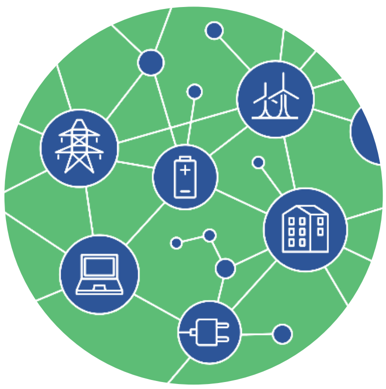
OSMOSE

OPTIMAL SYSTEM-MIX OF FLEXIBILITY
SOLUTIONS FOR EUROPEAN ELECTRICITY

Optimal Sizing and Siting of Storage Facilities

Internal Deliverable T1.4.1



Contact: www.osmose-h2020.eu

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773406

Document properties

Project Information

Programme	**O**ptimal **S**ystem-**M**ix **O**f Flexibility **S**olutions For **E**uropean Electricity
Project acronym	OSMOSE
Grant agreement number	773406
Number of the Deliverable	Internal Deliverable of T1.4.1 (MS3)
WP/Task related	WP1 / Sub-Task 1.4.1

Document information

Document Name	Optimal Sizing and Siting of Storage Facilities
Date of delivery	30/06/2021
Status and Version	V0
Number of pages	77

Responsible

Document Responsible	Ricardo Pastor – R&D NESTER
Author(s)	Ricardo Pastor, Gonçalo Glória, Aleksandr Egorov (R&D NESTER)
Reviewer(s)	Nuno Souza e Silva, Yang Wei (R&D NESTER), Albino Marques, Rui Pestana (REN)
Approver	

Dissemination Level

Type (distribution level)	☒ PU, Public ☐ CO – full consortium, Confidential, only for members of the consortium (including the Commission Services) ☐ CO – some partners, Confidential, only for some partners (list of partners to be defined)

Review History

Version	Date	Reviewer	Comment
V0	26-07-2021	Ricardo Pastor	

Table of content

Executive summary 1
List of acronyms and abbreviations 3
1 Introduction 4
1.1 Scope of proposed study 5
1.2 Position within WP1 and dependencies 6
1.3 Structure of the report 6
2 DESPlan tool 7
2.1 Dispersed Energy Storage Planning Problem 7
2.1.1 Mathematic formulation 8
2.1.2 Strategy to solve the DES planning problem 13
2.2 Introduction to EPSO 13
2.3 DESPlan algorithm logic 15
2.3.1 Flexibility Analysis 16
2.3.2 Single-interval EPSO 16
2.3.3 Multi-interval EPSO 17
2.4 Case study and main assumptions 18
2.4.1 2030 Case study 19
2.4.2 2050 Case study 20
2.5 Redistribution methodology 22
2.5.1 Load 22
2.5.2 Generation 22
2.5.3 Interconnections 37
3 Simulation Results 39
3.1 Simulation assumptions 39
3.2 DESPlan results for 2030 scenario 39
3.2.1 Case #1 – 15th February 2030 42
3.2.2 Case #2 – 14th May 2030 46
3.2.3 Case #3 – 5th July 2030 50
3.3 DESPlan results for 2050 scenario 57
3.3.1 Case #1 – 22nd of February 2050 59
3.3.2 Case #2 – 12nd of April 2050 64
3.3.3 Case #3 – 28th of June 2050 70

4 Conclusions......74

References......76

List of figures

Figure 2-1 – T1.4.1 dependencies with other tasks, used models and main outputs 7
Figure 2-2 – Working concept of EPSO algorithm 15
Figure 2-3 – DESPlan algorithm process...15
Figure 2-4 – Flexibility analysis (P1) 16
Figure 2-5 – Single-interval DESPlan (P1.1)...17
Figure 2-6 – Multi-interval EPSO (P2) Flowchart 18
Figure 2-7 – Estimated distribution of installed power solar power plants for large areas on the horizon 2031 [10]..21
Figure 2-8 – Flowchart of the methodology for CCGT type of the generation 26
Figure 2-9 – Flowchart of the methodology for Wind Onshore type of the generation...........29
Figure 2-10 – Flowchart of the methodology for Hydro Run-of-River type of the generation .31
Figure 2-11 – Flowchart of the methodology for Hydro Dam type of the generation.............34
Figure 2-12 – Flowchart of the methodology for Hydro Pump Storage type of the generation 37
Figure 2-13 – Cluster's representation of the e-Highways project for the CSW region..........38
Figure 3-1 – 2030 scenario – generation mix diagram of case #1......................................42
Figure 3-2 – 2030 scenario – Power flow in the branch connecting buses 1040-1060 for case #1...43
Figure 3-3 – Network single line diagram of the congestion area at hour 19 (case #1) 43
Figure 3-4 – 2030 scenario – BESS response resulting from the application of the DESPlan tool for case #1...44
Figure 3-5 – 2030 scenario – Power flow in the branch 1040-1060 for case #1 with BESS ..45
Figure 3-6 – Network single line diagram of the congestion area at hour 19 (case #1) with BESS 45
Figure 3-7 – 2030 scenario – generation mix diagram of case #2......................................46
Figure 3-8 – 2030 scenario – Power flow in the branch 291-2987 for case #2.....................47
Figure 3-9 – Network single line diagram of the congestion area at hour 14 (case #2) 47
Figure 3-10 – 2030 scenario – BESS response resulting from the application of the DESPlan tool for case #2...48
Figure 3-11 – 2030 scenario – Power flow in the branch 291-2987 for case #2 with BESS ..49
Figure 3-12 – Network single line diagram of the congestion area at hour 14 (case #2) with BESS 49
Figure 3-13 – 2030 scenario – generation mix diagram of case #3....................................50
Figure 3-14 – 2030 scenario – Power flow in the branch 291-2987 for case #3...................51
Figure 3-15 – Network single line diagram of the congestion area at hour 03 (case #3) 51
Figure 3-16 – 2030 scenario – Power flow in the branch 1040-1060 for case #3.................52
Figure 3-17 – Network single line diagram of the congestion area at hour 22 (case #3) 52
Figure 3-18 –2030 scenario – BESS response in bus 2987 resulting from the application of the DESPlan tool for case #3 53
Figure 3-19 – 2030 scenario – BESS response in buses 1040&1060 resulting from the application of the DESPlan tool for case #3..54
Figure 3-20 – 2030 scenario – Power flow in the branch 291-2987 for case #3 with BESS ..54

Figure 3-21 – Network single line diagram of the congestion area at hour 03 (case #3) with BESS 55
Figure 3-22 – 2030 scenario – Power flow in the branch 1040-1060 for case #3 with BESS 55
Figure 3-23 – Network single line diagram of the congestion area at hour 22 (case #3) with BESS 56
Figure 3-24 – 2050 scenario – generation mix diagram of case #1......................................60
Figure 3-25 – 2050 scenario – Power flow in the branch 1040-1060 for case #1 61
Figure 3-26 – Network single line diagram of the congestion area at hour 5 (case #1) 61
Figure 3-27 – BESS response resulting from the application of the DESPlan tool for case #1 62
Figure 3-28 – 2050 scenario – Power flow in the branch 1040-1060 for case #1 with BESS 63
Figure 3-29 – Network single line diagram of the congestion area at hour 5 (case #1) with BESS 63
Figure 3-30 – 2050 scenario – generation mix diagram of case #2......................................64
Figure 3-31 – 2050 scenario – Power flow in the branches 422-622 for case #2 65
Figure 3-32 – 2050 scenario – Power flow in the branches 122-622 for case #2 65
Figure 3-33 – Network single line diagram (bus 422) at hour 12 (case #2) 66
Figure 3-34 – Network single line diagram (bus 122) at hour 12 (case #2) 66
Figure 3-35 – BESS response resulting from the application of the DESPlan tool for case #2 67
Figure 3-36 – 2050 scenario – Power flow in the branches 422-622 for case #2 with BESS.68
Figure 3-37 – 2050 scenario – Power flow in the branches 122-622 for case #2 with BESS.68
Figure 3-38 – Network single line diagram (bus 422) at hour 12 (case #2) with BESS..........69
Figure 3-39 – Network single line diagram (bus 122) at hour 12 (case #2) with BESS..........69
Figure 3-40 – 2050 scenario – generation mix diagram of case #3......................................70
Figure 3-41 – 2050 scenario – Power flow in the branch 246-268 for case #3......................71
Figure 3-42 – Network single line diagram of the congestion area at hour 15 (case #3) 71
Figure 3-43 – BESS response resulting from the application of the DESPlan tool for case #3 72
Figure 3-44 – 2050 scenario – Power flow in the branch 246-268 for case #3 with BESS 73
Figure 3-45 – Network single line diagram of the congestion area at hour 15 (case #3) with BESS 73

List of tables

Table 2.1 – Installed capacity per technology in 2030 Model 20
Table 2.2 – Installed capacity per technology in 2050 Model 21
Table 2.3 – The correspondence between the data from Task 1.2 and the network model...23
Table 2.4 – The distribution of generation by type of connection in detailed network model .24
Table 3.1 – Summary of the 2030 congestions detected per month 40
Table 3.2 – 2030 cases summary for assessment into DESPlan tool 41
Table 3.3 – Summary of the 2050 congestions detected per month 57
Table 3.4 – 2050 cases summary for assessment into DESPlan tool 59

Executive summary

This report presents the internal deliverable *Optimal Sizing and Siting of Storage Facilities*, which is responsibility of R&D NESTER, within the scope of the activities performed under T1.4.1. In this internal deliverable a brief description of the Dispersed Energy Storage tool (DESPlan), the methodology developed as well as simulation results and their correspondent analysis will be presented.

As WP1 focus on the Optimal Mix of Flexibilities, it started by proposing long-term scenarios for 2030 and 2050, which differ on the levels of demand, installed capacities, investment options, and on the amount and location of flexibility options. Based on those scenarios, the time series of supply and demand were generated by RTE using its ANTARES model, aiming to assess and validate the referred scenarios.

Using data from T1.1 and T1.2 as input, R&D NESTER redistributes the time series into the model of the Portuguese transmission network, detailed up to the 60kV level (distribution level), for 2030 and 2050 time horizons using a methodology developed for this effect. This methodology is explained in detail in the report.

Then, it resorts to the DESPlan tool to perform the simulation of network for the entire dataset (average scenario for both 2030 and 2050) and analyses the results in search for possible congestions that may arise.

The most significant congestion cases were selected for the application of the DESPlan tool to determine the optimal sizing and siting of BESS solutions capable of avoiding the congestions identified. The results of the simulations performed for the selected cases are presented in this internal deliverable as technical solutions. The congestions observed includes:

- Transmission lines;
- Power transformers;
- Combinations of the previous.

As key results from the simulations with the DESPlan toon, it is possible to conclude that:

- For both average scenarios 2030 and 2050, the DESPlan tool identified several potential congestions in several branches in the adapted detailed network models for both time horizons.
- The congestions identified in the 2050 scenario were more frequent and more severe (higher amplitude), than the ones identified in the 2030 scenario.
- Bearing in mind the fact that the simulations were made assuming the network with all its branches available (“N condition”), it’s fair to say that even so the approach was benevolent in the sense that more stressful situations (e.g. N-1 contingency criterion), which are typically targeted at transmission network planning, were not addressed in this study.

- The DESPlan tool successfully solved all the selected cases in both scenarios at the minimum cost, as the affected branches continued to be exploited close to their rated capacity.
- Some of the solutions found for the cases presented a very high cost, which may compromise their eventual economic viability from the network planner perspective as an alternative to more traditional network reinforcement options (such as lines or power transformers).
- It is not possible to exclude the effect of the assumptions taken into consideration, especially for the scenario 2050, since no major network reinforcements, in both lines and power transformers, were considered from the 2030 model.
- We were surprised to note that in both scenarios (2030 and 2050) Portugal is always importing energy from Spain (and Europe). Even in the 2050 scenario, with PV generation reaching 12GW of production around 12h00, which was more than enough to cover the National load in most summer days for 3 or 4 hours, the country still continues to import energy from Spain in every hour of the year. This behaviour does not look realistic in our perspective.
- Finally, it seems clear that the need for network reinforcement will have to continue in order to prepare the transmission network for the challenges of a near-zero carbon economy, although the plurality of the flexibility options available for investment may be more broad.

The DESPlan tool successfully solved all the selected cases in both scenarios at the minimum cost. With the contribution of the BESS, the congested branches were able to continued being exploited close to their rated capacity without overloading.

These studies may help describing potential congestion cases that may arise in the Portuguese transmission network if the network development is carried out as described in this report and conditions established in the OSMOSE scenarios occur.

List of acronyms and abbreviations

You can find in the table below the list of the acronyms and abbreviations used in this document.

Acronym	Meaning
ANTARES	Sequential Monte-Carlo simulator designed for short to long-term studies of large interconnected power grids. It simulates the economic behaviour of the whole transmission-generation system, throughout the year and with a resolution of one hour.
BESS	Battery Energy Storage System
CCGT	Combined Cycle Gas Turbine
CDF	Cumulative Distribution Function
CSW	Continental South West Region
DESPlan	Dispersed Energy Storage Planning tool
DSM	Demand Side Management
ES	Spain
EV	Electric Vehicle
GTC	Grid Transfer Capacity
NECP	National Energy and Climate Plan
NRA	National Regulatory Authority
NTC	Net Transfer Capacity
OCGT	Open Cycle Gas Turbine
PT	Portugal
REN	Redes Energéticas Nacionais
RES	Renewable Energy Sources
RTE	Réseau de Transport d'Electricité
TSO	Transmission System Operator

1 Introduction

Power system's planning is a process in which the aim is to decide which new investments, or upgrades on existing ones, are needed to adequately satisfy the system needs for the foreseen time horizon. The power system is an ensemble of generation facilities, substations, transformers, transmission lines and/or cables as well as other support devices essential to maintain and control several parameters as frequency and voltage levels.

Power system planning mainly comprises demand and supply forecasting as well as network expansion planning. The planning decision should consider where to allocate the core elements, when to install them and what are their specifications. From different perspectives, power system planning can be classified into long-term and short-term planning, transmission and distribution planning and static and dynamic planning [1]. An optimal planning approach will achieve a desired power system structure at the end of planning period and meet fundamental requirement as follow [2]:

- The transmission and distribution capacity are adequate and in the proper proportion;
- Voltage support devices are sufficient in order to ensure security and power quality of power system during normal and fault conditions;
- Power supply should ensure appropriate reliability, flexibility and economics.

Network planning is central in the development of the electrical power systems. It must cope with the constant evolution of the system, either in size or in new operational behaviour imposed by new technology. It requires thorough and continuous study to assure robust and secure operation.

If on the one hand, renewable energy sources (RES) and new distributed energy resources (DER) have deeply transformed the electrical system by increasing uncertainty and variability, it is also true that they are deemed to be part of the strategy to provide the needed flexibility to the system, exploiting their technical characteristics and advantages or through their combination with flexible resources, such as battery storage.

Distributed energy storage (DES) devices are typically connected to the network using power electronics (converter-based interfaces), meaning these are capable of proving a fast and modular response, both for power consumption and injection, and provide flexibility when needed. Such capabilities may support the system in the form of ancillary services and facilitate the integration of RES, but may also be explored to enhance the overall capacity of the network itself, by avoiding the overload of lines and transformers in periods in which otherwise they would not allow the complete integration of such resources. In order to access the capability of DES to mitigate the risk of congestions in the system, and evaluate the respective cost of the solution when compared to a business-as-usual (BAU) capacity expansion approaches, the DES planning (DESplan) tool has been applied. This alternative to traditional grid reinforcement may postpone investments, limit system costs and optimize assets' planning and operation.

The objective of the DESplan tool is to determine the optimal size and location of new DES units over the grid, while ensuring safe operation conditions, to reduce (and ultimately avoid) lines and transformers overloads, and thus serve as a congestion management (CM) planning tool. The tool takes also into account the economical aspect of the problem, by accounting as well with the incurring costs of new DES installations, and hence providing a comparing term for the BAU approaches. It should be noted the tool provides a techno-economic analysis only, meaning ownership or operation strategies of the DES are not discussed.

By minimizing the cost of the solutions while respecting the loading limits for lines and transformers (and also buses voltages), the tool should provide the following results, for the grid, scenario and candidate nodes under study:

- Location and size of DES;
- Cost of solution (according to the considered reference costs);

The tool runs over Python™ language combined with the power systems calculation engine PSS/e. This engine is a critical part of the tool, taking advantage of a Python application programming interface (API) that is iteratively called to calculate and assess the network conditions, closing the loop in the optimization process.

The logical and mathematical formulation of the problem with the aforementioned requirements is set on a complex mixed-integer linear programing strategy. Meta-heuristics approaches like local search, dynamic objective functions and naturally inspired strategies could then suit the problem configuration. This tool resorts to the Evolutionary Particle Swarm Optimization (EPSO) algorithm [12] to generate the set of solutions.

In this report, only the application of the DESPlan tool to the OSMOSE scenarios is presented and discussed. The base network topology used was the Portuguese transmission network model for 2029, provided by the Portuguese TSO (REN) under a Non-Disclosure Agreement, specifically for this task of the OSMOSE project. The network model was adapted according to the respective OSMOSE scenarios based on the investments considered in the national transmission network development plan.

1.1 Scope of proposed study

This report presents the internal deliverable *Optimal Sizing and Siting of Storage Facilities*, which R&D NESTER is responsible for within WP1 and its sub-task 1.4.1. Additionally, dependencies from T1.4.1 with other tasks within WP1 are presented, as well as the main assumptions that were established aiming at homogenizing concepts and combining different data sources.

In this report, the main objective is the application of the DESPlan tool for congestion management. Furthermore, a methodology implemented to redistribute the OSMOSE time series provided by T1.2 will be described. This methodology allows to redistribute the aggregated time series for the Portuguese power system into a detailed model of the

Portuguese transmission network provided by the Portuguese TSO in the scope of this task. This model is detailed up to the 63kV level (distribution voltage level in Portugal).

The main results will focus on:

- Providing the sizing and siting of energy storage solutions capable of avoiding the network congestions identified in the simulated scenarios.
- Compatibility of the network to accommodate the OSMOSE scenarios within the acceptable ranges of operation.

The DESPlan tool will be used to study the operation of the Portuguese power system following the conditions (scenarios) stablished in T1.1 and T1.2. It will also provide feedback on how the power system reacts to the scenarios and if the flexibility means considered are sufficient to ensure the proper operation of the power system or whether it might require additional flexibility (e.g. energy storage) to avoid congestion scenarios.

1.2 Position within WP1 and dependencies

The dependencies of T1.4.1 with other WP1 tasks are illustrated in Figure 2-1. T1.1 was initially responsible for defining mid and long-term scenarios, regarding the evolution of installed capacities and identifying which RES and flexibility options should be the focus for 2030 and 2050 at European level. Additionally, T1.1 identified the locations (clusters) where those investments should occur, as well as demand levels per cluster.

The main simulation model in T1.4.1 is the DESplan (Dispersed Energy Storage Planning). This tool requires a network model from the network that will be target as the focus of the flexibility studies. The DESplan studies were based on T1.1 and T1.2 inputs on long-term security-of-supply studies for the European power system, in an attempt of validating T1.1 scenarios in the Portuguese context, providing feedback whenever necessary with suggestions for future iterations of T1.1 models.

Results from T1.2, namely demand and supply time-series, as well as flexibility options are used as input for T1.4.1, combined with the scenarios defined by T1.1. A redistribution methodology was implemented to fit the scenarios and time-series to the network model of the Portuguese network in a realistic way.

1.3 Structure of the report

The report is structured as follows: section 2 is focus on the DESPlan tool. The mathematical formulation, the evolutionary algorithm used to find the solutions (EPSO) and the logic of the DESPlan tool is also briefly introduced. The redistribution methodology developed specifically in the context of the OSMOSE project is also explained in detail in this section. Section 3 describes the simulations performed for 2030 and 2050 scenarios and the corresponding results. Finally, the last section describes the main conclusions of the report.

2 DESPlan tool

In the electrical system's value chain, the TSO is the entity responsible for the overall system management, including the dispatch (supply/demand balance), transmission network planning and development, investment and operation, as well as asset management. Reliability, security, and flexibility are therefore critical for TSOs. Energy storage is considered an alternative for multiple development strategies, including black start, integration of RES, system balancing or network investment deferral.

On the system planning level, the DESplan tool provides a contribution on the definition of the near-optimal sizing and siting of energy storage solutions. With the reduction of energy storage costs, it is becoming suitable solution to provide additional network flexibility, also at transmission level. In terms of congestion management, the tool can provide non-conventional options for capacity expansion, that is to say, some investment in network expansion could be postponed by the adoption of energy storage solutions. Consequently, the system costs for network development could be curbed and the assets optimized.

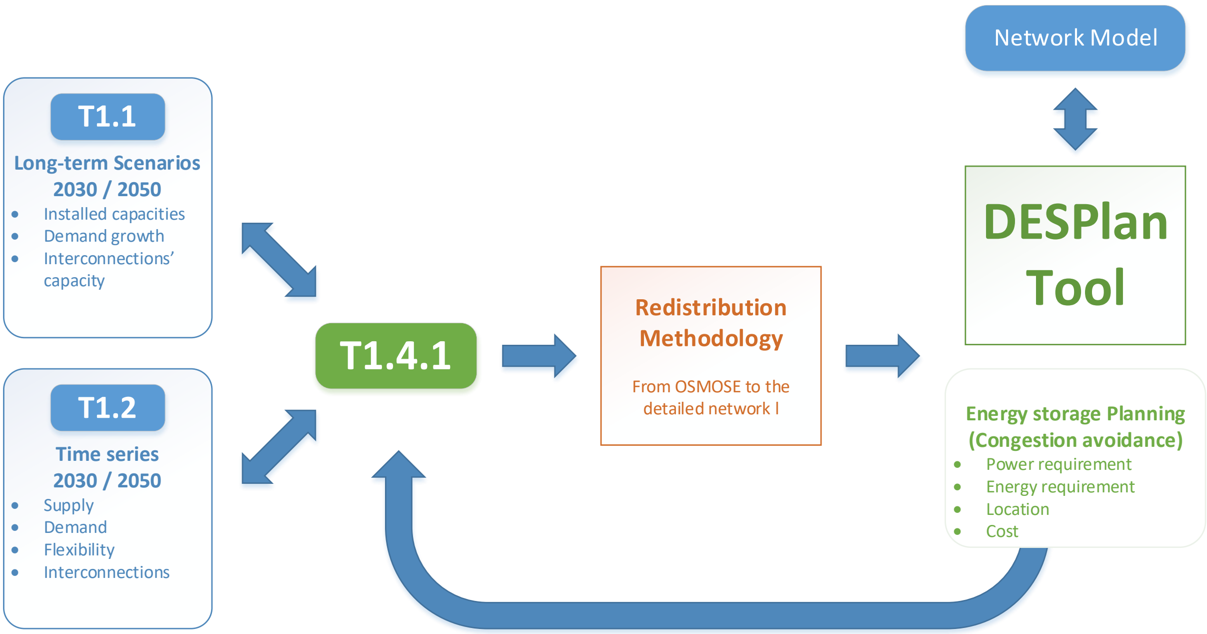


Figure 2-1 – T1.4.1 dependencies with other tasks, used models and main outputs

2.1 Dispersed Energy Storage Planning Problem

Network planning comprises the definition and scheduling of the necessary upgrades and new investments that need to be made to overcome current and future network barriers capable of threaten the power system's security and reliability. Network reinforcements must be aligned with the system's development needs (e.g. additional flexibility, different generation mix, presence of new technologies as well as different topologies), as well as comply with new network codes or deal with congestion management problems.

Network planning is a complex process, which requires studies covering several domains, including network and power exchange simulations. To perform those studies the network planners use several methods and algorithms. Possibly, the one of the most known algorithms is the Optimal Power Flow (OPF) algorithm. The classic OPF consists in find the best combination of generation units and generation levels that allow the network to fed all the loads and keeping the system between the permitted boundaries of nodal voltage and branches power flow, allowing to preserve the system stability.

The network assessment and the impact of distributed energy storage reinforcements on the network flexibility are frequently made through a multi-interval power flow calculation. This is a method used in several energy storage planning tools [3] to assess time dependent network problems, which need an evaluation of network parameters in the hour or minute basis. This is particularly important in energy storage planning, as those facilities have two important dimensions in terms of its requirements: power and energy.

The electricity network flexibility analysis consists in performing a power flow analysis for a specific period (e.g. 24 hours) divided into several intervals (e.g. every 1 hour or 15 minutes), in order to identify network congestions and quantify those congestions in terms of amplitude (Power) and duration (Energy). This analysis allows recognizing the network flexibility requirements for dimensioning energy storage facilities.

The electricity network only requires to keep enough capacity margins to allow electricity delivery without overloads. Therefore, the flexibility of a specific network is related to its transmission capacity margin, in a fixed scenario. The flexibility analysis can be carried out as a device or substation-level simulation with foretold demand and supply profiles, which are compared with the rated capacity of network branches according to the operational criteria. Then, out-limit situations may emerge, especially in some periods such as peak or valley hours.

In order to provide an efficient strategy to improve network flexibility, a holistic methodology was built for dispersed energy storage planning. This approach aims to plan energy storage in electricity networks, based on operation scenarios and through the estimation of potential economic benefits (and costs), storage capacity, energy and location.

2.1.1 Mathematic formulation

The following indexes are used to describe the formulation in both single and multi-interval problems, assuming the network planner performs the role of decision-maker.

i, j — Indexes related to the network buses, from 1 to N.

t — Index linked to the set of time intervals used in the optimization process, from 1 to T.

2.1.1.1 Multi-interval Objective Function

The objective function for the multi-interval DES planning problem is:

$$\min\left[\sum_{i=1}^{N}(\mathrm{CP_i}\overline{\mathrm{R}}_i + \mathrm{CW_i}\overline{\mathrm{S}}_i) + \sum_{i=1}^{N}(\mathrm{f_i}\delta) + \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j\neq i}^{N}(\mathrm{CPEN}_{i,j,t})\right] \tag{1}$$

The multi-interval optimization problem aims at finding solutions that minimize the cost of the DES system, for all the intervals, in terms of power, energy and number of facilities at the time that minimizes network congestions.

The DES power cost for each bus is given by:

$$\mathrm{CP_i}\overline{\mathrm{R}}_i\,, \qquad \forall i \in N \tag{2}$$

$$\overline{\mathrm{R}}_i = \max\{|r_i(t)|\}, \qquad \forall t \in T \tag{3}$$

Where,

$\mathrm{CP_i}$ – Power cost of the technology used in node i (€/MW);

$\overline{\mathrm{R}}_i$ – Rated power requirement for the facility in node i (MW).

$r_i(t)$ – Storage power requirement at node i and interval t.

The DES energy cost for each bus is given by:

$$\mathrm{CW_i}\overline{\mathrm{S}}_i\,, \qquad \forall i \in N \tag{4}$$

$$\overline{\mathrm{S}}_i = \max\{|s_i(t)|\}, \qquad \forall t \in T \tag{5}$$

$$s_i(t) = s_i(t-1) - r_i(t)\Delta t\,, \qquad \forall i \in N \tag{6}$$

$$\Delta t = \frac{\text{interval duration (minutes)}}{60} \tag{7}$$

Where,

CW_i – Energy cost of the technology used in node i (€/MWh);

$\bar{S}_i$ – Energy requirement for the facility in node i (MWh);

$s_i(t)$ – Storage energy requirement level at node i and interval t ($s_i(0) = 0$).

The DES facility cost for each bus is given by:

$$f_i \delta \tag{8}$$

Where,

f_i – Facility status;

$$f_i = \begin{cases} 1, & \exists t \in T: r_i(t) \neq 0 \\ 0, & \text{otherwise} \end{cases}, \qquad \forall i \in N$$

δ – Cost per facility [€/facility].

The congestion penalties are consequence of the power flows in the network and they are taken into account through the following equation:

$$CPEN_{i,j} = c_{ij} \times \bar{q}_{ij}(t) \times \Delta t \times VOLL \times \beta \tag{9}$$

Where,

$$c_{ij}(t) = \begin{cases} 1, & q_{ij}(t) > \bar{q}_{ij}(t) \quad \forall t \in T \\ 0, & \text{otherwise} \end{cases} \tag{10}$$

$$\beta \in \mathbb{R}^+ \tag{11}$$

Where,

$\bar{q}_{ij}$ – Rated power flow between nodes i,j;

$VOLL$ – Value of Lost Load;

β – Security coefficient.

VOLL stands for the value of lost load (in €/MWh), c_{ij} is a binary variable which is related to the existence (or not) of congestion in the branch which connects node i to j and $\bar{q}_{ij}(t)$ is the rated power flow of the same branch. If there is network congestion during one interval, the value of the penalty will increase proportionally to the rated power of the branch, the time duration of the interval and value of the lost load. Additionally, a security coefficient (β) seeks to provide the decision-maker's perspective on the acceptance degree of network congestions. If $1 \leq \beta \leq 100$, there is a high acceptance degree of network congestions (if economically reasonable). Otherwise, if $\beta > 100$, the decision-maker is unwilling to accept network congestions. That is to say, the higher the β, the lower the decision-maker's tolerance concerning congestion events. This evaluation is made for all branches and all intervals considered.

The optimization problem is subject to several constraints, as follows.

Transmission Constraints

$$V_i V_j Y_{ij} \left(\theta_i(t) - \theta_j(t)\right) \leq \bar{q}_{ij}(t) \ , \ i \neq j \in N \tag{12}$$

$$q_i(t) = \sum_{j=1}^{N} V_i V_j Y_{ij} \left(\theta_i(t) - \theta_j(t)\right) \ , \ i \in N \tag{13}$$

$$q_i(t) = g_i(t) - d_i(t) + r_i(t) \ , \ i \in N \tag{14}$$

Where,

V_i – Voltage level in node i;

θ_i – Voltage angle in node i;

Y_{ij} – Admittance matrix element resorting to nodes i,j;

$q_i(t)$ – Net power flow at node i and interval t;

$g_i(t)$ – Generation at node i and interval t;

$d_i(t)$ – Demand at node i and interval t;

Equation (12) is the power flow constraint for all branches. Equations (13)–(14) gives the net power flow on each node i and interval t. The power flow is the result of the several injections from the generation $g_i(t)$, demand $d_i(t)$ or storage $r_i(t)$ facilities.

Energy Storage Constraints

$$\bar{R}_i \leq \bar{R}_i^{\,*}, \qquad t \in T, i \in N \tag{15}$$

$$\bar{S}_i \leq \bar{S}_i^{\,*}, \qquad t \in T, i \in N \tag{16}$$

$$s_i(t) = s_i(t-1) - r_i(t)\,\Delta t\,, \qquad i \in N, \forall t \in T \tag{17}$$

Where,

$\bar{R}_i, \bar{R}_i^{\,*}$ – It corresponds to the current power requirement and the maximum power requirement for node i, respectively. The maximum power requirement ($\bar{R}_i^{\,*}$) is defined by the user and the current requirement ($\bar{R}_i$)initial value is zero and is considered an assumption;

$\bar{S}_i, \bar{S}_i^{\,*}$ – It corresponds to the current energy requirement and the maximum energy requirement for node i, respectively. The maximum energy requirement ($\bar{S}_i^{\,*}$) is defined by the user and the current requirement ($\bar{S}_i$) initial value is zero and is considered an assumption;

The energy storage constraints are related to the rated power and energy constraints (15)–(16) that DES facilities are subject to and the energy conservation (17) that should exist between intervals.

This formulation allows the algorithm to deploy DES into the network and solve congestion problems with minimum power, energy and facility requirements, taking into account the whole period constraints and, ultimately, minimizing the costs of the solution.

2.1.1.2 Single-interval Objective Function

The objective function for the single-interval DES planning problem is the following:

$$\min\left[\sum_{i=1}^{N}(|CP_i r_i|) + \sum_{i=1}^{N}(f_i\delta) + \sum_{i=1}^{N}\sum_{j\neq i}^{N}\left(CPEN_{i,j}\right)\right] \tag{18}$$

This function attempts to minimize, for the interval that is applied: the cost (CP_i) per unit of power used (r_i) to solve the network congestion; the cost (δ) per facility (f_i) required; and the penalty costs $\left(CPEN_{i,j}\right)$ associated with the existence of network congestions.

The power costs are calculated according to the power used to solve the congestion in the interval t:

$$|CP_i r_i(t)|\,, \;\; \forall i \in N \tag{19}$$

The facility costs and congestion penalty costs are calculated as mentioned in equations (9)–(11), but applied for a single period only. This problem is also subject to the same transmission constrains presented in (12)–(14), in order to validate the solution in the network.

2.1.2 Strategy to solve the DES planning problem

Network planning assumes an essential role in the development of a power system. Currently, the DES is deemed as a likely strategy for transmission system flexibility enhancement, leading to, among other benefits, to higher levels of RES integration and congestion management.

The problem of planning DES systems in transmission networks is gaining momentum among the TSOs. While most of the literature tend to focus on the maximization of RES integration or ancillary services supply, provided by this kind of technology [4] [3], there is another capability that DES is able to provide due to its fast response ability and modularity (i.e. flexibility enhancement). DES systems can enhance the capacity of network assets, such as lines and power transformers, during short periods in which they experience short term overloads.

The problem of finding the site and size for energy storage facilities can be formulated as a complex mixed-integer linear programing problem. To solve similar problems several meta-heuristics can be used, including local search, dynamic objective functions and naturally inspired strategies. In this deliverable we resort to the Evolutionary Particle Swarm Optimization (EPSO) algorithm to solve the problem [5]. The EPSO algorithm will be introduced in the following sub-section of the document.

2.2 Introduction to EPSO

The EPSO algorithm is based in the classical Particle Swarm Optimization (PSO) model [6]. The swarm optimization algorithms are part of the evolutionary algorithms that simulates natural swarm behavior towards the optimum solution.

The EPSO algorithm uses evolutionary strategies (evolutionary programming) [7] [8] to self-adapt and guide their particles (solutions) through the search space. Those particles are then selected through an evolutionary paradigm which can be strictly stochastic (e.g. stochastic tournament) or deterministically driven (e.g. elitism selection).

Swarm algorithms are a special kind of evolutionary algorithms, as their particles follow a complex zoological behavior which includes social or swarms behaviors. The behavior of the particles is dictated by three main elements: habit, memory and cooperation [6]. The habit, or also called inertia element, drives the particles according to its previous movement. The memory factor affects the particles in a way that they try to get back to its prior best position. Finally, the third element interacts with the particles inducing their information sharing, guiding them to the best position found by any particle of its group in the whole search space.

As described in [5], the main structure behind the operation of EPSO is the following:

- REPLICATION – each particle is replicated (cloned) r times;
- MUTATION – each particle has its weights mutated;
- REPRODUCTION – each mutated particle generates descendants according to the particle movement rule;
- EVALUATION – each new particle has its fitness evaluated;

- SELECTION – the best particles are selected to become the next generation by stochastic tournament or other methods (e.g. elitism).

The movement rule of the particles in the swarm is dictated as shown below. Given a particle X_i , a new particle X_i^{new} results from:

$$X_i^{new} = X_i + V_i^{new} \tag{20}$$

$$V_i^{new} = w_{i0}^* V_i + w_{i1}^* (b_i - X_i) + w_{i2}^* \left(b_g^* - X_i\right) \tag{21}$$

The main difference between the classical PSO and the EPSO comes from the mutation of weights (w_{ik}). The weights suffer mutation according to:

$$w_{ik}^* = w_{ik} + \tau N(0,1) \tag{22}$$

Where $N(0,1)$ is a random variable with Gaussian distribution of 0 mean and variance of 1. Still the best global b_g is affected by the random distribution according to the following expression:

$$b_g^* = b_g + \tau' N(0,1) \tag{23}$$

The strategic parameters τ, τ' are learning parameters that are fixed and affects the mutation of the algorithm elements.

This scheme benefits from two main “impulses” into the right direction: (1) the Darwinist mechanism for particles’ selection and (2) the improved convergence capacity when compared with classical PSO.

Additionally, the EPSO algorithm benefits from its self-adapting characteristic as it depends on the mutation and selection of its strategic parameters to guide the swarm evolution.

A graphical representation of the process is presented in Figure 2-2:

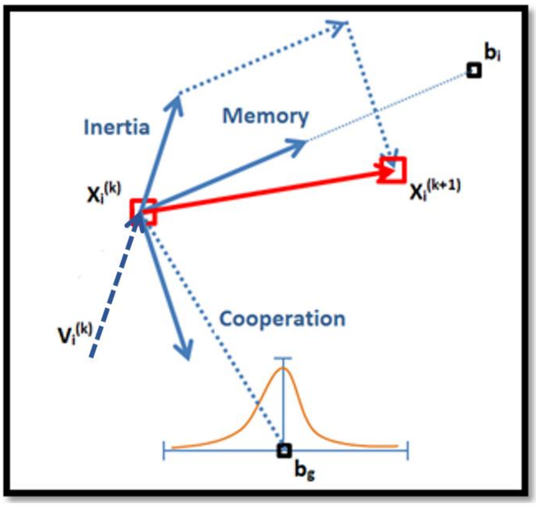


Figure 2-2 – Working concept of EPSO algorithm

2.3 DESPlan algorithm logic

This sub-section presents the logic of the DESPlan tool algorithm. The DESPlan algorithm gathers two main parts: (P1) Flexibility Analysis, (P2) Multi-Interval DESPlan. Each part is visible in Figure 2-3, as P1 and P2. The first step of the algorithm consists in loading the base case. The base case includes information of network characteristics, and supply and demand data for the whole simulation period. The simulation period is divided into a set of discrete intervals which represents the status of the network for the considered interval (e.g. each 15 or 60 min). It is assumed that during each interval the network remains steady, changing its status from interval to interval only. The DESPlan algorithm process is shown in Figure 2-3.

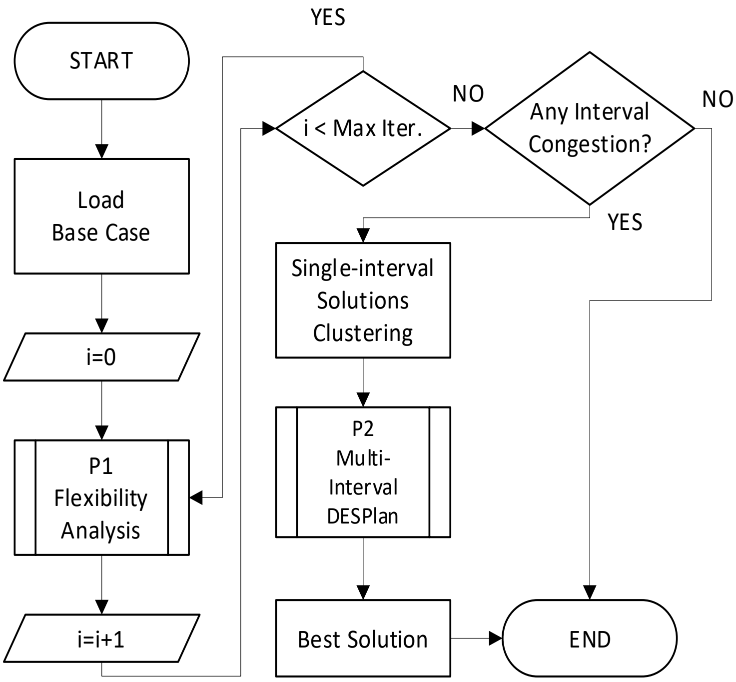


Figure 2-3 – DESPlan algorithm process

The objective of the DESPlan algorithm is to find the combination of site and size of DES facilities, in the network, that minimizes the cost of the solution. This means finding the optimal power $(\bar{R}_i)$, energy $(\bar{S}_i)$ and number of locations' requirement for the DES solution. Finally, the algorithm returns the solution and the associated cost. This allows the network planner to have an additional grid expansion alternative to consider in the planning options portfolio.

2.3.1 Flexibility Analysis

The first part the DESPlan algorithm simulates the network for each of the considered intervals, to assess the network condition (P1). For each interval (e.g. hour) the algorithm evaluates the flexibility margin of the network through the identification of potential network congestions. The flexibility analysis process is presented in Figure 2-4.

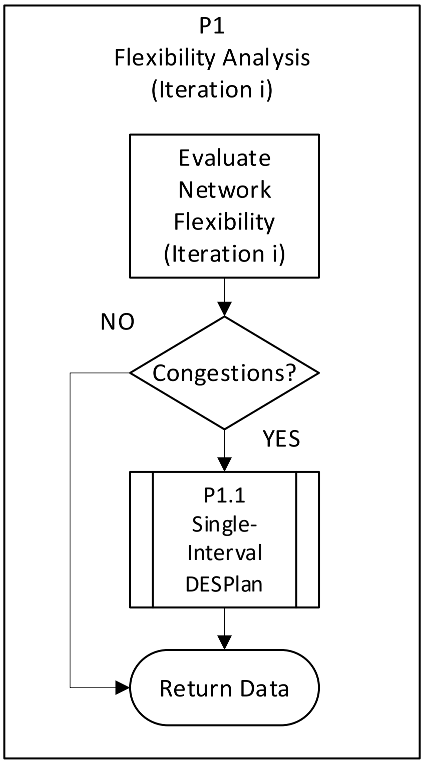


Figure 2-4 – Flexibility analysis (P1)

If network congestion is detected, a simulation of the single-interval EPSO algorithm (P1.1) is performed in order to solve the congestion.

2.3.2 Single-interval EPSO

For the interval in which the congestion was detected, the single-interval EPSO algorithm will find the minimum requirement of DES which solves the network congestion. The process of the single-interval DESPlan is shown in Figure 2-5.

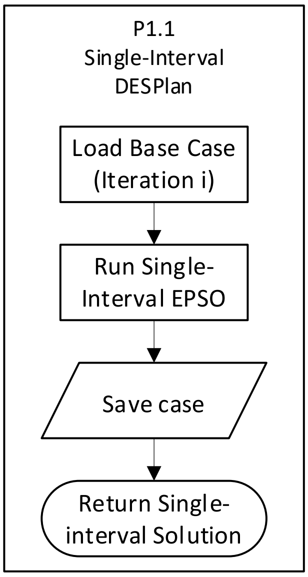


Figure 2-5 – Single-interval DESPlan (P1.1)

Firstly, the base case for the considered interval (t) is loaded and then the Single-interval EPSO algorithm is started. After finding the best solution, taking into account only this isolated interval, the algorithm saves the solution case file in the PSS/E™ format (.sav) for later analysis if needed by the planner.

The algorithm return the solution case data for reporting and continues for the next interval simulation and analysis until the last interval is reached, as presented before in Figure 2-3.

2.3.3 Multi-interval EPSO

As shown in Figure 2-3, after completing the entire period simulation, the DESPlan algorithm moves to the Multi-interval DESPlan problem, by finding the near-optimal set of sizing and siting for DES which minimizes the power and energy requirements of the DES system for the entire period of analysis.

In order to include the information (solutions) obtained from previous simulations – Single-interval DESPlan – which ignored the temporal dependency, the initial solutions found in the single-interval DESPlan are included in the original swarm of the Multi-interval EPSO, as a first approximation of the near-optimal solution.

In Figure 2-6 the flowchart regarding the Multi-interval DESPlan algorithm (P2) is presented.

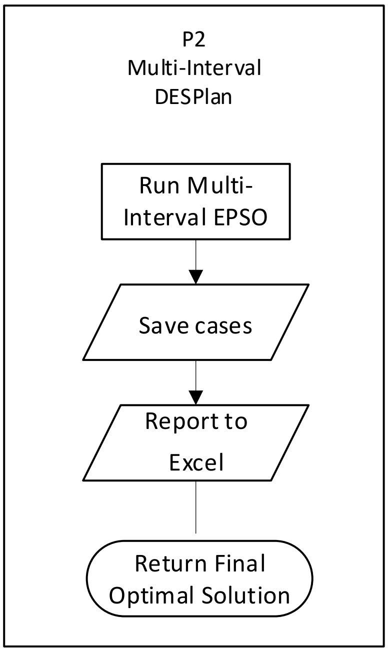


Figure 2-6 – Multi-interval EPSO (P2) Flowchart

If there was any network congestion detected during the entire period simulation, the Multi-interval EPSO algorithm will be started, including previous solutions found at each Single-interval EPSO. This Multi-interval EPSO algorithm takes into account the time-dependence which actually exists between the several intervals, due to the continuous operation of the system. The main objective of the Multi-interval EPSO algorithm is to minimize the requirement (and associated cost) of power, energy and number of DES facilities for the whole period of time considering solutions which allows the network overcome its lack of flexibility.

2.4 Case study and main assumptions

There is a need to create two case studies networks in order to study the data sets scenarios for 2030 and 2050. For these two case studies certain assumptions were made with the intention of predict as close as possible the Portuguese transmission network in these time horizons.

A script that automatically develops the 8760[1] scenarios cases files (.sav) for each of the correspondent years was developed. Each of the cases files incorporate the hourly datasets profiles (time series) provided by T1.2 from OSMOSE, already redistributed accordingly to the methodology that is explained later in section 2.5.

It was necessary to make some adaptations to the original network model provided by the Portuguese TSO in order to approximate the model to the time horizon considered in the OSMOSE dataset.

[1] The OSMOSE dataset provided by T1.2 doesn't consider the 31 of December and for that reason, in practice, were only studied 8736 periods for each year.

Additionally, all the studies, for both scenarios, were performed considered the network with all branches available ("N condition").

The adaptations are explained below:

- The Portuguese system's clustering considered in OSMOSE model has 4 links with the neighbouring Spain (i.e. links 01es-12pt, 02es-12pt, 08es-13pt, 09es-13pt). Nevertheless, the actual number interconnections between both transmission systems (Portugal and Spain) are currently 8. For this reason, it was needed to adapt the network model in order to consider an equivalent model of the Spanish system, being the slack bus located in this equivalent Spanish system, using equivalent generators that represent the power flow exchanged between countries.
- Adjustment of the installed capacity for each of the technologies considered in the OSMOSE dataset. This action was performed only when the installed capacity of the Portuguese system considered for the OSMOSE dataset was not enough to be able to provide the required power output considered.
- The load distribution proportion in the model was kept (within what was possible) in order to reflect regional characteristics of the demand.

2.4.1 2030 Case study

The 2030 Portuguese transmission network model follows the PDIRT 2020-2029 [9]. The PDIRT consists in the long-term development and investment plan for the electricity transmission network, which is the official public document that explores the investment plans approved by the NRA for the next 10 years. From 2020 until 2029 is foreseen the reinforcement of some EHV/HV transformers and lines (400kV and 220 kV), the decommissioning of thermal power plants and the installation of some new hydro power plants, some of them with reversible capability. As assumption, it was considered that the 2030 Portuguese transmission network model will consist in the same model that is foreseen for 2029, which is the horizon of the current PDIRT.

A brief description of 2030 Portuguese transmission network planning model is presented. The 2030 Portuguese transmission system model has a total installed capacity of 32 GW of which around 25 GW are renewable technologies based, as illustrated in Table 2.1.

Table 2.1 – Installed capacity per technology in 2030 Model

Technology	Installed Power [GW]
Hydro	8.55
Wind	8.00
Solar	8.10
Biomass	1.33
Natural Gas	3.83
Coal	1.76
Others	0.44
TOTAL	**32.01**

The peak load of the system typically occurs during winter months. In 2030, the e-Highway dataset foresees an annual peak load correspondent to a maximum load of 9.75 GW, and an off-peak correspondent to a minimum load of 3.25 GW. The annual peak load foreseen represents less than one third of the total generation installed capacity in the 2030 Portuguese transmission network model.

Concerning voltage levels of the system, the Portuguese transmission network is operated by the system operator (REN) at the 150 kV, 220 kV and 400 kV extra high voltage (EHV) levels. The model goes until the interface TSO/DSO that corresponds to the EHV/HV interface. In the HV bays is only considered the distribution energy resources (DER) connected to them.

2.4.2 2050 Case study

For the 2050 Portuguese transmission network, we followed the latest version of the PDIRT 2022-2031 [10]. From the previous case study (sub-chapter 2.4.1) the only change is related with the increase of solar installed power and the called “others” technology, in which are included the batteries and Power to Gas (P2G).

Table 2.2 – Installed capacity per technology in 2050 Model

Technology	Installed Power [GW]
Hydro	8.55
Wind	8.00
Solar	12.50
Biomass	1.33
Natural Gas	3.83
Coal	1.76
Others	2.62
TOTAL	**38.59**

For the PV power plants forecasted for 2050, we followed the initially the 2031 foreseen distribution map presented in the Figure 2-7.

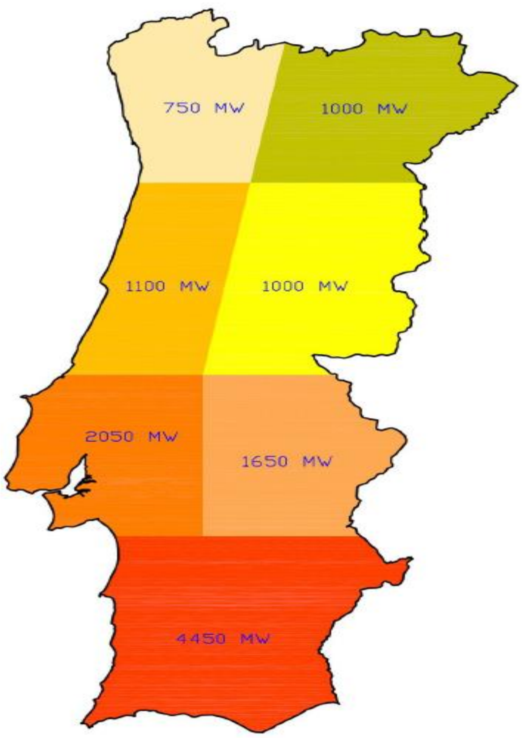


Figure 2-7 – Estimated distribution of installed power solar power plants for large areas on the horizon 2031 [10]

The source with the greatest weight in the overall installed capacity is solar power as can be seen in Table 2.2. It is expected that by 2031 the value of its installed power may increase to close to 12.0 GW, with the area distribution presented in the map. In this solar component, it should be noted that the estimated value for its evolution from the 2030 and 2050 models horizons is of almost 4 GW. We assumed that these 4 GW of PV power plants were distributed in the 2050 network model according to the geographical distribution presented in the Figure 2-7. Is possible to observe a marked discrepancy between the areas with the greatest consumption - the coastal strip between Braga and Setubal and the Algarve coast - and those with the greatest solar production.

Additionally in the 2050 planning network model, we needed to add power stations that represent batteries and P2G technologies that did not exist in the 2030 model. In the total were added 2.1 GW of power capacity.

2.5 Redistribution methodology

This sub-section describes the data redistribution methodology implemented to redistribute the aggregated time-series data from the Portuguese clusters (clusters 12 and 13), provided by T1.2, into the detailed model of the Portuguese transmission network.

2.5.1 Load

The redistribution of loads is based on historical data from the Portuguese TSO. This data includes the natural load of 63 substations and the consumption pattern of large industrial consumers connected to the Extra High Voltage (EHV – 400kV, 220kV, 150kV) network and also at the distribution level (63kV), which consist of 19 large consumers. Since this data only contains active power load, the reactive power load was calculated in accordance with another dataset, provided by the Portuguese TSO, which contains the active and reactive power load for 4 days in a year from different seasons. For every season, the power factor was calculated and used in the calculation for 63 substations from the dataset with natural load and 17 large industrial consumers. For remaining 2 large industrial consumers, connected to 400 kV grid, due to the absence of the data on their reactive power, the power factor was taken as 0.2 p.u. Further hourly load data from Task 1.2 was used to calculate the hourly load power for each substation in the network model.

2.5.2 Generation

The hourly generation data for the scenarios is taken from OSMOSE task 1.2. It consists of 13 different types of technologies:

- Combined cycle gas turbine;
- Open cycle gas turbine;
- Biomass;
- Bioenergy with carbon capture and storage;
- Biogas;

- Waste;
- Geothermal;
- Photovoltaic;
- Wind onshore;
- Wind offshore;
- Hydro – run-of-river;
- Hydro – dam;
- Hydro – pump storage.

Since the grid data for several types of generation in the network model is agglomerated in one type comparing to the hourly data from Task 1.2, it was necessary to define the correspondence between the two datasets. This correspondence in presented in Table 2.3.

Table 2.3 – The correspondence between the data from Task 1.2 and the network model

The hourly generation data from Task 1.2	The generation data from the TSO model
Combined cycle gas turbine (CCGT)	Combined cycle gas turbine (CCGT)
Open cycle gas turbine (OCGT)	Open cycle gas turbine (OCGT)
Biomass	Cogeneration
Bioenergy with carbon capture and storage	Other
Biogas	
Waste	
Geothermal	
Photovoltaic	Solar
Wind onshore	Wind onshore
Wind offshore	Wind offshore
Hydro – run-of-river	Hydro – run-of-river
Hydro – dam	Hydro – dam
Hydro – pump storage	Hydro – pump storage

Since biomass generation dataset from Task 1.2 was not directly mapped in the Portuguese network model, it was mapped into the cogeneration generation type since there was no cogeneration data in the dataset from T1.2 and due to the similarity of the two generation profiles which provided almost constant power in their daily cycle.

Also, it is important to note that the Portuguese network model includes three kinds of generation:

1. Generators connected at the distribution level (60 kV), which represent the aggregated value of embedded generation in that specific branch of the network (e.g. distributed generation, DER);
2. Generators connected to HV (63kV) or EHV (400, 220, 150 kV) levels, which represent equivalent power plants (e.g. wind farms, PV power plants), which include the generator and transformer group;

3. Generators, connected to the low voltage side of the transformer on the power plant, representing an individual generator group.

For the 3rd type of the generators and for several types of 2nd type of the generators the historical production data from 2019 was considered. For the 1st type (embedded generation) a distribution methodology was applied.

The distribution of generation by type of connection to the network is presented in Table 2.4.

Table 2.4 – The distribution of generation by type of connection in detailed network model

The generation data from the detailed network model	Types of the generation by its connection
Combined cycle gas turbine (CCGT)	3
Open cycle gas turbine (OCGT)	1
Cogeneration	1
Other	1
Solar	1, 2
Wind onshore	1, 2
Wind offshore	2
Hydro – run-of-river	1, 3
Hydro – dam	1, 2, 3
Hydro – pump storage	3

The calculation methodology for each of the types of generation will be presented below.

2.5.2.1 Combined cycle gas turbine (CCGT)

This type of the generation is represented by 4 power plants and 10 generators. The historical data considered as base profile (2019 data) consists of the hourly generating power of each power plant. To redistribute this data among the generators, the following methodology, consisting of **4 steps**, is applied.

On the step 1, the working generators are selected based on the historical data and following the next criteria:

- If the generating power considering the historical data is equal or less than 90% of the capacity of the largest generator of the chosen power plant, it is considered that only one generator on the power plant is in service;
- If the generating power considered in the historical data is greater than 90% of the capacity of one generator the first criteria is not viable. Then, if the generating power is less or equal than 90% of the sum of the capacities of the available generators in the chosen power plant (two, three, four, …) it is considered that additional generators of the power plant will have to be in service and their generation will be divided according to the installed capacity of each generator.

On the step 2, the share of the generation power of every working generator is calculated in order to redistribute the time series dataset, coming from Task 1.2.

On the step 3, the merit order list of the generators is created. The generators are sorted according to full-load hours (utilization rate), which is calculated as a sum of the generation power for every hour in the year, divided by the generator's nominal capacity.

On the step 4, the hourly generation data for CCGT from Task 1.2 is used to calculate the hourly generation power for each generator out of the 10 existing in detailed network model. On this last step, depending on the power provided by the dataset from Task 1.2, there are **3 actions** possible for redistribution of the time series data into the detailed network model:

1. After calculation, all the working generators are able to generate the calculated power without the overload of any of them (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
2. After calculation, there are some overloaded generators, but it is still possible to re-dispatch the power between working generators (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
3. After calculation, there are some overloaded generators and it is impossible to re-dispatch the power between working generators without violating the 90% limit of the installed capacity of each generator. In this case, additional "out-of-service" generators will need to be turned on to avoid the overload of any working generator. The "out-of-service" generators will be selected according to the merit order list based on the full-load hours in the reference historical data.

In case action 1 is feasible, the redistributed data from the time series provided by T1.2 is directly inserted into the detailed network model.

In case action 1 is not possible, but action 2 feasible, the generators that had a loading higher than 90% of their rated capacity will be limited to 90% their installed capacity, all the remaining active power will be distributed among the other working generators in accordance with merit order list.

In the case neither action 1 nor action 2 are possible, all working generators will be limited at 90% of their installed capacity. Additionally, "out of service" generators will be turned on in accordance with the merit order list. As result of this being an automatic process, the active power generation limit of reconnected generators was limited to 70% of their installed capacity, to ensure enough reactive power flexibility to allow voltage control.

The flowchart shown in Figure 2-8 illustrates this methodology. The green elements represent the input data, the yellow elements represent the methodology steps, the grey elements describe the methodology of selection of working generators, the red elements are the possible actions for the redistribution of OSMOSE time series, finally the blue element represent the resulting file.

Figure 2-8 – Flowchart of the methodology for CCGT type of the generation

2.5.2.2 Open cycle gas turbine (OCGT)

This type of the generation is represented by 1 generator, connected to 63 kV grid. The dataset from Task 1.2 is substituted directly into the detailed network model.

2.5.2.3 Cogeneration

This type of the generation is represented by 28 power plants and 28 aggregated generators, connected to 63 kV grid. The historical data considered as base profile (2019 data) does not have the hourly generating power of each power plant. The dataset from Task 1.2 is distributed among the 28 generators into the detailed network model accordingly to their active power generation capacity.

2.5.2.4 Other

This type of the generation is represented by 20 power plants and 20 aggregated generators, connected to 63 kV grid. The historical data considered as base profile (2019 data) does not have the hourly generating power of each power plant. The dataset from Task 1.2 is distributed among the 20 generators into the detailed network model accordingly to their active power generation capacity.

2.5.2.5 Solar

This type of the generation is represented by 65 power plants and 79 generators, 60 of which are connected to 63 kV grid (distributed generation), 19 – to HV and EHV grid (generator-transformer group of the power plant). The historical data considered as base profile (2019 data) has the data for only one solar power plant, which means that it has only one generation profile. Since the generation profile from the dataset from Task 1.2 has the higher priority than the historical data considered as base profile (2019 data), the dataset from Task 1.2 is distributed among the 79 generators into the detailed network model accordingly to their active power generation capacity.

2.5.2.6 Wind onshore

This type of the generation is represented by 54 power plants and 54 generators, 39 of which are connected to 63 kV grid (distributed generation), 15 – to HV and EHV grid (generator-transformer group of the power plant). The historical data considered as base profile (2019 data) consists of the hourly generating power of the power plants, connected to HV and EHV grid. To redistribute this data among all generators, the following methodology, consisting of **4 steps**, is applied.

On the step 1, the share of all generators is calculated:

- for distributed generation, the determining factor for calculating the share is the maximum active power of every generator;
- for generators, connected to HV and EHV grid, the determining factor for calculating the share is the historical data considered as base profile (2019 data).

On the step 2, the sorted list of the generators, connected to HV and EHV grid, is created. The generators are sorted according to full-load hours (utilization rate), which is calculated as a sum of the generation power for every hour in the year, divided by the generator's nominal capacity.

On the step 3, the hourly generation data for Wind Onshore from Task 1.2 is used to calculate the hourly generation power for each generator connected to HV and EHV grid in the detailed network model. On this step, depending on the power, provided by the dataset from Task 1.2, there are **3 actions** possible for redistribution of the time series data into the detailed network model:

1. After calculation, all the working generators are able to generate the calculated power without the overload of any of them (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
2. After calculation, there are some overloaded generators, but it is still possible to re-dispatch the power between working generators (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
3. After calculation, there are some overloaded generators and it is impossible to re-dispatch the power between working generators without violating the 90% limit of the installed capacity of each generator. In this case, additional "out-of-service" generators will need to be turned on to avoid the overload of any working generator. The "out-of-service" generators will be selected according to the merit order list based on the full-load hours in the reference historical data.

In case action 1 is feasible, the redistributed data from the time series provided by T1.2 is directly inserted into the detailed network model.

In case action 1 is not possible, but action 2 feasible, the generators that had a loading higher than 90% of their rated capacity will be limited to 90% their installed capacity, all the remaining active power will be distributed among the other working generators in accordance with merit order list.

In the case neither action 1 nor action 2 are possible, all working generators will be limited at 90% of their installed capacity. Additionally, "out of service" generators will be turned on in accordance with the merit order list. As result of this being an automatic process, the active power generation limit of reconnected generators was limited to 70% of their installed capacity, to ensure enough reactive power flexibility to allow voltage control.

On the step 4, the hourly generation data for Wind Onshore from Task 1.2 is used to calculate the hourly generation power for each generator connected to 63 kV grid (distributed generation) in detailed network model using the share from the first step.

The flowchart shown on Figure 2-9 illustrates this methodology. The green elements represent the input data, the yellow elements represent the methodology steps, the grey elements describe the methodology of selection of working generators, the red elements are the possible actions for the redistribution of OSMOSE time series, finally the blue element represent the resulting file.

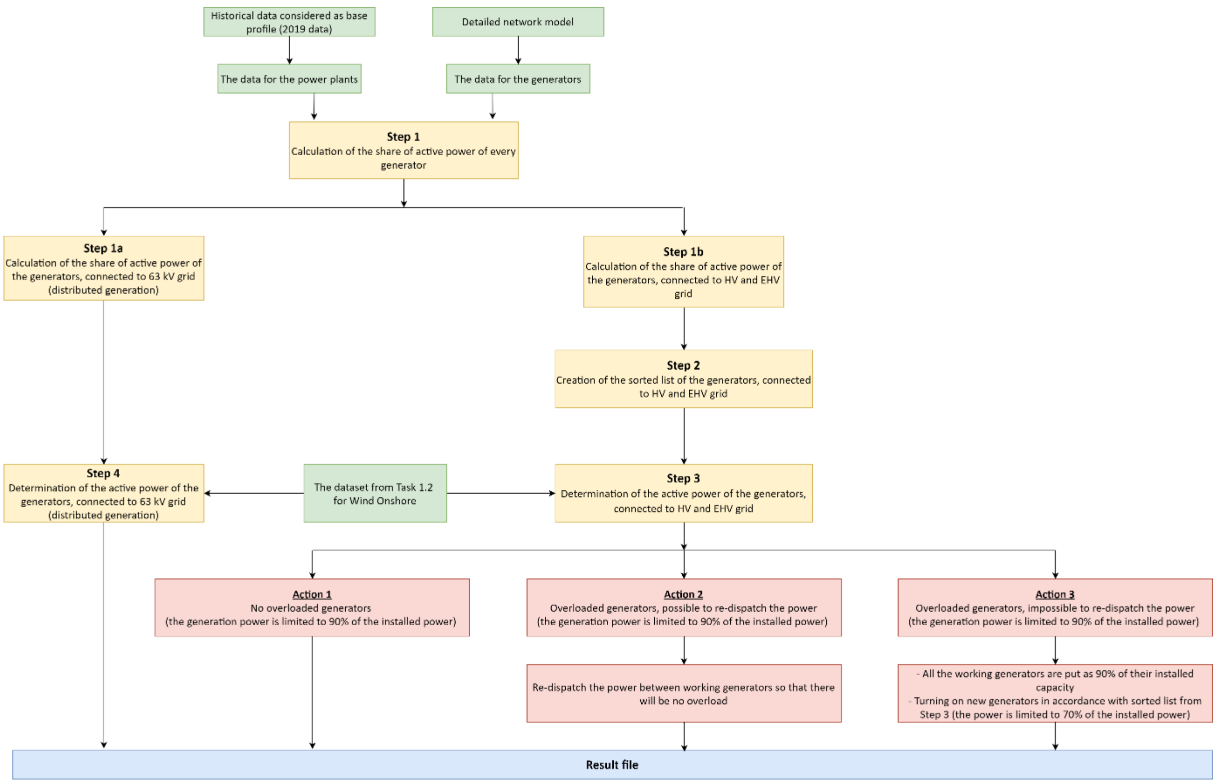


Figure 2-9 – Flowchart of the methodology for Wind Onshore type of the generation

2.5.2.7 Wind offshore

This type of the generation is represented by 1 generator, connected to 150 kV grid. The dataset from Task 1.2 is substituted directly into the detailed network model.

2.5.2.8 Hydro – run-of-river

This type of the generation is represented by 37 power plants and 60 generators, 23 of which are connected to 63 kV grid (distributed generation), 37 – to the low voltage side of the transformer on the power plant. The historical data considered as base profile (2019 data) consists of the hourly generating power of the power plants, connected to 6 kV, 10 kV and 15 kV grid. To redistribute this data among all generators, the following methodology, consisting of **5 steps**, is applied.

On the step 1, the share of all generators is calculated:

- for distributed generation, the determining factor for calculating the share is the maximum active power of every generator;
- for generators, connected to the low voltage side of the transformer on the power plant, the determining factor for calculating the share is the historical data considered as base profile (2019 data).

On the step 2, for calculation of the share of the generators, connected to the low voltage side of the transformer of the power plant, the generators in service are selected based on the historical data and following the next criteria:

- If the generating power considering the historical data is equal or less than 90% of the capacity of the largest generator of the chosen power plant, it is considered that only one generator on the power plant is in service;
- If the generating power considered in the historical data is greater than 90% of the capacity of one generator the first criteria is not viable. Then, if the generating power is less or equal than 90% of the sum of the capacities of the available generators in the chosen power plant (two, three, four, …) it is considered that additional generators of the power plant will have to be in service and their generation will be divided according to the installed capacity of each generator.

On the step 3, the sorted list of the generators, connected to the low voltage side of the transformer of the power plant, is created. The generators are sorted according to full-load hours (utilization rate), which is calculated as a sum of the generation power for every hour in the year, divided by the generator's nominal capacity.

On the step 4, the hourly generation data for Hydro Run-of-River from Task 1.2 is used to calculate the hourly generation power for each generator connected to the low voltage side of the transformer of the power plant existing in detailed network model. On this step, depending on the power provided by the dataset from Task 1.2, there are **3 actions** possible for redistribution of the time series data into the detailed network model:

1. After calculation, all the working generators are able to generate the calculated power without the overload of any of them (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
2. After calculation, there are some overloaded generators, but it is still possible to re-dispatch the power between working generators (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
3. After calculation, there are some overloaded generators and it is impossible to re-dispatch the power between working generators without violating the 90% limit of the installed capacity of each generator. In this case, additional "out-of-service" generators will need to be turned on to avoid the overload of any working generator. The "out-of-service" generators will be selected according to the merit order list based on the full-load hours in the reference historical data.

In case action 1 is feasible, the redistributed data from the time series provided by T1.2 is directly inserted into the detailed network model.

In case action 1 is not possible, but action 2 feasible, the generators that had a loading higher than 90% of their rated capacity will be limited to 90% their installed capacity, all the remaining active power will be distributed among the other working generators in accordance with merit order list.

In the case neither action 1 nor action 2 are possible, all working generators will be limited at 90% of their installed capacity. Additionally, “out of service” generators will be turned on in accordance with the merit order list. As result of this being an automatic process, the active power generation limit of reconnected generators was limited to 90% of their installed capacity, to ensure enough reactive power flexibility to allow voltage control.

On the step 5, the hourly generation data for Hydro Run-of-River from Task 1.2 is used to calculate the hourly generation power for each generator connected to 63 kV grid (distributed generation) in detailed network model using the share from the step 1.

The flowchart shown in Figure 2-10 illustrates this methodology. The green elements represent the input data, the yellow elements represent the methodology steps, the grey elements describe the methodology of selection of working generators, the red elements are the possible actions for the redistribution of OSMOSE time series, finally the blue element represent the resulting file.

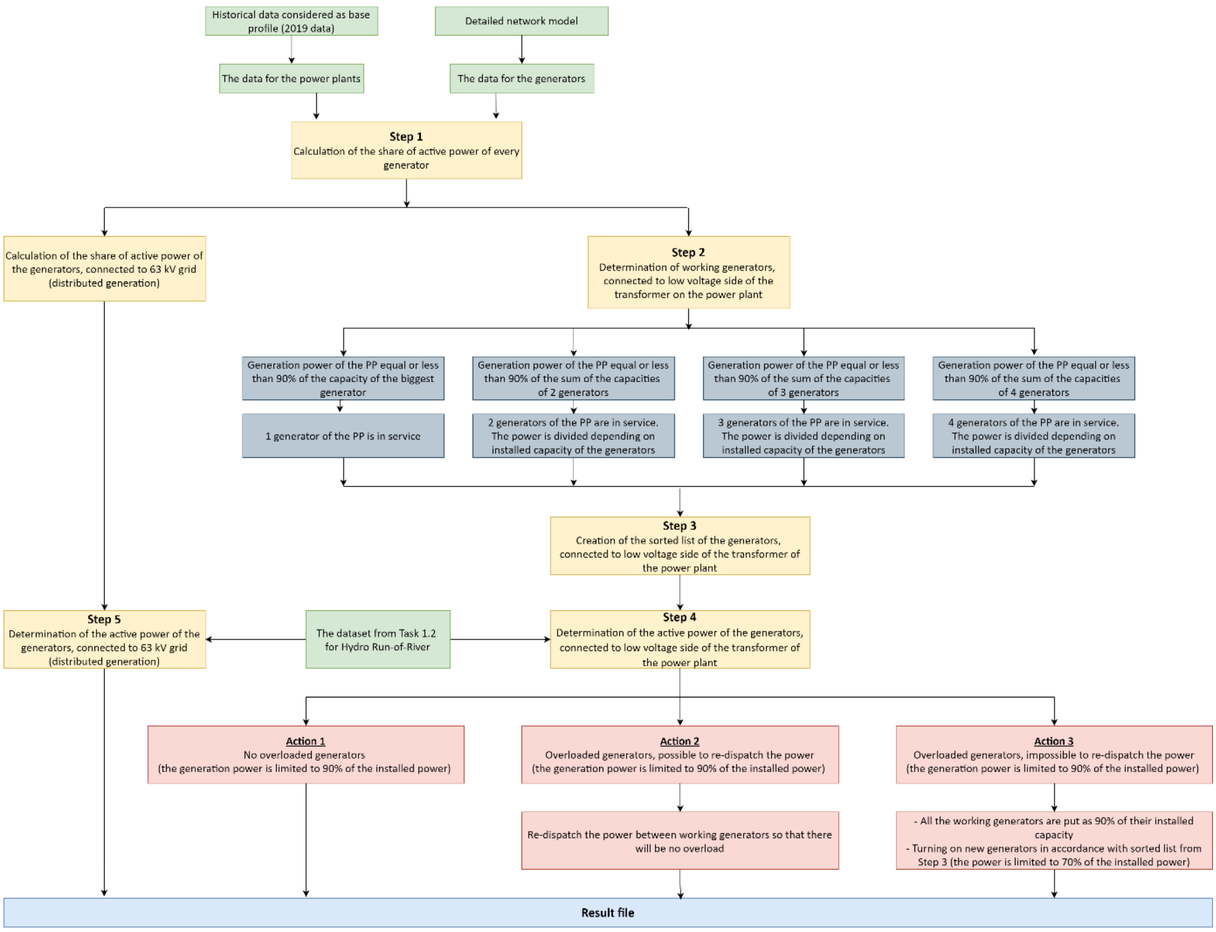


Figure 2-10 – Flowchart of the methodology for Hydro Run-of-River type of the generation

2.5.2.9 Hydro – dam

This type of the generation is represented by 16 power plants and 29 generators, 4 of which are connected to 63 kV grid (distributed generation), 25 – to the low voltage side of the transformer on the power plant. The historical data considered as base profile (2019 data) consists of the hourly generating power of the power plants, connected to 6 kV, 10 kV and 15 kV grid. To redistribute this data among all generators, the following methodology, consisting of **4 steps**, is applied.

On the step 1, the share of all generators is calculated:

- for distributed generation, the determining factor for calculating the share is the maximum active power of every generator;
- for generators, connected to the low voltage side of the transformer on the power plant, the determining factor for calculating the share is the historical data considered as base profile (2019 data).

On the step 2, for calculation of the share of the generators, connected to the low voltage side of the transformer of the power plant, the generators in service are selected based on the historical data and following the next criteria:

- If the generating power considering the historical data is equal or less than 90% of the capacity of the largest generator of the chosen power plant, it is considered that only one generator on the power plant is in service;
- If the generating power considered in the historical data is greater than 90% of the capacity of one generator the first criteria is not viable. Then, if the generating power is less or equal than 90% of the sum of the capacities of the available generators in the chosen power plant (two, three, four, …) it is considered that additional generators of the power plant will have to be in service and their generation will be divided according to the installed capacity of each generator.

On the step 3, the sorted list of the generators is created. The generators are sorted according to full-load hours (utilization rate), which is calculated as a sum of the generation power for every hour in the year, divided by the generator's nominal capacity.

On the step 4, the hourly generation data for Hydro Dam from Task 1.2 is used to calculate the hourly generation power for each generator in detailed network model. On this step, depending on the power provided by the dataset from Task 1.2, there are **4 actions** possible for redistribution of the time series data into the detailed network model:

1. After calculation, all the working generators are able to generate the calculated power without the overload of any of them (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
2. After calculation, there are some overloaded generators, but it is still possible to re-dispatch the power between working generators (in order to have a reactive power

reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);

3. After calculation, there are some overloaded generators and it is impossible to re-dispatch the power between working generators without violating the 90% limit of the installed capacity of each generator. In this case, additional “out-of-service” generators will need to be turned on to avoid the overload of any working generator. The “out-of-service” generators will be selected according to the merit order list based on the full-load hours in the reference historical data.
4. After calculation, there are some overloaded generators and it is impossible to re-dispatch the power between all of the generators without violating the 90% limit of the installed capacity of each generator.

In case action 1 is feasible, the redistributed data from the time series provided by T1.2 is directly inserted into the detailed network model.

In case action 1 is not possible, but action 2 feasible, the generators that had a loading higher than 90% of their rated capacity will be limited to 90% their installed capacity, all the remaining active power will be distributed among the other working generators in accordance with merit order list.

In case action 1 and action 2 are not possible, but action 3 is feasible, all working generators will be limited at 90% of their installed capacity. Additionally, “out of service” generators will be turned on in accordance with the merit order list. As result of this being an automatic process, the active power generation limit of reconnected generators was limited to 90% of their installed capacity, to ensure enough reactive power flexibility to allow voltage control.

In case neither action 1 nor action 2 nor action 3 are possible, all working generators will be limited at 90% of their installed capacity, the remaining power will be transferred into the calculation of the Hydro – Pump storage.

The flowchart shown in Figure 2-11 illustrates this methodology. The green elements represent the input data, the yellow elements represent the methodology steps, the grey elements describe the methodology of selection of working generators, the red elements are the possible actions for the redistribution of OSMOSE time series, finally the blue element represent the resulting file and the remaining power to transfer into the calculation of the Hydro – Pump storage.

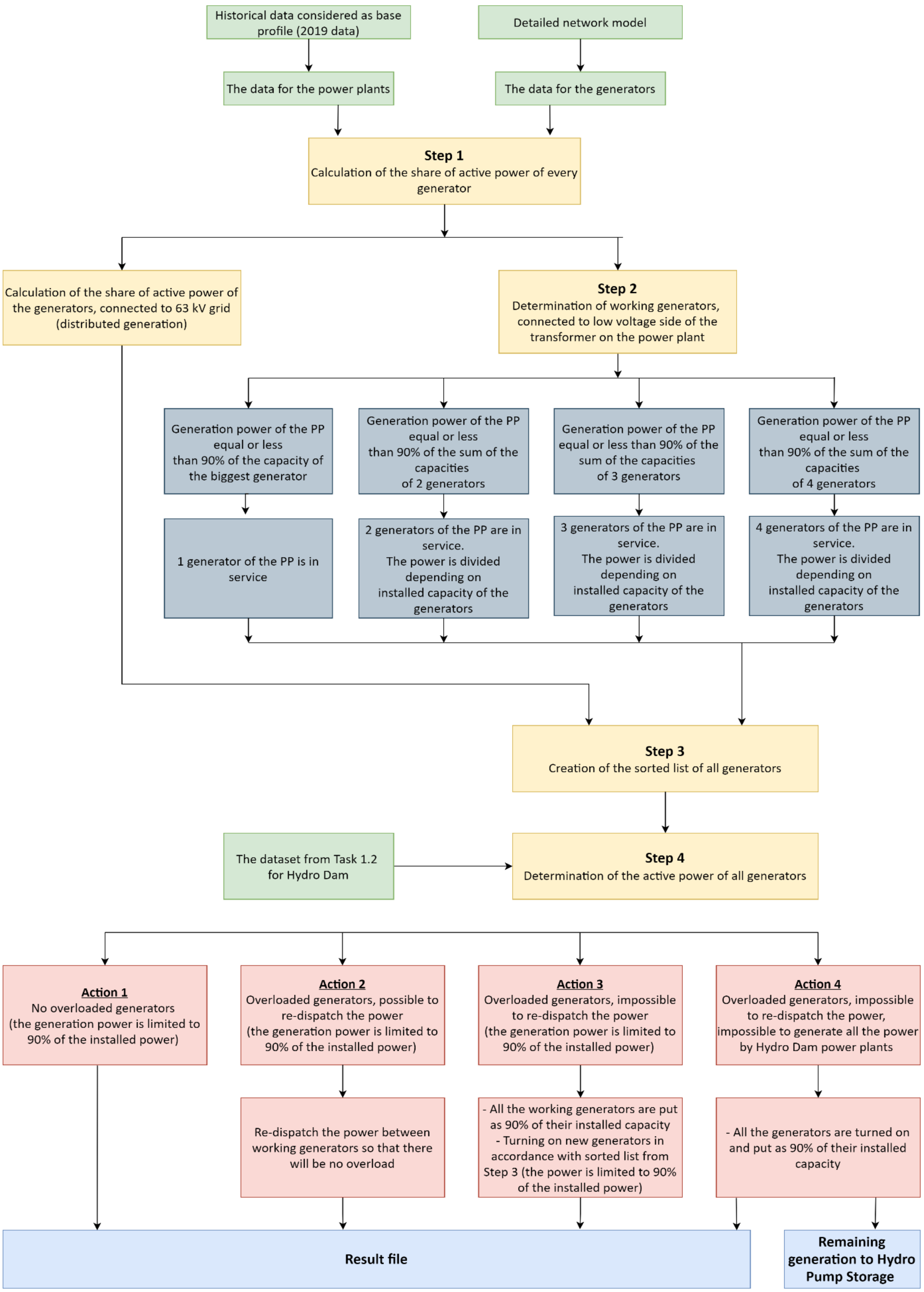


Figure 2-11 – Flowchart of the methodology for Hydro Dam type of the generation

2.5.2.10 Hydro – pump storage

This type of the generation is represented by 4 power plants and 10 generators, connected to the low voltage side of the transformer at the power plant. The historical data considered as base profile (2019 data) consists of the hourly generating power of each power plant. To redistribute this data among the generators, the following methodology, consisting of **4 steps**, is applied.

On the step 1, the working generators are selected based on the historical data and following the next criteria:

- If the generating power considering the historical data is equal or less than 90% of the capacity of the largest generator of the chosen power plant, it is considered that only one generator on the power plant is in service;
- If the generating power considered in the historical data is greater than 90% of the capacity of one generator the first criteria is not viable. Then, if the generating power is less or equal than 90% of the sum of the capacities of the available generators in the chosen power plant (two, three, four, …) it is considered that additional generators of the power plant will have to be in service and their generation will be divided according to the installed capacity of each generator.

On the step 2, the share of the generation power of every working generator is calculated in order to redistribute the time series dataset, coming from Task 1.2.

On the step 3, the merit order list of the generators is created. The generators are sorted according to full-load hours (utilization rate), which is calculated as a sum of the generation power for every hour in the year, divided by the generator's nominal capacity.

On the step 4, the sum of hourly generation data for Hydro – Pump Storage from Task 1.2 and the remaining power transferred from the calculation of Hydro – Dam is used to calculate the hourly generation power for each generator out of 10 existing in detailed network model. On this step, depending on the power, there are **3 actions** possible for redistribution of the time series data into detailed the network model:

1. After calculation, all the working generators are able to generate the calculated power without the overload of any of them (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
2. After calculation, there are some overloaded generators, but it is still possible to re-dispatch the power between working generators (in order to have a reactive power reserve on every generator, the generation power was limited to 90% of the installed capacity of each generator);
3. After calculation, there are some overloaded generators and it is impossible to re-dispatch the power between working generators without violating the 90% limit of the installed capacity of each generator. In this case, additional "out-of-service" generators

will need to be turned on to avoid the overload of any working generator. The "out-of-service" generators will be selected according to the merit order list based on the full-load hours in the reference historical data.

In case action 1 is feasible, the redistributed data from the time series provided by T1.2 is directly inserted into the detailed network model.

In case action 1 is not possible, but action 2 feasible, the generators that had a loading higher than 90% of their rated capacity will be limited to 90% their installed capacity, all the remaining active power will be distributed among the other working generators in accordance with merit order list.

In the case neither action 1 nor action 2 are possible, all working generators will be limited at 90% of their installed capacity. Additionally, "out of service" generators will be turned on in accordance with the merit order list. As result of this being an automatic process, the active power generation limit of reconnected generators was limited to 70% of their installed capacity, to ensure enough reactive power flexibility to allow voltage control.

The flowchart shown in Figure 2-12 illustrates this methodology. The green elements represent the input data, the yellow elements represent the methodology steps, the grey elements describe the methodology of selection of working generators, the red elements are the possible actions for the redistribution of OSMOSE time series, finally the blue element represent the resulting file.

Figure 2-12 – Flowchart of the methodology for Hydro Pump Storage type of the generation

2.5.3 Interconnections

T1.4.1 case study comprises the Portuguese power system, including its interconnections with Spain. The time series provided by T1.2, from whose results T1.4.1 are directly depended and related, is based on the e-Highways project[2] EU power system clustering, representing Portugal as 2 clusters (with an internal in interconnection between them) and four major interconnections between the Portuguese clusters and the clusters from neighbouring Spain.

Figure 2-13 shows the clusters and interconnections considered in the original e-Highways project for the Continental South-West (CSW) region.

[2] The e-Highway2050 project was supported by the EU Seventh Framework Programme and aimed at developing a methodology to support the planning of the Pan-European Transmission Network, focusing on 2020 to 2050, to ensure the reliable delivery of renewable electricity and pan-European market integration. The project was concluded in the end of 2015.

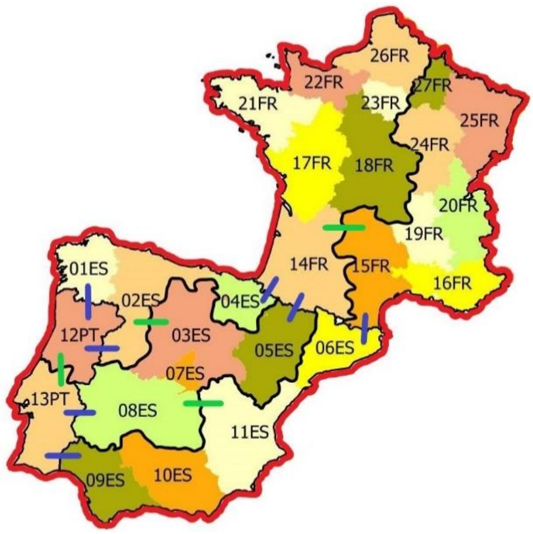


Figure 2-13 – Cluster's representation of the e-Highways project for the CSW region

Within the scope of T1.4.1, the 2 clusters from Portugal were aggregated into one single cluster and the interconnections with Spain were maintained. From the Spanish system, only the clusters with direct interconnection with the Portuguese cluster were considered. Thus, the considered clusters are:

The originated 7 clusters result from:

- Cluster 1: 12PT + 13PT
- Cluster 2: 01ES
- Cluster 3: 02ES
- Cluster 4: 08ES
- Cluster 5: 09ES

There are 4 interconnections that connect clusters from different countries with respective GTC defined and provided by T1.2.

The interconnection power flows[3] were redistributed according to the actual location of the interconnection lines in the network. Thus, the redistribution of the flows considers the following correspondence:

- Interconnection between 12PT and 01ES: 2 interconnections at 400kV
- Interconnection between 12PT and 02ES: 1 interconnection at 400kV and 3 at 220kV
- Interconnection between 13PT and 08ES: 2 interconnections at 400kV
- Interconnection between 13PT and 09ES: 1 interconnections at 400kV

[3] One aspect that was noticed about the interconnection power flow in both OSMOSE average scenarios is that Portugal is importing energy through Spain in every single period for both time horizons (2030 and 2050). This happens even considering that most of its generation mix is based on renewable energy sources.

3 Simulation Results

For the simulation of the OSMOSE scenarios for the selected time horizons, 2030 and 2050, the dataset representing the average of the 11 years provided by T1.2 was considered for each one of the scenarios. After redistributing the time series for each of the OSMOSE scenarios into the Portuguese detailed network model using the methodology described in the previous section, the cases for each hour period were simulated and analysed using the DESPlan tool. The DESPlan tool resorts to PSS/e software to perform the power flow calculations, allowing perform a steady-state assessment of the system, in a multi period approach.

The DESPlan tool analyses the hourly cases for the complete year (in this case 8736 cases files, since the 31st of December is not part of the time series) for each of the OSMOSE scenarios provided by T1.2. The tool calculates the power flow for each of the cases and reports the existence of overloads, including in which branches it has occurred.

Based in these reports, the most significant cases, for which the most severe network congestions (higher amplitude and duration) were selected and addressed using the DESPlan tool with the purpose of identifying the most adequate BESS alternative solutions to grid expansion, by determining the sizing and siting of BESS facilities that can solve the overloads and ensure the maintenance of network security from the planning perspective.

3.1 Simulation assumptions

For the simulation and calculation of the costs of the solutions the following considerations were assumed:

- BESS power costs: 10.000 EUR/MW [11]
- BESS energy costs: 200.000 EUR/MWh [11]
- Facility cost (per location): 1.000.000 EUR
- β: 500
- Cost of energy acquisition for the BESS was not considered, since it is a planning tool.

3.2 DESPlan results for 2030 scenario

In this sub-chapter the results of the DESPlan analysis and BESS solutions found for the average scenario for 2030 horizon are presented.

Relatively to the steady-state analysis results from the redistribution of the T1.2 time series, all the 8760 hours were analysed in order to identify the periods (i.e. days, hours) in which potential congestions were detected, and more specifically, the most severe cases. In total were identified 2798 cases (hours) out of the 8736 (32%) in which at least one branch of the grid is overloaded. In the Table 3.1 is presented the summary of the 2030 scenario in terms of number of overloaded cases detected per month.

Table 3.1 – Summary of the 2030 congestions detected per month

Month	Nº of overload cases / Nº of cases	Maximum overload registered (%)
January	436 / 744	101.8
February	418 / 672	101.8
March	418 / 744	101.8
April	342 / 720	101.8
May	286 / 744	108.3
June	157 / 720	101.8
July	78 / 744	103.3
August	11 / 744	101.8
September	95 / 720	101.8
October	139 / 744	101.8
November	161 / 720	101.8
December	257 / 720	101.8
Total	**2798 / 8736**	

It is possible to see that, from the simulation results' analysis, the months in which it was observed a higher predominance of congestions detected were the winter season months. Nevertheless, the highest overload detected in the 2030 OSMOSE scenario was in the month of May, which exceeded in 8.3% the respective branch limit. Most of the overloads detected stay below 2% of the respective branch limits, which is a relatively minor overload.

From the analysis of the steady-state simulations' results, two branches were identified as the ones that appeared more often in the list of overloaded braches. These two branches were also the ones that showed higher amplitude of the overloads detected.

The braches identified are the following:

- Line connecting buses 1040-1060, at 150kV which connects two hydro power plants to a transmission substation.
- Line connecting buses 291-2987, at 220kV which connects a transmission substation and 2 wind farms.

These two branches were selected to be the ones addressed in the 2030 OSMOSE scenario cases and were subject to the application of the DESPlan tool. The days selected for the BESS assessment are presented in the Table 3.2. The cases were selected among the 8760 cases of the 2030 scenario as result of the steady state analysis, selecting the most representative and most serious cases in terms of the overloads detected.

Table 3.2 – 2030 cases summary for assessment into DESPlan tool

Month	February	May	July
Day	15th	14th	5th
Nº of periods overloaded (out of 24)	17	1	4
Nº of lines overloaded	1	1	2
Nº of transformers overloaded	-	-	-
Lines overloaded	Line 1040-1060	Line 291-2987	Line 1040-1060 Line 291-2987
Transformers overloaded	-	-	-
Maximum overload (%)	101.8	108.3	103.3 101 (respectively)
Case #	1	2	3

3.2.1 Case #1 – 15th February 2030

The first case, was detected at 15th of February of 2030. The line connecting buses 1040-1060 becomes overloaded during 17 periods of the day. The load diagram of this case is presented in Figure 3-1. The 17 periods overloaded occur from hour 01:00 to 10:00 and from 18:00 to 24:00. The maximum congestion registered in this case occurs at 19:00 hour.

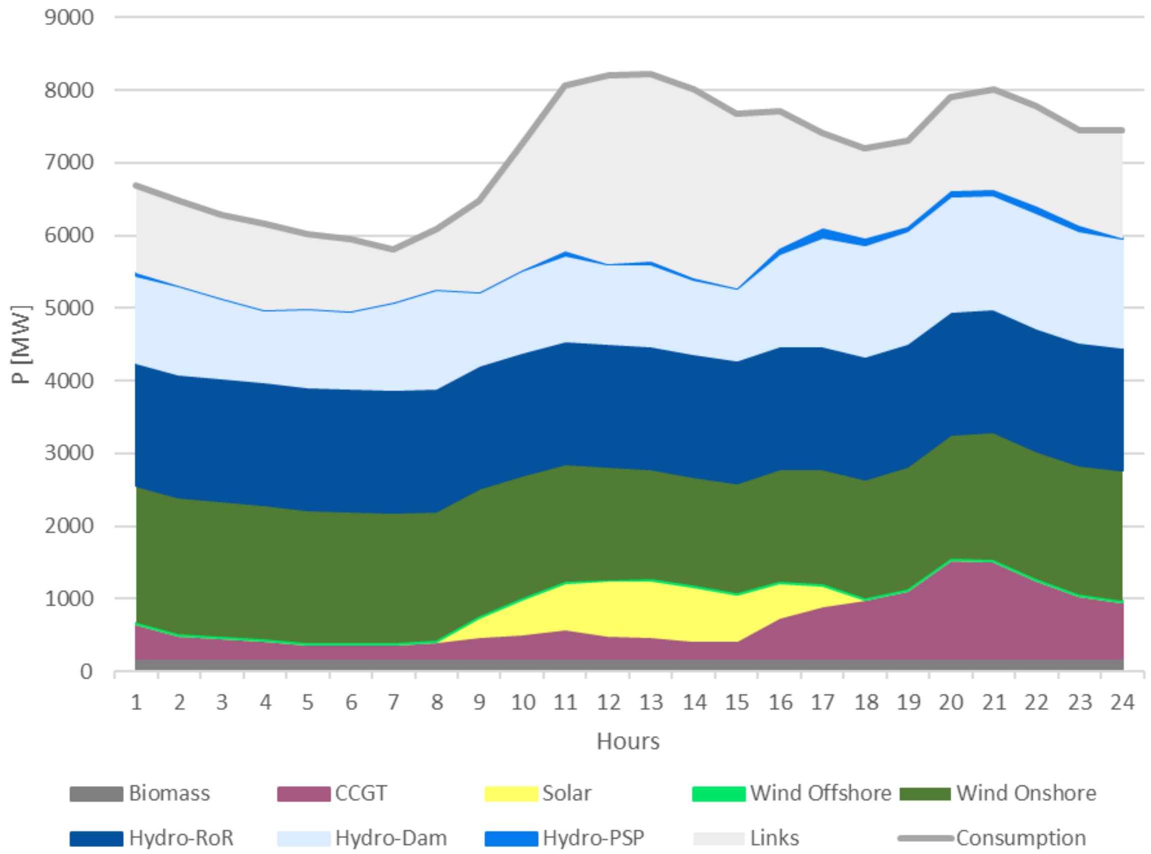


Figure 3-1 – 2030 scenario – generation mix diagram of case #1

As can be seen in Figure 3-1, the generation mix in this day is mostly based on renewable energy sources (hydro, wind and solar), as it is generally in OSMOSE scenarios considered. In this 2030 scenario, there is still some generation from CCGT power plants, especially at peak hours. The contribution of the interconnections is also quite relevant reaching almost 33% of the total load in some periods of the day.

In terms of the branch addressed in this case, line connecting buses 1040-1060, an illustration of the power flow in each hour is provided in Figure 3-2.

Similarly, Figure 3-3 presents the network single line diagram of the area of the congestion detected during the period of maximum overload.

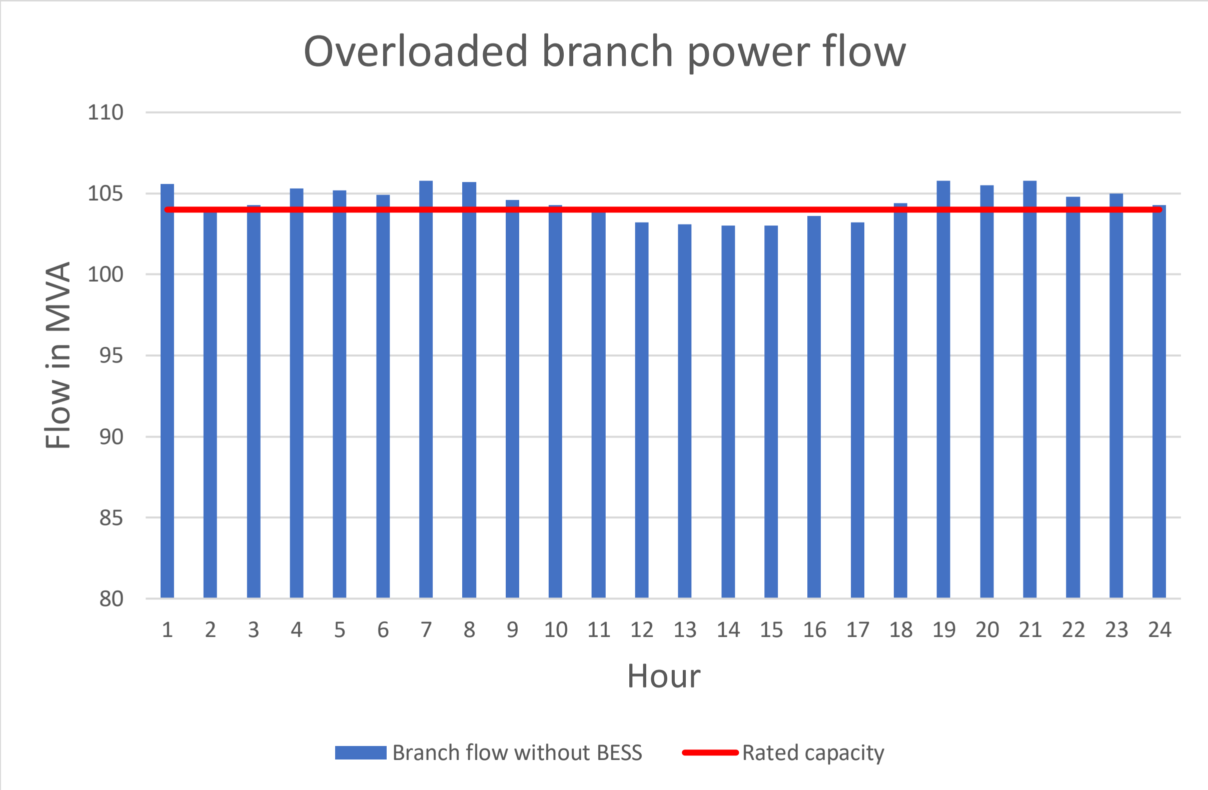


Figure 3-2 – 2030 scenario – Power flow in the branch connecting buses 1040-1060 for case #1

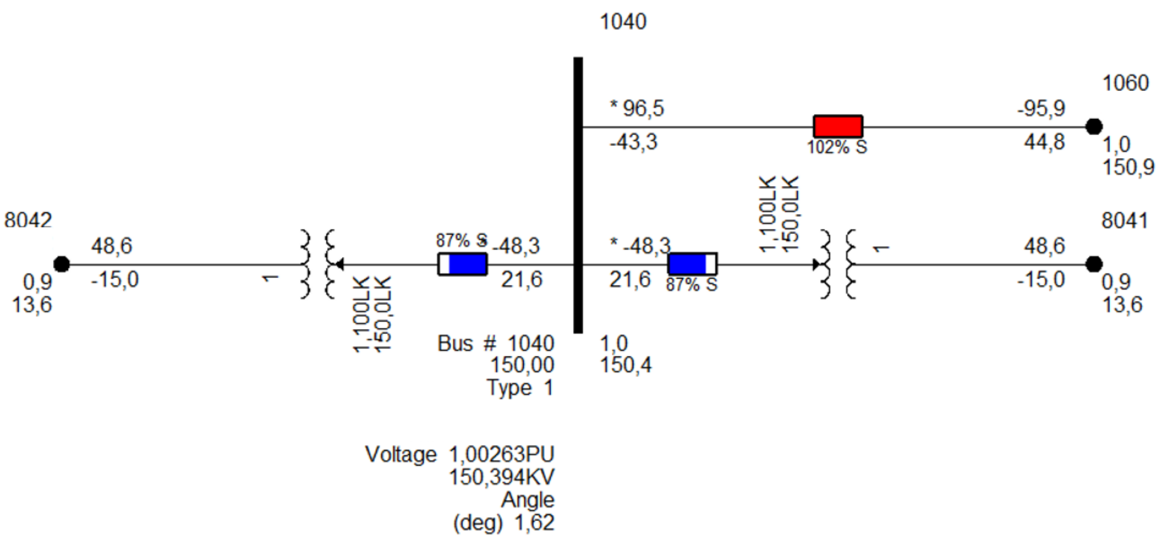


Figure 3-3 – Network single line diagram of the congestion area at hour 19 (case #1)

It is possible to notice that based on the simulation there are 16 periods (hours) in which congestions were detected in this branch. The overload reaches 2% above the rated capacity.

The line overload was detected when the two generators of the hydro power plant are operating at a higher rate (over 90%), which overloads the line responsible to direct the power flow to transmission network.

The DESPlan tool was applied for case #1 in order to find a suitable BESS solution capable of solving the congestions of the identified branch. The DESPlan tool considered as candidate nodes the substation buses located one node away from the congested branch. After running the tool for the 24 hour, the tool provided an alternative solution using a BESS. The solution would consist on a **2MW/20.4MWh** system installed at **bus 1040 (150kV)**, with an approximate cost of **5.098.000 EUR** based on reference costs.

Figure 3-4 describes the response of the BESS for case #1.

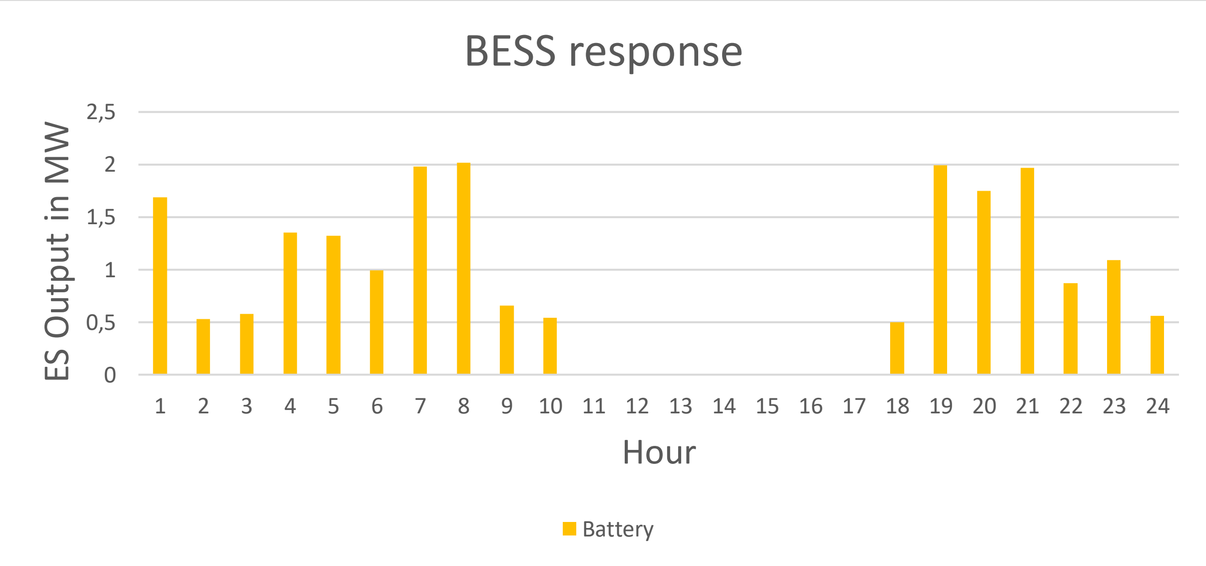


Figure 3-4 – 2030 scenario – BESS response resulting from the application of the DESPlan tool for case #1

As result, the overload was avoided for the whole assessment period. Figure 3-5 and Figure 3-6 show the power flow in the branch considering the effect of the installation of the BESS.

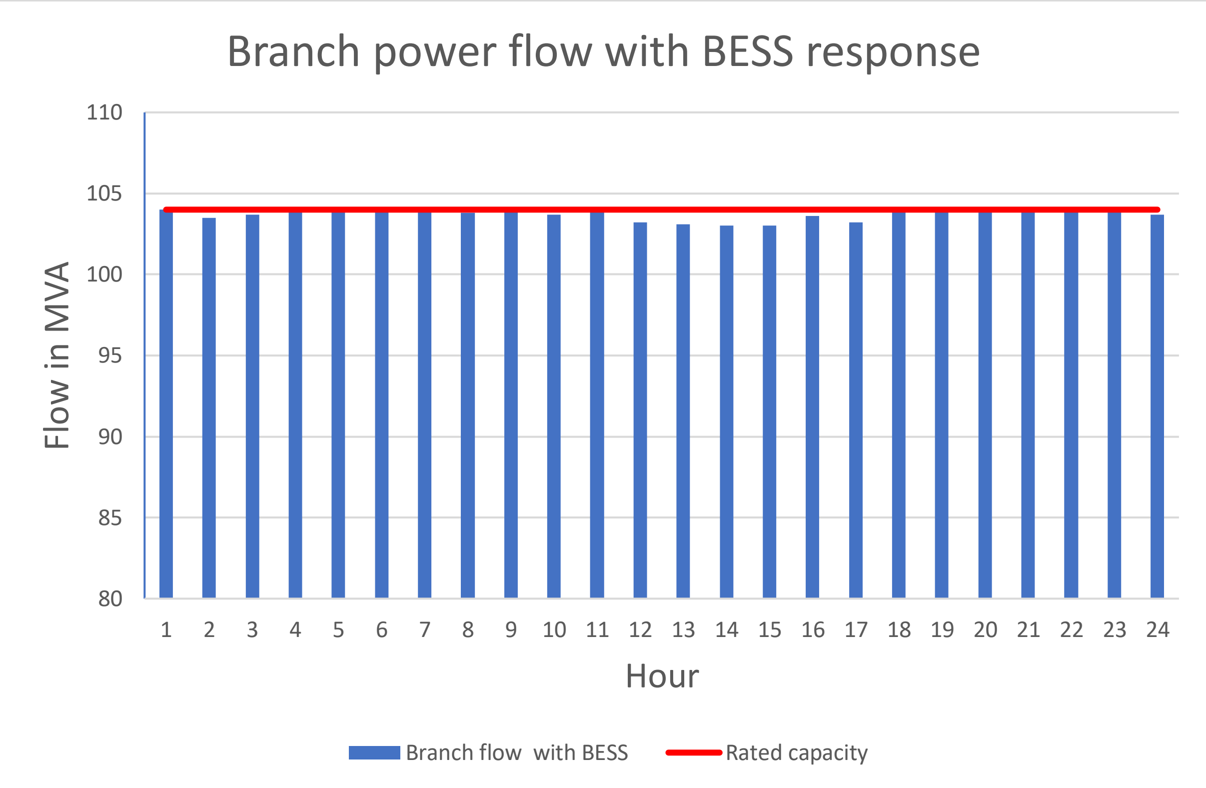


Figure 3-5 – 2030 scenario – Power flow in the branch 1040-1060 for case #1 with BESS

As can be seen, the overload is solved for the entire period of analysis.

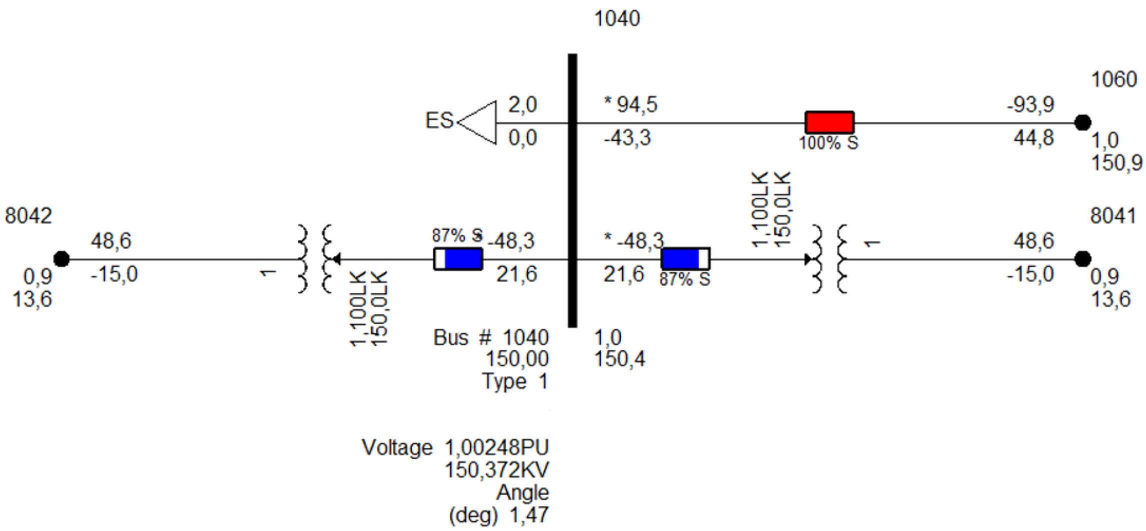


Figure 3-6 – Network single line diagram of the congestion area at hour 19 (case #1) with BESS

3.2.2 Case #2 – 14th May 2030

The second case selected was at 14th of May of 2030. The line connecting buses 291-2987 becomes overloaded during 1 period (hour) of the day. Nevertheless, the congestion of this branch occurs several times, being this is the one with higher amplitude. The load diagram of this case is presented in Figure 3-7. The period in which the overload was detected occurs at 14:00.

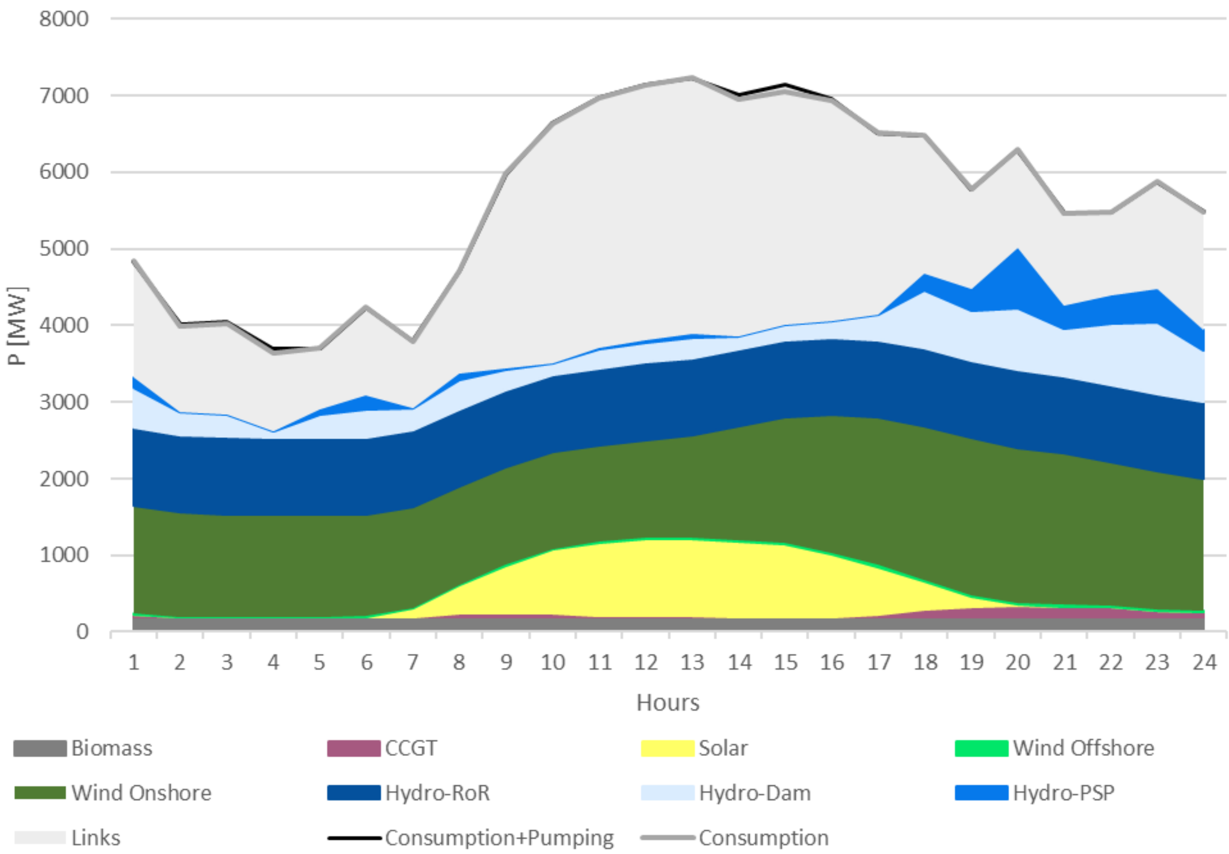


Figure 3-7 – 2030 scenario – generation mix diagram of case #2

As can be seen in Figure 3-7, the generation mix in this day is mostly based on renewable energy sources (hydro, wind and solar), as well as a great contribution from interconnections in some period of the day, reaching around 47% of the total load in some periods of the day.

In terms of the branch addressed in this case, line connecting buses 291-2987, an illustration of the power flow in each hour is provided in Figure 3-8.

Similarly, Figure 3-9 presents the network single line diagram of the area of the congestion detected during the period of maximum overload.

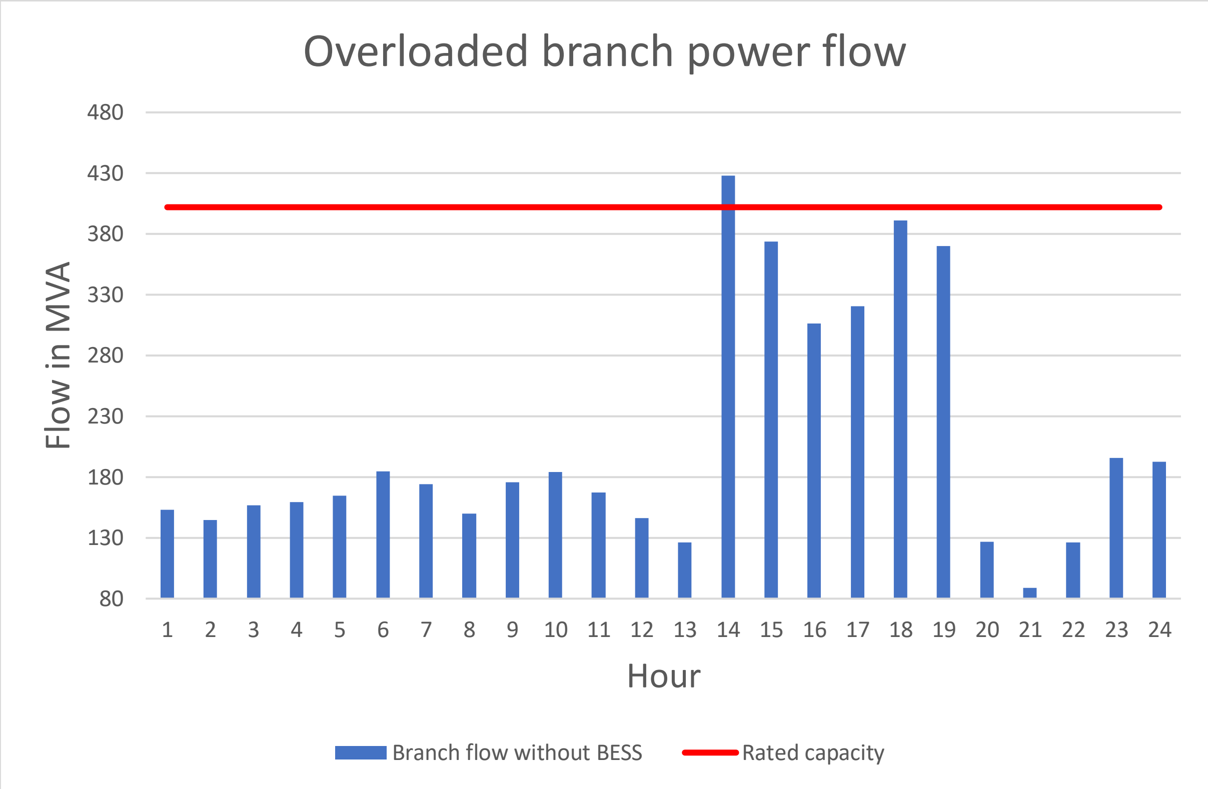


Figure 3-8 – 2030 scenario – Power flow in the branch 291-2987 for case #2

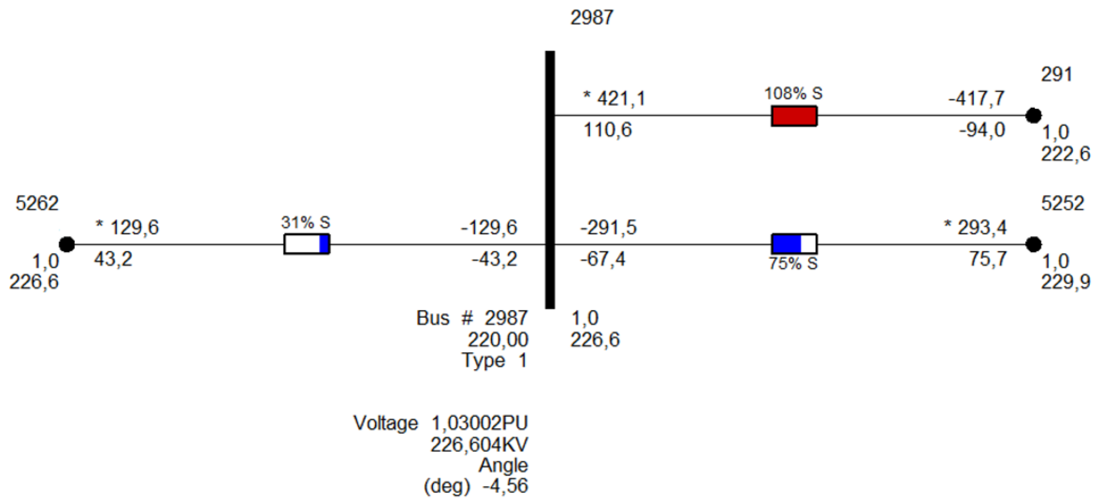


Figure 3-9 – Network single line diagram of the congestion area at hour 14 (case #2)

It is possible to notice that based on the simulation results there is 1 period (hour) in which a congestion was detected in this branch. The overload reaches 8% above the rated capacity.

The line overload was detected when the two wind farms connected to buses 5252 and 5262 operate at almost nominal power (over 90%), which results in the overload the line responsible to direct the power flow to transmission network due also to the reactive power flow.

The DESPlan tool was applied for case #2 in order to find a suitable BESS solution capable of solving the congestion identified. The DESPlan tool considered as candidate nodes the substation buses located one node away from the congested branch. After running the tool for the 24 hour, the tool provided an alternative solution using a BESS. The solution would consist on a **28.1MW/28.1MWh** system installed at **bus 2987(220kV)**, with an approximate cost of **6.880.000 EUR** based on reference costs.

Figure 3-10 describes the response of the BESS for case #2.

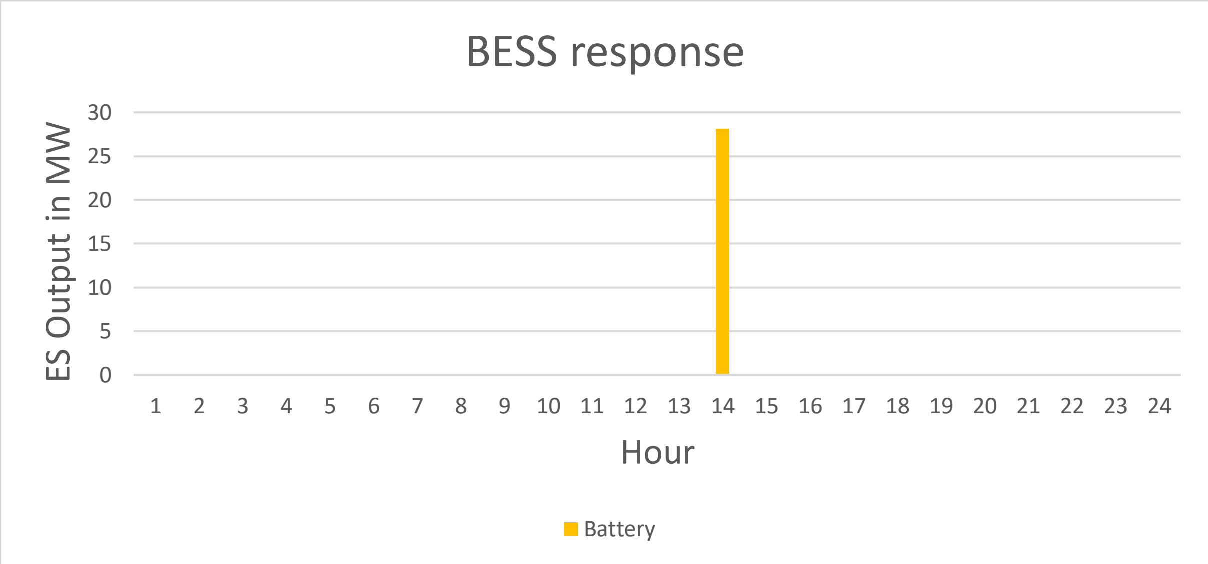


Figure 3-10 – 2030 scenario – BESS response resulting from the application of the DESPlan tool for case #2

As result, the overload was avoided for the whole assessment period. Figure 3-11 and Figure 3-12 show the power flow in the branch considering the effect of the installation of the BESS.

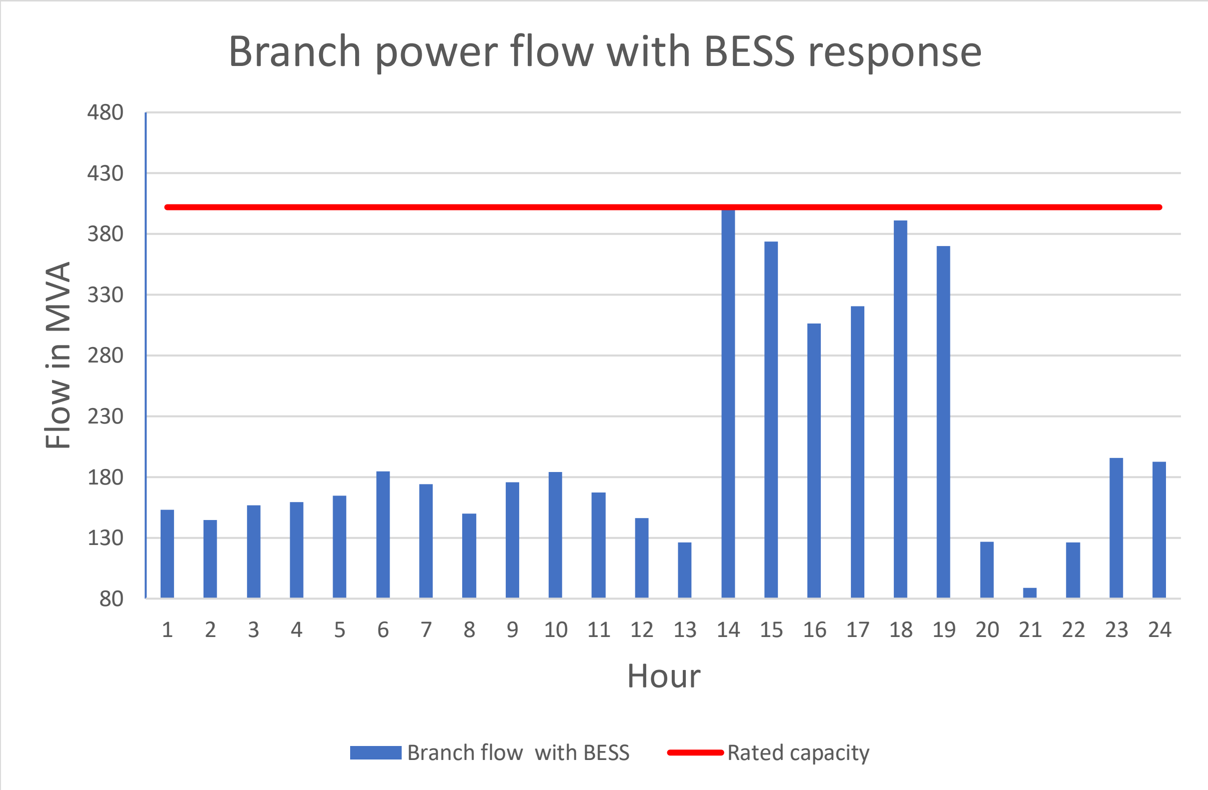


Figure 3-11 – 2030 scenario – Power flow in the branch 291-2987 for case #2 with BESS

As can be seen, the overload is solved for the entire period of analysis.

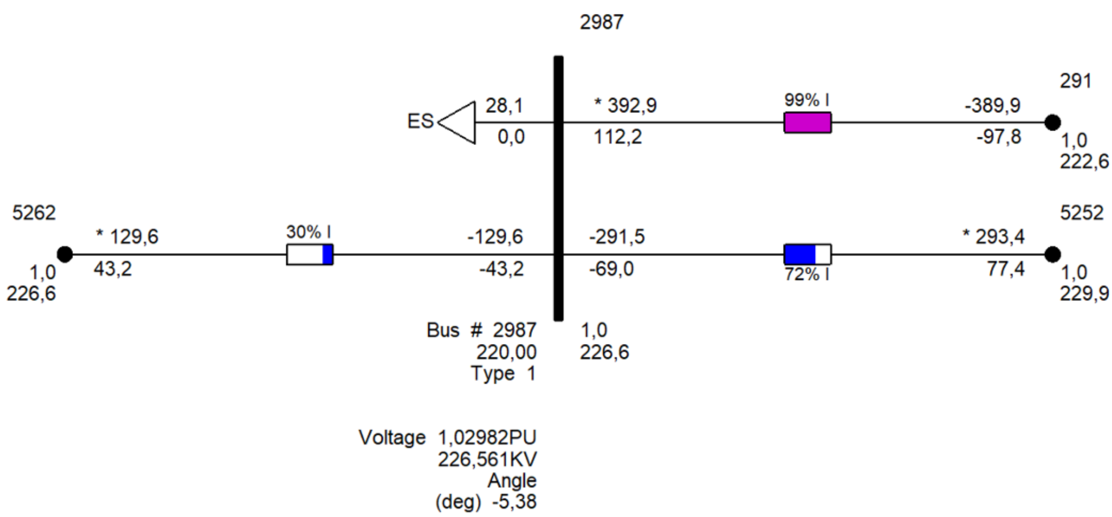


Figure 3-12 – Network single line diagram of the congestion area at hour 14 (case #2) with BESS

3.2.3 Case #3 – 5th July 2030

The third case selected is related to the 5th of July of 2030. In this case instead of a single branch overloaded there are two. The two branches are: 1) line connecting buses 291-2987, and 2) line connecting buses 1040-1060.

The load diagram of this case is presented in Figure 3-13. The period in which the overloads were detected occurs at between 03:00 and 04:00 and between 20:00and 22:00.

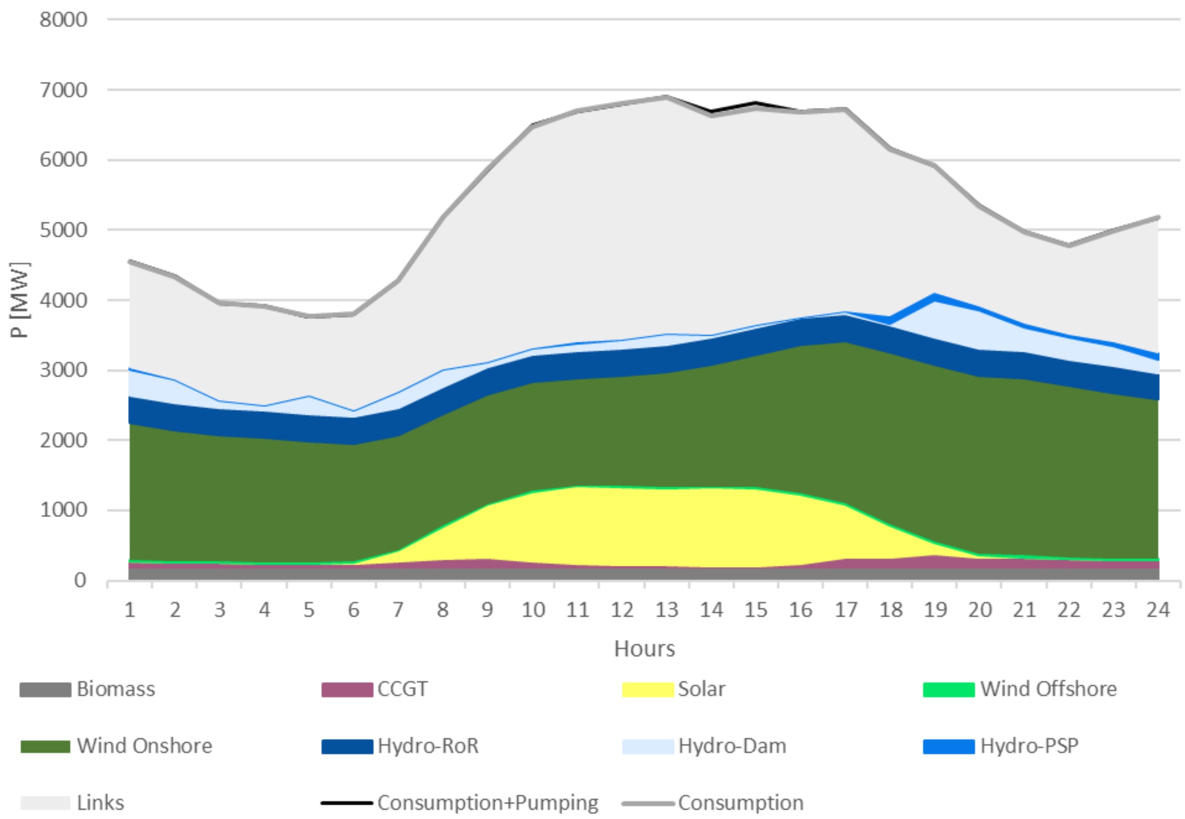


Figure 3-13 – 2030 scenario – generation mix diagram of case #3

As can be seen in Figure 3-13, the generation mix in this day is mostly based on wind and solar, as well as a great contribution from interconnections in some period of the day, reaching around 50% of the total load in some periods of the day.

In terms of the branches addressed in this case, the lines connecting buses 291-2987 and 1040-1060, an illustration of the power flow in each one of them for each hour is provided in Figure 3-8.

Similarly, Figure 3-9 and presents the network single line diagram of the area of the congestion detected during the period of maximum overload.

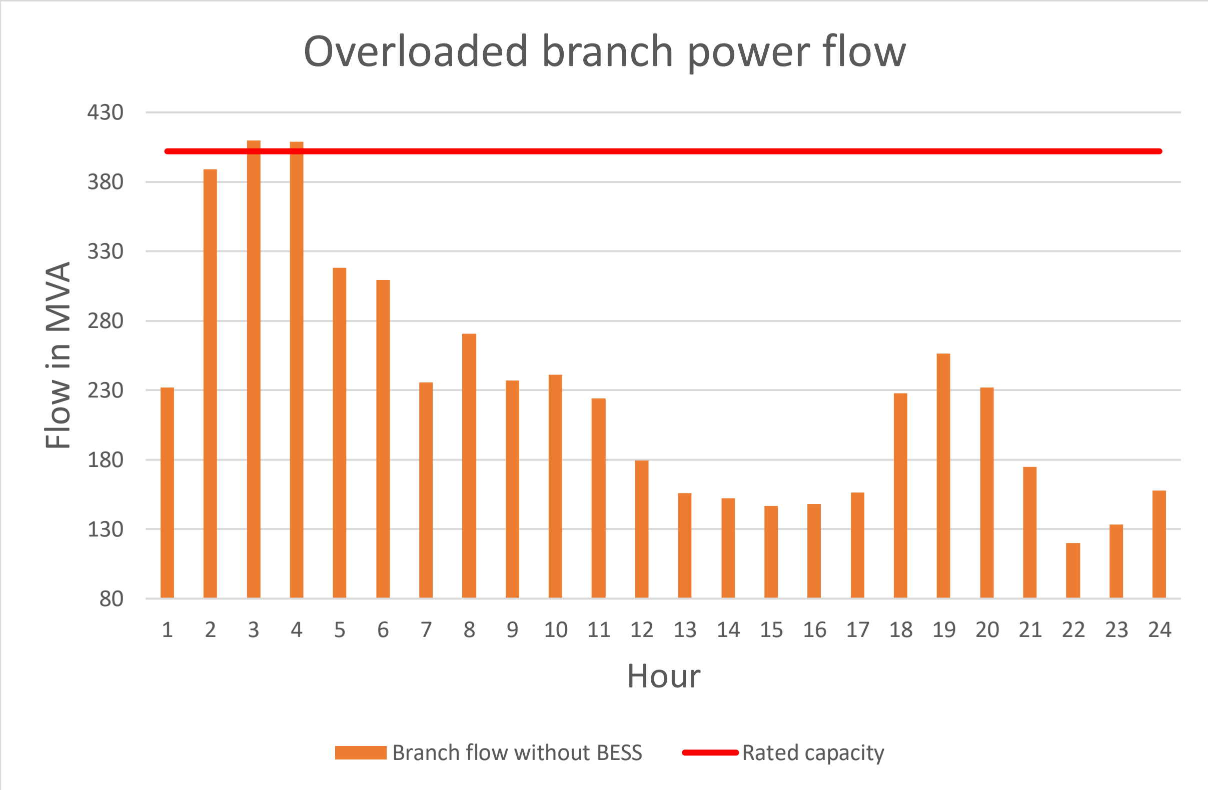


Figure 3-14 – 2030 scenario – Power flow in the branch 291-2987 for case #3

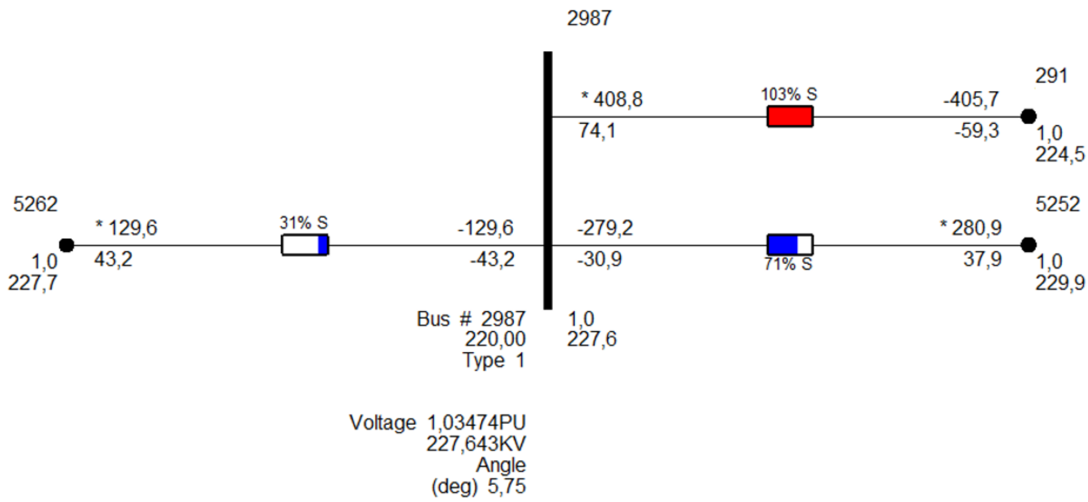


Figure 3-15 – Network single line diagram of the congestion area at hour 03 (case #3)

It is possible to notice that based on the simulation results there are 2 periods (hours) in which a congestion was detected in this branch. The overload reaches 3% above the rated capacity.

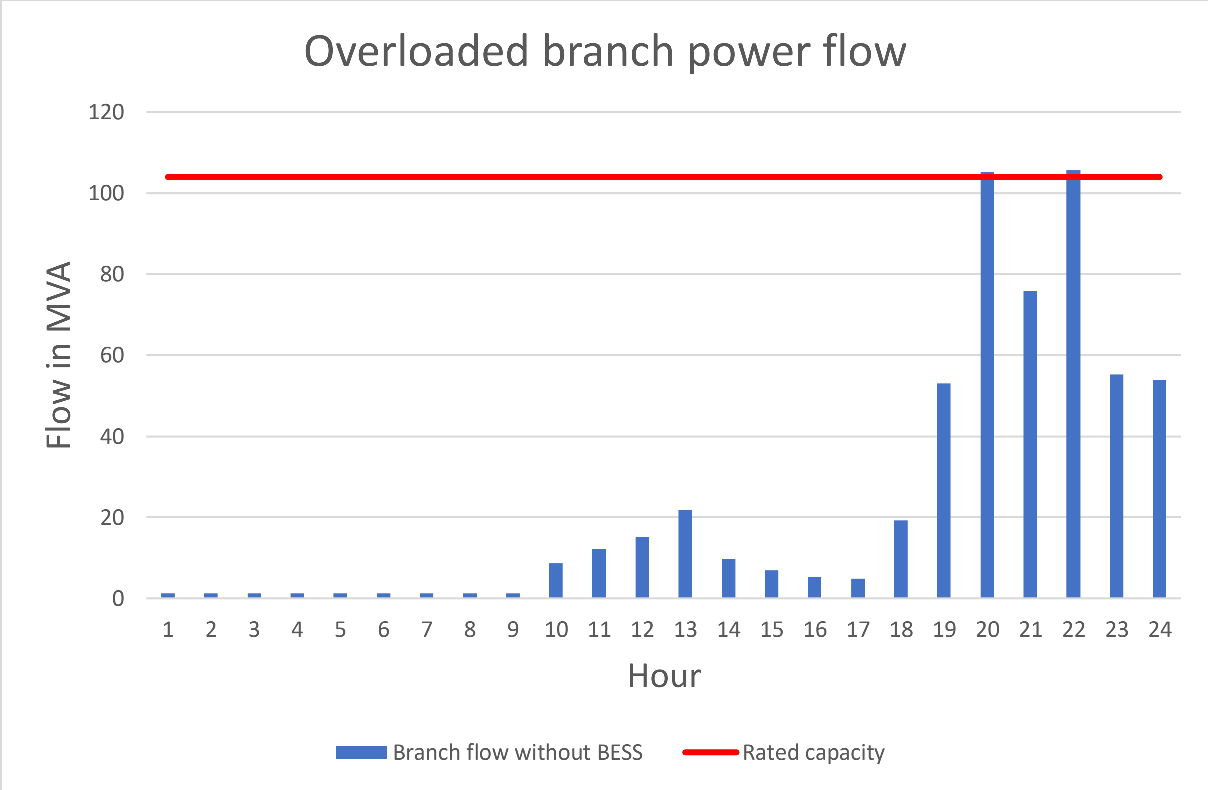


Figure 3-16 – 2030 scenario – Power flow in the branch 1040-1060 for case #3

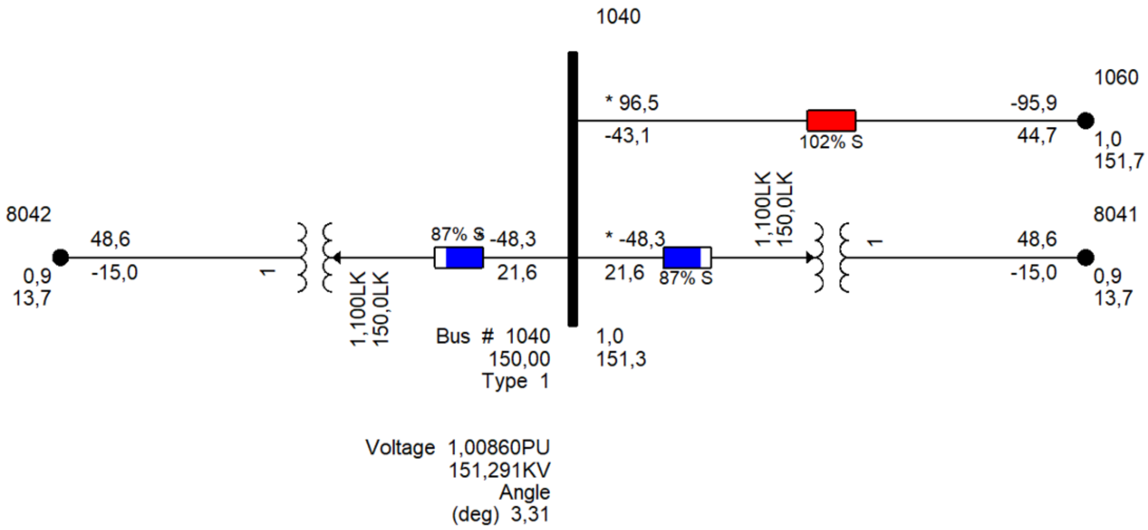


Figure 3-17 – Network single line diagram of the congestion area at hour 22 (case #3)

It is possible to notice that based on the simulation results there are 2 periods (hours) in which a congestion was detected in this branch. The overload reaches around 2% above the rated capacity.

The overloads were detected in days in which the power plants connected to these lines are producing almost at nominal level namely the hydro power plants connected at nodes 8041 and 8042 and the two wind farms connected to buses 5252 and 5262 operate at almost nominal power (over 90%). This results in the overload of the lines responsible to direct the power flow to transmission network, in both cases there is also an impact of the reactive power flow on the lines' current loading.

The DESPlan tool was applied for case #3 in order to find a suitable BESS solution capable of solving both congestion identified. The DESPlan tool considered as candidate nodes the substation buses located one node away from the congested branches. After running the tool for the 24 hour, for both congestions, the tool provided an alternative solution using a BESS. The solution would consist on **3 systems**: **2.2MW/2.1MWh** installed at **bus 1040(150kV)**, **5.0MW/2.5MWh** installed at **bus 1060 (150kV)** and **8.4MW/14.5MWh** installed at **bus 2987 (220kV)**, with an approximate total cost of **6.976.000 EUR** based on reference costs.

Figure 3-18 and Figure 3-19 describe the response of the BESS for case #3 for both lines.

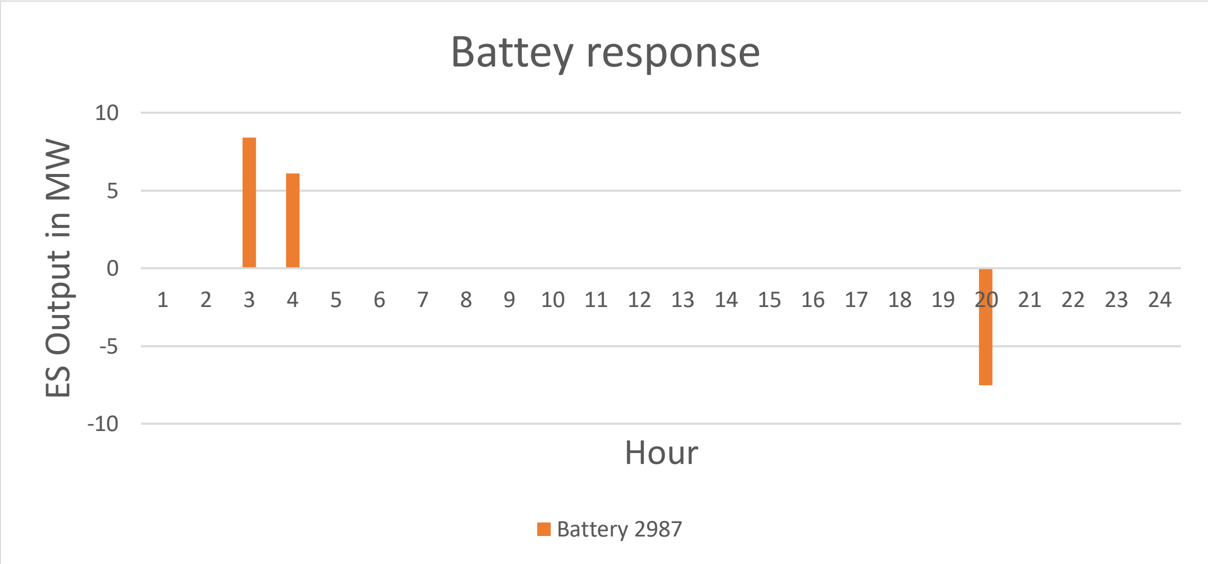


Figure 3-18 –2030 scenario – BESS response in bus 2987 resulting from the application of the DESPlan tool for case #3

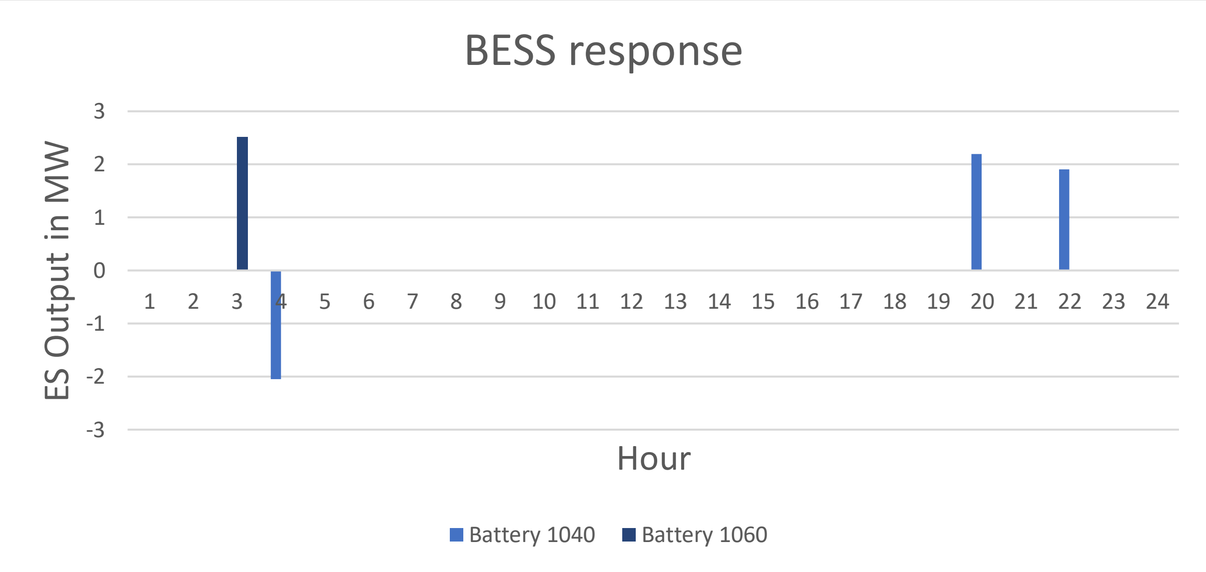


Figure 3-19 – 2030 scenario – BESS response in buses 1040&1060 resulting from the application of the DESPlan tool for case #3

As result the overload was avoided for the whole assessment period. Figure 3-20,Figure 3-21, Figure 3-22 and Figure 3-23 show the power flow in the corresponding branch considering the effect of the installation of the BESS.

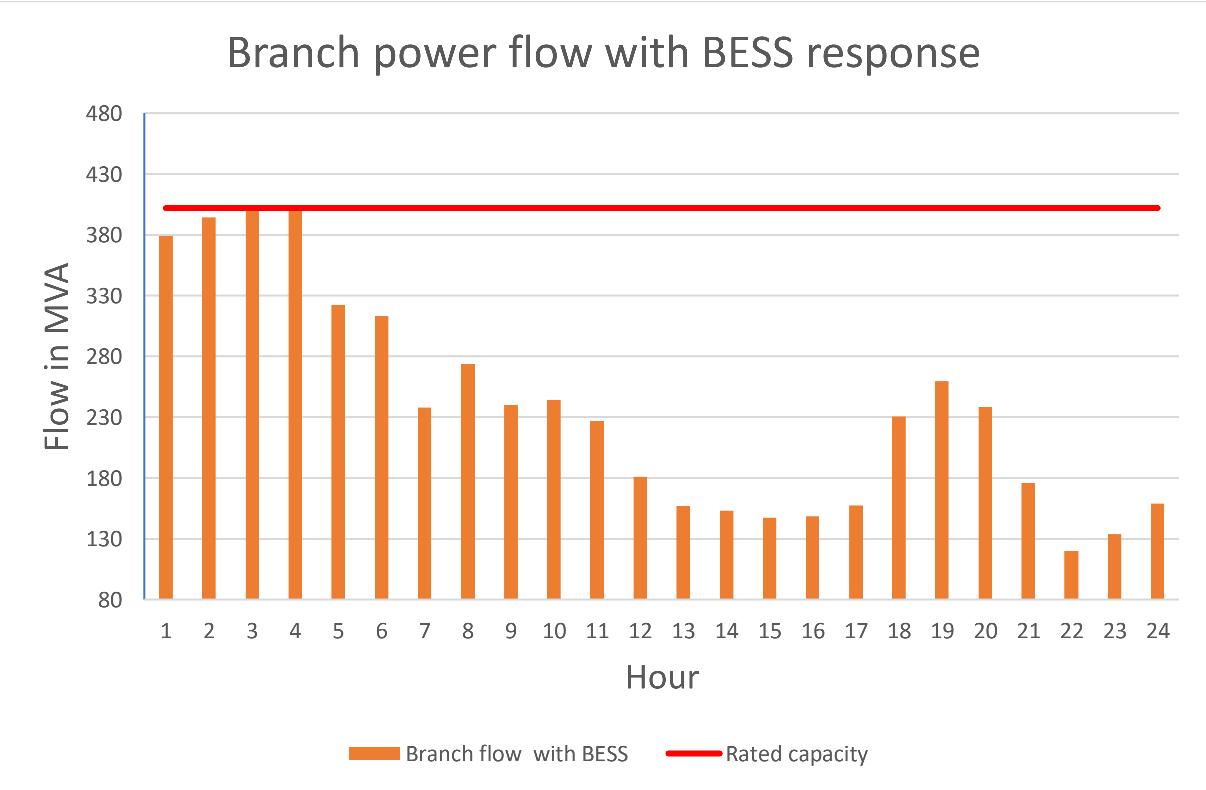


Figure 3-20 – 2030 scenario – Power flow in the branch 291-2987 for case #3 with BESS

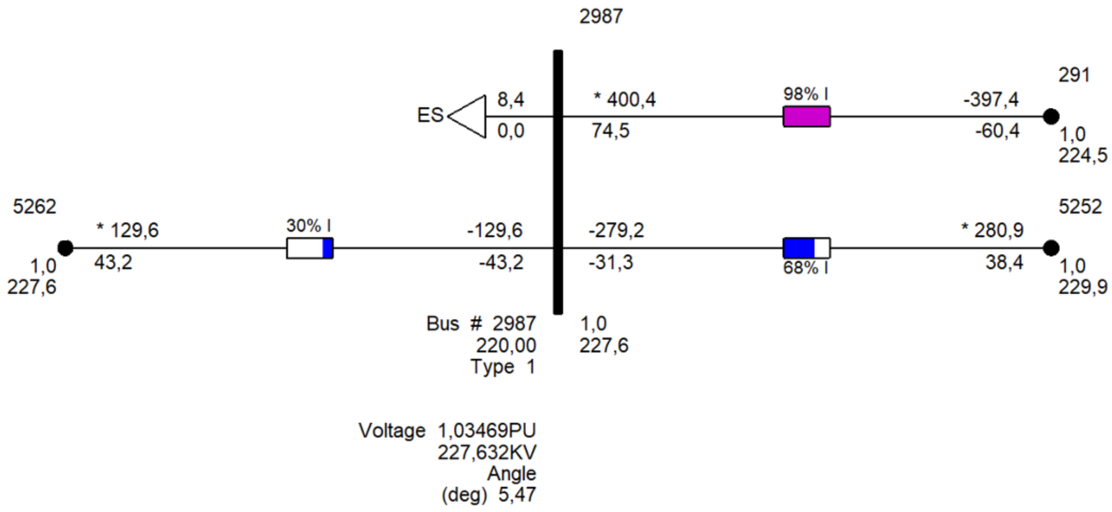


Figure 3-21 – Network single line diagram of the congestion area at hour 03 (case #3) with BESS

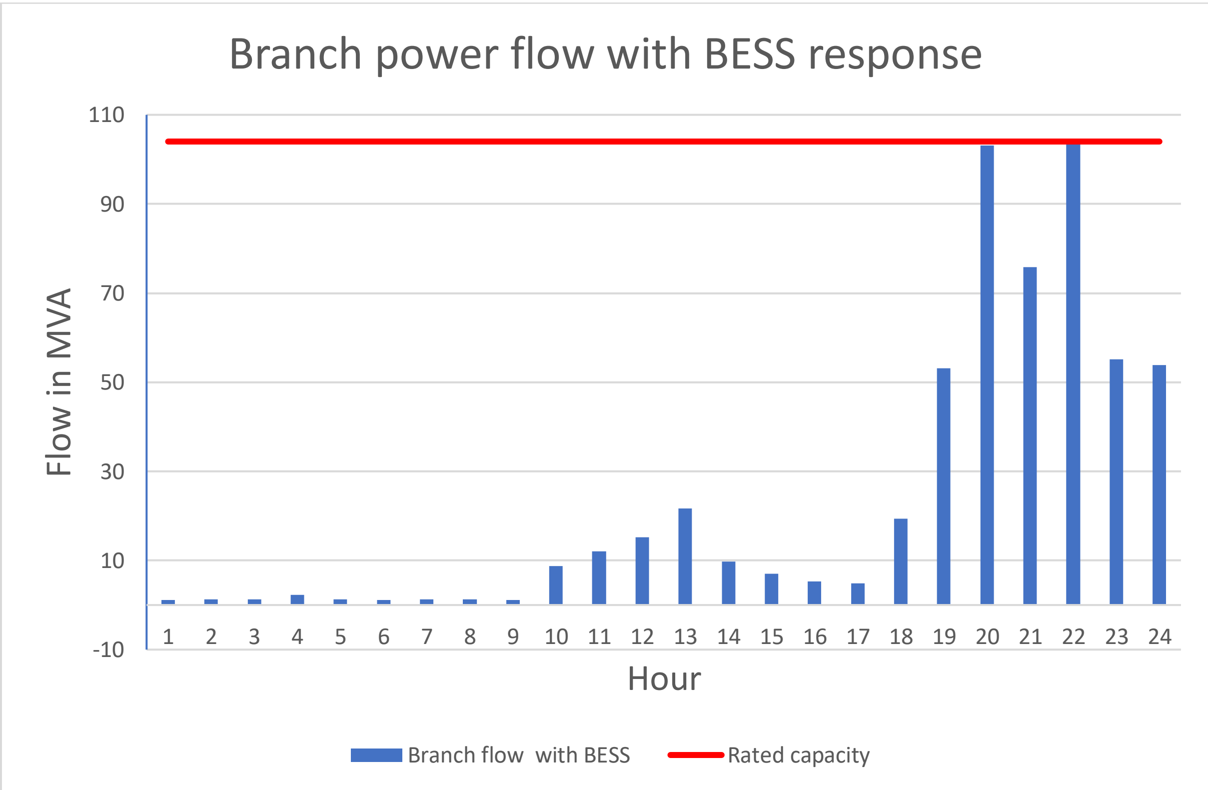


Figure 3-22 – 2030 scenario – Power flow in the branch 1040-1060 for case #3 with BESS

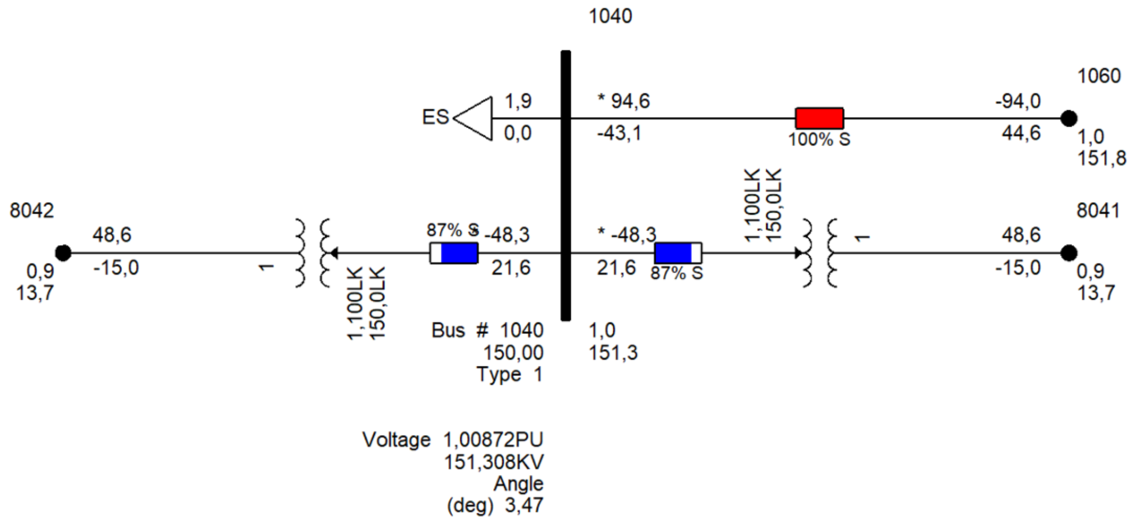


Figure 3-23 – Network single line diagram of the congestion area at hour 22 (case #3) with BESS

As can be seen, the overloads were solved for the entire period of analysis.

3.3 DESPlan results for 2050 scenario

In this sub-chapter the results of the DESPlan analysis and BESS solutions found for the average scenario for 2050 horizon are presented.

Relatively to the steady-state analysis results from the redistribution of the T1.2 time series, all the 8736 hours (the 31st of December is not part of the OSMOSE time series) were analysed in order to identify the periods (i.e. days, hours) in which potential congestions were detected, and more specifically, the most severe cases. In total were identified 4348 cases (hours) out of the 8736 (49.8%) in which at least one branch of the grid is overloaded. In the Table 3.3 the summary of the 2050 scenario in terms of number of overloaded cases detected per month is presented.

Table 3.3 – Summary of the 2050 congestions detected per month

Month	Nº of overloaded cases / Nº of cases	Maximum overload registered (%)
January	524 / 744	109.1
February	506 / 672	112.3
March	523 / 744	138.0
April	505 / 720	142.6
May	402 / 744	155.1
June	368 / 720	113.6
July	353 / 744	115.9
August	253 / 744	116.4
September	130 / 720	109.8
October	211 / 744	109.8
November	249 / 720	109.8
December	324 / 720	108.6
Total	**4348 / 8736**	

Comparing this table with the one that sums up the number of overloaded hours for 2030 (Table 3.1) it is possible to see that the number of cases in the 2050 scenario, in which at least one overload was detected, is almost the double than in the 2030 scenario. Additionally, the maximum amplitude of overloads registered in 2050 for each month is also larger than in 2030.

This means that these kind of events became more frequent in the 2050 scenario, but also that events detected were also more serious. The largest overload detected in the simulations occurs in May and it reaches 155% of the nominal capacity of the respective branch.

Similarly to what happened in the 2030 scenario, it is possible to see that in the 2050 scenario the Winter and Spring months are the ones in which more congestion events were identified. From the analysis of the results, several braches were identified as the ones that have higher probability of potentially generating contingencies in the future (considering the assumptions):

- Line connecting buses 1040-1060, at 150kV which connects two hydro power plants to a transmission substation.
- Line connecting buses 291-2987, at 220kV which connects a transmission substation and 2 wind farms.
- Line connecting buses 246-268, at 220kV which connects two transmission substations.
- Line connecting buses 218-5212, at 220kV which connects a transmission substation with a large load centre.
- Line connecting buses 414-460, at 400kV which connects two transmission substations.

Also, in this case some transformers' branches were identified as the ones that have higher probability of potentially generating contingencies in the future (considering the assumptions):

- 150kV-63kV transformer between buses 122-6225/6.
- 220kV-63kV transformer between buses 223-623.
- 400kV-63kV transformer between buses 422-6223/4.
- 220kV-63kV transformer between buses 246-646.

Additionally, from the 8760 cases of the 2050 OSMOSE dataset, in 177 it was not possible to converge the power flow solution. This means that the results obtained for these cases (hours) are not valid and thus, could not be considered for further analysis with the DESPLAN tool on the 2050 scenario.

From the selected cases, three will be described in more detail in this report for the 2050 OSMOSE scenario (see table Table 3.4). Similarly to what happened in the 2030 scenario, the DESPlan tool results for its application in the selected cases will be presented in the next sub-sections. The selected cases for the BESS assessment are highlighted in the Table 3.4 (in bold). The cases were selected among the 8760 cases of the 2030 scenario as result of the steady state analysis, selecting the most frequent and most serious cases in terms of the overloads detected.

Table 3.4 – 2050 cases summary for assessment into DESPlan tool

Month	February	April	June
Day	22th	12th	28th
Nº of periods overloaded (out of 24)	23	22	20
Nº of lines overloaded	3	5	4
Nº of transformers overloaded	0	7	6
Lines overloaded	**Line 1040-1060** Line 291-2987 Line 246-268	Line 1040-1060 Line 291-2987 Line 246-268 Line 414-460 Line 218-5212	Line 1040-1060 Line 291-2987 **Line 246-268** Line 414-460
Transformers overloaded	-	**122-6225** **122-6226** **223-623** **223-623** 246-646 **422-6223** **422-6224**	122-6225 122-6226 223-623 223-623 422-6223 422-6224
Maximum overload (%)	112.27	111.6	110.2
Case #	1	2	3

These three cases were selected according to the severity, continuity and diversity of overloads registered during the days. In the following subsections, the DESplan results for some of these congestions will be presented.

3.3.1 Case #1 – 22nd of February 2050

For the first case it was selected the 22nd of February of 2050. In this case congestions were detected in almost all hours of the day. The exception is at 8h in the morning, in which no congestion was detected. During the remaining 23 periods, there is always one or more branches overloaded. During the day, three different overloads were detected. In this case we focus on the line connecting buses 1040-1060.

The load diagram of this case is presented in Figure 3-24.

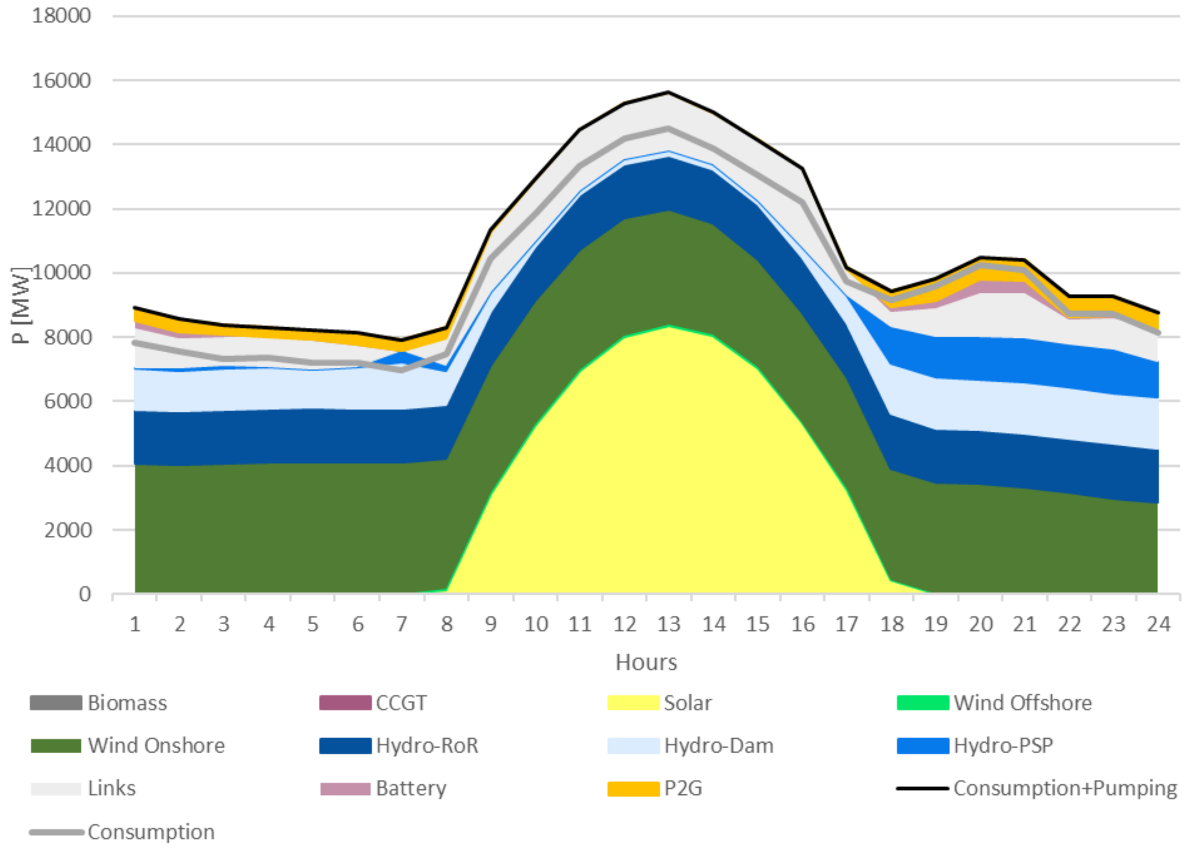


Figure 3-24 – 2050 scenario – generation mix diagram of case #1

The first thing that arises from Figure 3-24 is the inexistence of large thermal generation (e.g. CCGT) in the generation mix. In fact, the generation mix is entirely based on RES. During the day, the contribution of solar power reaches around 8GW which is about the level of demand expected in 2030.

In terms of the branch presented in this case, line connecting buses 1040-1060, an illustration of the power flow in each hour is provided in Figure 3-25.

Similarly, Figure 3-26 presents the network single line diagram of the area of the congestion detected during the period of maximum overload.

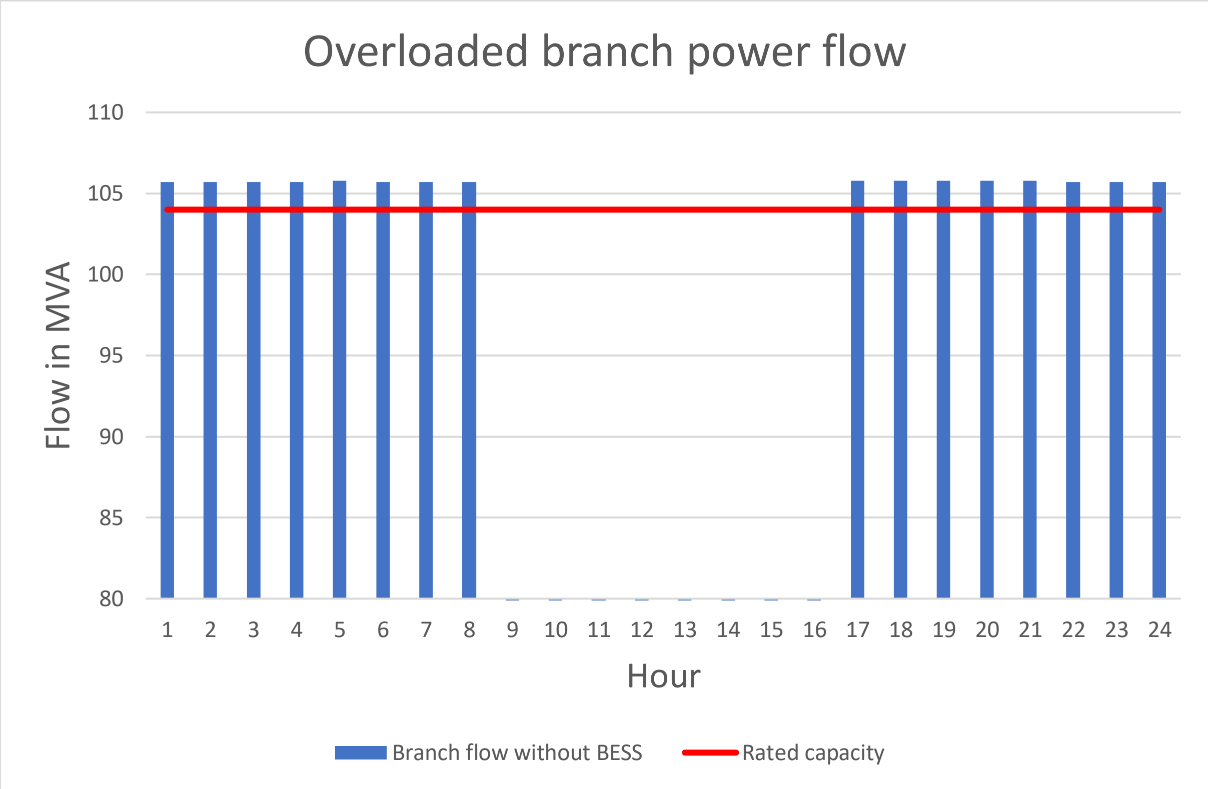


Figure 3-25 – 2050 scenario – Power flow in the branch 1040-1060 for case #1

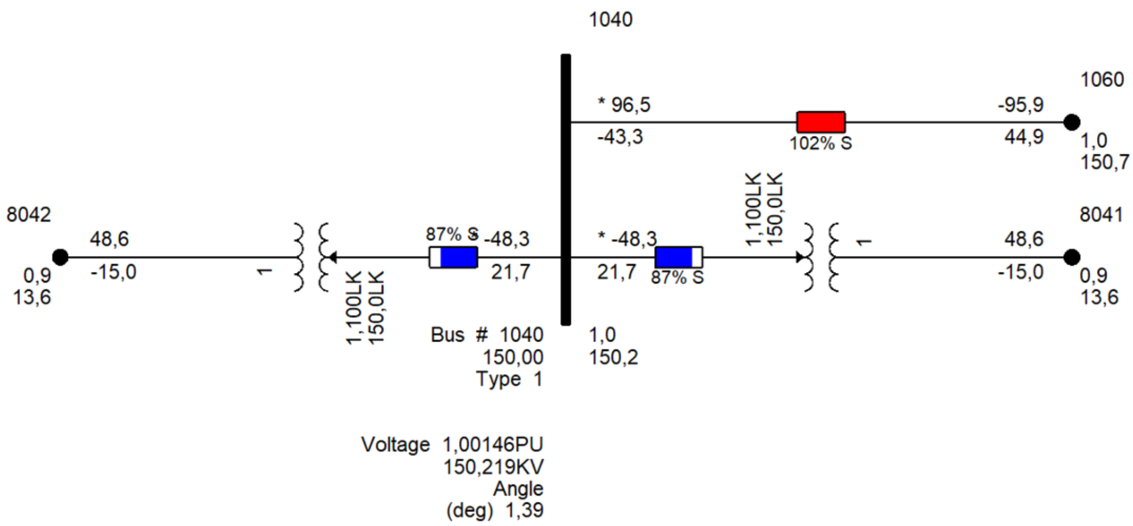


Figure 3-26 – Network single line diagram of the congestion area at hour 5 (case #1)

It is possible to notice that based on the simulation there are 16 periods (hours) in which congestions were detected in this branch. The overload reaches around 2% above the rated capacity.

The line overload was detected when the two generators of the hydro power plant are operating at a higher rate (over 90%), combined with a situation in which the network requests reactive contribution from the same generators, overloading the line responsible to direct the power flow to the transmission network.

The DESPlan tool was applied for case #1 in order to find a suitable BESS solution capable of solving the congestions of the identified branch. The DESPlan tool considered as candidate nodes the substation buses located one node away from the congested branch. After running the tool for the 24 hour, the tool provided an alternative solution using a BESS. The solution would consist on a **15.6MW/15.2MWh** system installed at **bus 1040 (150kV)**, with an approximate total cost of **4.196.000 EUR** based on reference costs.

Figure 3-27 describes the response of the BESS for case #1.

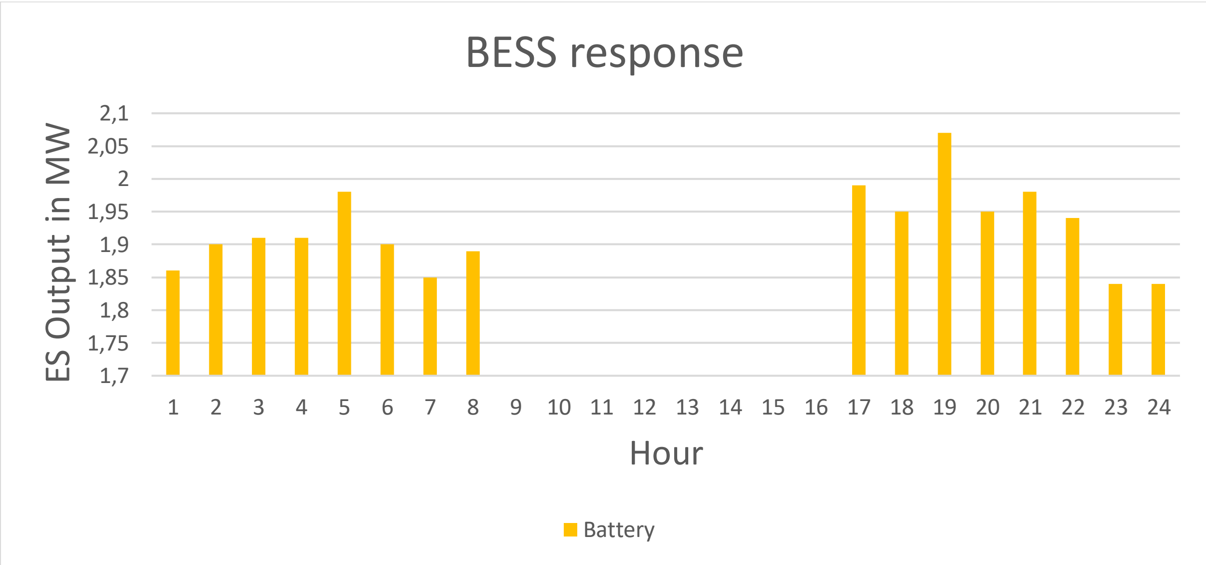


Figure 3-27 – BESS response resulting from the application of the DESPlan tool for case #1

As result, the overload was avoided for the whole assessment period. Figure 3-28 shows the power flow in the branch considering the effect of the installation of the BESS.

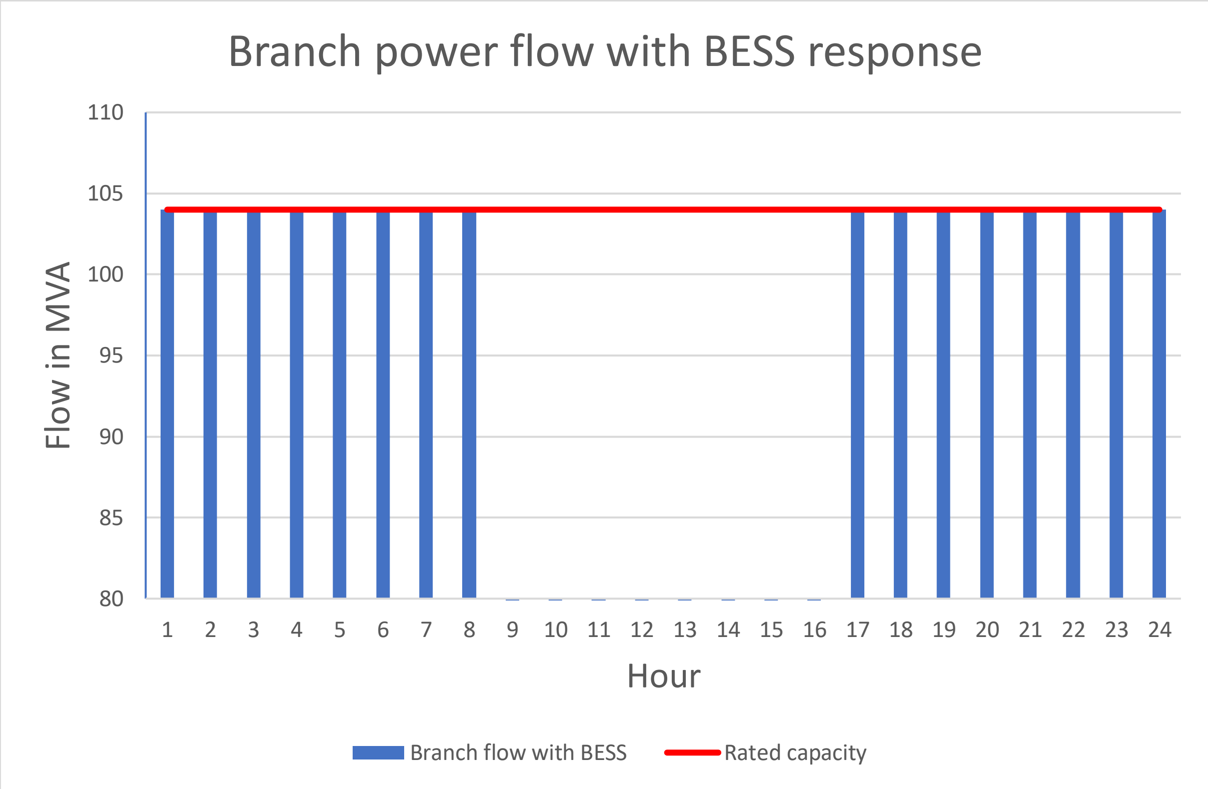


Figure 3-28 – 2050 scenario – Power flow in the branch 1040-1060 for case #1 with BESS

As can be seen, the overload is solved for the entire period of analysis. In Figure 3-29 it is possible to see the branch in hour 5 (worst case) with the action of the BESS.

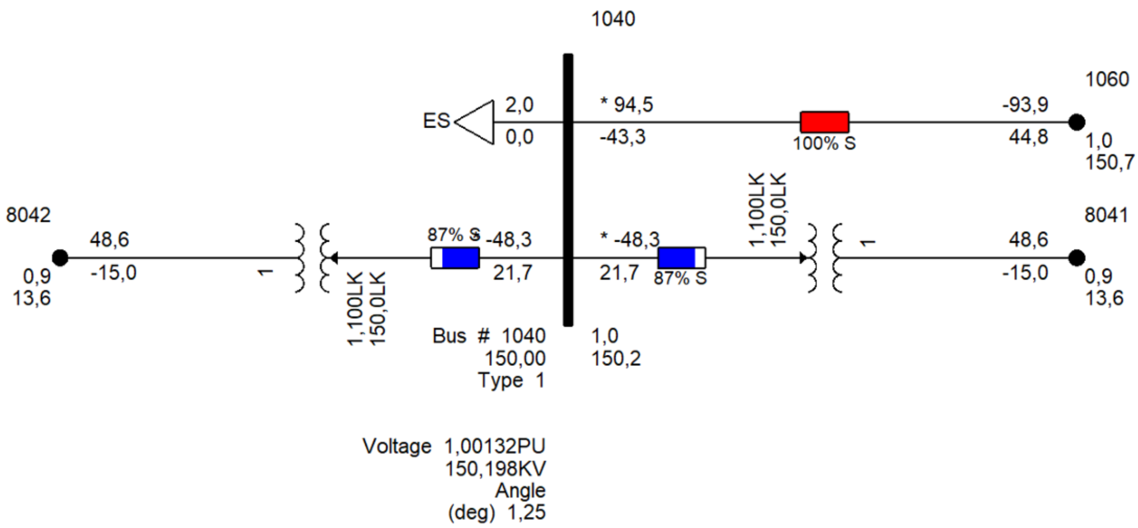


Figure 3-29 – Network single line diagram of the congestion area at hour 5 (case #1) with BESS

3.3.2 Case #2 – 12nd of April 2050

The second case selected is referred to the 12nd of April of 2050. In this case there are 12 simultaneous congestions that were identified during the simulations (five different lines and seven transformers), that occur in almost all hours of the day.

The load diagram of this case is presented in Figure 3-30.

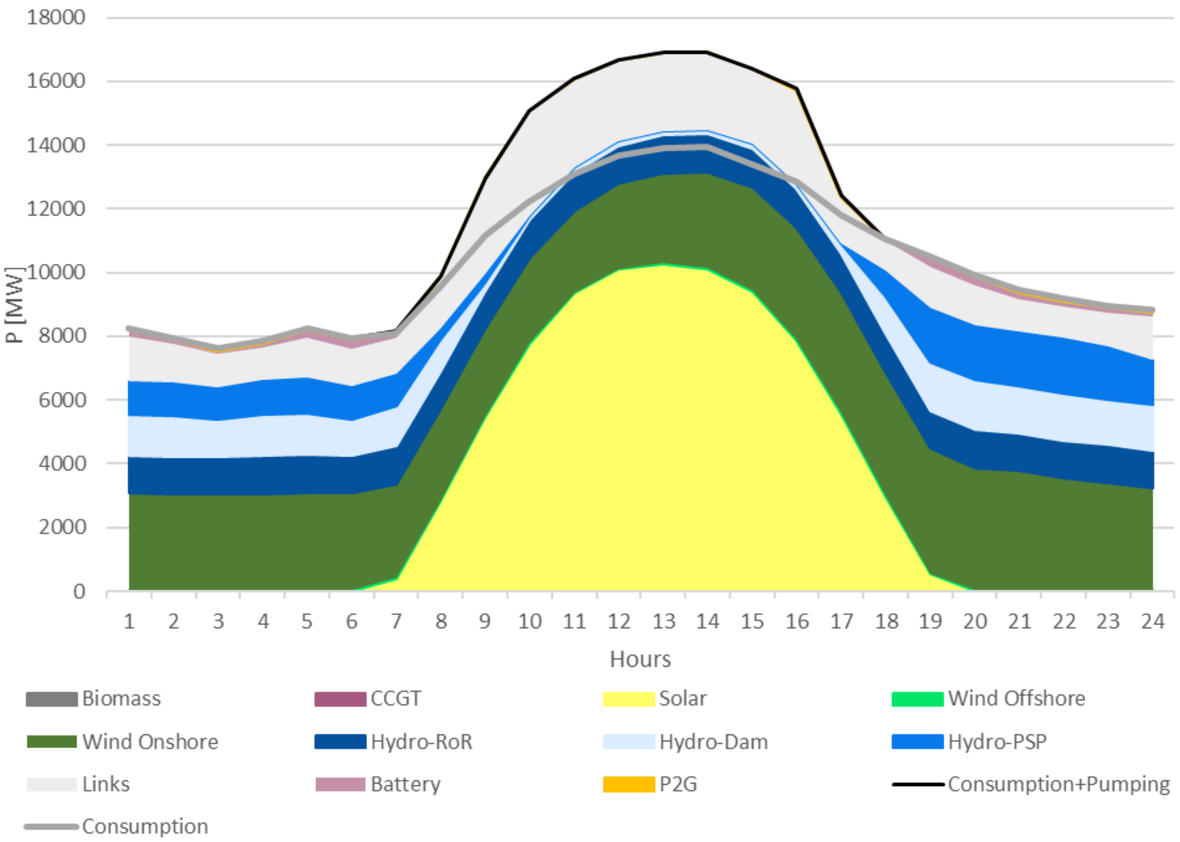


Figure 3-30 – 2050 scenario – generation mix diagram of case #2

The first thing that arises from Figure 3-30 is the inexistence of large thermal generation (e.g. CCGT) in the generation mix. In fact, the generation mix is entirely based on RES. During the day, the contribution of solar power reaches around 10GW, which is significant in the Portuguese context, as it is more than the demand level expected by 2030.

In terms of the branches presented in the selected case, the focus will be on the transformers connecting buses 122-422, 422-622 (through buses 6223/6224) and 122-622 (through buses 6225/6226). An illustration of the power flow in each hour is provided in Figure 3-31 and Figure 3-32.

Similarly, Figure 3-26 presents the network single line diagram of the area of the congestion detected during the period of maximum overload.

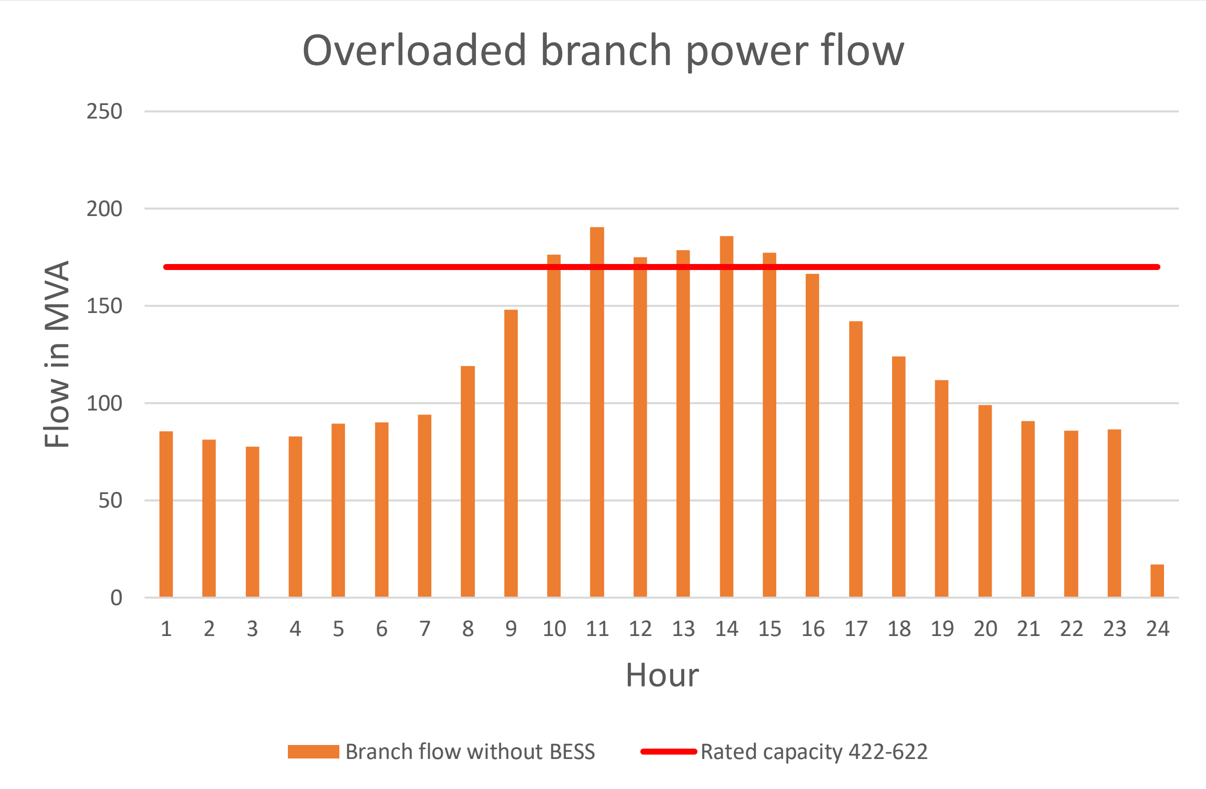


Figure 3-31 – 2050 scenario – Power flow in the branches 422-622 for case #2

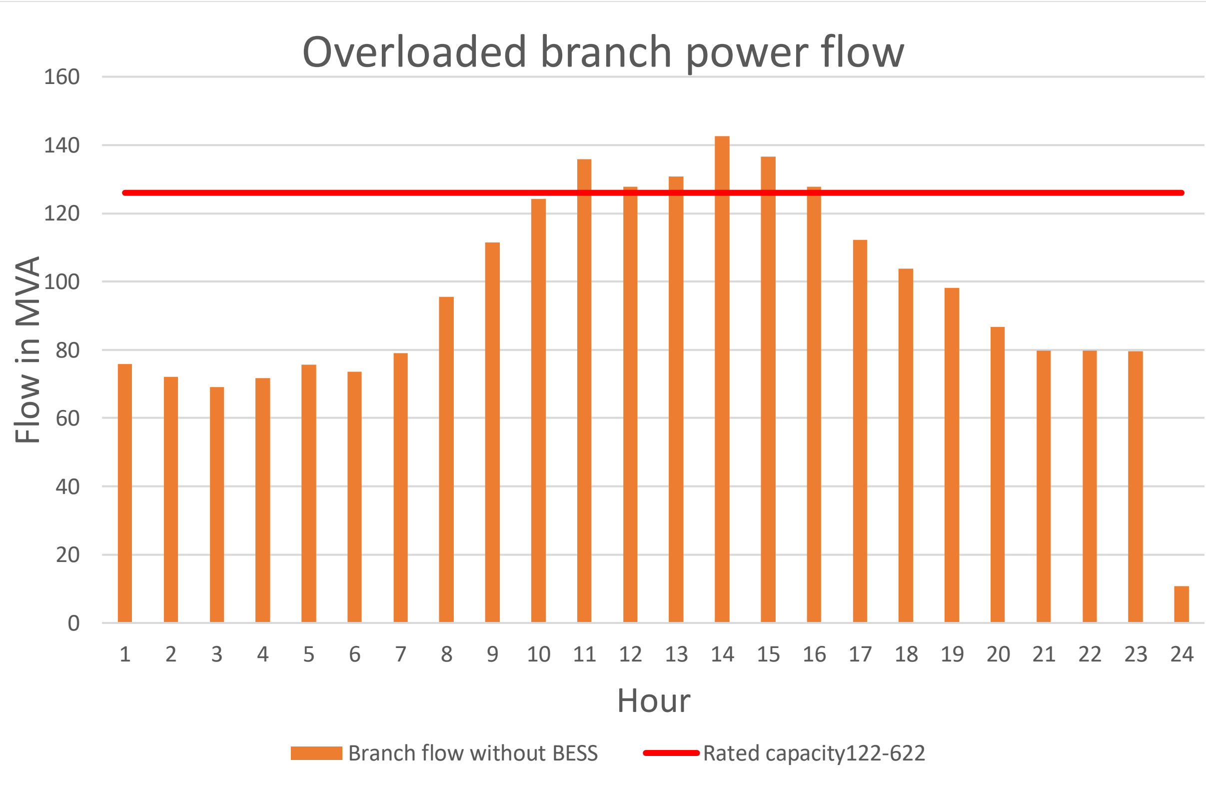


Figure 3-32 – 2050 scenario – Power flow in the branches 122-622 for case #2

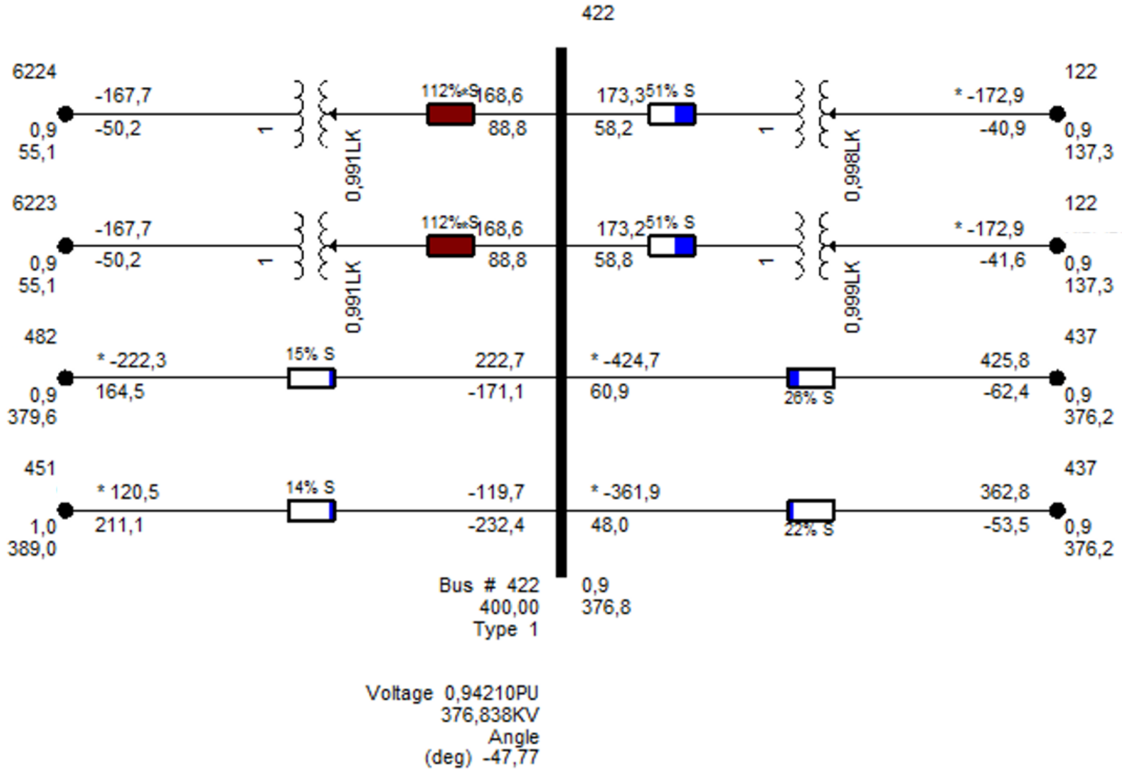


Figure 3-33 – Network single line diagram (bus 422) at hour 12 (case #2)

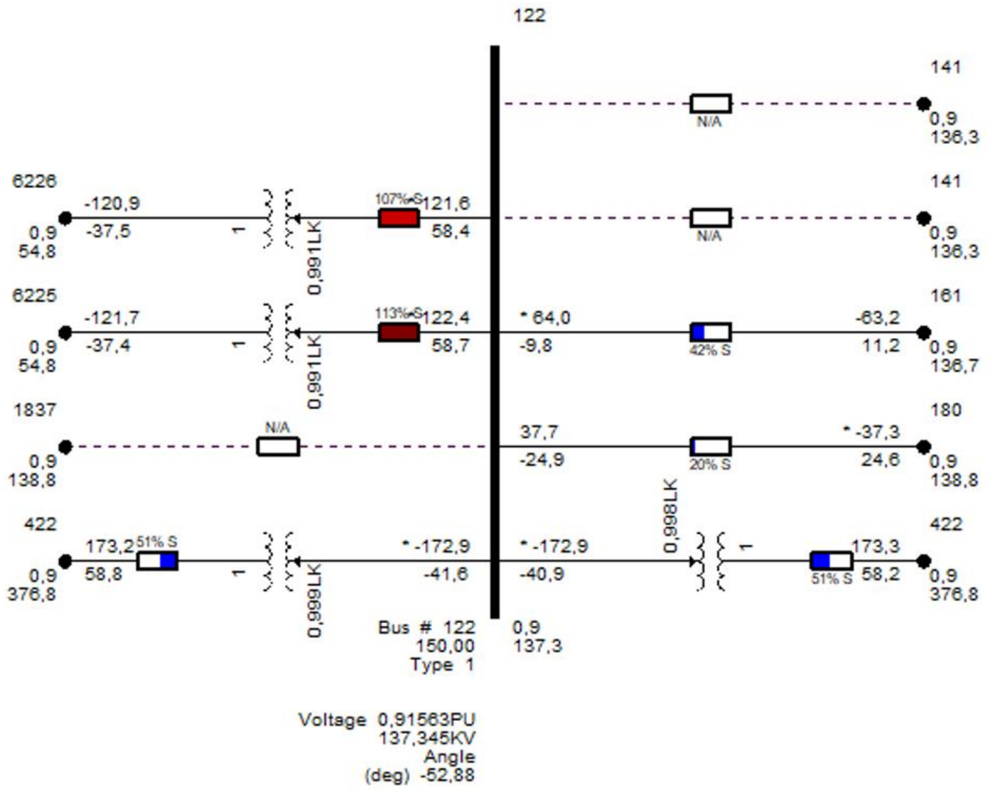


Figure 3-34 – Network single line diagram (bus 122) at hour 12 (case #2)

It is possible to notice that based on the simulation there are 7 periods (hours) in which multiple congestions were detected in these branches. The maximum overload reaches around 13% above the rated capacity of one of the transformers. The overloads are caused by a combination of factors (i.e. load, generation, power flow transits) that culminate in this situation.

The DESPlan tool was applied for case #2 in order to find a suitable BESS solution capable of solving the congestions of the identified branch. The DESPlan tool considered as candidate nodes the substation buses located one node away from the congested branches. After running the tool for the 24 hour, the tool provided an alternative solution using a BESS. The solution would consist on **7 systems**: **10.8MW/10.8MWh** installed at **bus 122 (150kV)**, **6.0MW/3.8MWh** installed at **bus 422 (400kV)**, **34.7MW/119.2MWh** installed at **bus 622 (60kV)**, **15.5MW/20.4MWh** installed at **bus 6223 (60kV)**, **44.2MW/93.4MWh** installed at **bus 6224 (60kV)**, **32.8MW/80.3MWh** installed at **bus 6225 (60kV)** and **28.2MW/56MWh** installed at **bus 6226 (60kV)**. The combined cost of the solutions would reach approximately cost of **85.501.000 EUR**.

Figure 3-35 describes the response of the BESS for case #2.

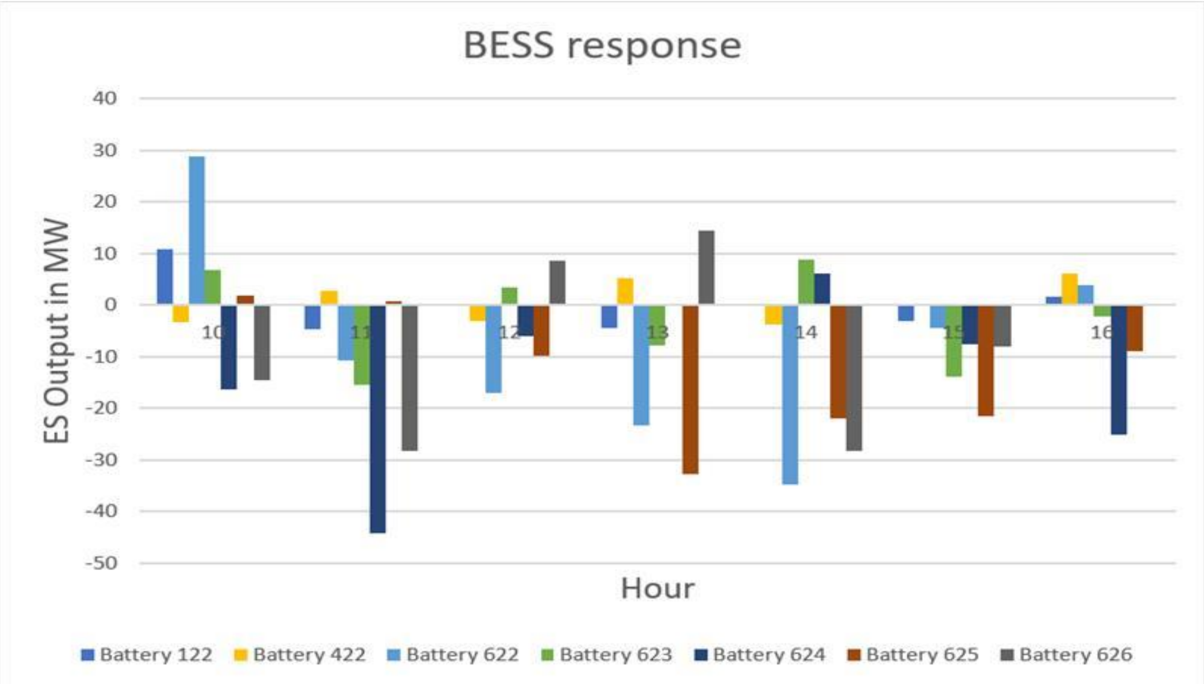


Figure 3-35 – BESS response resulting from the application of the DESPlan tool for case #2

As result, the overload was avoided for the whole assessment period. Nevertheless, in this case, due to the complexity the BESS solution is distributed along several buses. Additionally, due to the fact that the overloads are significant considering the capacity of the transformers (13% of the rated capacity) the solutions found involves large amounts of BESS. Although it is technically feasible, it may struggle to be economically competitive against traditional network upgrades (e.g. transformer reinforcement). This would require additional analysis, as this aspect is not addressed in this report.

Figure 3-36 and Figure 3-37 shows the power flow in the branches considering the effect of the installation of the BESS.

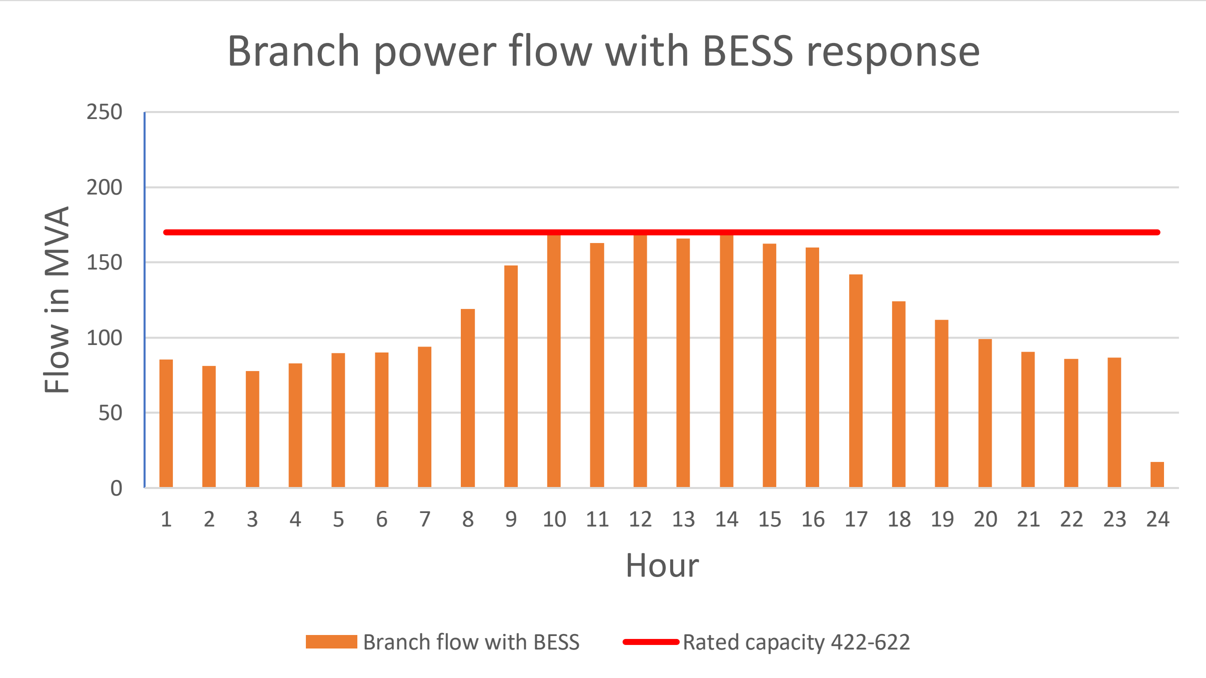


Figure 3-36 – 2050 scenario – Power flow in the branches 422-622 for case #2 with BESS

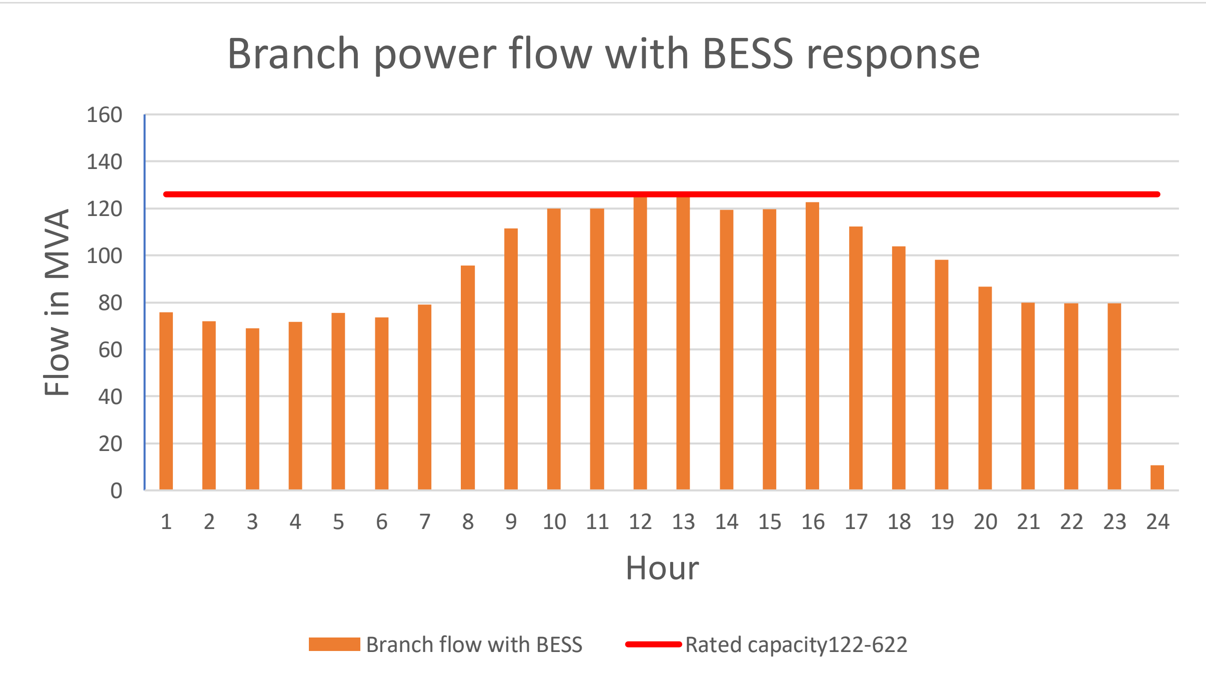


Figure 3-37 – 2050 scenario – Power flow in the branches 122-622 for case #2 with BESS

As can be seen, the overloads are solved for the entire period of analysis. In Figure 3-29 it is possible to see the branch in hour 5 (worst case) with the action of the BESS.

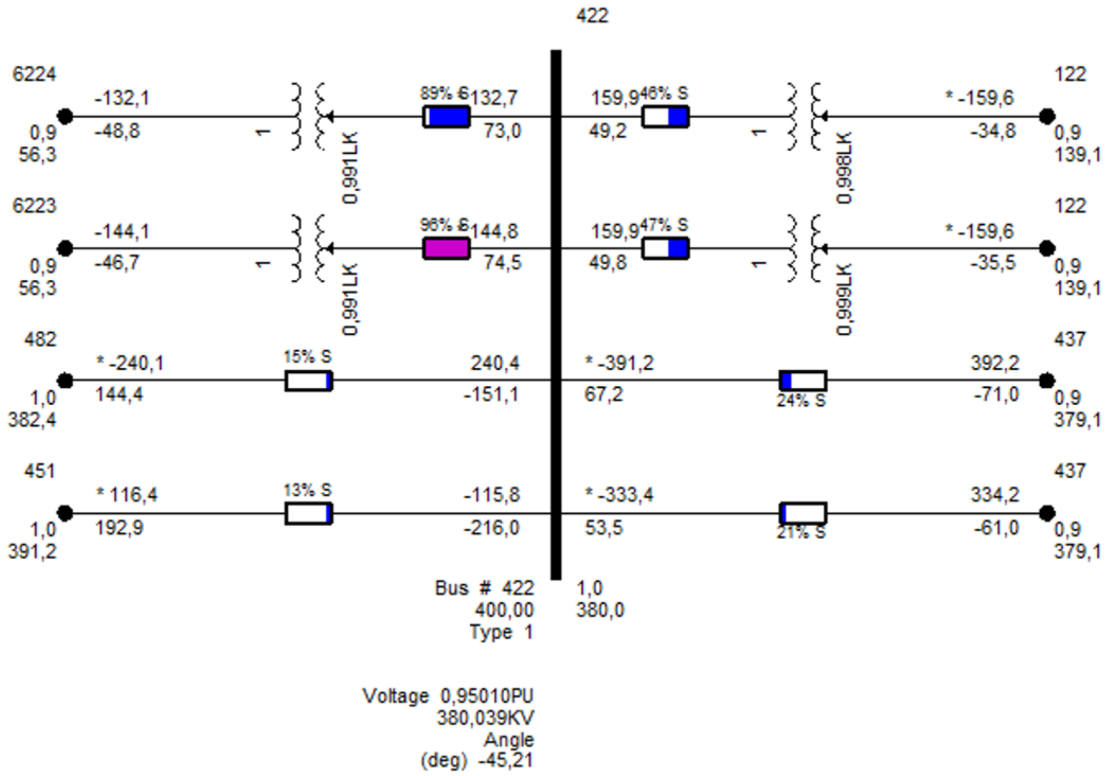


Figure 3-38 – Network single line diagram (bus 422) at hour 12 (case #2) with BESS

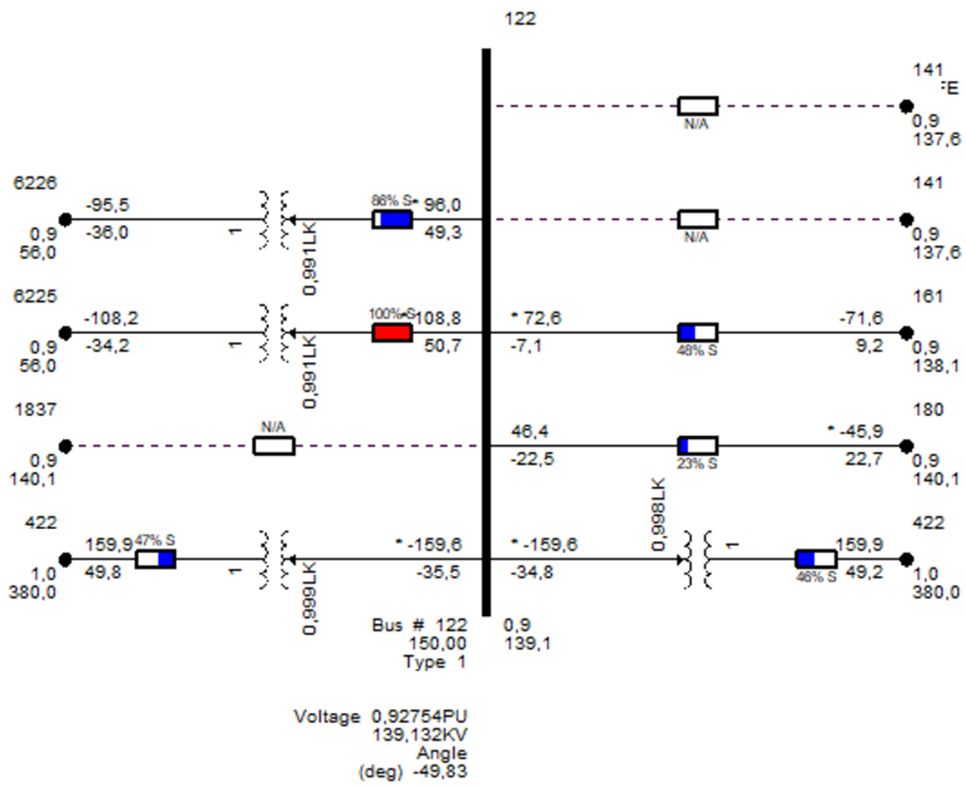


Figure 3-39 – Network single line diagram (bus 122) at hour 12 (case #2) with BESS

3.3.3 Case #3 – 28th of June 2050

The third case selected is related to the 28th of June of 2050. In this case there are 10 simultaneous congestions that were identified during the simulations (four different lines and six transformers), that occur in almost all hours of the day. In this case we focus on the line connecting buses 246-268.

The load diagram of this case is presented in Figure 3-40.

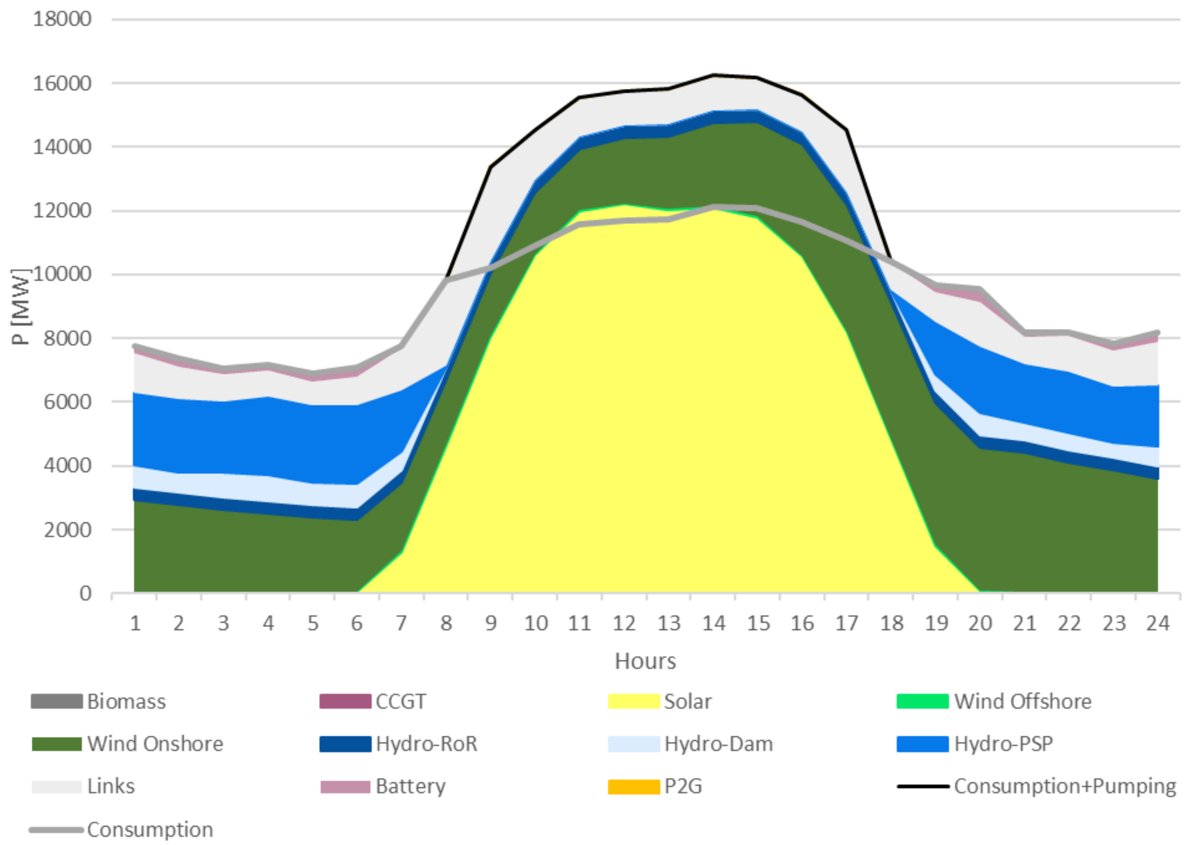


Figure 3-40 – 2050 scenario – generation mix diagram of case #3

As in the previous cases, it's clear that the inexistence of large thermal generation (e.g. CCGT) in the generation mix continues very present in the 2050 OSMOSE scenario. The generation mix in this case is entirely based on RES. During the day, the contribution of solar power reaches around 12GW which, and in some hours (i.e. 10h, 11h, 12h) the generation from PV alone is higher than the national demand. It is curious than even in this situation, the system continues importing energy from Spain, according to the OSMOSE 2050 scenario.

In terms of the branch presented in this case, line connecting buses 246-268, an illustration of the power flow in each hour is provided in Figure 3-41.

Similarly, Figure 3-42 presents the network single line diagram of the area of the congestion detected during the period of maximum overload.

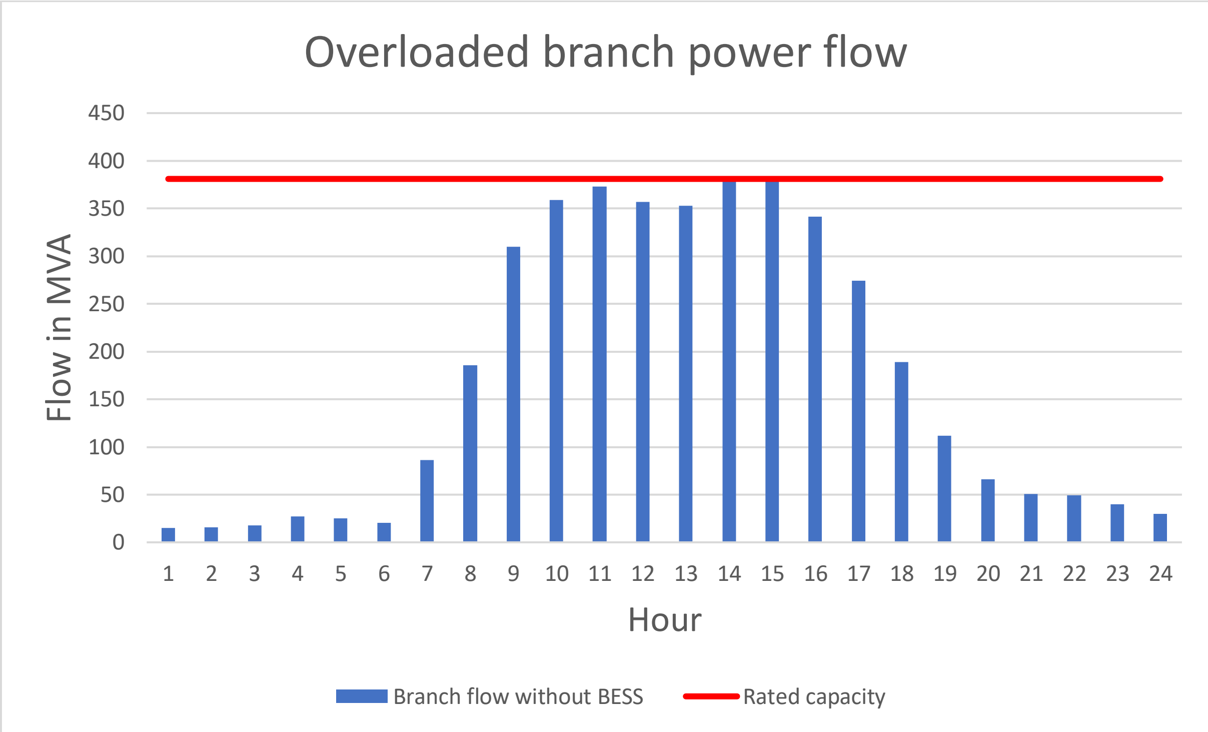


Figure 3-41 – 2050 scenario – Power flow in the branch 246-268 for case #3

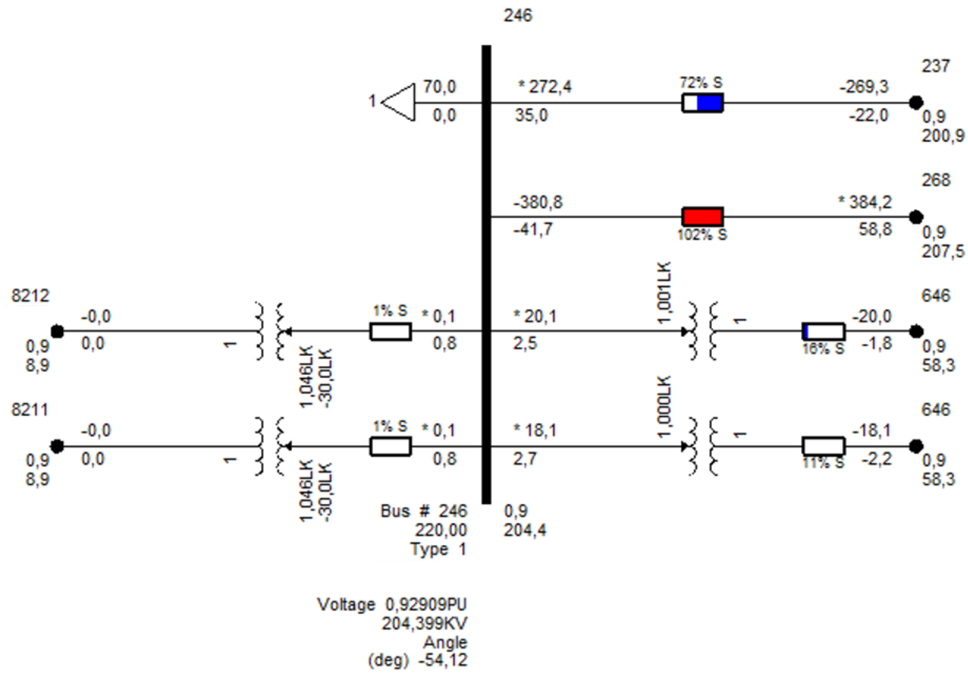


Figure 3-42 – Network single line diagram of the congestion area at hour 15 (case #3)

It is possible to notice that based on the simulation there is 1 period (hour) in which congestion is detected in this branch. The overload reaches around 2% above the rated capacity.

The line overload was detected in a situation of high level of RES production at the power plants connected at substation 268, which eventually triggers this overload on the line responsible to direct the power flow from substation 268 to the transmission network.

The DESPlan tool was applied for case #3 in order to find a suitable BESS solution capable of solving the congestion of the identified branch. The DESPlan tool considered as candidate nodes the substation buses located one node away from the congested branch. After running the tool for the 24 hour, the tool provided an alternative solution using a BESS. The solution would consist on a **3.8MW/3.8MWh** system installed at **bus 246 (220kV)**, with an approximate cost of **1.798.000 EUR**.

Figure 3-43 describes the response of the BESS for case #3.

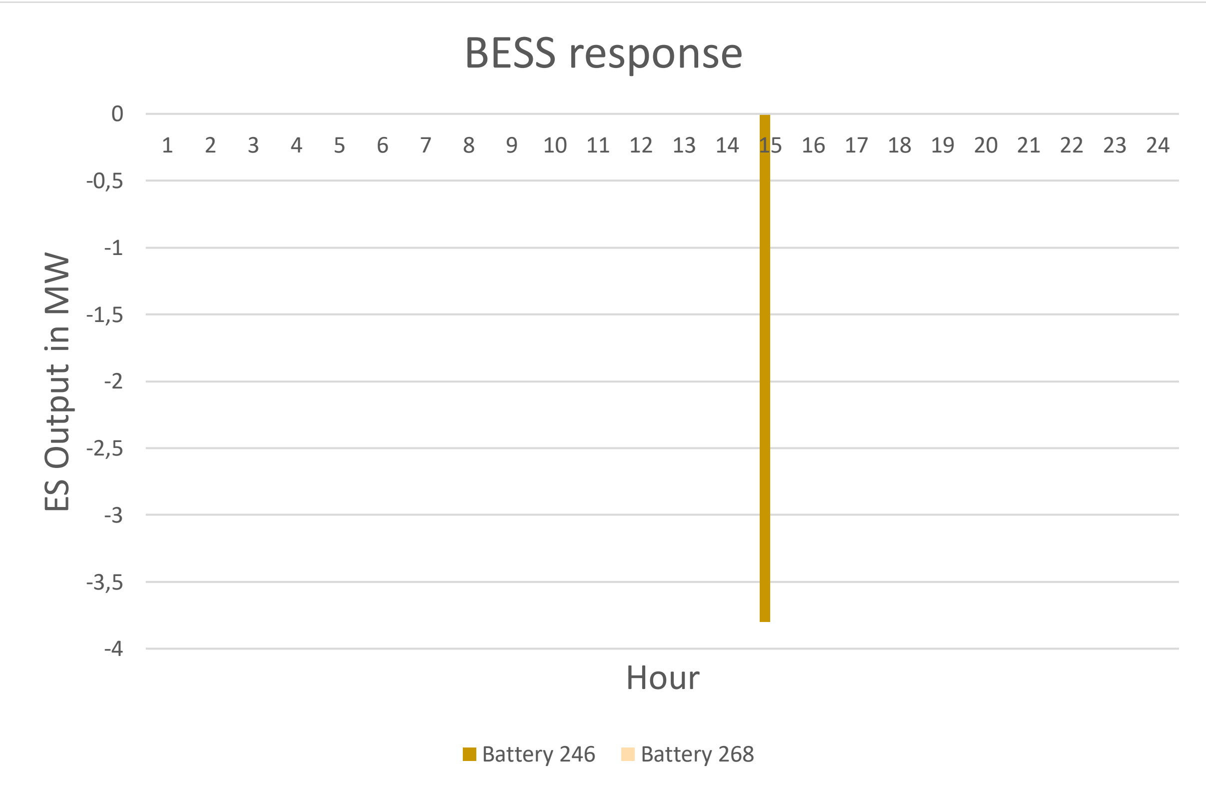


Figure 3-43 – BESS response resulting from the application of the DESPlan tool for case #3

As result, the overload was avoided for the whole assessment period. Figure 3-44 shows the power flow in the branch considering the effect of the installation of the BESS.

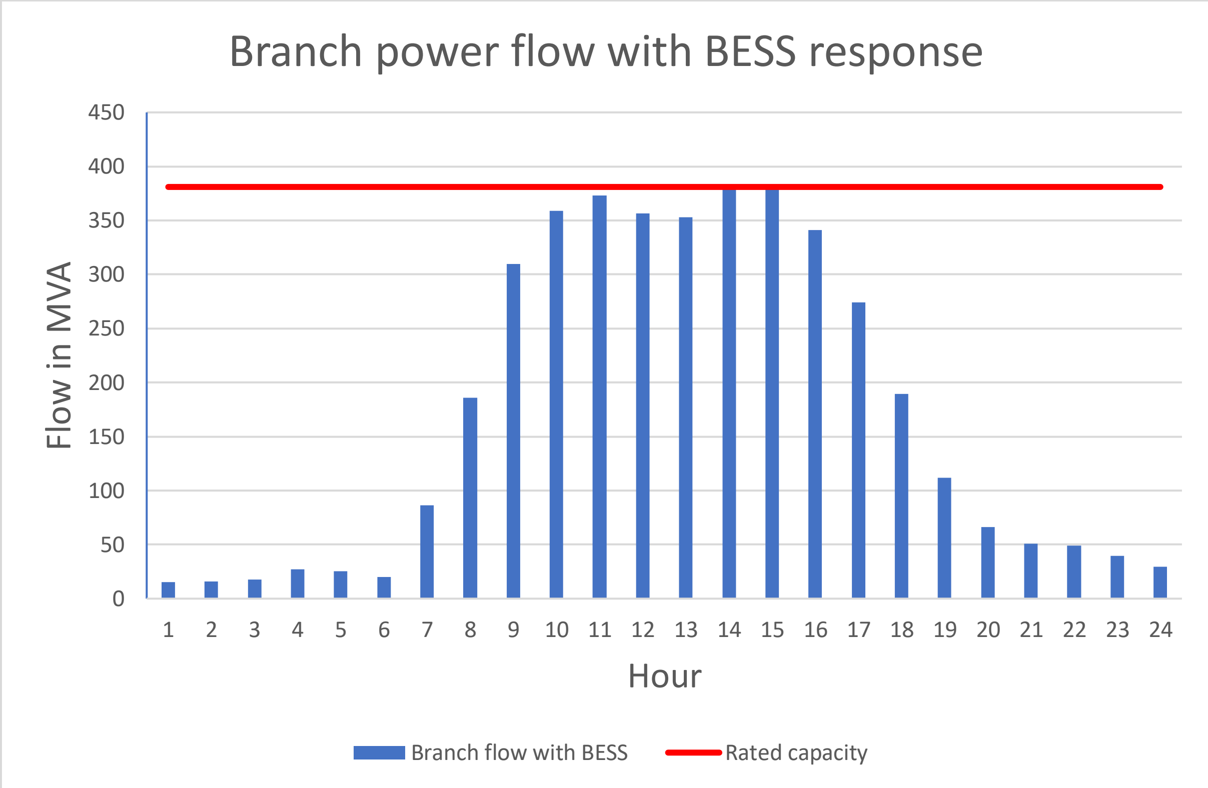


Figure 3-44 – 2050 scenario – Power flow in the branch 246-268 for case #3 with BESS

As can be seen, the overload is solved for the entire period of analysis. In Figure 3-45 it is possible to see the branch in hour 15 (worst case) with the action of the BESS.

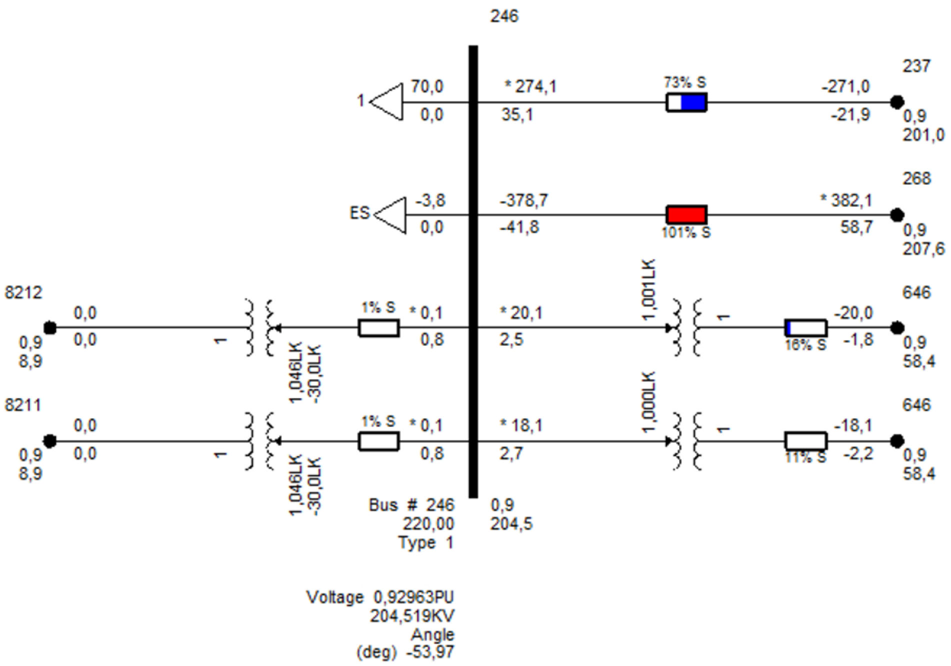


Figure 3-45 – Network single line diagram of the congestion area at hour 15 (case #3) with BESS

4 Conclusions

In this section presents the main conclusions and the key takeaways from all the studies and analyses carried-out within T1.4.1 activities. The key findings are gathered and highlighted.

In this report, the Dispersed Energy Storage Planning tool (DESPlan) was used to perform an analysis of the average scenarios for 2030 and 2050 time horizons, provided by OSMOSE T1.1 and T1.2 for the Portuguese power system. The analysis focused on the identification and resolution of potential network congestions in the Portuguese transmission network, up to the 60kV level (distribution level). The tool provided technical alternatives for network reinforcement based on Battery Energy Storage System (BESS) solutions.

For the effective mapping of the T1.2 datasets produced with ANTARES (which represented the Portuguese power system as two clusters) into the detailed network model of the Portuguese transmission system, a redistribution methodology was developed and implemented. This methodology allowed redistributing the aggregated values of load, generation and interconnection flows according to the actual location of these resources in the detailed Portuguese network model as well as integrating a realistic behaviour of the of RES present in the network (i.e. wind, solar and hydro) according to historical data.

This required the preparation of the data received from T1.2, as well as taking some modelling assumptions in order to adjust the network model to the actual installed capacity of different technologies considered in the OSMOSE's scenarios. These decisions allowed the simulations to be performed, but it also turned the network model more sensitive to supply and demand changes, which resulted in difficulties in converging the power flow calculations in a few number of periods.

This situation was noticed mainly in the 2050 scenario simulations, in which the supply and demand scenarios were more extreme and for which the long-term planning data was rather scarce.

The DESPlan tool was capable of finding the sizing and siting for BESS flexibility sources in order to solve the potential congestions detected for both 2030 and 2050 time horizons. On the other hand, the solutions found were not compared against traditional investment options (e.g. new lines or transformers), being this analysis focused on the search for technical solutions for the congestion problems based on BESS.

From the results of the simulations with the DESPlan toon and further analysis, it is possible to conclude that:

- For both average scenarios 2030 and 2050, the DESPlan tool identified several potential congestions in several branches in the adapted detailed network models for both time horizons.
- The congestions identified in the 2050 scenario were more frequent and more severe (higher amplitude), than the ones identified in the 2030 scenario.

- Bearing in mind the fact that the simulations were made assuming the network with all its branches available (“N condition”), it’s fair to say that even so the approach was benevolent in the sense that more stressful situations (e.g. N-1 contingency criterion), which are typically targeted at transmission network planning, were not addressed in this study.
- The DESPlan tool successfully solved all the selected cases in both scenarios at the minimum cost, as the affected branches continued to be exploited close to their rated capacity.
- Some of the solutions found for the cases presented a very high cost, which may compromise their eventual economic viability from the network planner perspective as an alternative to more traditional network reinforcement options (such as lines or power transformers).
- It is not possible to exclude the effect of the assumptions taken into consideration, especially for the scenario 2050, since no major network reinforcements, in both lines and power transformers, were considered from the 2030 model.
- We were surprised to note that in both scenarios (2030 and 2050) Portugal is always importing energy from Spain (and Europe). Even in the 2050 scenario, with PV generation reaching 12GW of production around 12h00, which was more than enough to cover the National load in most summer days for 3 or 4 hours, the country still continues to import energy from Spain in every hour of the year. This behaviour does not look realistic in our perspective.
- Finally, it seems clear that the need for network reinforcement will have to continue in order to prepare the transmission network for the challenges of a near-zero carbon economy, although the plurality of the flexibility options available for investment may be more broad.

References

[1] H. Seifi and M. S. Sepasian, Electric Power System Planning, Springer-Verlag Berlin Heidelberg, 2011.

[2] H. Cheng, Power System Planning, 2nd version, China Electric Power Press, 2014.

[3] R. Jabr, I. Dzafic and B. Pal, "Robust Optimizaion of Storage Investment on Transmission Networks," *Proceedings for IEEE Transactions on Power Systems,* vol. 30, pp. 531-539, January, 2014.

[4] H. Pandzic, Y. Wang, T. Qiu, Y. Dvorkin and D. Kirschen, "Near-Optimal Method for Siting and Sizing of Distributed Storage in a Transmission Network," *IEEE Transactions on Power System,* pp. 1-13, October, 2014.

[5] V. Miranda and N. Fonseca, "EPSO – Best-of-Two-Worlds Meta-Heuristic Applied to Power System Problems," in *Proceedings of the 2002 Congress on Evolutionary Computation*, Honolulu, USA, 2002.

[6] J. Kennedy and R. Eberhart, "Particle Swarm Optimization," in *Proceedings of the 1995 IEEE International Conference on Neural Networks*, Perth, Australia, 1995.

[7] I. Rechenberg, Evolutionsstrategie-Optimierung Technischer Systeme nach Prinzipen der Biologischen Evolution, Stuttgard: Frommann-Holzboog, 1973.

[8] H. Schwefel, Evolution and Optimum Seeking, New York, NY: Ed. Wiley, 1995.

[9] REN, "PDIRT- Plano de desenvolvimento e investimento da rede nacional de transporte 2020-2029," 2019.

[10] REN, "PDIRT- Plano de desenvolvimento e investimento da rede nacional de transporte 2022-2031," 2021.

[11] e. a. Abengoa Hidrogeno, "COMMERCIALISATION OF ENERGY STORAGE IN EUROPE," 03 2015. [Online]. Available: https://www.fch.europa.eu/sites/default/files/CommercializationofEnergyStorageFinal_3.pdf. [Accessed 01 04 2021].

[12] C. Gerbaulet and C. Lorenz, "dynELMOD: A Dynamic Investment and Dispatch Model for the Future European Electricity Market," *DIW Data Documentation,* 2017.

[13] J. Deane, A. Chiodi, M. Gargiulo and B. P. Ó. Gallachóir, "Soft-linking of a power systems model to an energy systems model," *Energy,* vol. 42, pp. 303-312, 2012.

[14] K. Löffler, K. Hainsch, T. Burandt, P.-Y. Oei, C. Kemfert and C. von Hirschhauen, “Designing a Model for the Global Energy System—GENeSYS-MOD: An Application of the Open-Source Energy Modeling System (OSeMOSYS),” *Energies,* vol. 10, no. 1468, 2017.

[15] K. Hainsch, T. Burandt, C. Kemfert, K. Löffler, P.-Y. Oei and C. von Hirschhausen, “Emission Pathways Towards a Low-Carbon Energy System for Europe: A Model-Based Analysis of Decarbonization Scenarios,” *DIW Discussion Paper,* vol. 1745, 2018.

[16] K. Jacqué, “Potentialanalyse und Modellierung von Lastverschiebung durch Demand-Side-Management und Elektromobilität im Kontext des Energiesystems der Zukunft,” 2013.

[17] M. M. d. Silva, *Energy Planning with Electricity Storage and Sustainable Mobility: The Study of an Isolated System,* MIT Portugal Program, Faculdade de Engenharia da Universidade do Porto, Portugal, 2013.

[18] M. M. d. Silva, J. Ye, T. Shi and R. Pastor, “Planning Energy Storage in Power Transmission Networks,” in *2014 IEEE Green Energy and Systems Conference (IGESC)*, Long Beach, CA, November, 2014.

[19] A. Rosso and S. W. Eckroad, “Energy Storage for Relief of Transmission Congestion,” *IEEE Transactions on Smart Grid,* vol. 5, pp. 1138-1146, 2014.

[20] Z. X. Hu and W. T. Jewell, “Optimal power flow analysis of energy storage for congestion relief, emissions reduction, and cost savings,” in *Proc. 2011 IEEE/PES Power Systems Conference and Exposition (PSCE), pp.1-8*, 20-23 March, 2011.

[21] B. Sang, D. Wang, B. Yang, J. Ye and Y. Tao, “Optimal Allocation of Energy Storage System for Smoothing the Output Fluctuations of New Energy,” *Proceedings of the CSEE,* Vols. 34, no.22, pp. 3700-3706, August, 2014.

[22] T. Brekken, A. Yokochi, A.V. Jpiamme, et al., A. Yokochi, A. Jpiamme and et al., “Optimal Energy Storage Sizing and Control for Wind Power Applications,” *IEEE Transactions on Sustainable Energy,* vol. 2, pp. 69-77, January, 2011.

[23] P. Harsha and M. Dahleh, “Optimal sizing of energy storage for efficient integration of renewable energy,” in *50th IEEE Conference on Decision and Control and European Control Conference*, 12-15 December, 2011.

[24] X. Qin, B. Li, T. Xia, S. Ma, Y. Wang, Y. Zhang, Q. Zhou, P. Zeng, N. Liu and X. Sheng, “Study of the Application of Active Power Adjustment and Control Technology based on Modem Energy Storage into Power System Stability Control and Voltage Adjustment,” in *International Conference on Power System Technology (POWERCON 2014)*, Chengdu, 20-22 October, 2014.