to load the file but is not displayed in the GUI.)

The “RES Production Forecast” table should define the active power forecast values for all renewable generators at all time-step instants within the defined time horizon. This table should be filled similarly to what was described above. In this case the columns “Producer Description”, “Producer Type” and “Hour” are automatically filled during “Clear” (and cannot be edited) and the user should fill the “P (MW)” values.



Producer Description	Producer Type	Hour	P (MW)
XPTO 1	WIND	00:00	1.23
XPTO 1	WIND	01:00	2.01
XPTO 1	WIND	02:00	1.89
...	...	...	...
XYZ 2	P.V.	05:00	0
XYZ 2	P.V.	06:00	0.2
XYZ 2	P.V.	07:00	0.9
XYZ 2	P.V.	08:00	1.4

Figure 3-20 – "RES Production Forecast" table.

Running the tool:

After defining all parameters, the user may press the “Execute” button to run the FS.

The tool runs the ScOPF algorithm, described in section above, for the inputs defined in the FS control window. During the calculations, the control window changes the “Execute” button to indicate that the calculations are in progress:

Figure 3-21 – "Executing" button.

This button returns to the normal aspect when the calculations are finished. The user may consult the results of this run in the PAS Result GUI, which is described in the next sub-section.

3.4.4 Flexibility Scheduler Results

The results of the FS could be presented by the PAS Results GUI application. After running the FS, a new tab separator is added to the FS results window. The name of this tab identifies the date/time when the FS tool has run (e.g. in the figure “Flexibility Scheduler @2019.03.18 12:45”):

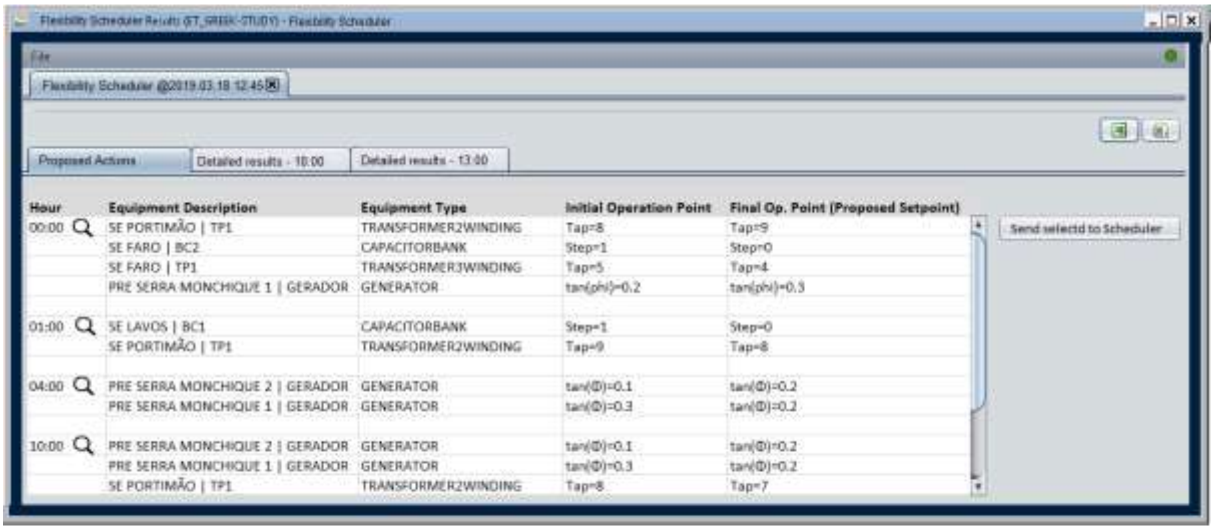


Figure 3-22 – "Flexibility Results" window.

Like in any other ScateX# PAS Results application, the button  allows the user to export the FS results to an Excel file. This file contains a different datasheet for each tab separator shown in the GUI. The button  is similar, but in this case, it creates multiple CSV files with the same data.

Initially, the results are shown with only the "Proposed Actions" separator. Later, new other separators for "Detailed results" can be created by the user (see below).

The "Proposed Actions" separator presents a list of suggested actions for the chosen resources and according to the parameters defined in the control window. Each action is planned for a time step in the defined time horizon. Besides identifying the flexibility resource, this list shows also the current set point at that time step, and the new set point proposed by the FS to be executed at that time.

The list presents actions grouped by time step instant. In the time column there is a "View" icon  that lets the user view the details of the calculations for that time instant. When the user presses this button icon, a new "Detailed results – *hh:mm*" separator tab is created, as illustrated in the figure below.

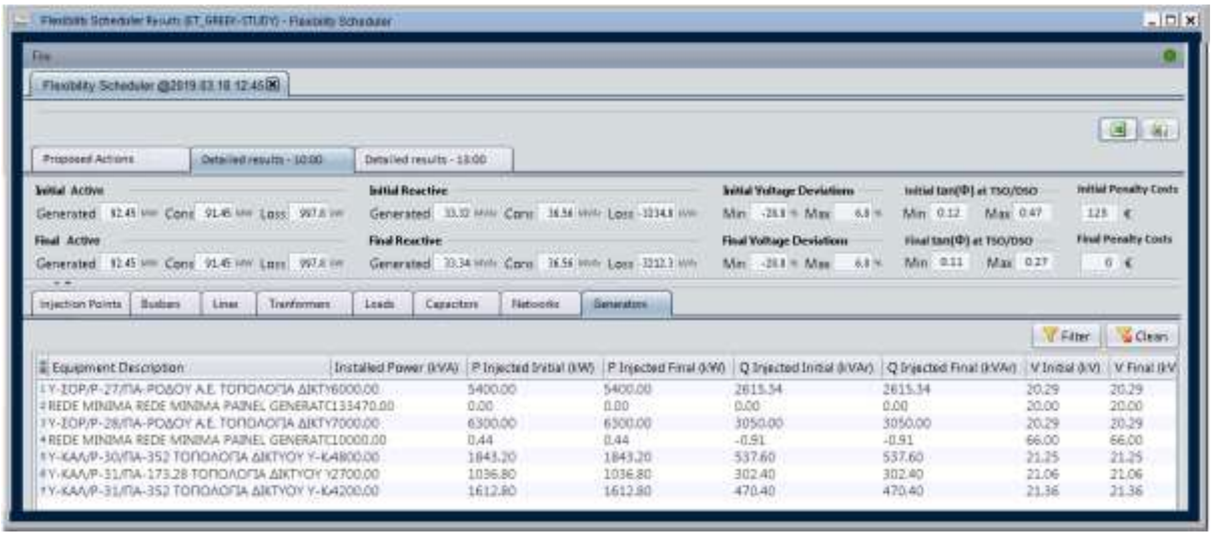


Figure 3-23 – "Detailed Results" separator.

This tab separator presents the global computed metrics for the grid in the initial operation point and in the operation point resulting from executing the block of proposed actions at the considered time step instant. This includes the following computed global results (before and after execution of the actions):

- Generated active and reactive power;
- Consumption active and reactive power;
- Active and reactive power losses;
- Maximum and minimum voltage deviations;
- Maximum and minimum tan(Φ) at TSO/DSO interface;
- Reactive power penalty costs resulting from the violation of the defined tan(Φ) limits at TSO/DSO interface;

The Filter buttons 

allow the standard tabular filtering features that are available in ScateX# PAS Results applications.

In addition to the global metrics described above, it is also possible to consult the results for each type of equipment modelled in the grid. For example, the figure above illustrates the results for generators, showing columns for the injected active and reactive power and for Voltage, before and after executing the proposed set of actions.

There is also the "Injection Points" table that aims to present the same metrics referred above but calculated at each TSO/DSO interface node. As illustrated in the figure below, this table identifies the interface node and displays the generated and consumed *P* and *Q*, the losses, voltage and tan(Φ) at this interface node, before and after executing the proposed set of actions.

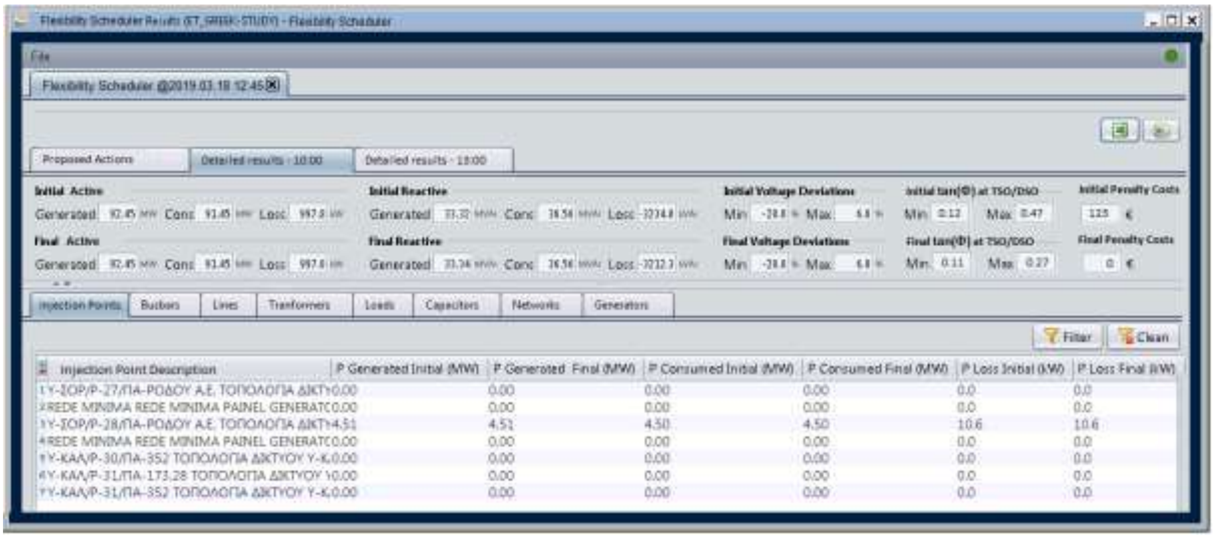


Figure 3-24 – "Detailed Results - Injection Points" table.

3.4.5 Executing the Proposed Actions

There will be two different manners of executing the actions displayed in the "Proposed Actions" list:

- **Execute each action individually:**
  The user right clicks on the corresponding line and selects the "Execute" menu option.
  This means that there is no real scheduling and the user is responsible for executing each action when convenient
  This could be used for test purposes, within the OSMOSE validation task, but it is not expected to be used frequently in real operation
- **Schedule the execution of selected actions:**
  The user selects some lines in the "Proposed Actions" list (normally he will select all lines) and then presses the "Send Selected to Scheduler" button 

  .
  The selected lines are sent to the SCADA Scheduler, which is responsible for automatically execute actions at scheduled instants.

As explained in section 3.4.1, the FS may run in real world or in study environments. The overall user interaction and results presentation is similar in both environments, but the main difference is the control actions over the grid equipment in the real-world vs the simulated environment in study mode. In study mode the operator may execute the proposed FS controls and further validate in a simulated environment the expected results running power flows.

3.5 Summary on the Flexiblity Scheduler Arquitecture Design

This chapter characterises the FS tool developed within the scope of the project. It gives also an insight over its architecture, including the functional modules and interfaces implemented.

The described architecture is comprehensively characterised and explained on a user interaction perspective. Similiarly, the proposed modules to schedule and manage flexibility according to a set of operational goals, execute and validate the required actions are also characterized. This provides fundamental guidelines to understand and explore the potential of the presented tool.

The FS tool is a solution to manage flexibility, framed in different operational time horizons (e.g., near real-time operation, operational planning), and implements optimal reactive power management actions to handle technical challenges (e.g., balancing, voltage control) in the interconnected system's operation. The interaction between TSOs and DSOs is the focus of the implementation, based strictly in the efficient management of the reactive power. Despite from being technically feasible, the implementation of active power management in the FS is out of the scope of the project, standing as a potential development to address in a future expansion of the FS tool.

4 Laboratorial test setup

In this section, the laboratorial setup used to test and validate the FS tool will be described in detail. The operational scenarios considered for the FS tool testing will be presented and characterized. Also, the network models considered in each simulation tool, FS tool and RTPSS (OPAL/Hypersim), will be presented and described. Finally, the use case and sequence diagram implemented to simulate the exchange of information between the TSO and the DSO for the reactive power optimisation will be described, including the optimisation and the validation of the optimisation results.

For the validation of the FS tool the transmission network area around the city of Porto, Portugal was selected. More precisely two VHV/HV substations, and a distribution circuit (60kV) that connects both VHV substation through the distribution network (which is not visible in Figure 4-1, but is described in sections 4.2 and 4.3). In Figure 4-1, 400kV lines are represented in red, 220kV lines in green.

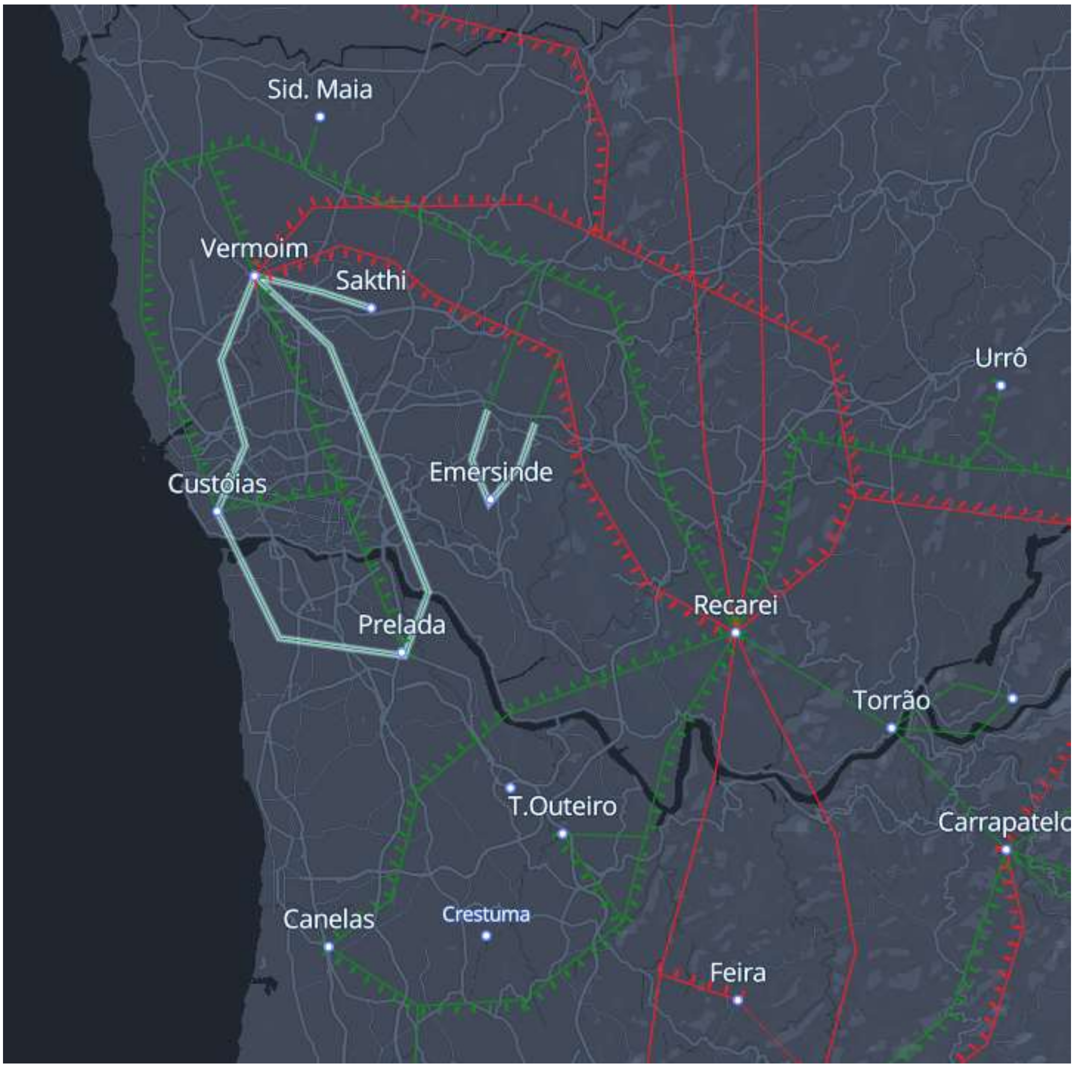


Figure 4-1 – Transmission network area selected for the test case [24]

As the information about the distribution network is scarce (due to the lack of publically available information about the distribution network area), a representative model was created and used in the FS tool by EFACEC.

Generally, the distribution network (60kV) is not represented in the transmission network model, as it is not part of the transmission network, except for the 60kV bus bars of the transmission substations. The distribution grid is thus, generally represented through loads representative of the entire (net) load connected to the distribution substation on the other end of the distribution line. The exception to this are the areas where the DSO operates the distribution network with a meshed topology, as opposed to the usual radial topology. In that case, the TSO normally has an area of observability that encompasses part of the distribution network in order to be aware of power flows between its transmission substations through the distribution grid.

The simulations done in this project focus, precisely, on a zone of the grid where the distribution network interconnects two transmission substations, allowing for the operation of the distribution grid(s) by the DSO in both meshed and radial topologies. Furthermore, there is renewable generation present in the distribution grid, which may cause situations in which power flows from distribution to the transmission level.

4.1 Operational scenarios

In the simulation of power systems, the use of operational scenarios to describe potential circumstances that may occur is a common approach from network planners. The objective of the operational scenarios is to consider the effect on the grid of different variables (e.g. generation, load or topology changes). In this case, and considering the use case “Validation of the optimal operational schedule from the DSO Flexibility Scheduler System” that will be described in more detail in section 4.4, the variables considered for the creation of the scenarios were:

1. **Topology**: operational state of the distribution mesh connecting the two VHV substations (open mesh and closed mesh)
2. **RES**: level of renewable resources present in the distribution network. For this purpose in the high RES scenario it was considered 2 additional RES generators (1 wind power plant and 1 solar power plant) connected at the distribution network, while in the low RES scenario only the existing generation was considered.
3. **Availability of transmission assets**: the availability of the transmission flexibility assets (i.e. shunt capacitors’ banks at VHV substations), which can be either available or not available for the optimisation process.
4. **Optimisation objective**: the 2 optimisation options from the FS tool (i.e. according to total losses or costs).

The topology and availability of transmission assets scenarios are configured in the “Flexibility file” and “Maintenance file”. On the one hand, in the “Maintenance file” the network operation plan (e.g. switching, reconfiguration) is reflected with the operation planned for the day-ahead (e.g. connection of capacitor banks), while the assets available for ScOPF optimisation are included in the “Flexibility file”.

Additionally, the forecast of generation and load was based on real historical data from the transmission area considered. This information is mapped into the “Forecast file” for each hour as part of the set of configuration files from the FS tool.

Furthermore, for the consideration of reactive power tariffs associated with the tan(Φ) (ratio between reactive power and active power) of the generators and at the interconnection between the transmission and distribution networks (in this case NetCons), which differ depending on the hour of day as follow:

- From 22:00 to 08:00
  - tan(Φ) of the generators should stay between the range of [-1; 1]
  - tan(Φ) of the NetCons should stay between the range of [0; 1]
- From 08:00 to 22:00
  - tan(Φ) of the generators should stay between the range of [-0,2; 0,2]
  - tan(Φ) of the NetCons should stay between the range of [-1; 0,3]

These operational limits were included in the “Limits file” from the FS tool for each hour with an associated cost, which would be applied in case the operation point of the generators goes beyond the established limit for the simulated hour.

Figure 4-2 depicts the organization of the 16 test cases resulting from the combination of the 4 variables that constitute the operational scenarios.

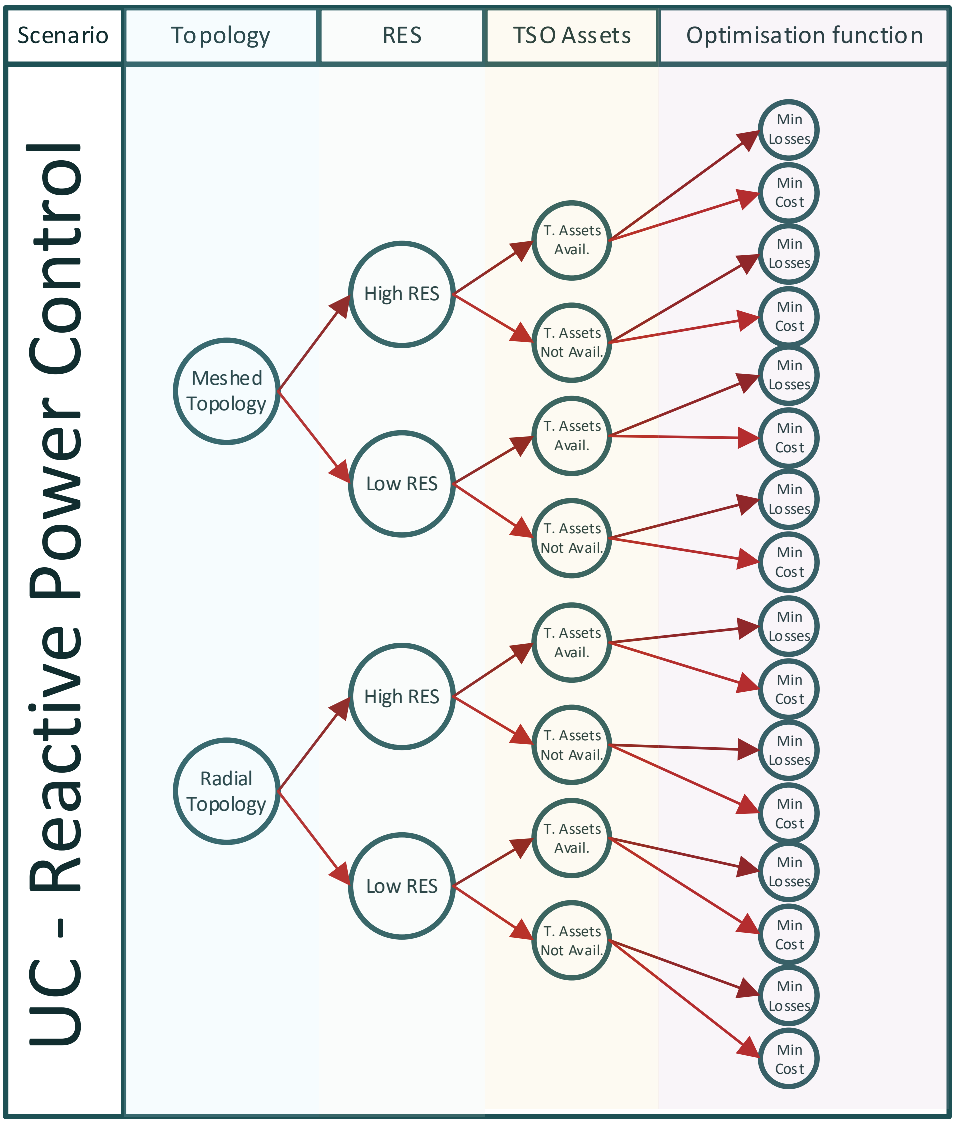


Figure 4-2 – Operational scenarios considered for the test cases

4.2 Flexibility Scheduler tool network model

The Flexibility Scheduler (FS) tool takes into account an artificial network model representative of part of the distribution network existing in the area selected for the FS validation tests. Figure 4-3 shows a high-level representation of the distribution network single line diagram modelled in the FS tool.

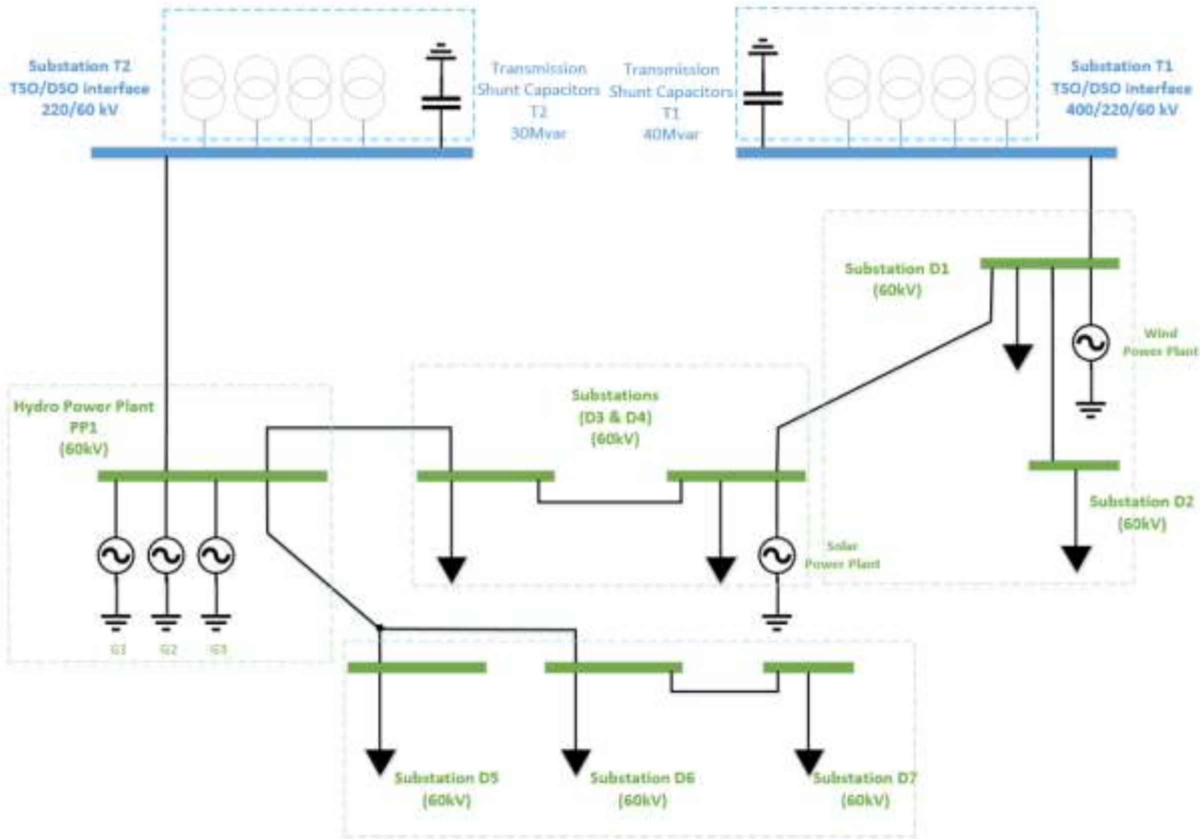


Figure 4-3 – Flexibility Scheduler network representation

In Figure 4-3 it is possible to see the two transmission substations (i.e. T1 and T2), partially represented as two pairs of four transformers, also described as equivalent network connections (Netcons) in the FS model. The distribution (60kV) mesh is composed of 4 major subsets of substations, including:

1) The D1 substation, which comprises a load connection, one wind power plant of 3.4 MW and a connection to secondary substation (D2).
2) The D3 and D4 substations interconnected with each other, loads and a solar power plant of 1.2 MW.
3) The PP1 substation represents a hydropower plant, which includes 3 generators of 35MW each.
4) Lastly, the subset of D5, D6 and D7 substations.

Table 4.1 provides more details about additional network characteristics and Figure 4-4 presents the load diagrams of the 3 distribution substations subsets which contain loads.

Table 4.1 – Flexibility Scheduler network model

Asset	# of assets	Total installed capacity at transmission level (in MW/Mvar/MVA)	Total installed capacity at distribution level (in MW/Mvar/MVA)
Nodes	216	-	-
Lines	28	-	-
Generator	5	-	109,6
Load	11	-	-
Power Transformer	17	1084*	241
Shunt capacitor	8**	70	24,7

* Equivalent Netcons capacity

** 2 capacitor banks in the transmission network and 6 capacitor banks in the distribution network

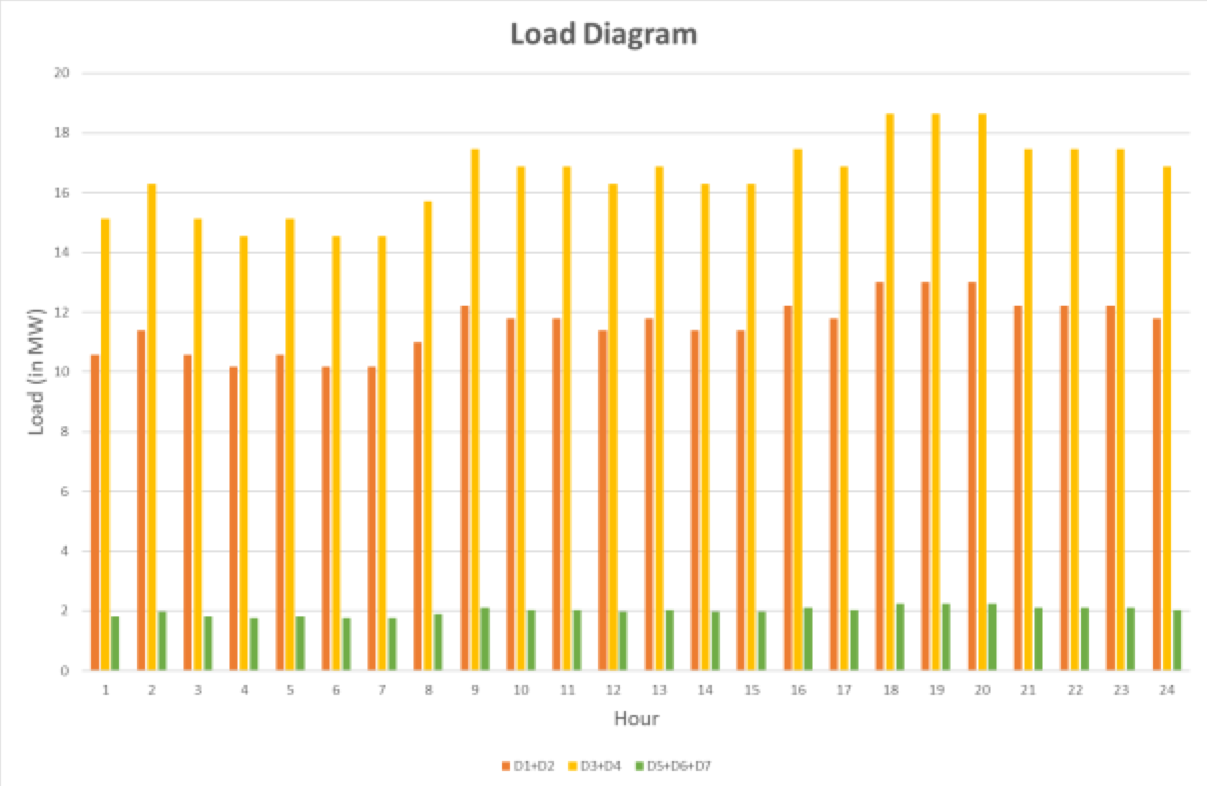


Figure 4-4 – Load diagram of the distribution substations' subsets

In terms of renewable generation, the generation profiles considered in the use cases are presented in Figure 4-5, Figure 4-6 and Figure 4-7.

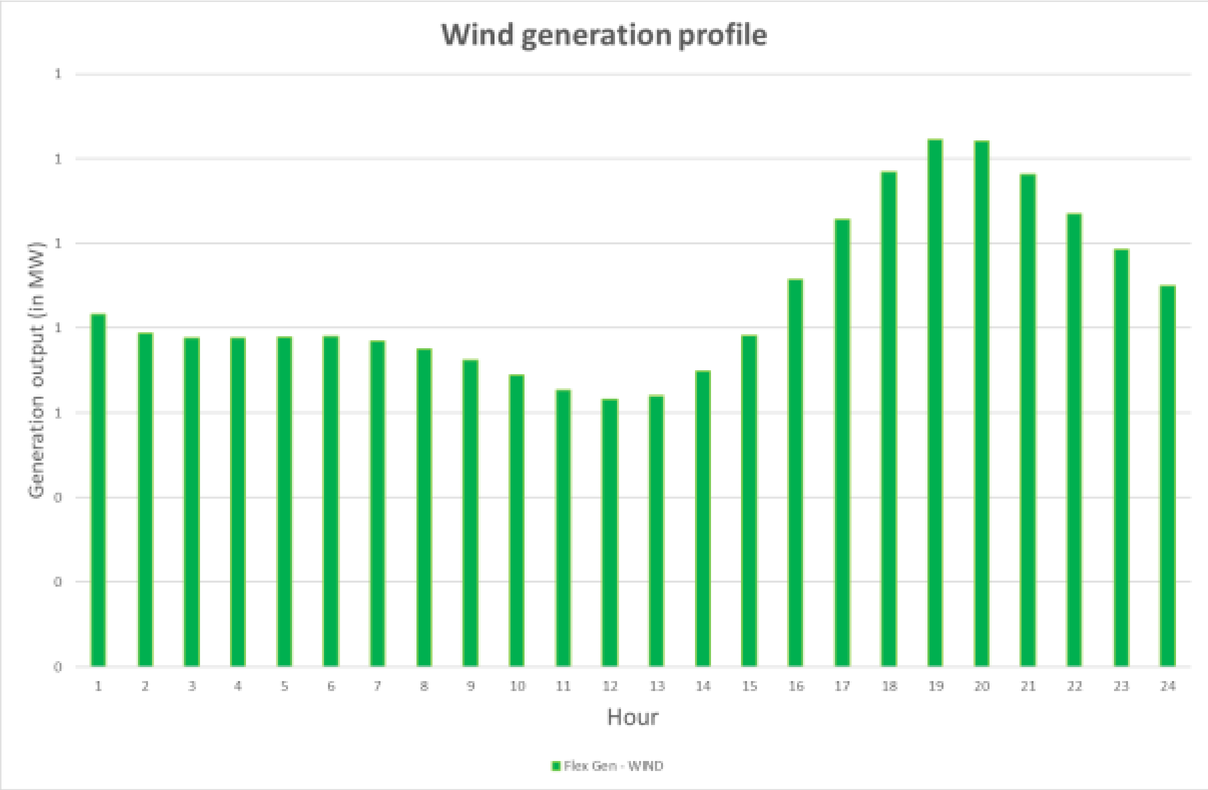


Figure 4-5 – Production diagram of the wind power plant (at D1 substation)

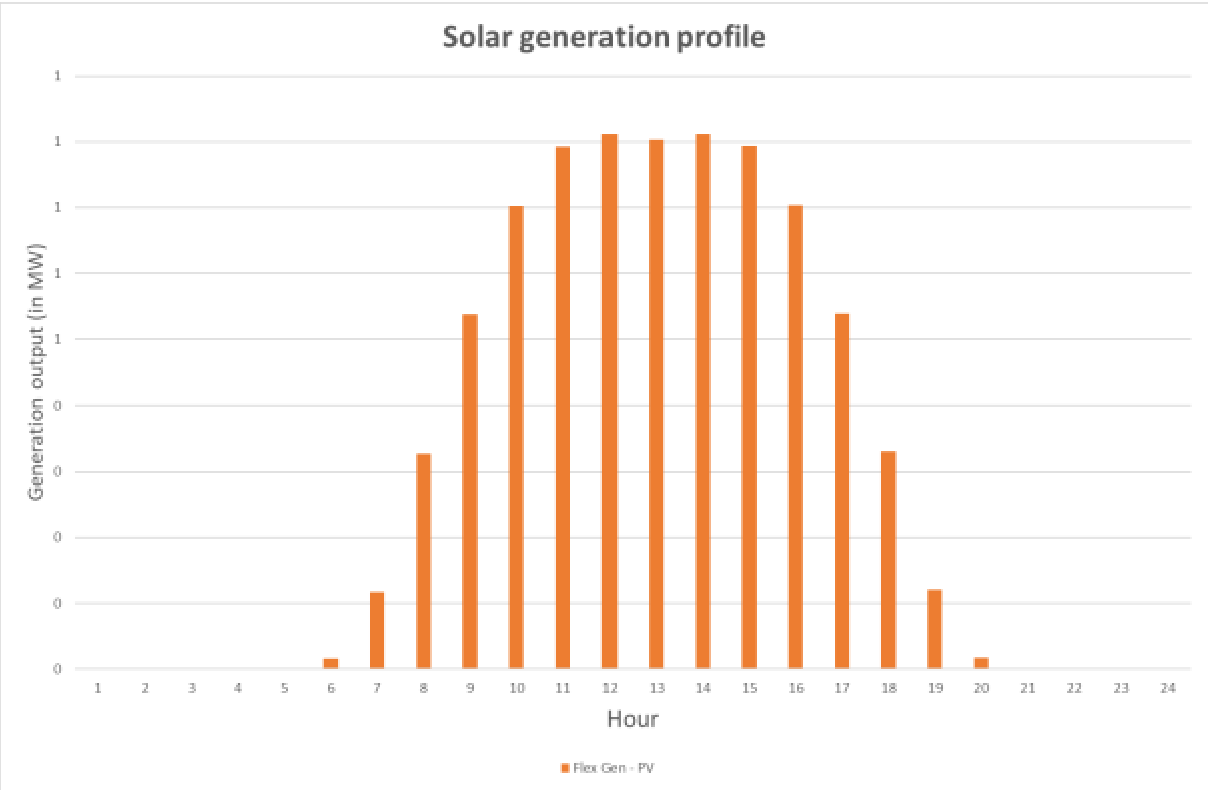


Figure 4-6 – Production diagram of the solar power plant (at D3 substation)

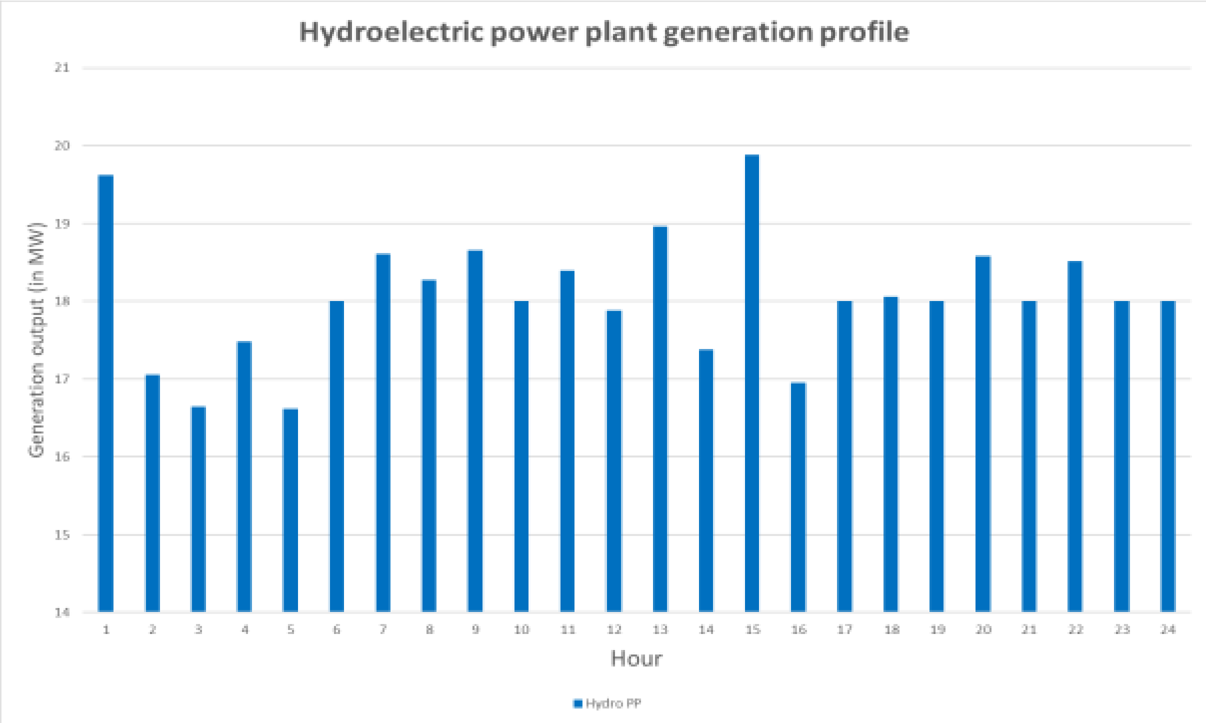


Figure 4-7 – Production diagram of the hydropower plant (at PP1 power plant)

In the case of the scenario which considers the distribution mesh opened (explored in antenna) the network will assume the following configuration shown in Figure 4-8.

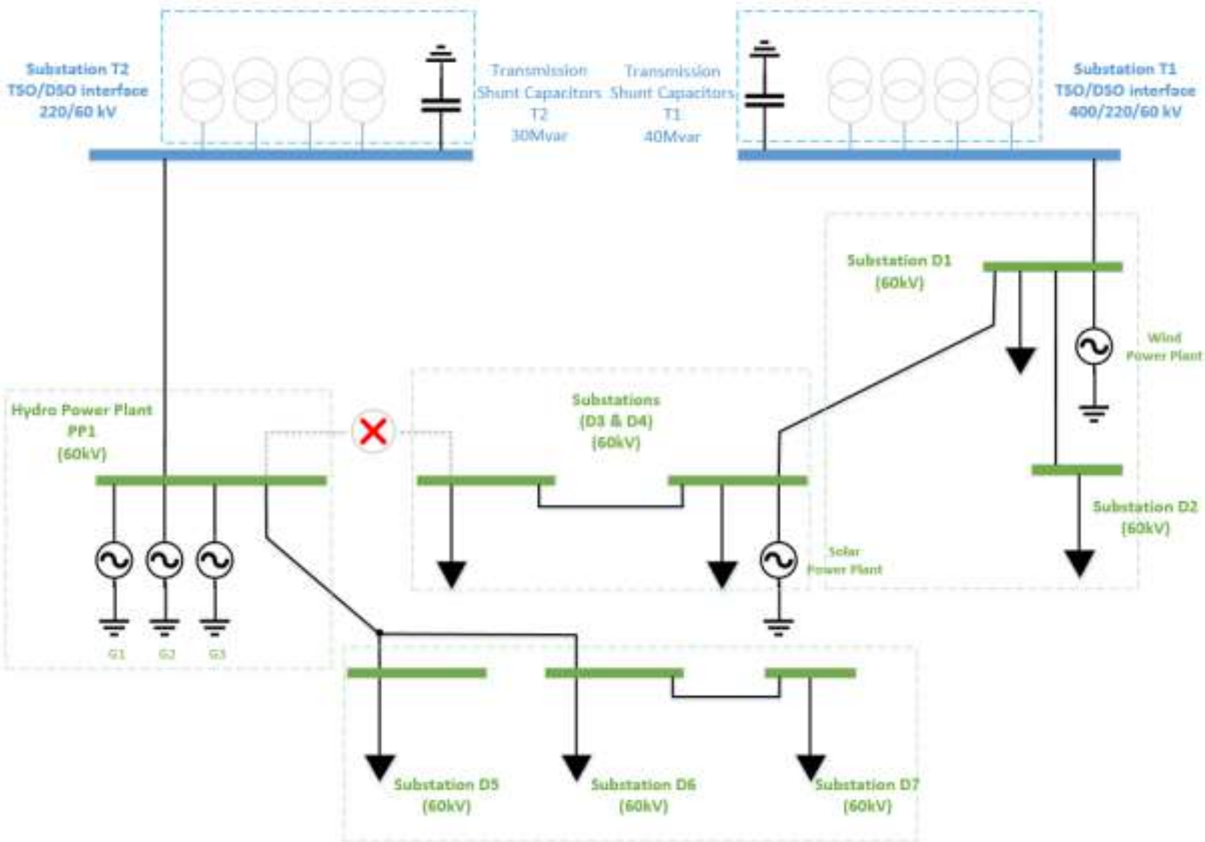


Figure 4-8 – Flexibility Scheduler network representation (with open mesh)

The network model of the distribution network embedded in the FS tool is much more detailed than the one considered in the RTPSS (OPAL/Hypersim), described in section 4.3. Similarly, the level of detail of the transmission network is reduced, being limited to the 60kV busbar of the transmission substations (i.e. Substation T1 and T2), as well as the flexibility assets connected to it and available for the optimisation from the FS tool. Considering that only the observability area at the 60kV busbar from the TSO substation is accessible, having also visibility on the flexibility assets (i.e. switched shunt capacitors) available at the transmission level. The FS tool will consider all this information when determining the day-ahead network optimisation.

4.2.1 Flexibility Scheduler Python Interface

As described in section 3.1 the FS tool requires as input a set of files, which should be set according to a specific format defined by EFACEC. This is most of the times a time consuming and demanding task, prone to human error.

In order to avoid such risks and turn the interface process more efficient, an automation procedure was developed using Python language to configure the interface files for the FS tool. This Python script is capable of preparing the input files required by the FS tool according to the file format defined by EFACEC, for each scenario or use case to be simulated. The Python script also allows to run the FS tool automatically and save the results of the simulation for each scenario or use case.

4.3 RTPSS network model

The network simulated in the RTPSS (OPAL/Hypersim) represents a section of the Portuguese transmission network model. This section has both the 400 kV and 220 kV (VHV), including substations interfacing these two levels (400/220), and between each of these with the 60 kV (HV) level (400/60 and 220/60). MV levels elements are not modelled.

The simulated network model corresponds closely to the representation in Figure 4-9. Equivalent generators were used to represent the remaining grid, outside the shown area (both at 400 kV and at 220 kV). Additionally, since two transmission grid substations interfacing with the distribution grid (60 kV), substations T1 and T2, are also connected through the distribution grid (when this one is operated in a meshed topology), this connection is also modelled.

In the Figure 4-9, this distribution grid is not explicitly represented, only generally through the dashed dark blue line, which does not show the actual route of the distribution grid lines, but clearly identifies the two transmission substations it connects through the 60 kV. The actual detail of this 60 kV section of the grid can be seen in Figure 4-10 (for meshed grid operation) and Figure 4-11 (for radial grids operation).

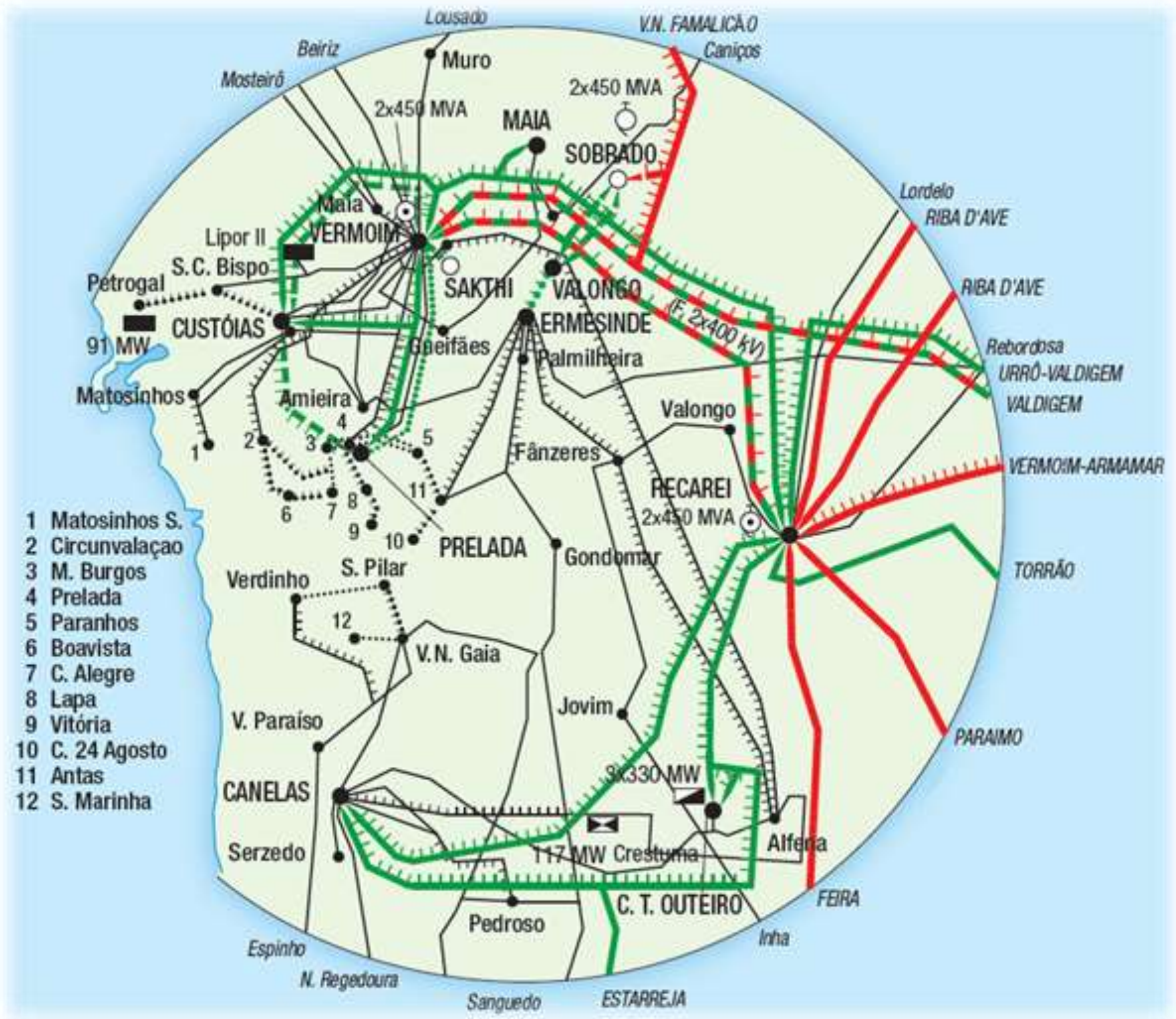


Figure 4-9 – Map of section of transmission grid modelled in RTPSS (Source: REE)

The voltage levels below 60 kV are not modelled, thus the 60 kV nodes of the modelled distribution grid do not have any transformer (to MV) connected to them, but only an equivalent load and generator to represent the aggregated load and generation at node level respectively.

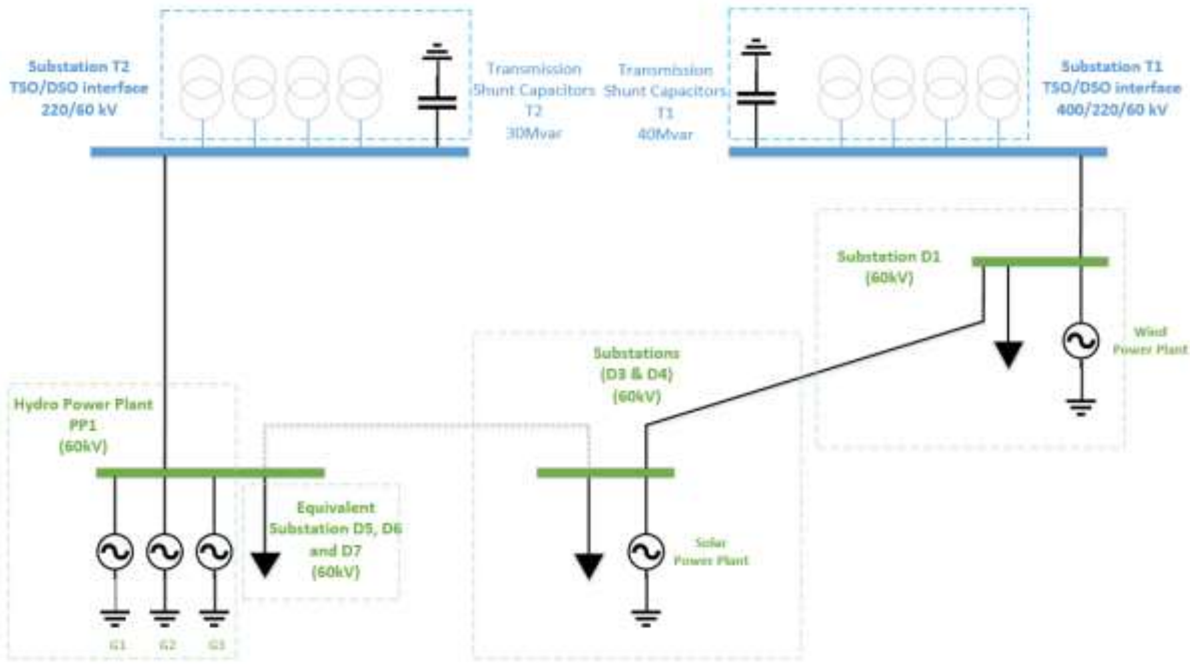


Figure 4-10 – RTPSS distribution network representation (meshed operation)

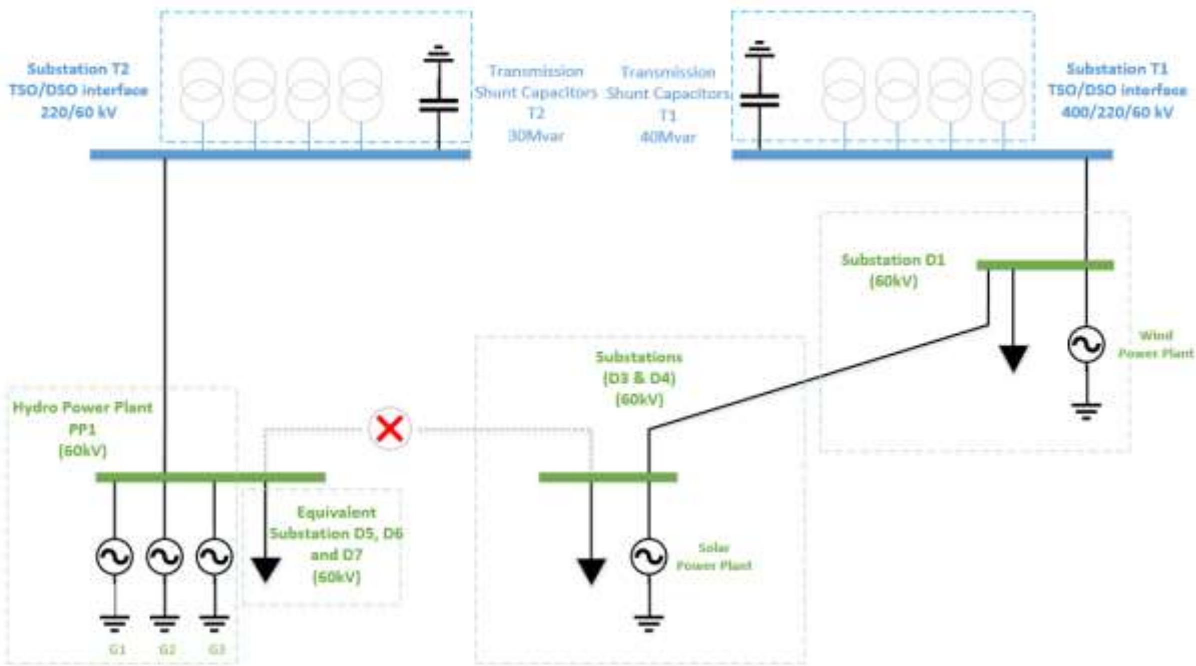


Figure 4-11 – RTPSS distribution network representation (radial operation)

In addition to the 2 VHV/HV substations shown in Figure 4-10 and Figure 4-11, substations T1 and T2, interfacing transmission and distribution grids, more relevant for the use case, the modelled network has also another 4 VHV/HV substations, and 3 switching substations.

Substation T1 interfaces both 400 kV and 220 kV to the 60 kV, while Substation T2 interfaces the 220 kV to the 60 kV. In two of the modelled substations, autotransformers allow the transit of power between 400 kV and 220 kV levels (total of 1800 MVA).

In terms of lines, the modelled network contains, other than the 60 kV lines already represented in Figure 4-10 and Figure 4-11, 26 transmission lines of either 400 kV or 220 kV.

Regarding generation, the transmission network has a CCGT power plant connected to the 220 kV level. Additionally, the network has 4 slack machines, placed in both the 400 kV and 220 kV levels, representing the transmission network that is not considered in the model. Neither T1 and T2 substations are directly connected to slack machines.

The following table presents some details about the network model used in the simulation.

Table 4-2 – RTPSS network model data

Asset	# of assets	Total installed capacity at transmission level (in MW/Mvar/MVA)	Total installed capacity at distribution level (in MW/Mvar/MVA)
Nodes	50	-	-
Lines	30 (*)	-	-
Generator	8 (**)	1182	109,6 (***)
Load	11 (**)	-	-
Power Transformer	29	6020	-
Shunt capacitor	4 (****)	360	-

* 26 lines in the transmission network and 4 lines in the distribution network
** 3 generators and 8 loads in the transmission network and 5 generators and 3 loads in the distribution network
*** same as modelled in distribution network model in FS tool
**** 4 substations with capacitor banks, the actual power value can depend on which bay is connected at a given time

4.4 Use case and sequence diagram

This subsection describes the sequence diagram from the use case "Validation of the optimal operational schedule from the DSO Flexibility Scheduler System" for the simulation and assessment of the FS tool's results. The validation of the results is mainly focused on the assessment of the impact of the planning decisions at both transmission level and TSO-DSO interface, as the visibility over the distribution network is limited from the TSO perspective (RTPSS simulation).

The sequence diagram described in Figure 4-12 reflects the exchange of information required between the TSO and DSO, taking into account their respective actions and the information exchanged on the observability area. Figure 4-12 depicts the sequence diagram for the validation of the FS tool.

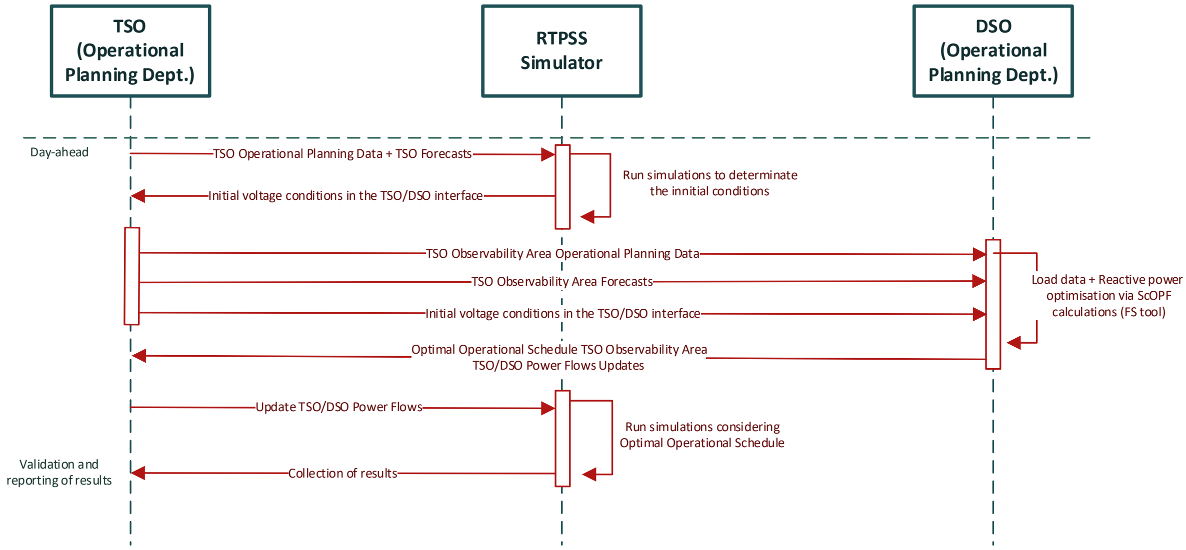


Figure 4-12 – Sequence diagram of the use case for the validation of the FS tool

The process was designed to be initiated in the day-ahead, thus performing 24h ahead planning. The process follows the following steps:

1. The TSO prepares the operational planning data and forecasts for the TSO network and DSO observability area (i.e. generation, load).
2. The TSO loads the operational planning data and forecasts in the RTPSS and runs the TSO operational scenarios in the RTPSS, pre-validating and determining the initial condition of the system.
3. The initial conditions (i.e. voltage) in the TSO/DSO interface are collected by the TSO.
4. The TSO prepares and shares the information related to the TSO observability area with the DSO, including the configuration files from the FS tool.
5. The initial conditions of the system (i.e. initial voltage in the TSO/DSO interface) are **loaded in to the FS tool** by the DSO using the configuration files provided by the TSO and the ScOPF calculations are performed for the entire period of analysis (i.e. 24 hour ahead).
6. The optimal operational schedule for the DSO network and for the TSO observability area are generated by the **FS tool** and the latter is exchanged with the TSO, including the TSO/DSO power flow updates resulting from the ScOPF algorithm results for each hour of the period of analysis.
7. The TSO/DSO interface power flows are updated in the RTPSS by the TSO and the simulations are run again considering the ScOPF results.
8. The RTPSS results are collected and validated by the TSO in order to ensure there is no negative impact at the transmission level. In case the result has a negative impact at transmission level, the solution is **rejected**, the DSO is informed and the process starts all over again.

This use case is described in more detail according to IEC62559-2 in Annex F – Use case description based on IEC62559-2.

5 Simulation results

This section presents the simulation results for each of the test cases. There are 16 test cases, which depend on grid conditions (grid topology, availability of RES) and optimisation options (optimisation function, availability of transmission assets). From each starting scenario, resulting from a specific grid condition, derive four test cases by applying the combinations of optimisation options used in the ScOPF (FS tool).

Section 5.1 presents the starting scenarios and the test cases, and establishes the correspondence between each of the test cases to the starting scenario. Section 5.2 presents the results of each test case in comparison to the starting scenario it derived from (without the optimisation).

5.1 Starting scenarios and simulation test cases

Figure 5-1 presents all the simulation test cases as already shown in 4.1, but in this instance, focusing on their clustering, according to the starting scenario.

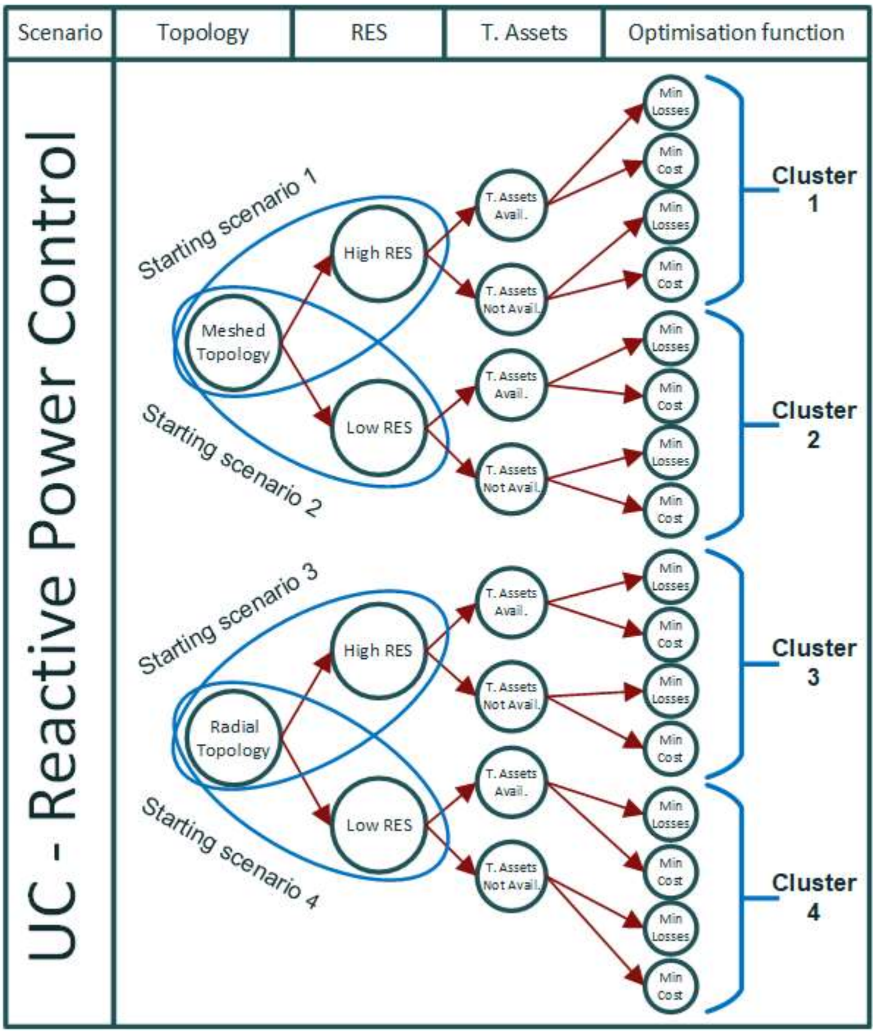


Figure 5-1 – Illustration of test case starting scenarios and clustering

As can be observed, a specific distribution network condition, defined by its topology (meshed or radial) and amount of RES present, corresponds to a starting scenario. By applying different optimisation conditions (availability of the transmission assets as optimisation levers, and optimisation algorithm), 4 test cases are then created for each scenario.

Table 5-1 assigns an ID to each test case, and identifies to which cluster the test case belongs to, based on corresponding starting scenario.

Table 5-1 – Test case ID

Test case number	Distribution network topology	RES penetration	Transmission assets available	Optimisation function	Cluster
1	Meshed	High	Not available	min losses	1
2	Meshed	High	Available	min losses	1
3	Meshed	Low	Not available	min losses	2
4	Meshed	Low	Available	min losses	2
5	Meshed	High	Not available	min costs	1
6	Meshed	High	Available	min costs	1
7	Meshed	Low	Not available	min costs	2
8	Meshed	Low	Available	min costs	2
9	Radial	High	Not available	min losses	3
10	Radial	High	Available	min losses	3
11	Radial	Low	Not available	min losses	4
12	Radial	Low	Available	min losses	4
13	Radial	High	Not available	min costs	3
14	Radial	High	Available	min costs	3
15	Radial	Low	Not available	min costs	4
16	Radial	Low	Available	min costs	4

5.2 Test cases results and validation

The following subsection (5.2) presents the data of test cases simulation results. The graphics preented show a specific variable (active power (P), reactive power (Q), voltage (U)) for a specific location (a substation at transmission/distribution interface), for all test cases considered in the same cluster (different optimisation options in the FS tool) as well as for the corresponding starting scenario (simulation without optimisation by the FS tool). The graphics data in table format are available in the annexes.

The figures show the active and reactive power as well as the voltage at the transmission/distribution interface, or, in other words, the power flow in the line connecting transmission substation (60kV busbar) and the distribution grid considered as well as the voltage at the HV bus of the transmission substation.

5.2.1 Cluster 1

This is the test case cluster based on the scenario for meshed distribution grid operation with high penetration of RES. The source data of the graphics is available in

Annex A – Cluster 1 simulation results. Figure 5-2 to Figure 5-7 shows the results for Cluster 1 test cases.

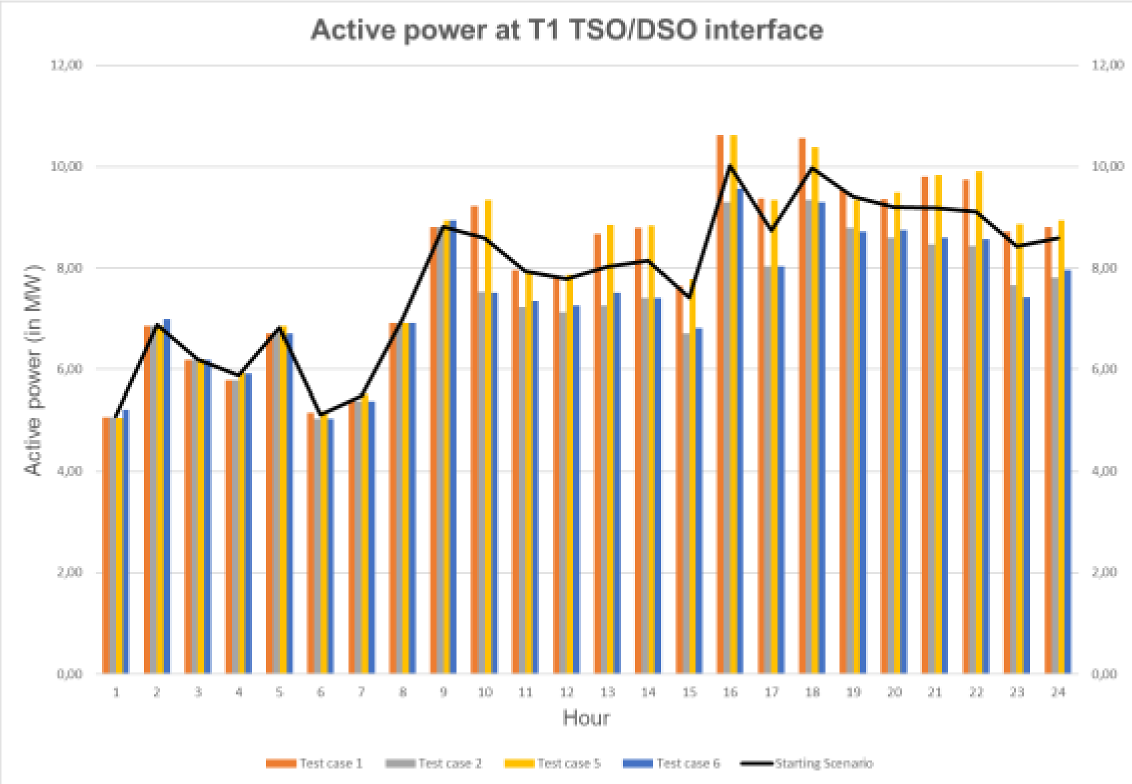


Figure 5-2 – Active Power profile at T1 TSO/DSO interface for cluster 1 test cases

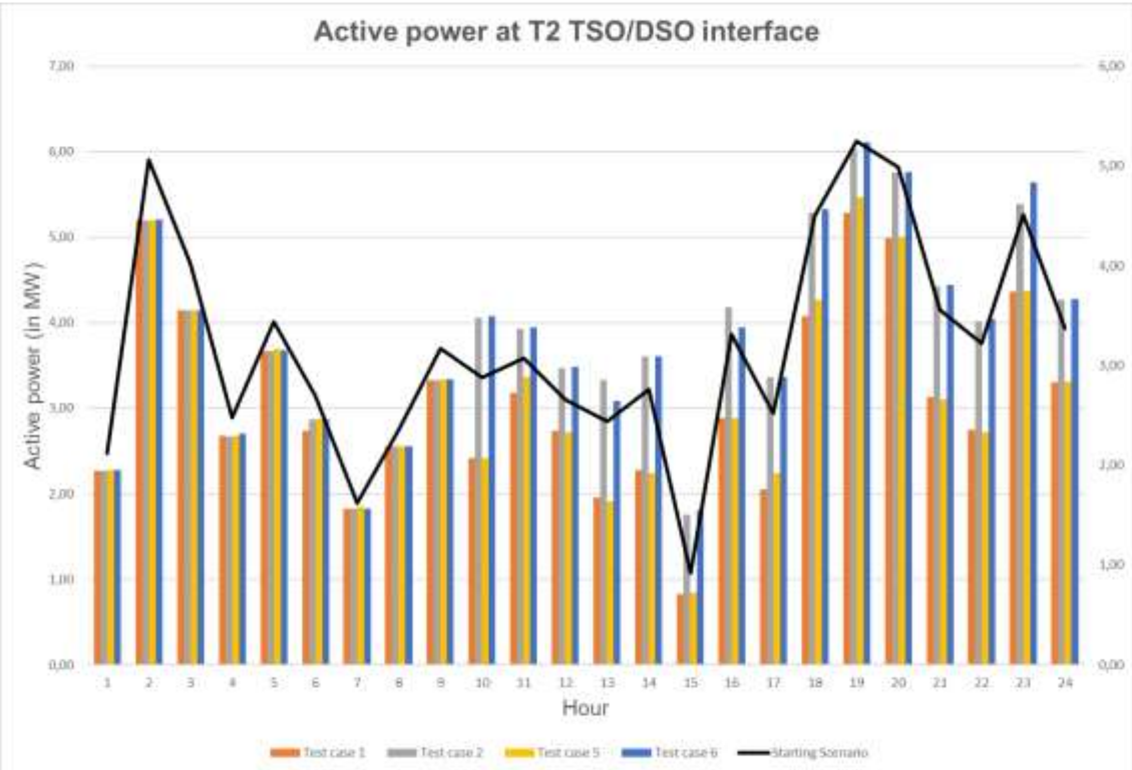


Figure 5-3 – Active Power profile at T2 TSO/DSO interface for cluster 1 test cases

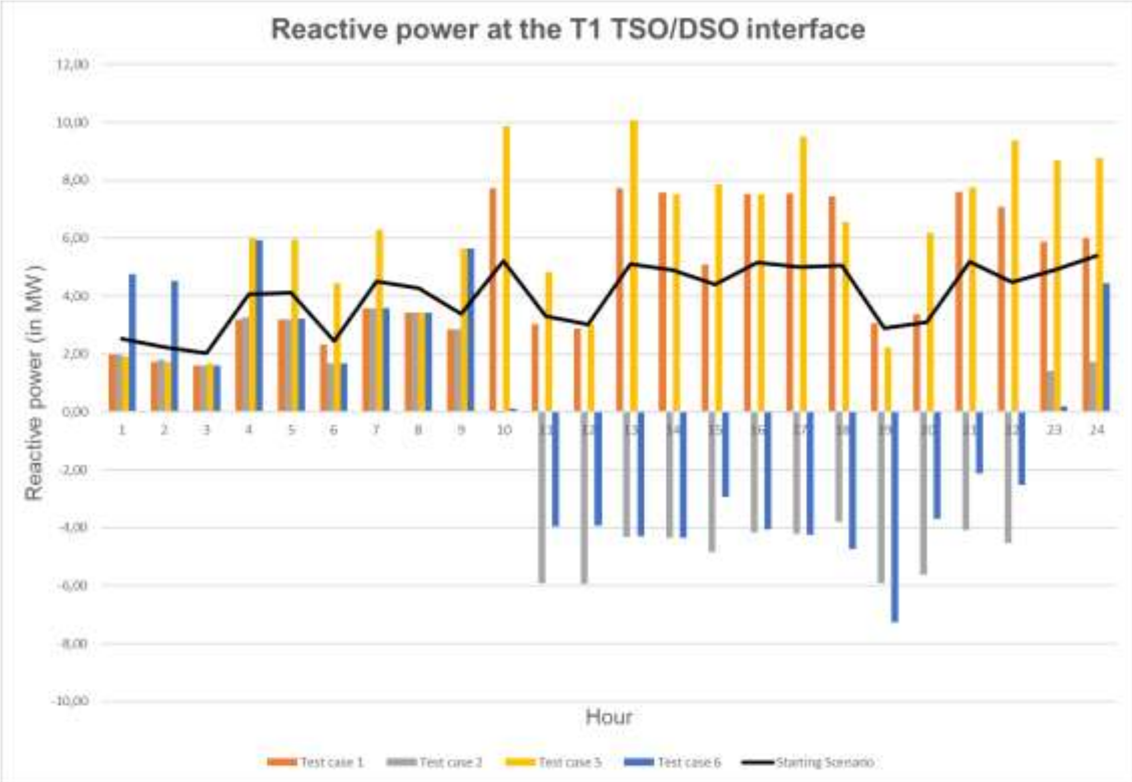


Figure 5-4 – Reactive Power profile at T1 TSO/DSO interface for cluster 1 test cases

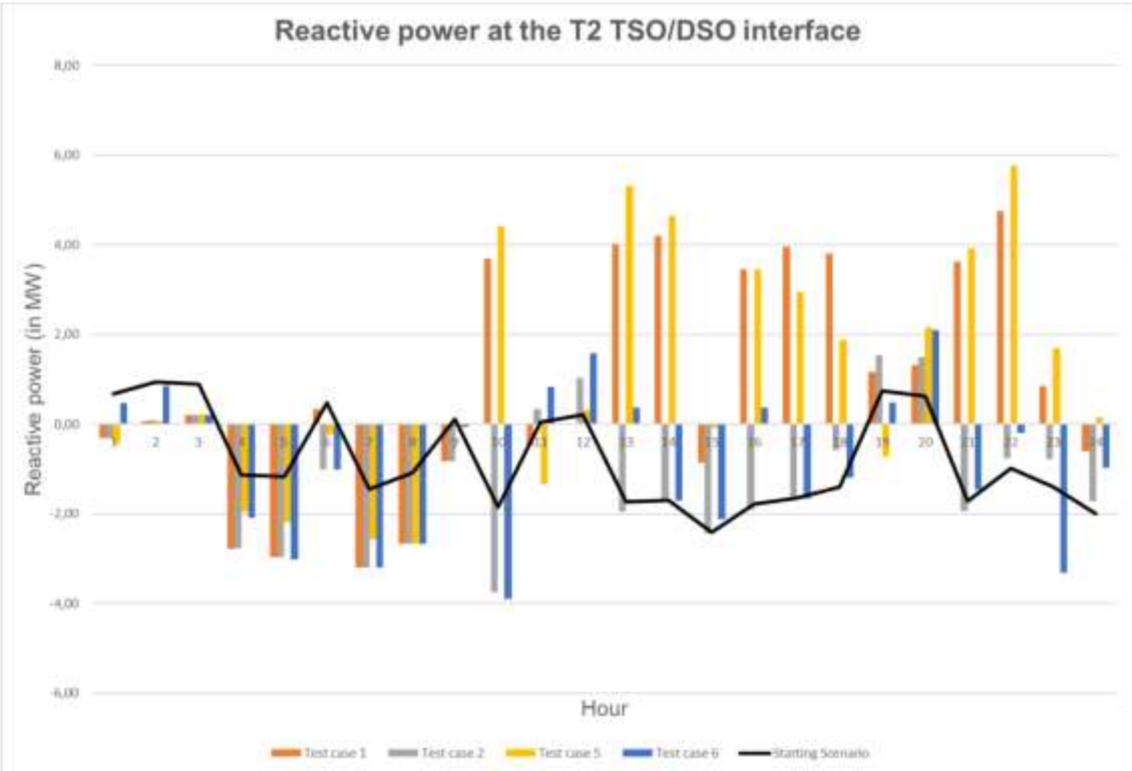


Figure 5-5 – Reactive Power profile at T2 TSO/DSO interface for cluster 1 test cases

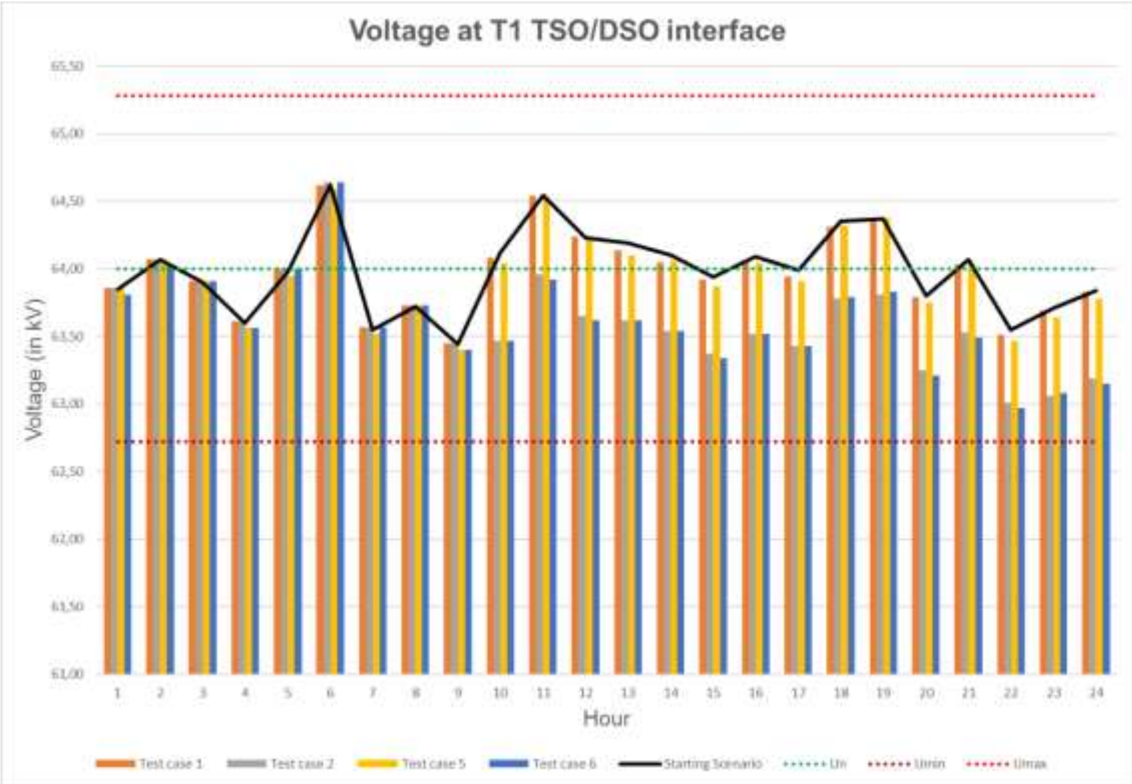


Figure 5-6 – Voltage at T1 TSO/DSO interface for cluster 1 test cases

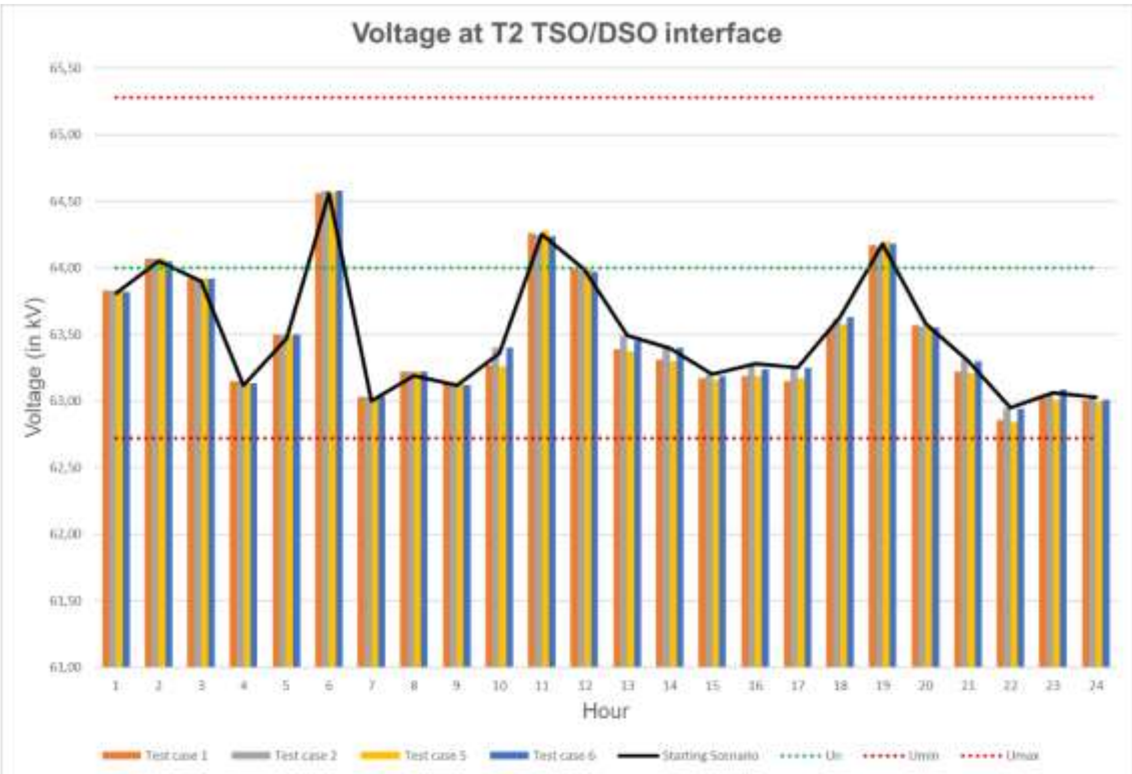


Figure 5-7 – Voltage at T2 TSO/DSO interface for cluster 1 test cases

5.2.1.1 Test case 1

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are not considered as a flexibility option and the optimisation function is focused on the minimisation of grid losses. From Table 5-2 to Table 5-5 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-2 – FS voltage results for test case 1

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,96	63,96
2	63,98	63,98	63,98	64,10
3	63,98	63,98	64,00	64,09
4	63,98	63,98	63,79	64,03
5	63,98	63,98	63,72	63,99
6	63,98	63,98	63,84	63,84
7	63,98	63,98	63,78	64,00
8	63,98	63,98	63,80	64,01
9	63,98	63,98	63,93	64,05
10	63,98	63,98	63,67	62,88
11	63,98	63,98	63,75	63,82
12	63,98	63,98	63,81	63,82
13	63,98	63,98	63,70	62,87
14	63,98	63,98	63,70	62,86
15	63,98	63,98	63,67	63,43
16	63,98	63,98	63,65	62,90
17	63,98	63,98	63,68	62,88
18	63,98	63,98	63,71	62,97
19	63,98	63,98	63,85	63,77
20	63,98	63,98	63,92	63,80
21	63,98	63,98	63,67	62,91
22	63,98	63,98	63,77	62,96
23	63,98	63,98	63,75	63,43
24	63,98	63,98	63,65	63,44

As can be seen in Table 5-2, the FS results from test case 1 show that the voltage stays within the acceptable range [64kV±2%] for both substations.

Table 5-3 – FS capacitor banks results for test case 1

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-4 – FS losses results for test case 1

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	208,26	-225,12	191,80	-236,47	-16,47	-11,35
2	195,10	-388,96	194,30	-399,85	-0,80	-10,89
3	186,41	-474,81	185,99	-482,53	-0,42	-7,72
4	185,77	-418,82	182,98	-439,38	-2,79	-20,56
5	188,34	-458,08	184,54	-480,81	-3,80	-22,73
6	188,19	-412,56	188,19	-412,56	0,00	0,00
7	187,97	-362,26	185,14	-383,25	-2,83	-20,99
8	190,81	-355,12	188,52	-374,00	-2,29	-18,88
9	198,48	-263,72	197,69	-275,73	-0,79	-12,01
10	198,05	-318,53	258,39	101,02	60,34	419,55
11	198,56	-290,37	197,00	-301,07	-1,56	-10,70
12	192,26	-367,86	192,06	-369,18	-0,21	-1,32

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	199,82	-237,76	263,43	212,20	63,61	449,96
14	192,90	-398,81	257,08	54,00	64,18	452,81
15	197,23	-185,06	207,38	-112,89	10,15	72,17
16	198,62	-380,07	253,08	-2,82	54,47	377,24
17	196,13	-325,33	256,01	97,58	59,88	422,91
18	208,47	-236,62	261,29	136,45	52,82	373,07
19	207,93	-250,14	209,83	-235,44	1,90	14,70
20	207,89	-208,48	210,57	-185,03	2,67	23,45
21	201,37	-255,14	257,86	137,33	56,49	392,48
22	199,78	-224,67	256,51	194,84	56,73	419,51
23	203,08	-253,57	218,16	-147,94	15,09	105,63
24	199,55	-274,23	208,83	-213,91	9,27	60,33
				TOTAL VARIATION	**475,65**	**3446,67**

Table 5-5 – FS objective function fitness for test case 1

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	306931000	3220530	-303710470
2	1397470	1384100	-13370
3	1675650	1656690	-18960
4	2808370	2756360	-52010
5	2076260	2015220	-61040
6	2615800	2598140	-17660
7	203191	196864	-6327
8	63968,9	188,5	-63780,4
9	198,4	197,6	-0,8
10	755701	683612	-72089
11	3027970	2994300	-33670
12	3320450	3283040	-37410
13	841171	762660	-78511
14	797291	725811	-71480
15	1314450	1293180	-21270
16	619889	547076	-72813
17	740404	665536	-74868
18	654675	571910	-82765
19	1927840	1907630	-20210
20	2008040	1988610	-19430
21	701882	627303	-74579
22	723744	638084	-85660
23	1126850	1099400	-27450
24	1137750	1123620	-14130
Global	**337470015**	**32740062**	**-304729953**

In this test case, although the optimisation strategy was to minimize losses, the optimisation results showed an increase of the overall losses of the system. Nevertheless, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-6 – FS final results for test case 1 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,11	0,72	63,98	2,15	-0,03	63,96
2	6,92	0,83	63,98	5,07	0,01	64,10
3	6,25	0,72	63,98	4,04	0,13	64,09
4	5,89	0,63	63,98	2,49	-1,21	64,03
5	6,84	0,86	63,98	3,47	-1,61	63,99
6	5,14	2,93	63,98	2,70	-1,19	63,84
7	5,51	0,82	63,98	1,63	-1,44	64,00
8	7,02	0,86	63,98	2,38	-1,08	64,01
9	8,85	0,90	63,98	3,20	0,12	64,05
10	8,65	12,36	63,98	2,93	-1,84	62,88
11	7,96	2,95	63,98	3,11	-1,33	63,82
12	7,84	2,90	63,98	2,67	-0,93	63,82
13	8,07	12,57	63,98	2,50	-1,72	62,87
14	8,21	12,57	63,98	2,80	-1,68	62,86
15	7,45	5,67	63,98	0,93	-2,40	63,43
16	10,07	11,86	63,98	3,38	-1,76	62,90
17	8,79	12,26	63,98	2,58	-1,64	62,88
18	10,04	11,74	63,98	4,55	-1,40	62,97
19	9,45	3,88	63,98	5,28	-0,62	63,77
20	9,23	3,83	63,98	5,03	-0,11	63,80
21	9,26	12,06	63,98	3,61	-1,72	62,91
22	9,19	11,85	63,98	3,26	-0,96	62,96
23	8,45	7,15	63,98	4,56	-1,40	63,43
24	8,63	6,41	63,98	3,39	-2,00	63,44

Table 5-7 – RTPSS final results for test case 1 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,07	1,99	63,86	2,27	-0,25	63,83
2	6,84	1,68	64,08	5,21	-0,02	64,07
3	6,20	1,61	63,91	4,14	0,25	63,92
4	5,79	3,23	63,61	2,66	-2,66	63,14
5	6,71	3,15	64,00	3,67	-2,97	63,50
6	5,06	1,76	64,63	2,85	-0,80	64,58
7	5,38	3,58	63,57	1,83	-3,20	63,03
8	6,92	3,44	63,73	2,56	-2,67	63,22
9	8,80	2,90	63,45	3,32	-0,77	63,13
10	9,23	7,75	64,07	2,41	3,76	63,27
11	8,00	3,23	64,54	3,14	-0,06	64,26
12	7,84	2,92	64,24	2,74	0,10	64,00
13	8,67	7,75	64,14	1,95	4,09	63,39
14	8,80	7,60	64,05	2,27	4,27	63,30
15	7,80	5,81	63,91	0,68	0,71	63,15
16	10,63	7,57	64,04	2,89	3,53	63,19
17	9,39	7,62	63,94	2,04	4,10	63,15
18	10,58	7,39	64,31	4,07	3,85	63,54
19	9,59	3,35	64,36	5,22	1,79	64,16
20	9,41	3,67	63,79	4,93	1,95	63,56
21	9,81	7,68	64,03	3,12	3,71	63,22
22	9,77	7,21	63,51	2,73	4,98	62,85
23	8,92	6,84	63,67	4,17	2,87	62,99
24	8,95	6,72	63,81	3,16	0,90	62,98

Table 5-8 – Comparison between FS and RTPSS final results for test case 1 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,26	7,34	0,08	0,69	1,74	1,05	-0,12	-0,13
2	11,98	12,05	0,07	0,84	1,66	0,82	0,10	-0,03
3	10,28	10,34	0,06	0,85	1,86	1,01	-0,07	-0,17
4	8,38	8,45	0,07	-0,58	0,57	1,15	-0,37	-0,89
5	10,31	10,38	0,07	-0,75	0,18	0,93	0,02	-0,49
6	7,84	7,91	0,07	1,75	0,96	-0,79	0,65	0,74
7	7,14	7,21	0,07	-0,62	0,38	1,00	-0,41	-0,97
8	9,41	9,48	0,07	-0,22	0,77	0,99	-0,25	-0,79
9	12,05	12,12	0,07	1,02	2,13	1,11	-0,53	-0,92
10	11,58	11,64	0,06	10,52	11,51	0,99	0,09	0,39
11	11,07	11,14	0,07	1,62	3,17	1,55	0,56	0,44
12	10,51	10,58	0,07	1,97	3,02	1,05	0,26	0,18
13	10,57	10,62	0,05	10,85	11,84	0,99	0,16	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
14	11,01	11,07	0,06	10,89	11,87	0,98	0,07	0,44
15	8,39	8,48	0,09	3,27	6,52	3,25	-0,07	-0,28
16	13,45	13,52	0,07	10,10	11,10	1,00	0,06	0,29
17	11,37	11,43	0,06	10,62	11,72	1,10	-0,04	0,27
18	14,59	14,65	0,06	10,34	11,24	0,90	0,33	0,57
19	14,73	14,81	0,08	3,26	5,14	1,88	0,38	0,39
20	14,26	14,34	0,08	3,71	5,62	1,91	-0,19	-0,24
21	12,86	12,93	0,07	10,34	11,39	1,05	0,05	0,31
22	12,44	12,50	0,06	10,89	12,19	1,30	-0,47	-0,11
23	13,00	13,09	0,09	5,75	9,71	3,96	-0,31	-0,44
24	12,02	12,11	0,09	4,41	7,62	3,21	-0,17	-0,46

Table 5-8 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are within the range [0,05; 0,09]MW, [-0,79; 3,96]Mvar, [-0,53; 0,65]kV for T1 and [-0,97; 0,74]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-8 to Figure 5-10 depicts the comparison of the results for test case 1.

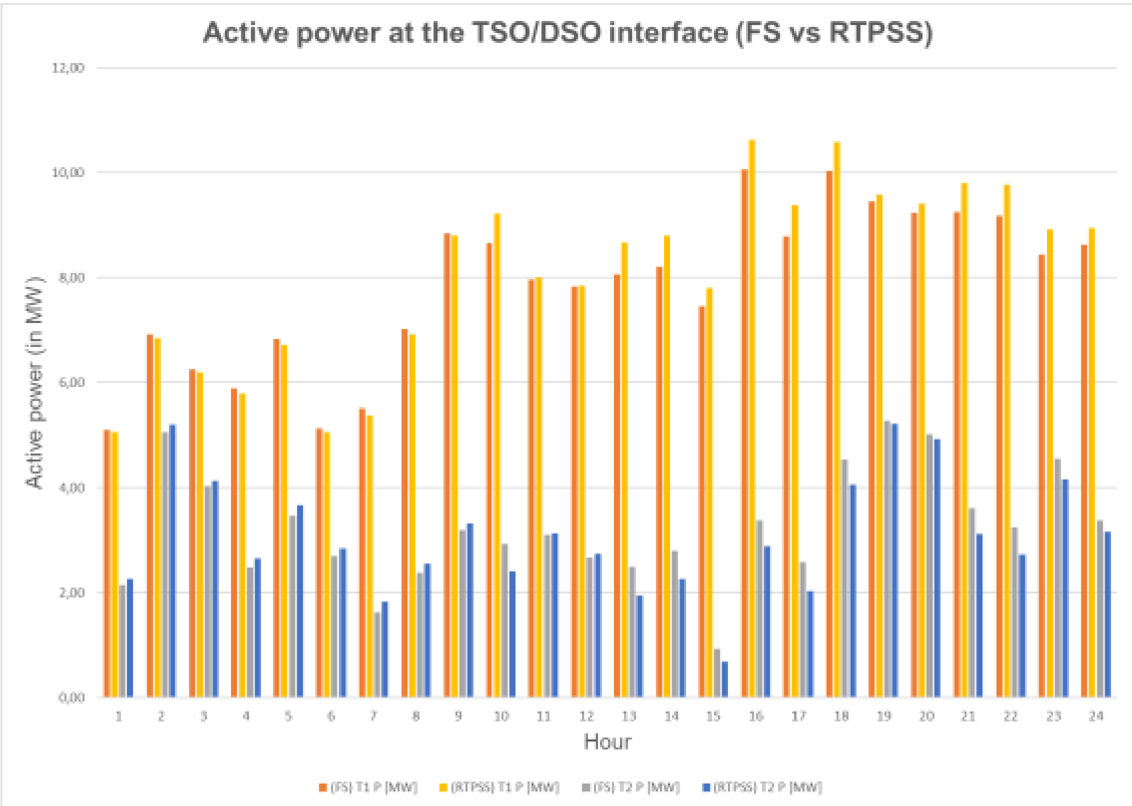


Figure 5-8 – Active Power results at TSO/DSO interface for test case 1

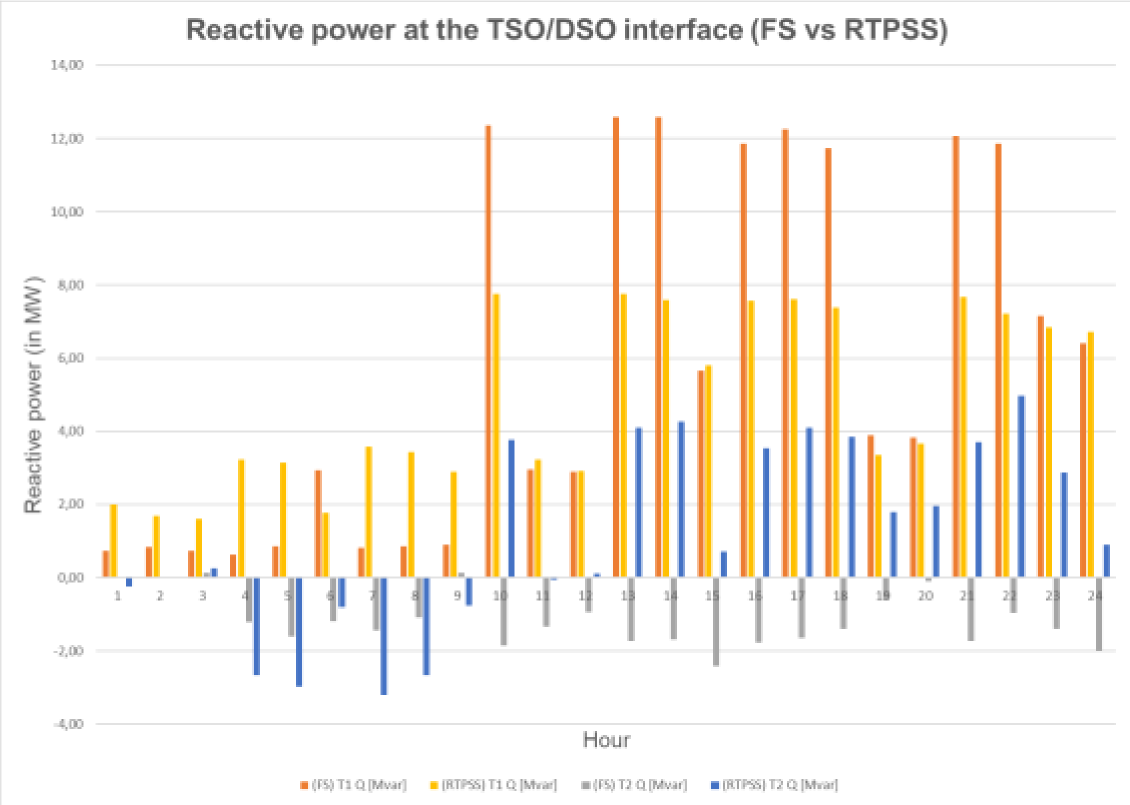


Figure 5-9 – Reactive Power results at TSO/DSO interface for test case 1

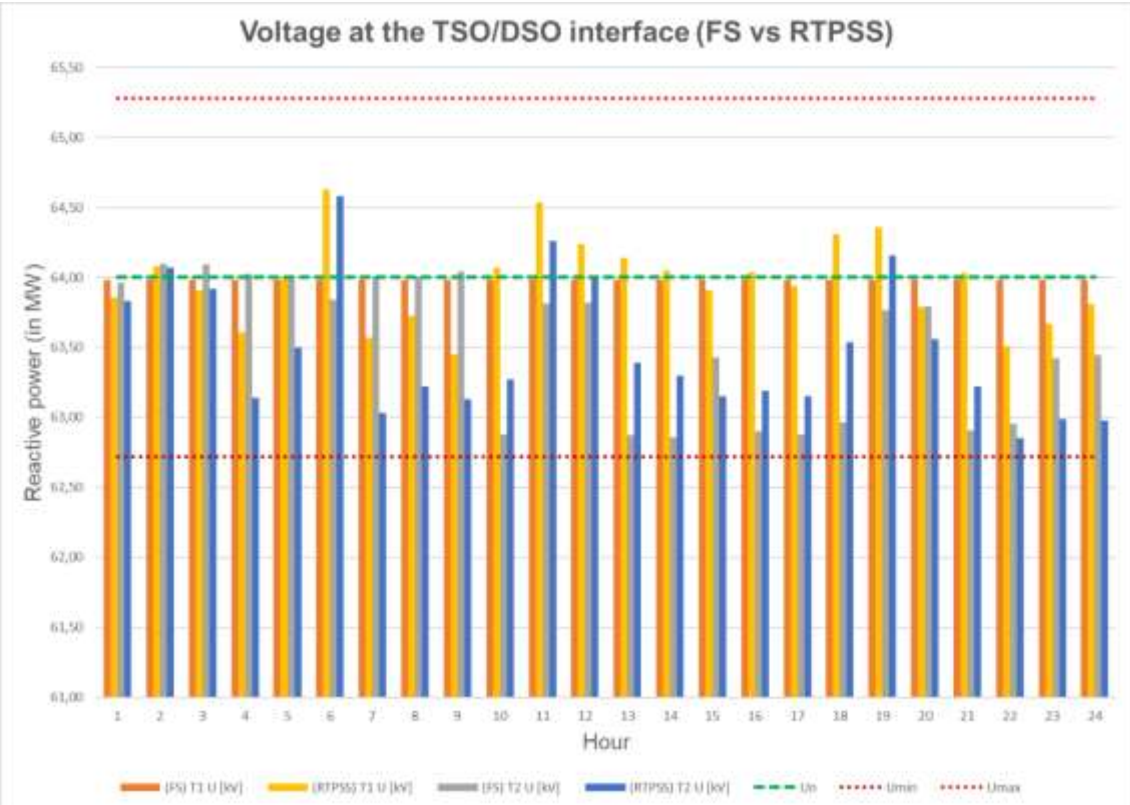


Figure 5-10 – Voltage results at TSO/DSO interface for test case 1

5.2.1.2 Test case 2

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are considered as a flexibility option and the optimisation function is focused on the minimisation of grid losses. From Table 5-9 to Table 5-12 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-9 – FS voltage results for test case 2

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,96	63,96
2	63,98	63,98	63,98	64,10
3	63,98	63,98	64,00	64,09
4	63,98	63,98	63,79	64,03
5	63,98	63,98	63,72	63,99
6	63,98	63,98	63,84	64,05
7	63,98	63,98	63,78	64,00
8	63,98	63,98	63,80	64,01
9	63,98	63,98	63,93	64,05
10	63,98	63,98	63,67	64,30
11	63,98	63,98	64,51	64,02
12	63,98	63,98	63,99	63,99
13	63,98	63,98	63,86	64,00
14	63,98	63,98	63,86	63,97
15	63,98	63,98	63,83	63,93
16	63,98	63,98	63,81	63,94
17	63,98	63,98	63,84	63,95
18	63,98	63,98	63,86	63,86
19	63,98	63,98	64,03	64,03
20	63,98	63,98	64,10	64,08
21	63,98	63,98	63,83	63,96
22	63,98	63,98	63,93	63,99
23	63,98	63,98	63,91	64,00
24	63,98	63,98	63,65	63,95

As can be seen in Table 5-9, the FS results from test case 2 show that the voltage stays within the acceptable range [64kV±2%] for both substations.

Table 5-10 – FS capacitor banks results for test case 2

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	0	0	0
11	40	0	30	30
12	40	0	30	30
13	40	0	0	0
14	40	0	0	0
15	40	0	0	0
16	40	0	0	0
17	40	0	0	0
18	40	0	0	0
19	40	0	30	30
20	40	0	30	30
21	40	0	0	0
22	40	0	0	0
23	40	0	0	0
24	40	0	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-11 – FS losses results for test case 2

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	208,26	-225,12	191,80	-236,47	-16,47	-11,35
2	195,10	-388,96	194,31	-399,64	-0,79	-10,68
3	186,41	-474,81	185,99	-482,53	-0,42	-7,72
4	185,77	-418,82	182,99	-439,18	-2,78	-20,36
5	188,34	-458,08	184,54	-480,81	-3,80	-22,73
6	188,19	-412,56	185,90	-431,99	-2,29	-19,42
7	187,97	-362,26	185,14	-383,25	-2,83	-20,99
8	190,81	-355,12	188,52	-374,00	-2,29	-18,88
9	198,48	-263,72	197,69	-275,73	-0,79	-12,01
10	198,05	-318,53	205,05	-285,84	7,00	32,70
11	212,71	-244,83	202,07	-244,73	-10,65	0,10
12	197,30	-309,56	197,30	-309,56	0,00	0,00
13	203,52	-183,22	202,63	-196,85	-0,89	-13,63

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
14	196,95	-342,42	196,30	-352,28	-0,65	-9,86
15	202,23	-123,21	201,44	-135,17	-0,79	-11,97
16	202,22	-325,70	201,38	-336,84	-0,85	-11,14
17	199,98	-270,10	199,24	-280,69	-0,74	-10,59
18	212,04	-183,37	212,04	-183,37	0,00	0,00
19	212,76	-193,91	212,76	-193,91	0,00	0,00
20	213,62	-149,60	213,60	-147,37	-0,02	2,23
21	204,82	-201,45	203,85	-214,03	-0,97	-12,58
22	204,38	-167,51	204,11	-174,35	-0,26	-6,84
23	207,01	-198,31	199,54	-276,01	-7,48	-77,70
24	199,55	-274,23	194,58	-299,99	-4,97	-25,75
				TOTAL VARIATION	**-53,73**	**-289,16**

Table 5-12 – FS objective function fitness for test case 2

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	306931000	3220530	-303710470
2	1397470	1384180	-13290
3	1675650	1656690	-18960
4	2808370	2756480	-51890
5	2076260	2015220	-61040
6	2615800	2566490	-49310
7	203191	196864	-6327
8	63968,9	188,5	-63780,4
9	198,4	197,6	-0,8
10	755701	25313,8	-730387,2
11	13898600	2180500	-11718100
12	2522090	2487000	-35090
13	203,5	202,6	-0,9
14	196,9	196,2	-0,7
15	390597	382659	-7938
16	202,2	201,3	-0,9
17	199,9	199,2	-0,7
18	212	212	0
19	1226100	1213800	-12300
20	1277840	1269020	-8820
21	204,8	203,8	-1
22	204,3	204,1	-0,2
23	77150,2	73845,8	-3304,4
24	207011	138250	-68761
Global	**338128421**	**21568648**	**-316559773**

In this test case the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-13 – FS final results for test case 2 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,11	0,72	63,98	2,15	-0,03	63,96
2	6,92	0,93	63,98	5,07	0,01	64,10
3	6,25	0,72	63,98	4,04	0,13	64,09
4	5,89	0,74	63,98	2,49	-1,21	64,03
5	6,84	0,86	63,98	3,47	-1,61	63,99
6	5,14	0,72	63,98	2,70	-0,99	64,05
7	5,51	0,82	63,98	1,63	-1,44	64,00
8	7,02	0,86	63,98	2,38	-1,08	64,01
9	8,85	0,90	63,98	3,20	0,12	64,05
10	8,62	-2,93	63,98	2,90	-1,84	64,30
11	7,96	-5,40	63,98	3,11	-1,14	64,02
12	7,84	-5,11	63,98	2,67	-0,77	63,99
13	8,03	-5,55	63,98	2,47	-1,72	64,00
14	8,18	-5,35	63,98	2,78	-1,68	63,97
15	7,45	-5,88	63,98	0,93	-2,40	63,93
16	10,04	-5,29	63,98	3,36	-1,76	63,94
17	8,76	-5,23	63,98	2,55	-1,64	63,95
18	10,01	-3,99	63,98	4,53	-1,40	63,86
19	9,45	-5,03	63,98	5,28	-0,38	64,03
20	9,24	-5,31	63,98	5,03	0,15	64,08
21	9,23	-5,31	63,98	3,58	-1,72	63,96
22	9,16	-5,33	63,98	3,23	-0,96	63,99
23	8,44	1,02	63,98	4,55	-1,40	64,00
24	8,62	1,02	63,98	3,38	-2,00	63,95

Table 5-14 – RTPSS final results for test case 2 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,07	1,99	63,86	2,27	-0,25	63,83
2	6,86	1,74	64,07	5,20	0,12	64,07
3	6,20	1,61	63,91	4,14	0,25	63,92
4	5,78	3,19	63,61	2,67	-2,73	63,14
5	6,71	3,15	64,00	3,67	-2,97	63,50
6	5,04	1,70	64,64	2,86	-0,94	64,58
7	5,38	3,58	63,57	1,83	-3,20	63,03
8	6,92	3,44	63,73	2,56	-2,67	63,22
9	8,80	2,90	63,45	3,32	-0,77	63,13
10	7,61	-0,14	63,47	3,98	-3,04	63,38
11	7,04	-1,78	63,88	4,11	-0,38	64,26
12	6,90	-1,45	63,57	3,68	0,14	63,99
13	7,06	-0,06	63,54	3,53	-2,71	63,50
14	7,19	-0,33	63,47	3,82	-2,72	63,42
15	6,54	-0,57	63,30	1,92	-2,89	63,21
16	9,06	-0,20	63,45	4,40	-3,06	63,30
17	7,77	-0,39	63,36	3,61	-3,09	63,27
18	9,02	-0,27	63,72	5,59	-2,64	63,65
19	8,56	-1,96	63,74	6,25	0,36	64,18
20	8,37	-0,57	63,16	5,96	0,63	63,58
21	8,23	-0,22	63,46	4,65	-3,25	63,33
22	8,20	-0,63	62,94	4,26	-2,08	62,97
23	7,67	1,16	63,07	5,39	-0,77	63,05
24	7,81	1,50	63,20	4,27	-1,73	63,03

Table 5-15 – Comparison between FS and RTPSS final results for test case 2 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,26	7,34	0,08	0,69	1,74	1,05	-0,12	-0,13
2	11,98	12,06	0,08	0,94	1,86	0,92	0,09	-0,03
3	10,28	10,34	0,06	0,85	1,86	1,01	-0,07	-0,17
4	8,38	8,45	0,07	-0,48	0,46	0,94	-0,37	-0,89
5	10,31	10,38	0,07	-0,75	0,18	0,93	0,02	-0,49
6	7,84	7,90	0,06	-0,27	0,76	1,03	0,66	0,53
7	7,14	7,21	0,07	-0,62	0,38	1,00	-0,41	-0,97
8	9,41	9,48	0,07	-0,22	0,77	0,99	-0,25	-0,79
9	12,05	12,12	0,07	1,02	2,13	1,11	-0,53	-0,92
10	11,53	11,59	0,06	-4,77	-3,18	1,59	-0,51	-0,92
11	11,07	11,15	0,08	-6,54	-2,16	4,38	-0,10	0,24
12	10,51	10,58	0,07	-5,88	-1,31	4,57	-0,41	0,00

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	10,50	10,59	0,09	-7,27	-2,77	4,50	-0,44	-0,50
14	10,95	11,01	0,06	-7,03	-3,05	3,98	-0,51	-0,55
15	8,38	8,46	0,08	-8,28	-3,46	4,82	-0,68	-0,72
16	13,40	13,46	0,06	-7,05	-3,26	3,79	-0,53	-0,64
17	11,31	11,38	0,07	-6,87	-3,48	3,39	-0,62	-0,68
18	14,54	14,61	0,07	-5,39	-2,91	2,48	-0,26	-0,21
19	14,74	14,81	0,07	-5,40	-1,60	3,80	-0,24	0,15
20	14,26	14,33	0,07	-5,16	0,06	5,22	-0,82	-0,50
21	12,81	12,88	0,07	-7,03	-3,47	3,56	-0,52	-0,63
22	12,39	12,46	0,07	-6,29	-2,71	3,58	-1,04	-1,02
23	12,98	13,06	0,08	-0,38	0,39	0,77	-0,91	-0,95
24	12,00	12,08	0,08	-0,98	-0,23	0,75	-0,78	-0,92

Table 5-15 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,06; 0,09]MW, [0,75; 5,22]Mvar, [-1,04; 0,66]kV for T1 and [-1,02; 0,53]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-11 to Figure 5-13 depicts the comparison of the results for test case 2.

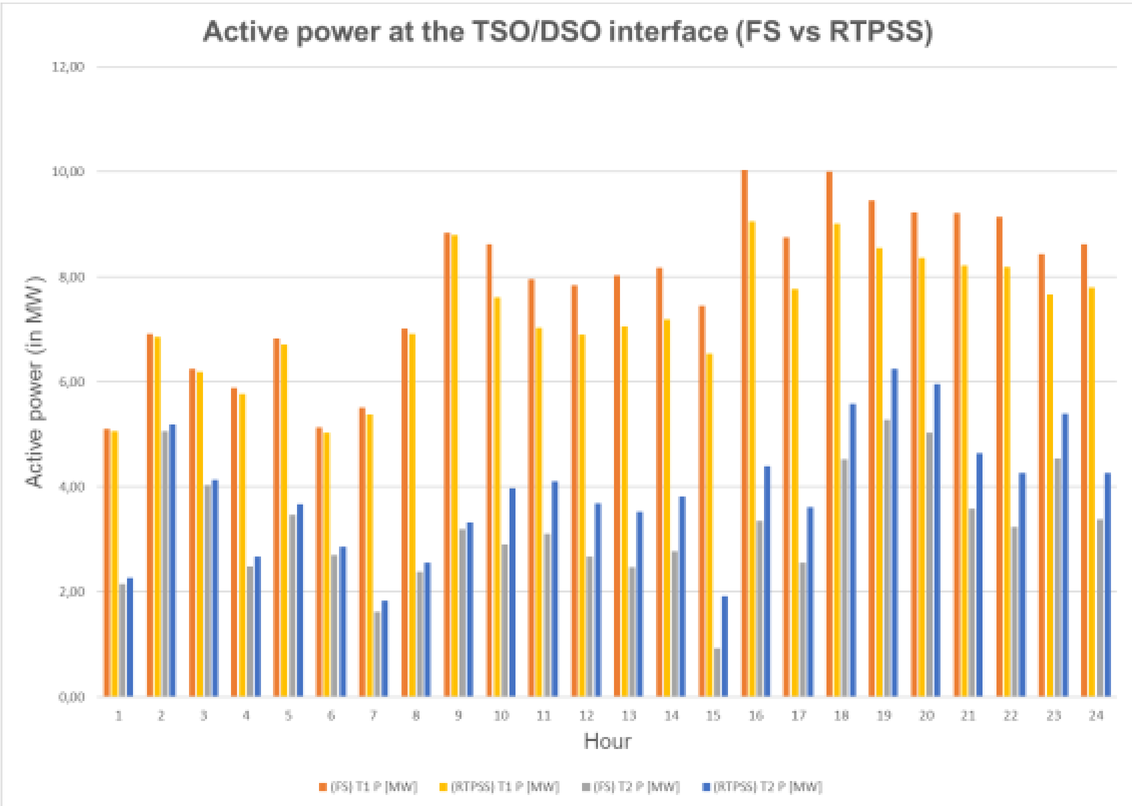


Figure 5-11 – Active Power results at TSO/DSO interface for test case 2

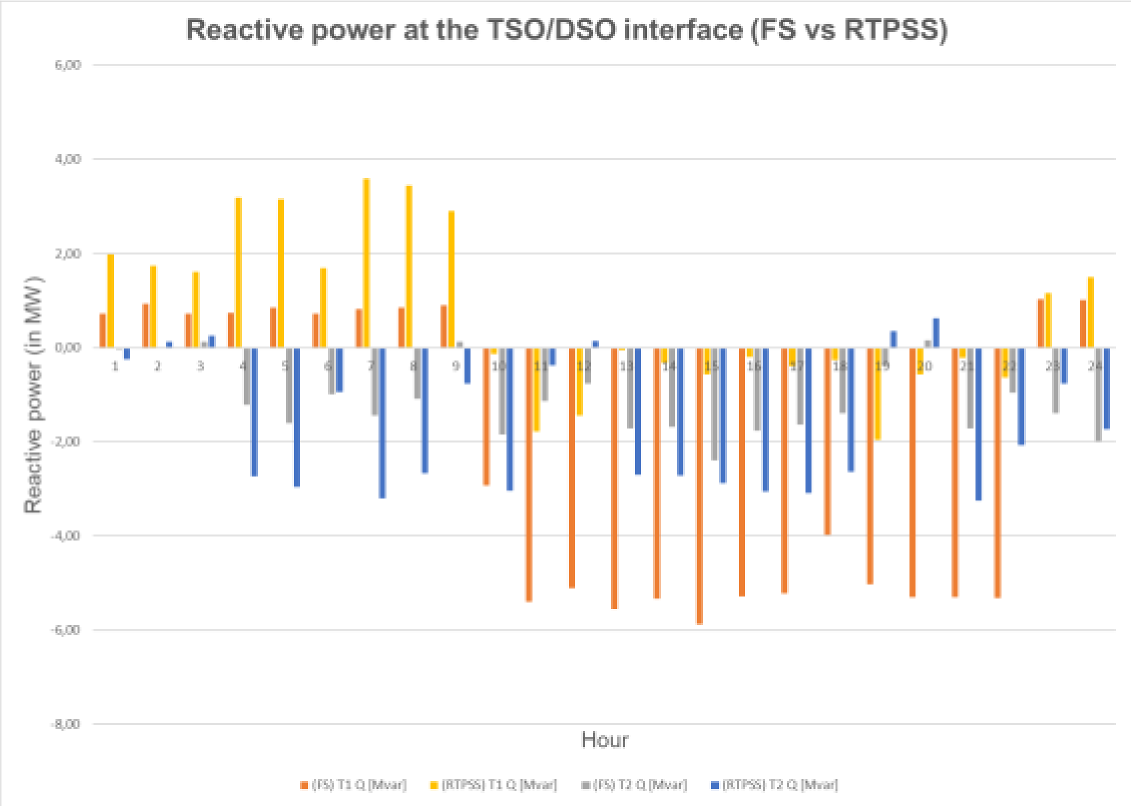


Figure 5-12 – Reactive Power results at TSO/DSO interface for test case 2

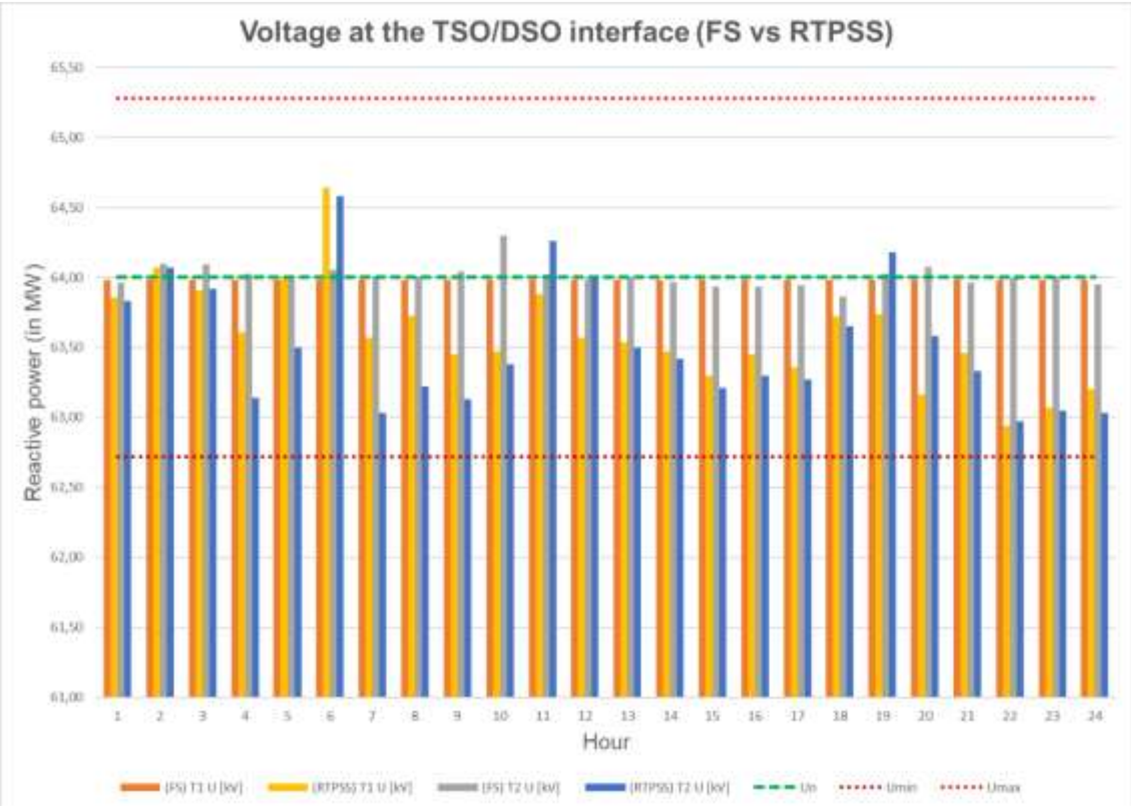


Figure 5-13 – Voltage results at TSO/DSO interface for test case 2

5.2.1.3 Test case 5

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are not considered as a flexibility option and the optimisation function is focused on the minimisation of costs. From Table 5-16 to Table 5-19 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-16 – FS voltage results for test case 5

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,96	63,96
2	63,98	63,98	63,92	64,10
3	63,98	63,98	63,92	64,09
4	63,98	63,98	63,71	63,94
5	63,98	63,98	63,65	63,91
6	63,98	63,98	63,76	63,98
7	63,98	63,98	63,71	63,96
8	63,98	63,98	63,74	64,01
9	63,98	63,98	63,86	63,98
10	63,98	63,98	63,60	62,80
11	63,98	63,98	63,69	64,01
12	63,98	63,98	64,14	63,77
13	63,98	63,98	63,93	62,72
14	63,98	63,98	63,65	62,80
15	63,98	63,98	63,96	63,36
16	63,98	63,98	63,58	62,90
17	63,98	63,98	63,61	63,06
18	63,98	63,98	63,94	63,24
19	63,98	63,98	64,11	64,08
20	63,98	63,98	64,25	63,71
21	63,98	63,98	63,60	62,87
22	63,98	63,98	63,72	62,84
23	63,98	63,98	63,70	63,35
24	63,98	63,98	63,58	63,37

As can be seen in Table 5-16, the FS results from test case 5 show that the voltage stays within the acceptable range [64kV±2%] for both substations.

Table 5-17 – FS capacitor banks results for test case 5

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-18 – FS losses results for test case 5

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	208,26	-225,12	193,34	-237,80	-14,92	-12,68
2	315,22	2297,73	194,30	-399,85	-120,92	-2697,58
3	341,95	3072,99	186,00	-482,33	-155,95	-3555,32
4	342,30	3129,76	337,87	3108,60	-4,43	-21,16
5	345,16	3089,86	339,50	3066,40	-5,66	-23,46
6	344,61	3136,74	340,83	3116,73	-3,78	-20,01
7	344,29	3185,71	339,91	3164,72	-4,38	-20,99
8	347,00	3191,74	188,52	-374,00	-158,48	-3565,74
9	354,12	3281,96	352,54	3269,90	-1,58	-12,06
10	354,77	3227,21	385,65	2805,04	30,88	-422,17
11	319,38	2396,23	351,38	3255,74	32,00	859,51
12	347,16	3183,11	197,85	-289,31	-149,31	-3472,42

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	354,30	3306,15	401,93	2994,96	47,64	-311,19
14	313,53	2286,54	269,83	344,93	-43,70	-1941,61
15	349,53	3363,03	365,13	3434,14	15,60	71,11
16	355,22	3164,39	253,31	1,86	-101,91	-3162,53
17	352,68	3220,19	395,60	3600,04	42,92	379,85
18	363,22	3306,67	240,63	84,62	-122,59	-3222,05
19	364,90	3301,13	207,82	-231,53	-157,08	-3532,66
20	364,70	3345,49	367,87	3364,47	3,17	18,98
21	358,08	3290,08	264,31	172,02	-93,77	-3118,06
22	320,22	2460,18	388,63	2935,39	68,41	475,21
23	323,77	2431,76	377,56	3402,96	53,79	971,20
24	356,40	3271,45	366,99	3331,96	10,58	60,51
				TOTAL VARIATION	**-833,47**	**-26275,32**

Table 5-19 – FS objective function fitness for test case 5

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	306931000	3246520	-303684480
2	2257920	1383930	-873990
3	3073800	1656780	-1417020
4	5303710	5089500	-214210
5	3859980	3707470	-152510
6	5022080	4705430	-316650
7	569068	361444	-207624
8	538315	197,9	-538117,1
9	301886	172130	-129756
10	1178190	864422	-313768
11	4737880	5334050	596170
12	6033900	3367500	-2666400
13	1472430	982614	-489816
14	1172070	819516	-352554
15	2352150	2057770	-294380
16	957575	547443	-410132
17	1159360	979415	-179945
18	1124820	611577	-513243
19	3378300	1978760	-1399540
20	3556680	3294520	-262160
21	1082550	628081	-454469
22	1046940	796478	-250462
23	1672380	1706440	34060
24	1855710	1793630	-62080
Global	**360638694**	**46085618**	**-314553076**

In this test case, the optimisation strategy was to minimize costs. Nevertheless, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-20 – FS final results for test case 5 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,11	0,50	63,98	2,15	-0,01	63,96
2	6,92	0,83	63,98	5,07	0,01	64,10
3	6,25	0,82	63,98	4,04	0,12	64,09
4	5,97	4,36	63,98	2,56	-1,30	63,94
5	6,92	4,48	63,98	3,54	-1,68	63,91
6	5,23	4,34	63,98	2,77	-1,06	63,98
7	5,60	4,16	63,98	1,70	-1,44	63,96
8	7,02	0,86	63,98	2,38	-1,08	64,01
9	8,93	4,45	63,98	3,27	0,12	63,98
10	8,72	15,27	63,98	2,98	-1,84	62,80
11	8,04	3,68	63,98	3,18	-1,15	64,01
12	7,84	3,35	63,98	2,67	-0,97	63,77
13	8,14	16,25	63,98	2,56	-1,72	62,72
14	8,22	12,96	63,98	2,81	-1,68	62,80
15	7,54	9,21	63,98	1,01	-2,40	63,36
16	10,07	11,86	63,98	3,38	-1,76	62,90
17	8,86	13,16	63,98	2,65	-1,64	63,06
18	10,03	8,87	63,98	4,54	-1,40	63,24
19	9,45	0,85	63,98	5,28	-0,32	64,08
20	9,32	7,56	63,98	5,10	-0,19	63,71
21	9,26	12,49	63,98	3,61	-1,72	62,87
22	9,26	15,20	63,98	3,32	-0,96	62,84
23	8,53	10,80	63,98	4,63	-1,40	63,35
24	8,72	9,95	63,98	3,46	-2,00	63,37

Table 5-21 – RTPSS final results for test case 5 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	4,46	2,61	63,85	5,85	1,60	63,79
2	4,07	1,52	64,08	5,71	0,24	64,06
3	3,63	1,44	63,92	4,93	0,42	63,91
4	4,13	3,01	63,62	4,26	-2,43	63,14
5	4,32	3,03	64,00	4,14	-2,83	63,50
6	3,51	1,42	64,64	4,88	-0,67	64,58
7	4,11	1,98	63,60	4,49	-5,42	63,06
8	8,97	3,33	63,73	8,19	-1,39	63,19
9	10,75	5,47	63,40	7,21	0,50	63,11
10	5,76	8,53	64,07	1,75	3,95	63,27
11	5,37	3,86	64,53	3,63	0,12	64,25
12	5,03	3,69	64,23	2,90	0,49	63,99
13	5,47	8,39	64,14	2,29	4,28	63,38
14	5,14	8,42	64,04	1,58	4,55	63,30
15	5,70	6,23	63,91	1,92	0,62	63,15
16	6,65	8,55	64,03	0,90	3,80	63,18
17	6,33	11,09	63,88	1,27	4,86	63,14
18	6,31	8,48	64,29	2,12	4,24	63,54
19	6,09	6,93	64,30	4,07	2,67	64,14
20	5,67	4,39	63,78	4,03	1,95	63,56
21	5,84	8,62	64,02	1,37	3,99	63,21
22	6,34	8,05	63,50	1,66	5,21	62,85
23	5,24	7,40	63,67	3,32	2,60	62,99
24	5,78	7,38	63,80	2,60	0,92	62,98

Table 5-22 – Comparison between FS and RTPSS final results for test case 5 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,26	10,31	3,05	0,49	4,21	3,72	-0,13	-0,17
2	11,98	9,78	-2,20	0,84	1,76	0,92	0,10	-0,04
3	10,28	8,56	-1,72	0,95	1,86	0,91	-0,06	-0,18
4	8,53	8,39	-0,14	3,07	0,58	-2,49	-0,36	-0,80
5	10,46	8,46	-2,00	2,80	0,20	-2,60	0,02	-0,41
6	7,99	8,39	0,40	3,28	0,75	-2,53	0,66	0,60
7	7,29	8,60	1,31	2,72	-3,44	-6,16	-0,38	-0,90
8	9,41	17,16	7,75	-0,22	1,94	2,16	-0,25	-0,82
9	12,20	17,96	5,76	4,57	5,97	1,40	-0,58	-0,87
10	11,71	7,51	-4,20	13,43	12,48	-0,95	0,09	0,47
11	11,22	9,00	-2,22	2,54	3,98	1,44	0,55	0,24
12	10,51	7,93	-2,58	2,38	4,18	1,80	0,25	0,22

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	10,70	7,76	-2,94	14,53	12,67	-1,86	0,16	0,66
14	11,03	6,72	-4,31	11,28	12,97	1,69	0,06	0,50
15	8,54	7,62	-0,92	6,81	6,85	0,04	-0,07	-0,21
16	13,45	7,55	-5,90	10,10	12,35	2,25	0,05	0,28
17	11,51	7,60	-3,91	11,52	15,95	4,43	-0,10	0,08
18	14,57	8,43	-6,14	7,47	12,72	5,25	0,31	0,30
19	14,73	10,16	-4,57	0,53	9,60	9,07	0,32	0,06
20	14,42	9,70	-4,72	7,36	6,34	-1,02	-0,20	-0,15
21	12,87	7,21	-5,66	10,77	12,61	1,84	0,04	0,34
22	12,57	8,00	-4,57	14,24	13,26	-0,98	-0,48	0,01
23	13,16	8,56	-4,60	9,40	10,00	0,60	-0,31	-0,36
24	12,18	8,38	-3,80	7,95	8,30	0,35	-0,18	-0,39

Table 5-22 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [-6,14; 7,75]MW, [-6,16; 9,07]Mvar, [-0,58; 0,66]kV for T1 and [-0,90; 0,66]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-14 to Figure 5-16 depicts the comparison of the results for test case 5.

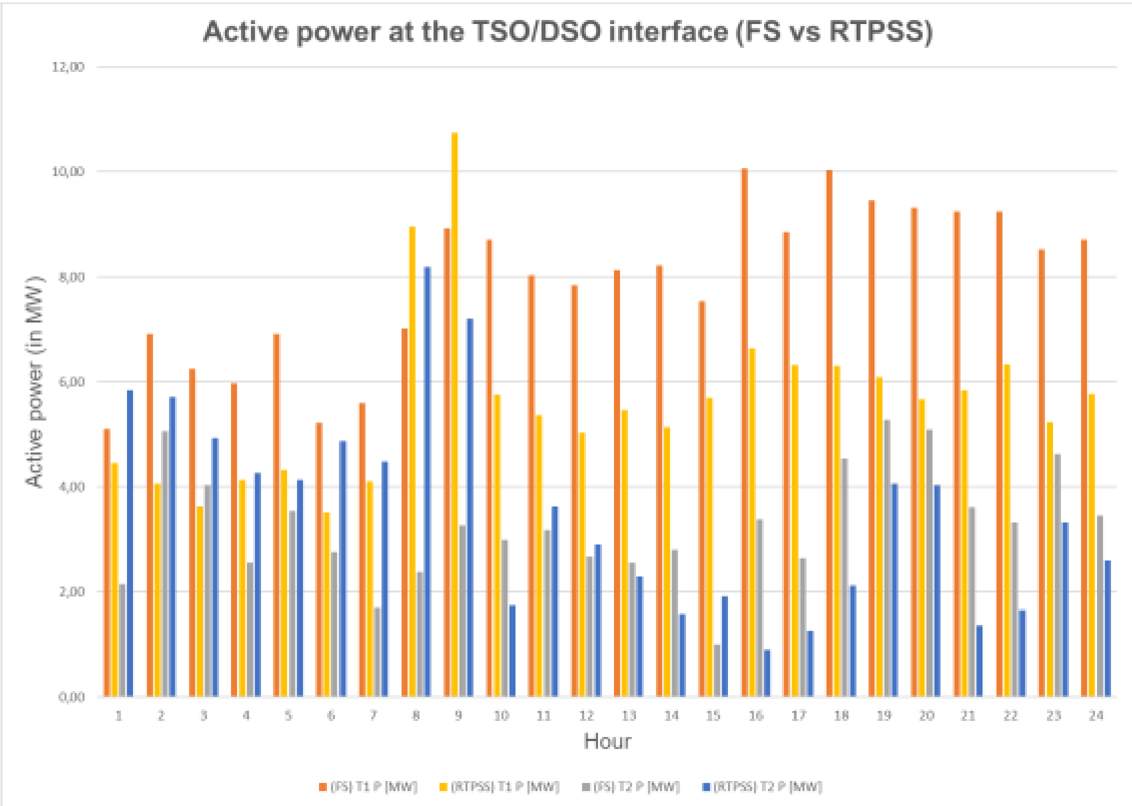


Figure 5-14 – Active Power results at TSO/DSO interface for test case 5

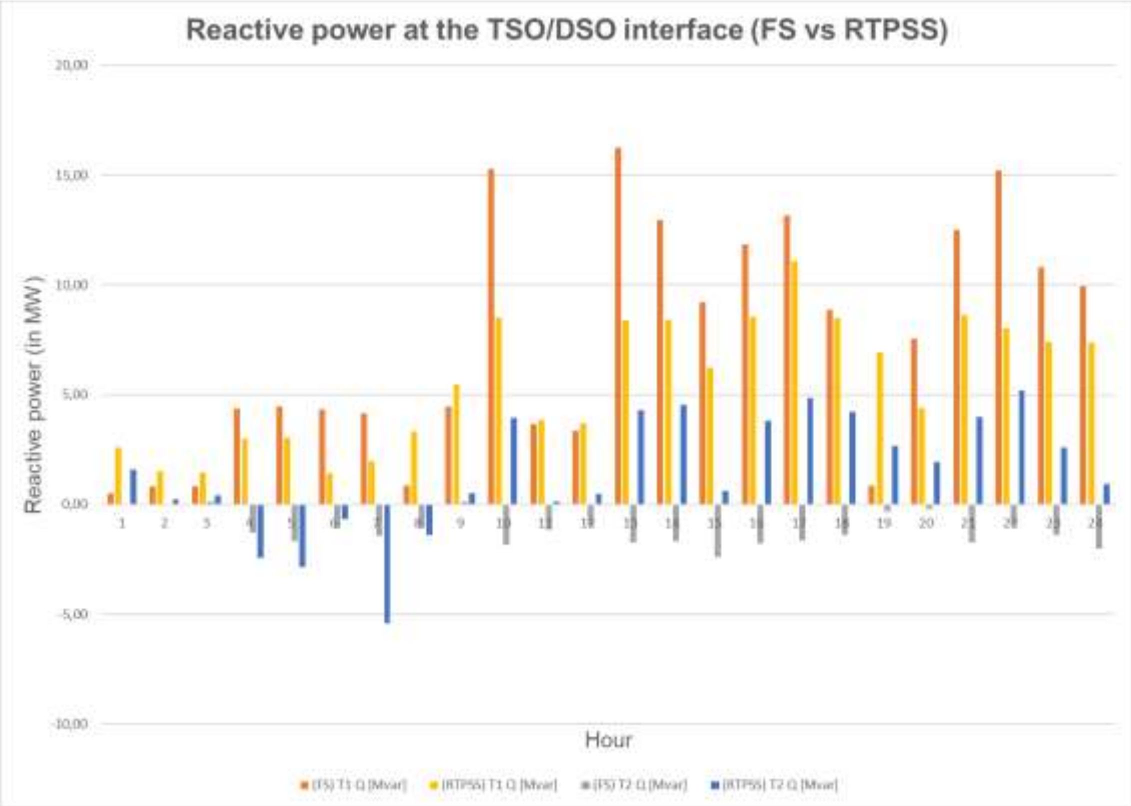


Figure 5-15 – Reactive Power results at TSO/DSO interface for test case 5

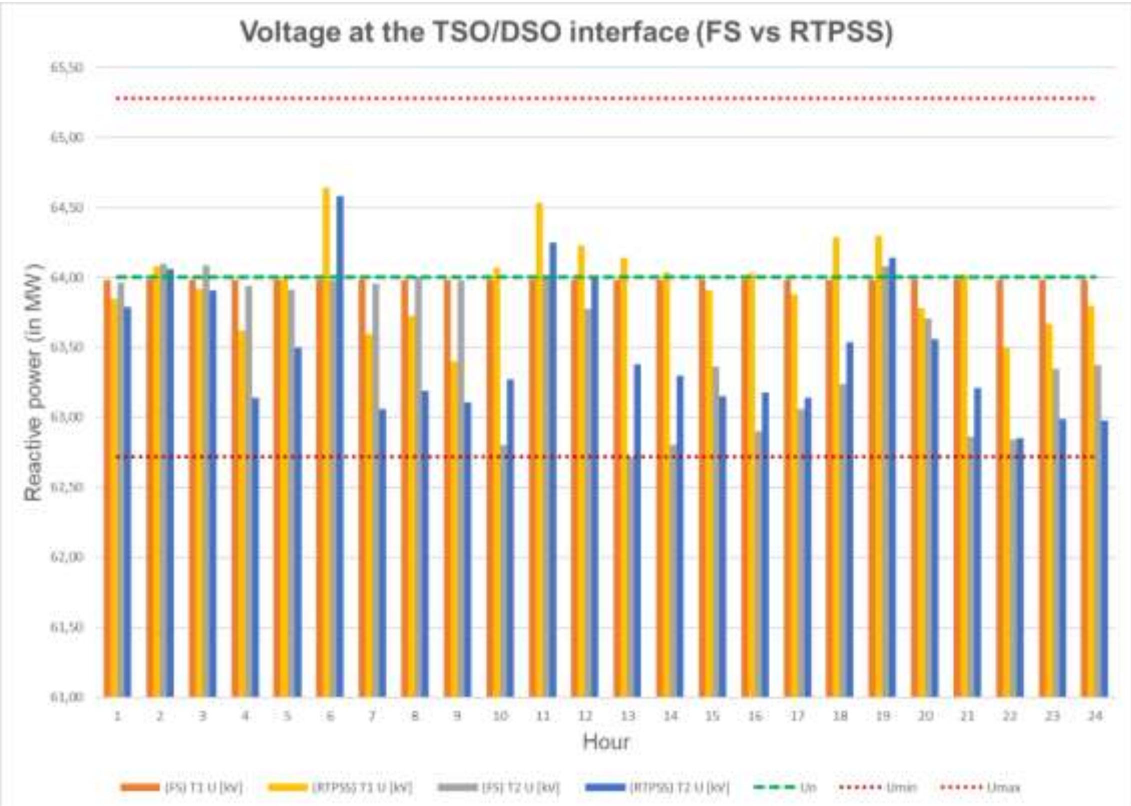


Figure 5-16 – Voltage results at TSO/DSO interface for test case 5

5.2.1.4 Test case 6

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are considered as a flexibility option and the optimisation function is focused on the minimisation of costs. From Table 5-23 to Table 5-26 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-23 – FS voltage results for test case 6

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,96	63,96
2	63,98	63,98	63,90	64,02
3	63,98	63,98	63,92	64,09
4	63,98	63,98	63,71	63,96
5	63,98	63,98	63,65	64,00
6	63,98	63,98	63,76	64,05
7	63,98	63,98	63,71	64,00
8	63,98	63,98	63,74	64,01
9	63,98	63,98	63,86	63,98
10	63,98	63,98	63,60	64,32
11	63,98	63,98	64,44	63,97
12	63,98	63,98	63,93	63,93
13	63,98	63,98	63,81	63,66
14	63,98	63,98	63,89	63,97
15	63,98	63,98	63,78	63,92
16	63,98	63,98	64,07	63,60
17	63,98	63,98	63,87	63,95
18	63,98	63,98	63,82	63,95
19	63,98	63,98	64,43	64,18
20	63,98	63,98	64,06	64,01
21	63,98	63,98	63,78	63,92
22	63,98	63,98	63,88	63,94
23	63,98	63,98	63,86	64,36
24	63,98	63,98	63,88	63,88

As can be seen in Table 5-23, the FS results from test case 6 show that the voltage stays within the acceptable range [64kV±2%] for both substations.

Table 5-24 – FS capacitor banks results for test case 6

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	0	0	0
11	40	0	30	30
12	40	0	30	30
13	40	0	0	0
14	40	0	0	0
15	40	0	0	0
16	40	0	0	0
17	40	0	0	0
18	40	0	0	0
19	40	0	30	30
20	40	0	30	30
21	40	0	0	0
22	40	0	0	0
23	40	0	0	0
24	40	0	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-25 – FS losses results for test case 6

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	208,26	-225,12	346,72	3312,45	138,46	3537,57
2	350,96	3158,70	349,28	3147,47	-1,68	-11,23
3	341,95	3072,99	185,99	-482,53	-155,96	-3555,52
4	342,30	3129,76	337,75	3108,53	-4,55	-21,23
5	345,16	3089,86	184,55	-480,50	-160,61	-3570,36
6	344,61	3136,74	185,90	-431,99	-158,71	-3568,73
7	344,29	3185,71	185,14	-383,25	-159,15	-3568,96
8	347,00	3191,74	188,52	-374,00	-158,48	-3565,74
9	354,12	3281,96	352,54	3269,90	-1,58	-12,06
10	354,77	3227,21	205,85	-286,12	-148,93	-3513,33
11	364,14	3300,43	355,23	3319,99	-8,91	19,56
12	350,61	3255,56	350,61	3255,56	0,00	0,00
13	357,22	3380,87	219,94	-104,13	-137,28	-3485,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
14	230,55	162,82	196,30	-352,28	-34,25	-515,10
15	355,65	3442,12	358,81	3478,73	3,17	36,61
16	359,34	3253,67	241,00	233,16	-118,34	-3020,51
17	233,11	234,79	199,24	-280,74	-33,87	-515,53
18	365,71	3379,10	217,92	-121,35	-147,79	-3500,45
19	311,66	1812,29	216,87	-194,14	-94,79	-2006,43
20	332,53	2557,53	366,95	3418,34	34,42	860,81
21	358,52	3361,41	356,94	3349,41	-1,58	-12,00
22	357,78	3395,89	357,23	3389,47	-0,55	-6,42
23	360,67	3365,48	209,63	-243,11	-151,05	-3608,59
24	353,33	3267,10	349,42	3245,37	-3,90	-21,73
				TOTAL VARIATION	**-1505,90**	**-33624,37**

Table 5-26 – FS objective function fitness for test case 6

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	306931000	5821990	-301109010
2	2513920	2488100	-25820
3	3073800	1656700	-1417100
4	5303710	5087680	-216030
5	3859980	2015360	-1844620
6	5022080	2566500	-2455580
7	569068	196873	-372195
8	538315	197,9	-538117,1
9	301886	172130	-129756
10	1178190	742,1	-1177447,9
11	19883900	4005740	-15878160
12	4728140	4661650	-66490
13	181716	256,5	-181459,5
14	6164,7	206,1	-5958,6
15	843921	698744	-145177
16	391,4	6157,3	5765,9
17	6204	209,2	-5994,8
18	99625,2	228,8	-99396,4
19	5357750	1256420	-4101330
20	1989120	2266910	277790
21	137599	388,4	-137210,6
22	69630,2	388,7	-69241,5
23	139486	77525,2	-61960,8
24	402168	378699	-23469
Global	**363137765**	**33359796**	**-329777968**

In this test case the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-27 – FS final results for test case 6 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,20	4,34	63,98	2,21	-0,10	63,96
2	7,00	4,45	63,98	5,13	-0,06	64,02
3	6,25	0,72	63,98	4,04	0,13	64,09
4	5,97	4,14	63,98	2,56	-1,28	63,96
5	6,84	0,85	63,98	3,47	-1,60	64,00
6	5,14	0,72	63,98	2,70	-0,99	64,05
7	5,51	0,82	63,98	1,63	-1,44	64,00
8	7,02	0,86	63,98	2,38	-1,08	64,01
9	8,93	4,45	63,98	3,27	0,12	63,98
10	8,62	-2,93	63,98	2,90	-1,84	64,32
11	8,04	-2,90	63,98	3,18	-1,19	63,97
12	7,92	-2,51	63,98	2,74	-0,82	63,93
13	8,04	-3,19	63,98	2,48	-1,72	63,66
14	8,18	-5,35	63,98	2,78	-1,68	63,97
15	7,53	-3,67	63,98	1,00	-2,40	63,92
16	10,06	-2,89	63,98	3,38	-1,76	63,60
17	8,76	-5,23	63,98	2,55	-1,64	63,95
18	10,02	-5,53	63,98	4,53	-1,40	63,95
19	9,46	-7,56	63,98	5,29	-0,24	64,18
20	9,32	-2,69	63,98	5,10	0,09	64,01
21	9,31	-2,85	63,98	3,65	-1,72	63,92
22	9,24	-2,77	63,98	3,30	-0,96	63,94
23	8,44	-2,77	63,98	4,55	-1,40	64,36
24	8,71	4,47	63,98	3,45	-2,00	63,88

Table 5-28 – RTPSS final results for test case 6 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	4,06	2,10	63,86	5,55	0,35	63,81
2	4,08	1,34	64,08	6,19	0,18	64,06
3	3,80	1,56	63,92	4,96	0,52	63,91
4	3,96	2,89	63,62	3,93	-2,49	63,14
5	4,18	2,95	64,01	3,78	-2,80	63,50
6	3,47	1,40	64,64	5,11	-0,76	64,58
7	4,11	1,98	63,60	4,49	-5,42	63,06
8	9,33	3,30	63,73	8,53	-1,37	63,19
9	10,42	1,40	63,47	7,48	-2,52	63,16
10	9,09	-0,58	63,48	10,77	-3,28	63,38
11	4,99	0,79	63,84	5,57	-0,11	64,25
12	4,56	-1,84	63,58	4,57	-0,61	64,01
13	8,54	-5,18	63,63	8,78	0,73	63,44
14	8,68	-4,01	63,53	6,86	-3,34	63,43
15	6,94	-4,65	63,37	6,67	1,06	63,13
16	10,55	-4,31	63,53	6,86	-1,51	63,27
17	8,88	-4,70	63,43	6,14	0,77	63,20
18	10,83	-4,25	63,78	8,66	-0,59	63,61
19	5,32	-5,85	63,81	5,08	1,62	64,16
20	5,31	-5,52	63,25	5,00	1,73	63,56
21	9,11	-4,30	63,53	6,68	0,92	63,26
22	10,12	-4,67	63,01	7,64	-0,05	62,93
23	6,18	-2,71	63,14	6,17	3,20	62,98
24	5,86	4,38	63,15	4,25	-0,78	63,01

Table 5-29 – Comparison between FS and RTPSS final results for test case 6 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,41	9,61	2,20	4,24	2,45	-1,79	-0,12	-0,15
2	12,14	10,27	-1,87	4,39	1,52	-2,87	0,10	0,04
3	10,28	8,76	-1,52	0,85	2,08	1,23	-0,06	-0,18
4	8,53	7,89	-0,64	2,87	0,40	-2,47	-0,36	-0,82
5	10,31	7,96	-2,35	-0,75	0,15	0,90	0,03	-0,50
6	7,84	8,58	0,74	-0,27	0,64	0,91	0,66	0,53
7	7,14	8,60	1,46	-0,62	-3,44	-2,82	-0,38	-0,94
8	9,41	17,86	8,45	-0,22	1,93	2,15	-0,25	-0,82
9	12,20	17,90	5,70	4,57	-1,12	-5,69	-0,51	-0,82
10	11,53	19,86	8,33	-4,77	-3,86	0,91	-0,50	-0,94
11	11,23	10,56	-0,67	-4,09	0,68	4,77	-0,14	0,28
12	10,67	9,13	-1,54	-3,33	-2,45	0,88	-0,40	0,08

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	10,52	17,32	6,80	-4,91	-4,45	0,46	-0,35	-0,22
14	10,95	15,54	4,59	-7,03	-7,35	-0,32	-0,45	-0,54
15	8,54	13,61	5,07	-6,07	-3,59	2,48	-0,61	-0,79
16	13,44	17,41	3,97	-4,65	-5,82	-1,17	-0,45	-0,33
17	11,31	15,02	3,71	-6,87	-3,93	2,94	-0,55	-0,75
18	14,55	19,49	4,94	-6,93	-4,84	2,09	-0,20	-0,34
19	14,74	10,40	-4,34	-7,80	-4,23	3,57	-0,17	-0,02
20	14,42	10,31	-4,11	-2,60	-3,79	-1,19	-0,73	-0,45
21	12,96	15,79	2,83	-4,57	-3,38	1,19	-0,45	-0,66
22	12,54	17,76	5,22	-3,73	-4,72	-0,99	-0,97	-1,01
23	12,99	12,35	-0,64	-4,17	0,49	4,66	-0,84	-1,38
24	12,16	10,11	-2,05	2,47	3,60	1,13	-0,83	-0,87

Table 5-29 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [-4,34; 8,45]MW, [-5,69; 4,77]Mvar, [-0,97; 0,66]kV for T1 and [-1,38; 0,53]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-17 to Figure 5-19 depicts the comparison of the results for test case 2.

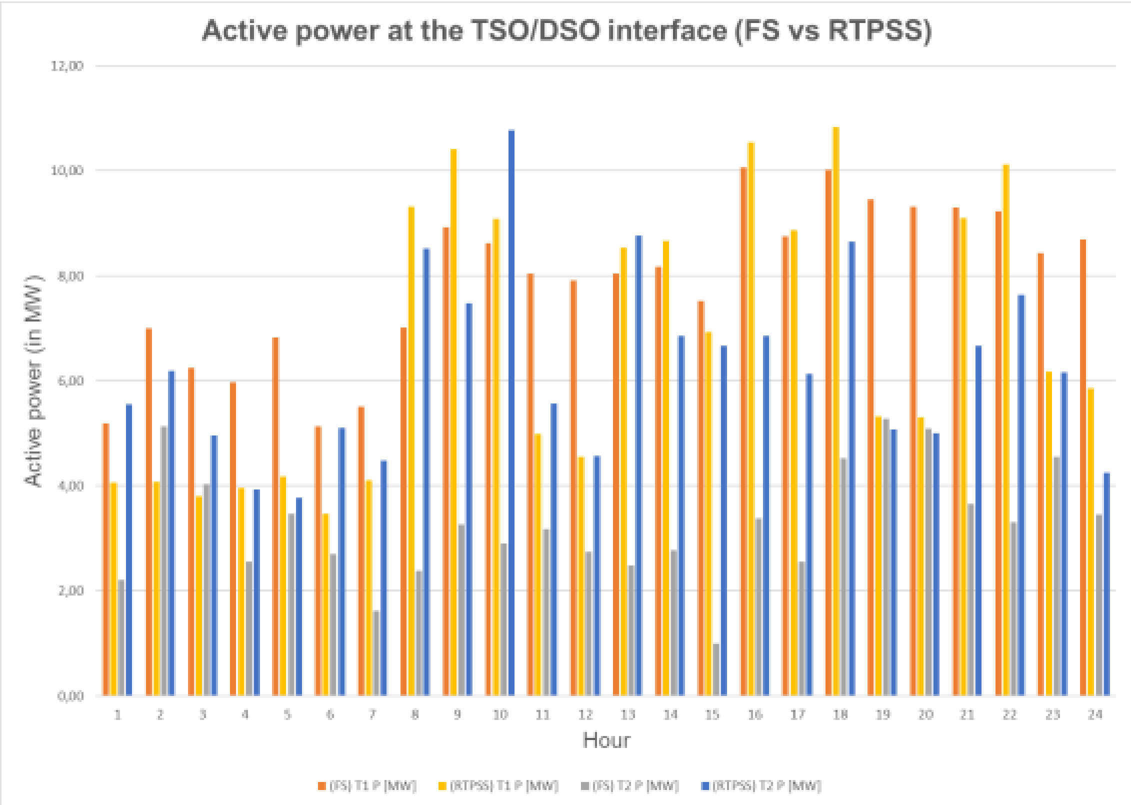


Figure 5-17 – Active Power results at TSO/DSO interface for test case 6

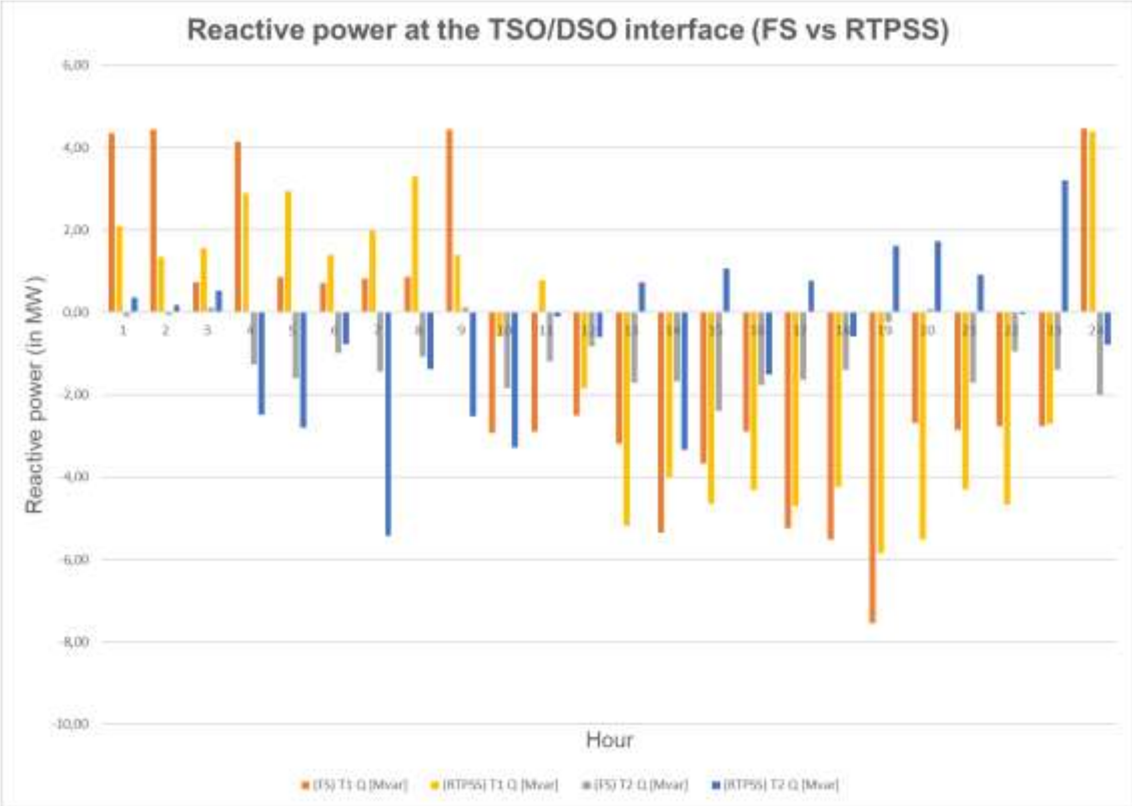


Figure 5-18 – Reactive Power results at TSO/DSO interface for test case 6

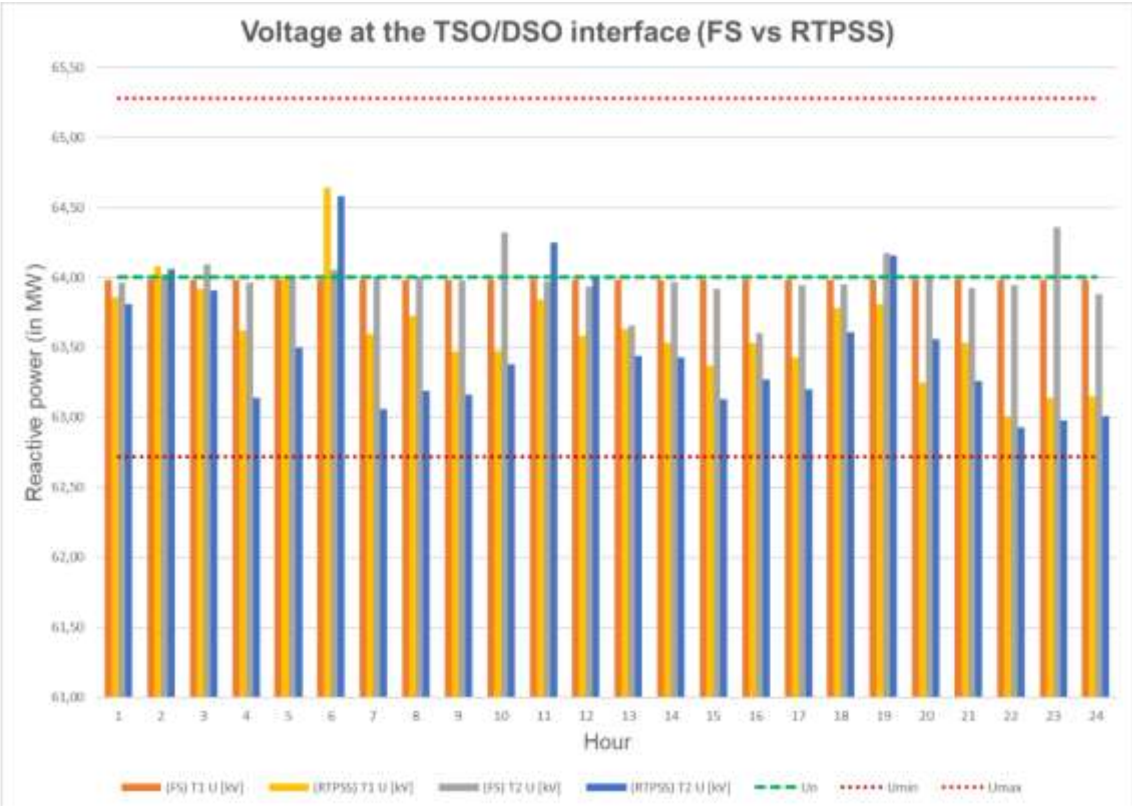


Figure 5-19 – Voltage results at TSO/DSO interface for test case 6

5.2.2 Cluster 2

This is the test case cluster based on the scenario for meshed distribution grid operation with low penetration of RES. The source data of the graphics is available in Annex B – Cluster 2 simulation results.

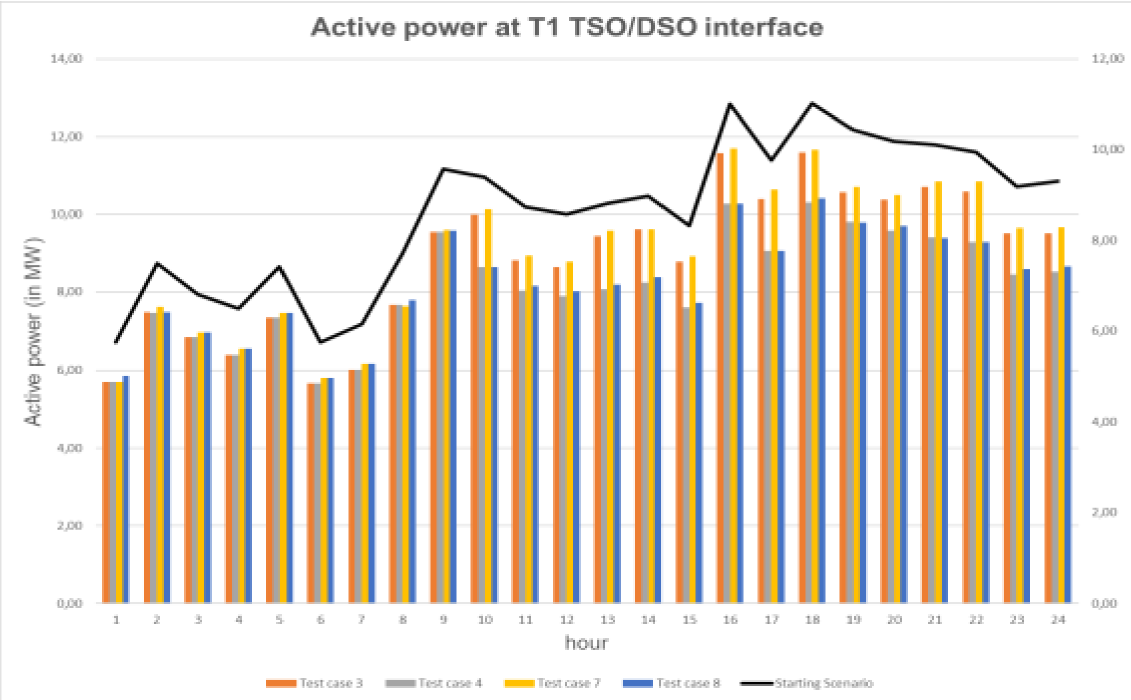


Figure 5-20 – Active Power profile at T1 TSO/DSO interface for cluster 2 test cases

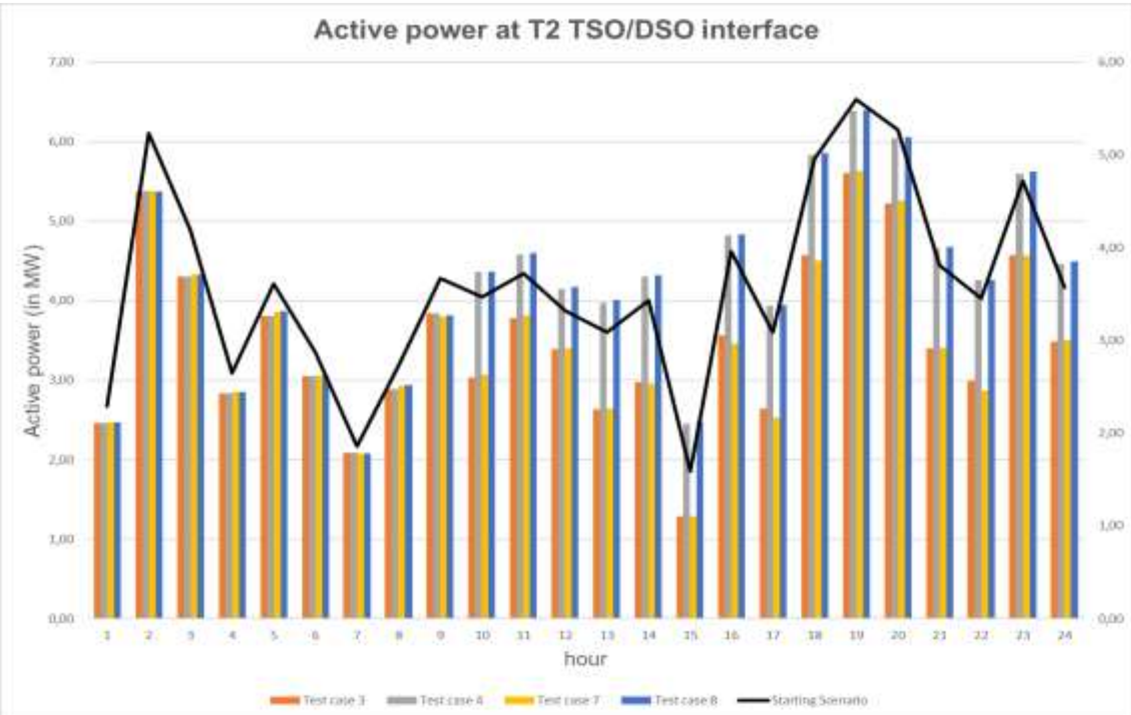


Figure 5-21 – Active Power profile at T2 TSO/DSO interface for cluster 2 test cases

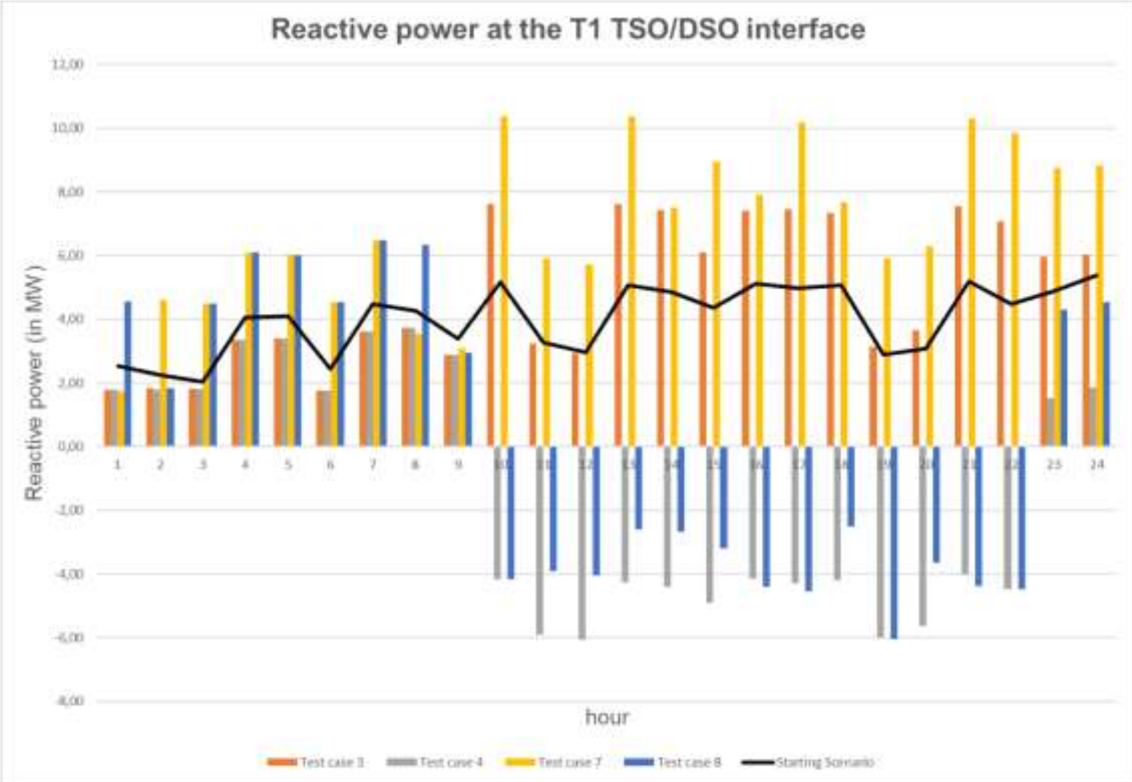


Figure 5-22 – Reactive Power profile at T1 TSO/DSO interface for cluster 2 test cases

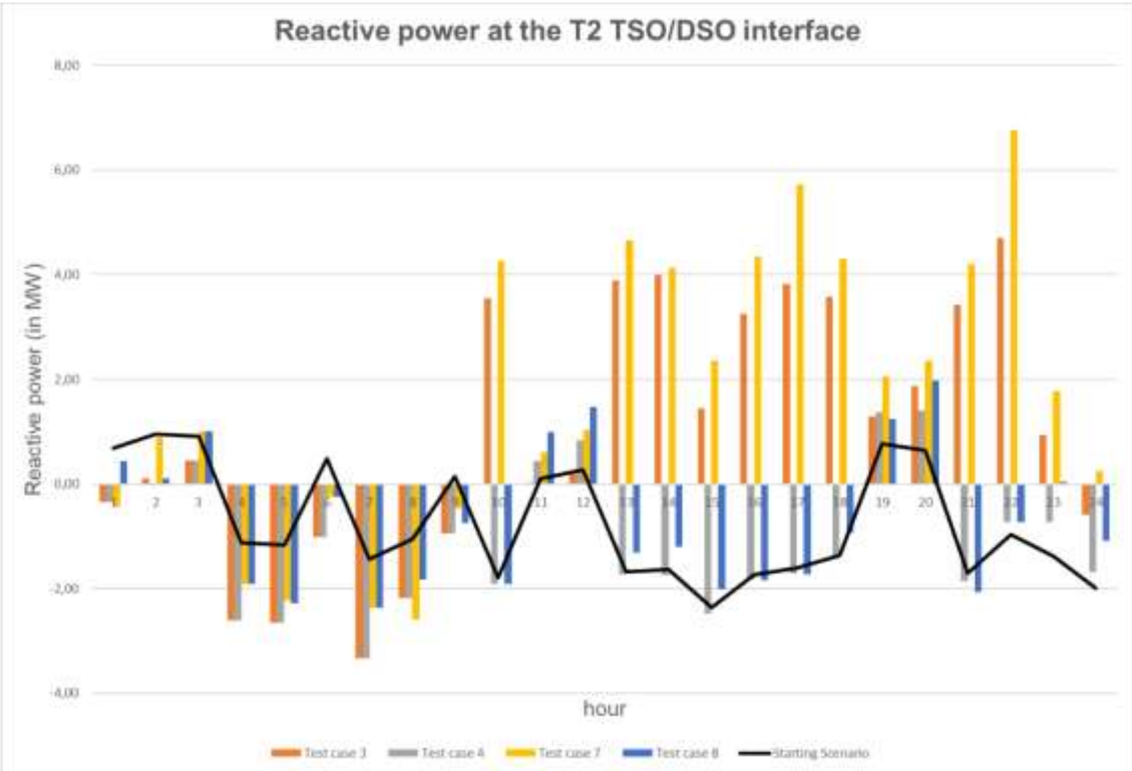


Figure 5-23 – Reactive Power profile at T2 TSO/DSO interface for cluster 2 test cases

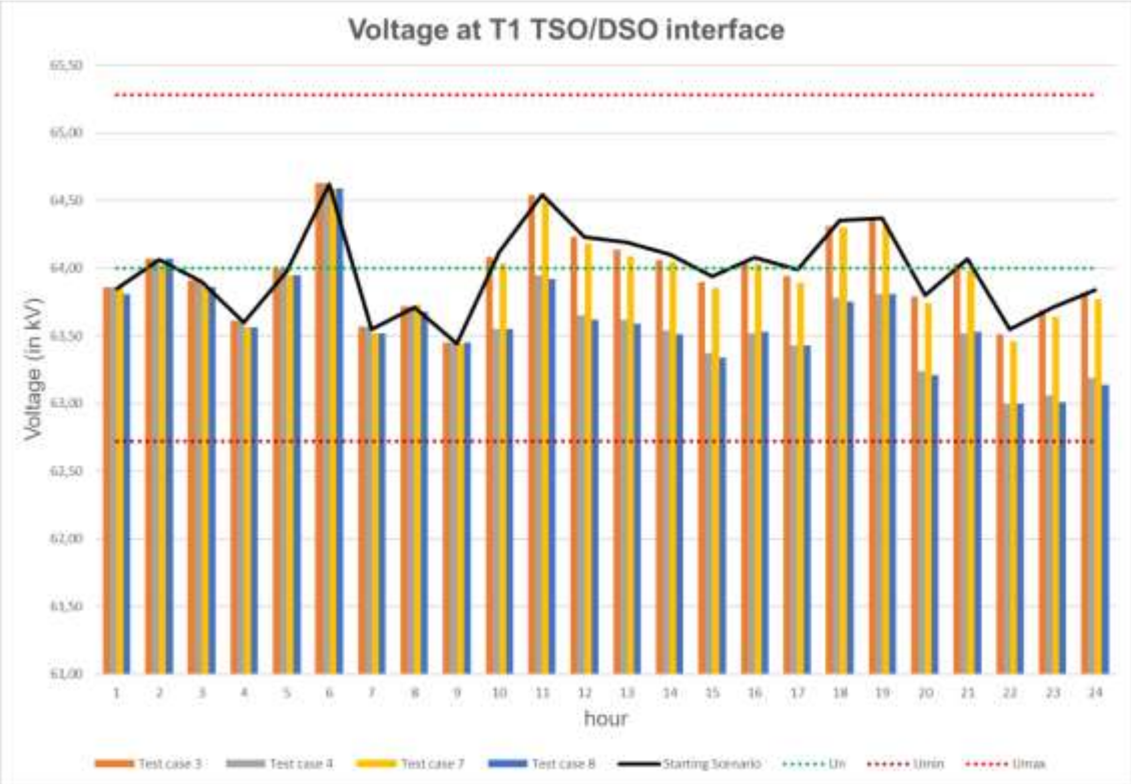


Figure 5-24 – Voltage at T1 TSO/DSO interface for cluster 2 test cases

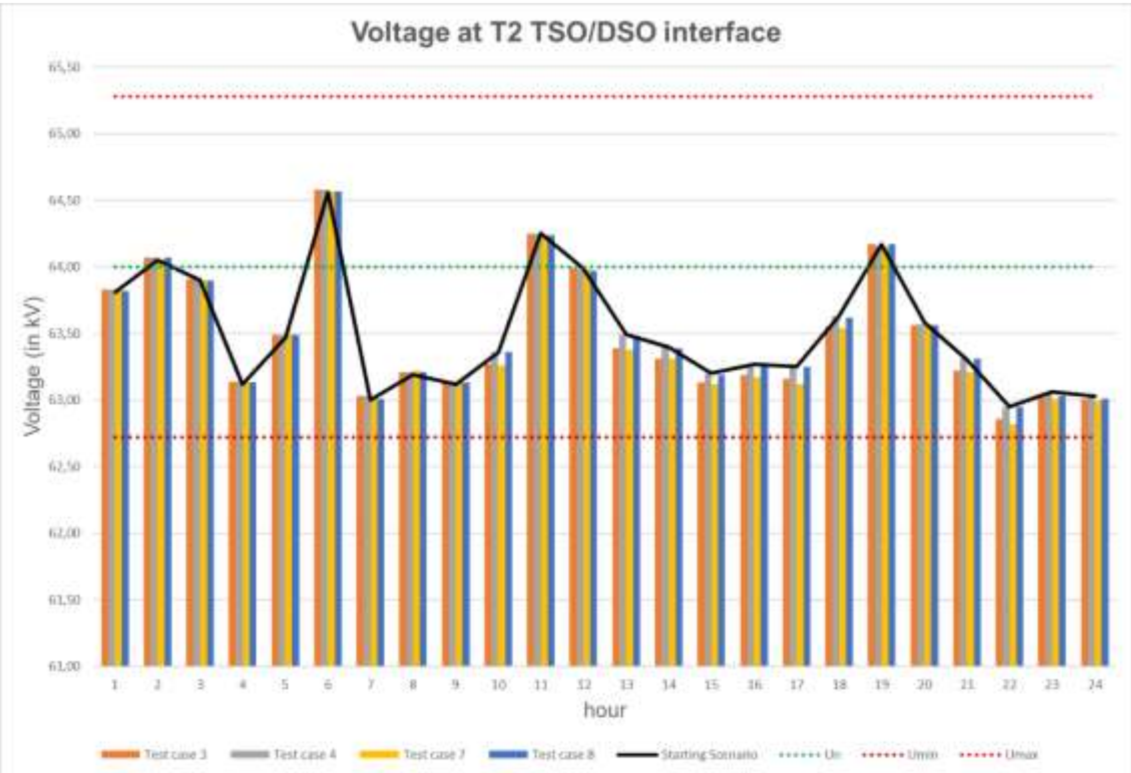


Figure 5-25 – Voltage at T2 TSO/DSO interface for cluster 2 test cases

5.2.2.1 Test case 3

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are not considered as a flexibility option and the optimisation function is focused on the minimisation of grid losses. From Table 5-30 to Table 5-33 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-30 – FS voltage results for test case 3

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,97	63,97
2	63,98	63,98	64,39	64,10
3	63,98	63,98	64,00	64,06
4	63,98	63,98	63,79	64,01
5	63,98	63,98	63,72	63,94
6	63,98	63,98	63,84	64,06
7	63,98	63,98	63,78	64,03
8	63,98	63,98	63,80	63,95
9	63,98	63,98	63,93	64,07
10	63,98	63,98	63,67	62,91
11	63,98	63,98	63,75	63,75
12	63,98	63,98	63,82	63,82
13	63,98	63,98	63,70	62,90
14	63,98	63,98	63,71	62,90
15	63,98	63,98	63,67	63,12
16	63,98	63,98	63,65	62,94
17	63,98	63,98	63,68	62,91
18	63,98	63,98	63,71	63,01
19	63,98	63,98	63,85	63,76
20	63,98	63,98	63,92	63,72
21	63,98	63,98	63,67	62,94
22	63,98	63,98	63,77	62,97
23	63,98	63,98	63,76	63,42
24	63,98	63,98	63,65	63,44

As can be seen in Table 5-30, the FS results from test case 3 show that the voltage stays within the acceptable range [64kV±2%] for both substations.

Table 5-31 – FS capacitor banks results for test case 3

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-32 – FS losses results for test case 3

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	209,63	-182,31	195,69	-133,56	-13,94	48,75
2	201,99	-322,75	196,14	-355,19	-5,85	-32,44
3	188,03	-431,03	187,67	-436,36	-0,36	-5,33
4	187,18	-375,71	184,37	-395,91	-2,81	-20,20
5	189,80	-414,75	186,12	-436,87	-3,68	-22,11
6	189,73	-330,59	187,34	-350,04	-2,38	-19,45
7	189,42	-280,53	186,53	-301,11	-2,89	-20,58
8	192,57	-272,59	190,46	-289,22	-2,11	-16,63
9	200,89	-178,90	200,15	-191,62	-0,74	-12,72
10	200,51	-233,68	257,25	159,04	56,74	392,72
11	200,98	-205,47	200,98	-205,47	0,00	0,00
12	194,51	-283,85	194,51	-283,85	0,00	0,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	202,08	-153,41	262,00	268,71	59,92	422,12
14	195,46	-313,55	254,71	102,61	59,25	416,16
15	199,31	-101,25	232,52	135,80	33,21	237,05
16	201,89	-292,52	251,82	51,40	49,93	343,92
17	199,00	-239,05	255,32	156,96	56,31	396,00
18	211,88	-148,73	260,22	191,11	48,35	339,85
19	211,14	-162,86	213,37	-145,81	2,23	17,05
20	210,95	-121,38	216,26	-77,42	5,31	43,96
21	203,83	-208,44	256,86	158,95	53,03	367,39
22	202,07	-178,62	257,73	232,32	55,66	410,94
23	205,12	-208,55	220,77	-98,67	15,65	109,88
24	201,46	-229,49	210,76	-169,12	9,30	60,37
				TOTAL VARIATION	**470,12**	**3456,70**

Table 5-33 – FS objective function fitness for test case 3

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	286699000	3057640	-283641360
2	4465280	1344780	-3120500
3	1609740	1596440	-13300
4	2658130	2601370	-56760
5	1999450	1947830	-51620
6	2453990	2423270	-30720
7	178079	174227	-3852
8	48170	190,4	-47979,6
9	200,8	200,1	-0,7
10	678332	606197	-72135
11	2539780	2515520	-24260
12	2698450	2671430	-27020
13	750073	671152	-78921
14	713604	639313	-74291
15	930790	887282	-43508
16	549740	478937	-70803
17	644621	569584	-75037
18	574290	496154	-78136
19	1761130	1748050	-13080
20	1857760	1838720	-19040
21	622511	548488	-74023
22	648704	563537	-85167
23	1040390	1015200	-25190
24	1061750	1049910	-11840
Global	**317183965**	**29445422**	**-287738543**

In this test case, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-34 – FS final results for test case 3 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,79	0,40	63,98	2,30	0,04	63,97
2	7,51	0,97	63,98	5,26	0,01	64,10
3	6,83	1,20	63,98	4,23	0,09	64,06
4	6,50	1,00	63,98	2,66	-1,23	64,01
5	7,47	1,45	63,98	3,62	-1,65	63,94
6	5,76	0,79	63,98	2,88	-0,98	64,06
7	6,17	0,70	63,98	1,85	-1,44	64,03
8	7,74	1,60	63,98	2,74	-1,04	63,95
9	9,62	0,75	63,98	3,69	0,16	64,07
10	9,45	12,08	63,98	3,52	-1,80	62,91
11	8,76	3,67	63,98	3,76	-1,35	63,75
12	8,60	3,01	63,98	3,35	-0,85	63,82
13	8,87	12,29	63,98	3,14	-1,68	62,90
14	9,03	12,18	63,98	3,50	-1,64	62,90
15	8,36	8,98	63,98	1,63	-2,36	63,12
16	11,06	11,47	63,98	4,01	-1,72	62,94
17	9,83	11,98	63,98	3,14	-1,60	62,91
18	11,09	11,35	63,98	5,00	-1,36	63,01
19	10,47	4,04	63,98	5,63	-0,58	63,76
20	10,21	4,71	63,98	5,32	-0,19	63,72
21	10,18	11,78	63,98	3,85	-1,72	62,94
22	10,02	11,79	63,98	3,49	-0,96	62,97
23	9,24	7,26	63,98	4,75	-1,36	63,42
24	9,34	6,45	63,98	3,58	-2,00	63,44

Table 5-35 – RTPSS final results for test case 3 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,73	1,86	63,86	2,44	-0,22	63,83
2	7,48	1,70	64,07	5,36	0,18	64,07
3	6,82	1,49	63,91	4,31	0,28	63,91
4	6,40	3,16	63,61	2,83	-2,68	63,14
5	7,32	3,00	64,00	3,84	-3,01	63,50
6	5,66	1,61	64,64	3,04	-0,94	64,58
7	6,03	3,49	63,57	2,07	-3,20	63,03
8	7,64	3,31	63,73	2,92	-2,53	63,22
9	9,57	2,74	63,45	3,81	-0,70	63,13
10	9,94	8,11	64,07	3,09	3,12	63,28
11	8,81	3,99	64,52	3,79	0,19	64,25
12	8,67	3,80	64,22	3,36	0,64	63,99
13	9,39	8,14	64,13	2,68	3,53	63,40
14	9,74	8,80	64,03	2,85	5,47	63,28
15	9,01	7,97	63,87	1,07	4,00	63,09
16	11,51	7,90	64,03	3,62	2,82	63,20
17	10,33	7,96	63,93	2,70	3,38	63,16
18	11,53	7,83	64,30	4,62	3,15	63,56
19	10,62	4,16	64,34	5,56	2,01	64,15
20	10,39	4,45	63,78	5,21	2,09	63,56
21	10,64	8,04	64,02	3,45	2,99	63,23
22	10,53	7,57	63,50	3,04	4,25	62,86
23	9,74	7,79	63,65	4,34	3,46	62,98
24	9,67	7,54	63,80	3,34	1,20	62,98

Table 5-36 – Comparison between FS and RTPSS final results for test case 3 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,09	8,17	0,08	0,44	1,64	1,20	-0,12	-0,14
2	12,77	12,84	0,07	0,98	1,88	0,90	0,09	-0,03
3	11,06	11,13	0,07	1,29	1,77	0,48	-0,07	-0,15
4	9,16	9,23	0,07	-0,24	0,48	0,72	-0,37	-0,87
5	11,09	11,16	0,07	-0,21	-0,01	0,20	0,02	-0,44
6	8,64	8,70	0,06	-0,19	0,67	0,86	0,66	0,52
7	8,02	8,10	0,08	-0,74	0,29	1,03	-0,41	-1,00
8	10,49	10,56	0,07	0,56	0,78	0,22	-0,25	-0,73
9	13,31	13,38	0,07	0,91	2,04	1,13	-0,53	-0,94
10	12,97	13,03	0,06	10,28	11,23	0,95	0,09	0,37
11	12,52	12,60	0,08	2,31	4,18	1,87	0,54	0,50
12	11,96	12,03	0,07	2,16	4,44	2,28	0,24	0,17

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	12,01	12,07	0,06	10,61	11,67	1,06	0,15	0,50
14	12,52	12,59	0,07	10,54	14,27	3,73	0,05	0,38
15	9,99	10,08	0,09	6,62	11,97	5,35	-0,11	-0,03
16	15,07	15,13	0,06	9,75	10,72	0,97	0,05	0,26
17	12,97	13,03	0,06	10,38	11,34	0,96	-0,05	0,25
18	16,09	16,15	0,06	9,99	10,98	0,99	0,32	0,55
19	16,10	16,18	0,08	3,45	6,17	2,72	0,36	0,39
20	15,53	15,60	0,07	4,52	6,54	2,02	-0,20	-0,16
21	14,03	14,09	0,06	10,06	11,03	0,97	0,04	0,29
22	13,51	13,57	0,06	10,83	11,82	0,99	-0,48	-0,11
23	13,99	14,08	0,09	5,90	11,25	5,35	-0,33	-0,44
24	12,92	13,01	0,09	4,45	8,74	4,29	-0,18	-0,46

Table 5-36 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,06; 0,09]MW, [0,20; 5,35]Mvar, [-0,53; 0,66]kV for T1 and [-1,00; 0,55]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-26 to Figure 5-28 depicts the comparison of the results for test case 3.

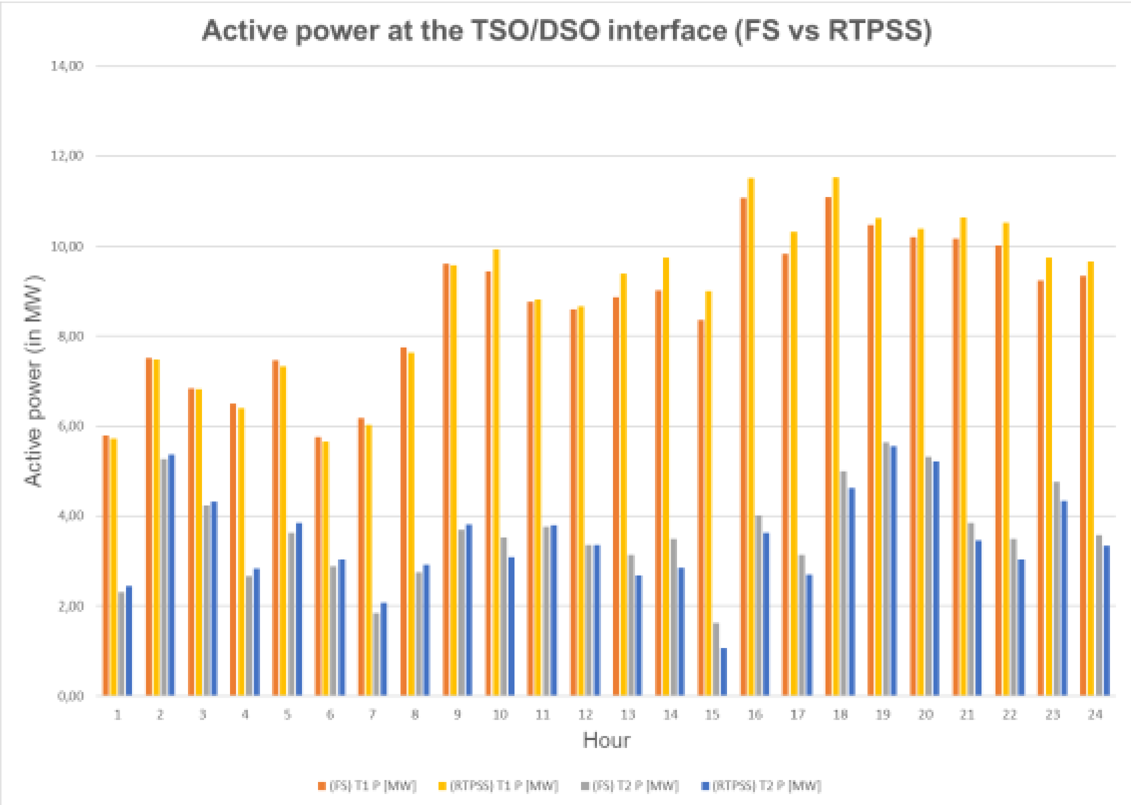


Figure 5-26 – Active Power results at TSO/DSO interface for test case 3

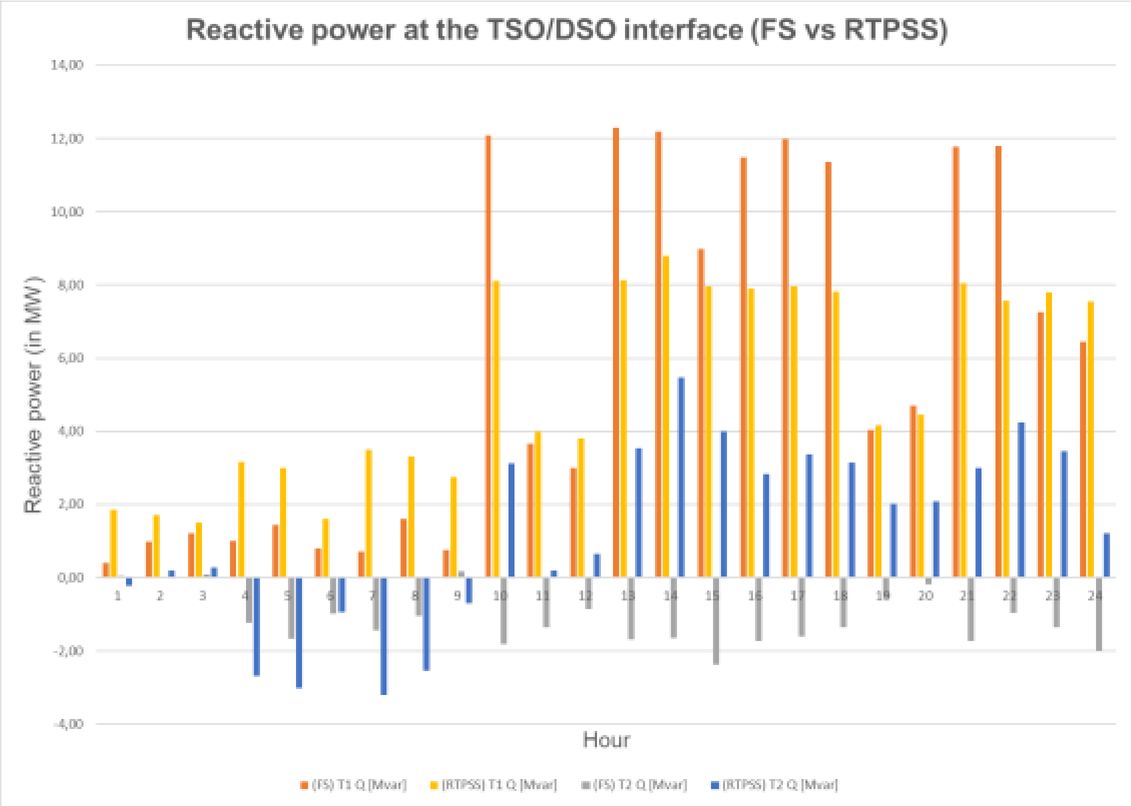


Figure 5-27 – Reactive Power results at TSO/DSO interface for test case 3

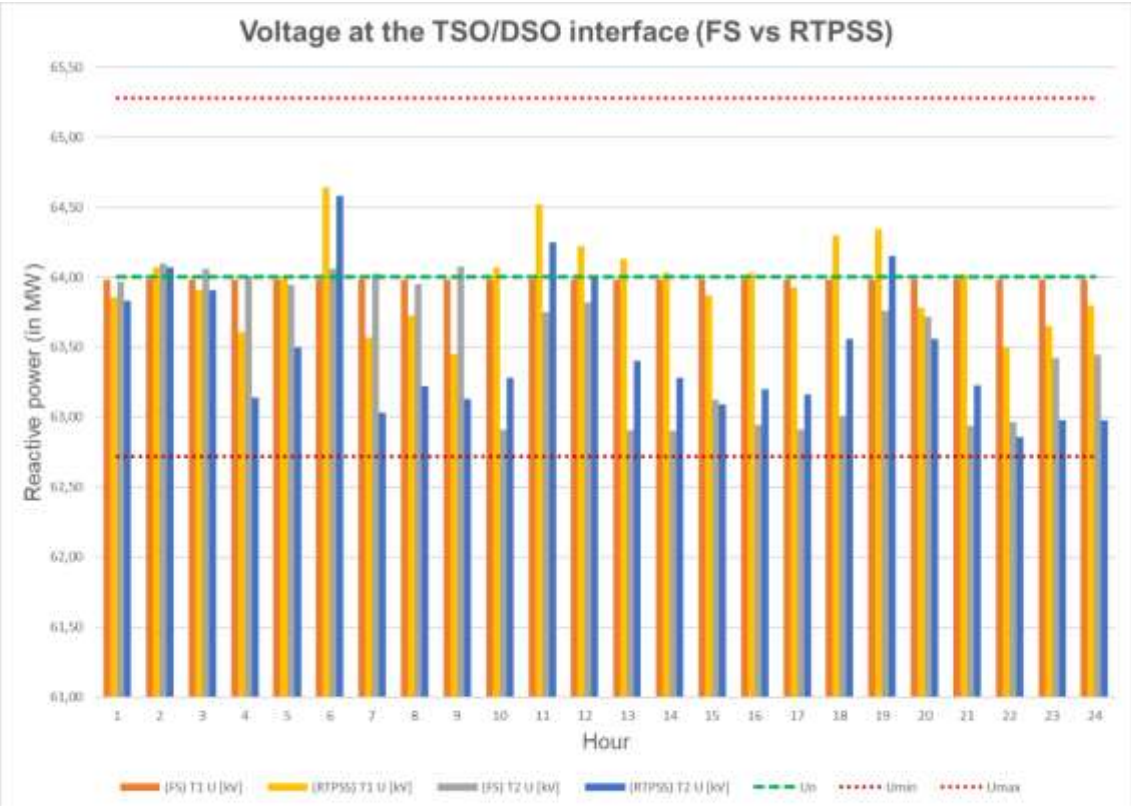


Figure 5-28 – Voltage results at TSO/DSO interface for test case 3

5.2.2.2 Test case 4

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are considered as a flexibility option and the optimisation function is focused on the minimisation of grid losses. From Table 5-37 to Table 5-40 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-37 – FS voltage results for test case 4

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,97	63,97
2	63,98	63,98	64,39	64,12
3	63,98	63,98	64,00	64,06
4	63,98	63,98	63,79	64,01
5	63,98	63,98	63,72	63,94
6	63,98	63,98	63,84	64,06
7	63,98	63,98	63,78	64,03
8	63,98	63,98	63,80	63,95
9	63,98	63,98	63,93	64,07
10	63,98	63,98	63,67	63,97
11	63,98	63,98	63,93	64,02
12	63,98	63,98	64,00	64,04
13	63,98	63,98	63,86	63,98
14	63,98	63,98	63,86	63,99
15	63,98	63,98	63,83	63,95
16	63,98	63,98	63,81	63,94
17	63,98	63,98	63,84	63,97
18	63,98	63,98	63,87	63,99
19	63,98	63,98	64,03	64,06
20	63,98	63,98	64,10	64,10
21	63,98	63,98	63,83	63,95
22	63,98	63,98	63,93	63,99
23	63,98	63,98	63,91	64,01
24	63,98	63,98	63,65	63,95

As can be seen in Table 5-37, the FS results from test case 4 show that the voltage stays within the acceptable range [64kV±2%] for both substations.

Table 5-38 – FS capacitor banks results for test case 4

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	0	0	0
11	40	0	30	30
12	40	0	30	30
13	40	0	0	0
14	40	0	0	0
15	40	0	0	0
16	40	0	0	0
17	40	0	0	0
18	40	0	0	0
19	40	0	30	30
20	40	0	30	30
21	40	0	0	0
22	40	0	0	0
23	40	0	0	0
24	40	0	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-39 – FS losses results for test case 4

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	209,63	-182,31	195,69	-133,56	-13,94	48,75
2	201,99	-322,75	196,15	-356,05	-5,83	-33,30
3	188,03	-431,03	187,67	-436,36	-0,36	-5,33
4	187,18	-375,71	184,37	-395,91	-2,81	-20,20
5	189,80	-414,75	186,12	-436,87	-3,68	-22,11
6	189,73	-330,59	187,34	-350,04	-2,38	-19,45
7	189,42	-280,53	186,53	-301,11	-2,89	-20,58
8	192,57	-272,59	190,46	-289,22	-2,11	-16,63
9	200,89	-178,90	200,15	-191,62	-0,74	-12,72
10	200,51	-233,68	202,94	-192,02	2,43	41,66
11	204,84	-151,11	204,41	-159,60	-0,43	-8,49
12	199,56	-225,13	199,52	-229,02	-0,04	-3,89
13	205,71	-98,75	204,78	-111,44	-0,92	-12,69

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
14	199,44	-257,04	198,78	-267,58	-0,65	-10,54
15	204,24	-39,26	203,43	-52,28	-0,81	-13,02
16	205,42	-238,04	204,55	-249,07	-0,86	-11,03
17	202,78	-183,70	202,02	-195,10	-0,75	-11,40
18	215,36	-95,38	214,58	-107,05	-0,77	-11,67
19	215,89	-106,49	215,85	-109,58	-0,04	-3,10
20	216,52	-62,62	216,52	-62,62	0,00	0,00
21	207,21	-154,82	206,22	-167,03	-0,99	-12,21
22	206,59	-121,52	206,31	-128,38	-0,27	-6,85
23	209,05	-153,15	201,66	-230,50	-7,38	-77,35
24	201,46	-229,49	196,47	-255,07	-5,00	-25,59
				TOTAL VARIATION	**-51,24**	**-267,73**

Table 5-40 – FS objective function fitness for test case 4

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	286699000	3057640	-283641360
2	4465280	1344900	-3120380
3	1609740	1596440	-13300
4	2658130	2601370	-56760
5	1999450	1947830	-51620
6	2453990	2423270	-30720
7	178079	174227	-3852
8	48170	190,4	-47979,6
9	200,8	200,1	-0,7
10	678332	202,9	-678129,1
11	1810720	1786310	-24410
12	1973680	1948960	-24720
13	205,7	204,7	-1
14	199,4	198,7	-0,7
15	116620	112176	-4444
16	205,4	204,5	-0,9
17	202,7	202	-0,7
18	215,3	214,5	-0,8
19	1145670	1138010	-7660
20	1212740	1202020	-10720
21	207,2	206,2	-1
22	206,5	206,3	-0,2
23	72489,2	69537,7	-2951,5
24	160854	132109	-28745
Global	**307284587**	**19536830**	**-287747757**

In this test case the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-41 – FS final results for test case 4 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,79	0,40	63,98	2,30	0,04	63,97
2	7,51	0,75	63,98	5,26	0,03	64,12
3	6,83	1,20	63,98	4,23	0,09	64,06
4	6,50	1,00	63,98	2,66	-1,23	64,01
5	7,47	1,45	63,98	3,62	-1,65	63,94
6	5,76	0,79	63,98	2,88	-0,98	64,06
7	6,17	0,70	63,98	1,85	-1,44	64,03
8	7,74	1,60	63,98	2,74	-1,04	63,95
9	9,62	0,75	63,98	3,69	0,16	64,07
10	9,42	-5,28	63,98	3,50	-1,80	63,97
11	8,76	-5,35	63,98	3,76	-1,10	64,02
12	8,60	-5,56	63,98	3,36	-0,64	64,04
13	8,84	-5,30	63,98	3,11	-1,68	63,98
14	9,00	-5,50	63,98	3,47	-1,64	63,99
15	8,34	-6,03	63,98	1,62	-2,36	63,95
16	11,03	-5,24	63,98	3,99	-1,72	63,94
17	9,80	-5,39	63,98	3,11	-1,60	63,97
18	11,06	-5,25	63,98	4,98	-1,36	63,99
19	10,48	-5,32	63,98	5,63	-0,30	64,06
20	10,21	-5,44	63,98	5,32	0,17	64,10
21	10,15	-5,16	63,98	3,83	-1,72	63,95
22	9,99	-5,28	63,98	3,47	-0,96	63,99
23	9,23	1,13	63,98	4,74	-1,36	64,01
24	9,33	1,16	63,98	3,57	-2,00	63,95

Table 5-42 – RTPSS final results for test case 4 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,72	1,90	63,86	2,45	-0,26	63,83
2	7,48	1,70	64,07	5,36	0,18	64,07
3	6,81	1,53	63,91	4,31	0,24	63,92
4	6,40	3,08	63,61	2,83	-2,70	63,14
5	7,32	3,07	64,00	3,84	-2,98	63,50
6	5,66	1,69	64,63	3,05	-1,02	64,58
7	6,03	3,49	63,57	2,07	-3,20	63,03
8	7,64	3,31	63,73	2,92	-2,53	63,22
9	9,57	2,74	63,45	3,81	-0,70	63,13
10	8,39	-0,35	63,48	4,60	-3,21	63,39
11	7,83	-1,82	63,88	4,76	-0,32	64,26
12	7,69	-1,49	63,57	4,34	0,20	63,99
13	7,81	-0,47	63,55	4,22	-3,09	63,51
14	8,01	-0,55	63,47	4,53	-2,98	63,42
15	7,44	-0,65	63,30	2,60	-2,89	63,21
16	10,06	-0,15	63,45	5,03	-2,78	63,29
17	8,82	-0,34	63,36	4,16	-2,82	63,27
18	10,08	-0,21	63,71	6,04	-2,37	63,65
19	9,59	-1,94	63,74	6,59	0,46	64,18
20	9,37	-1,56	63,17	6,24	0,54	63,58
21	9,16	-0,15	63,46	4,89	-3,10	63,33
22	9,05	-0,56	62,94	4,48	-1,94	62,97
23	8,45	1,32	63,06	5,61	-0,72	63,05
24	8,52	1,42	63,20	4,46	-1,73	63,03

Table 5-43 – Comparison between FS and RTPSS final results for test case 4 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,09	8,17	0,08	0,44	1,64	1,20	-0,12	-0,14
2	12,77	12,84	0,07	0,78	1,88	1,10	0,09	-0,05
3	11,06	11,12	0,06	1,29	1,77	0,48	-0,07	-0,14
4	9,16	9,23	0,07	-0,24	0,38	0,62	-0,37	-0,87
5	11,09	11,16	0,07	-0,21	0,09	0,30	0,02	-0,44
6	8,64	8,71	0,07	-0,19	0,67	0,86	0,65	0,52
7	8,02	8,10	0,08	-0,74	0,29	1,03	-0,41	-1,00
8	10,49	10,56	0,07	0,56	0,78	0,22	-0,25	-0,73
9	13,31	13,38	0,07	0,91	2,04	1,13	-0,53	-0,94
10	12,91	12,99	0,08	-7,08	-3,56	3,52	-0,50	-0,58
11	12,52	12,59	0,07	-6,45	-2,14	4,31	-0,10	0,24
12	11,96	12,03	0,07	-6,20	-1,29	4,91	-0,41	-0,05

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	11,95	12,03	0,08	-6,98	-3,56	3,42	-0,43	-0,47
14	12,46	12,54	0,08	-7,14	-3,53	3,61	-0,51	-0,57
15	9,96	10,04	0,08	-8,39	-3,54	4,85	-0,68	-0,74
16	15,02	15,09	0,07	-6,96	-2,93	4,03	-0,53	-0,65
17	12,91	12,98	0,07	-6,99	-3,16	3,83	-0,62	-0,70
18	16,04	16,12	0,08	-6,61	-2,58	4,03	-0,27	-0,34
19	16,11	16,18	0,07	-5,62	-1,48	4,14	-0,24	0,12
20	15,53	15,61	0,08	-5,27	-1,02	4,25	-0,81	-0,52
21	13,98	14,05	0,07	-6,88	-3,25	3,63	-0,52	-0,62
22	13,46	13,53	0,07	-6,24	-2,50	3,74	-1,04	-1,02
23	13,97	14,06	0,09	-0,23	0,60	0,83	-0,92	-0,96
24	12,91	12,98	0,07	-0,84	-0,31	0,53	-0,78	-0,92

Table 5-43 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,06; 0,09]MW, [0,22; 4,91]Mvar, [-1,04; 0,65]kV for T1 and [-1,02; 0,52]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-29 to Figure 5-31 depicts the comparison of the results for test case 4.

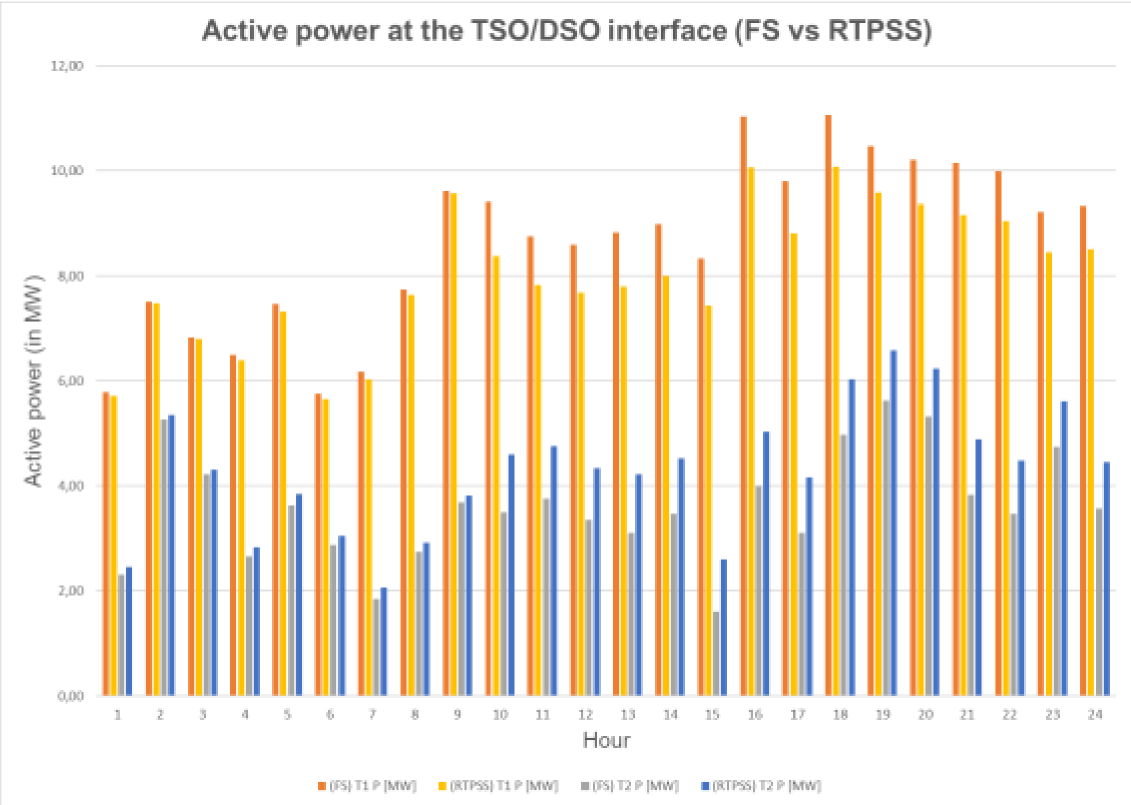


Figure 5-29 – Active Power results at TSO/DSO interface for test case 4

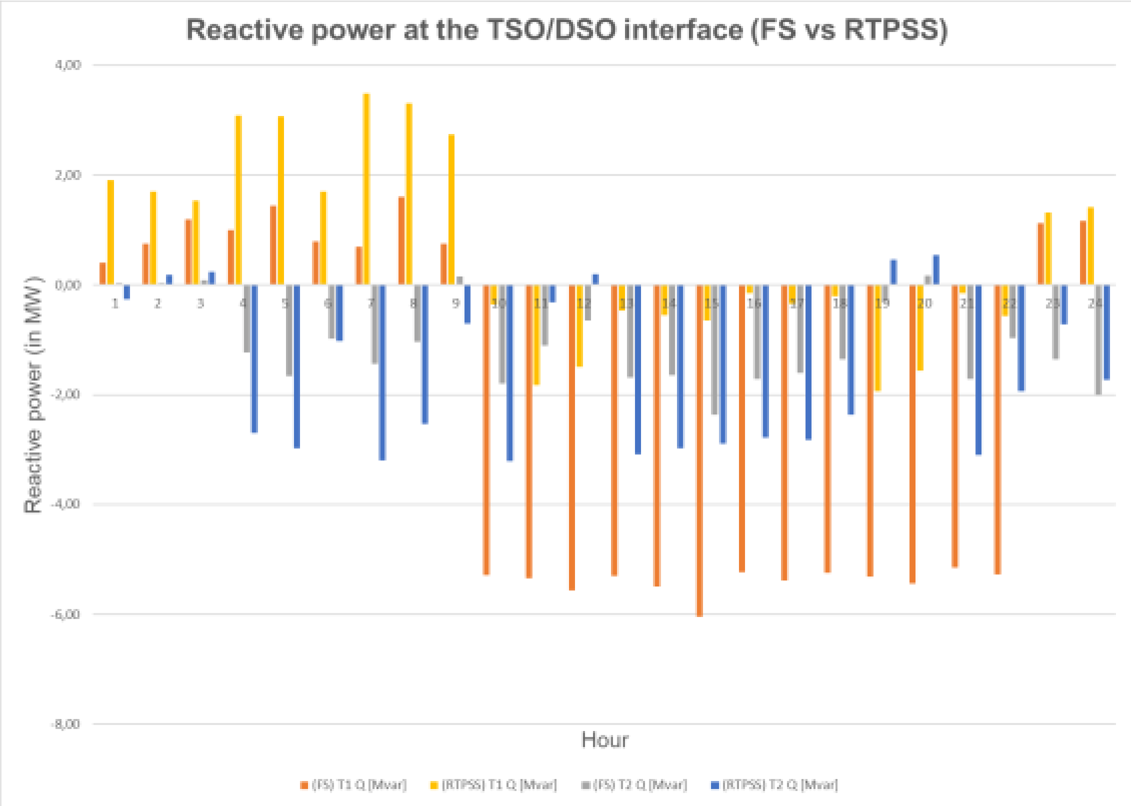


Figure 5-30 – Reactive Power results at TSO/DSO interface for test case 4

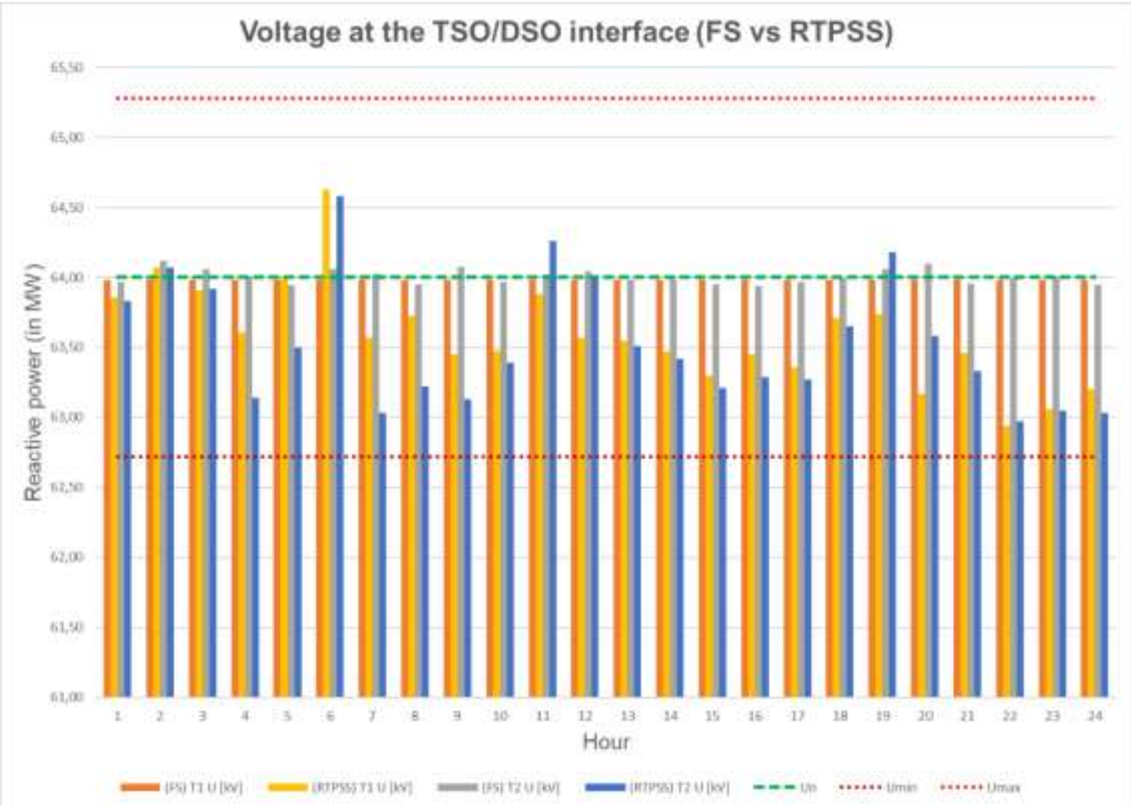


Figure 5-31 – Voltage results at TSO/DSO interface for test case 4

5.2.2.3 Test case 7

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are not considered as a flexibility option and the optimisation function is focused on the minimisation of costs. From Table 5-44 to Table 5-47 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-44 – FS voltage results for test case 7

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,97	63,97
2	63,98	63,98	64,31	64,02
3	63,98	63,98	63,92	64,01
4	63,98	63,98	63,71	63,94
5	63,98	63,98	63,65	63,92
6	63,98	63,98	63,76	63,98
7	63,98	63,98	63,71	63,93
8	63,98	63,98	63,74	64,01
9	63,98	63,98	63,86	64,01
10	63,98	63,98	63,60	62,85
11	63,98	63,98	64,02	63,71
12	63,98	63,98	63,74	63,73
13	63,98	63,98	63,63	62,84
14	63,98	63,98	63,64	62,88
15	63,98	63,98	63,62	63,03
16	63,98	63,98	63,59	62,79
17	63,98	63,98	63,63	62,67
18	63,98	63,98	63,66	62,91
19	63,98	63,98	63,79	63,68
20	63,98	63,98	63,84	63,68
21	63,98	63,98	63,60	62,87
22	63,98	63,98	63,70	62,71
23	63,98	63,98	63,70	63,34
24	63,98	63,98	63,58	63,36

As can be seen in Table 5-44, the FS results from test case 7 show that the voltage stays within the acceptable range [64kV±2%] for both substations with exception of 2 periods (17h and 22h) on which the value drops marginally below the limit (62,72kV), in less than 0,05kV.

Table 5-45 – FS capacitor banks results for test case 7

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-46 – FS losses results for test case 7

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	209,63	-182,31	195,70	-135,67	-13,93	46,64
2	354,96	3223,20	351,21	3191,63	-3,75	-31,57
3	343,60	3116,26	342,58	3108,49	-1,02	-7,77
4	343,74	3172,34	339,35	3151,36	-4,39	-20,98
5	346,65	3132,64	340,96	3109,43	-5,69	-23,21
6	346,20	3218,11	342,32	3198,04	-3,88	-20,07
7	345,79	3266,80	341,48	3245,87	-4,31	-20,93
8	348,78	3273,59	190,27	-291,05	-158,51	-3564,64
9	356,56	3366,08	200,20	-187,83	-156,35	-3553,91
10	357,26	3311,33	424,23	3871,13	66,97	559,80
11	356,15	3339,87	357,15	3335,46	1,01	-4,41
12	351,26	3262,60	351,16	3264,55	-0,10	1,95

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	358,79	3392,22	423,82	3815,51	65,02	423,29
14	352,02	3231,61	259,12	119,97	-92,90	-3111,64
15	320,16	2584,10	394,71	3696,02	74,55	1111,92
16	358,93	3250,99	271,84	181,73	-87,09	-3069,26
17	319,68	2445,34	404,53	3013,07	84,85	567,73
18	332,63	2535,05	273,55	275,06	-59,09	-2259,99
19	331,69	2522,04	370,42	3399,95	38,73	877,91
20	367,08	3424,25	371,91	3456,46	4,82	32,21
21	360,58	3336,07	418,31	3704,46	57,73	368,39
22	358,38	3366,05	409,55	3112,27	51,17	-253,78
23	325,82	2476,30	380,65	3451,56	54,84	975,26
24	358,75	3315,51	369,58	3379,95	10,83	64,44
				TOTAL VARIATION	**-80,49**	**-10912,62**

Table 5-47 – FS objective function fitness for test case 7

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	286699000	3057700	-283641300
2	4311380	2408030	-1903350
3	2941580	2914170	-27410
4	4928030	4787990	-140040
5	3651770	3568330	-83440
6	4605100	4427880	-177220
7	420326	318974	-101352
8	471769	199,7	-471569,3
9	261204	210,2	-260993,8
10	1046950	813992	-232958
11	4495480	4309210	-186270
12	4694880	4639860	-55020
13	1158290	881551	-276739
14	1118040	642865	-475175
15	1371180	1292050	-79130
16	838626	468811	-369815
17	930020	1218950	288930
18	804591	489348	-315243
19	2662240	2880760	218520
20	3075900	3023750	-52150
21	949684	717882	-231802
22	997471	818120	-179351
23	1538480	1569640	31160
24	1726970	1667720	-59250
Global	**335698961**	**46917993**	**-288780968**

In this test case, the optimisation strategy was to minimize costs. Nevertheless, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range in most of the period and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-48 – FS final results for test case 7 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,79	0,29	63,98	2,30	0,05	63,97
2	7,60	4,59	63,98	5,33	-0,06	64,02
3	6,92	4,49	63,98	4,30	0,05	64,01
4	6,58	4,51	63,98	2,73	-1,30	63,94
5	7,55	4,51	63,98	3,69	-1,67	63,92
6	5,84	4,42	63,98	2,95	-1,06	63,98
7	6,26	4,55	63,98	1,92	-1,44	63,93
8	7,74	1,00	63,98	2,74	-1,04	64,01
9	9,62	1,45	63,98	3,69	0,16	64,01
10	9,54	15,51	63,98	3,60	-1,80	62,85
11	8,85	6,95	63,98	3,83	-1,39	63,71
12	8,69	6,74	63,98	3,43	-0,93	63,73
13	8,96	15,84	63,98	3,21	-1,68	62,84
14	9,03	12,40	63,98	3,50	-1,64	62,88
15	8,44	12,74	63,98	1,71	-2,36	63,03
16	11,07	13,10	63,98	4,02	-1,72	62,79
17	9,91	16,63	63,98	3,21	-1,60	62,67
18	11,09	12,44	63,98	5,01	-1,36	62,91
19	10,56	7,66	63,98	5,70	-0,66	63,68
20	10,29	7,87	63,98	5,39	-0,22	63,68
21	10,26	15,32	63,98	3,92	-1,72	62,87
22	10,10	16,67	63,98	3,56	-0,96	62,71
23	9,33	10,91	63,98	4,82	-1,36	63,34
24	9,43	10,10	63,98	3,65	-2,00	63,36

Table 5-49 – RTPSS final results for test case 7 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	7,44	1,62	63,86	6,13	0,28	63,81
2	8,35	-5,12	64,19	7,45	-1,65	64,09
3	7,72	1,46	63,91	6,24	0,61	63,91
4	7,53	3,00	63,61	5,25	-2,30	63,13
5	8,01	3,09	64,00	5,26	-2,56	63,49
6	7,11	1,46	64,64	6,18	-0,53	64,57
7	7,37	3,39	63,57	4,93	-2,74	63,02
8	9,17	4,36	63,71	6,69	-3,84	63,23
9	11,26	3,69	63,43	7,93	-1,93	63,15
10	10,51	8,92	64,05	3,73	5,09	63,24
11	9,62	6,71	64,47	5,21	1,26	64,23
12	9,49	4,04	64,21	4,91	1,63	63,97
13	10,04	8,02	64,14	4,08	3,66	63,39
14	9,94	7,68	64,05	3,81	3,80	63,31
15	9,68	7,91	63,87	2,48	4,28	63,08
16	11,18	10,46	63,99	2,26	4,62	63,17
17	10,86	2,86	64,02	3,19	4,23	63,15
18	11,25	10,86	64,25	2,90	6,45	63,50
19	10,77	4,25	64,34	5,81	2,29	64,15
20	10,72	4,49	63,77	5,86	2,37	63,55
21	10,61	7,03	64,04	3,87	1,45	63,25
22	10,95	10,32	63,45	2,95	7,42	62,81
23	10,42	2,46	63,75	5,28	3,95	62,97
24	10,09	10,23	63,75	3,97	1,96	62,96

Table 5-50 – Comparison between FS and RTPSS final results for test case 7 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,09	13,57	5,48	0,34	1,90	1,56	-0,12	-0,16
2	12,93	15,80	2,87	4,53	-6,77	-11,30	0,21	0,07
3	11,22	13,96	2,74	4,54	2,07	-2,47	-0,07	-0,10
4	9,31	12,78	3,47	3,21	0,70	-2,51	-0,37	-0,81
5	11,24	13,27	2,03	2,84	0,53	-2,31	0,02	-0,43
6	8,79	13,29	4,50	3,36	0,93	-2,43	0,66	0,59
7	8,18	12,30	4,12	3,11	0,65	-2,46	-0,41	-0,91
8	10,49	15,86	5,37	-0,04	0,52	0,56	-0,27	-0,78
9	13,31	19,19	5,88	1,61	1,76	0,15	-0,55	-0,86
10	13,13	14,24	1,11	13,71	14,01	0,30	0,07	0,39
11	12,68	14,83	2,15	5,56	7,97	2,41	0,49	0,52
12	12,11	14,40	2,29	5,80	5,67	-0,13	0,23	0,24

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	12,17	14,12	1,95	14,16	11,68	-2,48	0,16	0,55
14	12,53	13,75	1,22	10,76	11,48	0,72	0,07	0,43
15	10,15	12,16	2,01	10,38	12,19	1,81	-0,11	0,05
16	15,09	13,44	-1,65	11,38	15,08	3,70	0,01	0,38
17	13,11	14,05	0,94	15,03	7,09	-7,94	0,04	0,48
18	16,10	14,15	-1,95	11,08	17,31	6,23	0,27	0,59
19	16,26	16,58	0,32	7,00	6,54	-0,46	0,36	0,47
20	15,68	16,58	0,90	7,66	6,86	-0,80	-0,21	-0,13
21	14,19	14,48	0,29	13,60	8,48	-5,12	0,06	0,38
22	13,66	13,90	0,24	15,71	17,74	2,03	-0,53	0,10
23	14,15	15,70	1,55	9,55	6,41	-3,14	-0,23	-0,37
24	13,08	14,06	0,98	8,10	12,19	4,09	-0,23	-0,40

Table 5-50 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [-1,95; 5,88]MW, [-11,30; 6,23]Mvar, [-0,55; 0,66]kV for T1 and [-0,91; 0,59]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-32 to Figure 5-34 depicts the comparison of the results for test case 7.

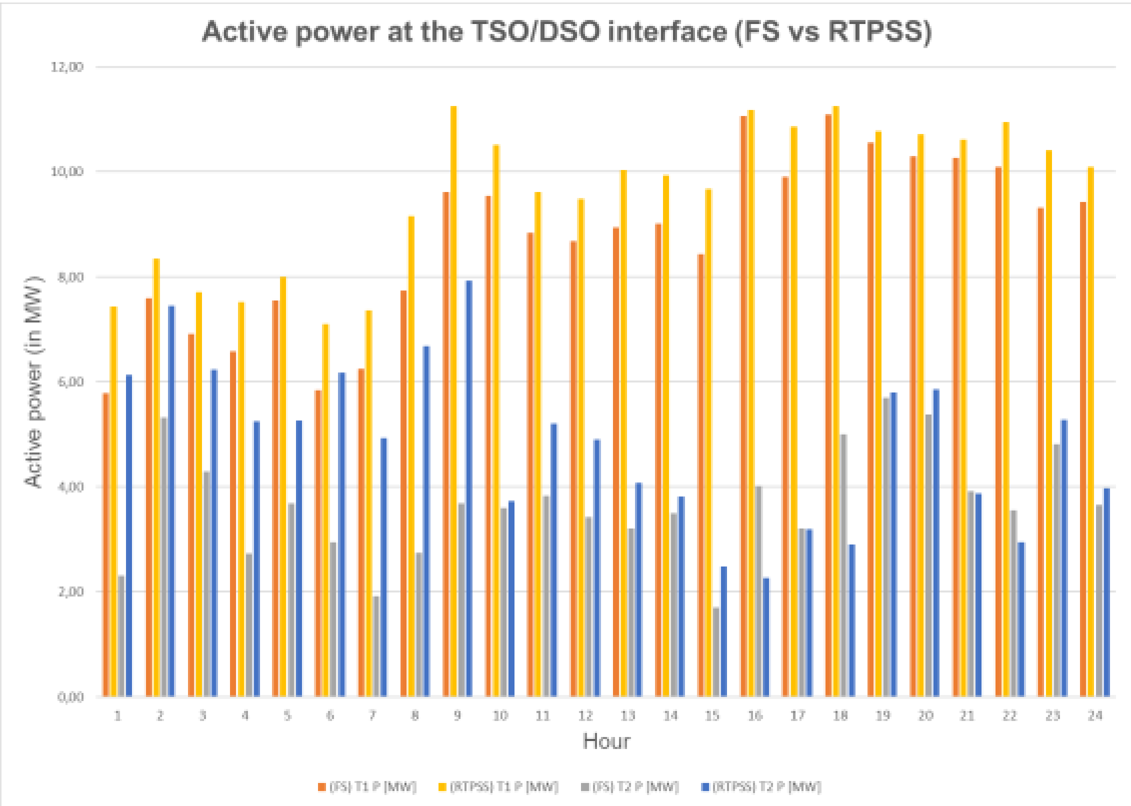


Figure 5-32 – Active Power results at TSO/DSO interface for test case 7

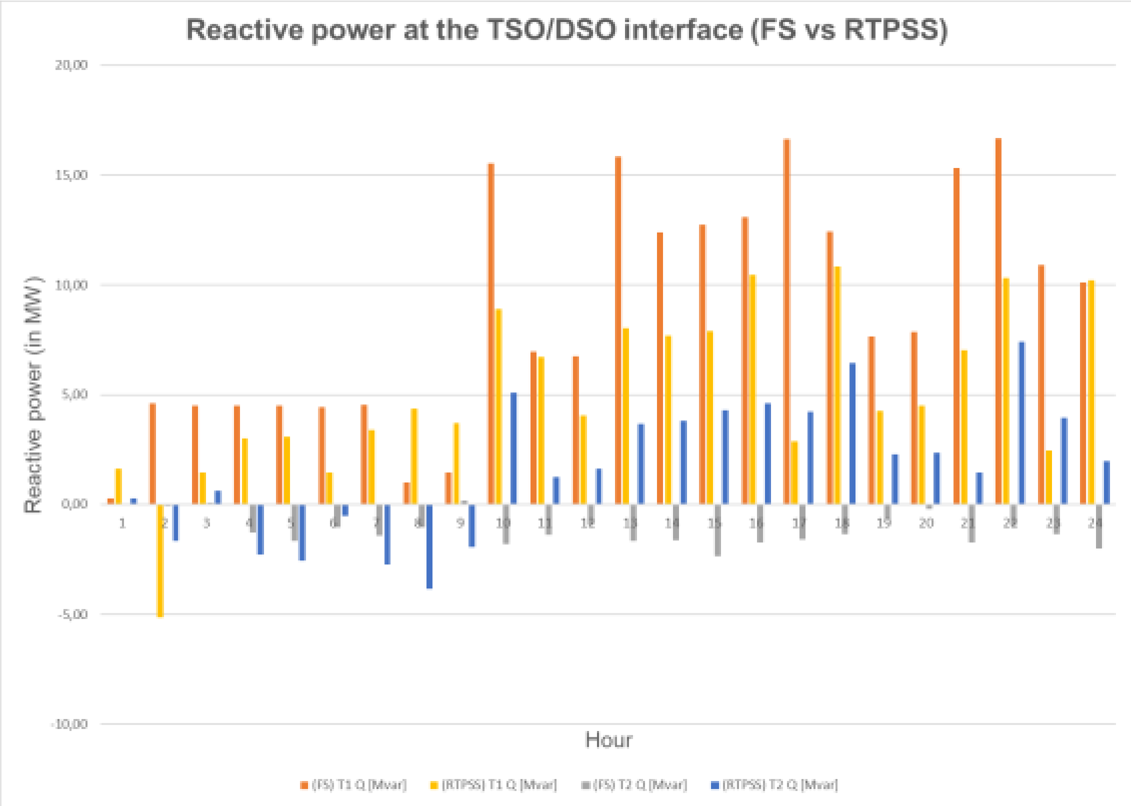


Figure 5-33 – Reactive Power results at TSO/DSO interface for test case 7

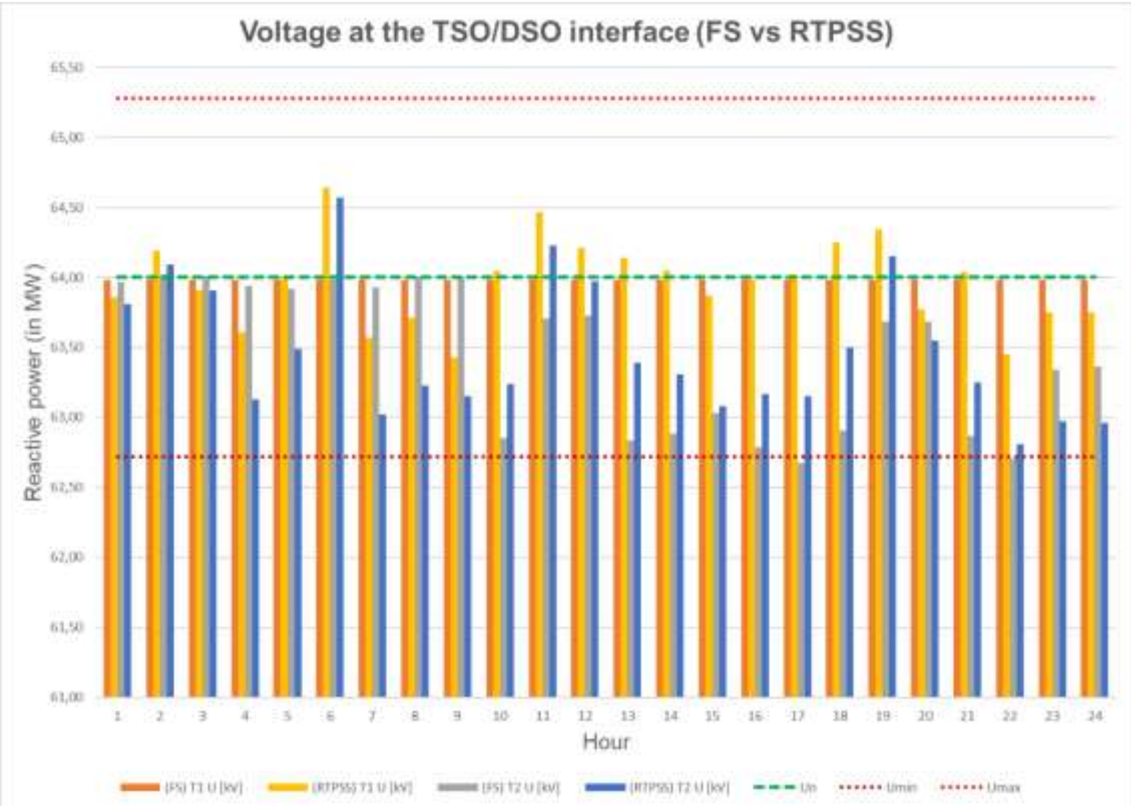


Figure 5-34 – Voltage results at TSO/DSO interface for test case 7

5.2.2.4 Test case 8

This test case corresponds to the optimised power flow solution for the grid in mesh in which transmission grid assets are considered as a flexibility option and the optimisation function is focused on the minimisation of costs. From Table 5-51 to Table 5-54 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-51 – FS voltage results for test case 8

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,97	63,97
2	63,98	63,98	64,31	64,10
3	63,98	63,98	63,92	64,01
4	63,98	63,98	63,71	63,94
5	63,98	63,98	63,65	63,93
6	63,98	63,98	63,76	63,98
7	63,98	63,98	63,71	63,93
8	63,98	63,98	63,74	63,94
9	63,98	63,98	63,86	64,05
10	63,98	63,98	63,60	63,97
11	63,98	63,98	63,88	63,96
12	63,98	63,98	63,94	63,98
13	63,98	63,98	63,81	63,96
14	63,98	63,98	64,18	63,95
15	63,98	63,98	64,14	63,93
16	63,98	63,98	64,12	63,95
17	63,98	63,98	64,15	63,98
18	63,98	63,98	64,18	63,96
19	63,98	63,98	64,39	64,08
20	63,98	63,98	64,04	64,04
21	63,98	63,98	63,78	63,99
22	63,98	63,98	64,24	63,99
23	63,98	63,98	63,86	63,94
24	63,98	63,98	63,58	63,90

As can be seen in Table 5-51, the FS results from test case 6 show that the voltage stays within the acceptable range [64kV±2%] for both substations.

Table 5-52 – FS capacitor banks results for test case 8

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	0	0	0
11	40	0	30	30
12	40	0	30	30
13	40	0	0	0
14	40	0	0	0
15	40	0	0	0
16	40	0	0	0
17	40	0	0	0
18	40	0	0	0
19	40	0	30	30
20	40	0	30	30
21	40	0	0	0
22	40	0	0	0
23	40	0	0	0
24	40	0	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-53 – FS losses results for test case 8

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	209,63	-182,31	350,41	3414,74	140,78	3597,05
2	354,96	3223,20	196,55	-355,29	-158,41	-3578,49
3	344,02	3116,18	342,58	3108,49	-1,44	-7,69
4	343,74	3172,34	339,77	3151,29	-3,97	-21,05
5	347,07	3132,56	340,90	3109,58	-6,17	-22,98
6	346,20	3218,11	342,32	3198,04	-3,88	-20,07
7	345,79	3266,80	341,48	3245,87	-4,31	-20,93
8	348,78	3273,59	345,21	3255,04	-3,57	-18,55
9	356,56	3366,08	200,11	-190,45	-156,45	-3556,53
10	357,26	3311,33	203,36	-192,12	-153,90	-3503,45
11	358,89	3412,97	357,63	3404,97	-1,25	-8,00
12	352,86	3339,32	352,66	3336,42	-0,20	-2,90
13	359,43	3464,62	360,15	3503,46	0,73	38,84

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
14	355,97	3326,64	354,14	3349,12	-1,83	22,48
15	360,67	3549,58	359,06	3574,43	-1,61	24,85
16	361,28	3340,81	207,28	-198,21	-154,00	-3539,02
17	359,43	3397,23	204,41	-142,09	-155,02	-3539,32
18	371,50	3482,14	370,26	3504,59	-1,24	22,45
19	376,79	3485,78	215,88	-111,22	-160,90	-3597,00
20	369,69	3500,96	369,69	3500,96	0,00	0,00
21	360,94	3407,33	208,93	-120,72	-152,01	-3528,05
22	364,93	3464,60	206,31	-128,38	-158,62	-3592,98
23	362,71	3410,02	356,70	3314,71	-6,01	-95,31
24	358,34	3315,61	355,08	3309,28	-3,26	-6,33
				TOTAL VARIATION	**-1146,53**	**-24952,98**

Table 5-54 – FS objective function fitness for test case 8

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	286699000	5475100	-281223900
2	4311380	1347650	-2963730
3	2945130	2914040	-31090
4	4928030	4793860	-134170
5	3656120	3567480	-88640
6	4605100	4427880	-177220
7	420326	318974	-101352
8	471769	237953	-233816
9	261204	210,1	-260993,9
10	1046950	213,5	-1046736,5
11	3399260	3258620	-140640
12	3667580	3585760	-81820
13	146432	392,1	-146039,9
14	388,1	385,5	-2,6
15	388313	201304	-187009
16	393,6	217,6	-176
17	391,8	214,6	-177,2
18	404,8	402,8	-2
19	4624840	1137130	-3487710
20	2149230	2130230	-19000
21	105689	219,3	-105469,7
22	416,3	216,6	-199,7
23	130495	209725	79230
24	613259	295251	-318008
Global	**324572102**	**33903429**	**-290668673**

In this test case the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-55 – FS final results for test case 8 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	5,87	4,04	63,98	2,37	-0,04	63,97
2	7,51	0,97	63,98	5,26	0,01	64,10
3	6,92	4,49	63,98	4,30	0,05	64,01
4	6,58	4,51	63,98	2,73	-1,30	63,94
5	7,55	4,40	63,98	3,69	-1,66	63,93
6	5,84	4,42	63,98	2,95	-1,06	63,98
7	6,26	4,55	63,98	1,92	-1,44	63,93
8	7,83	4,55	63,98	2,81	-1,04	63,94
9	9,62	1,05	63,98	3,69	0,16	64,05
10	9,42	-5,28	63,98	3,50	-1,80	63,97
11	8,85	-2,75	63,98	3,83	-1,15	63,96
12	8,69	-2,85	63,98	3,43	-0,70	63,98
13	8,92	-3,24	63,98	3,18	-1,68	63,96
14	9,08	-3,23	63,98	3,54	-1,64	63,95
15	8,42	-3,87	63,98	1,69	-2,36	63,93
16	11,03	-5,52	63,98	3,99	-1,72	63,95
17	9,80	-5,68	63,98	3,11	-1,60	63,98
18	11,15	-3,09	63,98	5,05	-1,36	63,96
19	10,48	-5,54	63,98	5,63	-0,28	64,08
20	10,29	-2,84	63,98	5,39	0,12	64,04
21	10,15	-5,75	63,98	3,83	-1,72	63,99
22	9,99	-5,28	63,98	3,47	-0,96	63,99
23	9,31	4,67	63,98	4,81	-1,36	63,94
24	9,42	4,45	63,98	3,65	-2,00	63,90

Table 5-56 – RTPSS final results for test case 8 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	7,62	1,70	63,86	6,54	0,26	63,81
2	8,45	4,11	64,03	7,30	0,72	64,05
3	8,05	4,10	63,87	6,67	1,38	63,89
4	7,67	5,75	63,56	5,28	-1,60	63,12
5	8,03	2,98	64,00	5,34	-2,65	63,49
6	7,01	1,41	64,64	5,97	-0,56	64,57
7	7,40	3,16	63,57	4,99	-2,73	63,02
8	9,17	4,36	63,71	6,69	-3,84	63,23
9	11,26	3,69	63,43	7,93	-1,93	63,15
10	10,66	-0,31	63,47	9,92	-3,64	63,39
11	9,36	1,51	63,82	7,97	0,49	64,24
12	9,01	0,73	63,53	7,15	0,55	63,98
13	11,43	-5,30	63,63	11,54	-1,86	63,48
14	9,85	-3,93	63,53	7,74	-1,13	63,39
15	10,32	-5,00	63,37	8,09	-1,08	63,17
16	11,64	-1,62	63,48	7,54	-0,82	63,25
17	10,87	-4,29	63,42	7,89	-1,21	63,23
18	11,89	-3,98	63,78	9,29	-0,91	63,62
19	9,92	-5,10	63,79	6,56	1,90	64,15
20	9,95	-4,76	63,23	6,73	2,07	63,55
21	11,00	-3,10	63,51	8,02	-1,28	63,29
22	10,84	-5,25	63,02	8,40	-2,61	62,97
23	9,33	1,49	63,06	7,51	-0,39	63,04
24	9,22	1,87	63,19	5,95	-1,36	63,02

Table 5-57 – Comparison between FS and RTPSS final results for test case 8 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,25	14,16	5,91	4,00	1,96	-2,04	-0,12	-0,16
2	12,77	15,75	2,98	0,98	4,83	3,85	0,05	-0,05
3	11,22	14,72	3,50	4,54	5,48	0,94	-0,11	-0,12
4	9,31	12,95	3,64	3,21	4,15	0,94	-0,42	-0,82
5	11,24	13,37	2,13	2,74	0,33	-2,41	0,02	-0,44
6	8,79	12,98	4,19	3,36	0,85	-2,51	0,66	0,59
7	8,18	12,39	4,21	3,11	0,43	-2,68	-0,41	-0,91
8	10,64	15,86	5,22	3,51	0,52	-2,99	-0,27	-0,71
9	13,31	19,19	5,88	1,21	1,76	0,55	-0,55	-0,90
10	12,91	20,58	7,67	-7,08	-3,95	3,13	-0,51	-0,58
11	12,68	17,33	4,65	-3,90	2,00	5,90	-0,16	0,28
12	12,11	16,16	4,05	-3,55	1,28	4,83	-0,45	0,00

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	12,10	22,97	10,87	-4,92	-7,16	-2,24	-0,35	-0,48
14	12,62	17,59	4,97	-4,87	-5,06	-0,19	-0,45	-0,56
15	10,11	18,41	8,30	-6,23	-6,08	0,15	-0,61	-0,76
16	15,03	19,18	4,15	-7,24	-2,44	4,80	-0,50	-0,70
17	12,91	18,76	5,85	-7,28	-5,50	1,78	-0,56	-0,75
18	16,20	21,18	4,98	-4,45	-4,89	-0,44	-0,20	-0,34
19	16,11	16,48	0,37	-5,82	-3,20	2,62	-0,19	0,07
20	15,68	16,68	1,00	-2,72	-2,69	0,03	-0,75	-0,49
21	13,98	19,02	5,04	-7,47	-4,38	3,09	-0,47	-0,70
22	13,46	19,24	5,78	-6,24	-7,86	-1,62	-0,96	-1,02
23	14,13	16,84	2,71	3,31	1,10	-2,21	-0,92	-0,90
24	13,07	15,17	2,10	2,45	0,51	-1,94	-0,79	-0,88

Table 5-57 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,37; 10,87]MW, [-2,99; 5,90]Mvar, [-0,96; 0,66]kV for T1 and [-1,02; 0,59]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-35 to Figure 5-37 depicts the comparison of the results for test case 8.

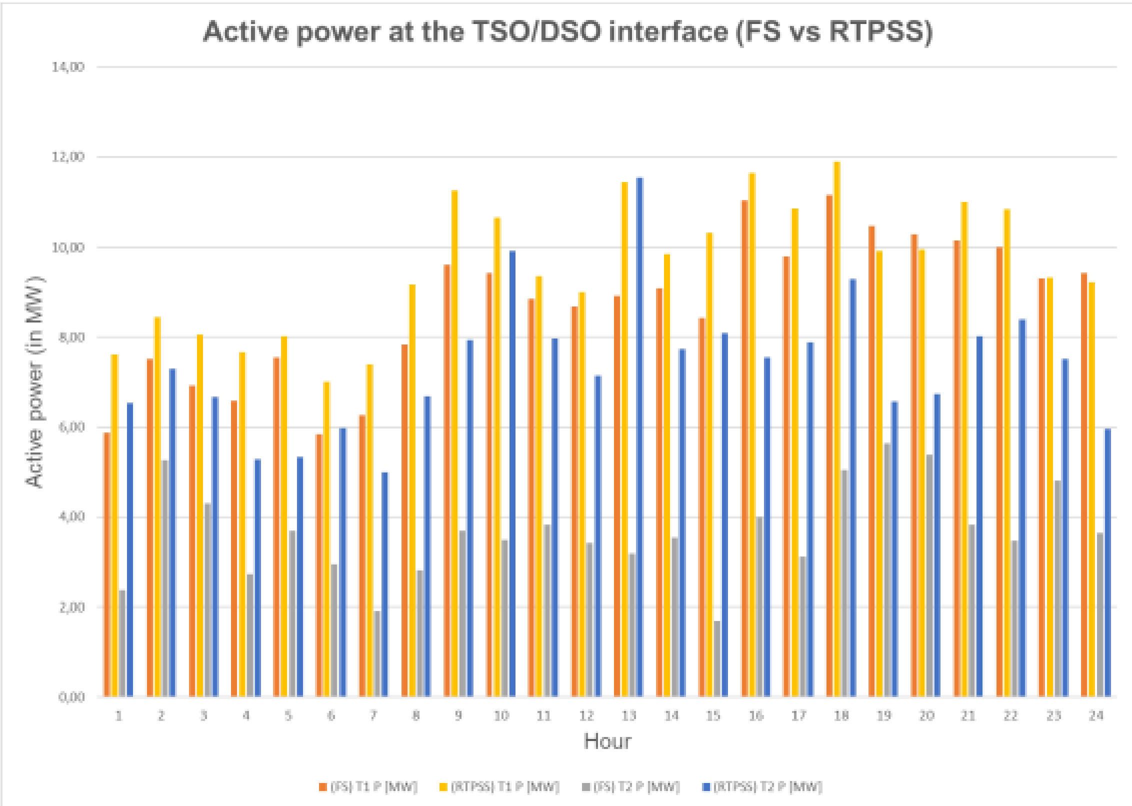


Figure 5-35 – Active Power results at TSO/DSO interface for test case 8

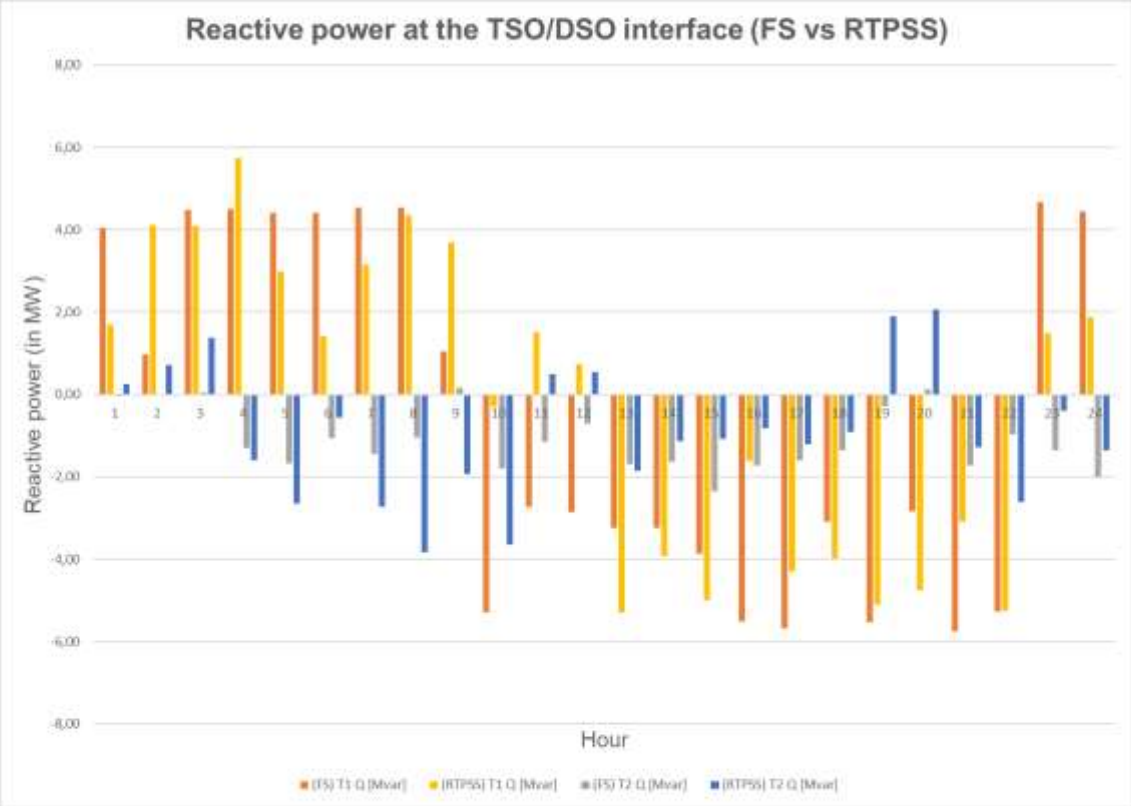


Figure 5-36 – Reactive Power results at TSO/DSO interface for test case 8

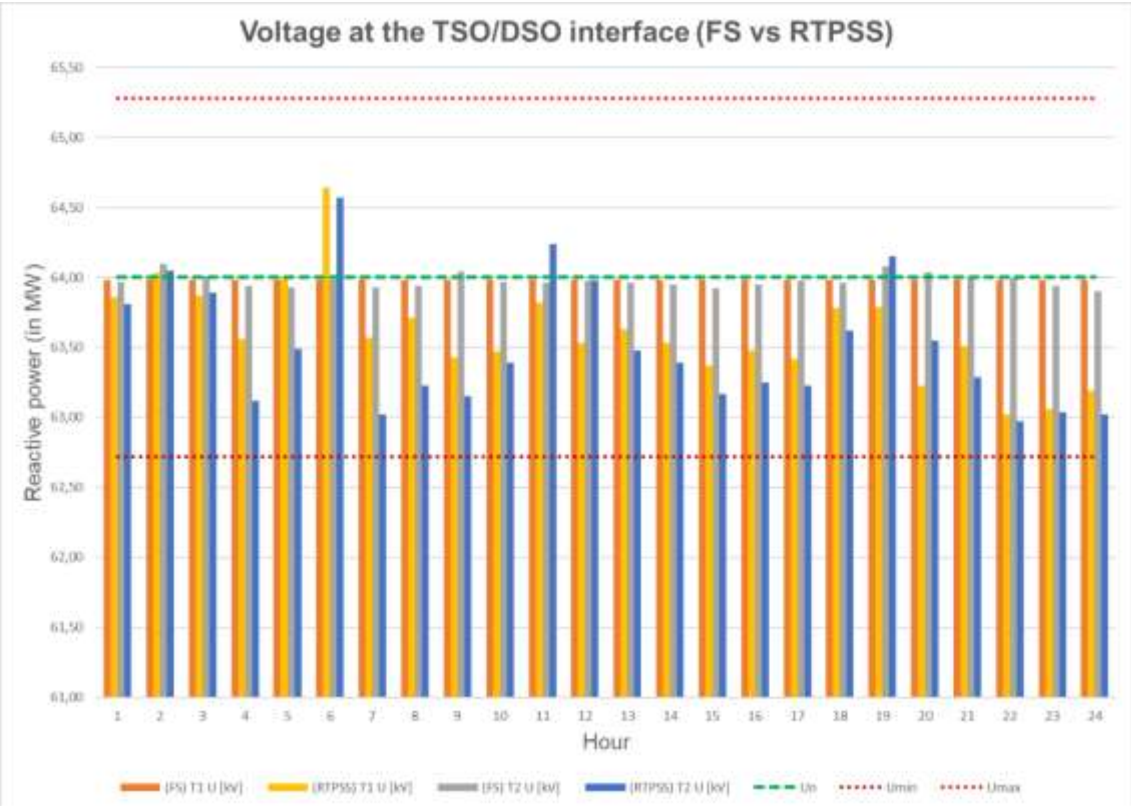


Figure 5-37 – Voltage results at TSO/DSO interface for test case 8

5.2.3 Cluster 3

This is the test case cluster based on the scenario for radial (open mesh) distribution grid operation with high penetration of RES. The source data of the graphics is available in Annex C – Cluster 3 simulation results.

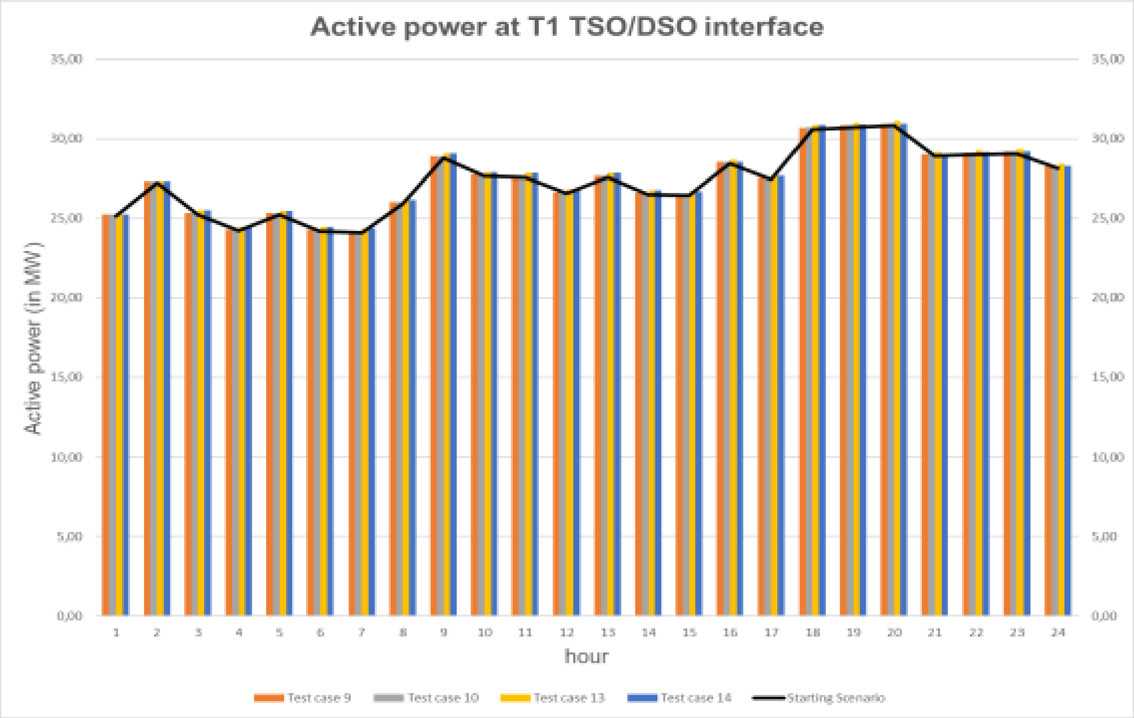


Figure 5-38 – Active Power profile at T1 TSO/DSO interface for cluster 3 test cases

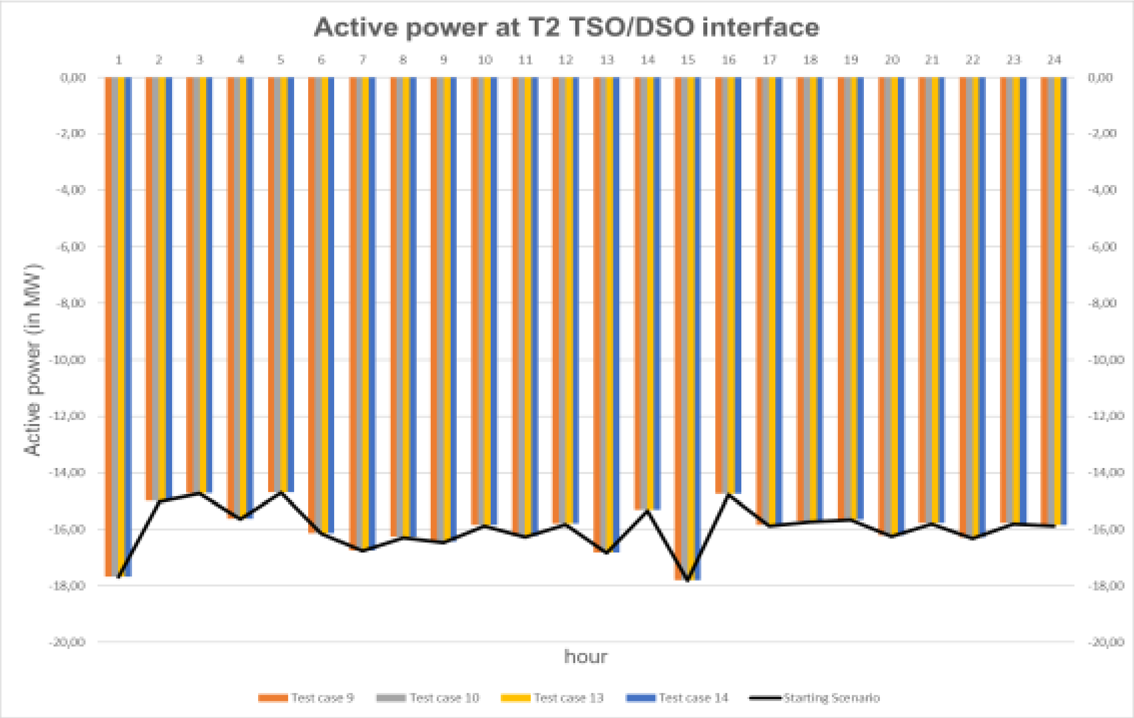


Figure 5-39 – Active Power profile at T2 TSO/DSO interface for cluster 3 test cases

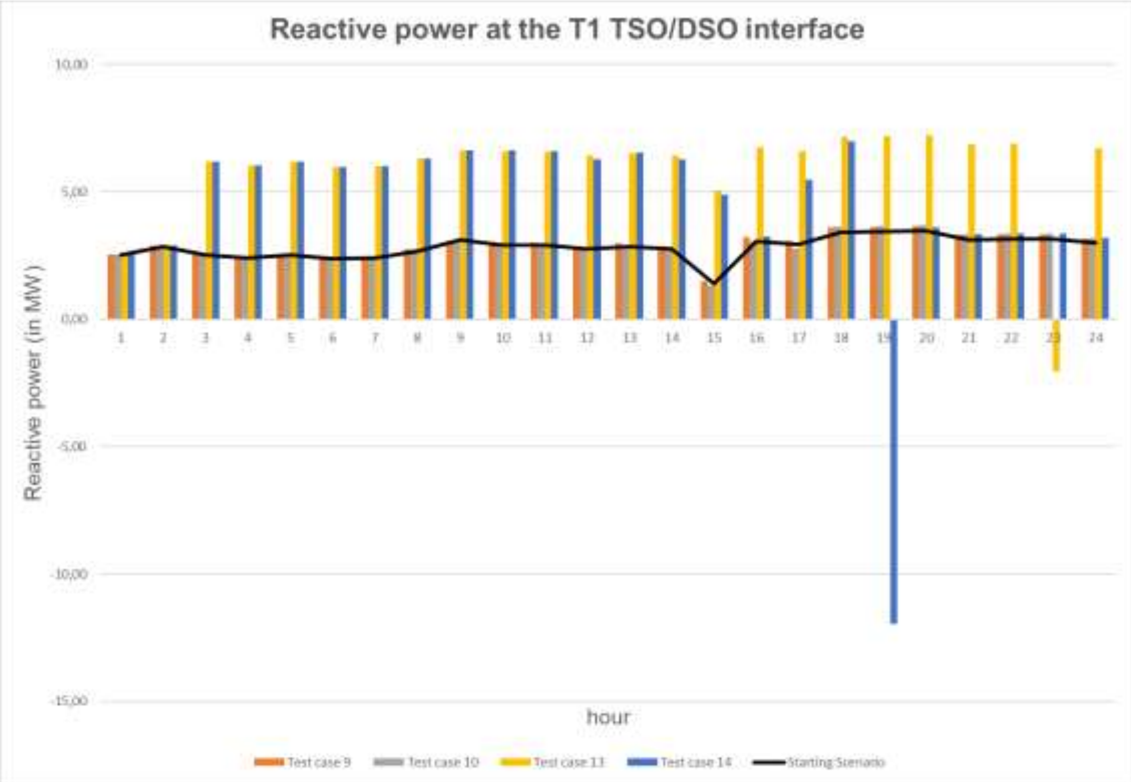


Figure 5-40 – Reactive Power profile at T1 TSO/DSO interface for cluster 3 test cases

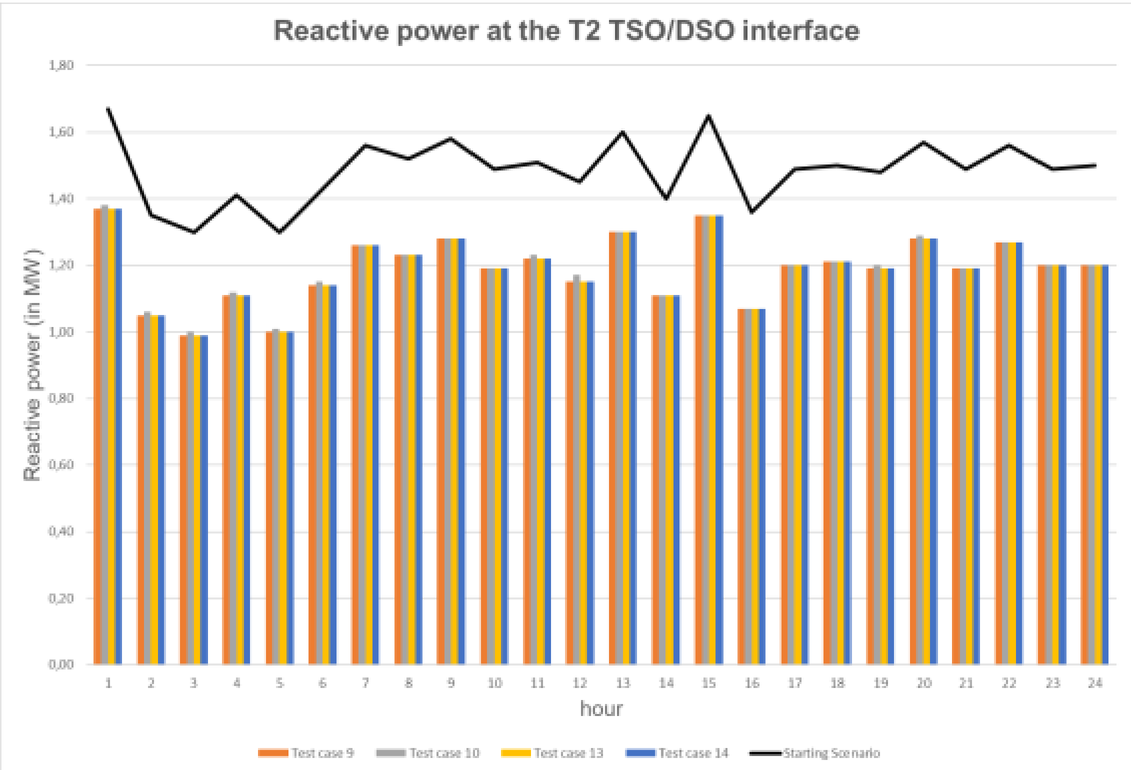


Figure 5-41 – Reactive Power profile at T2 TSO/DSO interface for cluster 3 test cases

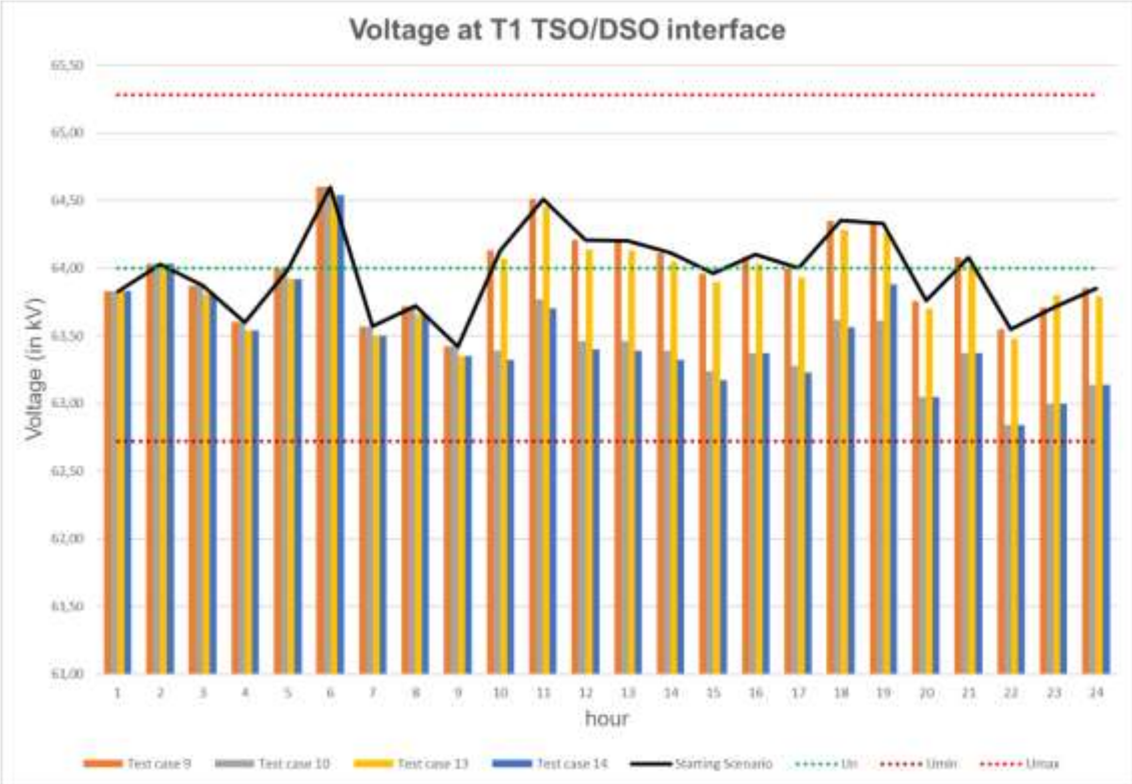


Figure 5-42 – Voltage at T1 TSO/DSO interface for cluster 3 test cases

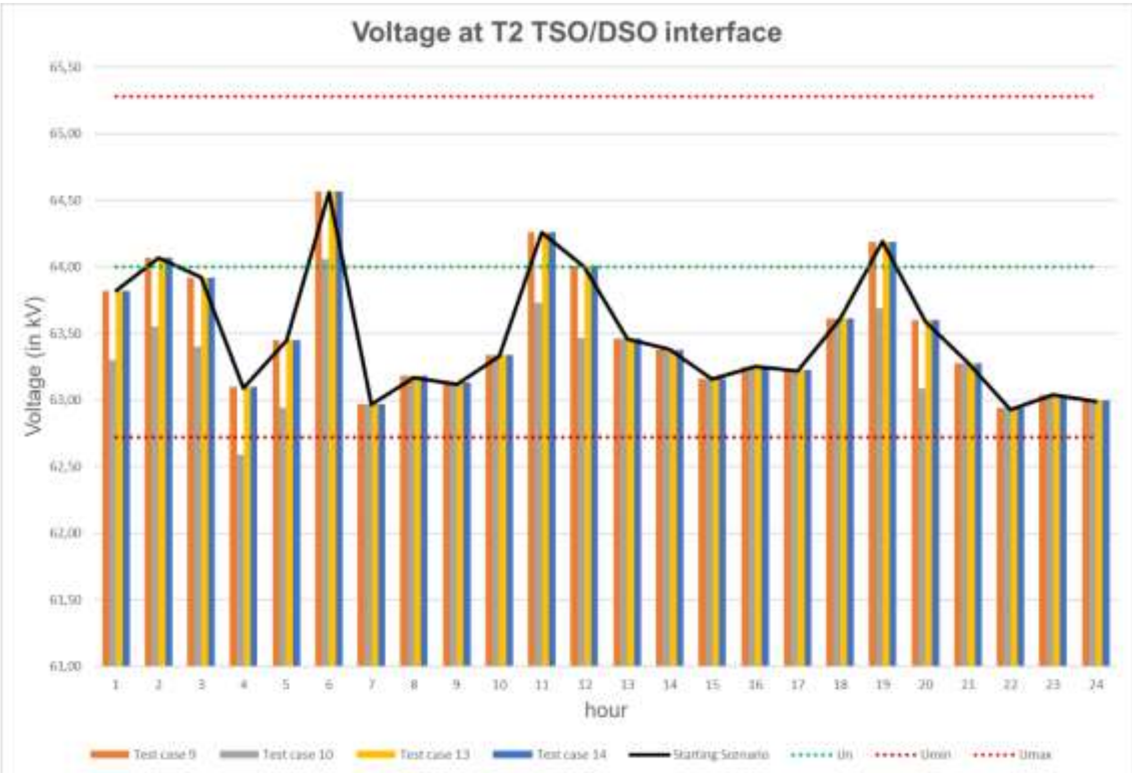


Figure 5-43 – Voltage at T2 TSO/DSO interface for cluster 3 test cases

5.2.3.1 Test case 9

This test case corresponds to the optimised power flow solution for the grid in antenna in which transmission grid assets are not considered as a flexibility option and the optimisation function is focused on the minimisation of grid losses. From Table 5-58 to Table 5-61 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-58 – FS voltage results for test case 9

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen in Table 5-58, the FS results from test case 9 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-59 – FS capacitor banks results for test case 9

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-60 – FS losses results for test case 9

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	381,10	355,73	365,60	357,80	-15,50	2,07
2	372,46	204,93	372,41	204,71	-0,05	-0,22
3	343,81	55,39	343,78	55,19	-0,04	-0,20
4	337,57	83,81	337,53	83,62	-0,04	-0,19
5	343,60	52,55	343,56	52,36	-0,04	-0,20
6	341,07	97,11	341,07	97,11	0,00	0,00
7	344,30	155,81	344,30	155,81	0,00	0,00
8	362,98	214,87	362,98	214,87	0,00	0,00
9	403,06	417,41	402,88	416,55	-0,18	-0,87
10	381,90	282,48	381,90	282,48	0,00	0,00
11	383,53	318,41	383,53	318,41	0,00	0,00
12	366,28	208,24	366,28	208,24	0,00	0,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	387,72	377,93	387,72	377,93	0,00	0,00
14	362,35	157,22	362,35	157,22	0,00	0,00
15	380,20	413,27	380,20	413,27	0,00	0,00
16	387,03	234,50	387,03	234,50	0,00	0,00
17	382,63	284,76	382,63	284,76	0,00	0,00
18	429,13	485,01	429,13	485,01	0,00	0,00
19	432,09	489,79	432,09	489,79	0,00	0,00
20	438,26	555,49	438,26	555,49	0,00	0,00
21	404,99	409,13	404,99	409,13	0,00	0,00
22	409,28	463,50	409,28	463,50	0,00	0,00
23	405,92	412,24	405,92	412,24	0,00	0,00
24	392,27	353,87	392,27	353,87	0,00	0,00
				TOTAL VARIATION	**-15,84**	**0,41**

Table 5-61 – FS objective function fitness for test case 9

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6032,4	134,2	-5898,2
2	109,8	109,7	-0,1
3	107	107	0
4	114,5	114,5	0
5	106,8	106,7	-0,1
6	119,1	119,1	0
7	124,8	124,8	0
8	120,8	120,8	0
9	123,2	123,2	0
10	117,5	117,5	0
11	121,1	121,1	0
12	116,8	116,8	0
13	126,5	126,4	-0,1
14	112,4	112,4	0
15	136	135,9	-0,1
16	108,1	108,1	0
17	117,5	117,5	0
18	117	117	0
19	116,4	116,4	0
20	121,7	121,6	-0,1
21	117,1	117,1	0
22	121,8	121,8	0
23	117,1	117,1	0
24	117,5	117,5	0
Global	**8743**	**2844**	**-5899**

In this test case, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-62 – FS final results for test case 9 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,11	1,89	63,98	-17,68	0,60	63,49
2	27,16	2,19	63,98	-15,00	0,35	63,49
3	25,17	1,89	63,98	-14,73	0,29	63,49
4	24,16	1,77	63,98	-15,63	0,37	63,49
5	25,17	1,89	63,98	-14,70	0,29	63,49
6	24,14	1,83	63,98	-16,15	0,42	63,49
7	24,05	1,83	63,98	-16,76	0,49	63,49
8	25,85	2,09	63,98	-16,27	0,47	63,49
9	28,70	2,30	63,98	-16,45	0,52	63,49
10	27,56	2,35	63,98	-15,86	0,45	63,49
11	27,51	2,35	63,98	-16,25	0,49	63,49
12	26,49	2,22	63,98	-15,81	0,43	63,49
13	27,51	2,28	63,98	-16,82	0,54	63,49
14	26,43	2,22	63,98	-15,31	0,38	63,49
15	26,36	0,84	63,98	-17,80	0,55	63,49
16	28,34	2,48	63,98	-14,75	0,35	63,49
17	27,36	2,35	63,98	-15,86	0,45	63,49
18	30,47	2,81	63,98	-15,71	0,48	63,49
19	30,61	2,82	63,98	-15,65	0,47	63,49
20	30,72	2,82	63,98	-16,23	0,53	63,49
21	28,80	2,56	63,98	-15,79	0,45	63,49
22	28,90	2,56	63,98	-16,30	0,51	63,49
23	28,98	2,56	63,98	-15,79	0,45	63,49
24	28,06	2,42	63,98	-15,86	0,45	63,49

Table 5-63 – RTPSS final results for test case 9 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,27	1,99	63,84	-17,67	1,37	63,82
2	27,34	2,45	64,04	-14,99	1,05	64,07
3	25,32	2,09	63,88	-14,71	0,99	63,92
4	24,31	1,95	63,61	-15,62	1,11	63,10
5	25,32	2,09	64,00	-14,69	1,00	63,45
6	24,28	2,42	64,60	-16,14	1,14	64,57
7	24,20	2,45	63,57	-16,75	1,26	62,97
8	26,02	2,76	63,72	-16,26	1,23	63,18
9	28,90	3,17	63,42	-16,44	1,28	63,13
10	27,75	3,05	64,13	-15,85	1,19	63,34
11	27,68	3,02	64,51	-16,24	1,22	64,26
12	26,66	2,88	64,21	-15,80	1,15	64,01
13	27,69	2,97	64,20	-16,81	1,30	63,46
14	26,60	2,88	64,11	-15,30	1,11	63,38
15	26,53	1,50	63,96	-17,79	1,35	63,16
16	28,53	3,21	64,09	-14,74	1,07	63,25
17	27,54	3,06	64,00	-15,85	1,20	63,23
18	30,70	3,60	64,35	-15,70	1,21	63,61
19	30,84	3,62	64,33	-15,64	1,19	64,19
20	30,96	3,66	63,76	-16,22	1,28	63,60
21	29,01	3,78	64,07	-15,78	1,19	63,28
22	29,11	3,81	63,54	-16,29	1,27	62,94
23	29,19	3,81	63,70	-15,78	1,20	63,04
24	28,26	3,63	63,84	-15,85	1,20	63,00

Table 5-64 – Comparison between FS and RTPSS final results for test case 9 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,43	7,60	0,17	2,49	3,36	0,87	-0,14	0,33
2	12,16	12,35	0,19	2,54	3,50	0,96	0,06	0,58
3	10,44	10,61	0,17	2,19	3,08	0,89	-0,10	0,43
4	8,53	8,69	0,16	2,14	3,06	0,92	-0,37	-0,39
5	10,47	10,63	0,16	2,18	3,09	0,91	0,02	-0,04
6	7,99	8,14	0,15	2,26	3,56	1,30	0,62	1,08
7	7,30	7,45	0,15	2,32	3,71	1,39	-0,41	-0,52
8	9,58	9,76	0,18	2,56	3,99	1,43	-0,26	-0,31
9	12,25	12,46	0,21	2,82	4,45	1,63	-0,56	-0,36
10	11,70	11,90	0,20	2,80	4,24	1,44	0,15	-0,15
11	11,26	11,44	0,18	2,84	4,24	1,40	0,53	0,77
12	10,68	10,86	0,18	2,65	4,03	1,38	0,23	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	10,69	10,88	0,19	2,82	4,27	1,45	0,22	-0,03
14	11,12	11,30	0,18	2,60	3,99	1,39	0,13	-0,11
15	8,56	8,74	0,18	1,39	2,85	1,46	-0,02	-0,33
16	13,59	13,79	0,20	2,83	4,28	1,45	0,11	-0,24
17	11,50	11,69	0,19	2,80	4,26	1,46	0,02	-0,26
18	14,76	15,00	0,24	3,29	4,81	1,52	0,37	0,12
19	14,96	15,20	0,24	3,29	4,81	1,52	0,35	0,70
20	14,49	14,74	0,25	3,36	4,94	1,58	-0,22	0,11
21	13,01	13,23	0,22	3,01	4,97	1,96	0,09	-0,21
22	12,59	12,82	0,23	3,06	5,08	2,02	-0,44	-0,55
23	13,19	13,41	0,22	3,01	5,01	2,00	-0,28	-0,45
24	12,20	12,41	0,21	2,87	4,83	1,96	-0,14	-0,49

Table 5-64 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,15; 0,25]MW, [0,87; 2,02]Mvar, [-0,56; 0,62]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-44 to Figure 5-46 depicts the comparison of the results for test case 9.

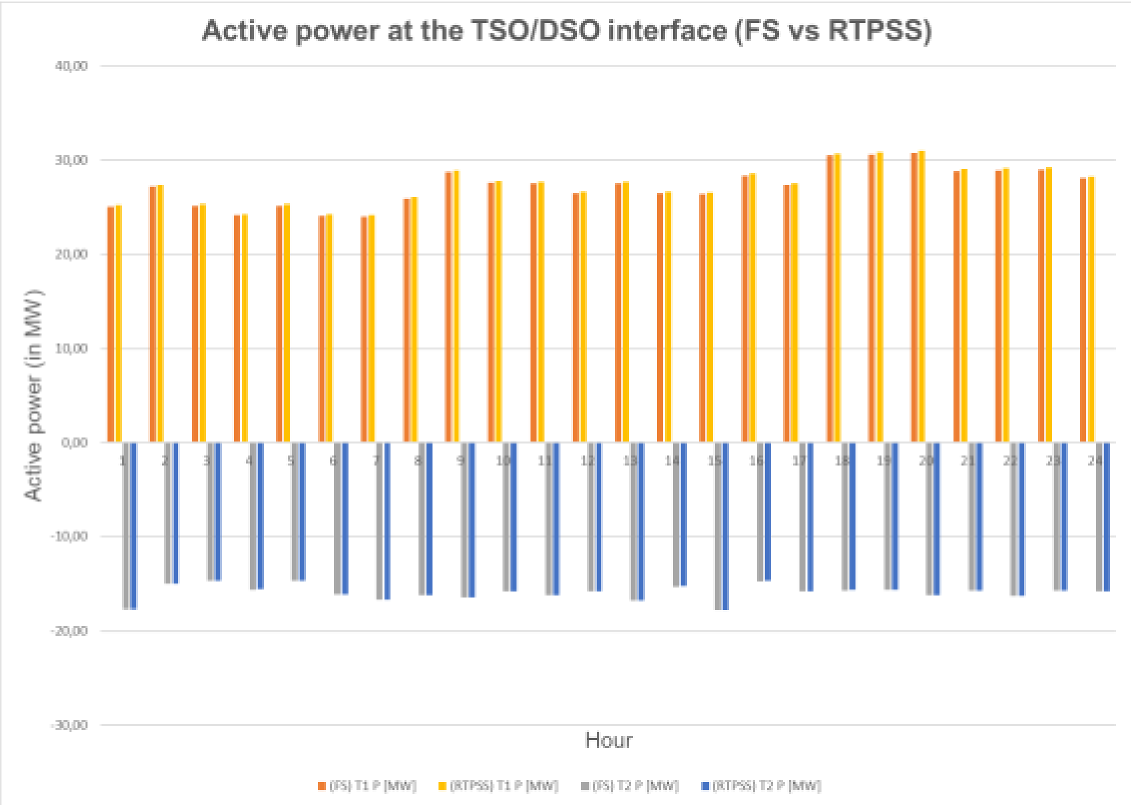


Figure 5-44 – Active Power results at TSO/DSO interface for test case 9

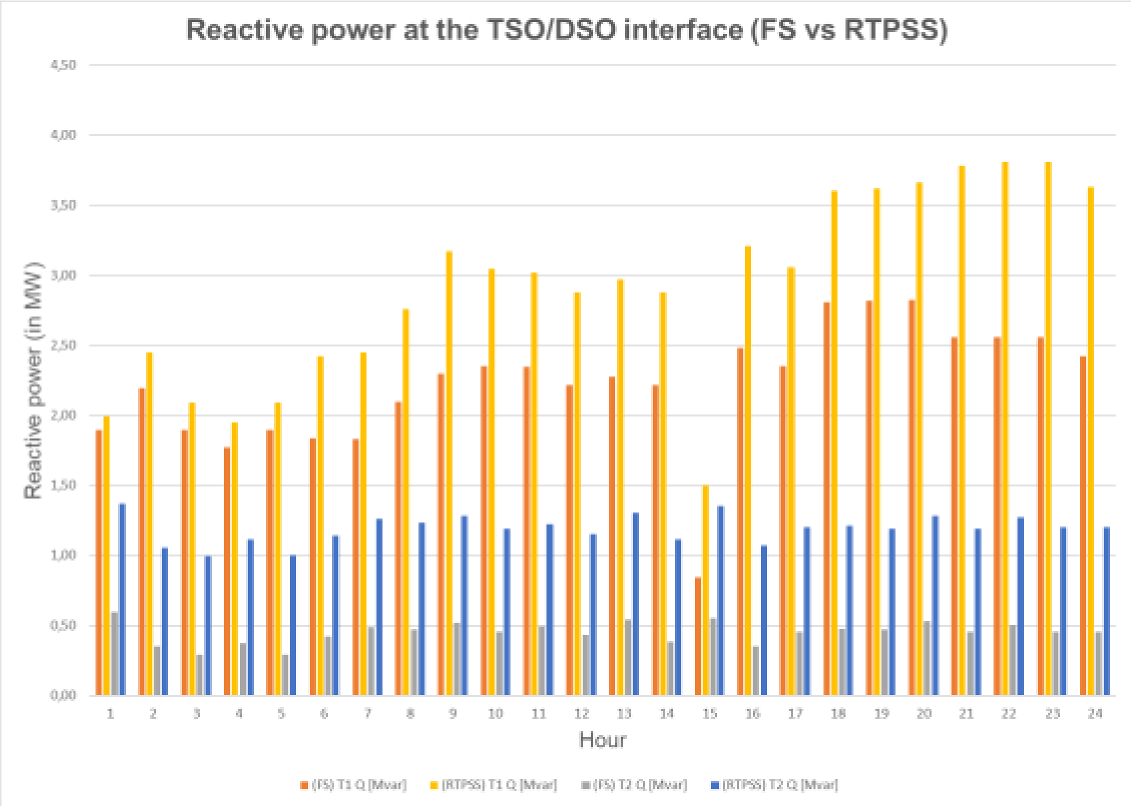


Figure 5-45 – Reactive Power results at TSO/DSO interface for test case 9

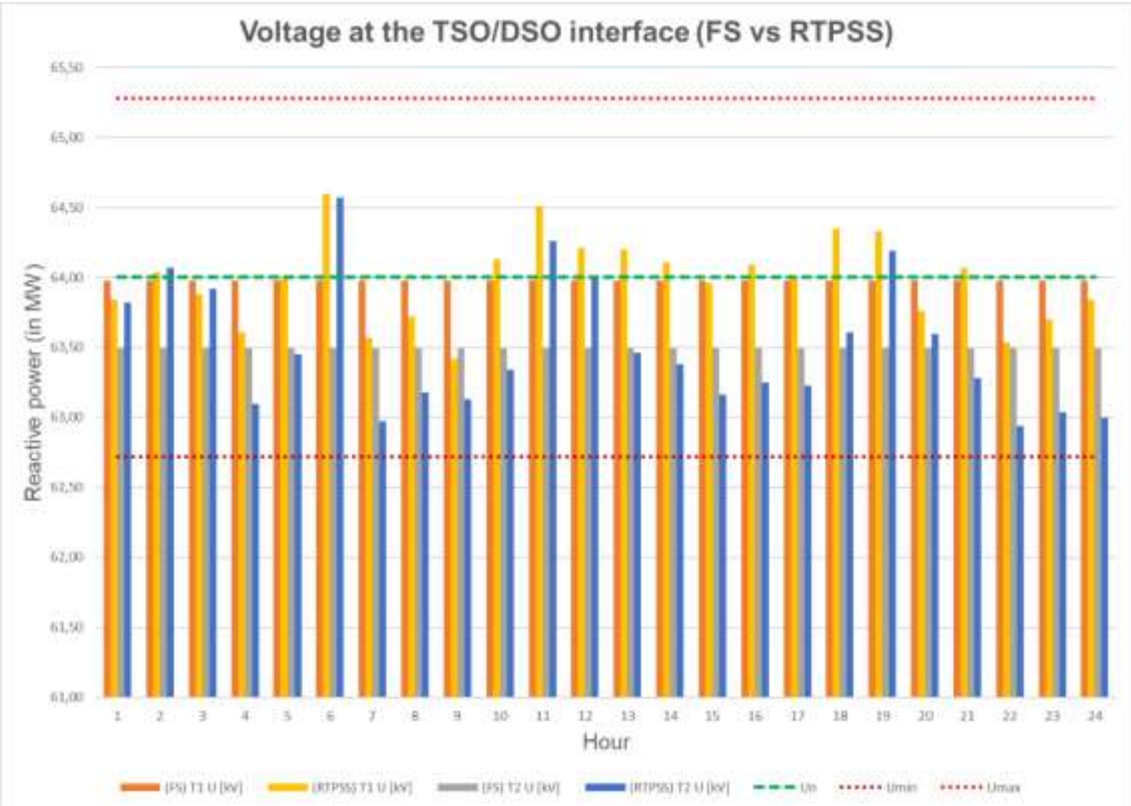


Figure 5-46 – Voltage results at TSO/DSO interface for test case 9

5.2.3.2 Test case 10

This test case corresponds to the optimised power flow solution in which transmission grid assets are considered as a flexibility option and the optimisation function is focused on the minimisation of grid losses. From Table 5-65 to Table 5-68 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-65 – FS voltage results for test case 10

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen in Table 5-65, the FS results from test case 10 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-66 – FS capacitor banks results for test case 10

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	0
3	0	0	30	0
4	0	0	30	0
5	0	0	30	0
6	0	0	30	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	0	0	0
11	40	0	30	0
12	40	0	30	0
13	40	0	0	0
14	40	0	0	0
15	40	0	0	0
16	40	0	0	0
17	40	0	0	0
18	40	0	0	0
19	40	0	30	0
20	40	0	30	0
21	40	0	0	0
22	40	0	0	0
23	0	0	0	0
24	0	0	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-67 – FS losses results for test case 10

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	381,10	355,73	365,60	357,80	-15,50	2,07
2	372,46	204,93	372,41	204,71	-0,05	-0,22
3	343,81	55,39	343,78	55,19	-0,04	-0,20
4	337,57	83,81	337,53	83,62	-0,04	-0,19
5	343,60	52,55	343,56	52,36	-0,04	-0,20
6	341,07	97,11	341,07	97,11	0,00	0,00
7	344,30	155,81	344,30	155,81	0,00	0,00
8	362,98	214,87	362,98	214,87	0,00	0,00
9	403,06	417,41	402,88	416,55	-0,18	-0,87
10	381,90	282,48	381,73	281,66	-0,17	-0,82
11	383,53	318,41	383,36	317,59	-0,17	-0,82
12	366,28	208,24	366,12	207,46	-0,16	-0,78
13	387,72	377,93	387,56	377,13	-0,16	-0,81

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
14	362,35	157,22	362,19	156,44	-0,16	-0,78
15	380,20	413,27	380,13	412,80	-0,06	-0,47
16	387,03	234,50	386,85	233,64	-0,18	-0,86
17	382,63	284,76	382,42	283,73	-0,21	-1,03
18	429,13	485,01	429,13	485,01	0,00	0,00
19	432,09	489,79	432,09	489,79	0,00	0,00
20	438,26	555,49	438,26	555,49	0,00	0,00
21	404,99	409,13	404,99	409,13	0,00	0,00
22	409,28	463,50	409,28	463,50	0,00	0,00
23	405,92	412,24	405,92	412,24	0,00	0,00
24	392,27	353,87	392,27	353,87	0,00	0,00
				TOTAL VARIATION	**-17,12**	**-5,97**

Table 5-68 – FS objective function fitness for test case 10

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6032,4	134,2	-5898,2
2	109,8	109,7	-0,1
3	107	107	0
4	114,5	114,5	0
5	106,8	106,7	-0,1
6	119,1	119,1	0
7	124,8	124,8	0
8	120,8	120,8	0
9	123,2	123,2	0
10	117,5	117,5	0
11	121,1	121,1	0
12	116,8	116,8	0
13	126,5	126,4	-0,1
14	112,4	112,4	0
15	136	135,9	-0,1
16	108,1	108,1	0
17	117,5	117,5	0
18	117	117	0
19	116,4	116,4	0
20	121,7	121,6	-0,1
21	117,1	117,1	0
22	121,8	121,8	0
23	117,1	117,1	0
24	117,5	117,5	0
Global	**8743**	**2844**	**-5899**

In this test case the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-69 – FS final results for test case 10 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,11	1,89	63,98	-17,68	0,60	63,49
2	27,16	2,19	63,98	-15,00	0,35	63,49
3	25,17	1,89	63,98	-14,73	0,29	63,49
4	24,16	1,77	63,98	-15,63	0,37	63,49
5	25,17	1,89	63,98	-14,70	0,29	63,49
6	24,14	1,83	63,98	-16,15	0,42	63,49
7	24,05	1,83	63,98	-16,76	0,49	63,49
8	25,85	2,09	63,98	-16,27	0,47	63,49
9	28,70	2,30	63,98	-16,45	0,52	63,49
10	27,56	2,15	63,98	-15,86	0,45	63,49
11	27,51	2,14	63,98	-16,25	0,49	63,49
12	26,49	2,02	63,98	-15,81	0,43	63,49
13	27,51	2,07	63,98	-16,82	0,54	63,49
14	26,43	2,02	63,98	-15,31	0,38	63,49
15	26,36	0,64	63,98	-17,80	0,55	63,49
16	28,34	2,28	63,98	-14,75	0,35	63,49
17	27,36	2,05	63,98	-15,86	0,45	63,49
18	30,47	2,81	63,98	-15,71	0,48	63,49
19	30,61	2,82	63,98	-15,65	0,47	63,49
20	30,72	2,82	63,98	-16,23	0,53	63,49
21	28,80	2,56	63,98	-15,79	0,45	63,49
22	28,90	2,56	63,98	-16,30	0,51	63,49
23	28,98	2,56	63,98	-15,79	0,45	63,49
24	28,06	2,42	63,98	-15,86	0,45	63,49

Table 5-70 – RTPSS final results for test case 10 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,27	1,99	63,84	-17,67	1,37	63,82
2	27,34	2,45	64,04	-14,99	1,05	64,07
3	25,32	2,09	63,88	-14,71	0,99	63,92
4	24,31	1,95	63,61	-15,62	1,11	63,10
5	25,32	2,09	64,00	-14,69	1,00	63,45
6	24,28	2,42	64,60	-16,14	1,14	64,57
7	24,20	2,45	63,57	-16,75	1,26	62,97
8	26,02	2,76	63,72	-16,26	1,23	63,18
9	28,90	3,17	63,42	-16,44	1,28	63,13
10	27,75	2,88	63,39	-15,85	1,19	63,34
11	27,69	2,85	63,77	-16,24	1,22	64,26
12	26,67	2,71	63,46	-15,80	1,15	64,01
13	27,70	2,80	63,46	-16,81	1,30	63,46
14	26,60	2,71	63,39	-15,30	1,11	63,38
15	26,53	1,33	63,24	-17,79	1,35	63,16
16	28,54	3,04	63,37	-14,74	1,07	63,25
17	27,55	2,79	63,28	-15,85	1,20	63,23
18	30,71	3,64	63,62	-15,70	1,21	63,61
19	30,85	3,66	63,61	-15,64	1,19	64,19
20	30,96	3,70	63,05	-16,22	1,28	63,60
21	29,02	2,80	63,38	-15,78	1,19	63,28
22	29,12	2,83	62,85	-16,29	1,27	62,94
23	29,20	2,83	63,01	-15,78	1,20	63,04
24	28,27	2,65	63,15	-15,85	1,20	63,00

Table 5-71 – Comparison between FS and RTPSS final results for test case 10 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,43	7,60	0,17	2,49	3,36	0,87	-0,14	0,33
2	12,16	12,35	0,19	2,54	3,50	0,96	0,06	0,58
3	10,44	10,61	0,17	2,19	3,08	0,89	-0,10	0,43
4	8,53	8,69	0,16	2,14	3,06	0,92	-0,37	-0,39
5	10,47	10,63	0,16	2,18	3,09	0,91	0,02	-0,04
6	7,99	8,14	0,15	2,26	3,56	1,30	0,62	1,08
7	7,30	7,45	0,15	2,32	3,71	1,39	-0,41	-0,52
8	9,58	9,76	0,18	2,56	3,99	1,43	-0,26	-0,31
9	12,25	12,46	0,21	2,82	4,45	1,63	-0,56	-0,36
10	11,70	11,90	0,20	2,60	4,07	1,47	-0,59	-0,15
11	11,26	11,45	0,19	2,64	4,07	1,43	-0,21	0,77
12	10,68	10,87	0,19	2,45	3,86	1,41	-0,52	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	10,69	10,89	0,20	2,62	4,10	1,48	-0,52	-0,03
14	11,12	11,30	0,18	2,40	3,82	1,42	-0,59	-0,11
15	8,56	8,74	0,18	1,19	2,68	1,49	-0,74	-0,33
16	13,59	13,80	0,21	2,63	4,11	1,48	-0,61	-0,24
17	11,50	11,70	0,20	2,50	3,99	1,49	-0,70	-0,26
18	14,76	15,01	0,25	3,29	4,85	1,56	-0,36	0,12
19	14,96	15,21	0,25	3,29	4,85	1,56	-0,37	0,70
20	14,49	14,74	0,25	3,36	4,98	1,62	-0,93	0,11
21	13,01	13,24	0,23	3,01	3,99	0,98	-0,60	-0,21
22	12,59	12,83	0,24	3,06	4,10	1,04	-1,13	-0,55
23	13,19	13,42	0,23	3,01	4,03	1,02	-0,97	-0,45
24	12,20	12,42	0,22	2,87	3,85	0,98	-0,83	-0,49

Table 5-71 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,15; 0,25]MW, [0,87; 1,63]Mvar, [-1,13; 0,62]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-47 to Figure 5-49 depicts the comparison of the results for test case 10.

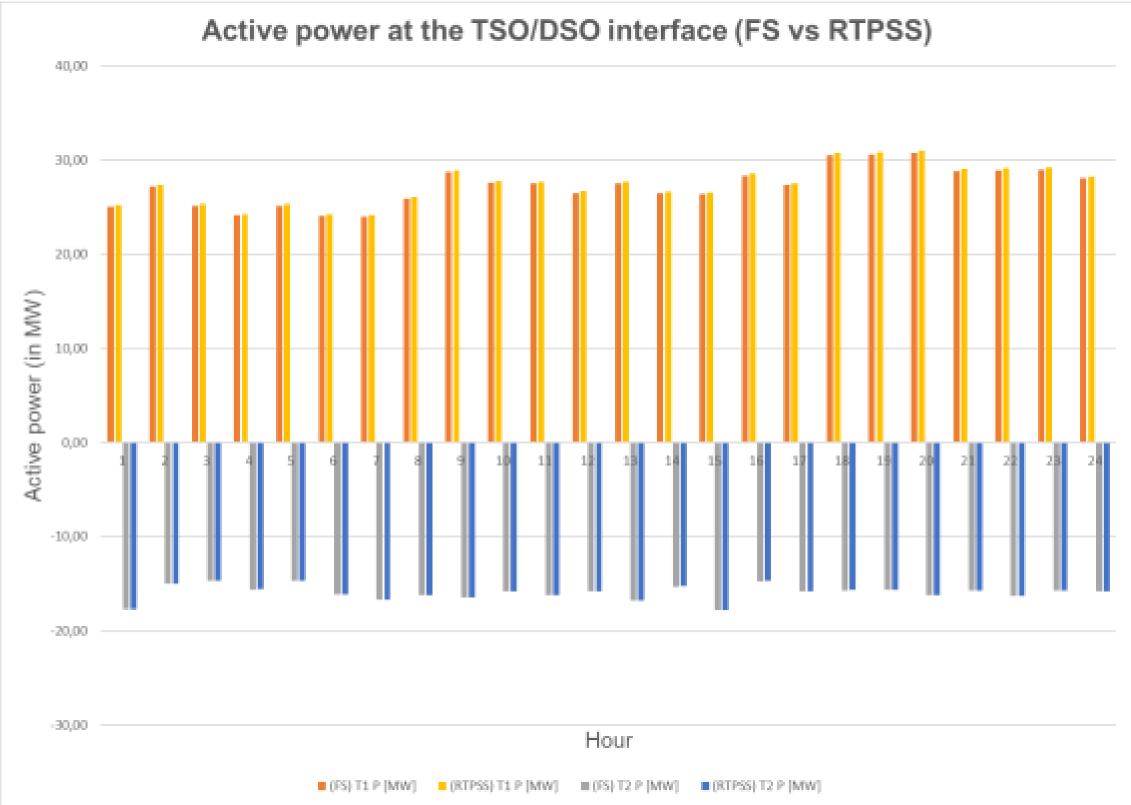


Figure 5-47 – Active Power results at TSO/DSO interface for test case 10

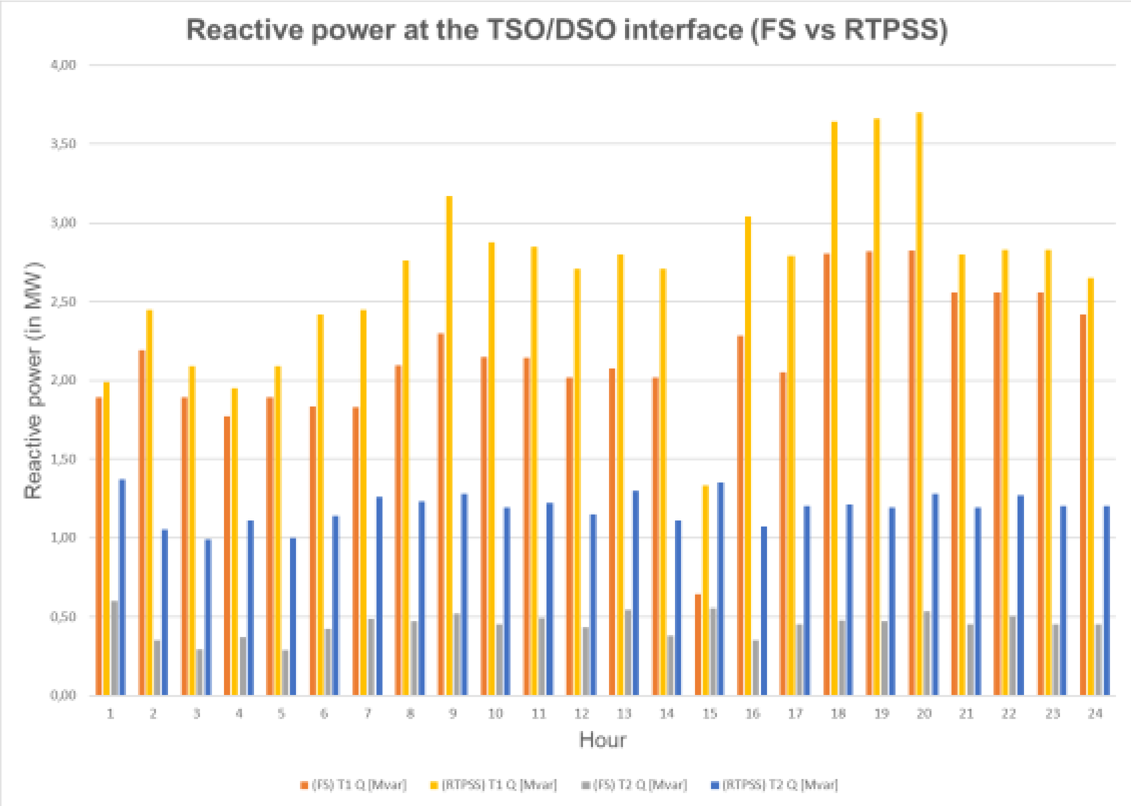


Figure 5-48 – Reactive Power results at TSO/DSO interface for test case 10

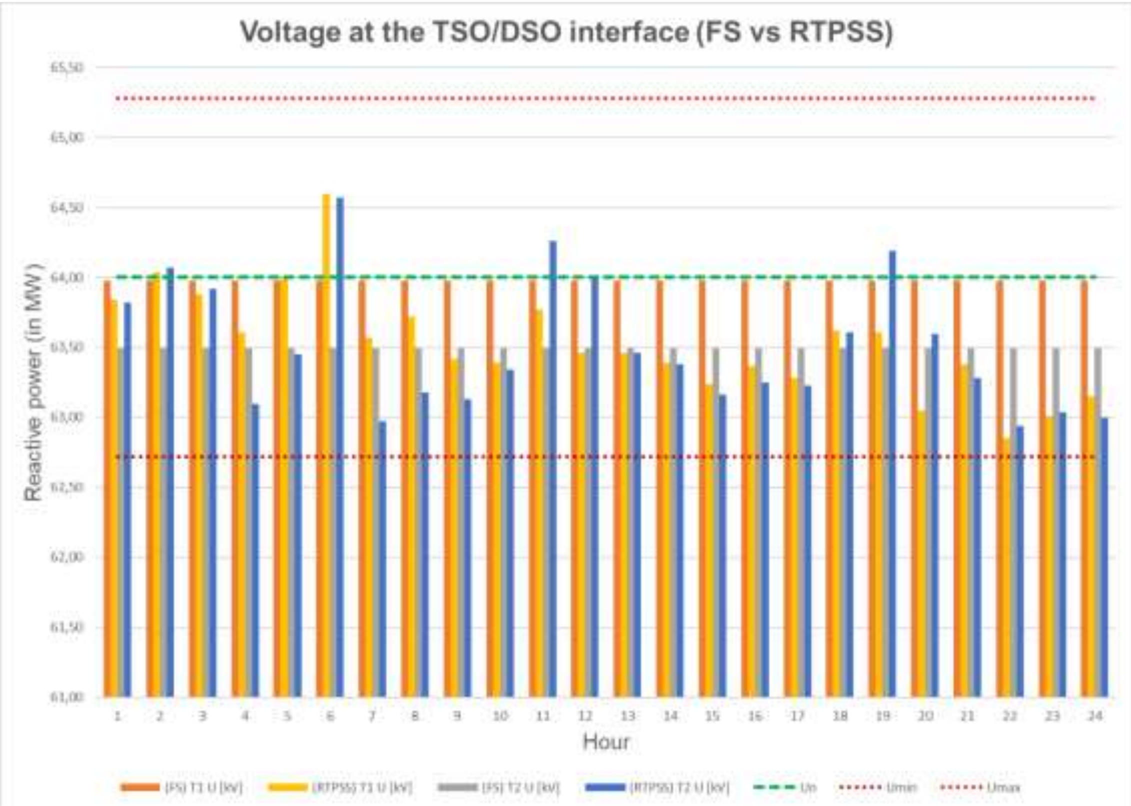


Figure 5-49 – Voltage results at TSO/DSO interface for test case 10

5.2.3.3 Test case 13

This test case corresponds to the optimised power flow solution in which transmission grid assets are not considered as a flexibility option and the optimisation function is focused on the minimisation of costs. From Table 5-72 to Table 5-75 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-72 – FS voltage results for test case 13

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen in Table 5-72, the FS results from test case 13 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-73 – FS capacitor banks results for test case 13

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-74 – FS losses results for test case 13

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	381,10	355,73	365,60	357,80	-15,50	2,07
2	528,18	3736,18	372,41	204,71	-155,76	-3531,47
3	499,33	3587,73	499,33	3587,73	0,00	0,00
4	492,99	3616,70	492,99	3616,70	0,00	0,00
5	499,11	3584,90	499,11	3584,90	0,00	0,00
6	496,48	3630,09	496,48	3630,09	0,00	0,00
7	499,70	3688,84	499,70	3688,84	0,00	0,00
8	518,56	3746,91	518,56	3746,91	0,00	0,00
9	558,92	3947,89	558,61	3947,02	-0,30	-0,87
10	537,65	3813,56	537,65	3813,56	0,00	0,00
11	539,28	3849,51	539,28	3849,51	0,00	0,00
12	521,94	3739,90	521,94	3739,90	0,00	0,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	543,43	3909,04	543,43	3909,04	0,00	0,00
14	518,01	3688,92	518,01	3688,92	0,00	0,00
15	535,05	3945,00	535,05	3945,00	0,00	0,00
16	542,87	3765,17	542,87	3765,17	0,00	0,00
17	538,39	3815,97	538,39	3815,97	0,00	0,00
18	585,21	4014,55	585,21	4014,55	0,00	0,00
19	588,18	4019,27	588,18	4019,27	0,00	0,00
20	594,36	4084,92	594,36	4084,92	0,00	0,00
21	560,90	3939,51	560,90	3939,51	0,00	0,00
22	565,18	3993,82	565,18	3993,82	0,00	0,00
23	561,83	3942,51	564,23	4027,98	2,40	85,47
24	550,79	3971,61	548,08	3884,64	-2,71	-86,97
				TOTAL VARIATION	**-171,88**	**-3531,77**

Table 5-75 – FS objective function fitness for test case 13

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6038,7	140,3	-5898,4
2	115	114,9	-0,1
3	112,1	112	-0,1
4	119,9	119,8	-0,1
5	111,9	111,7	-0,2
6	124,7	124,6	-0,1
7	130,6	130,5	-0,1
8	126,4	126,4	0
9	129	128,8	-0,2
10	123,1	123	-0,1
11	126,8	126,7	-0,1
12	122,3	122,2	-0,1
13	132,4	132,3	-0,1
14	117,7	117,6	-0,1
15	142,2	142,1	-0,1
16	113,3	113,2	-0,1
17	123,1	123	-0,1
18	122,5	122,4	-0,1
19	122	121,8	-0,2
20	127,4	127,3	-0,1
21	122,7	122,6	-0,1
22	127,5	127,4	-0,1
23	122,7	122,6	-0,1
24	123,1	123	-0,1
Global	**8877**	**2976**	**-5901**

In this test case, the optimisation strategy was to minimize costs. Nevertheless, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-76 – FS final results for test case 13 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,11	1,89	63,98	-17,68	0,60	63,49
2	27,16	2,19	63,98	-15,00	0,35	63,49
3	25,32	5,53	63,98	-14,73	0,29	63,49
4	24,32	5,40	63,98	-15,63	0,37	63,49
5	25,32	5,53	63,98	-14,70	0,29	63,49
6	24,30	5,37	63,98	-16,15	0,42	63,49
7	24,21	5,36	63,98	-16,76	0,49	63,49
8	26,01	5,63	63,98	-16,27	0,47	63,49
9	28,85	5,83	63,98	-16,45	0,52	63,49
10	27,72	5,88	63,98	-15,86	0,45	63,49
11	27,66	5,88	63,98	-16,25	0,49	63,49
12	26,65	5,75	63,98	-15,81	0,43	63,49
13	27,67	5,81	63,98	-16,82	0,54	63,49
14	26,58	5,75	63,98	-15,31	0,38	63,49
15	26,52	4,37	63,98	-17,80	0,55	63,49
16	28,49	6,02	63,98	-14,75	0,35	63,49
17	27,51	5,88	63,98	-15,86	0,45	63,49
18	30,63	6,34	63,98	-15,71	0,48	63,49
19	30,77	6,35	63,98	-15,65	0,47	63,49
20	30,87	6,35	63,98	-16,23	0,53	63,49
21	28,96	6,09	63,98	-15,79	0,45	63,49
22	29,05	6,09	63,98	-16,30	0,51	63,49
23	29,14	-2,81	63,98	-15,79	0,45	63,49
24	28,22	5,95	63,98	-15,86	0,45	63,49

Table 5-77 – RTPSS final results for test case 13 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,04	5,91	63,77	-17,67	1,37	63,82
2	26,81	2,71	64,03	-14,99	1,05	64,07
3	24,81	2,35	63,88	-14,71	0,99	63,92
4	23,96	5,76	63,54	-15,62	1,11	63,10
5	24,81	2,35	63,99	-14,69	1,00	63,45
6	23,78	2,18	64,61	-16,14	1,14	64,57
7	23,96	5,77	63,51	-16,75	1,26	62,97
8	25,84	2,64	63,72	-16,26	1,23	63,18
9	28,93	3,07	63,42	-16,44	1,28	63,13
10	10,04	7,33	64,08	-15,85	1,19	63,34
11	9,82	3,77	64,53	-16,24	1,22	64,26
12	9,39	7,22	64,16	-15,80	1,15	64,01
13	10,00	7,26	64,15	-16,81	1,30	63,46
14	9,43	7,22	64,06	-15,30	1,11	63,38
15	9,54	5,84	63,91	-17,79	1,35	63,16
16	10,62	7,45	64,04	-14,74	1,07	63,25
17	9,97	7,33	63,95	-15,85	1,20	63,23
18	11,96	7,72	64,30	-15,70	1,21	63,61
19	11,89	7,72	64,28	-15,64	1,19	64,19
20	11,89	7,73	63,72	-16,22	1,28	63,60
21	10,40	3,90	64,10	-15,78	1,19	63,28
22	10,40	3,90	63,56	-16,29	1,27	62,94
23	10,75	7,46	63,66	-15,78	1,20	63,04
24	10,23	7,34	63,80	-15,85	1,20	63,00

Table 5-78 – Comparison between FS and RTPSS final results for test case 13 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,43	7,37	-0,06	2,49	7,28	4,79	-0,21	0,33
2	12,16	11,82	-0,34	2,54	3,76	1,22	0,05	0,58
3	10,60	10,10	-0,50	5,82	3,34	-2,48	-0,10	0,43
4	8,69	8,34	-0,35	5,78	6,87	1,09	-0,44	-0,39
5	10,62	10,12	-0,50	5,81	3,35	-2,46	0,01	-0,04
6	8,15	7,64	-0,51	5,79	3,32	-2,47	0,63	1,08
7	7,45	7,21	-0,24	5,85	7,03	1,18	-0,47	-0,52
8	9,74	9,58	-0,16	6,10	3,87	-2,23	-0,26	-0,31
9	12,41	12,49	0,08	6,35	4,35	-2,00	-0,56	-0,36
10	11,86	-5,81	-17,67	6,33	8,52	2,19	0,10	-0,15
11	11,41	-6,42	-17,83	6,37	4,99	-1,38	0,55	0,77
12	10,84	-6,41	-17,25	6,18	8,37	2,19	0,18	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	10,85	-6,81	-17,66	6,35	8,56	2,21	0,17	-0,03
14	11,28	-5,87	-17,15	6,13	8,33	2,20	0,08	-0,11
15	8,71	-8,25	-16,96	4,93	7,19	2,27	-0,07	-0,33
16	13,74	-4,12	-17,86	6,37	8,52	2,15	0,06	-0,24
17	11,65	-5,88	-17,53	6,34	8,53	2,19	-0,03	-0,26
18	14,91	-3,74	-18,65	6,81	8,93	2,12	0,32	0,12
19	15,11	-3,75	-18,86	6,82	8,91	2,09	0,30	0,70
20	14,64	-4,33	-18,97	6,88	9,01	2,13	-0,26	0,11
21	13,17	-5,38	-18,55	6,54	5,09	-1,45	0,12	-0,21
22	12,75	-5,89	-18,64	6,59	5,17	-1,42	-0,42	-0,55
23	13,35	-5,03	-18,38	-2,36	8,66	11,02	-0,32	-0,45
24	12,36	-5,62	-17,98	6,40	8,54	2,14	-0,18	-0,49

Table 5-78 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [-18,97; 0,08]MW, [-2,48; 11,02]Mvar, [-0,56; 0,63]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-50 to Figure 5-52 depicts the comparison of the results for test case 13.

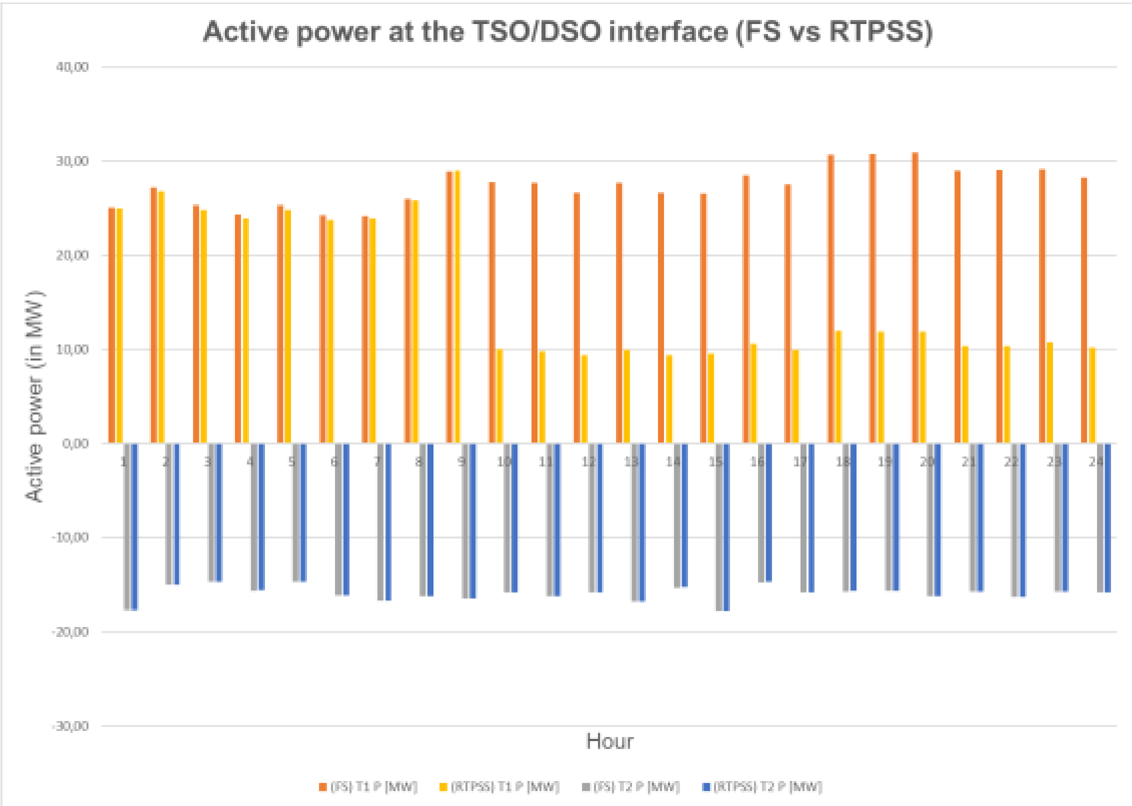


Figure 5-50 – Active Power results at TSO/DSO interface for test case 13

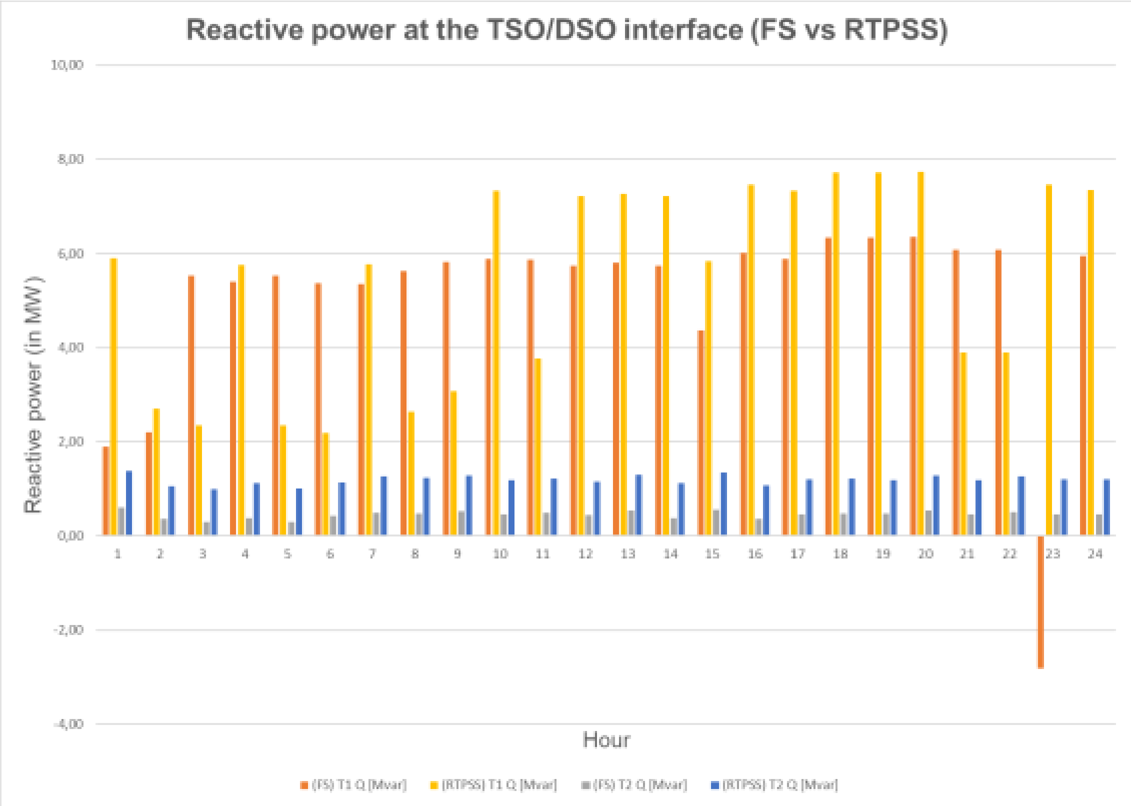


Figure 5-51 – Reactive Power results at TSO/DSO interface for test case 13

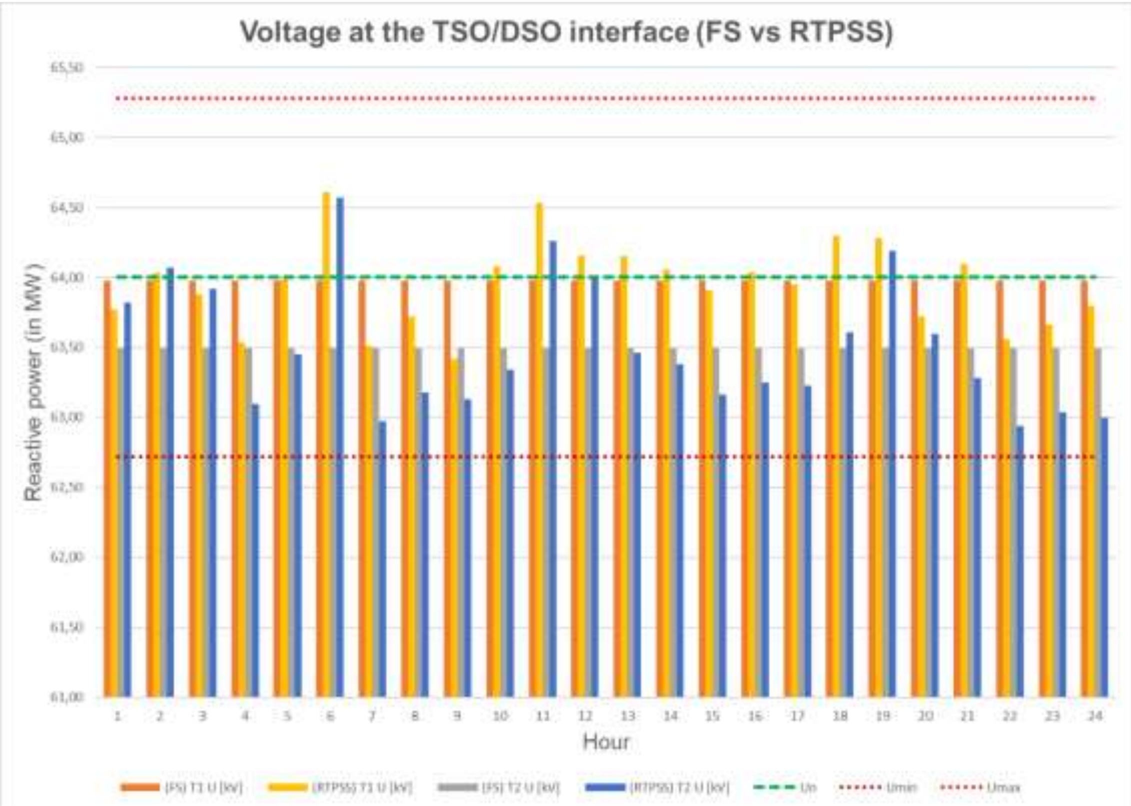


Figure 5-52 – Voltage results at TSO/DSO interface for test case 13

5.2.3.4 Test case 14

This test case corresponds to the optimised power flow solution in which transmission grid assets are considered as a flexibility option and the optimisation function is focused on the minimisation of costs. From Table 5-79 to Table 5-82 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-79 – FS voltage results for test case 14

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen in Table 5-79, the FS results from test case 14 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-80 – FS capacitor banks results for test case 14

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	0	0	0
11	40	0	30	30
12	40	0	30	30
13	40	0	0	0
14	40	0	0	0
15	40	0	0	0
16	40	0	0	0
17	40	0	0	0
18	40	0	0	0
19	40	0	30	30
20	40	0	30	30
21	40	0	0	0
22	40	0	0	0
23	40	0	0	0
24	0	0	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-81 – FS losses results for test case 14

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	381,10	355,73	365,60	357,80	-15,50	2,07
2	528,18	3736,18	372,41	204,71	-155,76	-3531,47
3	499,33	3587,73	499,33	3587,73	0,00	0,00
4	492,99	3616,70	492,99	3616,70	0,00	0,00
5	499,11	3584,90	499,11	3584,90	0,00	0,00
6	496,48	3630,09	496,48	3630,09	0,00	0,00
7	499,70	3688,84	499,70	3688,84	0,00	0,00
8	518,56	3746,91	518,56	3746,91	0,00	0,00
9	558,92	3947,89	558,61	3947,02	-0,30	-0,87
10	537,65	3813,56	537,65	3813,56	0,00	0,00
11	539,28	3849,51	539,28	3849,51	0,00	0,00
12	521,94	3739,90	521,66	3739,11	-0,28	-0,79
13	543,43	3909,04	543,43	3909,04	0,00	0,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
14	518,01	3688,92	517,73	3688,13	-0,28	-0,79
15	535,05	3945,00	534,87	3944,53	-0,18	-0,47
16	542,87	3765,17	387,03	234,50	-155,85	-3530,67
17	538,39	3815,97	502,33	2957,95	-36,05	-858,02
18	549,41	3157,87	584,98	4014,04	35,57	856,17
19	588,18	4019,27	465,47	685,39	-122,71	-3333,88
20	661,82	5289,33	438,20	555,22	-223,62	-4734,11
21	560,90	3939,51	417,84	406,71	-143,06	-3532,81
22	422,13	461,07	422,13	461,07	0,00	0,00
23	418,77	409,81	418,77	409,81	0,00	0,00
24	405,13	351,62	405,13	351,62	0,00	0,00
				TOTAL VARIATION	**-818,02**	**-18665,63**

Table 5-82 – FS objective function fitness for test case 14

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6038,8	140,3	-5898,5
2	115	114,9	-0,1
3	112,1	112	-0,1
4	119,9	119,8	-0,1
5	111,9	111,7	-0,2
6	124,7	124,6	-0,1
7	130,6	130,5	-0,1
8	126,4	126,4	0
9	129	128,8	-0,2
10	123,1	123	-0,1
11	126,8	126,6	-0,2
12	122,3	122,2	-0,1
13	132,4	132,2	-0,2
14	117,7	117,6	-0,1
15	142,3	142,1	-0,2
16	113,3	113,2	-0,1
17	123,1	123	-0,1
18	122,5	122,4	-0,1
19	121,9	121,8	-0,1
20	127,4	127,3	-0,1
21	122,7	122,6	-0,1
22	127,6	127,4	-0,2
23	122,7	122,6	-0,1
24	123,1	123	-0,1
Global	**8877**	**2976**	**-5901**

In this test case, the optimisation strategy was to minimize costs. Nevertheless, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-83 – FS final results for test case 14 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,11	1,89	63,98	-17,68	0,60	63,49
2	27,16	2,19	63,98	-15,00	0,35	63,49
3	25,32	5,53	63,98	-14,73	0,29	63,49
4	24,32	5,40	63,98	-15,63	0,37	63,49
5	25,32	5,53	63,98	-14,70	0,29	63,49
6	24,30	5,37	63,98	-16,15	0,42	63,49
7	24,21	5,36	63,98	-16,76	0,49	63,49
8	26,01	5,63	63,98	-16,27	0,47	63,49
9	28,85	5,83	63,98	-16,45	0,52	63,49
10	27,72	5,88	63,98	-15,86	0,45	63,49
11	27,66	5,88	63,98	-16,25	0,49	63,49
12	26,65	5,55	63,98	-15,81	0,43	63,49
13	27,67	5,81	63,98	-16,82	0,54	63,49
14	26,58	5,55	63,98	-15,31	0,38	63,49
15	26,52	4,17	63,98	-17,80	0,55	63,49
16	28,34	2,48	63,98	-14,75	0,35	63,49
17	27,48	4,73	63,98	-15,86	0,45	63,49
18	30,63	6,14	63,98	-15,71	0,48	63,49
19	30,64	-12,83	63,98	-15,65	0,47	63,49
20	30,72	2,72	63,98	-16,23	0,53	63,49
21	28,82	2,55	63,98	-15,79	0,45	63,49
22	28,91	2,56	63,98	-16,30	0,51	63,49
23	28,99	2,56	63,98	-15,79	0,45	63,49
24	28,08	2,42	63,98	-15,86	0,45	63,49

Table 5-84 – RTPSS final results for test case 14 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,04	5,91	63,77	-17,67	1,37	63,82
2	26,81	2,71	64,03	-14,99	1,05	64,07
3	24,81	2,35	63,88	-14,71	0,99	63,92
4	23,96	5,76	63,54	-15,62	1,11	63,10
5	24,81	2,35	63,99	-14,69	1,00	63,45
6	23,78	2,18	64,61	-16,14	1,14	64,57
7	23,96	5,77	63,51	-16,75	1,26	62,97
8	25,84	2,64	63,72	-16,26	1,23	63,18
9	28,93	3,07	63,42	-16,44	1,28	63,13
10	26,84	2,65	63,39	-15,85	1,19	63,34
11	27,80	2,62	63,77	-16,24	1,22	64,26
12	26,86	6,26	63,40	-15,80	1,15	64,01
13	27,90	6,35	63,39	-16,81	1,30	63,46
14	26,76	6,26	63,32	-15,30	1,11	63,38
15	26,32	1,21	63,24	-17,79	1,35	63,16
16	28,10	6,73	64,03	-14,74	1,07	63,25
17	26,74	6,10	63,22	-15,85	1,20	63,23
18	30,59	6,86	63,56	-15,70	1,21	63,61
19	30,51	6,86	63,56	-15,64	1,19	64,19
20	30,52	6,89	63,00	-16,22	1,28	63,60
21	28,56	6,49	63,32	-15,78	1,19	63,28
22	28,66	6,52	62,78	-16,29	1,27	62,94
23	28,67	2,98	63,01	-15,78	1,20	63,04
24	27,91	6,45	63,09	-15,85	1,20	63,00

Table 5-85 – Comparison between FS and RTPSS final results for test case 14 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	7,43	7,37	-0,06	2,49	7,28	4,79	-0,21	0,33
2	12,16	11,82	-0,34	2,54	3,76	1,22	0,05	0,58
3	10,60	10,10	-0,50	5,82	3,34	-2,48	-0,10	0,43
4	8,69	8,34	-0,35	5,78	6,87	1,09	-0,44	-0,39
5	10,62	10,12	-0,50	5,81	3,35	-2,46	0,01	-0,04
6	8,15	7,64	-0,51	5,79	3,32	-2,47	0,63	1,08
7	7,45	7,21	-0,24	5,85	7,03	1,18	-0,47	-0,52
8	9,74	9,58	-0,16	6,10	3,87	-2,23	-0,26	-0,31
9	12,41	12,49	0,08	6,35	4,35	-2,00	-0,56	-0,36
10	11,86	10,99	-0,87	6,33	3,84	-2,49	-0,59	-0,15
11	11,41	11,56	0,15	6,37	3,84	-2,53	-0,21	0,77
12	10,84	11,06	0,22	5,98	7,41	1,43	-0,58	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	10,85	11,09	0,24	6,35	7,65	1,30	-0,59	-0,03
14	11,27	11,46	0,19	5,93	7,37	1,44	-0,66	-0,11
15	8,71	8,53	-0,18	4,72	2,56	-2,16	-0,74	-0,33
16	13,59	13,36	-0,23	2,83	7,80	4,97	0,05	-0,24
17	11,62	10,89	-0,73	5,18	7,30	2,12	-0,76	-0,26
18	14,91	14,89	-0,02	6,61	8,07	1,46	-0,42	0,12
19	14,99	14,87	-0,12	-12,36	8,05	20,41	-0,42	0,70
20	14,49	14,30	-0,19	3,26	8,17	4,91	-0,98	0,11
21	13,02	12,78	-0,24	3,01	7,68	4,67	-0,66	-0,21
22	12,61	12,37	-0,24	3,06	7,79	4,73	-1,20	-0,55
23	13,20	12,89	-0,31	3,01	4,18	1,17	-0,97	-0,45
24	12,22	12,06	-0,16	2,87	7,65	4,78	-0,89	-0,49

Table 5-85 – Comparison between FS and RTPSS final results for test case 14 at TSO-DSO interface shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [-0,87; 0,24]MW, [-2,53; 20,41]Mvar, [-1,20; 0,63]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-53 to Figure 5-55 depicts the comparison of the results for test case 14.

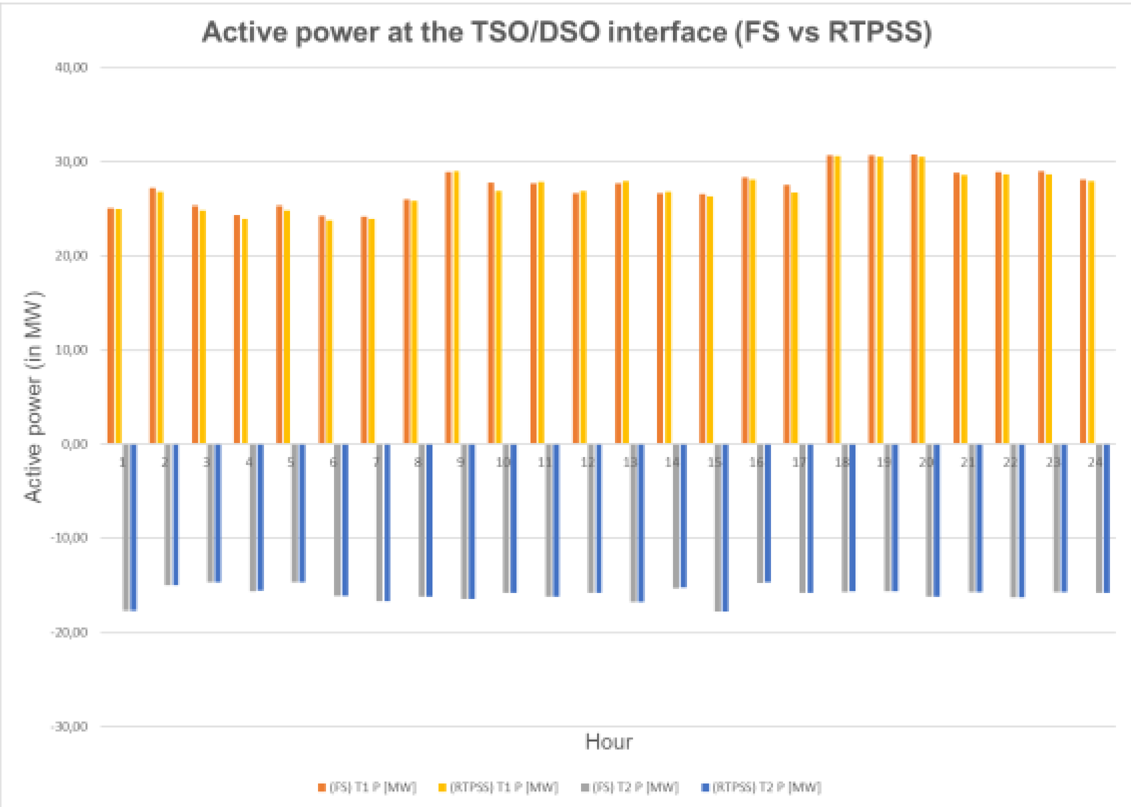


Figure 5-53 – Active Power results at TSO/DSO interface for test case 14

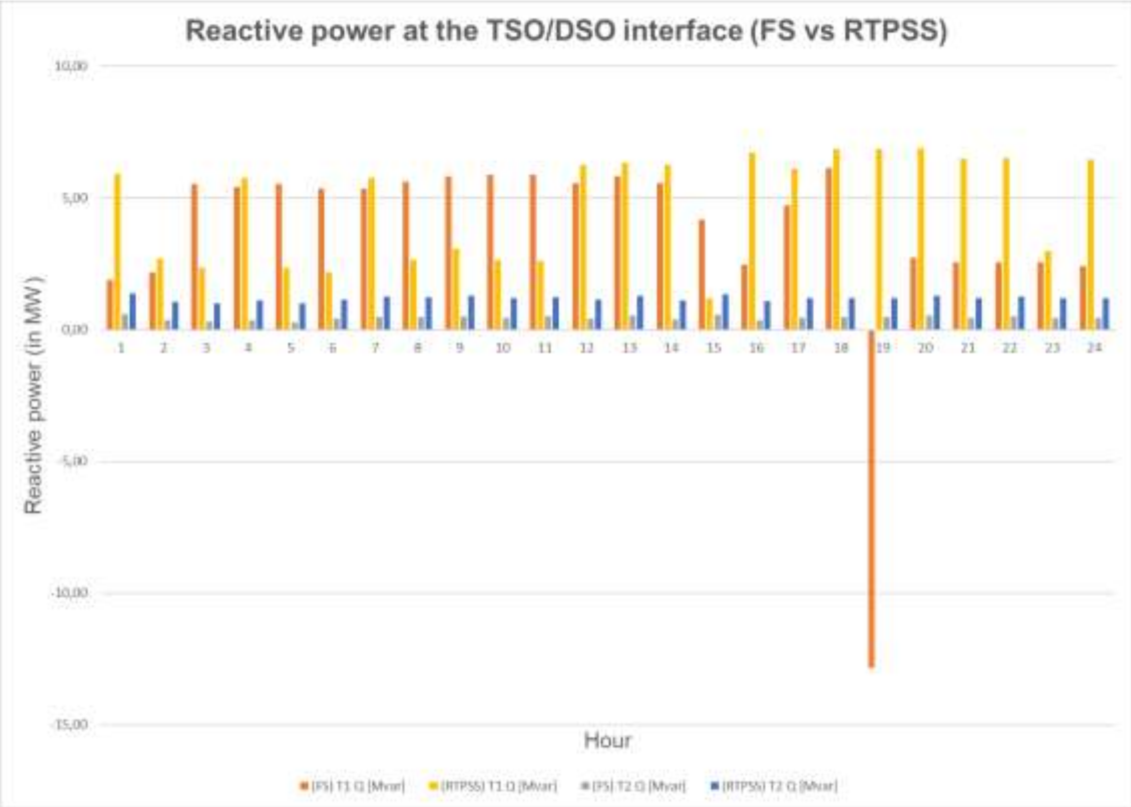


Figure 5-54 – Reactive Power results at TSO/DSO interface for test case 14

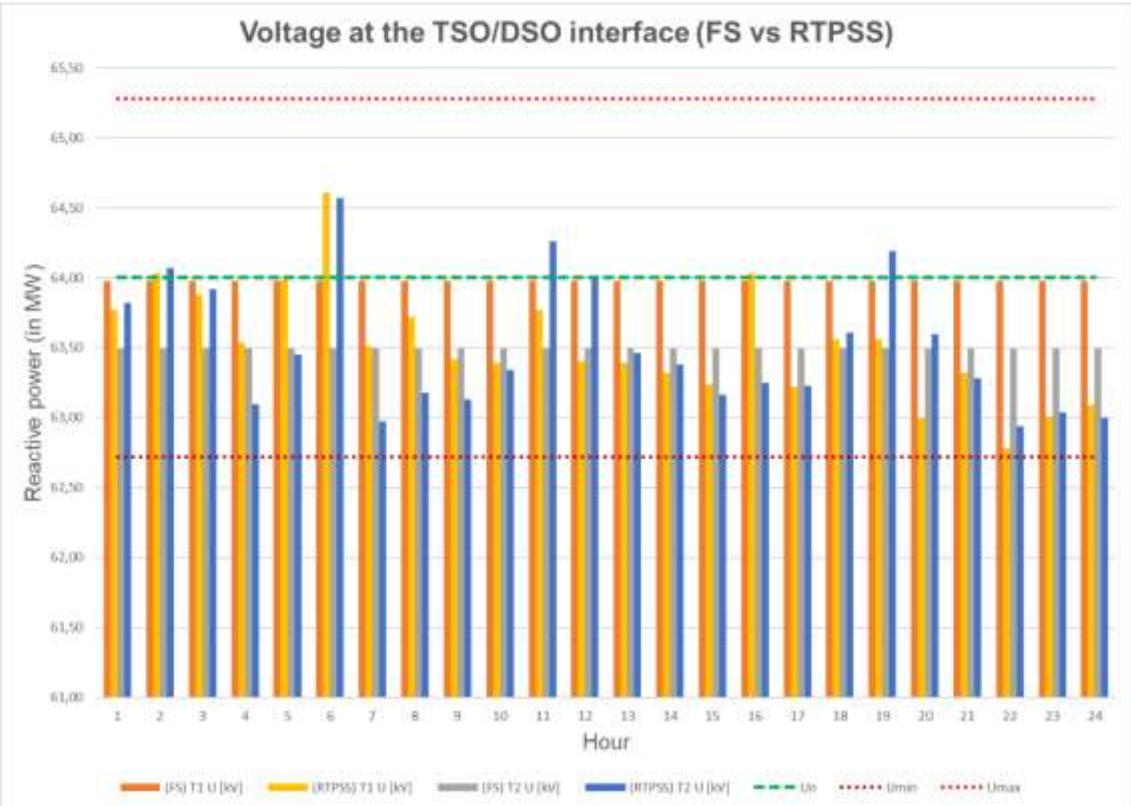


Figure 5-55 – Voltage results at TSO/DSO interface for test case 14

5.2.4 Cluster 4

This is the test case cluster based on the scenario for radial (open mesh) distribution grid operation with low penetration of RES. The source data of the graphics is available in Annex D – Cluster 4 simulation results.

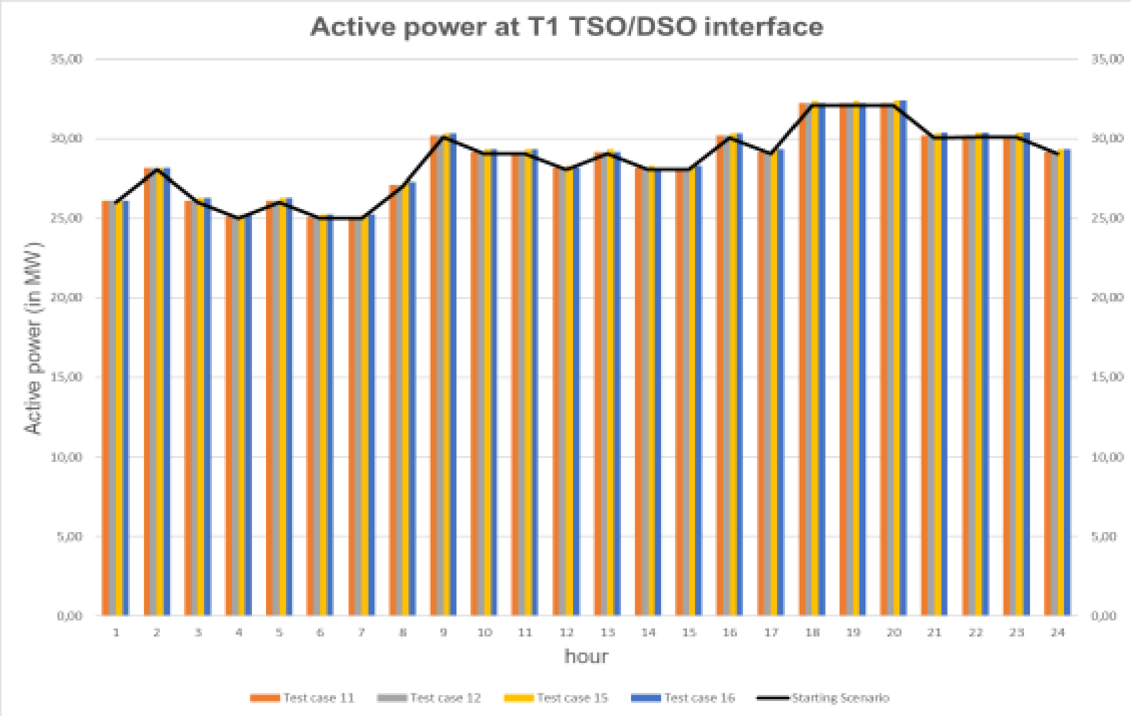


Figure 5-56 – Active Power profile at T1 TSO/DSO interface for cluster 4 test cases

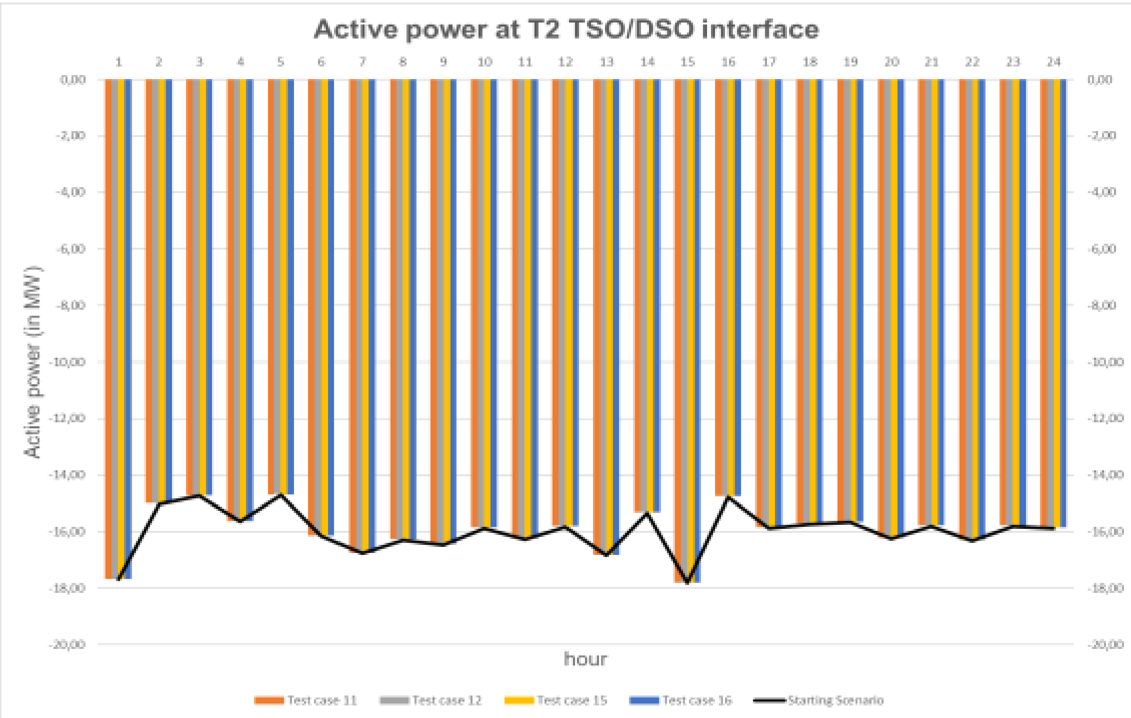


Figure 5-57 – Active Power profile at T2 TSO/DSO interface for cluster 4 test cases

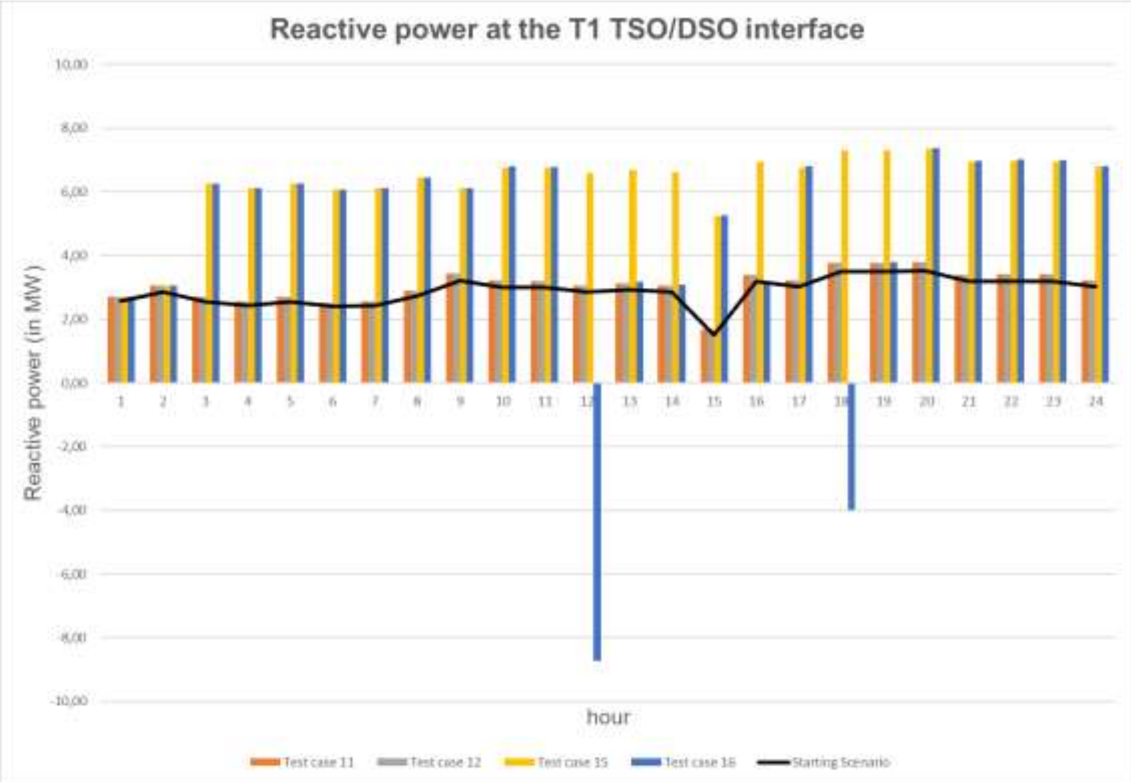


Figure 5-58 – Reactive Power profile at T1 TSO/DSO interface for cluster 4 test cases

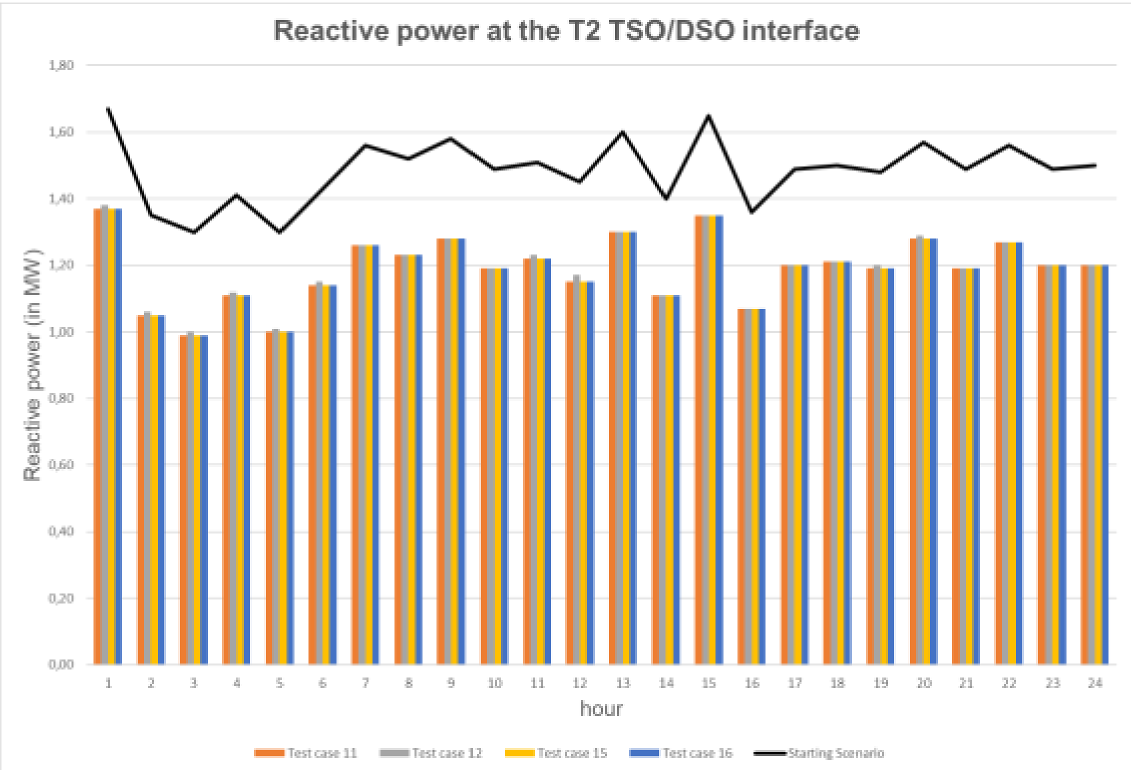


Figure 5-59 – Reactive Power profile at T2 TSO/DSO interface for cluster 4 test cases

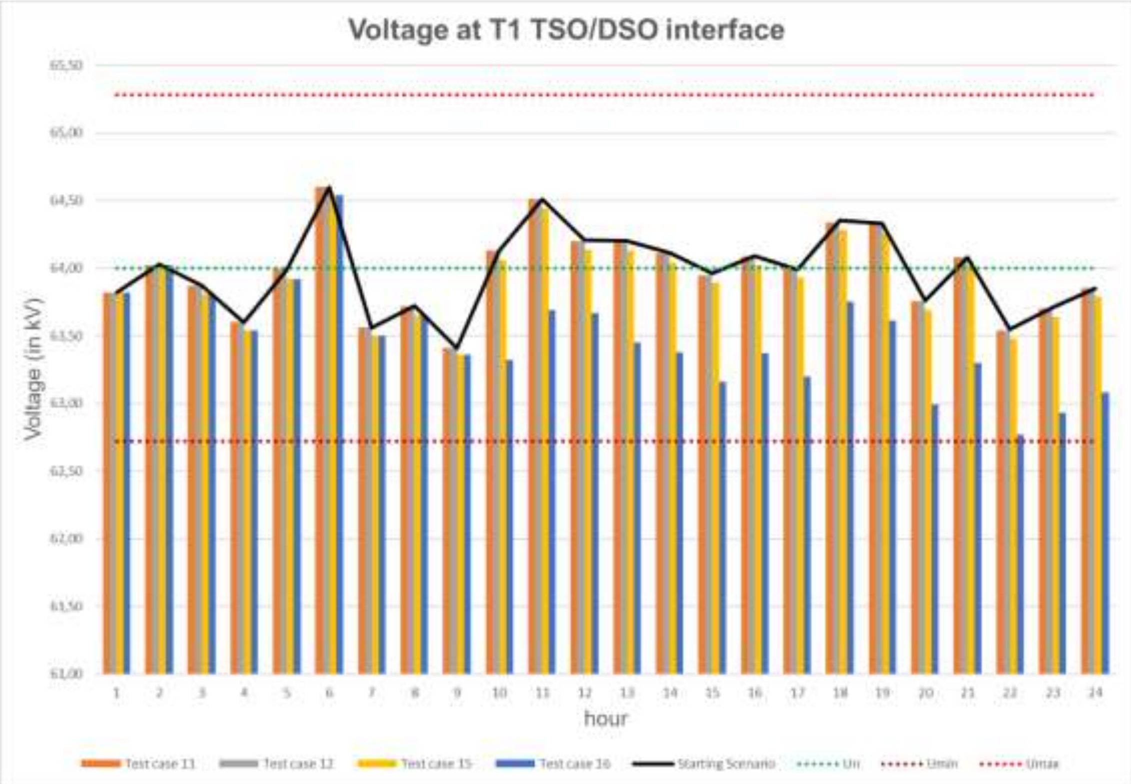


Figure 5-60 – Voltage at T1 TSO/DSO interface for cluster 4 test cases

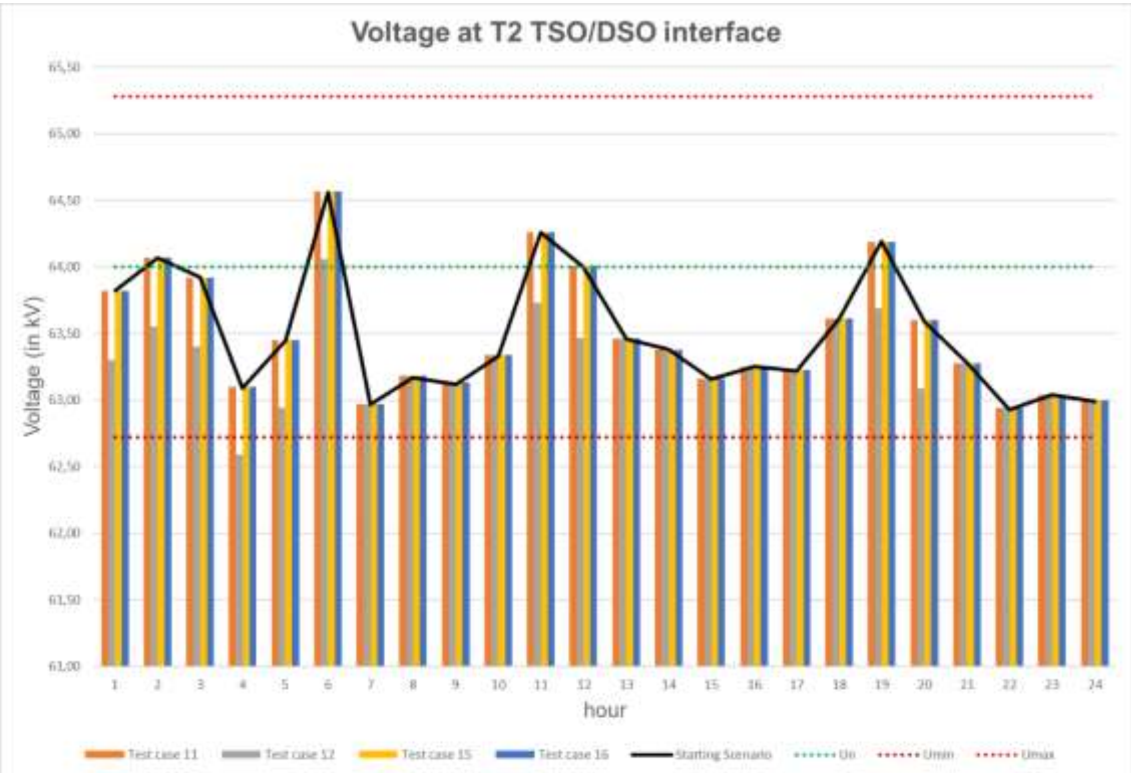


Figure 5-61 – Voltage at T2 TSO/DSO interface for cluster 4 test cases

5.2.4.1 Test case 11

This test case corresponds to the optimised power flow solution in which transmission grid assets are not considered as an optimisation lever and the optimisation function prioritises the minimisation of grid losses. From Table 5-86 to Table 5-89 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-86 – FS voltage results for test case 11

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen in Table 5-86, the FS results from test case 11 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-87 – FS capacitor banks results for test case 11

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-88 – FS losses results for test case 11

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	385,14	407,21	369,68	409,47	-15,46	2,26
2	376,60	256,69	376,60	256,69	0,00	0,00
3	347,59	105,99	347,59	105,99	0,00	0,00
4	341,19	133,93	341,19	133,93	0,00	0,00
5	347,39	103,18	347,39	103,18	0,00	0,00
6	344,99	185,94	344,99	185,94	0,00	0,00
7	349,60	249,14	349,60	249,14	0,00	0,00
8	371,84	319,68	371,84	319,68	0,00	0,00
9	416,35	536,51	416,35	536,51	0,00	0,00
10	397,17	408,08	397,17	408,08	0,00	0,00
11	400,06	448,12	400,06	448,12	0,00	0,00
12	382,37	336,59	382,37	336,59	0,00	0,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	404,33	507,91	404,33	507,91	0,00	0,00
14	378,76	286,63	378,76	286,63	0,00	0,00
15	396,68	543,06	396,68	543,06	0,00	0,00
16	404,08	365,92	404,08	365,92	0,00	0,00
17	397,17	408,08	397,17	408,08	0,00	0,00
18	442,19	603,39	442,19	603,39	0,00	0,00
19	441,74	597,13	441,74	597,13	0,00	0,00
20	446,01	656,65	446,01	656,65	0,00	0,00
21	411,45	468,54	411,45	468,54	0,00	0,00
22	415,25	521,28	415,25	521,28	0,00	0,00
23	411,45	468,54	411,45	468,54	0,00	0,00
24	397,17	408,08	397,17	408,08	0,00	0,00
				TOTAL VARIATION	**-15,46**	**2,26**

Table 5-89 – FS objective function fitness for test case 11

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6032,4	134,2	-5898,2
2	109,8	109,7	-0,1
3	107	107	0
4	114,5	114,5	0
5	106,8	106,7	-0,1
6	119,1	119,1	0
7	124,8	124,8	0
8	120,8	120,8	0
9	123,2	123,2	0
10	117,5	117,5	0
11	121,1	121,1	0
12	116,8	116,8	0
13	126,5	126,4	-0,1
14	112,4	112,4	0
15	136	135,9	-0,1
16	108,1	108,1	0
17	117,5	117,5	0
18	117	117	0
19	116,4	116,4	0
20	121,7	121,6	-0,1
21	117,1	117,1	0
22	121,8	121,8	0
23	117,1	117,1	0
24	117,5	117,5	0
Global	**8743**	**2844**	**-5899**

In this test case, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-90 – FS final results for test case 11 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,95	2,04	63,98	-17,68	0,60	63,49
2	27,95	2,35	63,98	-15,00	0,35	63,49
3	25,95	2,04	63,98	-14,73	0,29	63,49
4	24,94	1,92	63,98	-15,63	0,37	63,49
5	25,95	2,04	63,98	-14,70	0,29	63,49
6	24,94	1,92	63,98	-16,15	0,42	63,49
7	24,94	1,92	63,98	-16,76	0,49	63,49
8	26,94	2,20	63,98	-16,27	0,47	63,49
9	29,97	2,62	63,98	-16,45	0,52	63,49
10	28,97	2,48	63,98	-15,86	0,45	63,49
11	28,97	2,48	63,98	-16,25	0,49	63,49
12	27,95	2,35	63,98	-15,81	0,43	63,49
13	28,97	2,40	63,98	-16,82	0,54	63,49
14	27,95	2,35	63,98	-15,31	0,38	63,49
15	27,95	0,97	63,98	-17,80	0,55	63,49
16	29,97	2,62	63,98	-14,75	0,35	63,49
17	28,97	2,48	63,98	-15,86	0,45	63,49
18	31,98	2,92	63,98	-15,71	0,48	63,49
19	31,98	2,92	63,98	-15,65	0,47	63,49
20	31,98	2,92	63,98	-16,23	0,53	63,49
21	29,97	2,62	63,98	-15,79	0,45	63,49
22	29,97	2,62	63,98	-16,30	0,51	63,49
23	29,97	2,62	63,98	-15,79	0,45	63,49
24	28,97	2,48	63,98	-15,86	0,45	63,49

Table 5-91 – RTPSS final results for test case 11 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	26,11	1,62	63,84	-17,67	1,37	63,82
2	28,14	1,87	64,05	-14,99	1,05	64,07
3	26,11	1,52	63,89	-14,71	0,99	63,92
4	25,09	1,47	63,62	-15,62	1,11	63,10
5	26,11	1,51	64,01	-14,69	1,00	63,45
6	25,09	1,44	64,62	-16,14	1,14	64,57
7	25,10	1,38	63,58	-16,75	1,26	62,97
8	27,12	1,71	63,74	-16,26	1,23	63,18
9	30,20	2,04	63,43	-16,44	1,28	63,13
10	29,17	4,66	64,10	-15,85	1,19	63,34
11	29,17	4,64	64,48	-16,24	1,22	64,26
12	28,14	4,49	64,18	-15,80	1,15	64,01
13	29,17	4,58	64,17	-16,81	1,30	63,46
14	28,15	4,49	64,08	-15,30	1,11	63,38
15	28,14	3,11	63,93	-17,79	1,35	63,16
16	30,19	4,83	64,06	-14,74	1,07	63,25
17	29,17	4,66	63,97	-15,85	1,20	63,23
18	32,23	5,20	64,32	-15,70	1,21	63,61
19	32,23	5,20	64,30	-15,64	1,19	64,19
20	32,24	5,23	63,73	-16,22	1,28	63,60
21	30,20	4,83	64,05	-15,78	1,19	63,28
22	30,20	4,86	63,52	-16,29	1,27	62,94
23	30,20	4,85	63,68	-15,78	1,20	63,04
24	29,18	4,67	63,82	-15,85	1,20	63,00

Table 5-92 – Comparison between FS and RTPSS final results for test case 11 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,27	8,44	0,17	2,64	2,99	0,35	-0,14	0,33
2	12,95	13,15	0,20	2,70	2,92	0,22	0,07	0,58
3	11,22	11,40	0,18	2,34	2,51	0,17	-0,09	0,43
4	9,31	9,47	0,16	2,29	2,58	0,29	-0,36	-0,39
5	11,25	11,42	0,17	2,33	2,51	0,18	0,03	-0,04
6	8,79	8,95	0,16	2,35	2,58	0,23	0,64	1,08
7	8,19	8,35	0,16	2,41	2,64	0,23	-0,40	-0,52
8	10,67	10,86	0,19	2,67	2,94	0,27	-0,24	-0,31
9	13,53	13,76	0,23	3,14	3,32	0,18	-0,55	-0,36
10	13,11	13,32	0,21	2,93	5,85	2,92	0,12	-0,15
11	12,72	12,93	0,21	2,97	5,86	2,89	0,50	0,77
12	12,14	12,34	0,20	2,78	5,64	2,86	0,20	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	12,15	12,36	0,21	2,95	5,88	2,93	0,19	-0,03
14	12,64	12,85	0,21	2,73	5,60	2,87	0,10	-0,11
15	10,15	10,35	0,20	1,52	4,46	2,94	-0,05	-0,33
16	15,22	15,45	0,23	2,97	5,90	2,93	0,08	-0,24
17	13,11	13,32	0,21	2,93	5,86	2,93	-0,01	-0,26
18	16,27	16,53	0,26	3,40	6,41	3,01	0,34	0,12
19	16,33	16,59	0,26	3,40	6,39	2,99	0,32	0,70
20	15,76	16,02	0,27	3,46	6,51	3,05	-0,25	0,11
21	14,18	14,42	0,24	3,07	6,02	2,95	0,07	-0,21
22	13,67	13,91	0,24	3,12	6,13	3,01	-0,46	-0,55
23	14,18	14,42	0,24	3,07	6,05	2,98	-0,30	-0,45
24	13,11	13,33	0,22	2,93	5,87	2,94	-0,16	-0,49

Table 5-92 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,16; 0,27]MW, [0,17; 3,05]Mvar, [-0,55; 0,64]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-62 to Figure 5-64 depicts the comparison of the results for test case 11.

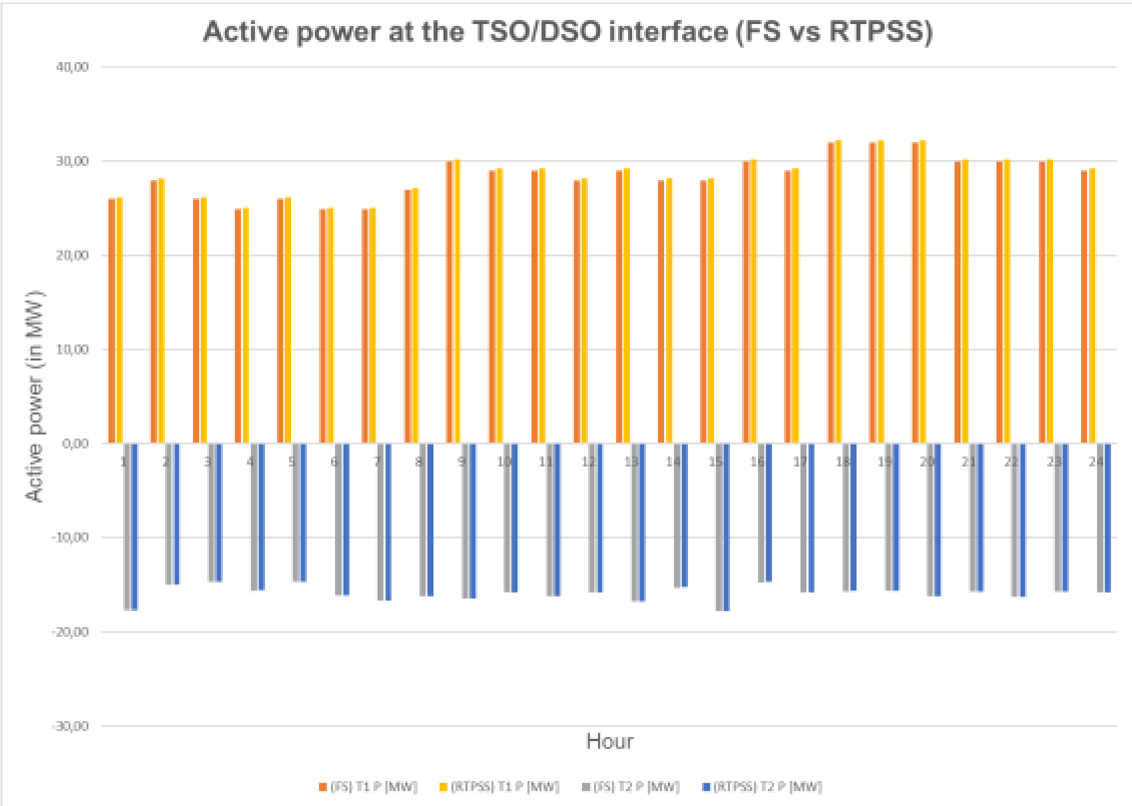


Figure 5-62 – Active Power results at TSO/DSO interface for test case 11

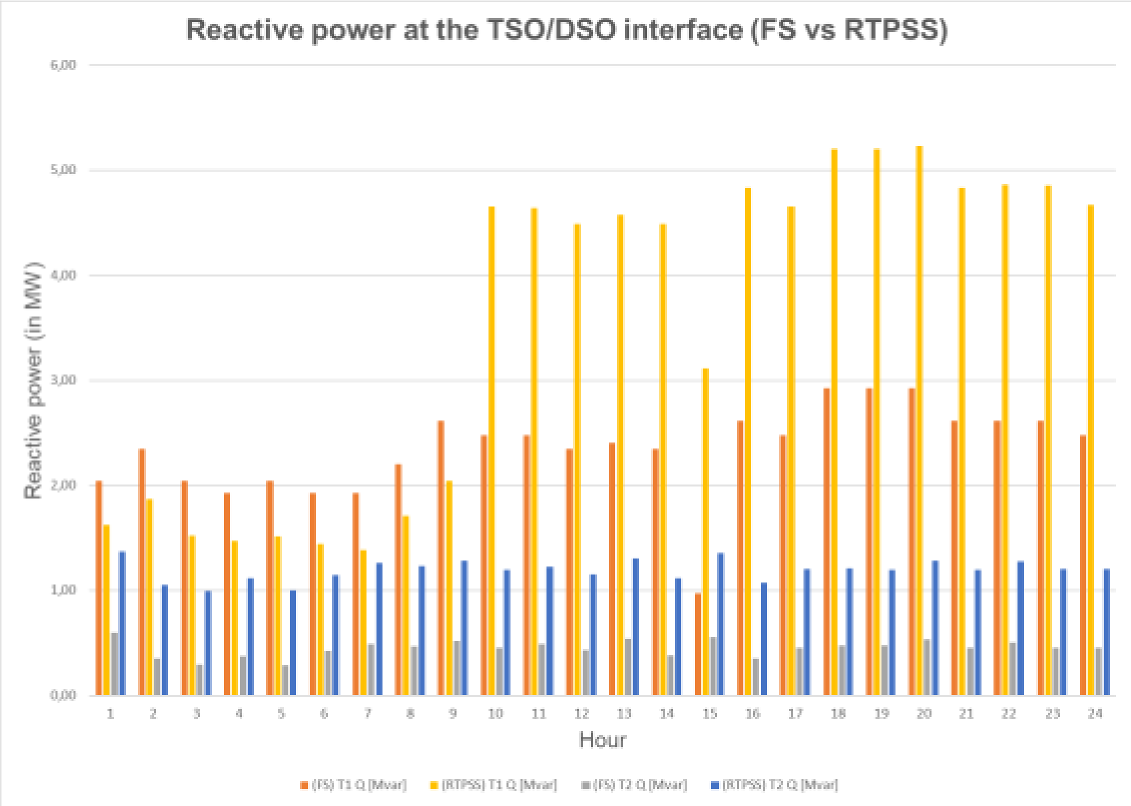


Figure 5-63 – Reactive Power results at TSO/DSO interface for test case 11

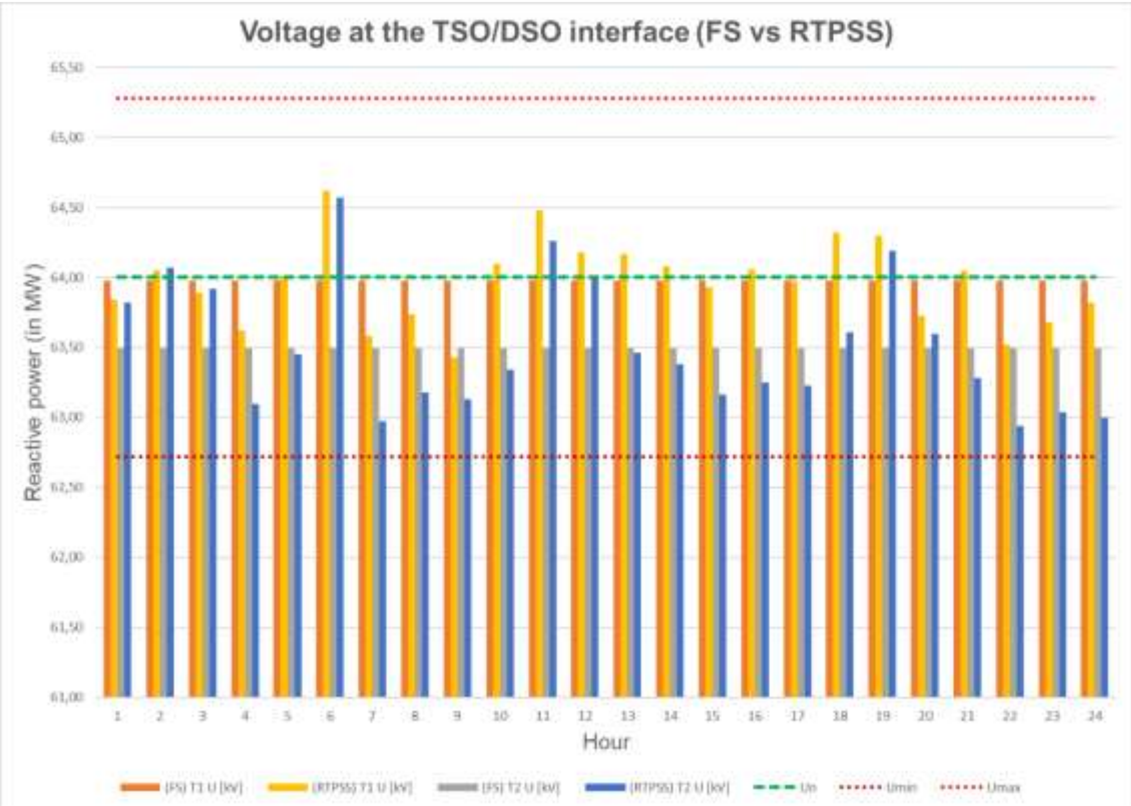


Figure 5-64 – Voltage results at TSO/DSO interface for test case 11

5.2.4.2 Test case 12

This test case corresponds to the optimised power flow solution in which transmission grid assets are considered as an optimisation lever and the optimisation function prioritises the minimisation of grid losses. From Table 5-93 to Table 5-96 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-93 – FS voltage results for test case 12

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen in Table 5-93, the FS results from test case 12 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-94 – FS capacitor banks results for test case 12

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	0
3	0	0	30	0
4	0	0	30	0
5	0	0	30	0
6	0	0	30	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	0
12	40	40	30	0
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	0
20	40	40	30	0
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-95 – FS losses results for test case 12

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	385,14	407,21	369,68	409,47	-15,46	2,26
2	376,60	256,69	376,60	256,69	0,00	0,00
3	347,59	105,99	347,59	105,99	0,00	0,00
4	341,19	133,93	341,19	133,93	0,00	0,00
5	347,39	103,18	347,39	103,18	0,00	0,00
6	344,99	185,94	344,99	185,94	0,00	0,00
7	349,60	249,14	349,60	249,14	0,00	0,00
8	371,84	319,68	371,84	319,68	0,00	0,00
9	416,35	536,51	416,35	536,51	0,00	0,00
10	397,17	408,08	397,17	408,08	0,00	0,00
11	400,06	448,12	400,06	448,12	0,00	0,00
12	382,37	336,59	382,37	336,59	0,00	0,00
13	404,33	507,91	404,33	507,91	0,00	0,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
14	378,76	286,63	378,76	286,63	0,00	0,00
15	396,68	543,06	396,68	543,06	0,00	0,00
16	404,08	365,92	404,08	365,92	0,00	0,00
17	397,17	408,08	397,17	408,08	0,00	0,00
18	442,19	603,39	442,19	603,39	0,00	0,00
19	441,74	597,13	441,74	597,13	0,00	0,00
20	446,01	656,65	446,01	656,65	0,00	0,00
21	411,45	468,54	411,45	468,54	0,00	0,00
22	415,25	521,28	415,25	521,28	0,00	0,00
23	411,45	468,54	411,45	468,54	0,00	0,00
24	397,17	408,08	397,17	408,08	0,00	0,00
				TOTAL VARIATION	**-15,46**	**2,26**

Table 5-96 – FS objective function fitness for test case 12

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6032,4	134,2	-5898,2
2	109,8	109,7	-0,1
3	107	107	0
4	114,5	114,5	0
5	106,8	106,7	-0,1
6	119,1	119,1	0
7	124,8	124,8	0
8	120,8	120,8	0
9	123,2	123,2	0
10	117,5	117,5	0
11	121,1	121,1	0
12	116,8	116,8	0
13	126,5	126,4	-0,1
14	112,4	112,4	0
15	136	135,9	-0,1
16	108,1	108,1	0
17	117,5	117,5	0
18	117	117	0
19	116,4	116,4	0
20	121,7	121,6	-0,1
21	117,1	117,1	0
22	121,8	121,8	0
23	117,1	117,1	0
24	117,5	117,5	0
Global	**8743**	**2844**	**-5899**

In this test case, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-97 – FS final results for test case 12 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,95	2,04	63,98	-17,68	0,60	63,49
2	27,95	2,35	63,98	-15,00	0,35	63,49
3	25,95	2,04	63,98	-14,73	0,29	63,49
4	24,94	1,92	63,98	-15,63	0,37	63,49
5	25,95	2,04	63,98	-14,70	0,29	63,49
6	24,94	1,92	63,98	-16,15	0,42	63,49
7	24,94	1,92	63,98	-16,76	0,49	63,49
8	26,94	2,20	63,98	-16,27	0,47	63,49
9	29,97	2,62	63,98	-16,45	0,52	63,49
10	28,97	2,48	63,98	-15,86	0,45	63,49
11	28,97	2,48	63,98	-16,25	0,49	63,49
12	27,95	2,35	63,98	-15,81	0,43	63,49
13	28,97	2,40	63,98	-16,82	0,54	63,49
14	27,95	2,35	63,98	-15,31	0,38	63,49
15	27,95	0,97	63,98	-17,80	0,55	63,49
16	29,97	2,62	63,98	-14,75	0,35	63,49
17	28,97	2,48	63,98	-15,86	0,45	63,49
18	31,98	2,92	63,98	-15,71	0,48	63,49
19	31,98	2,92	63,98	-15,65	0,47	63,49
20	31,98	2,92	63,98	-16,23	0,53	63,49
21	29,97	2,62	63,98	-15,79	0,45	63,49
22	29,97	2,62	63,98	-16,30	0,51	63,49
23	29,97	2,62	63,98	-15,79	0,45	63,49
24	28,97	2,48	63,98	-15,86	0,45	63,49

Table 5-98 – RTPSS final results for test case 12 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	26,11	1,62	63,84	-17,67	1,37	63,82
2	28,14	1,87	64,05	-14,99	1,05	64,07
3	26,11	1,52	63,89	-14,71	0,99	63,92
4	25,09	1,47	63,62	-15,62	1,11	63,10
5	26,11	1,51	64,01	-14,69	1,00	63,45
6	25,09	1,44	64,62	-16,14	1,14	64,57
7	25,10	1,38	63,58	-16,75	1,26	62,97
8	27,12	1,71	63,74	-16,26	1,23	63,18
9	30,20	2,04	63,43	-16,44	1,28	63,13
10	29,17	1,97	63,40	-15,85	1,19	63,34
11	29,17	1,95	63,78	-16,24	1,22	64,26
12	28,15	1,80	63,48	-15,80	1,15	64,01
13	29,17	1,89	63,47	-16,81	1,30	63,46
14	28,15	1,80	63,40	-15,30	1,11	63,38
15	28,14	0,93	63,24	-17,79	1,35	63,16
16	30,20	2,04	63,38	-14,74	1,07	63,25
17	29,18	1,97	63,29	-15,85	1,20	63,23
18	32,23	2,31	63,64	-15,70	1,21	63,61
19	32,23	2,31	63,63	-15,64	1,19	64,19
20	32,25	2,34	63,07	-16,22	1,28	63,60
21	30,19	2,04	63,39	-15,78	1,19	63,28
22	30,20	2,07	62,86	-16,29	1,27	62,94
23	30,20	2,06	63,02	-15,78	1,20	63,04
24	29,18	1,98	63,16	-15,85	1,20	63,00

Table 5-99 – Comparison between FS and RTPSS final results for test case 12 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,27	8,44	0,17	2,64	2,99	0,35	-0,14	0,33
2	12,95	13,15	0,20	2,70	2,92	0,22	0,07	0,58
3	11,22	11,40	0,18	2,34	2,51	0,17	-0,09	0,43
4	9,31	9,47	0,16	2,29	2,58	0,29	-0,36	-0,39
5	11,25	11,42	0,17	2,33	2,51	0,18	0,03	-0,04
6	8,79	8,95	0,16	2,35	2,58	0,23	0,64	1,08
7	8,19	8,35	0,16	2,41	2,64	0,23	-0,40	-0,52
8	10,67	10,86	0,19	2,67	2,94	0,27	-0,24	-0,31
9	13,53	13,76	0,23	3,14	3,32	0,18	-0,55	-0,36
10	13,11	13,32	0,21	2,93	3,16	0,23	-0,58	-0,15
11	12,72	12,93	0,21	2,97	3,17	0,20	-0,20	0,77
12	12,14	12,35	0,21	2,78	2,95	0,17	-0,50	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	12,15	12,36	0,21	2,95	3,19	0,24	-0,51	-0,03
14	12,64	12,85	0,21	2,73	2,91	0,18	-0,58	-0,11
15	10,15	10,35	0,20	1,52	2,28	0,76	-0,74	-0,33
16	15,22	15,46	0,24	2,97	3,11	0,14	-0,60	-0,24
17	13,11	13,33	0,22	2,93	3,17	0,24	-0,69	-0,26
18	16,27	16,53	0,26	3,40	3,52	0,12	-0,34	0,12
19	16,33	16,59	0,26	3,40	3,50	0,10	-0,35	0,70
20	15,76	16,03	0,28	3,46	3,62	0,16	-0,91	0,11
21	14,18	14,41	0,23	3,07	3,23	0,16	-0,59	-0,21
22	13,67	13,91	0,24	3,12	3,34	0,22	-1,12	-0,55
23	14,18	14,42	0,24	3,07	3,26	0,19	-0,96	-0,45
24	13,11	13,33	0,22	2,93	3,18	0,25	-0,82	-0,49

Table 5-99 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,16; 0,28]MW, [0,10; 0,76]Mvar, [-1,12; 0,64]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-62 to Figure 5-64 depicts the comparison of the results for test case 12.

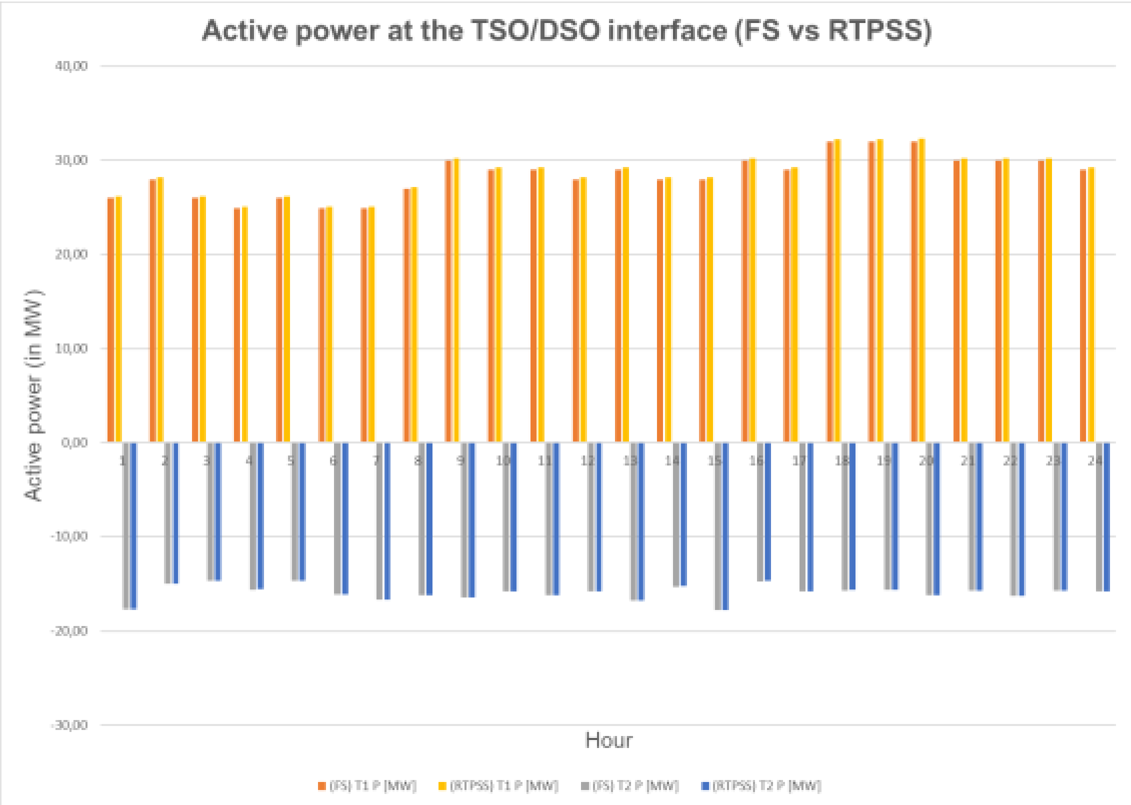


Figure 5-65 – Active Power results at TSO/DSO interface for test case 12

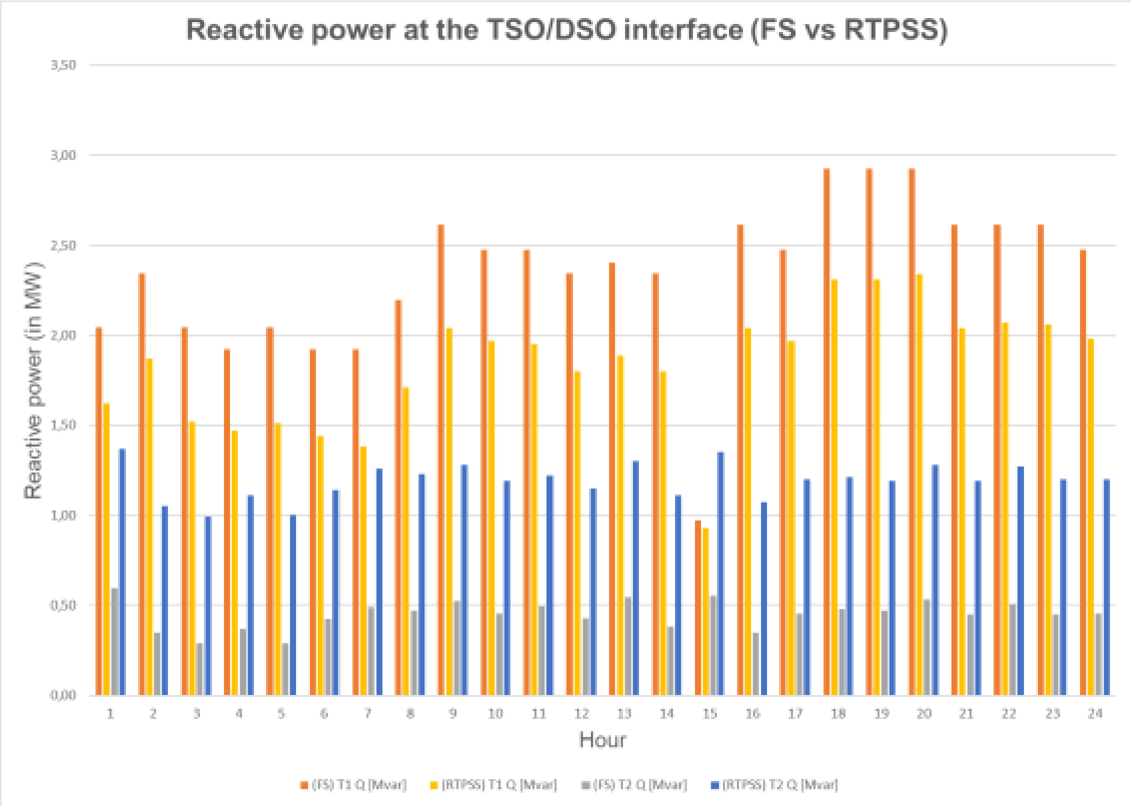


Figure 5-66 – Reactive Power results at TSO/DSO interface for test case 12

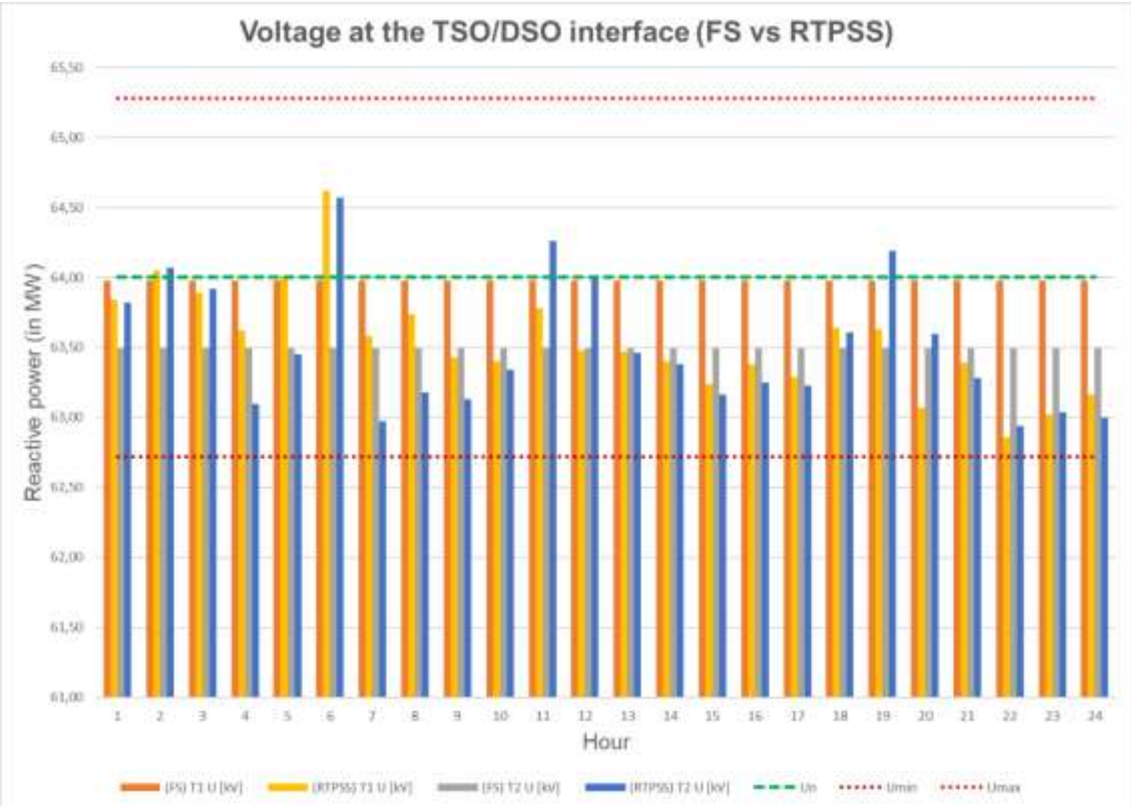


Figure 5-67 – Voltage results at TSO/DSO interface for test case 12

5.2.4.3 Test case 15

This test case corresponds to the optimised power flow solution in which transmission grid assets are not considered as an optimisation lever and the optimisation function prioritises the minimisation of costs. From Table 5-100 to Table 5-103 the results from the Flexibility Scheduler (FS) optimisation are provided.

Flexibility Scheduler (FS) results

Table 5-100 – FS voltage results for test case 15

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen in Table 5-100, the FS results from test case 15 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-101 – FS capacitor banks results for test case 15

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	40	0	0
11	40	40	30	30
12	40	40	30	30
13	40	40	0	0
14	40	40	0	0
15	40	40	0	0
16	40	40	0	0
17	40	40	0	0
18	40	40	0	0
19	40	40	30	30
20	40	40	30	30
21	40	40	0	0
22	40	40	0	0
23	40	40	0	0
24	40	40	0	0

As expected, the FS tool kept the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2), as these assets were not available for the optimisation in this test case.

Table 5-102 – FS losses results for test case 15

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	385,14	407,21	369,68	409,47	-15,46	2,26
2	532,34	3787,18	376,60	256,69	-155,74	-3530,49
3	503,13	3637,57	503,13	3637,57	0,00	0,00
4	496,64	3666,07	496,64	3666,07	0,00	0,00
5	502,92	3634,77	502,92	3634,77	0,00	0,00
6	500,43	3718,08	500,43	3718,08	0,00	0,00
7	505,05	3781,27	505,05	3781,27	0,00	0,00
8	527,48	3850,73	527,48	3850,73	0,00	0,00
9	572,28	4065,91	536,53	3209,33	-35,75	-856,58
10	517,27	3081,34	553,00	3938,02	35,73	856,68
11	555,89	3978,06	555,89	3978,06	0,00	0,00
12	538,11	3867,09	538,11	3867,09	0,00	0,00

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
13	560,12	4037,86	560,12	4037,86	0,00	0,00
14	534,50	3817,13	534,50	3817,13	0,00	0,00
15	551,62	4073,55	551,62	4073,55	0,00	0,00
16	560,01	3895,32	560,01	3895,32	0,00	0,00
17	553,00	3938,02	553,00	3938,02	0,00	0,00
18	598,34	4131,70	598,34	4131,70	0,00	0,00
19	597,89	4125,44	597,89	4125,44	0,00	0,00
20	602,16	4184,97	602,16	4184,97	0,00	0,00
21	567,38	3997,94	567,38	3997,94	0,00	0,00
22	571,19	4050,68	571,19	4050,68	0,00	0,00
23	567,38	3997,94	567,38	3997,94	0,00	0,00
24	553,00	3938,02	553,00	3938,02	0,00	0,00
				TOTAL VARIATION	**-171,23**	**-3528,13**

Table 5-103 – FS objective function fitness for test case 15

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6038,7	140,3	-5898,4
2	115	114,9	-0,1
3	112,1	112	-0,1
4	119,9	119,8	-0,1
5	111,8	111,7	-0,1
6	124,7	124,6	-0,1
7	130,6	130,5	-0,1
8	126,4	126,4	0
9	128,9	128,8	-0,1
10	123	123	0
11	126,8	126,7	-0,1
12	122,4	122,2	-0,2
13	132,4	132,3	-0,1
14	117,7	117,6	-0,1
15	142,3	142,1	-0,2
16	113,3	113,2	-0,1
17	123,1	123	-0,1
18	122,5	122,4	-0,1
19	121,9	121,8	-0,1
20	127,4	127,3	-0,1
21	122,7	122,6	-0,1
22	127,6	127,4	-0,2
23	122,7	122,6	-0,1
24	123,1	123	-0,1
Global	**8877**	**2976**	**-5901**

In this test case, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-104 – FS final results for test case 15 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,95	2,04	63,98	-17,68	0,60	63,49
2	27,95	2,35	63,98	-15,00	0,35	63,49
3	26,10	5,58	63,98	-14,73	0,29	63,49
4	25,10	5,45	63,98	-15,63	0,37	63,49
5	26,10	5,58	63,98	-14,70	0,29	63,49
6	25,10	5,45	63,98	-16,15	0,42	63,49
7	25,10	5,45	63,98	-16,76	0,49	63,49
8	27,10	5,73	63,98	-16,27	0,47	63,49
9	30,09	5,29	63,98	-16,45	0,52	63,49
10	29,12	6,01	63,98	-15,86	0,45	63,49
11	29,12	6,01	63,98	-16,25	0,49	63,49
12	28,11	5,88	63,98	-15,81	0,43	63,49
13	29,12	5,93	63,98	-16,82	0,54	63,49
14	28,11	5,88	63,98	-15,31	0,38	63,49
15	28,11	4,50	63,98	-17,80	0,55	63,49
16	30,13	6,15	63,98	-14,75	0,35	63,49
17	29,12	6,01	63,98	-15,86	0,45	63,49
18	32,14	6,45	63,98	-15,71	0,48	63,49
19	32,14	6,45	63,98	-15,65	0,47	63,49
20	32,14	6,45	63,98	-16,23	0,53	63,49
21	30,13	6,15	63,98	-15,79	0,45	63,49
22	30,13	6,15	63,98	-16,30	0,51	63,49
23	30,13	6,15	63,98	-15,79	0,45	63,49
24	29,12	6,01	63,98	-15,86	0,45	63,49

Table 5-105 – RTPSS final results for test case 15 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	26,11	1,62	63,84	-17,67	1,37	63,82
2	28,30	5,52	63,98	-14,99	1,05	64,07
3	26,27	4,96	63,83	-14,71	0,99	63,92
4	25,09	1,27	63,62	-15,62	1,11	63,10
5	26,27	5,06	63,94	-14,69	1,00	63,45
6	25,24	4,99	64,56	-16,14	1,14	64,57
7	25,25	5,02	63,52	-16,75	1,26	62,97
8	27,28	5,25	63,67	-16,26	1,23	63,18
9	30,35	5,39	63,37	-16,44	1,28	63,13
10	29,34	8,21	64,04	-15,85	1,19	63,34
11	29,34	8,19	64,42	-16,24	1,22	64,26
12	28,31	8,04	64,11	-15,80	1,15	64,01
13	29,33	8,14	64,10	-16,81	1,30	63,46
14	28,31	8,05	64,02	-15,30	1,11	63,38
15	28,31	6,67	63,86	-17,79	1,35	63,16
16	30,36	8,39	64,00	-14,74	1,07	63,25
17	29,34	8,22	63,90	-15,85	1,20	63,23
18	32,40	8,76	64,25	-15,70	1,21	63,61
19	32,40	8,76	64,23	-15,64	1,19	64,19
20	32,41	8,79	63,67	-16,22	1,28	63,60
21	30,36	8,39	63,99	-15,78	1,19	63,28
22	30,37	8,41	63,45	-16,29	1,27	62,94
23	30,36	8,41	63,62	-15,78	1,20	63,04
24	29,34	8,22	63,76	-15,85	1,20	63,00

Table 5-106 – Comparison between FS and RTPSS final results for test case 15 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,27	8,44	0,17	2,64	2,99	0,35	-0,14	0,33
2	12,95	13,31	0,36	2,70	6,57	3,87	0,00	0,58
3	11,38	11,56	0,18	5,87	5,95	0,08	-0,15	0,43
4	9,47	9,47	0,00	5,83	2,38	-3,45	-0,36	-0,39
5	11,41	11,58	0,17	5,86	6,06	0,20	-0,04	-0,04
6	8,95	9,10	0,15	5,88	6,13	0,25	0,58	1,08
7	8,34	8,50	0,16	5,94	6,28	0,34	-0,46	-0,52
8	10,82	11,02	0,20	6,20	6,48	0,28	-0,31	-0,31
9	13,65	13,91	0,26	5,81	6,67	0,86	-0,61	-0,36
10	13,26	13,49	0,23	6,46	9,40	2,94	0,06	-0,15
11	12,87	13,10	0,23	6,50	9,41	2,91	0,44	0,77
12	12,30	12,51	0,21	6,31	9,19	2,88	0,13	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	12,30	12,52	0,22	6,48	9,44	2,96	0,12	-0,03
14	12,80	13,01	0,21	6,26	9,16	2,90	0,04	-0,11
15	10,31	10,52	0,21	5,05	8,02	2,97	-0,12	-0,33
16	15,38	15,62	0,24	6,50	9,46	2,96	0,02	-0,24
17	13,26	13,49	0,23	6,46	9,42	2,96	-0,08	-0,26
18	16,43	16,70	0,27	6,93	9,97	3,04	0,27	0,12
19	16,49	16,76	0,27	6,93	9,95	3,02	0,25	0,70
20	15,91	16,19	0,28	6,98	10,07	3,09	-0,31	0,11
21	14,34	14,58	0,24	6,60	9,58	2,98	0,01	-0,21
22	13,83	14,08	0,25	6,65	9,68	3,03	-0,53	-0,55
23	14,34	14,58	0,24	6,60	9,61	3,01	-0,36	-0,45
24	13,26	13,49	0,23	6,46	9,42	2,96	-0,22	-0,49

Table 5-106 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,00; 0,36]MW, [-3,45; 3,87]Mvar, [-0,61; 0,58]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-68 to Figure 5-70 depicts the comparison of the results for test case 15.

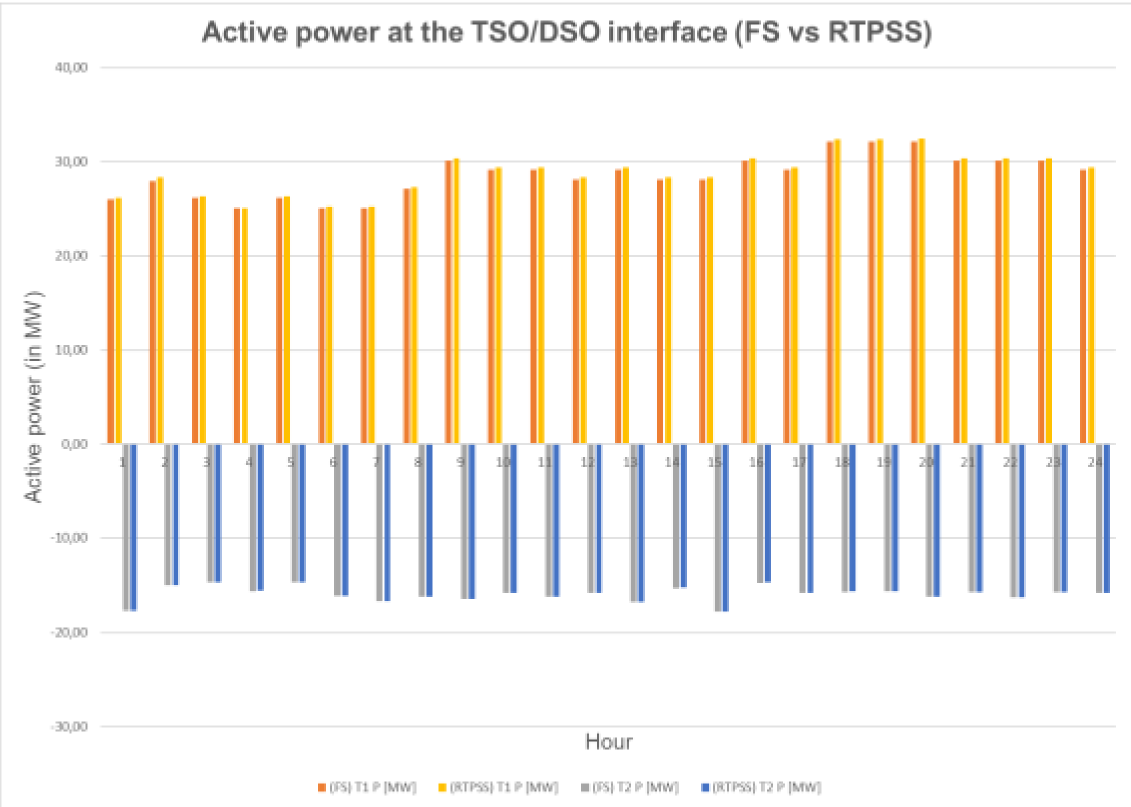


Figure 5-68 – Active Power results at TSO/DSO interface for test case 15

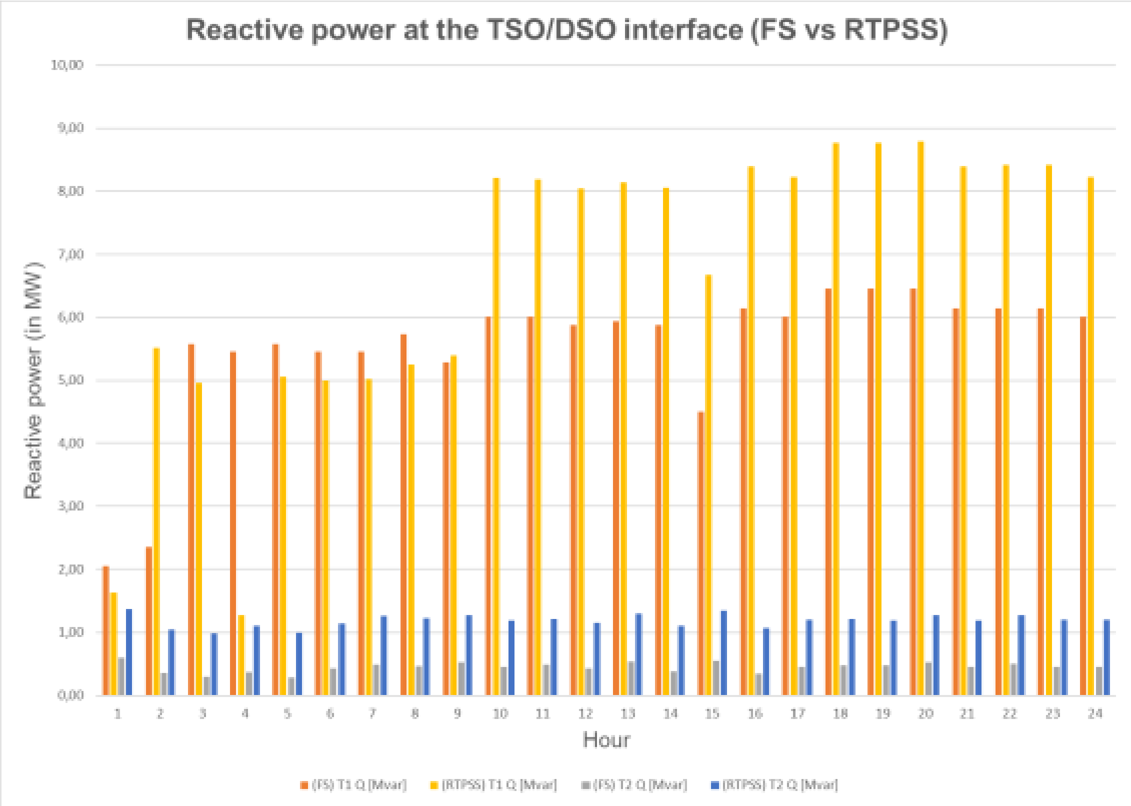


Figure 5-69 – Reactive Power results at TSO/DSO interface for test case 15

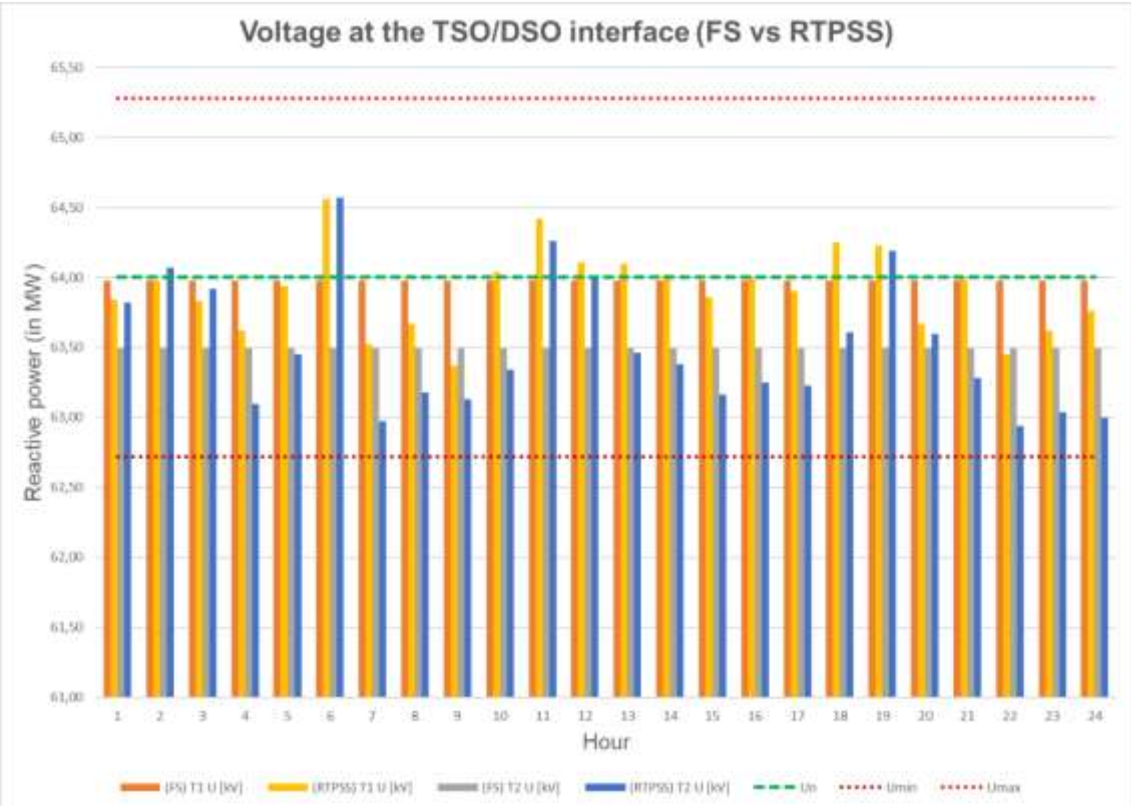


Figure 5-70 – Voltage results at TSO/DSO interface for test case 15

5.2.4.4 Test case 16

This test case corresponds to the optimised power flow solution in which transmission grid assets are considered as an optimisation lever and the optimisation function prioritises the minimisation of costs. From Table 5-107 to Table 5-110 the results from the Flexibility Scheduler (FS) optimisation are provided.

In this test case, the optimisation results showed a decrease of the overall losses of the system. Furthermore, the voltage limits at the TSO/DSO interfaces were maintained within the acceptable range and the fitness of the objective function of the FS tool was reduced, as expected.

Validation of the FS results with RTPSS

Next, a comparison between the simulation results of the FS tool and the results from the validation process with the RTPSS. The compsarion of results is made and presented in the following tables and figures.

Table 5-107 – FS voltage results for test case 16

Hour	T1 Initial [kV]	T1 Final [kV]	T2 Initial [kV]	T2 Final [kV]
1	63,98	63,98	63,49	63,49
2	63,98	63,98	63,49	63,49
3	63,98	63,98	63,49	63,49
4	63,98	63,98	63,49	63,49
5	63,98	63,98	63,49	63,49
6	63,98	63,98	63,49	63,49
7	63,98	63,98	63,49	63,49
8	63,98	63,98	63,49	63,49
9	63,98	63,98	63,49	63,49
10	63,98	63,98	63,49	63,49
11	63,98	63,98	63,49	63,49
12	63,98	63,98	63,49	63,49
13	63,98	63,98	63,49	63,49
14	63,98	63,98	63,49	63,49
15	63,98	63,98	63,49	63,49
16	63,98	63,98	63,49	63,49
17	63,98	63,98	63,49	63,49
18	63,98	63,98	63,49	63,49
19	63,98	63,98	63,49	63,49
20	63,98	63,98	63,49	63,49
21	63,98	63,98	63,49	63,49
22	63,98	63,98	63,49	63,49
23	63,98	63,98	63,49	63,49
24	63,98	63,98	63,49	63,49

As can be seen inTable 5-107, the FS results from test case 16 show that the voltage stays within the acceptable range [64kV±2%] for both substations. In fact, it remains constant over the simulation period.

Table 5-108 – FS capacitor banks results for test case 16

Hour	T1 Initial [Mvar]	T1 Final [Mvar]	T2 Initial [Mvar]	T2 Final [Mvar]
1	0	0	30	30
2	0	0	30	30
3	0	0	30	30
4	0	0	30	30
5	0	0	30	30
6	0	0	30	30
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	40	0	0	0
11	40	0	30	30
12	40	0	30	30
13	40	0	0	0
14	40	0	0	0
15	40	0	0	0
16	40	0	0	0
17	40	0	0	0
18	40	0	0	0
19	40	0	30	30
20	40	0	30	30
21	40	0	0	0
22	40	0	0	0
23	40	0	0	0
24	40	0	0	0

In this test case the FS tool changed the original plan for the transmission network assets (i.e. capacitor banks at T1 and T2.

Table 5-109 – FS losses results for test case 16

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
1	385,14	407,21	369,68	409,47	-15,46	2,26
2	532,34	3787,18	376,60	256,69	-155,74	-3530,49
3	503,13	3637,57	503,13	3637,57	0,00	0,00
4	496,64	3666,07	496,64	3666,07	0,00	0,00
5	502,92	3634,77	502,92	3634,77	0,00	0,00
6	500,43	3718,08	500,43	3718,08	0,00	0,00
7	505,05	3781,27	505,05	3781,27	0,00	0,00
8	527,48	3850,73	527,48	3850,73	0,00	0,00
9	572,28	4065,91	536,53	3209,33	-35,75	-856,58

Hour	InitTotPowLoss Real (kW)	InitTotPowLoss Imag (kvar)	TotPowLoss Real (kW)	TotPowLoss Imag (kvar)	Variation Ploss (kW)	Variation Qloss (kvar)
10	517,27	3081,34	553,00	3938,02	35,73	856,68
11	555,89	3978,06	555,89	3978,06	0,00	0,00
12	538,11	3867,09	397,44	454,87	-140,67	-3412,22
13	570,56	4176,40	404,33	507,91	-166,24	-3668,49
14	534,50	3817,13	378,76	286,63	-155,74	-3530,50
15	551,62	4073,55	551,62	4073,55	0,00	0,00
16	560,01	3895,32	560,65	3926,83	0,64	31,51
17	553,97	3970,94	553,00	3938,02	-0,97	-32,92
18	598,34	4131,70	460,13	699,32	-138,21	-3432,38
19	611,15	4220,91	441,74	597,13	-169,41	-3623,79
20	602,16	4184,97	602,16	4184,97	0,00	0,00
21	567,38	3997,94	567,38	3997,94	0,00	0,00
22	571,19	4050,68	571,19	4050,68	0,00	0,00
23	567,38	3997,94	567,38	3997,94	0,00	0,00
24	553,00	3938,02	553,00	3938,02	0,00	0,00
				TOTAL VARIATION	**-941,82**	**-21196,91**

Table 5-110 – FS objective function fitness for test case 16

Hour	dInitObjFunc	dFinalObjFunc	Variation
1	6038,8	140,3	-5898,5
2	115	114,9	-0,1
3	112,1	112	-0,1
4	119,9	119,8	-0,1
5	111,8	111,7	-0,1
6	124,7	124,6	-0,1
7	130,6	130,5	-0,1
8	126,4	126,4	0
9	128,9	128,8	-0,1
10	123	123	0
11	126,8	126,7	-0,1
12	122,3	122,2	-0,1
13	132,3	132,3	0
14	117,7	117,6	-0,1
15	142,2	142,1	-0,1
16	113,3	113,2	-0,1
17	123	123	0
18	122,4	122,4	0
19	121,9	121,8	-0,1
20	127,3	127,3	0
21	122,6	122,6	0
22	127,5	127,4	-0,1

Hour	dInitObjFunc	dFinalObjFunc	Variation
23	122,6	122,6	0
24	123	123	0
Global	**8876**	**2976**	**-5900**

Validation of the FS results with RTPSS

Table 5-111 – FS final results for test case 16 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	25,95	2,04	63,98	-17,68	0,60	63,49
2	27,95	2,35	63,98	-15,00	0,35	63,49
3	26,10	5,58	63,98	-14,73	0,29	63,49
4	25,10	5,45	63,98	-15,63	0,37	63,49
5	26,10	5,58	63,98	-14,70	0,29	63,49
6	25,10	5,45	63,98	-16,15	0,42	63,49
7	25,10	5,45	63,98	-16,76	0,49	63,49
8	27,10	5,73	63,98	-16,27	0,47	63,49
9	30,09	5,29	63,98	-16,45	0,52	63,49
10	29,12	6,01	63,98	-15,86	0,45	63,49
11	29,12	6,01	63,98	-16,25	0,49	63,49
12	27,97	-9,46	63,98	-15,81	0,43	63,49
13	28,97	2,40	63,98	-16,82	0,54	63,49
14	27,95	2,35	63,98	-15,31	0,38	63,49
15	28,11	4,50	63,98	-17,80	0,55	63,49
16	30,13	2,29	63,98	-14,75	0,35	63,49
17	29,12	6,01	63,98	-15,86	0,45	63,49
18	32,00	-4,84	63,98	-15,71	0,48	63,49
19	31,98	2,92	63,98	-15,65	0,47	63,49
20	32,14	6,45	63,98	-16,23	0,53	63,49
21	30,13	6,15	63,98	-15,79	0,45	63,49
22	30,13	6,15	63,98	-16,30	0,51	63,49
23	30,13	6,15	63,98	-15,79	0,45	63,49
24	29,12	6,01	63,98	-15,86	0,45	63,49

Table 5-112 – RTPSS final results for test case 16 at TSO-DSO interface

Hour	T1 P [MW]	T1 Q [Mvar]	T1 U [kV]	T2 P [MW]	T2 Q [Mvar]	T2 U [kV]
1	26,11	1,62	63,84	-17,67	1,37	63,82
2	28,30	5,52	63,98	-14,99	1,05	64,07
3	26,27	4,96	63,83	-14,71	0,99	63,92
4	25,09	1,27	63,62	-15,62	1,11	63,10
5	26,27	5,06	63,94	-14,69	1,00	63,45
6	25,24	4,99	64,56	-16,14	1,14	64,57
7	25,25	5,02	63,52	-16,75	1,26	62,97
8	27,28	5,25	63,67	-16,26	1,23	63,18
9	30,35	5,39	63,37	-16,44	1,28	63,13
10	29,34	5,51	63,34	-15,85	1,19	63,34
11	29,23	-13,46	64,06	-16,24	1,22	64,26
12	28,17	-9,99	63,69	-15,80	1,15	64,01
13	29,18	-1,78	63,54	-16,81	1,30	63,46
14	28,15	-1,97	63,47	-15,30	1,11	63,38
15	28,14	0,93	63,24	-17,79	1,35	63,16
16	30,20	-6,15	63,53	-14,74	1,07	63,25
17	29,34	5,52	63,22	-15,85	1,20	63,23
18	32,40	5,86	63,58	-15,70	1,21	63,61
19	32,24	2,21	63,64	-15,64	1,19	64,19
20	32,25	2,34	63,07	-16,22	1,28	63,60
21	30,20	2,55	63,38	-15,78	1,19	63,28
22	30,36	5,62	62,80	-16,29	1,27	62,94
23	30,36	5,61	62,96	-15,78	1,20	63,04
24	29,34	5,52	63,10	-15,85	1,20	63,00

Table 5-113 – Comparison between FS and RTPSS final results for test case 16 at TSO-DSO interface

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
1	8,27	8,44	0,17	2,64	2,99	0,35	-0,14	0,33
2	12,95	13,31	0,36	2,70	6,57	3,87	0,00	0,58
3	11,38	11,56	0,18	5,87	5,95	0,08	-0,15	0,43
4	9,47	9,47	0,00	5,83	2,38	-3,45	-0,36	-0,39
5	11,41	11,58	0,17	5,86	6,06	0,20	-0,04	-0,04
6	8,95	9,10	0,15	5,88	6,13	0,25	0,58	1,08
7	8,34	8,50	0,16	5,94	6,28	0,34	-0,46	-0,52
8	10,82	11,02	0,20	6,20	6,48	0,28	-0,31	-0,31
9	13,65	13,91	0,26	5,81	6,67	0,86	-0,61	-0,36
10	13,26	13,49	0,23	6,46	6,70	0,24	-0,64	-0,15
11	12,87	12,99	0,12	6,50	-12,24	-18,74	0,08	0,77
12	12,16	12,37	0,21	-9,03	-8,84	0,19	-0,29	0,52

Hour	FS (P) [MW]	RTPSS (P) [MW]	VARIATION (P) [MW]	FS (Q) [Mvar]	RTPSS (Q) [Mvar]	VARIATION (Q) [Mvar]	VARIATION (U) T1 [kV]	VARIATION (U) T2 [kV]
13	12,15	12,37	0,22	2,95	-0,48	-3,43	-0,44	-0,03
14	12,64	12,85	0,21	2,73	-0,86	-3,59	-0,51	-0,11
15	10,31	10,35	0,04	5,05	2,28	-2,77	-0,74	-0,33
16	15,38	15,46	0,08	2,64	-5,08	-7,72	-0,45	-0,24
17	13,26	13,49	0,23	6,46	6,72	0,26	-0,76	-0,26
18	16,29	16,70	0,41	-4,36	7,07	11,43	-0,40	0,12
19	16,33	16,60	0,27	3,40	3,40	0,00	-0,34	0,70
20	15,91	16,03	0,12	6,98	3,62	-3,36	-0,91	0,11
21	14,34	14,42	0,08	6,60	3,74	-2,86	-0,60	-0,21
22	13,83	14,07	0,24	6,65	6,89	0,24	-1,18	-0,55
23	14,34	14,58	0,24	6,60	6,81	0,21	-1,02	-0,45
24	13,26	13,49	0,23	6,46	6,72	0,26	-0,88	-0,49

Table 5-113 shows the comparison between the simulation results from FS tool and the RTPSS simulator. The variations are withing the range [0,00; 0,41]MW, [-18,74; 11,43]Mvar, [-1,18; 0,58]kV for T1 and [-0,55; 1,08]kV for T2. No out-of-limit voltage was detected in the RTPSS simulation. Figure 5-71 to Figure 5-73 depicts the comparison of the results for test case 15.

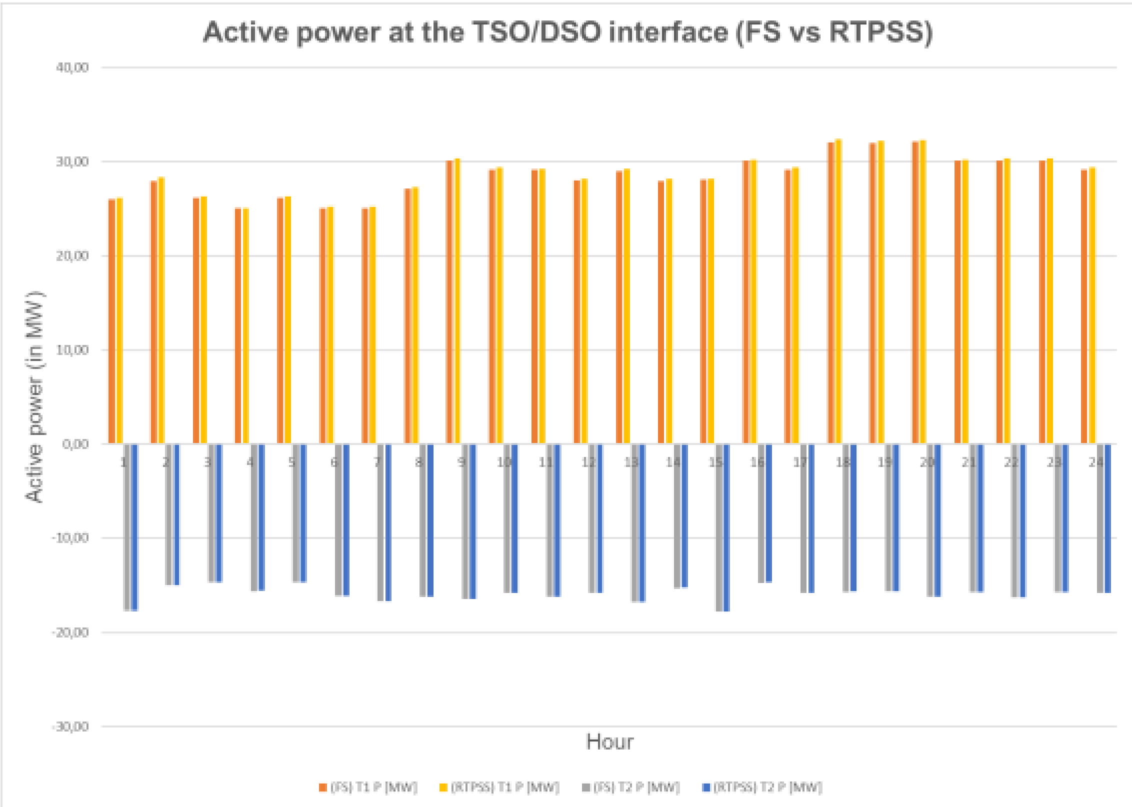


Figure 5-71 – Active Power results at TSO/DSO interface for test case 16

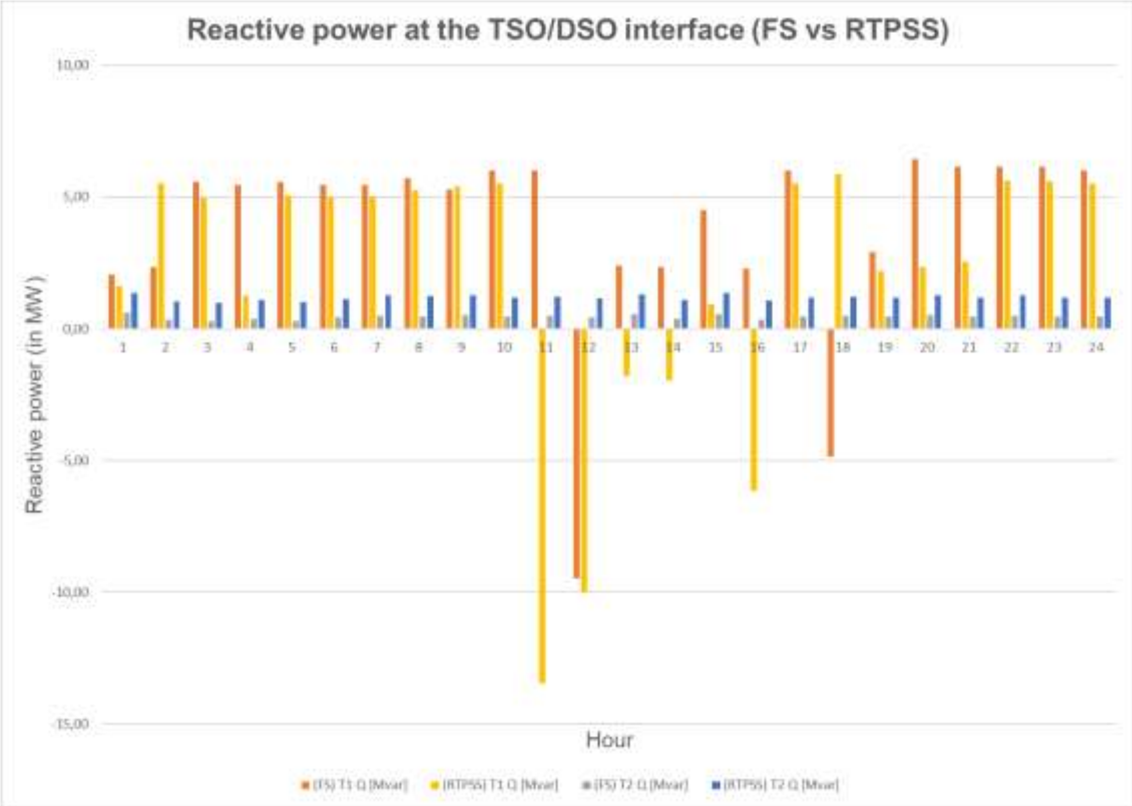


Figure 5-72 – Reactive Power results at TSO/DSO interface for test case 16

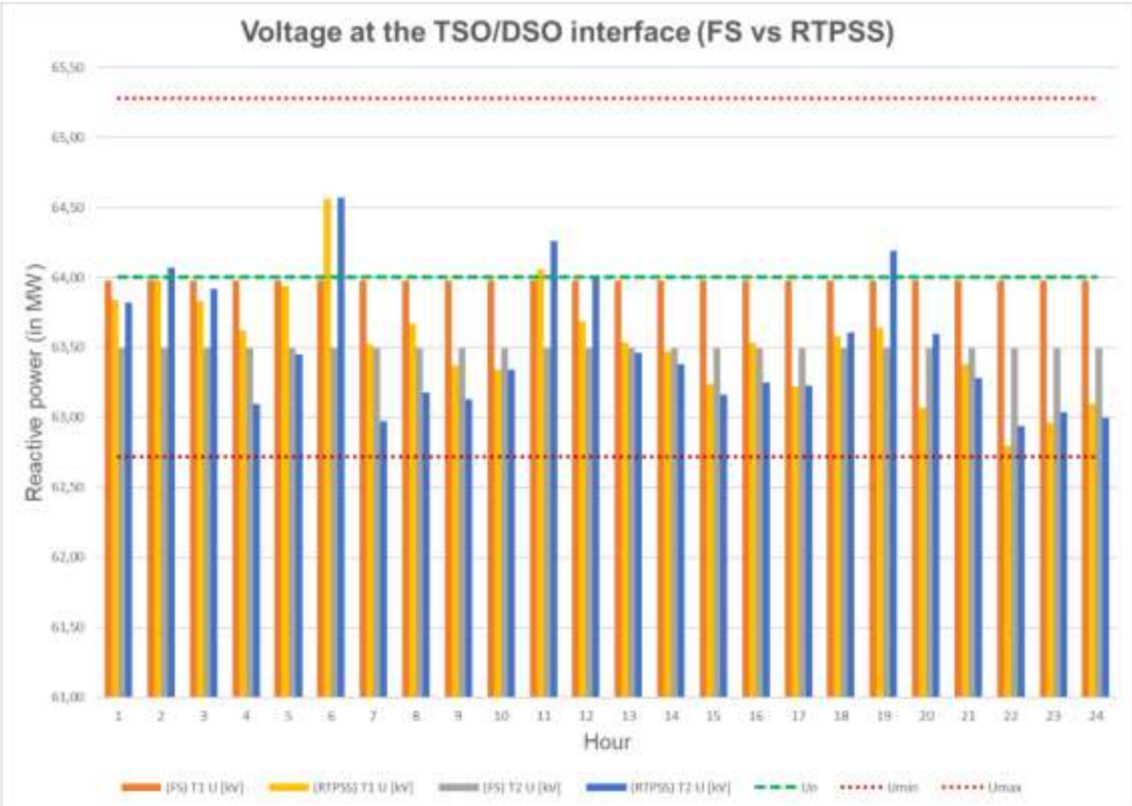


Figure 5-73 – Voltage results at TSO/DSO interface for test case 16

In face of the results for all test cases, it was not found any significant divergence in terms of the voltage and power flows from the transmission substation to/from the distribution grid that could compromise the validity of the solutions.

In all the test cases simulated, the results of validation process with the RTPSS about the solutions (i.e. operation schedule) provided by the FS tool resulted in a feasible solution from the TSO perspective, not violating the admissible voltage range at the TSO-DSO interface.

5.3 Resume and remarks

In total, 16 test cases were simulated and validated. The simulation focused on the reactive power optimisation in the distribution network considering the conditions established in the various scenarios defined.

The testing procedure followed the sequence diagram described in the previous section.

Table 5-114 presents a resume of the simulation results' validation in both platforms (FS tool and RTPSS).

Table 5-114 – Resume of simulation results

Test Case	FS tool – Voltage within the limits at the TSO-DSO interface	Losses (FS tool)	Objective function fitness (FS tool)	RTPSS – Voltage within the limits at the TSO-DSO interface – validation of FS tool results
1	YES	↗	↘	YES
2	YES	↘	↘	YES
3	YES	↘	↘	YES
4	YES	↘	↘	YES
5	YES	↘	↘	YES
6	YES	↘	↘	YES
7	NO*	↘	↘	YES
8	YES	↘	↘	YES
9	YES	↘	↘	YES
10	YES	↘	↘	YES
11	YES	↘	↘	YES
12	YES	↘	↘	YES
13	YES	↘	↘	YES
14	YES	↘	↘	YES
15	YES	↘	↘	YES
16	YES	↘	↘	YES

* Although the voltage limit was not respected, the values are marginally away from the minimum value (deviation <0,05kV).

As can be seen in the table above, in almost all test cases the resulting operational schedule from the FS tool lead to the maintenance of the voltage at the TSO-DSO interface (DSO observability area) within the acceptable limits. The only exception was test case 7 in which some values were slighltly below the limit, but just marginally (<0,05 kV). Similarly, the losses and the objective function fitness (i.e. costs) were reduced in almost all test cases, with exeption of one case, in which the losses increased as result of the restriction of the control variables.

The solutions found by the Flexibility Scheduler include the redschedule of capacitor banks at both transmission and distribution substations as well as tap positions of distribution power transformers and generator's reactive redispatch. In average, the reactive losses reduction for the 16 test cases was around 8,5 Mvar. Similarly, the reactive activation cost were reduced in 1/3 in average.

6 Conclusions and key takeaways

This section presents the main conclusions and key takeaways from this deliverable, related to T7.2 activities. The key findings are gathered and highlighted.

This deliverable provides an overview on the work developed on the TSO-DSO cooperation for the coordinated and optimal use of flexibilities, including a characterization of the flexibilities sources available in the energy system and the innovative coordination processes for joint operation of DFRs.

The majority of the requirements that are addressed, concerning the harmonization and efficiency of the coordination between TSOs and DSOs, are identified in this report. The transparency of communication and the effort to find synergies between operators are key elements. It is paramount to ensure that the best practices are followed in order to safeguard the liquidity of the flexibility markets.

On the activation of flexibility services, the coordination between stakeholders is imperative because this could generate a negative impact on the grid operation. With a clear data exchange framework, the operators are able to examine if the activation of a flexibility asset does not harm any part of the grid, as for example, causing imbalances in neighbour's grid(s). When the flexibility resource is connected to the distribution network, conflicts of interests may arise. For that reason, it is important to specify a list that defines the prioritization order according with the application of the flexibility service, looking from an overall system benefit perspective.

ENTSO-E and other organizations already provided some guidelines and recommendations to help designing a strengthened TSO-DSO coordination. In addition, the outcomes from some European projects, as TDX-ASSIST, are considered as a reference in this subject.

The set of requirements for flexibility activation and coordination at the operational planning stage were stated in this deliverable. The Flexibility Scheduler (FS) tool was implemented based on these requirements.

The FS tool is mainly a ScOPF that indicates the optimized control of DFRs taking into consideration the needs and constraints of the transmission side. As result, the tool provides to the user the flexibilities that should be activated as well as their set-points, for each hour for the next 24 hours. An overall perspective of the FS tool architecture is provided, including a review of its fundamental requirements.

This deliverable provides a full characterisation of the FS tool and its architecture, including the functional modules and interfaces implemented.

The FS tool is a solution to effectively manage flexibility, framed in different operational time horizons (e.g., real-time operation, operational planning), and to implement optimal reactive power management actions to handle technical challenges (e.g. congestion management and voltage control) in distributed networks considering the impact on the TSO-DSO interface.

The interaction between TSOs and DSOs is the focus of the implementation, based strictly in the efficient management of the reactive power. Despite being technically feasible, the implementation of active power management in the FS is out of the scope of the project, standing as a potential development to address in a future expansion of the FS tool.

Having in mind the needs for the real-time power system simulation (RTPSS) laboratory implementation and for the execution of the demonstration of the FS tool, the related main requirements were presented in this report. The laboratorial setup was described in detail, as well as the network models used in each platform (i.e. FS tool and RTPSS). Addtitionaly, the use case and sequence diagram were presented and described in detail according to IEC62559-2 standard.

Finally, the simulation results from the FS tool demonstration were presented and discussed. In total, 16 test cases were simulated focused on the reactive power optimisation in the distribution network considering the conditions at the TSO-DSO interface and the available assets at transmission level, following the sequence diagram introduced in section 4.

Generally, the resulting operational schedule provided by the FS tool lead to the maintenance of the voltage at the TSO-DSO interface (DSO observability area) within the acceptable limits. Similarly, those solutions lead to the reduction of losses and the objective function fitness (i.e. costs), with exception of one case, in which the losses increased as result of a restriction related to the lack of control variables from the TSO side.

On the other hand, the results of the validation in the RTPSS laboratory, which includes a detailed model of the transmission network and the TSO observability area on the DSO grid, show that all the operational schedules generated by the FS tool resulted in all voltage levels within the acceptable limit of operation.

Moreover, additional opportunities of development for the FS tool were identified and acknowledged by the manufacturer (EFACEC). Namelly, through the integration of the FS tool within ScateX#'s power applications suite. This would allow to further exploit the developments done in this project.

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Annex A – Cluster 1 simulation results

Table A-1 – Starting scenario 1 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,09	2,53	63,85	2,12	0,67	63,81
2	6,87	2,23	64,07	5,06	0,94	64,05
3	6,19	2,03	63,90	4,02	0,90	63,90
4	5,88	4,06	63,60	2,48	-1,13	63,12
5	6,81	4,11	63,98	3,44	-1,17	63,47
6	5,12	2,45	64,62	2,69	0,47	64,56
7	5,49	4,50	63,55	1,62	-1,45	63,00
8	7,00	4,28	63,72	2,36	-1,08	63,19
9	8,81	3,40	63,44	3,17	0,11	63,12
10	8,59	5,21	64,12	2,88	-1,84	63,36
11	7,94	3,31	64,54	3,07	0,04	64,25
12	7,79	3,01	64,23	2,66	0,21	63,99
13	8,02	5,11	64,19	2,44	-1,73	63,49
14	8,14	4,91	64,10	2,76	-1,69	63,40
15	7,42	4,41	63,94	0,92	-2,41	63,20
16	10,02	5,16	64,09	3,31	-1,78	63,28
17	8,74	5,01	63,99	2,52	-1,65	63,25
18	9,97	5,07	64,35	4,50	-1,40	63,63
19	9,41	2,89	64,37	5,25	0,74	64,18
20	9,20	3,09	63,80	4,99	0,62	63,58
21	9,19	5,19	64,07	3,56	-1,72	63,30
22	9,11	4,49	63,55	3,22	-0,98	62,95
23	8,42	4,89	63,71	4,51	-1,40	63,06
24	8,59	5,39	63,84	3,37	-2,00	63,03

Table A-2 – Test case 1 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,06	1,98	63,86	2,27	-0,31	63,83
2	6,85	1,73	64,07	5,20	0,07	64,07
3	6,19	1,60	63,91	4,15	0,20	63,92
4	5,78	3,19	63,61	2,68	-2,79	63,15
5	6,71	3,18	64,00	3,67	-2,96	63,50
6	5,16	2,34	64,62	2,74	0,33	64,56
7	5,38	3,58	63,57	1,83	-3,20	63,03
8	6,92	3,44	63,73	2,56	-2,67	63,22
9	8,80	2,86	63,45	3,33	-0,83	63,14
10	9,22	7,72	64,08	2,42	3,69	63,27
11	7,96	3,04	64,54	3,18	-0,48	64,26
12	7,84	2,88	64,24	2,74	0,03	64,00
13	8,67	7,72	64,14	1,96	4,02	63,39

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
14	8,79	7,57	64,05	2,28	4,20	63,31
15	7,64	5,09	63,92	0,83	-0,85	63,17
16	10,62	7,53	64,04	2,89	3,46	63,19
17	9,37	7,55	63,94	2,05	3,96	63,15
18	10,57	7,44	64,31	4,08	3,80	63,54
19	9,53	3,06	64,36	5,28	1,16	64,17
20	9,35	3,38	63,79	4,99	1,32	63,57
21	9,80	7,61	64,03	3,13	3,63	63,22
22	9,75	7,08	63,51	2,75	4,75	62,86
23	8,72	5,88	63,69	4,36	0,85	63,02
24	8,80	6,00	63,83	3,30	-0,61	63,01

Table A-3 – Test case 1 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	17	0
SE D3&D4 - TRANS 2	TRANS	13	10	0
SE D7 - TRANS 1	TRANS	7	1	0
SE D1 - TRANS 2	TRANS	12	4	0
PP1 - SYNG 1	SYNCGQ	0	1,2	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	14	0
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	18	0
SE D3&D4 - TRANS 2	TRANS	10	3	0
PP1 - SYNG 1	SYNCGQ	0	0,8	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	2,2	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	18	24	0
SE D3&D4 - TRANS 2	TRANS	3	2	0
PP1 - SYNG 1	SYNCGQ	0	2,4	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0

Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	16	0
SE D3&D4 - TRANS 2	TRANS	2	13	0
PP1 - SYNG 1	SYNCGQ	0	2,3	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	16	15	0
SE D3&D4 - TRANS 2	TRANS	13	8	0
PP1 - SYNG 1	SYNCGQ	0	2,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	12	0
SE D3&D4 - TRANS 2	TRANS	8	5	0
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	13	0
SE D3&D4 - TRANS 2	TRANS	5	7	0
PP1 - SYNG 1	SYNCGQ	0	-7,9	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	11	0
SE D3&D4 - TRANS 2	TRANS	7	17	0
PP1 - SYNG 1	SYNCGQ	0	0,6	0
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	11	7	0
SE D3&D4 - TRANS 2	TRANS	17	20	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	7	6	0
SE D3&D4 - TRANS 2	TRANS	20	17	0
PP1 - SYNG 1	SYNCGQ	0	-8,2	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	5	0

SE D3&D4 - TRANS 2	TRANS	17	20	0
PP1 - SYNG 1	SYNCGQ	0	-8,4	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	5	3	0
PP1 - SYNG 1	SYNCGQ	0	-2,4	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	3	7	0
SE D3&D4 - TRANS 2	TRANS	20	14	0
PP1 - SYNG 1	SYNCGQ	0	-7,5	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	7	11	0
SE D3&D4 - TRANS 2	TRANS	14	12	0
PP1 - SYNG 1	SYNCGQ	0	-8	0
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	11	15	0
SE D3&D4 - TRANS 2	TRANS	12	14	0
PP1 - SYNG 1	SYNCGQ	0	-7,4	0
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	14	0
SE D3&D4 - TRANS 2	TRANS	14	24	0
PP1 - SYNG 1	SYNCGQ	0	-0,7	0
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	13	0
SE D3&D4 - TRANS 2	TRANS	24	23	0
PP1 - SYNG 1	SYNCGQ	0	-1,1	0
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	23	0
PP1 - SYNG 1	SYNCGQ	0	-7,6	0
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	19	0
SE D3&D4 - TRANS 2	TRANS	23	21	0
PP1 - SYNG 1	SYNCGQ	0	-8,1	0
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	21	0
SE D3&D4 - TRANS 2	TRANS	21	16	0

PP1 - SYNG 1	SYNCGQ	0	-3,3	0
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	23	0
SE D3&D4 - TRANS 2	TRANS	16	17	0
PP1 - SYNG 1	SYNCGQ	0	-2,1	0

Table A-4 – Test case 2 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,06	1,98	63,86	2,27	-0,31	63,83
2	6,85	1,81	64,07	5,20	0,09	64,07
3	6,19	1,60	63,91	4,15	0,20	63,92
4	5,78	3,27	63,61	2,67	-2,77	63,15
5	6,71	3,18	64,00	3,67	-2,96	63,50
6	5,04	1,67	64,64	2,87	-1,00	64,58
7	5,38	3,58	63,57	1,83	-3,20	63,03
8	6,92	3,44	63,73	2,56	-2,67	63,22
9	8,80	2,86	63,45	3,33	-0,83	63,14
10	7,53	-0,03	63,47	4,06	-3,74	63,40
11	7,22	-5,90	63,96	3,93	0,34	64,25
12	7,12	-5,93	63,65	3,47	1,03	63,98
13	7,25	-4,32	63,62	3,33	-1,95	63,49
14	7,41	-4,35	63,54	3,61	-1,70	63,40
15	6,70	-4,83	63,37	1,76	-2,44	63,20
16	9,30	-4,15	63,52	4,18	-1,91	63,28
17	8,03	-4,22	63,43	3,36	-1,66	63,25
18	9,34	-3,81	63,78	5,28	-0,58	63,62
19	8,79	-5,92	63,81	6,03	1,53	64,16
20	8,60	-5,63	63,25	5,75	1,50	63,56
21	8,47	-4,08	63,53	4,42	-1,94	63,31
22	8,44	-4,52	63,01	4,02	-0,75	62,95
23	7,66	1,41	63,06	5,39	-0,77	63,05
24	7,81	1,74	63,19	4,27	-1,72	63,02

Table A-5 – Test case 2 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	17	0
SE D3&D4 - TRANS 2	TRANS	13	16	0
SE D7 - TRANS 1	TRANS	7	1	0
SE D1 - TRANS 2	TRANS	12	4	0
PP1 - SYNG 1	SYNCGQ	0	1,2	0

SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	14	0
SE D3&D4 - TRANS 2	TRANS	16	20	0
PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	16	0
SE D3&D4 - TRANS 2	TRANS	20	18	0
PP1 - SYNG 1	SYNCGQ	0	0,8	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	2,2	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	16	22	0
SE D3&D4 - TRANS 2	TRANS	18	20	0
PP1 - SYNG 1	SYNCGQ	0	2,4	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 6				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	20	13	0
PP1 - SYNG 1	SYNCGQ	0	1,9	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	13	0
SE D3&D4 - TRANS 2	TRANS	13	24	0
PP1 - SYNG 1	SYNCGQ	0	2,3	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	12	0
SE D3&D4 - TRANS 2	TRANS	24	11	0
PP1 - SYNG 1	SYNCGQ	0	2,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	9	0
SE D3&D4 - TRANS 2	TRANS	11	8	0
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0

SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	9	10	0
SE D3&D4 - TRANS 2	TRANS	8	12	0
D3&D4 - CAP 4	CAPAC	0	3,4	0
SE D7 - CAP 1	CAPAC	0	3	0
REN T1 - CAP 1	CAPAC	40	0	0
PP1 - SYNG 1	SYNCGQ	0	-0,5	0
SE D1 - WIND 1	SYNCGQ	0	0,3	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	7	0
SE D3&D4 - TRANS 2	TRANS	12	6	0
SE D1 - CAP 1	CAPAC	0	8,1	0
D3&D4 - CAP 4	CAPAC	3,4	0	0
SE D7 - CAP 1	CAPAC	3	0	0
PP1 - SYNG 1	SYNCGQ	0	0,8	0
Period(Hour) = 12				
No equipment changed in this period.				
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	7	6	0
SE D3&D4 - TRANS 2	TRANS	6	8	0
PP1 - SYNG 1	SYNCGQ	0	1,5	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	7	0
SE D3&D4 - TRANS 2	TRANS	8	11	0
PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	7	8	0
SE D3&D4 - TRANS 2	TRANS	11	14	0
PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	8	12	0
SE D3&D4 - TRANS 2	TRANS	14	15	0
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	13	0
SE D3&D4 - TRANS 2	TRANS	15	18	0

PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 18				
No equipment changed in this period.				
Period(Hour) = 19				
No equipment changed in this period.				
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	12	0
SE D3&D4 - TRANS 2	TRANS	18	21	0
PP1 - SYNG 1	SYNCGQ	0	-0,2	0
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	21	0
PP1 - SYNG 1	SYNCGQ	0	1,4	0
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	24	0
SE D3&D4 - TRANS 2	TRANS	21	22	0
PP1 - SYNG 1	SYNCGQ	0	0,7	0
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	22	12	0
SE D1 - CAP 1	CAPAC	8,1	0	0
PP1 - SYNG 1	SYNCGQ	0	2,6	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	22	0
SE D3&D4 - TRANS 2	TRANS	12	15	0
PP1 - SYNG 1	SYNCGQ	0	3,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0

Table A-6 – Test case 5 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,05	1,91	63,86	2,28	-0,44	63,83
2	6,85	1,73	64,07	5,20	0,07	64,07
3	6,20	1,68	63,91	4,15	0,22	63,92
4	5,93	6,00	63,56	2,68	-1,95	63,13
5	6,85	5,95	63,95	3,69	-2,19	63,49
6	5,18	4,45	64,59	2,88	-0,23	64,57
7	5,52	6,30	63,52	1,85	-2,57	63,02
8	6,92	3,44	63,73	2,56	-2,67	63,22
9	8,94	5,64	63,40	3,34	-0,06	63,12

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
10	9,34	9,88	64,04	2,42	4,42	63,26
11	7,94	4,84	64,51	3,36	-1,34	64,28
12	7,87	3,01	64,23	2,72	0,32	63,99
13	8,85	10,07	64,10	1,91	5,32	63,37
14	8,84	7,51	64,06	2,24	4,66	63,30
15	7,78	7,86	63,87	0,84	-0,08	63,16
16	10,62	7,53	64,04	2,89	3,46	63,19
17	9,34	9,50	63,91	2,24	2,95	63,17
18	10,38	6,55	64,32	4,27	1,88	63,58
19	9,34	2,22	64,38	5,47	-0,72	64,20
20	9,49	6,19	63,75	5,00	2,16	63,55
21	9,83	7,75	64,03	3,10	3,92	63,21
22	9,91	9,38	63,47	2,72	5,77	62,84
23	8,87	8,69	63,64	4,37	1,69	63,01
24	8,94	8,77	63,78	3,31	0,16	62,99

Table A-7 – Test case 5 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	15	0,004
SE D3&D4 - TRANS 2	TRANS	13	1	0,036
SE D7 - TRANS 1	TRANS	7	1	0,024
SE D1 - TRANS 2	TRANS	12	5	0,028
PP1 - SYNG 1	SYNCGQ	0	1,4	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	20	0,01
SE D3&D4 - TRANS 2	TRANS	1	3	0,006
SE D1 - TRANS 2	TRANS	5	4	0,004
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	16	0,008
SE D3&D4 - TRANS 2	TRANS	3	1	0,006
PP1 - SYNG 1	SYNCGQ	0	0,8	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	16	19	0,006
SE D3&D4 - TRANS 2	TRANS	1	3	0,006
PP1 - SYNG 1	SYNCGQ	0	2,1	0

SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	20	0,002
SE D3&D4 - TRANS 2	TRANS	3	1	0,006
PP1 - SYNG 1	SYNCGQ	0	2,4	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 6				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	1	21	0,06
PP1 - SYNG 1	SYNCGQ	0	1,9	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	21	0,002
SE D3&D4 - TRANS 2	TRANS	21	23	0,006
PP1 - SYNG 1	SYNCGQ	0	2,5	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	23	0,004
PP1 - SYNG 1	SYNCGQ	0	2,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	22	0,002
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	23	13	0,03
SE D1 - TRANS 2	TRANS	4	5	0,004
PP1 - SYNG 1	SYNCGQ	0	-8,1	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	21	0,002
SE D3&D4 - TRANS 2	TRANS	13	19	0,018
SE D1 - TRANS 2	TRANS	5	4	0,004
D3&D4 - CAP 1	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-0,2	0
SE D3&D4 - PV 1	SYNCGQ	0	-0,5	0
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**

SE D3&D4 - TRANS 1	TRANS	21	16	0,01
SE D3&D4 - TRANS 2	TRANS	19	20	0,003
D3&D4 - CAP 1	CAPAC	3,4	0	0,003
SE D7 - CAP 1	CAPAC	0	3	0,003
PP1 - SYNG 1	SYNCGQ	0	-3,5	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	16	14	0,004
SE D3&D4 - TRANS 2	TRANS	20	23	0,009
SE D1 - TRANS 2	TRANS	4	5	0,004
SE D7 - CAP 1	CAPAC	3	0	0,003
PP1 - SYNG 1	SYNCGQ	0	-9,2	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	12	0,004
SE D3&D4 - TRANS 2	TRANS	23	20	0,009
SE D1 - TRANS 2	TRANS	5	4	0,004
D3&D4 - CAP 2	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-12,5	0
SE D3&D4 - PV 1	SYNCGQ	0	0,2	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	17	0,01
SE D3&D4 - TRANS 2	TRANS	20	14	0,018
D3&D4 - CAP 2	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,4	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	22	0,01
SE D3&D4 - TRANS 2	TRANS	14	13	0,003
PP1 - SYNG 1	SYNCGQ	0	-7,6	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	13	18	0,015
SE D7 - CAP 1	CAPAC	0	3	0,003
PP1 - SYNG 1	SYNCGQ	0	-8,5	0
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	21	0,002
SE D3&D4 - TRANS 2	TRANS	18	15	0,009
PP1 - SYNG 1	SYNCGQ	0	-7,8	0

SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	22	0,002
SE D3&D4 - TRANS 2	TRANS	15	7	0,024
D3&D4 - CAP 1	CAPAC	0	3,4	0,003
SE D7 - CAP 1	CAPAC	3	0	0,003
PP1 - SYNG 1	SYNCGQ	0	-1,5	0
SE D1 - WIND 1	SYNCGQ	0	-0,4	0
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	13	0,018
SE D3&D4 - TRANS 2	TRANS	7	20	0,039
D3&D4 - CAP 1	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	-1,2	0
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	17	0,008
SE D3&D4 - TRANS 2	TRANS	20	3	0,051
SE D1 - TRANS 2	TRANS	4	5	0,004
PP1 - SYNG 1	SYNCGQ	0	-8	0
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	23	0,012
SE D3&D4 - TRANS 2	TRANS	3	9	0,018
PP1 - SYNG 1	SYNCGQ	0	-8,7	0
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	21	0,004
SE D3&D4 - TRANS 2	TRANS	9	2	0,021
SE D1 - TRANS 2	TRANS	5	4	0,004
PP1 - SYNG 1	SYNCGQ	0	-3,4	0
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	22	0,002
SE D3&D4 - TRANS 2	TRANS	2	7	0,015
PP1 - SYNG 1	SYNCGQ	0	-2,1	0

Table A-8 – Test case 6 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,21	4,76	63,81	2,28	0,47	63,82
2	6,99	4,51	64,02	5,21	0,85	64,05
3	6,19	1,60	63,91	4,15	0,20	63,92

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
4	5,91	5,94	63,56	2,70	-2,08	63,13
5	6,70	3,23	64,00	3,68	-3,01	63,50
6	5,04	1,67	64,64	2,87	-1,00	64,58
7	5,38	3,58	63,57	1,83	-3,20	63,03
8	6,92	3,44	63,73	2,56	-2,67	63,22
9	8,94	5,64	63,40	3,34	-0,06	63,12
10	7,51	0,11	63,47	4,08	-3,89	63,40
11	7,35	-3,95	63,92	3,95	0,83	64,24
12	7,25	-3,94	63,62	3,49	1,59	63,97
13	7,51	-4,30	63,62	3,09	0,37	63,45
14	7,41	-4,35	63,54	3,61	-1,70	63,40
15	6,81	-2,94	63,34	1,81	-2,12	63,19
16	9,56	-4,05	63,52	3,95	0,37	63,24
17	8,03	-4,23	63,43	3,36	-1,65	63,25
18	9,29	-4,73	63,79	5,33	-1,19	63,63
19	8,71	-7,27	63,83	6,11	0,49	64,18
20	8,74	-3,68	63,21	5,76	2,10	63,55
21	8,60	-2,12	63,49	4,44	-1,46	63,30
22	8,57	-2,52	62,97	4,04	-0,20	62,94
23	7,42	0,19	63,08	5,64	-3,32	63,09
24	7,96	4,44	63,15	4,28	-0,97	63,01

Table A-9 – Test case 6 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	19	0,012
SE D7 - TRANS 1	TRANS	7	1	0,024
SE D1 - TRANS 2	TRANS	12	4	0,032
PP1 - SYNG 1	SYNCGQ	0	1,2	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	20	0,002
SE D3&D4 - TRANS 2	TRANS	13	5	0,024
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	23	0,006
SE D3&D4 - TRANS 2	TRANS	5	2	0,009
PP1 - SYNG 1	SYNCGQ	0	0,8	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0

Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	24	0,002
SE D3&D4 - TRANS 2	TRANS	2	7	0,015
PP1 - SYNG 1	SYNCGQ	0	2,3	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	20	0,008
SE D3&D4 - TRANS 2	TRANS	7	18	0,033
PP1 - SYNG 1	SYNCGQ	0	2,5	0
Period(Hour) = 6				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	23	0,006
SE D3&D4 - TRANS 2	TRANS	18	22	0,012
PP1 - SYNG 1	SYNCGQ	0	1,9	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	22	18	0,012
PP1 - SYNG 1	SYNCGQ	0	2,3	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	24	0,002
PP1 - SYNG 1	SYNCGQ	0	2,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	23	0,002
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	22	0,002
SE D3&D4 - TRANS 2	TRANS	18	21	0,009
D3&D4 - CAP 4	CAPAC	0	3,4	0,003
SE D7 - CAP 1	CAPAC	0	3	0,003
REN T1 - CAP 1	CAPAC	40	0	0,04
PP1 - SYNG 1	SYNCGQ	0	-0,2	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	24	0,004

SE D3&D4 - TRANS 2	TRANS	21	9	0,036
SE D1 - CAP 1	CAPAC	0	8,1	0,008
D3&D4 - CAP 4	CAPAC	3,4	0	0,003
SE D7 - CAP 1	CAPAC	3	0	0,003
PP1 - SYNG 1	SYNCGQ	0	0,8	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 12				
No equipment changed in this period.				
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	22	0,004
SE D7 - TRANS 1	TRANS	1	2	0,004
SE D1 - TRANS 2	TRANS	4	9	0,02
PP1 - SYNG 1	SYNCGQ	0	-2,4	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D7 - TRANS 1	TRANS	2	1	0,004
SE D1 - TRANS 2	TRANS	9	4	0,02
PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	17	0,01
SE D3&D4 - TRANS 2	TRANS	9	8	0,003
SE D7 - CAP 1	CAPAC	0	3	0,003
PP1 - SYNG 1	SYNCGQ	0	-1,7	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	24	0,014
SE D1 - TRANS 2	TRANS	4	9	0,02
SE D7 - CAP 1	CAPAC	3	0	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,5	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	23	0,002
SE D3&D4 - TRANS 2	TRANS	8	9	0,003
SE D1 - TRANS 2	TRANS	9	4	0,02
PP1 - SYNG 1	SYNCGQ	0	1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	22	0,002

SE D3&D4 - TRANS 2	TRANS	9	10	0,003
SE D1 - TRANS 2	TRANS	4	6	0,008
D3&D4 - CAP 1	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,9	0
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	21	0,002
SE D3&D4 - TRANS 2	TRANS	10	21	0,033
SE D1 - TRANS 2	TRANS	6	5	0,004
D3&D4 - CAP 1	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	1,1	0
SE D1 - WIND 1	SYNCGQ	0	1	0
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	19	0,004
SE D3&D4 - TRANS 2	TRANS	21	18	0,009
SE D1 - TRANS 2	TRANS	5	4	0,004
PP1 - SYNG 1	SYNCGQ	0	-0,3	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	17	0,004
PP1 - SYNG 1	SYNCGQ	0	1,5	0
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	16	0,002
PP1 - SYNG 1	SYNCGQ	0	0,7	0
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	16	21	0,01
SE D3&D4 - TRANS 2	TRANS	18	3	0,045
SE D1 - CAP 1	CAPAC	8,1	0	0,008
SE D7 - CAP 1	CAPAC	0	3	0,003
PP1 - SYNG 1	SYNCGQ	0	3,1	0
SE D1 - WIND 1	SYNCGQ	0	0,2	0
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	19	0,004
SE D3&D4 - TRANS 2	TRANS	3	1	0,006
SE D7 - CAP 1	CAPAC	3	0	0,003
PP1 - SYNG 1	SYNCGQ	0	3,1	0
SE D1 - WIND 1	SYNCGQ	0	0,2	0

Annex B – Cluster 2 simulation results

Table B-1 – Starting scenario results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,74	2,53	63,85	2,29	0,68	63,81
2	7,49	2,24	64,06	5,23	0,95	64,05
3	6,80	2,03	63,90	4,19	0,91	63,90
4	6,49	4,06	63,60	2,65	-1,12	63,12
5	7,42	4,11	63,98	3,61	-1,16	63,47
6	5,74	2,45	64,62	2,87	0,48	64,56
7	6,14	4,49	63,55	1,86	-1,43	63,00
8	7,71	4,26	63,71	2,73	-1,05	63,19
9	9,58	3,38	63,44	3,67	0,15	63,12
10	9,39	5,17	64,12	3,47	-1,79	63,36
11	8,74	3,27	64,54	3,72	0,10	64,25
12	8,58	2,96	64,23	3,32	0,27	63,99
13	8,81	5,06	64,19	3,09	-1,67	63,49
14	8,98	4,86	64,10	3,43	-1,63	63,40
15	8,32	4,37	63,94	1,59	-2,36	63,20
16	11,00	5,12	64,08	3,96	-1,73	63,27
17	9,77	4,98	63,99	3,09	-1,60	63,25
18	11,02	5,06	64,35	4,96	-1,36	63,63
19	10,43	2,89	64,37	5,60	0,77	64,17
20	10,18	3,09	63,80	5,27	0,64	63,58
21	10,11	5,19	64,07	3,81	-1,71	63,30
22	9,95	4,49	63,55	3,45	-0,96	62,95
23	9,19	4,89	63,71	4,72	-1,38	63,06
24	9,30	5,39	63,84	3,57	-1,99	63,03

Table B-2 – Test case 3 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,71	1,78	63,86	2,46	-0,35	63,83
2	7,47	1,84	64,07	5,37	0,11	64,07
3	6,83	1,80	63,91	4,30	0,45	63,91
4	6,40	3,36	63,61	2,83	-2,61	63,14
5	7,34	3,41	63,99	3,81	-2,65	63,49
6	5,66	1,76	64,63	3,05	-1,01	64,58
7	6,02	3,61	63,57	2,09	-3,33	63,03
8	7,67	3,74	63,72	2,89	-2,18	63,21
9	9,55	2,87	63,45	3,84	-0,95	63,14
10	10,00	7,62	64,08	3,03	3,55	63,27
11	8,81	3,23	64,54	3,78	0,03	64,25
12	8,64	2,92	64,23	3,39	0,19	63,99

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
13	9,44	7,62	64,14	2,63	3,89	63,39
14	9,61	7,43	64,06	2,97	3,99	63,31
15	8,77	6,11	63,90	1,29	1,45	63,13
16	11,57	7,41	64,04	3,56	3,25	63,19
17	10,39	7,46	63,94	2,64	3,82	63,16
18	11,59	7,33	64,31	4,57	3,58	63,55
19	10,57	3,14	64,36	5,61	1,29	64,17
20	10,38	3,65	63,79	5,22	1,87	63,56
21	10,70	7,54	64,03	3,40	3,43	63,22
22	10,59	7,08	63,51	2,99	4,70	62,86
23	9,50	5,95	63,69	4,57	0,94	63,02
24	9,51	6,03	63,82	3,49	-0,59	63,01

Table B-3 – Test case 3 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	10	0
SE D3&D4 - TRANS 2	TRANS	13	22	0
SE D7 - TRANS 1	TRANS	7	1	0
SE D1 - TRANS 2	TRANS	12	4	0
D3&D4 - CAP 4	CAPAC	0	3,4	0
PP1 - SYNG 1	SYNCGQ	0	-2,3	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	6	0
SE D3&D4 - TRANS 2	TRANS	22	20	0
D3&D4 - CAP 4	CAPAC	3,4	0	0
PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	5	0
PP1 - SYNG 1	SYNCGQ	0	0,5	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	5	1	0
PP1 - SYNG 1	SYNCGQ	0	2	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	2	0
Period(Hour) = 6				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	2	0

Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	1	6	0
SE D3&D4 - TRANS 2	TRANS	20	23	0
PP1 - SYNG 1	SYNCGQ	0	2,6	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	1	0
SE D3&D4 - TRANS 2	TRANS	23	19	0
PP1 - SYNG 1	SYNCGQ	0	1,5	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	1,5	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	1	13	0
SE D3&D4 - TRANS 2	TRANS	19	24	0
PP1 - SYNG 1	SYNCGQ	0	-7,6	0
Period(Hour) = 11				
No equipment changed in this period.				
Period(Hour) = 12				
No equipment changed in this period.				
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	17	0
SE D3&D4 - TRANS 2	TRANS	24	19	0
PP1 - SYNG 1	SYNCGQ	0	-7,9	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	20	0
PP1 - SYNG 1	SYNCGQ	0	-8	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	23	0
SE D3&D4 - TRANS 2	TRANS	19	22	0
PP1 - SYNG 1	SYNCGQ	0	-5,5	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	22	0
PP1 - SYNG 1	SYNCGQ	0	-7,1	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	-7,7	0
Period(Hour) = 18				

Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	22	23	0
SE D3&D4 - TRANS 2	TRANS	22	24	0
PP1 - SYNG 1	SYNCGQ	0	-7	0
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	17	0
SE D3&D4 - TRANS 2	TRANS	24	16	0
PP1 - SYNG 1	SYNCGQ	0	-0,8	0
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	18	0
PP1 - SYNG 1	SYNCGQ	0	-1,8	0
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	18	19	0
SE D3&D4 - TRANS 2	TRANS	16	19	0
PP1 - SYNG 1	SYNCGQ	0	-7,3	0
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	-8	0
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	20	0
SE D3&D4 - TRANS 2	TRANS	19	20	0
PP1 - SYNG 1	SYNCGQ	0	-3,4	0
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	18	0
SE D3&D4 - TRANS 2	TRANS	20	24	0
PP1 - SYNG 1	SYNCGQ	0	-2,1	0

Table B-4 – Test case 4 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,71	1,78	63,86	2,46	-0,35	63,83
2	7,46	1,78	64,07	5,38	-0,03	64,07
3	6,83	1,80	63,91	4,30	0,45	63,91
4	6,40	3,36	63,61	2,83	-2,61	63,14
5	7,34	3,41	63,99	3,81	-2,65	63,49
6	5,66	1,76	64,63	3,05	-1,01	64,58
7	6,02	3,61	63,57	2,09	-3,33	63,03
8	7,67	3,74	63,72	2,89	-2,18	63,21
9	9,55	2,87	63,45	3,84	-0,95	63,14

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
10	8,64	-4,17	63,55	4,36	-1,91	63,36
11	8,03	-5,90	63,95	4,58	0,43	64,25
12	7,89	-6,06	63,65	4,15	0,84	63,98
13	8,06	-4,25	63,62	3,97	-1,72	63,49
14	8,24	-4,41	63,54	4,30	-1,74	63,40
15	7,60	-4,89	63,37	2,45	-2,48	63,20
16	10,27	-4,14	63,52	4,82	-1,82	63,27
17	9,05	-4,27	63,43	3,94	-1,71	63,25
18	10,30	-4,19	63,78	5,83	-1,40	63,63
19	9,80	-5,98	63,81	6,39	1,38	64,16
20	9,57	-5,64	63,24	6,04	1,41	63,57
21	9,40	-4,02	63,52	4,66	-1,85	63,31
22	9,29	-4,48	63,00	4,26	-0,73	62,95
23	8,45	1,52	63,06	5,60	-0,73	63,05
24	8,52	1,85	63,19	4,46	-1,68	63,02

Table B-5 – Test case 4 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	18	0
SE D3&D4 - TRANS 2	TRANS	13	24	0
SE D7 - TRANS 1	TRANS	7	1	0
SE D1 - TRANS 2	TRANS	12	4	0
D3&D4 - CAP 4	CAPAC	0	3,4	0
PP1 - SYNG 1	SYNCGQ	0	-2,3	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	18	15	0
D3&D4 - CAP 4	CAPAC	3,4	0	0
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	14	0
SE D3&D4 - TRANS 2	TRANS	24	20	0
PP1 - SYNG 1	SYNCGQ	0	0,5	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	10	0
PP1 - SYNG 1	SYNCGQ	0	2	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	6	0

PP1 - SYNG 1	SYNCGQ	0	2	0
Period(Hour) = 6				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	2	0
PP1 - SYNG 1	SYNCGQ	0	2	0
Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	2	6	0
SE D3&D4 - TRANS 2	TRANS	20	23	0
PP1 - SYNG 1	SYNCGQ	0	2,6	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	1	0
SE D3&D4 - TRANS 2	TRANS	23	19	0
PP1 - SYNG 1	SYNCGQ	0	1,5	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	1,5	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	1	2	0
SE D3&D4 - TRANS 2	TRANS	19	23	0
SE D1 - CAP 1	CAPAC	0	8,1	0
REN T1 - CAP 1	CAPAC	40	0	0
PP1 - SYNG 1	SYNCGQ	0	1,4	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	2	3	0
SE D3&D4 - TRANS 2	TRANS	23	20	0
PP1 - SYNG 1	SYNCGQ	0	0,8	0
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	3	5	0
SE D3&D4 - TRANS 2	TRANS	20	16	0
PP1 - SYNG 1	SYNCGQ	0	0,4	0
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	5	2	0
SE D3&D4 - TRANS 2	TRANS	16	20	0
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	20	24	0
PP1 - SYNG 1	SYNCGQ	0	1,3	0

Period(Hour) = 15				
Name/Designation	EqpType	InitPos	FinalPos	dCost
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 16				
Name/Designation	EqpType	InitPos	FinalPos	dCost
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 17				
Name/Designation	EqpType	InitPos	FinalPos	dCost
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 18				
Name/Designation	EqpType	InitPos	FinalPos	dCost
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 19				
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	2	1	0
SE D3&D4 - TRANS 2	TRANS	24	22	0
PP1 - SYNG 1	SYNCGQ	0	0,3	0
Period(Hour) = 20				
No equipment changed in this period.				
Period(Hour) = 21				
Name/Designation	EqpType	InitPos	FinalPos	dCost
PP1 - SYNG 1	SYNCGQ	0	1,3	0
Period(Hour) = 22				
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	1	3	0
PP1 - SYNG 1	SYNCGQ	0	0,7	0
Period(Hour) = 23				
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 2	TRANS	22	23	0
SE D1 - CAP 1	CAPAC	8,1	0	0
PP1 - SYNG 1	SYNCGQ	0	2,6	0
Period(Hour) = 24				
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	3	4	0
SE D3&D4 - TRANS 2	TRANS	23	24	0
PP1 - SYNG 1	SYNCGQ	0	3,1	0

Table B-6 – Test case 7 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,70	1,75	63,86	2,47	-0,43	63,83
2	7,61	4,62	64,02	5,38	0,89	64,05
3	6,95	4,49	63,86	4,33	1,01	63,90
4	6,54	6,11	63,56	2,85	-1,91	63,13

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
5	7,45	6,03	63,95	3,86	-2,22	63,49
6	5,80	4,53	64,59	3,06	-0,24	64,57
7	6,18	6,48	63,52	2,08	-2,36	63,01
8	7,63	3,55	63,73	2,93	-2,59	63,22
9	9,59	3,09	63,44	3,80	-0,46	63,13
10	10,13	10,36	64,03	3,07	4,26	63,26
11	8,93	5,91	64,49	3,82	0,60	64,24
12	8,78	5,72	64,18	3,40	1,03	63,98
13	9,58	10,38	64,09	2,64	4,66	63,38
14	9,62	7,50	64,05	2,96	4,14	63,31
15	8,92	8,94	63,85	1,29	2,36	63,12
16	11,69	7,91	64,03	3,46	4,35	63,17
17	10,63	10,17	63,89	2,53	5,73	63,12
18	11,67	7,67	64,30	4,50	4,31	63,54
19	10,71	5,91	64,31	5,63	2,06	64,15
20	10,50	6,30	63,74	5,26	2,35	63,55
21	10,84	10,31	63,98	3,41	4,20	63,21
22	10,85	9,85	63,46	2,87	6,76	62,82
23	9,65	8,75	63,64	4,57	1,78	63,01
24	9,66	8,83	63,77	3,50	0,25	62,99

Table B-7 – Test case 7 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	10	0,006
SE D3&D4 - TRANS 2	TRANS	13	7	0,018
SE D7 - TRANS 1	TRANS	7	1	0,024
SE D1 - TRANS 2	TRANS	12	4	0,032
D3&D4 - CAP 4	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,2	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	19	0,018
SE D3&D4 - TRANS 2	TRANS	7	3	0,012
D3&D4 - CAP 4	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	22	0,006
SE D3&D4 - TRANS 2	TRANS	3	2	0,003
PP1 - SYNG 1	SYNCGQ	0	0,8	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**

SE D3&D4 - TRANS 2	TRANS	2	3	0,003
PP1 - SYNG 1	SYNCGQ	0	2,1	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	15	0,014
SE D3&D4 - TRANS 2	TRANS	3	1	0,006
PP1 - SYNG 1	SYNCGQ	0	2,5	0
Period(Hour) = 6				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	19	0,008
PP1 - SYNG 1	SYNCGQ	0	2	0
Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	13	0,012
PP1 - SYNG 1	SYNCGQ	0	2,3	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	2,1	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	14	0,002
SE D3&D4 - TRANS 2	TRANS	1	2	0,003
PP1 - SYNG 1	SYNCGQ	0	0,8	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	15	0,002
SE D3&D4 - TRANS 2	TRANS	2	1	0,003
SE D7 - CAP 1	CAPAC	0	3	0,003
PP1 - SYNG 1	SYNCGQ	0	-10,4	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	10	0,01
SE D3&D4 - TRANS 2	TRANS	1	19	0,054
SE D7 - TRANS 1	TRANS	1	2	0,004
SE D7 - CAP 1	CAPAC	3	0	0,003
PP1 - SYNG 1	SYNCGQ	0	0,3	0
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	17	0,014
SE D3&D4 - TRANS 2	TRANS	19	13	0,018
SE D7 - TRANS 1	TRANS	2	1	0,004
PP1 - SYNG 1	SYNCGQ	0	-0,1	0
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**

SE D3&D4 - TRANS 1	TRANS	17	20	0,006
SE D3&D4 - TRANS 2	TRANS	13	4	0,027
PP1 - SYNG 1	SYNCGQ	0	-7,9	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	24	0,008
SE D3&D4 - TRANS 2	TRANS	4	18	0,042
SE D7 - TRANS 1	TRANS	1	2	0,004
SE D1 - TRANS 2	TRANS	4	5	0,004
PP1 - SYNG 1	SYNCGQ	0	-8,2	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	22	0,004
SE D1 - TRANS 2	TRANS	5	4	0,004
PP1 - SYNG 1	SYNCGQ	0	-5,7	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	18	0,008
SE D3&D4 - TRANS 2	TRANS	18	1	0,051
SE D7 - TRANS 1	TRANS	2	1	0,004
SE D1 - TRANS 2	TRANS	4	5	0,004
PP1 - SYNG 1	SYNCGQ	0	-8,6	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	18	20	0,004
PP1 - SYNG 1	SYNCGQ	0	-9,5	0
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	15	0,01
PP1 - SYNG 1	SYNCGQ	0	-8	0
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	22	0,014
SE D3&D4 - TRANS 2	TRANS	1	3	0,006
SE D1 - TRANS 2	TRANS	5	4	0,004
PP1 - SYNG 1	SYNCGQ	0	-0,8	0
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	15	0,014
SE D3&D4 - TRANS 2	TRANS	3	8	0,015
PP1 - SYNG 1	SYNCGQ	0	-1,4	0
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	15	21	0,012

SE D3&D4 - TRANS 2	TRANS	8	10	0,006
PP1 - SYNG 1	SYNCGQ	0	-7,3	0
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	17	0,008
SE D3&D4 - TRANS 2	TRANS	10	1	0,027
SE D1 - TRANS 2	TRANS	4	5	0,004
PP1 - SYNG 1	SYNCGQ	0	-10	0
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	8	0,018
SE D3&D4 - TRANS 2	TRANS	1	17	0,048
SE D7 - TRANS 1	TRANS	1	2	0,004
SE D1 - TRANS 2	TRANS	5	4	0,004
PP1 - SYNG 1	SYNCGQ	0	-3,5	0
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	8	5	0,006
SE D3&D4 - TRANS 2	TRANS	17	18	0,003
SE D7 - TRANS 1	TRANS	2	1	0,004
PP1 - SYNG 1	SYNCGQ	0	-2,2	0

Table B-8 – Test case 8 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	5,86	4,56	63,81	2,47	0,43	63,82
2	7,47	1,84	64,07	5,37	0,11	64,07
3	6,95	4,49	63,86	4,33	1,01	63,90
4	6,54	6,11	63,56	2,85	-1,91	63,13
5	7,45	6,00	63,95	3,87	-2,28	63,49
6	5,80	4,53	64,59	3,06	-0,24	64,57
7	6,18	6,48	63,52	2,08	-2,36	63,01
8	7,78	6,33	63,68	2,94	-1,82	63,21
9	9,57	2,96	63,45	3,82	-0,74	63,13
10	8,64	-4,17	63,55	4,36	-1,91	63,36
11	8,16	-3,91	63,92	4,60	0,99	64,24
12	8,02	-4,04	63,62	4,17	1,47	63,97
13	8,18	-2,59	63,59	4,01	-1,32	63,48
14	8,38	-2,68	63,51	4,32	-1,20	63,39
15	7,72	-3,20	63,34	2,48	-2,01	63,19
16	10,27	-4,40	63,53	4,83	-1,84	63,27
17	9,05	-4,54	63,43	3,95	-1,73	63,25
18	10,42	-2,50	63,75	5,86	-0,93	63,62
19	9,78	-6,04	63,81	6,40	1,24	64,17
20	9,70	-3,65	63,21	6,06	1,97	63,56

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
21	9,38	-4,38	63,53	4,68	-2,07	63,31
22	9,29	-4,48	63,00	4,26	-0,73	62,95
23	8,59	4,30	63,01	5,62	0,04	63,03
24	8,65	4,55	63,14	4,49	-1,09	63,01

Table B-9 – Test case 8 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	7	0,012
SE D3&D4 - TRANS 2	TRANS	13	19	0,018
SE D7 - TRANS 1	TRANS	7	1	0,024
SE D1 - TRANS 2	TRANS	12	4	0,032
D3&D4 - CAP 4	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,3	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	7	3	0,008
SE D3&D4 - TRANS 2	TRANS	19	10	0,027
SE D7 - TRANS 1	TRANS	1	2	0,004
D3&D4 - CAP 4	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	1,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	3	4	0,002
SE D7 - TRANS 1	TRANS	2	1	0,004
PP1 - SYNG 1	SYNCGQ	0	0,8	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	4	2	0,004
SE D3&D4 - TRANS 2	TRANS	10	22	0,036
SE D7 - TRANS 1	TRANS	1	2	0,004
PP1 - SYNG 1	SYNCGQ	0	2,1	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	2	6	0,008
SE D3&D4 - TRANS 2	TRANS	22	21	0,003
SE D7 - TRANS 1	TRANS	2	1	0,004
PP1 - SYNG 1	SYNCGQ	0	2,6	0
Period(Hour) = 6				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	8	0,004
SE D3&D4 - TRANS 2	TRANS	21	17	0,012

PP1 - SYNG 1	SYNCGQ	0	2	0
Period(Hour) = 7				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	8	11	0,006
SE D3&D4 - TRANS 2	TRANS	17	4	0,039
PP1 - SYNG 1	SYNCGQ	0	2,3	0
Period(Hour) = 8				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
PP1 - SYNG 1	SYNCGQ	0	2,1	0
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	11	12	0,002
SE D3&D4 - TRANS 2	TRANS	4	3	0,003
PP1 - SYNG 1	SYNCGQ	0	1,2	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	11	0,002
SE D3&D4 - TRANS 2	TRANS	3	2	0,003
SE D7 - TRANS 1	TRANS	1	2	0,004
SE D1 - CAP 1	CAPAC	0	8,1	0,008
REN T1 - CAP 1	CAPAC	40	0	0,04
PP1 - SYNG 1	SYNCGQ	0	1,4	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	11	6	0,01
SE D3&D4 - TRANS 2	TRANS	2	5	0,009
SE D7 - TRANS 1	TRANS	2	1	0,004
PP1 - SYNG 1	SYNCGQ	0	0,8	0
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	5	0,002
SE D3&D4 - TRANS 2	TRANS	5	9	0,012
PP1 - SYNG 1	SYNCGQ	0	0,3	0
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	9	14	0,015
D3&D4 - CAP 2	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,1	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	14	13	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,3	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**

SE D3&D4 - TRANS 1	TRANS	5	23	0,036
SE D3&D4 - TRANS 2	TRANS	13	12	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,2	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	22	0,002
SE D7 - TRANS 1	TRANS	1	2	0,004
PP1 - SYNG 1	SYNCGQ	0	-2,3	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	12	11	0,003
SE D7 - TRANS 1	TRANS	2	1	0,004
D3&D4 - CAP 2	CAPAC	3,4	0	0,003
D3&D4 - CAP 1	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,3	0
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	20	0,004
SE D3&D4 - TRANS 2	TRANS	11	12	0,003
SE D7 - TRANS 1	TRANS	1	2	0,004
D3&D4 - CAP 2	CAPAC	0	3,4	0,003
D3&D4 - CAP 1	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	-2,2	0
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	14	0,012
SE D3&D4 - TRANS 2	TRANS	12	10	0,006
SE D7 - TRANS 1	TRANS	2	1	0,004
D3&D4 - CAP 2	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	0,5	0
Period(Hour) = 20				
No equipment changed in this period.				
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	13	0,002
SE D3&D4 - TRANS 2	TRANS	10	7	0,009
SE D7 - TRANS 1	TRANS	1	2	0,004
D3&D4 - CAP 2	CAPAC	0	3,4	0,003
PP1 - SYNG 1	SYNCGQ	0	-2	0
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	12	0,002
SE D3&D4 - TRANS 2	TRANS	7	15	0,024
SE D7 - TRANS 1	TRANS	2	1	0,004

D3&D4 - CAP 2	CAPAC	3,4	0	0,003
PP1 - SYNG 1	SYNCGQ	0	0,7	0
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	19	0,014
SE D3&D4 - TRANS 2	TRANS	15	13	0,006
SE D1 - CAP 1	CAPAC	8,1	0	0,008
PP1 - SYNG 1	SYNCGQ	0	2,6	0
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	22	0,006
SE D3&D4 - TRANS 2	TRANS	13	16	0,009
SE D7 - CAP 1	CAPAC	0	3	0,003
PP1 - SYNG 1	SYNCGQ	0	0,2	0

Annex C – Cluster 3 simulation results

Table C-1 – Starting scenario results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	25,16	2,54	63,83	-17,70	1,67	63,82
2	27,24	2,85	64,03	-15,02	1,35	64,07
3	25,21	2,54	63,87	-14,74	1,30	63,92
4	24,21	2,41	63,60	-15,63	1,41	63,09
5	25,21	2,54	63,99	-14,71	1,30	63,45
6	24,19	2,37	64,60	-16,15	1,43	64,56
7	24,10	2,40	63,57	-16,76	1,56	62,97
8	25,92	2,67	63,72	-16,29	1,52	63,17
9	28,79	3,13	63,42	-16,47	1,58	63,12
10	27,64	2,92	64,13	-15,88	1,49	63,33
11	27,58	2,90	64,51	-16,27	1,51	64,26
12	26,56	2,77	64,21	-15,83	1,45	64,00
13	27,58	2,84	64,20	-16,84	1,60	63,46
14	26,49	2,77	64,11	-15,33	1,40	63,38
15	26,43	1,40	63,96	-17,82	1,65	63,16
16	28,42	3,07	64,10	-14,77	1,36	63,25
17	27,44	2,93	64,00	-15,88	1,49	63,22
18	30,57	3,41	64,35	-15,73	1,50	63,61
19	30,72	3,43	64,33	-15,67	1,48	64,19
20	30,83	3,47	63,76	-16,25	1,57	63,59
21	28,90	3,13	64,08	-15,81	1,49	63,28
22	28,99	3,16	63,55	-16,32	1,56	62,93
23	29,07	3,16	63,71	-15,81	1,49	63,04
24	28,15	2,99	63,85	-15,88	1,50	62,99

Table C-2 – Test case 9 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	25,26	2,54	63,83	-17,67	1,37	63,82
2	27,35	2,89	64,03	-14,99	1,05	64,07
3	25,32	2,54	63,87	-14,71	0,99	63,92
4	24,31	2,40	63,60	-15,62	1,11	63,10
5	25,32	2,53	63,99	-14,69	1,00	63,45
6	24,28	2,42	64,60	-16,14	1,14	64,57
7	24,20	2,45	63,57	-16,75	1,26	62,97
8	26,02	2,76	63,72	-16,26	1,23	63,18
9	28,90	3,07	63,42	-16,44	1,28	63,13
10	27,75	3,05	64,13	-15,85	1,19	63,34
11	27,68	3,02	64,51	-16,24	1,22	64,26
12	26,66	2,88	64,21	-15,80	1,15	64,01

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
13	27,69	2,97	64,20	-16,81	1,30	63,46
14	26,60	2,88	64,11	-15,30	1,11	63,38
15	26,53	1,50	63,96	-17,79	1,35	63,16
16	28,53	3,21	64,09	-14,74	1,07	63,25
17	27,54	3,06	64,00	-15,85	1,20	63,23
18	30,70	3,60	64,35	-15,70	1,21	63,61
19	30,84	3,62	64,33	-15,64	1,19	64,19
20	30,96	3,66	63,76	-16,22	1,28	63,60
21	29,01	3,31	64,08	-15,78	1,19	63,28
22	29,11	3,34	63,55	-16,29	1,27	62,94
23	29,19	3,34	63,71	-15,78	1,20	63,04
24	28,26	3,16	63,85	-15,85	1,20	63,00

Table C-3 – Test case 9 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	21	0
SE D3&D4 - TRANS 2	TRANS	13	22	0
SE D1 - TRANS 2	TRANS	12	4	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D7 - TRANS 1	TRANS	7	1	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	22	0
SE D3&D4 - TRANS 2	TRANS	22	23	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	23	0
SE D3&D4 - TRANS 2	TRANS	23	24	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	24	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	23	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				

No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	22	0
SE D3&D4 - TRANS 2	TRANS	24	18	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
No equipment changed in this period.				
Period(Hour) = 11				
No equipment changed in this period.				
Period(Hour) = 12				
No equipment changed in this period.				
Period(Hour) = 13				
No equipment changed in this period.				
Period(Hour) = 14				
No equipment changed in this period.				
Period(Hour) = 15				
No equipment changed in this period.				
Period(Hour) = 16				
No equipment changed in this period.				
Period(Hour) = 17				
No equipment changed in this period.				
Period(Hour) = 18				
No equipment changed in this period.				
Period(Hour) = 19				
No equipment changed in this period.				
Period(Hour) = 20				
No equipment changed in this period.				
Period(Hour) = 21				
No equipment changed in this period.				
Period(Hour) = 22				
No equipment changed in this period.				
Period(Hour) = 23				
No equipment changed in this period.				
Period(Hour) = 24				
No equipment changed in this period.				

Table C-4 – Test case 10 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	25,27	2,54	63,83	-17,67	1,38	63,30

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
2	27,35	2,89	64,03	-14,99	1,06	63,55
3	25,32	2,54	63,87	-14,72	1,00	63,40
4	24,31	2,40	63,60	-15,62	1,12	62,59
5	25,32	2,53	63,99	-14,69	1,01	62,94
6	24,28	2,42	64,60	-16,14	1,15	64,06
7	24,20	2,45	63,57	-16,75	1,26	62,97
8	26,02	2,76	63,72	-16,26	1,23	63,18
9	28,90	3,07	63,42	-16,44	1,28	63,13
10	27,75	2,88	63,39	-15,85	1,19	63,34
11	27,69	2,85	63,77	-16,24	1,23	63,73
12	26,67	2,71	63,46	-15,80	1,17	63,47
13	27,70	2,80	63,46	-16,81	1,30	63,46
14	26,60	2,71	63,39	-15,30	1,11	63,38
15	26,53	1,33	63,24	-17,79	1,35	63,16
16	28,54	3,04	63,37	-14,74	1,07	63,25
17	27,55	2,79	63,28	-15,85	1,20	63,23
18	30,71	3,64	63,62	-15,70	1,21	63,61
19	30,85	3,66	63,61	-15,64	1,20	63,69
20	30,96	3,70	63,05	-16,22	1,29	63,09
21	29,02	3,35	63,37	-15,78	1,19	63,28
22	29,12	3,38	62,84	-16,29	1,27	62,94
23	29,20	3,37	63,00	-15,78	1,20	63,04
24	28,27	3,19	63,14	-15,85	1,20	63,00

Table C-5 – Test case 10 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	21	0
SE D3&D4 - TRANS 2	TRANS	13	22	0
SE D1 - TRANS 2	TRANS	12	4	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D7 - TRANS 1	TRANS	7	1	0
REN T2 - CAP 1	CAPAC	30	0	0
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	22	0
SE D3&D4 - TRANS 2	TRANS	22	23	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 3				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	23	0
SE D3&D4 - TRANS 2	TRANS	23	24	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0

Period(Hour) = 4				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	24	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 5				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	24	23	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				
No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	22	0
SE D3&D4 - TRANS 2	TRANS	24	18	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	18	19	0
REN T1 - CAP 1	CAPAC	40	0	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	19	20	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	20	17	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	17	18	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	18	19	0

SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	19	20	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	20	17	0
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	24	0
SE D3&D4 - TRANS 2	TRANS	17	16	0
SE D1 - WIND 1	SYNCGQ	0	0,2	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 18				
No equipment changed in this period.				
Period(Hour) = 19				
No equipment changed in this period.				
Period(Hour) = 20				
No equipment changed in this period.				
Period(Hour) = 21				
No equipment changed in this period.				
Period(Hour) = 22				
No equipment changed in this period.				
Period(Hour) = 23				
No equipment changed in this period.				
Period(Hour) = 24				
No equipment changed in this period.				

Table C-6 – Test case 13 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	25,26	2,54	63,83	-17,67	1,37	63,82
2	27,35	2,89	64,03	-14,99	1,05	64,07
3	25,49	6,19	63,81	-14,71	0,99	63,92
4	24,47	6,05	63,54	-15,62	1,11	63,10
5	25,48	6,18	63,92	-14,69	1,00	63,45
6	24,45	5,97	64,54	-16,14	1,14	64,57
7	24,36	6,00	63,50	-16,75	1,26	62,97
8	26,18	6,31	63,66	-16,26	1,23	63,18

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
9	29,07	6,62	63,35	-16,44	1,28	63,13
10	27,91	6,60	64,07	-15,85	1,19	63,34
11	27,84	6,58	64,45	-16,24	1,22	64,26
12	26,82	6,43	64,14	-15,80	1,15	64,01
13	27,85	6,52	64,13	-16,81	1,30	63,46
14	26,76	6,43	64,05	-15,30	1,11	63,38
15	26,69	5,05	63,90	-17,79	1,35	63,16
16	28,70	6,76	64,03	-14,74	1,07	63,25
17	27,70	6,61	63,93	-15,85	1,20	63,23
18	30,86	7,16	64,28	-15,70	1,21	63,61
19	31,00	7,18	64,26	-15,64	1,19	64,19
20	31,12	7,22	63,70	-16,22	1,28	63,60
21	29,18	6,86	64,02	-15,78	1,19	63,28
22	29,27	6,89	63,48	-16,29	1,27	62,94
23	29,35	-2,04	63,80	-15,78	1,20	63,04
24	28,43	6,71	63,79	-15,85	1,20	63,00

Table C-7 – Test case 13 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	14	0,002
SE D1 - TRANS 2	TRANS	12	4	0,032
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D7 - TRANS 1	TRANS	7	1	0,024
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	13	14	0,003
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 3				
No equipment changed in this period.				
Period(Hour) = 4				
No equipment changed in this period.				
Period(Hour) = 5				
No equipment changed in this period.				
Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				
No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - WIND 1	SYNCGQ	0	0,1	0

SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	22	0,016
SE D3&D4 - TRANS 2	TRANS	14	9	0,015
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	19	0,006
SE D3&D4 - TRANS 2	TRANS	9	12	0,009
Period(Hour) = 12				
No equipment changed in this period.				
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	19	22	0,006
SE D3&D4 - TRANS 2	TRANS	12	5	0,021
Period(Hour) = 14				
No equipment changed in this period.				
Period(Hour) = 15				
No equipment changed in this period.				
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	22	20	0,004
SE D3&D4 - TRANS 2	TRANS	5	18	0,039
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	23	0,006
SE D3&D4 - TRANS 2	TRANS	18	6	0,036
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	23	21	0,004
SE D3&D4 - TRANS 2	TRANS	6	19	0,039
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	21	17	0,008
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	20	0,006
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	20	18	0,004
SE D3&D4 - TRANS 2	TRANS	19	12	0,021
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	12	11	0,003

Period(Hour) = 23				
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	18	22	0,008
SE D3&D4 - TRANS 2	TRANS	11	7	0,012
SE D1 - CAP 1	CAPAC	0	8,1	0,008
Period(Hour) = 24				
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	22	15	0,014
SE D3&D4 - TRANS 2	TRANS	7	18	0,033
SE D1 - CAP 1	CAPAC	8,1	0	0,008

Table C-8 – Test case 14 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	25,26	2,54	63,83	-17,67	1,37	63,82
2	27,35	2,89	64,03	-14,99	1,05	64,07
3	25,49	6,19	63,81	-14,71	0,99	63,92
4	24,47	6,05	63,54	-15,62	1,11	63,10
5	25,48	6,18	63,92	-14,69	1,00	63,45
6	24,45	5,97	64,54	-16,14	1,14	64,57
7	24,36	6,00	63,50	-16,75	1,26	62,97
8	26,18	6,31	63,66	-16,26	1,23	63,18
9	29,07	6,62	63,35	-16,44	1,28	63,13
10	27,91	6,63	63,32	-15,85	1,19	63,34
11	27,85	6,61	63,70	-16,24	1,22	64,26
12	26,83	6,26	63,40	-15,80	1,15	64,01
13	27,86	6,55	63,39	-16,81	1,30	63,46
14	26,76	6,26	63,32	-15,30	1,11	63,38
15	26,69	4,88	63,17	-17,79	1,35	63,16
16	28,54	3,25	63,37	-14,74	1,07	63,25
17	27,68	5,47	63,23	-15,85	1,20	63,23
18	30,87	6,99	63,56	-15,70	1,21	63,61
19	30,90	-11,96	63,88	-15,64	1,19	64,19
20	30,96	3,60	63,05	-16,22	1,28	63,60
21	29,03	3,34	63,37	-15,78	1,19	63,28
22	29,14	3,37	62,84	-16,29	1,27	62,94
23	29,22	3,37	63,00	-15,78	1,20	63,04
24	28,28	3,19	63,14	-15,85	1,20	63,00

Table C-9 – Test case 14 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	13	14	0,002
SE D1 - TRANS 2	TRANS	12	4	0,032

SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D7 - TRANS 1	TRANS	7	1	0,024
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	13	14	0,003
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 3				
No equipment changed in this period.				
Period(Hour) = 4				
No equipment changed in this period.				
Period(Hour) = 5				
No equipment changed in this period.				
Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				
No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
REN T1 - CAP 1	CAPAC	40	0	0,04
Period(Hour) = 11				
No equipment changed in this period.				
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 13				
No equipment changed in this period.				
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 15				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - WIND 1	SYNCGQ	0	0,1	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 16				
No equipment changed in this period.				
Period(Hour) = 17				

Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D1 - TRANS 2	TRANS	4	5	0,004
SE D1 - WIND 1	SYNCGQ	0	0,2	0
SE D3&D4 - PV 1	SYNCGQ	0	0,1	0
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - TRANS 2	TRANS	5	4	0,004
SE D1 - WIND 1	SYNCGQ	0	0,2	0
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	14	16	0,006
SE D1 - TRANS 2	TRANS	4	3	0,004
SE D1 - CAP 1	CAPAC	0	8,1	0,008
D3&D4 - CAP 3	CAPAC	0	3,4	0,003
D3&D4 - CAP 1	CAPAC	0	3,4	0,003
SE D1 - WIND 1	SYNCGQ	0	0,2	0
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	14	8	0,012
SE D3&D4 - TRANS 2	TRANS	16	14	0,006
SE D1 - TRANS 2	TRANS	3	4	0,004
SE D1 - CAP 1	CAPAC	8,1	0	0,008
D3&D4 - CAP 3	CAPAC	3,4	0	0,003
D3&D4 - CAP 1	CAPAC	3,4	0	0,003
SE D1 - WIND 1	SYNCGQ	0	0,1	0
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	8	16	0,016
SE D1 - TRANS 2	TRANS	4	12	0,032
Period(Hour) = 22				
No equipment changed in this period.				
Period(Hour) = 23				
No equipment changed in this period.				
Period(Hour) = 24				
No equipment changed in this period.				

Annex D – Cluster 4 simulation results

Table D-1 – Starting scenario results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	26,00	2,57	63,82	-17,70	1,67	63,82
2	28,04	2,87	64,03	-15,02	1,35	64,07
3	26,00	2,56	63,87	-14,74	1,30	63,92
4	25,00	2,43	63,60	-15,63	1,41	63,09
5	26,00	2,56	63,99	-14,71	1,30	63,45
6	24,99	2,40	64,60	-16,15	1,43	64,56
7	25,00	2,43	63,56	-16,76	1,56	62,97
8	27,02	2,73	63,72	-16,29	1,52	63,17
9	30,08	3,21	63,41	-16,47	1,58	63,12
10	29,06	3,01	64,13	-15,88	1,49	63,33
11	29,06	3,00	64,51	-16,27	1,51	64,26
12	28,04	2,87	64,21	-15,83	1,45	64,00
13	29,06	2,94	64,20	-16,84	1,60	63,46
14	28,04	2,87	64,11	-15,33	1,40	63,38
15	28,04	1,50	63,96	-17,82	1,65	63,16
16	30,07	3,18	64,09	-14,77	1,36	63,25
17	29,06	3,02	63,99	-15,88	1,49	63,22
18	32,10	3,49	64,35	-15,73	1,50	63,61
19	32,10	3,49	64,33	-15,67	1,48	64,19
20	32,11	3,52	63,76	-16,25	1,57	63,59
21	30,07	3,18	64,08	-15,81	1,49	63,28
22	30,08	3,20	63,55	-16,32	1,56	62,93
23	30,08	3,20	63,71	-15,81	1,49	63,04
24	29,07	3,02	63,85	-15,88	1,50	62,99

Table D-2 – Test case 11 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	26,11	2,70	63,82	-17,67	1,37	63,82
2	28,14	3,06	64,02	-14,99	1,05	64,07
3	26,11	2,70	63,87	-14,71	0,99	63,92
4	25,10	2,56	63,60	-15,62	1,11	63,10
5	26,11	2,70	63,99	-14,69	1,00	63,45
6	25,09	2,52	64,60	-16,14	1,14	64,57
7	25,10	2,56	63,56	-16,75	1,26	62,97
8	27,12	2,89	63,72	-16,26	1,23	63,18
9	30,20	3,43	63,41	-16,44	1,28	63,13
10	29,17	3,22	64,13	-15,85	1,19	63,34
11	29,16	3,20	64,51	-16,24	1,22	64,26
12	28,14	3,05	64,20	-15,80	1,15	64,01

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
13	29,17	3,14	64,19	-16,81	1,30	63,46
14	28,14	3,06	64,11	-15,30	1,11	63,38
15	28,14	1,68	63,95	-17,79	1,35	63,16
16	30,19	3,39	64,09	-14,74	1,07	63,25
17	29,17	3,22	63,99	-15,85	1,20	63,23
18	32,23	3,76	64,34	-15,70	1,21	63,61
19	32,23	3,76	64,32	-15,64	1,19	64,19
20	32,23	3,79	63,76	-16,22	1,28	63,60
21	30,19	3,39	64,08	-15,78	1,19	63,28
22	30,20	3,42	63,54	-16,29	1,27	62,94
23	30,19	3,41	63,70	-15,78	1,20	63,04
24	29,17	3,23	63,85	-15,85	1,20	63,00

Table D-3 – Test case 11 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	8	0
SE D3&D4 - TRANS 2	TRANS	13	19	0
SE D1 - TRANS 2	TRANS	12	4	0
SE D7 - TRANS 1	TRANS	7	1	0
Period(Hour) = 2				
No equipment changed in this period.				
Period(Hour) = 3				
No equipment changed in this period.				
Period(Hour) = 4				
No equipment changed in this period.				
Period(Hour) = 5				
No equipment changed in this period.				
Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				
No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
No equipment changed in this period.				
Period(Hour) = 10				
No equipment changed in this period.				
Period(Hour) = 11				
No equipment changed in this period.				
Period(Hour) = 12				
No equipment changed in this period.				

Period(Hour) = 13				
No equipment changed in this period.				
Period(Hour) = 14				
No equipment changed in this period.				
Period(Hour) = 15				
No equipment changed in this period.				
Period(Hour) = 16				
No equipment changed in this period.				
Period(Hour) = 17				
No equipment changed in this period.				
Period(Hour) = 18				
No equipment changed in this period.				
Period(Hour) = 19				
No equipment changed in this period.				
Period(Hour) = 20				
No equipment changed in this period.				
Period(Hour) = 21				
No equipment changed in this period.				
Period(Hour) = 22				
No equipment changed in this period.				
Period(Hour) = 23				
No equipment changed in this period.				
Period(Hour) = 24				
No equipment changed in this period.				

Table D-4 – Test case 12 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	26,11	2,70	63,82	-17,67	1,38	63,30
2	28,14	3,06	64,02	-14,99	1,06	63,55
3	26,11	2,70	63,87	-14,72	1,00	63,40
4	25,10	2,56	63,60	-15,62	1,12	62,59
5	26,11	2,70	63,99	-14,68	1,01	62,94
6	25,09	2,52	64,60	-16,14	1,15	64,06
7	25,10	2,56	63,56	-16,75	1,26	62,97
8	27,12	2,89	63,72	-16,26	1,23	63,18
9	30,20	3,43	63,41	-16,44	1,28	63,13
10	29,17	3,22	64,13	-15,85	1,19	63,34
11	29,16	3,20	64,51	-16,24	1,23	63,73
12	28,14	3,05	64,20	-15,80	1,17	63,47
13	29,17	3,14	64,19	-16,81	1,30	63,46
14	28,14	3,06	64,11	-15,30	1,11	63,38
15	28,14	1,68	63,95	-17,79	1,35	63,16
16	30,19	3,39	64,09	-14,74	1,07	63,25
17	29,17	3,22	63,99	-15,85	1,20	63,23

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
18	32,23	3,76	64,34	-15,70	1,21	63,61
19	32,23	3,76	64,32	-15,64	1,20	63,69
20	32,23	3,79	63,76	-16,22	1,29	63,09
21	30,19	3,39	64,08	-15,78	1,19	63,28
22	30,20	3,42	63,54	-16,29	1,27	62,94
23	30,19	3,41	63,70	-15,78	1,20	63,04
24	29,17	3,23	63,85	-15,85	1,20	63,00

Table D-5 – Test case 12 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	8	0
SE D3&D4 - TRANS 2	TRANS	13	19	0
SE D1 - TRANS 2	TRANS	12	4	0
SE D7 - TRANS 1	TRANS	7	1	0
REN T2 - CAP 1	CAPAC	30	0	0
Period(Hour) = 2				
No equipment changed in this period.				
Period(Hour) = 3				
No equipment changed in this period.				
Period(Hour) = 4				
No equipment changed in this period.				
Period(Hour) = 5				
No equipment changed in this period.				
Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				
No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
No equipment changed in this period.				
Period(Hour) = 10				
No equipment changed in this period.				
Period(Hour) = 11				
No equipment changed in this period.				
Period(Hour) = 12				
No equipment changed in this period.				
Period(Hour) = 13				
No equipment changed in this period.				
Period(Hour) = 14				
No equipment changed in this period.				

Period(Hour) = 15				
No equipment changed in this period.				
Period(Hour) = 16				
No equipment changed in this period.				
Period(Hour) = 17				
No equipment changed in this period.				
Period(Hour) = 18				
No equipment changed in this period.				
Period(Hour) = 19				
No equipment changed in this period.				
Period(Hour) = 20				
No equipment changed in this period.				
Period(Hour) = 21				
No equipment changed in this period.				
Period(Hour) = 22				
No equipment changed in this period.				
Period(Hour) = 23				
No equipment changed in this period.				
Period(Hour) = 24				
No equipment changed in this period.				

Table D-6 – Test case 15 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	26,11	2,70	63,82	-17,67	1,37	63,82
2	28,14	3,06	64,02	-14,99	1,05	64,07
3	26,27	6,25	63,81	-14,71	0,99	63,92
4	25,26	6,11	63,54	-15,62	1,11	63,10
5	26,27	6,25	63,92	-14,69	1,00	63,45
6	25,25	6,07	64,54	-16,14	1,14	64,57
7	25,26	6,11	63,50	-16,75	1,26	62,97
8	27,28	6,44	63,65	-16,26	1,23	63,18
9	30,32	6,12	63,36	-16,44	1,28	63,13
10	29,33	6,77	64,06	-15,85	1,19	63,34
11	29,33	6,75	64,44	-16,24	1,22	64,26
12	28,30	6,60	64,14	-15,80	1,15	64,01
13	29,33	6,69	64,13	-16,81	1,30	63,46
14	28,31	6,61	64,04	-15,30	1,11	63,38
15	28,30	5,23	63,89	-17,79	1,35	63,16
16	30,35	6,94	64,02	-14,74	1,07	63,25
17	29,33	6,77	63,93	-15,85	1,20	63,23
18	32,39	7,31	64,28	-15,70	1,21	63,61
19	32,39	7,31	64,26	-15,64	1,19	64,19
20	32,40	7,35	63,69	-16,22	1,28	63,60
21	30,35	6,95	64,02	-15,78	1,19	63,28

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
22	30,36	6,97	63,48	-16,29	1,27	62,94
23	30,36	6,96	63,64	-15,78	1,20	63,04
24	29,34	6,78	63,79	-15,85	1,20	63,00

Table D-7 – Test case 15 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	10	0,006
SE D1 - TRANS 2	TRANS	12	4	0,032
SE D7 - TRANS 1	TRANS	7	1	0,024
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	7	0,006
Period(Hour) = 3				
No equipment changed in this period.				
Period(Hour) = 4				
No equipment changed in this period.				
Period(Hour) = 5				
No equipment changed in this period.				
Period(Hour) = 6				
No equipment changed in this period.				
Period(Hour) = 7				
No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - TRANS 2	TRANS	4	5	0,004
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	7	3	0,008
SE D3&D4 - TRANS 2	TRANS	13	19	0,018
SE D1 - TRANS 2	TRANS	5	4	0,004
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	3	11	0,016
SE D3&D4 - TRANS 2	TRANS	19	21	0,006
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	11	18	0,014
SE D3&D4 - TRANS 2	TRANS	21	24	0,009
Period(Hour) = 13				

Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	18	6	0,024
SE D3&D4 - TRANS 2	TRANS	24	22	0,006
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	17	0,022
SE D3&D4 - TRANS 2	TRANS	22	21	0,003
Period(Hour) = 15				
No equipment changed in this period.				
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	16	0,002
SE D3&D4 - TRANS 2	TRANS	21	24	0,009
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	16	12	0,008
SE D3&D4 - TRANS 2	TRANS	24	22	0,006
Period(Hour) = 18				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	11	0,002
SE D3&D4 - TRANS 2	TRANS	22	21	0,003
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	11	18	0,014
SE D3&D4 - TRANS 2	TRANS	21	24	0,009
Period(Hour) = 20				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	18	6	0,024
SE D3&D4 - TRANS 2	TRANS	24	22	0,006
Period(Hour) = 21				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	6	17	0,022
SE D3&D4 - TRANS 2	TRANS	22	21	0,003
Period(Hour) = 22				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	17	16	0,002
SE D3&D4 - TRANS 2	TRANS	21	24	0,009
Period(Hour) = 23				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	16	18	0,004
Period(Hour) = 24				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	18	21	0,006
SE D3&D4 - TRANS 2	TRANS	24	14	0,03

Table D-8 – Test case 16 results data

Hour	T1 P (MW)	T1 Q (Mvar)	T1 U (kV)	T2 P (MW)	T2 Q (Mvar)	T2 U (kV)
1	26,11	2,70	63,82	-17,67	1,37	63,82
2	28,14	3,06	64,02	-14,99	1,05	64,07
3	26,27	6,25	63,81	-14,71	0,99	63,92
4	25,26	6,11	63,54	-15,62	1,11	63,10
5	26,27	6,25	63,92	-14,69	1,00	63,45
6	25,25	6,07	64,54	-16,14	1,14	64,57
7	25,26	6,11	63,50	-16,75	1,26	62,97
8	27,28	6,44	63,65	-16,26	1,23	63,18
9	30,32	6,12	63,36	-16,44	1,28	63,13
10	29,35	6,80	63,32	-15,85	1,19	63,34
11	29,34	6,78	63,69	-16,24	1,22	64,26
12	28,17	-8,72	63,67	-15,80	1,15	64,01
13	29,18	3,18	63,45	-16,81	1,30	63,46
14	28,15	3,09	63,38	-15,30	1,11	63,38
15	28,31	5,26	63,16	-17,79	1,35	63,16
16	30,35	3,10	63,37	-14,74	1,07	63,25
17	29,35	6,81	63,20	-15,85	1,20	63,23
18	32,26	-3,97	63,75	-15,70	1,21	63,61
19	32,24	3,80	63,61	-15,64	1,19	64,19
20	32,41	7,38	62,99	-16,22	1,28	63,60
21	30,36	6,98	63,30	-15,78	1,19	63,28
22	30,37	7,01	62,77	-16,29	1,27	62,94
23	30,37	7,00	62,93	-15,78	1,20	63,04
24	29,34	6,81	63,08	-15,85	1,20	63,00

Table D-9 – Test case 16 equipment change proposals from FS

Period(Hour) = 1				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	13	10	0,006
SE D1 - TRANS 2	TRANS	12	4	0,032
SE D7 - TRANS 1	TRANS	7	1	0,024
Period(Hour) = 2				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	7	0,006
Period(Hour) = 3				
No equipment changed in this period.				
Period(Hour) = 4				
No equipment changed in this period.				
Period(Hour) = 5				
No equipment changed in this period.				
Period(Hour) = 6				

No equipment changed in this period.				
Period(Hour) = 7				
No equipment changed in this period.				
Period(Hour) = 8				
No equipment changed in this period.				
Period(Hour) = 9				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D1 - TRANS 2	TRANS	4	5	0,004
Period(Hour) = 10				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	7	9	0,004
SE D1 - TRANS 2	TRANS	5	4	0,004
REN T1 - CAP 1	CAPAC	40	0	0,04
Period(Hour) = 11				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	9	10	0,002
SE D3&D4 - TRANS 2	TRANS	13	11	0,006
Period(Hour) = 12				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	11	3	0,024
SE D1 - CAP 1	CAPAC	0	8,1	0,008
D3&D4 - CAP 1	CAPAC	0	3,4	0,003
Period(Hour) = 13				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	10	12	0,004
SE D3&D4 - TRANS 2	TRANS	3	4	0,003
SE D1 - CAP 1	CAPAC	8,1	0	0,008
D3&D4 - CAP 1	CAPAC	3,4	0	0,003
Period(Hour) = 14				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	12	11	0,002
SE D3&D4 - TRANS 2	TRANS	4	6	0,006
Period(Hour) = 15				
No equipment changed in this period.				
Period(Hour) = 16				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	11	10	0,002
SE D3&D4 - TRANS 2	TRANS	6	7	0,003
D3&D4 - CAP 4	CAPAC	0	3,4	0,003
Period(Hour) = 17				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 2	TRANS	7	6	0,003
D3&D4 - CAP 4	CAPAC	3,4	0	0,003
Period(Hour) = 18				

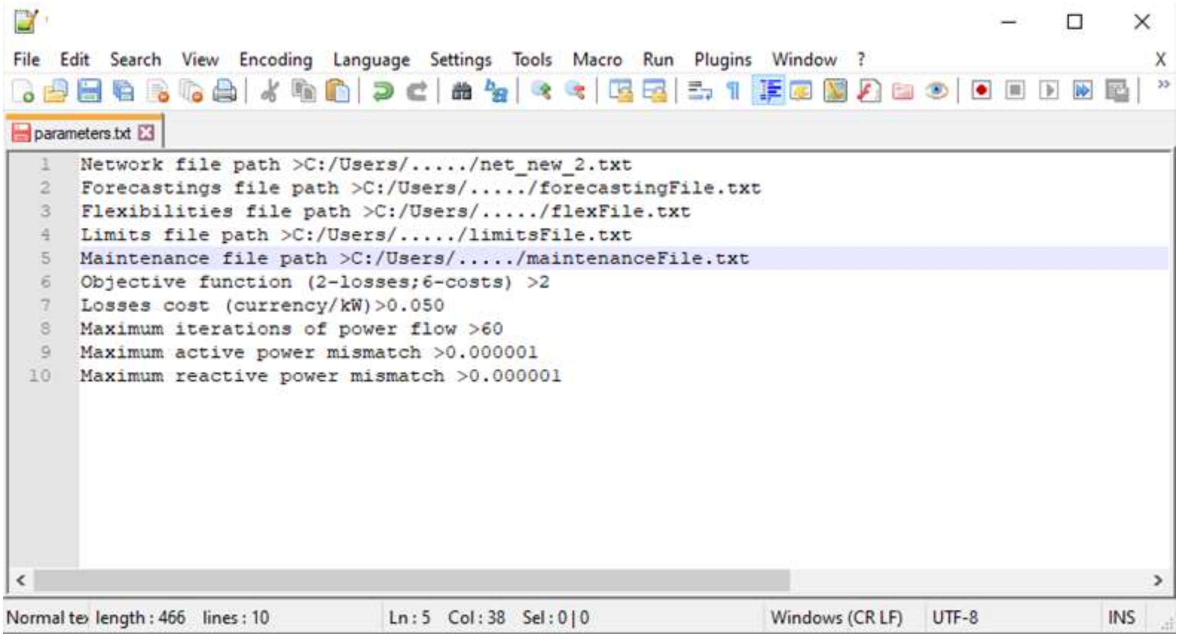
Name/Designation	EqpType	InitPos	FinalPos	dCost
SE D3&D4 - TRANS 1	TRANS	10	9	0,002
SE D3&D4 - TRANS 2	TRANS	6	3	0,009
D3&D4 - CAP 3	CAPAC	0	3,4	0,003
D3&D4 - CAP 1	CAPAC	0	3,4	0,003
Period(Hour) = 19				
Name/Designation	**EqpType**	**InitPos**	**FinalPos**	**dCost**
SE D3&D4 - TRANS 1	TRANS	9	8	0,002
SE D3&D4 - TRANS 2	TRANS	3	2	0,003
D3&D4 - CAP 3	CAPAC	3,4	0	0,003
D3&D4 - CAP 1	CAPAC	3,4	0	0,003
Period(Hour) = 20				
No equipment changed in this period.				
Period(Hour) = 21				
No equipment changed in this period.				
Period(Hour) = 22				
No equipment changed in this period.				
Period(Hour) = 23				
No equipment changed in this period.				
Period(Hour) = 24				
No equipment changed in this period.				

Annex E – Flexibility Scheduler User Interface Details

Flexibility Scheduler input data

Configuration file

An example of the configuration file is presented in the figure below.



```
Network file path >C:/Users/...../net_new_2.txt
Forecastings file path >C:/Users/...../forecastingFile.txt
Flexibilities file path >C:/Users/...../flexFile.txt
Limits file path >C:/Users/...../limitsFile.txt
Maintenance file path >C:/Users/...../maintenanceFile.txt
Objective function (2-losses;6-costs) >2
Losses cost (currency/kW)>0.050
Maximum iterations of power flow >60
Maximum active power mismatch >0.000001
Maximum reactive power mismatch >0.000001
```

Figure E-1 – Configuration file example

The parameters to be passed are defined in the following table.

Table E-1 – Configuration file parameters.

Parameter	Description
1	Path to the network file
2	Path to the forecast file
3	Path to the flexibility file
4	Path to the limits file
5	Path to the maintenance file
6	Objective function to be used by the FS (2 for losses minimization and 6 for costs minimization)
7	Losses cost
8	Number of iterations of the internal power flow algorithm
9	Maximum error mismatch for the active power during the power flow calculation
10	Maximum error mismatch for the reactive power during the power flow calculation

Network file

The figure below, shows an example of the network file. It should be noted that many of the fields are not visualized due to the length of the file. The FS is prepared to deal with a wide variety of equipment that can be found in an electrical grid and allows for substantial detail in the modelling of each type. For the sake of comprehension, only the most important fields will be described next in this manual.

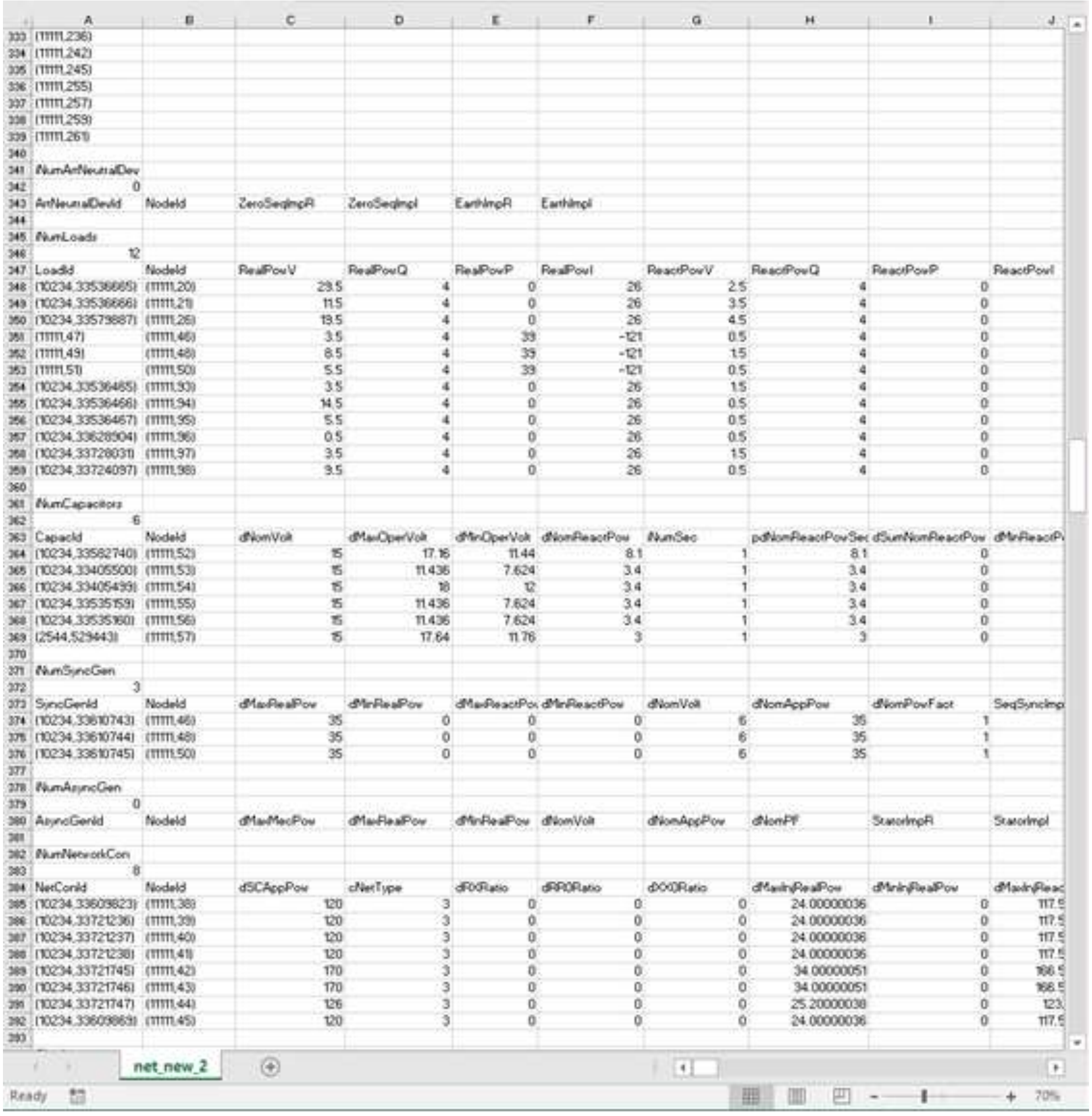


Figure E-2 – Network file example

The following tables contain the names and descriptions of the main fields of data contained in the Network file.

Table E-2 – General fields of Network file.

Field name	Field description
iStepsHorizonUC	Number of periods to be considered during the optimization
iMinutePerInterval	Duration of each period (minutes)

Table E-3 – Network file node equipment fields.

Field name	Field description
iNumNodes	Number of nodes of the network

Field name	Field description
NodeId	Identifier of the node [format: (012345,012345)] (Note: all the Ids use this format)
BusbarOwnerId	Busbar where the node belongs to
VoltMeasMagV	Voltage magnitude measurement
VoltMeasMagQ	Quality status of the voltage magnitude measurement (-1: invalid; 0: valid)
SpecVoltMagV	Specified voltage magnitude of this equipment

Table E-4 – Load equipment fields of Network file.

Field name	Field description
iNumLoads	Number of loads in the network
LoadId	Identifier of the load
NodeId	Identifier of the node where the equipment is located
RealPowV	Active power measurement value
RealPowQ	Quality status of the measurement (-1: invalid; 0: valid)
ReactPowV	Reactive power measurement value
ReactPowQ	Quality status of the measurement (-1: invalid; 0: valid)
CurrentMagV	Current magnitude measurement value
CurrentMagQ	Quality status of the measurement (-1: invalid; 0: valid)
ApparentPowerV	Apparent power measurement value
ApparentPowerQ	Quality status of the measurement (-1: invalid; 0: valid)
CurrentPowFactorV	Power factor measurement value
CurrentPowFactorQ	Quality status of the measurement (-1: invalid; 0: valid)
VoltageMagV	Voltage magnitude measurement value
VoltageMagQ	Quality status of the measurement (-1: invalid; 0: valid)
dNomAppPow	Nominal apparent power of the load
dMedPowFactor	Average power factor
dPowRate	Maximum power rate for this load
cLoadStatus	status field (bitwise field)

Table E-5 – Capacitor bank equipment fields of Network file.

Field name	Field description
iNumCapacitors	Number of capacitor banks in the network
CapacId	Identifier of the equipment
NodeId	Identifier of the node where it is located
dNomVolt	Nominal voltage
dMaxOperVolt	Maximum operation voltage
dMinOperVolt	Minimum operation voltage
dNomReactPow	Nominal reactive power
iNumSec	Number of sections (taps) of the capacitor bank
pdNomReactPowSec1	[Array:size=iNumSec] Nominal reactive power for the first section. If there are more than one section, there will be pdNomReactPowSec2, pdNomReactPowSec3
dSumNomReactPow	Sum of the nominal reactive power of all sections
dMinReactPowOut	Minimum value of reactive power

Field name	Field description
InjReactPowV	Reactive power measurement value
InjReactPowQ	Measurement quality status
InjCurrentV	Current magnitude measurement value
InjCurrentQ	Measurement quality status
InjApparentPowerV	Apparent power measurement value
InjApparentPowerQ	Measurement quality status
VoltageMagV	Voltage magnitude measurement value
VoltageMagQ	Measurement quality status

Table E-6 – Synchronous generator equipment fields of Network file.

Field name	Field description
iNumSyncGen	Number of synchronous generator in the network
SyncGenId	Identifier of the generator
NodeId	Identifier of the node
dMaxRealPow	Maximum active power generated
dMinRealPow	Minimum active power generated
dMaxReactPow	Maximum reactive power generated
dMinReactPow	Minimum reactive power generated
dNomVolt	Nominal voltage
dNomAppPow	Nominal apparent power
dNomPowFact	Nominal power factor
dPartFactor	Participation factor of the generator to the imbalances. [0 (default); 100]
cInd	Type of producer {0 – regular; 1 – independent producer that can also consume; 3 – independent producer that cannot consume]
InjRealPowV	Injected active power measurement
InjRealPowQ	Measurement quality status
InjReactPowV	Reactive power measurement
InjReactPowQ	Measurement quality status
InjCurrentV	Current magnitude measurement
InjCurrentQ	Measurement quality status
InjApparentPowerV	Apparent power measurement
InjApparentPowerQ	Measurement quality status
InjCurrentPFV	Power factor measurement
InjCurrentPFQ	Measurement quality status
VoltageMagV	Voltage magnitude measurement
VoltageMagQ	Measurement quality status

Table E-7 – Network interconnection equipment fields of Network file.

Field name	Field description
iNumNetworkCon	Number of network connections
NetConId	Identifier of the network connection
NodeId	Identifier of the node

Field name	Field description
dMaxInjRealPow	Maximum active power injection
dMinInjRealPow	Minimum active power injection
dMaxInjReactPow	Maximum reactive power injection
dMinInjReactPow	Minimum reactive power injection
dPartFactor	Participation factor of the connection to the imbalances. [0 (default); 100]
InjRealPowV	Active power measurement
InjRealPowQ	Measurement quality status
InjReactPowV	Reactive power measurement
InjReactPowQ	Measurement quality status
InjCurrentV	Current magnitude measurement
InjCurrentQ	Measurement quality status
InjApparentPowerV	Apparent power measurement
InjApparentPowerQ	Measurement quality status
InjCurrentPFV	Power factor measurement
InjCurrentPFQ	Measurement quality status
VoltageMagV	Voltage magnitude measurement
VoltageMagQ	Measurement quality status
dNomVolt	Nominal voltage

Table E-8 – Line equipment fields of Network file.

Field name	Field description
iNumLines	Number of lines
LineId	Identifier of the line
FromNodeId	Identifier of the node FROM
ToNodeId	Identifier of the node TO
SeqSerImpR	Positive sequence series resistance (Ohm/km)
SeqSerImpI	Positive sequence series reactance (Ohm/km)
dNomAppPow	Nominal apparent power
dNomCurrent	Nominal current magnitude
FromRealPowV	Active power measurement FROM > TO
FromRealPowQ	Measurement quality status
FromReactPowV	Reactive power measurement FROM > TO
FromReactPowQ	Measurement quality status
ToRealPowV	Active power measurement TO > FROM
ToRealPowQ	Measurement quality status
ToReactPowV	Reactive power measurement TO > FROM
ToReactPowQ	Measurement quality status
FromCurrentV	Current measurement FROM
FromCurrentQ	Measurement quality status
FromApparentPowerV	Apparent power measurement FROM
FromApparentPowerQ	Measurement quality status
FromCurrentPFV	Power factor measurement FROM
FromCurrentPFQ	Measurement quality status

Field name	Field description
ToCurrentV	Current measurement TO
ToCurrentQ	Measurement quality status
ToApparentPowerV	Apparent power measurement TO
ToApparentPowerQ	Measurement quality status
ToCurrentPFV	Power factor measurement TO
ToCurrentPFQ	Measurement quality status
FromVoltageMagV	Voltage magnitude measurement FROM
FromVoltageMagQ	Measurement quality status
ToVoltageMagV	Voltage magnitude measurement TO
ToVoltageMagQ	Measurement quality status
dLineLength	Line length (km)

Table E-9 – Transformer equipment fields of Network file.

Field name	Field description
iNumTrans	Number of power transformers
TransId	Identifier of the transformers
MagAdmR	Magnetizing resistance of the transformer
MagAdmI	Magnetizing reactance of the transformer
dNomAppPow	Nominal apparent power
TransWindId1	Identifier of the primary winding
TransId1	Identifier of the transformer
NodeId1	Identifier of the primary winding node
cWindconTyp1	Primary winding connection {1-D; 2-Y; 3-Yo}
SeqSerImp1R	Primary winding series resistance
SeqSerImp1I	Primary winding series reactance
NeutEarthImp1R	Primary winding neutral earthing resistance
NeutEarthImp1I	Primary winding neutral earthing reactance
dNomAppPow1	Primary winding nominal apparent power
dNomVolT2	Primary winding nominal voltage
iNomTapPos1	Primary winding nominal tap position
iMaxTapPos1	Primary winding maximum tap position
iMinTapPos1	Primary winding lowest tap position
dStepSizeInc1	Primary winding step size increment
dPhaseShifT2	Primary winding phase shift per step position
ActTapPos1V	Primary winding actual tap position
ActTapPos1Q	Measurement quality status
RealPow1V	Primary winding active power measurement
RealPow1Q	Measurement quality status
ReactPow1V	Primary winding reactive power measurement
ReactPow1Q	Measurement quality status
CurrenT2V	Primary winding current magnitude measurement
CurrenT2Q	Measurement quality status
CurrentPF1V	Primary winding power factor measurement

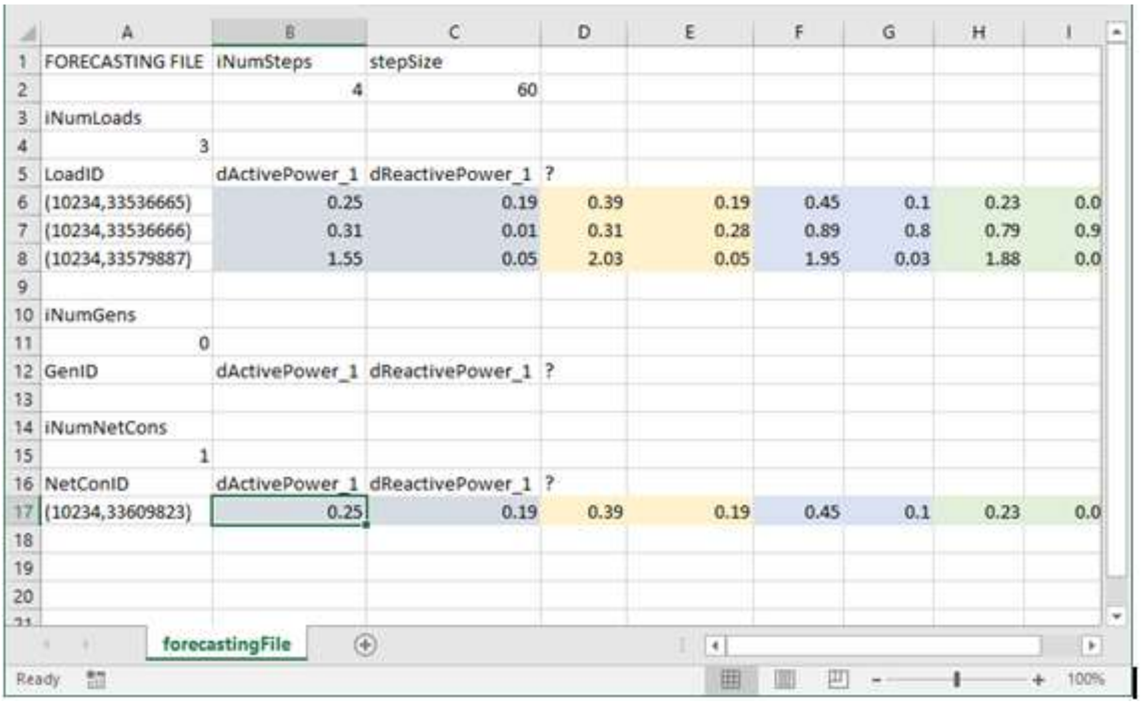
Field name	Field description
CurrentPF1Q	Measurement quality status
ApparentPower1V	Primary winding apparent power measurement
ApparentPower1Q	Measurement quality status
VoltageMag1V	Primary winding voltage magnitude measurement
VoltageMag1Q	Measurement quality status
TransWindId2	Identifier of the secondary winding
TransId2	Identifier of the transformer
NodeId2	Identifier of the secondary winding node
cWindconTyp2	Secondary winding connection {1-D; 2-Y; 3-Yo}
SeqSerImp2R	Secondary winding series resistance
SeqSerImp2I	Secondary winding series reactance
NeutEarthImp2R	Secondary winding neutral earthing resistance
NeutEarthImp2I	Secondary winding neutral earthing reactance
dNomAppPow2	Secondary winding nominal apparent power
dNomVolT1	Secondary winding nominal voltage
iNomTapPos2	Secondary winding nominal tap position
iMaxTapPos2	Secondary winding maximum tap position
iMinTapPos2	Secondary winding lowest tap position
dStepSizeInc2	Secondary winding step size increment
dPhaseShifT1	Secondary winding phase shift per step position
ActTapPos2V	Secondary winding actual tap position
ActTapPos2Q	Measurement quality status
RealPow2V	Secondary winding active power measurement
RealPow2Q	Measurement quality status
ReactPow2V	Secondary winding reactive power measurement
ReactPow2Q	Measurement quality status
CurrenT1V	Secondary winding current magnitude measurement
CurrenT1Q	Measurement quality status
CurrentPF2V	Secondary winding power factor measurement
CurrentPF2Q	Measurement quality status
ApparentPower2V	Secondary winding apparent power measurement
ApparentPower2Q	Measurement quality status
VoltageMag2V	Secondary winding voltage magnitude measurement
VoltageMag2Q	Measurement quality status

Forecast file

It is expected that for each load, generator and network connection there is a forecasted value of active power and value of reactive power for each period of the optimization horizon. The figure below shows an example of a file of this type. Since, in the example, there are 4 optimization periods (iNumSteps = 4), there must be 4 pairs of active and reactive power for each equipment. The first pair corresponds to the forecasted values for the first period, the second pair corresponds to the second period, and so on.

Similar fields of specification are required for all the synchronous generator equipments and network connection equipments.

In the example of forecasts file illustrated by the following figure there are 3 loads and 1 network connection but no synchronous generator.



	A	B	C	D	E	F	G	H	I
1	FORECASTING FILE	iNumSteps	stepSize						
2		4	60						
3	iNumLoads								
4	3								
5	LoadID	dActivePower_1	dReactivePower_1	?					
6	(10234,33536665)	0.25	0.19	0.39	0.19	0.45	0.1	0.23	0.0
7	(10234,33536666)	0.31	0.01	0.31	0.28	0.89	0.8	0.79	0.9
8	(10234,33579887)	1.55	0.05	2.03	0.05	1.95	0.03	1.88	0.0
9									
10	iNumGens								
11	0								
12	GenID	dActivePower_1	dReactivePower_1	?					
13									
14	iNumNetCons								
15	1								
16	NetConID	dActivePower_1	dReactivePower_1	?					
17	(10234,33609823)	0.25	0.19	0.39	0.19	0.45	0.1	0.23	0.0

Figure E-3 – Forecast file example

The following tables contain the names and descriptions of the main fields of data contained in the Forecast file.

Table E-10 – General fields of Forecast file.

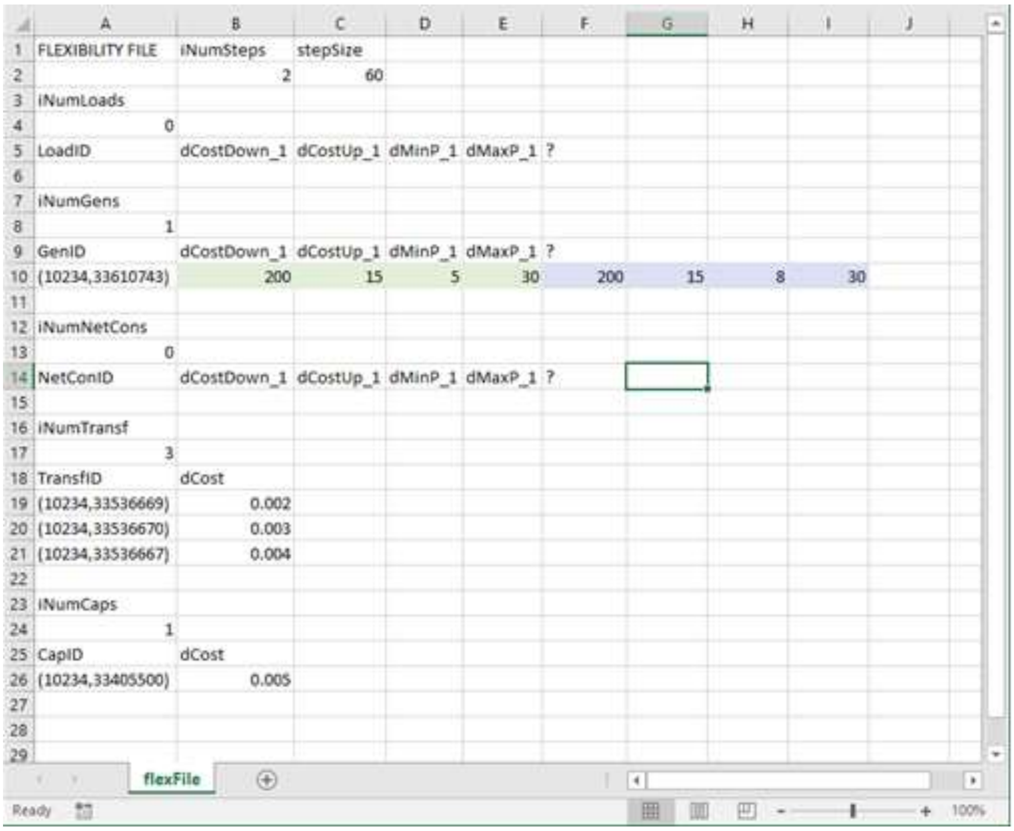
Field name	Field description
iNumSteps	Number of periods to be considered during the optimization
stepSize	Duration of each period

Table E-11 – Load equipement fields of Forecast file.

Field name	Field description
iNumLoads	Number of loads with forecasts
LoadID	Identifier of the load
dActivePower_1	Active power forecast for the first period [Array:size=iNumSteps]
dReactivePower_1	Reactive power forecast for the first period [Array:size=iNumSteps]

Flexibility file

From this file the algorithm gets to know which equipment can provide flexibility and at what cost (in the case of costs optimization). Figure below illustrates how the file should be filled using a simulation for two periods ahead. Values with blue background for first period and with green background for second period).



	A	B	C	D	E	F	G	H	I
1	FLEXIBILITY FILE	iNumSteps	stepSize						
2		2	60						
3	iNumLoads								
4	0								
5	LoadID	dCostDown_1	dCostUp_1	dMinP_1	dMaxP_1	?			
7	iNumGens								
8	1								
9	GenID	dCostDown_1	dCostUp_1	dMinP_1	dMaxP_1	?			
10	(10234,33610743)	200	15	5	30	200	15	8	30
12	iNumNetCons								
13	0								
14	NetConID	dCostDown_1	dCostUp_1	dMinP_1	dMaxP_1	?			
16	iNumTransf								
17	3								
18	TransfID	dCost							
19	(10234,33536669)	0.002							
20	(10234,33536670)	0.003							
21	(10234,33536667)	0.004							
23	iNumCaps								
24	1								
25	CapID	dCost							
26	(10234,33405500)	0.005							

Figure E-4 – Flexibility file example

The following tables contain the names and descriptions of the main fields of data contained in the Flexibility file.

Table E-12 – General fields of Flexibility file.

Field name	Field description
iNumSteps	Number of periods to be considered during the optimization
stepSize	Duration of each period

Table E-13 – Load equipement fields of Flexibility file.

Field name	Field description
iNumLoads	Number of loads with forecasts
LoadId	Identifier of the load
dCostDown_1	Cost of reducing consumption during the first period [Array:size=iNumSteps]
dCostUp_1	Cost of increasing consumption during the first period [Array:size=iNumSteps]
dMinP_1	Lowest value of active power (limit for the reduction) during the first period [Array:size=iNumSteps]
dMaxP_1	Highest value of active power (limit for the increase) during the first period [Array:size=iNumSteps]

Table E-14 – Generator equipement fields of Flexibility file.

Field name	Field description
iNumGens	Number of generators in this file
GenID	Identifier of the generator
dCostDown_1	Cost of reducing generation during the first period [Array:size=iNumSteps]
dCostUp_1	Cost of increasing generation during the first period [Array:size=iNumSteps]
dMinP_1	Lowest value of active power (limit for the reduction) during the first period [Array:size=iNumSteps]
dMaxP_1	Highest value of active power (limit for the increase) during the first period [Array:size=iNumSteps]

Table E-15 – Network connection equipement fields of Flexibility file.

Field name	Field description
iNumNetCons	Number of network connections in this file
NetConID	Identifier of the network connection
dCostDown_1	Cost of reducing power injection during the first period [Array:size=iNumSteps]
dCostUp_1	Cost of increasing power injection during the first period [Array:size=iNumSteps]
dMinP_1	Lowest value of active power (limit for the reduction) during the first period [Array:size=iNumSteps]
dMaxP_1	Highest value of active power (limit for the increase) during the first period [Array:size=iNumSteps]

Table E-16 – Power transformer equipement fields of Flexibility file.

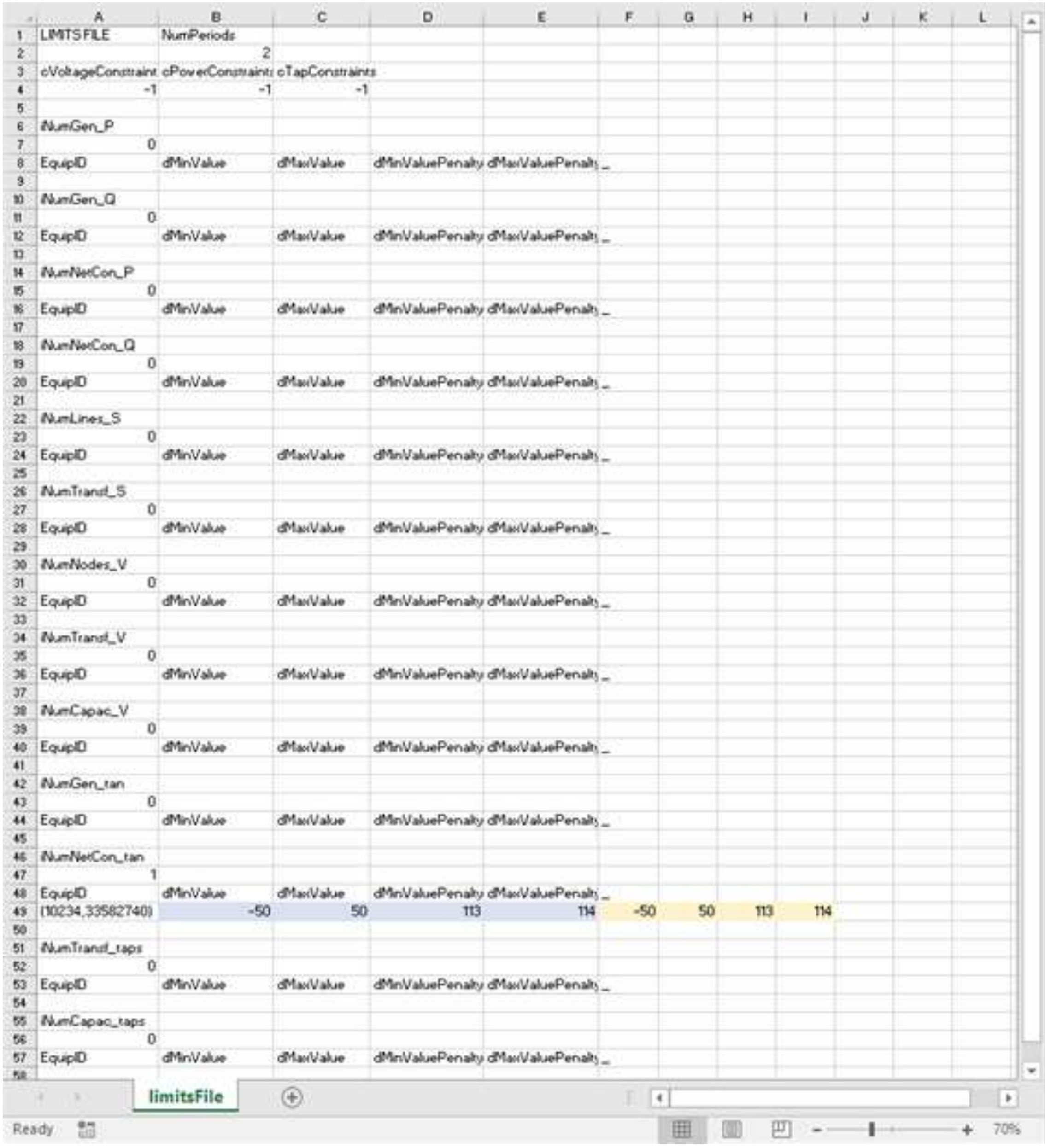
Field name	Field description
iNumTransf	Number of power transformers in this file
TransfId	Identifier of the transformer
dCost	Cost of changing a tap position (similar cost for each time step)

Table E-17 – Capacitor bank equipement fields of Flexibility file.

Field name	Field description
iNumCaps	Number of capacitor banks in this file
CapacId	Identifier of the capacitor bank
dCost	Cost of changing a capacitor block (similar cost for each time step)

Limits file

This file is used to enforce constraints through penalizations when violated. In the scope of this project only the constraint regarding the ratio between reactive and active power ($\tan\varphi$) at interconnections and generators is to be considered. The figure below illustrates how the file should be filled using a simulation for two periods ahead.



	A	B	C	D	E	F	G	H	I
1	LIMITSFILE	NumPeriods							
2		2							
3	cVoltageConstraint	cPowerConstraints	cTapConstraints						
4	-1	-1	-1						
5									
6	iNumGen_P								
7	0								
8	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
9									
10	iNumGen_Q								
11	0								
12	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
13									
14	iNumNetCon_P								
15	0								
16	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
17									
18	iNumNetCon_Q								
19	0								
20	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
21									
22	iNumLines_S								
23	0								
24	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
25									
26	iNumTransf_S								
27	0								
28	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
29									
30	iNumNodes_V								
31	0								
32	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
33									
34	iNumTransf_V								
35	0								
36	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
37									
38	iNumCapac_V								
39	0								
40	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
41									
42	iNumGen_tan								
43	0								
44	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
45									
46	iNumNetCon_tan								
47	1								
48	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
49	(10234,33582740)	-50	50	113	114	-50	50	113	114
50									
51	iNumTransf_taps								
52	0								
53	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			
54									
55	iNumCapac_taps								
56	0								
57	EquipID	dMinValue	dMaxValue	dMinValuePenalty	dMaxValuePenalty	_			

Figure E-5 – Limits file example

The following tables contain the names and descriptions of the main fields of data contained in the Limits file.

Table E-18 – General fields of Limits file.

Field name	Field description
iNumSteps	Number of periods to be considered during the optimization

Table E-19 – Generator equipement fields of Forecast file.

Field name	Field description
iNumGen_tan	Number of generators to enforce the tan φ constraint
EquipID	Identifier of the generator

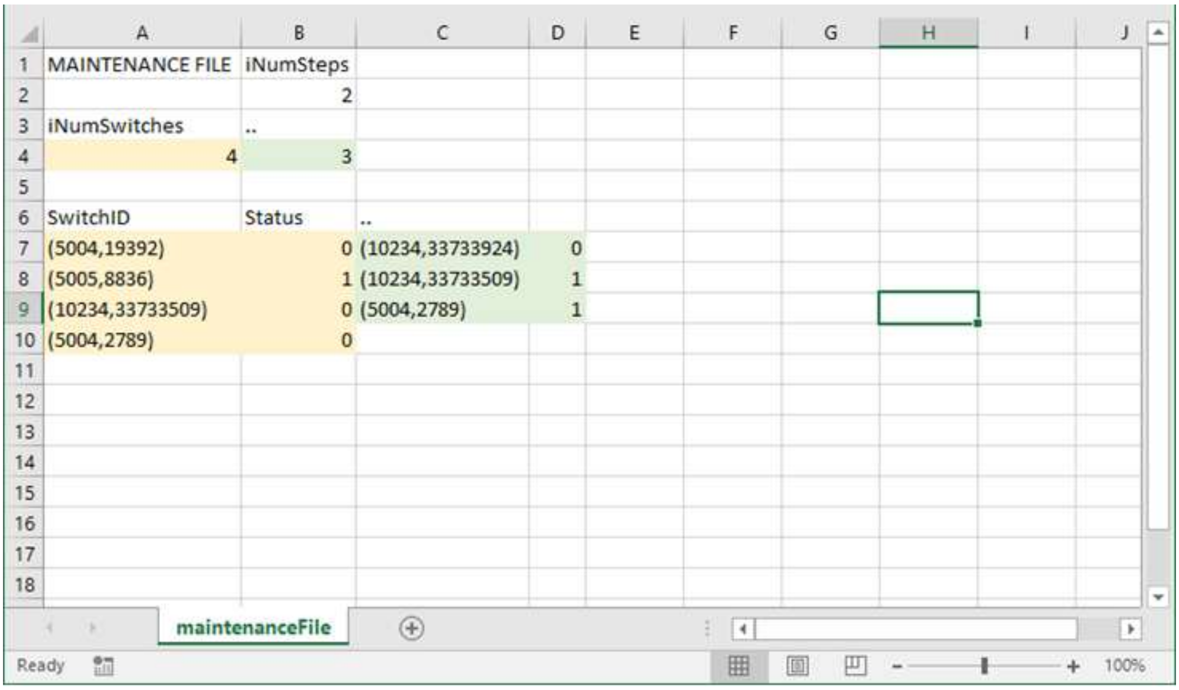
Field name	Field description
dMinValue	Minimum value of tan φ
dMaxValue	Maximum value of tan φ
dMinValuePenalty	Penalty if minimum value is violated [Array:size=iNumSteps]
dMaxValuePenalty	Penalty if maximum value is violated [Array:size=iNumSteps]

Table E-20 – Network connection equipement fields of Forecast file.

Field name	Field description
iNumNetCon_tan	Number of generators to enforce the tan φ constraint
EquipID	Identifier of the network connection
dMinValue	Minimum value of tan φ
dMaxValue	Maximum value of tan φ
dMinValuePenalty	Penalty if minimum value is violated [Array:size=iNumSteps]
dMaxValuePenalty	Penalty if maximum value is violated [Array:size=iNumSteps]

Maintenance file

This file allows the user to provide information about maintenances happening in the network during the optimization horizon. To accomplish this, the position of each switching device that will be maneuvered must be specified for each period. The figure below illustrates how the file should be filled using a simulation for two periods ahead.



	A	B	C	D
1	MAINTENANCE FILE	iNumSteps		
2		2		
3	iNumSwitches	..		
4	4	3		
5				
6	SwitchID	Status	..	
7	(5004,19392)	0	(10234,33733924)	0
8	(5005,8836)	1	(10234,33733509)	1
9	(10234,33733509)	0	(5004,2789)	1
10	(5004,2789)	0		

Figure E-6 – Maintenance file example

The following table contains the names and descriptions of the main fields of data contained in the Maintenance file.

Table E-21 – General fields of Maintenance file.

Field name	Field description
iNumSteps	Number of periods to be considered during the optimization
iNumSwitches	Number of switches whose position will be changed for each period [Array:size=iNumSteps]
SwitchID	Identifier of the switch [Array:size=iNumSteps]
Status	Position of the switch {0-open; 1-closed} [Array:size=iNumSteps]

Flexibility Scheduler results

After every run of the FS a set of files is produced, namely:

- **Global results file**
  - Shows a summary of results from all simulation periods.
- **Global results per period file**
  - Displays the Global results of a simulation period, we will have as many files as there are simulation periods
- **Equipment results per period file**
  - Displays the detailed results of each of the different types of equipment for a simulation period, once again here we will have as many files as there are simulation periods

Global results file

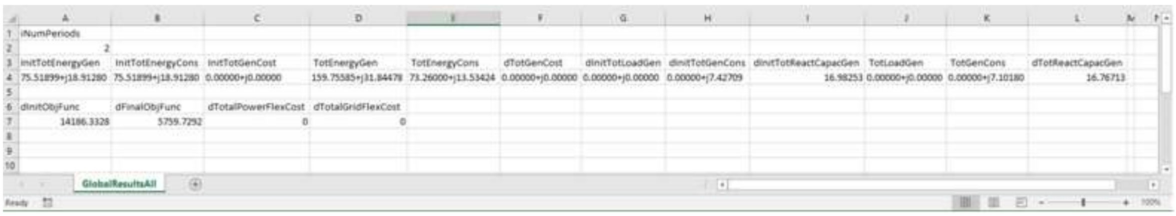


Figure E-7 – Global results file

The following table contains the names and descriptions of the main fields of data contained in the Global results file.

Table E-22 – Data fields of "Global results" file.

Field name	Field description
iNumPeriods	Number of periods optimized
InitTotEnergyGen	Initial total real and reactive energy generation
InitTotEnergyCons	Initial total real and reactive energy consumption
InitTotGenCost	Initial total active and reactive energy generation cost
TotEnergyGen	Final total real and reactive energy generation
TotEnergyCons	Final total real and reactive energy consumption
dTotGenCost	Final total active and reactive energy generation cost
dInitTotLoadGen	Initial total real and reactive energy generation by the loads
dInitTotGenCons	Initial total real and reactive energy consumption by the generators
dInitTotReactCapacGen	Initial total reactive energy generated by capacitor banks
TotLoadGen	Final total real and reactive energy generation by the loads

Field name	Field description
TotGenCons	Final total real and reactive energy consumption by the generators
dTotReactCapacGen	Final total reactive energy generated by capacitor banks
dInitObjFunc	Initial value of the objective function
dFinalObjFunc	Final value of the objective function
dTotalPowerFlexCost	Total cost of activating power flexibility
dTotalGridFlexCost	Total cost of activating grid flexibility

Global results per period

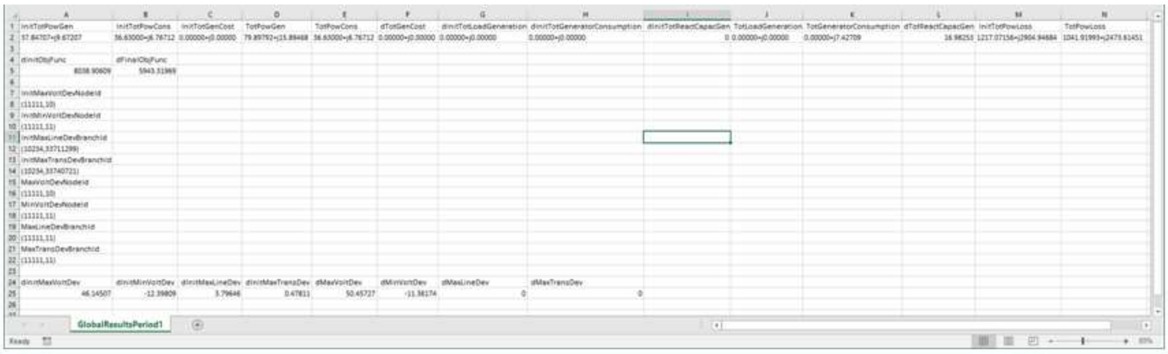


Figure E-8 – Global results per period file

The following table contains the names and descriptions of the main fields of data contained in the Global results per period file.

Table E-23 – Data fields of "Global results per period" file.

Field name	Field description
InitTotPowGen	Initial total real and reactive power generation
InitTotPowCons	Initial total real and reactive power consumption
InitdTotGenCost	Initial total active and reactive power generation cost
TotPowGen	Final total real and reactive power generation
TotPowCons	Final total real and reactive power consumption
dTotGenCost	Final total active and reactive power generation cost
dInitTotLoadGeneration	Initial total real and reactive power generation by the loads
dInitTotGeneratorConsumption	Initial total real and reactive power consumption by the generators
dInitTotReactCapacGen	Initial total reactive power generated by capacitor bank
TotLoadGeneration	Final total real and reactive power generation by the loads.
TotGeneratorConsumption	Final total real and reactive power consumption by the generators
dTotReactCapacGen	Final total reactive power generated by capacitor banks
InitTotPowLoss	Initial total real and reactive power losses.
TotPowLoss	Final total real and reactive power losses
dInitObjFunc	Initial value of the objective function
dFinalObjFunc	Final value of the objective function
InitMaxVoltDevNodeId	Unique identifier of the NODE with the initial maximum voltage magnitude deviation to the nominal value

Field name	Field description
InitMinVoltDevNodeId	Unique identifier of the NODE with the initial minimum voltage magnitude deviation to the nominal value
InitMaxLineDevBranchId	Unique identifier of the LINE with the initial maximum line current deviation to the nominal value
InitMaxTransDevBranchId	Unique identifier of the TRANSFORMER with the initial maximum transformer current deviation to the nominal value
MaxVoltDevNodeId	Unique identifier of the NODE with the final maximum voltage magnitude deviation to nominal value
MinVoltDevNodeId	Unique identifier of the NODE with the final minimum voltage magnitude deviation to the nominal value
MaxLineDevBranchId	Unique identifier of the LINE with the final maximum line current deviation to the nominal value
MaxTransDevBranchId	Unique identifier of the TRANSFORMER with the final maximum transformer current deviation to the nominal value
dInitMaxVoltDev	Initial maximum voltage magnitude deviation to the nominal value
dInitMinVoltDev	Initial minimum voltage magnitude deviation to the nominal value
dInitMaxLineDev	Initial maximum line current deviation to the nominal value
dInitMaxTransDev	Initial maximum transformer current deviation to the nominal value
dMaxVoltDev	Final maximum voltage magnitude deviation to the nominal value
dMinVoltDev	Final minimum voltage magnitude deviation to the nominal value
dMaxLineDev	Final maximum line current deviation to the nominal value
dMaxTransDev	Final maximum transformer current deviation to the nominal value

Equipment results per period

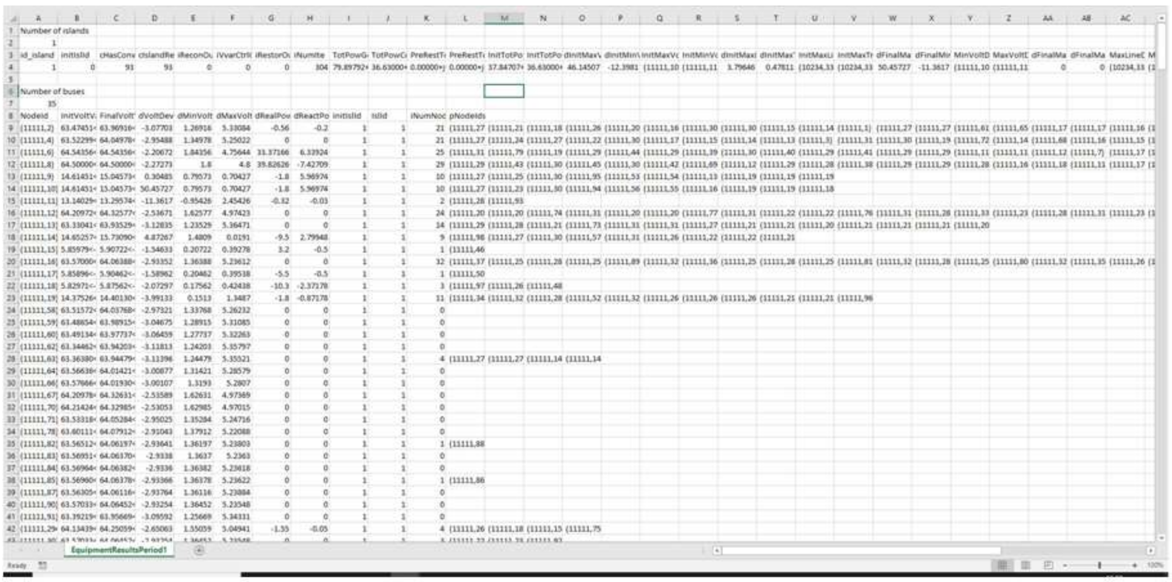


Figure E-9 – Equipment result per period file

The following tables contain the names and descriptions of the main fields of data contained in the Equipment results per period file.

Table E-24 – Island equipment fields of "Equipment results per period" file.

Field name	Field description
id_island	Island ID on DATASET
initIslId	Unique final island identifier (may be different from the initial identifier!!!)
cHasConv	Convergence flag: 0 – has converged 1 – has not converged It can also take the following values: ERROR_NO_CONTROL_EQUIP (90) – the optimization process was not run because the island has no controllable equipment In this case, the power flow results are included in this structure and in all island related equipment structures; ERROR_NO_OPTIM_SUCCESS (91) – the optimization process was run but it had no success It also can happen when the network is already in the optimal solution; ERROR_ISLAND_NOT_CONSIDERED (92) – the island was not considered in the optimization process because or it has no node and/or it has no controller and/or it has no load; WARNING_NO_VOLTAGE_LIMITS_REACHED (93) – the control process was run for this island and was not successful for target voltage bandwidth; ERROR_VOLTAGE (3) – the power flow at starting point returns this error; ERROR_ITER_MAX (14) – the power flow at starting point returns this error
iNumIte	Number of power flow studies run for this island
TotPowGen	Final total real and reactive power generation in the island
TotPowCons	Final total real and reactive power consumption in the island
TotLoadGeneration	Final total real and reactive power load generation in the island
TotGeneratorConsumption	Final total real and reactive power generator consumption in the island
dTotReactCapacGen	Final total reactive power generated by capacitor banks in the island
InitTotPowGen	Initial total real and reactive power generation in the island
InitTotPowCons	Initial total real and reactive power consumption in the island
InitTotLoadGeneration	Total real and reactive power load generation in the island
InitTotGeneratorConsumption	Initial total real and reactive power generator consumption in the island
dInitTotReactCapacGen	Initial total reactive power generated by capacitor banks in the island
MaxErrRealPow	Maximum absolute error for the real power mismatch
MaxErrReactPow	Maximum absolute error for the reactive power mismatch
dInitMaxVoltDev	Initial maximum voltage magnitude deviation to the nominal value
dInitMinVoltDev	Initial minimum voltage magnitude deviation to the nominal value
dInitMaxLineDev	Initial maximum line current deviation to the nominal value
dInitMaxTransDev	Initial maximum transformer current deviation to the nominal value
dMaxVoltDev	Final maximum voltage magnitude deviation to the nominal value
dMinVoltDev	Final minimum voltage magnitude deviation to the nominal value
dMaxLineDev	Final maximum line current deviation to the nominal value

Field name	Field description
dMaxTransDev	Final maximum transformer current deviation to the nominal value
InitMaxVoltDevNodeId	Unique identifier of the NODE with the initial maximum voltage magnitude deviation to the nominal value
InitMinVoltDevNodeId	Unique identifier of the NODE with the initial minimum voltage magnitude deviation to the nominal value
InitMaxCurrDevLineId	Unique identifier of the LINE with the initial maximum line current deviation to the nominal value
InitMaxCurrDevTransfId	Unique identifier of the TRANSFORMER with the initial maximum transformer current deviation to the nominal value
MaxVoltDevNodeId	Unique identifier of the NODE with the final maximum voltage magnitude deviation to nominal value
MinVoltDevNodeId	Unique identifier of the NODE with the final minimum voltage magnitude deviation to the nominal value
MaxCurrDevLineId	Unique identifier of the LINE with the final maximum line current deviation to the nominal value
MaxCurrDevTransfId	Unique identifier of the TRANSFORMER with the final maximum transformer current deviation to the nominal value
InitTotLoss	Initial total real and reactive power losses in this island
TotPowLoss	Final total real and reactive power losses in this island

Table E-25 – Node equipment (buses and single nodes) fields of "Equipment results per period" file.

Field name	Field description
NodeId	Identifier of the node
InitVoltVal	Initial value for voltage in the node
VoltVal	Final value for voltage in the node
dVoltDev	Magnitude voltage deviation from nominal or from specified value for voltage
dMaxVolt	Maximum voltage limit
dMinVolt	Minimum voltage limit
dRealPowInj	Injected real power in the node
dReactPowInj	Injected reactive power in the node
iNumNodes	Number of nodes with the same results (belongs to the same bus)
pNodeId	Array of identifiers of nodes with the same results

Table E-26 – Busbar equipment fields of "Equipment results per period" file.

Field name	Field description
BusbarId	Identifier of the node
InitVoltVal	Initial value for voltage in the node
VoltVal	Final value for voltage in the node
dVoltDev	Magnitude voltage deviation from nominal or from specified value for voltage
dMaxVolt	Maximum voltage limit
dMinVolt	Minimum voltage limit
dRealPowInj	Injected real power in the node

Field name	Field description
dReactPowInj	Injected reactive power in the node
initIslId	Unique initial busbar island identifier
IslId	Unique final busbar island identifier (may be different from the initial identifier!)

Table E-27 – Capacitor bank equipment fields of "Equipment results per period" file.

Field name	Field description
CapacId	Identifier of the capacitor bank
initIslId	Unique initial capacitor bank island identifier
VoltVal	Final value for voltage in the capacitor bank
dInitNomReactPow	Initial nominal reactive power in operation
dNomReactPow	Final nominal reactive power in operation
dInitReactPowInj	Initial injected reactive power
dReactPowInj	Final injected reactive power
dMaxReactPow	Maximum reactive power in operation
dMinReactPow	Minimum reactive power in operation
cUsedInAlg	If it was used during the optimization process
InitVoltVal	Initial value for voltage in the capacitor bank
IslId	Unique final capacitor bank island identifier (may be different from the initial identifier!)

Table E-28 – Line equipment fields of "Equipment results per period" file.

Field name	Field description
LineId	Identifier of the line segment
dFromRealPow	Real power flow in the line (out of the FROM node)
dToRealPow	Real power flow in the line (out of the TO node)
dRealPowLoss	Real power losses in the line
dFromReactPow	Reactive power flow in the line (out of the FROM node)
dToReactPow	Reactive power flow in the line (out of the TO node)
dReactPowLoss	Reactive power losses in the line
FromCurrent	Current flow in the line (out of the FROM node)
ToCurrent	Current flow in the line (out of the TO node)
initIslId	Unique initial line island identifier
IslId	Unique final line island identifier (may be different from the initial identifier!)

Table E-29 – Generator equipment fields of "Equipment results per period" file.

Field name	Field description
GenId	Identifier of the generator
initdGenCost	Generator initial active power generation cost
dGenCost	Generator active power generation cost
dInitRealPowInj	Initial injected real power of the generator
dRealPowInj	Final injected real power of the generator

Field name	Field description
dInitReactPowInj	Initial injected reactive power of the generator
dReactPowInj	Final injected reactive power of the generator
GenCurrentInj	Current magnitude and phase injected by the generator
InitVoltVal	Initial value for voltage in the node of the generator
FinalVoltVal	Final value for voltage in the node of the generator
dMaxVolt	Maximum voltage limit
dMinVolt	Minimum voltage limit
cUsedInAlg	If it was used during the optimization process
initIslId	Unique initial generator island identifier
IslId	Unique final generator island identifier (may be different from the initial identifier!)

Table E-30 – Network connection equipment fields of "Equipment results per period" file.

Field name	Field description
NetConId	Identifier of the network connection
initdGenCost	Network Connection initial active power generation cost
dGenCost	Network Connection active power generation cost
dInitRealPowInj	Initial injected real power of the network connection
dRealPowInj	Final injected real power of the network connection
dInitReactPowInj	Initial injected reactive power of the network connection
dReactPowInj	Final injected reactive power of the network connection
NetConCurrentInj	Per phase current magnitude and angle injected by the network connection
InitVoltVal	Initial value for voltage in the node of the network connection
FinalVoltVal	Final value for voltage in the node of the network connection
dMaxVolt	Maximum voltage limit
dMinVolt	Minimum voltage limit
cUsedInAlg	If it was used during the optimization process
initIslId	Unique initial network connection island identifier
IslId	Unique final network connection island identifier (may be different from the initial identifier!)

Table E-31 – Power transformer equipment fields of "Equipment results per period" file.

Field name	Field description
TransId	Identifier of the transformer
dPriRealPow	Real power flow in the transformer primary winding
dSecRealPow	Real power flow in the transformer secondary winding
dTerRealPow	Real power flow in the transformer tertiary winding (where applicable)
dRealPowLoss	Real power losses in the transformer
dPriReactPow	Reactive power flow in the transformer primary winding
dSecReactPow	Reactive power flow in the transformer secondary winding
dTerReactPow	Reactive power flow in the transformer tertiary winding (where applicable)
dReactPowLoss	Reactive power losses in the transformer
PriCurrent	Current flow in the transformer primary winding

Field name	Field description
SecCurrent	Current flow in the transformer secondary winding
TerCurrent	Current flow in the transformer tertiary winding (where applicable)
InitWindTapPos	Initial winding tap position
WindTapPos	Final winding tap position
iMaxWindTapPos	Maximum winding tap position
iMinWindTapPos	Minimum winding tap position
cUsedInAlg	If it was used during the optimization process
initIslId	Unique initial transformer island identifier
IslId	Unique final transformer island identifier (may be different from the initial identifier!)

Table E-32 – Load equipment fields of "Equipment results per period" file.

Field name	Field description
LoadId	Identifier of the equipment
dInitRealPow	Initial real power or, if 2 terminals equipment, real power out of the FROM node
dRealPow	Final real power or, if 2 terminals equipment, real power out of the FROM node
dInitReactPow	Initial reactive power or, if 2 terminals equipment, reactive power out of the FROM node
dReactPow	Final reactive power or, if 2 terminals equipment, reactive power out of the FROM node
InitCurrent	Initial current magnitude and phase or, if 2 terminals equipment, current magnitude and phase out of the FROM node
Current	Final current magnitude and phase or, if 2 terminals equipment, current magnitude and phase out of the FROM node
InitVoltVal	Initial voltage magnitude and phase of the equipment
VoltVal	Final voltage magnitude and phase of the equipment
cUsedInAlg	If it was used during the optimization process
initIslId	Unique initial equipment island identifier
IslId	Unique final equipment island identifier (may be different from the initial identifier!)

Table E-33 – Equipment changed fields of "Equipment results per period" file.

Field name	Field description
EquipId	Identifier of the equipment
cTypeEq	Equipment type 0x00 – Transformer tap position 0x01 – Capacitor bank tap position 0x02 – Generator active power 0x03 – Network connection active power 0x04 – Switching Devices state 0x05 – Generator reactive power 0x06 – Network connection reactive power 0x07 – Load active power 0x08 – Load reactive power

Field name	Field description
dInitVal	Initial value
dFinalVal	Final value
dCost	Cost of change

Table E-34 – Equipment changed fields of "Equipment results per period" file.

Field name	Field description
EquipId	Identifier of the equipment
cEqpType	Equipment type 0x00 – Transformer 0x01 – Line 0x02 – Node 0x03 – Generator 0x04 – Network connection
cConstraintType	Constraint type 0x00 – Voltage magnitude 0x01 – Current 0x02 – tan φ
dFinalVal	Final value
dMinVal	Minimum limit
dMaxVal	Maximum limit
iNumEquip	Number of equipment connected to the equipment (only for nodes)
pEquipId	Array containing the unique identifiers for all the equipment connected to the equipment (only for nodes)

Annex F – Use case description based on IEC62559-2

Validation of the optimal operational schedule from the DSO Flexibility Scheduler (FS) System

Based on IEC 62559-2 edition 1

1. Description of the use case

1.1 Name of the use-case

Use case identification		
ID	***Area/Domain/Zone(s)***	***Name of the use case***
1	Energy Systems/ Transmission system, Distribution system/ Short-term Planning	Validation of the optimal operational schedule from the DSO Flexibility Scheduler System

1.2 Version management

Version management				
Version No.	***Date***	***Name of author(s)***	***Changes***	***Approval status***
1	2021-01-18	Gonçalo Glória		Final

1.3 Scope and objective of use case

Scope and objectives of the use case	
Scope	The scope of this system use case is the validation through Lab Testing of the Flexibility Scheduler tool (FS) results related with TSO-DSO coordination for efficient exploitation of the flexibility sources.
Objective(s)	The main objectives of this UC are: • Assess the impact of the actions optimized by the FS through jointly laboratorial simulation of transmission and distribution networks; • Validate the 24 hours ahead FS results in terms of reactive power control (Q set-points, power factor ranges, voltage set-points)
Related business case(s)	

1.4 Narrative of use case

Narrative of use case
Short description
Impact assessment of FS (with multiperiod optimisation) for reactive power control of a TSO-DSO network, under different scenarios: RES penetration levels (high, low), TSO flexibility assets scenarios (accessible, not accessible) and DSO network topology (radial or meshed).
Complete description
The Flexibility Scheduler (FS), will be developed by EFACEC in the scope of sub-task 7.2.2 “Development of a Flexibility Scheduler”. The FS is a tool developed with the purpose of helping the DSOs to exploit distribution level flexibilities, whilst taking into account transmission-level constraints and available flexibility assets. The core of the tool is an Optimal Power Flow (OPF) for the optimised control of distribution-connected flexibilities. This OPF specifically incorporates RES forecast, constraints of the transmission grid, and needs of reactive power to/from the transmission grid. This allows the reduction of losses, to optimise the coordination with the transmission level, and to optimise the exploitation of flexibility. It also allows the minimization of costs related with limits violations fees and flexibility activation cost. This UC presents the methodology and tests to study the impact of the actions optimised by the FS, through jointly lab simulations of both networks (transmission and distribution). For that purpose, a set of operational and topological scenarios will be developed taking into account forecasts of RES present in distribution networks. The outcome of this task will be a report that validates (or not) through power flow simulation the reactive power set-points, power factor ranges and voltage set-points for voltage control at the connection point between the TSOs and the DSOs according to the FS tool suggested actions, forecasted for the next 24 hours. All the FS actions for each of the 24 hours ahead are sent from FS tool to the lab simulation tool (Hypersim), that has there represented all the TSO network under study.

1.5 Key performance indicators

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI 1	Reduction of losses	Variation of losses	
KPI 2	Assessment of cost	Overall cost of flexibility activation	
KPI 3	Voltage violations overcame	Number of buses out of the operation limits	

1.6 Use case conditions

Use case conditions
Assumptions
The focus of the FS is on the management of reactive power.
Transmission system connected generators operate in tan(Φ) range {-0,2;+0,2}
The FS tool is to be used for the day-ahead (next 24 hours), with a time resolution of 1 hour (same as the market).
Prerequisites
The FS is executed upon user request
Load forecasts need to be considered to DSO (in FS tool) and TSO (in Hypersim) networks
Renewable Energy Sources (RES) production forecasts need to be considered for to DSO (in FS tool) and TSO (in Hypersim) networks
Maximum and minimum voltage values in any node of the modelled grid;
Maximum capacity should be considered for lines and transformers.

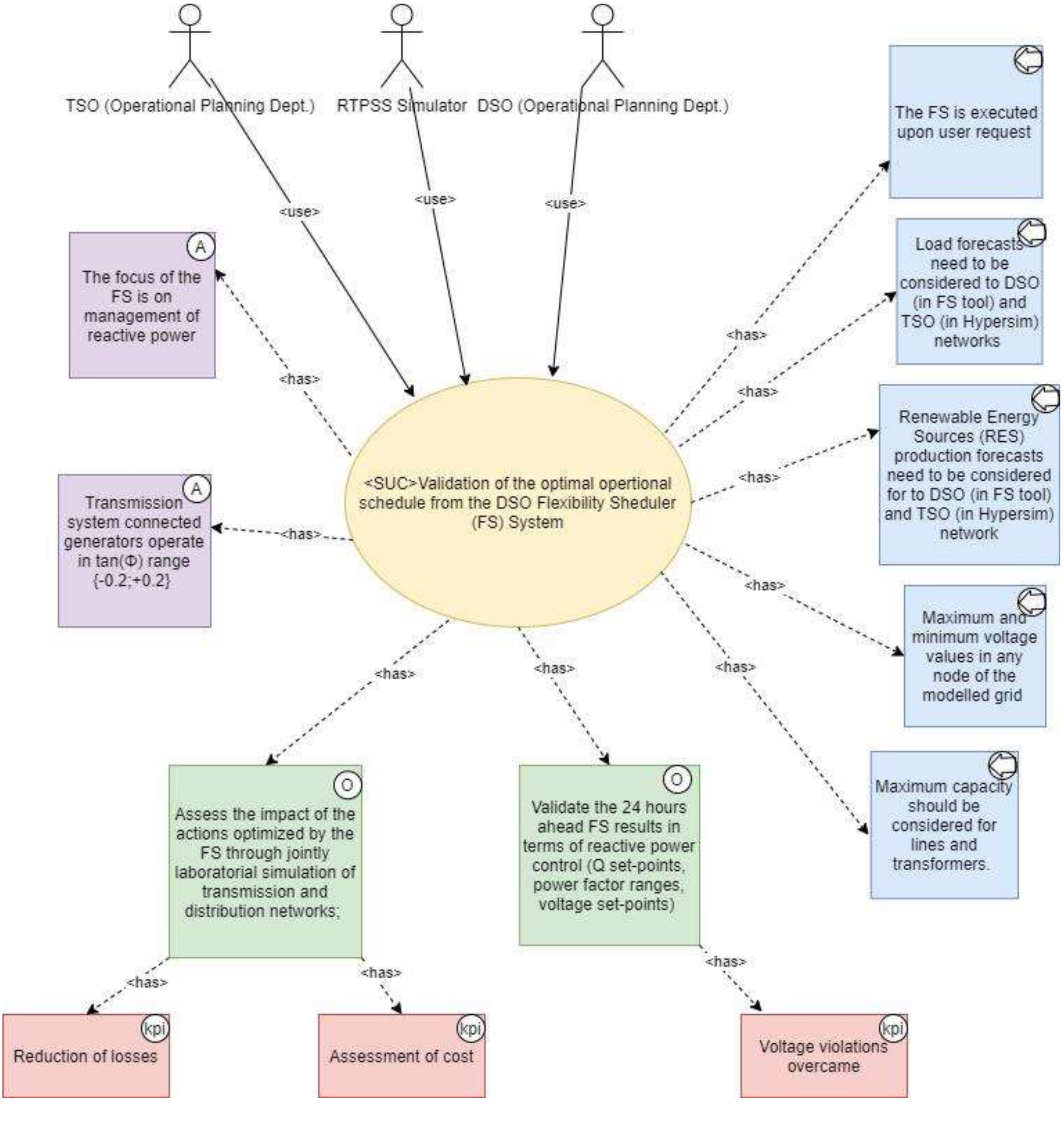
1.7 Further information to the use case for classification/mapping

Classification information
Relation to the other use cases
Level of depth
General
Prioritization
High
Generic, regional or national relation
National
Nature of the use case
Further keywords for classification
Congestion management, Flexibility, TSO-DSO

1.8 General remarks

General remarks
The different scenarios are related with different DSO topologies networks (meshed or radial) and for each of them some variations are considered: RES penetration levels (high, low) and TSO flexibility assets scenarios (accessible, not accessible).

2 Diagrams of use case

Diagram(s) of use case


3 Technical details
3.1 Actors

Actors			
Actor name	***Actor type***	***Actor description***	***Further information specific to this use case***
DSO	Operator	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long term ability of the system to meet reasonable demands for the distribution of electricity or gas. That definition is provided for by art. 2 n. 6 Dir 2007/72/EC with regards to electricity and by art. 2 (6) Dir 2007/73/EC with regards to gas. In the electricity sector distribution means the transport of electricity on high-voltage, medium-voltage and low-voltage distribution systems with a view to its delivery to customers, but does not include supply according to art. 2 (5) Dir, 2007/72/EC. Accordingly, distribution in the gas sector means the transport of natural gas through regional pipeline networks with a view to its delivery to customers, but not including supply. DSOs have to act according to art. 25, 26, 27 Dir. 2007/72/EC (with regards to electricity) and to art. 25, 26, 27 Dir. 2007/73/EC (with regards to gas). The aforementioned provisions provide the tasks and duties of DSOs. One of the main characteristics of the DSO is that it shall be independent at least in terms of its legal form, organisation and decision making from other activities not relating to distribution within a vertically integrated undertaking. Unlike the transmission system operator, the DSO is not affected by ownership unbundling.	
TSO	Operator	According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area. Source : EU Commission Task Force for Smart Grids, EG3	
RTPSS Simulator	System	Real-time Power System Simulator, OPAL-Hypersim.	

4 Step by step analysis of use case
4.1 Overview of scenarios

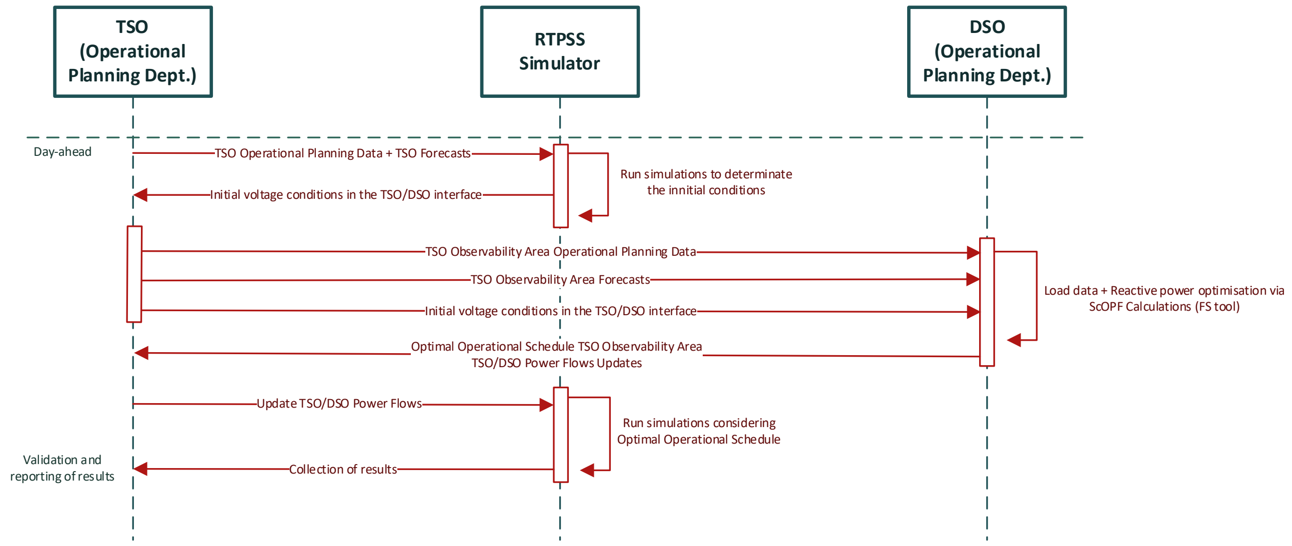
Scenario conditions						
No.	***Scenario name***	***Scenario description***	***Primary actor***	***Triggering event***	***Pre-condition***	***Post-condition***
Sc.1						

4.2 Steps – Scenarios

Scenario							
Scenario name		Sc.1-					
Step No.	***Event***	***Name of process/activity***	***Description of process/activity***	***Service***	***Information producer (actor)***	***Information receiver (actor)***	***Information exchanged (IDs)***
St.1		TSO Operational Planning Data + TSO Forecasts	The TSO prepares the operational planning data and forecasts for the TSO network and DSO observability area (i.e. generation, load).		TSO (Operational Planning Dept.)	RTPSS Simulator	Info1 and Info2

St.2		Run simulations to determine the initial conditions	The TSO loads the operational planning data and forecasts in the RTPSS and runs the TSO operational scenarios in the RTPSS, pre-validating and determining the initial condition of the system.				
St.3		Initial voltage conditions in the TSO-DSO interface	The initial conditions (i.e. voltage) in the TSO-DSO interface are collected by the TSO.		RTPSS Simulator	TSO (Operational Planning Dept.)	Info 5
St.4		TSO observability area operational planning data	The TSO prepares and shares the operational planning data from the TSO observability area with the DSO.		TSO (Operational Planning Dept.)	DSO (Operational Planning Dept.)	Info3
St.5		TSO observability area forecasts	The TSO prepares and shares the information related to the TSO observability area and forecasts with the DSO.		TSO (Operational Planning Dept.)	DSO (Operational Planning Dept.)	Info 4
St.6		Initial voltage conditions in the TSO-DSO interface	The TSO shares the initial conditions of the system (i.e. initial voltage in the TSO-DSO interface), resulting from its valiation of the TSO operational planning, with the DSO.		TSO (Operational Planning Dept.)	DSO (Operational Planning Dept.)	Info 5
St.7		Load data	The DSO loads the configuration files provided by the TSO in the FS tool, are loaded in to the FS tool by the DSO using the configuration files provided by the TSO, together with its own data about the DSO network.				
St.8		Reactive power optimisation via ScOPF (FS tool)	The ScOPF calculations are performed for the entire period of analysis (i.e. 24 hour ahead). The optimal operational schedule for the DSO network and for the TSO observability area are generated by the FS tool.				
St.9		Optimal Operational Schedule TSO observability Area and TSO-DSO Power Flows updates	The DSO observability area results are exchanged with the TSO, including the TSO-DSO power flow updates resulting from the ScOPF algorithm results for each hour of the period of analysis.		DSO (Operational Planning Dept.)	TSO (Operational Planning Dept.)	Info 6
St.10		Update TSO-DSO Power Flows updates	The TSO-DSO interface power flows are updated in the RTPSS.		TSO (Operational Planning Dept.)	RTPSS Simulator	Info 7
St.11		Run Simulations considering Optimal Operational Schedule	The TSO runs simulations again considering the ScOPF results.				
St.12		Collection of results	The RTPSS results are collected by the TSO.		RTPSS Simulator	TSO (Operational Planning Dept.)	Info 8
St.13		Validation and reporting of results	The RTPSS results are validated by the TSO in order to ensure there is no negative impact at the transmission level. In case the result has a negative impact at transmission level, the solution **is rejected,** the DSO is				

			informed and the process starts all over again.				



5 Information exchanged

Information exchanged			
Information exchange, ID	***Name of information***	***Description of information exchanged***	***Requirement, R-IDs***
Inf.1	TSO operational planning data	TSO operational planning data for the TSO network.	
Inf.2	TSO forecasts	Generation (including renewable generation) and load forecast for the TSO network.	
Inf.3	TSO observability area Operational Planning Data	TSO operational planning data for the TSO network and TSO observability area. Including, activation plan of the flexibility assets in the TSO-DSO interface.	
Inf.4	TSO observability area Forecasts	Generation (including renewable generation) and load forecast for the TSO observability area (in DSO network).	
Inf.5	Initial voltage conditions in the TSO/DSO interface	Voltage conditions in the TSO-DSO interface after the simulation and validation of the TSO operational schedule in RTPSS.	
Inf.6	Optimal operational schedule for TSO observability area	Network simulation results for the DSO observability area (TSO network).	
Inf.7	TSO/DSO power flow updates	New power flow values resulting from the FS tool simualtions calculated for the branches conneting TSO-DSO networks (TSO-DSO interface).	

Inf.8	Collection of results (FS Results)	Network simulation results for the DSO network and DSO observability area. Actions proposed by the FS tool for the flexibility assets in the DSO grid and DSO observability area (TSO network).	

6 Requirements (optional)

Requirements (optional)		
Categories ID	***Category name for requirements***	***Category description***
Requirement R-ID	***Requirement name***	***Requirement description***
Req.1		
Req.2		
Req.3		
Req.4		
Req.5		
Req.6		
Req.7		

7 Common terms and definitions

Common terms and definitions	
Term	***Definition***

8 Custom information (optional)

Custom information (optional)		
Key	***Value***	***Refers to section***