ATTEST

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# WP2

## Toolbox Specification, Support Tools and Test Cases

# Test cases

D2.3

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# Executive Summary

This deliverable describes the work developed in the course of ATTEST's task T2.3 – "Test cases". The main objective of ATTEST is to develop and operationalize a modular open-source toolbox comprising a suite of innovative tools to support TSOs / DSOs operating, maintaining and planning the energy systems of 2030 and beyond in an optimized and coordinated manner. The testing and validation of the ATTEST toolbox and its components requires the use of different test cases. This deliverable presents the methodology used to produce the test cases and describes them in detail. It is the objective of the ATTEST consortium to make available to the community most of the test cases presented in this deliverable, duly anonymized, and as long as they are deemed non-confidential by their owners.

Test cases in the context of ATTEST are based on real (or realistic) electric power networks, corresponding to either transmission or distribution systems, from several countries considering distinct different voltage levels and under different operating conditions. The test cases take into account mainly the penetration of different low carbon technologies (renewable energy sources, EVs, storage, etc.), load and (conventional and renewable) generation scenarios and flexibility sources. Official documents and data projections were gathered in order to define the potential configurations of these power systems in 2030 and beyond.

Therefore, the main outcome of the deliverable D2.3 is a set of files comprising network files and input data such as tables, related to the developed test cases. The present deliverable contains thus the description of the twenty-eight test cases developed in this task as well as guidelines for creating further test cases addressing future scenarios.

The remainder of this document is structured as follows:

Chapter 1 explains what a test case is, the methodology for building them and how they will be used in other project tasks.

Chapter 2 describes future scenarios of power generation and demand for the countries related to the test cases, along with a set of guidelines for the creation of further test cases addressing future scenarios.

Chapter 3 presents the methodology for including flexibility in the test cases along with a tool developed in task T2.3, which aids the computation of flexibility bands.

Chapter 4 presents a table with an overview of the test cases and each test case is described in each section.

Annex 1 presents an example of a test case network file.

Annex 2 presents an example of a test case auxiliary file.

Annex 3 presents an example of the results of a power flow obtained from a test case.

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onshore, 'PVP': photovoltaic power plant, 'SH1': Small hydro P ≤ 10 MW, 'SH3': small hydro 10 MW < P ≤ 30 MW, 'HRP': hydro run-of-river and poundage, 'HWR': hydro water reservoir, 'HPS – GEN': Hydro power working as generator, 'HPS-PUM': Hydro power working as pump, 'FOG': fossil gas. ............... 50
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# Abbreviations and Acronyms

| ACRONYM / ABBREVIATION | Extensive form |
|---|---|
| CPV | Concentrated Photovoltaics |
| CSP | Concentrated Solar Power |
| DG | Distributed Generation |
| DR | Demand Response |
| EHV | Extra High Voltage |
| EV | Electric Vehicle |
| HV | High Voltage |
| LV | Low Voltage |
| MV | Medium Voltage |
| PV | Photovoltaics |
| WP | Work Package |

# 1. Test cases in ATTEST: rationale and format

The objective of creating the test cases envisioned in task T2.3 is to support the development and evaluation of performance of the ATTEST toolbox components, namely the tools that are being developed in Work Packages (WP) 3, 4 and 5.

The main objective of the ATTEST project is to develop and operationalize a modular open-source toolbox comprising a suite of innovative tools to support TSOs / DSOs operating, maintaining and planning the energy systems of 2030 and beyond in an optimized and coordinated manner. To develop the ATTEST's toolbox, it was decided to create a set of relevant test cases that will serve the purpose of testing and demonstrating the toolbox components.

A test case consists of a series of files containing electric grid information (e.g., grid topology, generation and load data, assets data, etc.) that support simulating a real (or realistic) situation, whether it is a scenario for long term planning, operation or asset management. Given that the tools developed in various tasks of ATTEST are inherently connected, with some interdependencies, it was decided to define an internal format for the test cases, that is detailed in Section 1.2.

These cases will serve as input to the tools developed in WP3 (planning tools), WP4 (operation tools) and WP5 (asset management tools), allowing to test their performance. Even if these tools solve different problems, they also share some common data (i.e., the grid topology consisting of location of generators, loads, overhead and underground power lines and transformers). Besides these common features, there are specific data that are only relevant for one WP but not for the others, as illustrated in Figure 1.

In Figure 1 the blue color refers to data produced by task T2.3, while the gray color are data sets which are WP specific and generated locally partially relying on the guidelines provided by task T2.3.

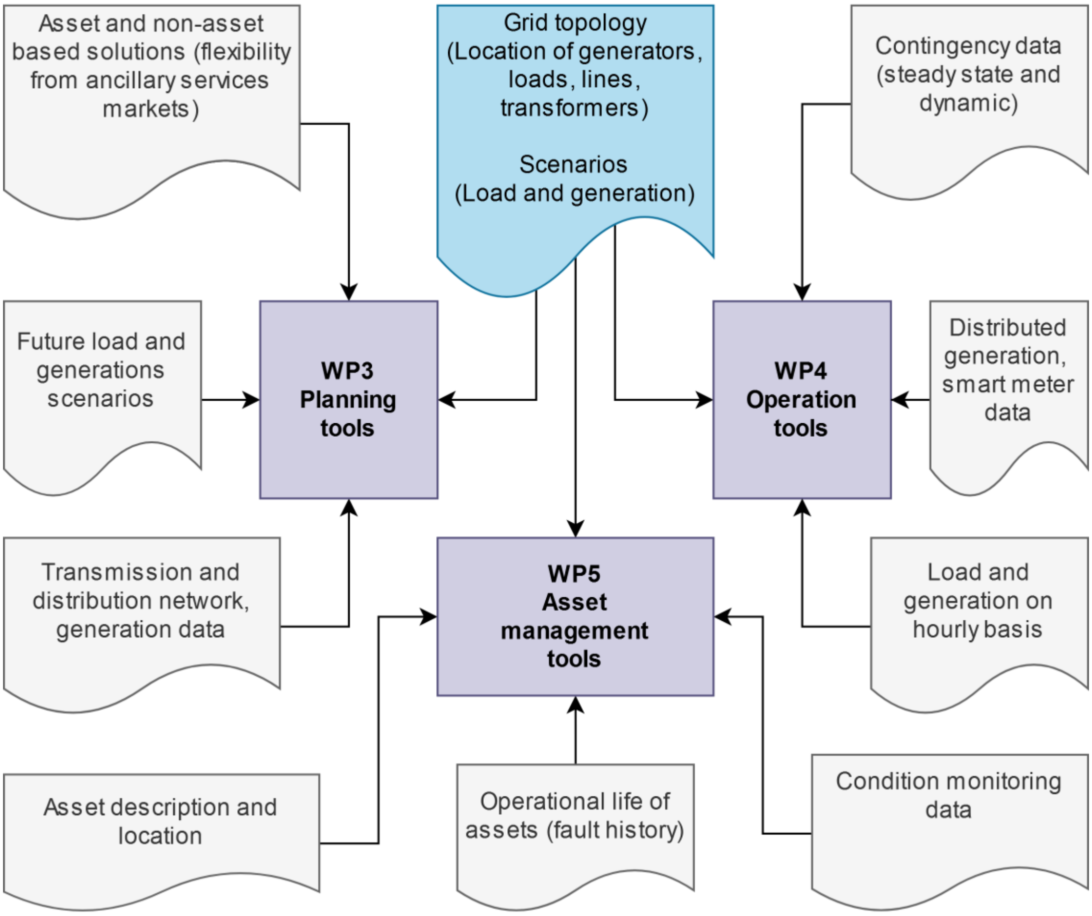



FIGURE 1 - TEST CASES INPUTS

An overview of the WPs and its relation to test cases is as follows:

- WP3 tools concern network planning, therefore the emphasis will be on how to invest in assets that allow energy to be transferred from generation to consumption nodes[1] over the years. In order to address scenarios of investment on new network assets such as a new transmission lines or storage, this WP requires scenarios modeling the evolution of demand and installed power per generation technology;
- WP4 tools are rather focused on the day-ahead and real-time operation of the grid, for instance simulating how a congestion situation can be solved using flexibility, and the relevant data is therefore the load and generation in all nodes at the moment when a contingency occurs;
- WP5 tools focus on asset management and address the condition of the assets and strategies to carry out the maintenance, computing indicators which are based on information of assets such as age, materials and time required for corrective maintenance.

In the remainder of this section the internal ATTEST data format is introduced, the methodology for building consistent test cases are presented and finally the structure of the rest of the deliverable is presented.

[1] A "node" in the context of this deliverable is an electric node, e.g. a busbar in a physical substation.

## 1.1 The internal ATTEST test case format

For the sake of consistency across different WPs, an internal format was agreed by the Consortium.

The basic internal format of a test case is constituted by:

- Network file (including grid topology, nodes, generators, consumption, all of which connected by power lines or transformers)
- Auxiliary files (which are specific to each WP)

As can be understood from Figure 1, the network data are common to and will be shared by all WPs. A common format widely used in both academia and industry is the MATPOWER format [1], so it was agreed that the internal format would use a text file compatible with the MATPOWER structure in an initial phase of the project. This file provides a "snapshot" or "steady-state" at a given time, which typically includes a converged power flow solution. At a later project stage these files may be converted to CIM format. An example of a network file is presented in Annex 1.

For the auxiliary files, Comma-Separated Values (CSV) files, spreadsheets and Excel-compatible formats are used. These contain additional data that may serve as input to the network files. Specifically, an additional file may contain the expected installed power by generation technology in a future scenario (required by WP3), the variation of load and generation on 24 hours in one day (required by WP4) or the list of lines containing information of length, type (overhead, underground), model, conductors and date of commissioning (required by WP5). An example of a complementary file is presented in Annex 2.

The test cases are, therefore, easily usable by anyone interested in performing traditional power systems steady state analysis. The only exception in this sense is the test case labelled as HR_Tx_dyn_2020 in Table 8, which includes file formats compatible with software such as Power System Simulation for Engineering, widely known as PSS/E [2], and that are intended for dynamic simulation purposes.

## 1.2 Methodology for building consistent test cases

A part of the task T2.3 is to outline the methodology that allows ATTEST task leaders to build test cases for the future scenarios. As was explained in the previous section, the network file of the test case represents a system at steady state, or a "snapshot" based on a converged power flow solution. Thereby, a configuration of the grid with a realistic situation of supply and demand is provided, according to the methodology provided hereafter.

The methodology for building the test cases begins with the existing network and installed capacity in 2020 in Croatia, Portugal, Spain and the UK. The next step was to collect official policy documents (such as ten-year development plans for transmission and distribution, energy strategy) and projections that make possible high-level estimations of generation and consumption of energy up to 2050.

However, a full characterization of the future grid depends on a number of variables that can only be estimated up to a certain point. For example, while policy makers design future scenarios that predict evolution of demand and which generation technologies with how much power will be installed in the

[2]https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/pss-software/pss-e.html

power system in 2050 (as in Chapter 2), it is not possible to know in advance the evolution of the topology (I.e., which power lines and substations will be built) after 2030 – this is in fact a task to be developed within the framework of WP3. Besides, the design of such scenarios with the evolution of topology need to be such that they must allow for the power flow to converge and still be realistic and interesting for the contingencies to be studied in WP4.

For these reasons, in this stage of the project, test cases are built for the existing topology in 2020, which is readily available, and guidelines for designing future scenarios on top of them are presented in the next chapter. The exceptional test cases regarding future scenarios are the ones addressing the Portuguese Transmission grid, which were designed until the year 2050.

During the project, the Consortium expects to deliver most of these test cases to the scientific community, along with additional ones developed in the course of the project, fostering benchmarking, comparison and reproducibility.

The remainder of this deliverable is as follows:

- Chapter 2 presents a set of tables comprising scenarios for the evolution of installed power and expected demand in Portugal, UK and Croatia, along with guidelines for the probable location of generation units. These scenarios are necessary for building test cases concerning 2030 and beyond;
- Chapter 3 presents a methodology for the inclusion of flexibility from Low Voltage (LV) and a tool that allows for flexibility calculation and inclusion in test cases;
- Chapter 4 overviews the twenty-eight test cases developed in the Task 2.3, with a dedicated Section to each of them.

# 2. Power systems demand and generation evolution: 2020-2050

This chapter presents the estimations considered regarding the evolution of power systems up to 2050 taking into account publicly available policy documents with projections of supply and demand from 2020 to 2050.

Each section presents two extreme scenarios: one which follows a business-as-usual scenario, and other that follows a much more ambitious target regarding renewable energy sources integration. It is therefore expected that the real evolution of the power systems will be somewhere in the middle of these two scenarios. The choice of extreme scenarios enables to proceed with a robust network planning, which is envisioned in WP3.

Each section addresses the evolution of both installed power and demand in the following countries: Portugal, UK and Croatia, along with guidelines for placing the generators in the networks. For Spain no data is presented, because test cases only concern the distribution grid (see Chapter 4).

## 2.1 Portugal

The data presented in this section relies on [2], which concerns data until 2040. The data related to 2050 has been linearly extrapolated.

Table 1 and Table 2 address two possible evolutions, with 10 year10-year step, until 2050: one of "active economy", i.e., more trending towards renewables and electrification of the economy, whereas "slow progression" represents a lower demand increase and less renewables in the generation mix.

TABLE 1 - EVOLUTION OF THE PORTUGUESE POWER SYSTEM - ACTIVE ECONOMY [2], WITH OWN PROJECTIONS FOR 2050

| | Technology | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Generation installed capacity [MW] | Coal | 1756 | 0 | 0 | 0 |
| | Natural gas | 3829 | 2839 | 2839 | 2839 |
| | Nuclear | 0 | 0 | 0 | 0 |
| | Hydro - Large | 6388 | 8097 | 8097 | 8097 |
| | Hydro – "P < 30 MW" | 619 | 635 | 635 | 635 |
| | Wind onshore | 5370 | 8901 | 12926 | 16652 |
| | Wind offshore | 25 | 260 | 528 | 776 |
| | Solar (PV, CPV, CSP) | 1078 | 8300 | 13745 | 20255 |
| | Marine | 1 | 70 | 148 | 221 |
| | Other thermal (geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable) | 1697 | 1804 | 1833 | 1860 |
| | Distributed solar PV* | 553 | 1610 | 2157 | 3011 |
| Demand | | 50.844 TWh | 59.429 TWh; 1.69% mean annual growth | 73.017 TWh; 2.29% mean annual growth | 86.640 TWh; 1.87% mean annual growth |

* Represents all micro and mini solar production facilities that are dispersed throughout the country. Its assigned production should be discounted to the total demand.

TABLE 2 - EVOLUTION OF THE PORTUGUESE POWER SYSTEM - SLOW PROGRESSION [2], WITH OWN PROJECTIONS FOR 2050

| | Technology | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Generation installed capacity [MW] | Coal | 1756 | 0 | 0 | 0 |
| | Natural gas | 3829 | 2839 | 2839 | 2839 |
| | Nuclear | 0 | 0 | 0 | 0 |
| | Hydro - Large | 6388 | 8097 | 8097 | 8097 |
| | Hydro – "P < 30 MW" | 619 | 635 | 635 | 635 |
| | Wind onshore | 5370 | 5787 | 6045 | 6409 |
| | Wind offshore | 25 | 150 | 200 | 300 |
| | Solar (PV, CPV, CSP) | 1078 | 6200 | 7550 | 8806 |
| | Marine | 1 | 50 | 105 | 156 |
| | Other thermal (geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable) | 1697 | 1747 | 1747 | 1747 |
| | Distributed solar PV* | 553 | 1610 | 2157 | 3011 |
| Demand | | 50.054 TWh | 53.357 TWh; 0.66% mean annual growth | 60. 398 TWh; 1.32% mean annual growth | 67.405 TWh; 1.16% mean annual growth |

* Represents all micro and mini solar production facilities that are dispersed throughout the country. Its assigned production should be discounted to the total demand.

Scrutinizing both scenarios in more detail, the main differences concern wind and solar power installation. Wind power in the "active economy" scenario is more than the double of the "slow progression" one, and solar power is 2.3 times higher in the former than in the latter. In either case, coal is decommissioned before 2030 while 990 MW of natural gas are decommissioned until 2030, after which it stagnates. Hydro power is also the same for both scenarios, and stagnates before 2030, due to hydropower dams' construction that is on its way. Other renewables are slightly higher in the "active economy" scenario, but nonetheless they represent only 4% of total installed power.

It can be understood from Figure 2 that the total amount of installed power is quite different on both scenarios: in 2030 the "active economy" scenario has already more installed power than the "slow progression" scenario will achieve in 2050. Since this difference comes from decentralized power such as solar and wind, this will necessarily have a significant impact in the planning phase of both transmission and distribution grids, and this fact will impact from the tools developed in the course of the ATTEST project.

Regarding the power demand, a huge variation also exists in both scenarios, even if the mean annual growth of demand apparently presents a small difference, it results in a demand 29% higher in 2050 for the "active economy" scenario.

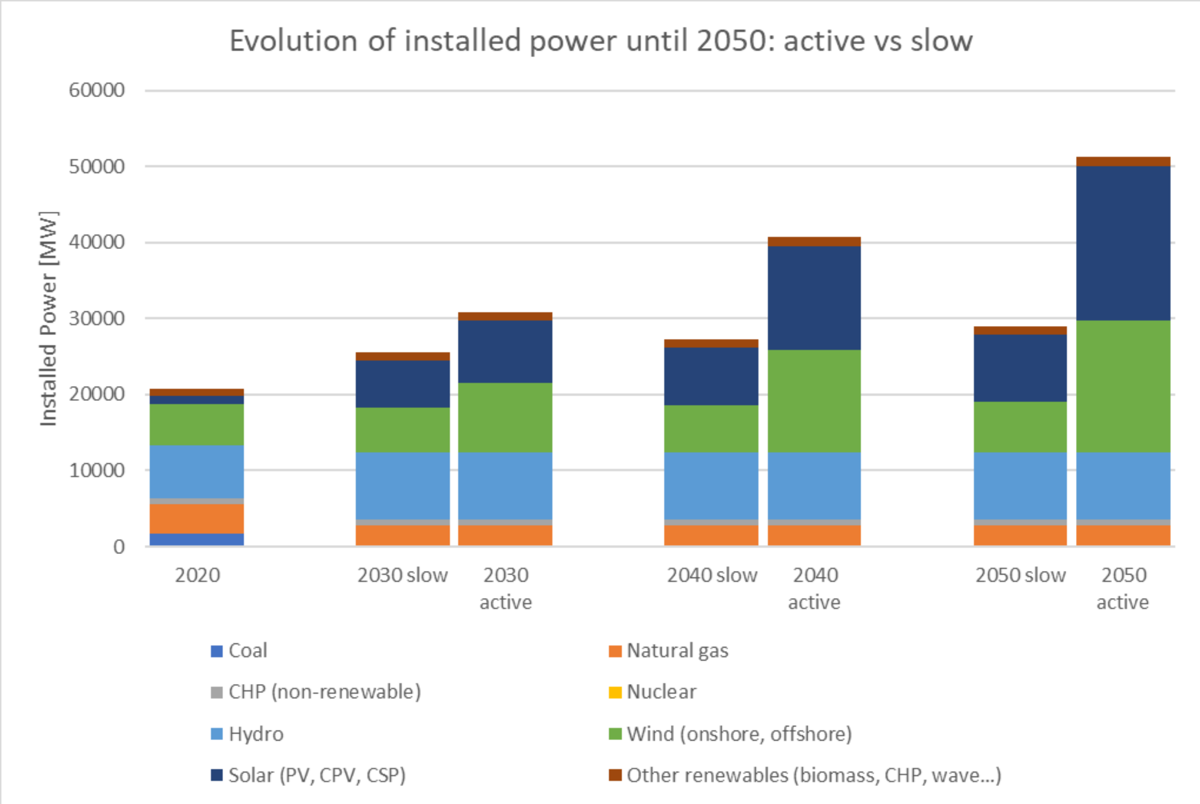



FIGURE 2 - EVOLUTION OF INSTALLED POWER IN PORTUGAL IN TWO SCENARIOS FOR THE YEARS 2020-2050

### 2.1.1 Guidelines for building future test cases

As detailed in the previous section, the main drivers for installed power evolution in Portugal are solar and wind power. The following guidelines were used to build test cases from 2030-2050 presented in Chapter 4.

Solar power can be divided into two components: distributed solar photovoltaics (PV) and solar farms. Distributed solar PV can be equally distributed among residential areas, whereas solar farms will likely be installed in the south and Alentejo region, due to a higher solar irradiation and lower land costs. In fact, from Figure 3, it can be noticed that 41% of the expected power installed in solar farms in 2029 will be in this region.

Although Figure 3 shows several areas, in the scope of the ATTEST project only two areas were considered: the south and Alentejo region (accounts for 41% of the total installed power) and the remaining of the country (accounts for 59% of the total installed power). Thus, the new power to be installed in 2030 and beyond was distributed in two different ways, according to these two areas:

- Within the south and Alentejo region: some of the new power assigned to this area was proportionally distributed according to the installed power of the pre-existing solar power plants. The remaining power was distributed by five new solar power plants, all connected to the Extra High Voltage (EHV) level.
- In the remaining of the country: much of the new power assigned to this area was distributed by eighteen new solar power plants, eight of them connected to the EHV level. The remaining power was equally distributed by all the pre-existing solar power plants.

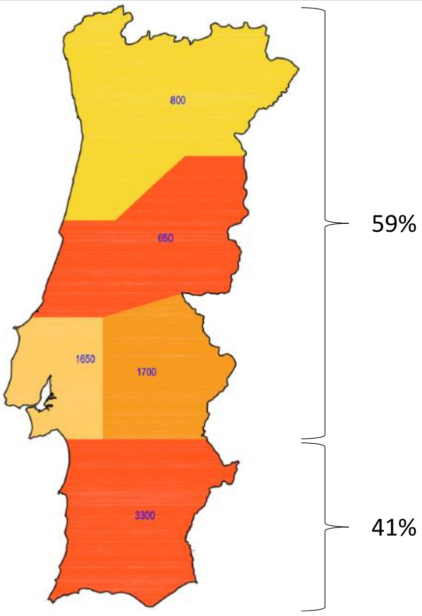



FIGURE 3 - PREDICTION OF THE DISTRIBUTION OF INSTALLED POWER IN SOLAR ENERGY PROJECTS IN THE 2029 HORIZON [3]

In terms of wind power onshore, since facilities in areas with more potential already exist in 2020, it is likely that the installed power increase will happen in these areas, in what is known as “repowering”, i.e., using the same infrastructures and replacing wind turbines by others with higher power rates. In this sense, the new power to be installed in 2030 and beyond was equally distributed by all wind power plants. It is important to state that four new wind farms were considered, two of them connected to 60 kV and the others connected to 220 kV.

The rationale followed for the remaining generation technologies, namely the “small hydro (P < 30 MW)”, the “wind offshore”, the “marine” and the “other thermal” one, was similar to the aforementioned one, i.e., the new power to be installed in 2030 and beyond was equally distributed by the existing generators.

It is worth mentioning that the total installed power to be considered in each test case (i.e., 2030, 2040 and 2050) was determined taking into account the installed power reported in the latest document released by the Portuguese Transmission System Operator (TSO) [4], which refers to 2019, and the percentual evolutions stemmed from Table 1 and Table 2. For this reason, the total installed power considered in each test case (see Chapter 4) may differ from the one shown in Table 1 and Table 2.

Regarding the network infrastructure, the investments envisioned by the Portuguese TSO on the latest development plan for the transmission network [3] were considered, which encompass:

- The commissioning of 10 new power transformers;
- The replacement of 8 existing power transformers;
- The commissioning of 26 new power lines (segments) of 400 kV;
- The commissioning of 8 new power lines (segments) of 220 kV, plus the uprating of 6 existing power lines;
- The commissioning of 18 new power lines/cables (segments) of 150 kV.

It is important to notice that, in some cases, the commissioning of those new power lines involved the decommissioning of the existing ones.

Since the development plan of the transmission network spans over a period of ten years (2020-2029, in this case [3]), the network topology considered in the 2040 and 2050 test cases is the same as the one considered in the 2030 test case.

With regard to particular Portuguese distribution networks presented in detail later on this document (see Sections 4.8 to 4.12), the Portuguese DSO provided specific values of load growth considering the evolution of consumption in the regions of these segments of the grid up to 2050. This information can be considered when studying future scenarios.

The load growth is represented in a homothetic manner, I.e., being equally distributed along the nodes. For each Portuguese distribution case as in 2020, the load increase rates for 2030, 2040 and 2050 are also stated (see Section 4.8 to 4.12).

## 2.2 UK

The data collected in this section refers and builds upon [5], from which two extreme scenarios were collected. Table 3 and Table 4 present these scenarios: in the original document the scenario with more electrification and renewable integration is called "Two degrees" and the more conservative scenario is called "Steady progression". In order to keep the nomenclature consistent with all the cases in this deliverable we renamed the "Steady progression" as "Slow progression" and the "Two degrees" as "Active Economy", and we refer to [5] for more details about assumptions of each.

TABLE 3 - EVOLUTION OF UK GENERATION MIX AND DEMAND – SLOW PROGRESSION, LABELLED "STEADY PROGRESSION" IN [5]

| | Technology | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Generation installed capacity [MW] | CCGT | 28606 | 30595 | 28589 | 22170 |
| | OCGT | 1801 | 1665 | 2563 | 2563 |
| | CHP (Biomass, Gas, Coal, ACT, Anaerobic Digestion, Biogas, Geothermal, Sewage, Biofuel and Waste) | 5046 | 5731 | 4705 | 5737 |
| | Coal | 10199 | 0 | 0 | 0 |
| | Oil and AGT | 552 | 173 | 173 | 115 |
| | Nuclear | 9229 | 7036 | 9566 | 9566 |
| | Wind Onshore | 12435 | 17055 | 17813 | 18170 |
| | Wind Offshore | 8542 | 26050 | 36574 | 37693 |
| | Hydro | 1817 | 1890 | 1896 | 1900 |
| | Pumped Storage | 2744 | 2744 | 4454 | 5064 |
| | Unspecified (Biomass, Gas, Tidal, Wave, ACT, Anaerobic Digestion, Landfill Gas, Sewage, Biofuel, Diesel, Solar PV, Waste and CCS) | 22455 | 27109 | 34334 | 40792 |
| Demand | | 312.2 TWh | 326.7 TWh; 0.45% annual growth | 363.8 TWh; 1.08% annual growth | 409.7 TWh; 1.2% annual growth |

TABLE 4 - EVOLUTION OF UK GENERATION MIX AND DEMAND - ACTIVE ECONOMY, LABELLED "TWO DEGREES" IN [5]

| | Technology | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Generation installed capacity [MW] | CCGT | 28606 | 21051 | 9709 | 4074 |
| | OCGT | 1801 | 894 | 894 | 894 |
| | CHP (Biomass, Gas, Coal, ACT, Anaerobic Digestion, Biogas, Geothermal, Sewage, Biofuel and Waste) | 5046 | 6286 | 5623 | 6914 |
| | Coal | 10199 | 0 | 0 | 0 |
| | Oil and AGT | 552 | 190 | 132 | 92 |
| | Nuclear | 9229 | 4556 | 12206 | 16606 |
| | Wind Onshore | 12435 | 20445 | 22732 | 24565 |
| | Wind Offshore | 8542 | 33620 | 45993 | 54093 |
| | Hydro | 1817 | 1926 | 1958 | 1989 |
| | Pumped Storage | 2744 | 5054 | 5214 | 5814 |
| | Unspecified (Biomass, Gas, Tidal, Wave, ACT, Anaerobic Digestion, Landfill Gas, Sewage, Biofuel, Diesel, Solar PV, Waste and CCS) | 22455 | 36845 | 63665 | 66589 |
| Demand | | 312.2 TWh | 327 TWh; 0.8% annual growth | 409 TWh; 1.6% annual growth | 451 TWh; 1% annual growth |

Comparing both scenarios, some differences exist especially if we consider the 2050 scenarios. For instance, the Demand is 10% higher in active economy scenario, which in turn reflects in 27% higher installed power in this scenario in 2050. This difference is largely driven by wind power: onshore and offshore have more 23 GW in the "active economy", traded by roughly the same amount of installed natural gas. Nuclear power is roughly the same in the "slow progression" in 2020 and 2050, whereas in "active economy" it almost doubles, increasing more than 7 GW. Under the umbrella of "unspecified" (Biomass, Gas, Tidal, Wave, ACT, Anaerobic Digestion, Landfill Gas, Sewage, Biofuel, Diesel, Solar PV, Waste and CCS) there is a significant difference: in "active economy" they represent 67 GW whereas in slow progression this figure is 40 GW: this difference is largely driven by solar power (26 GW in the latter versus 41 GW in the former).

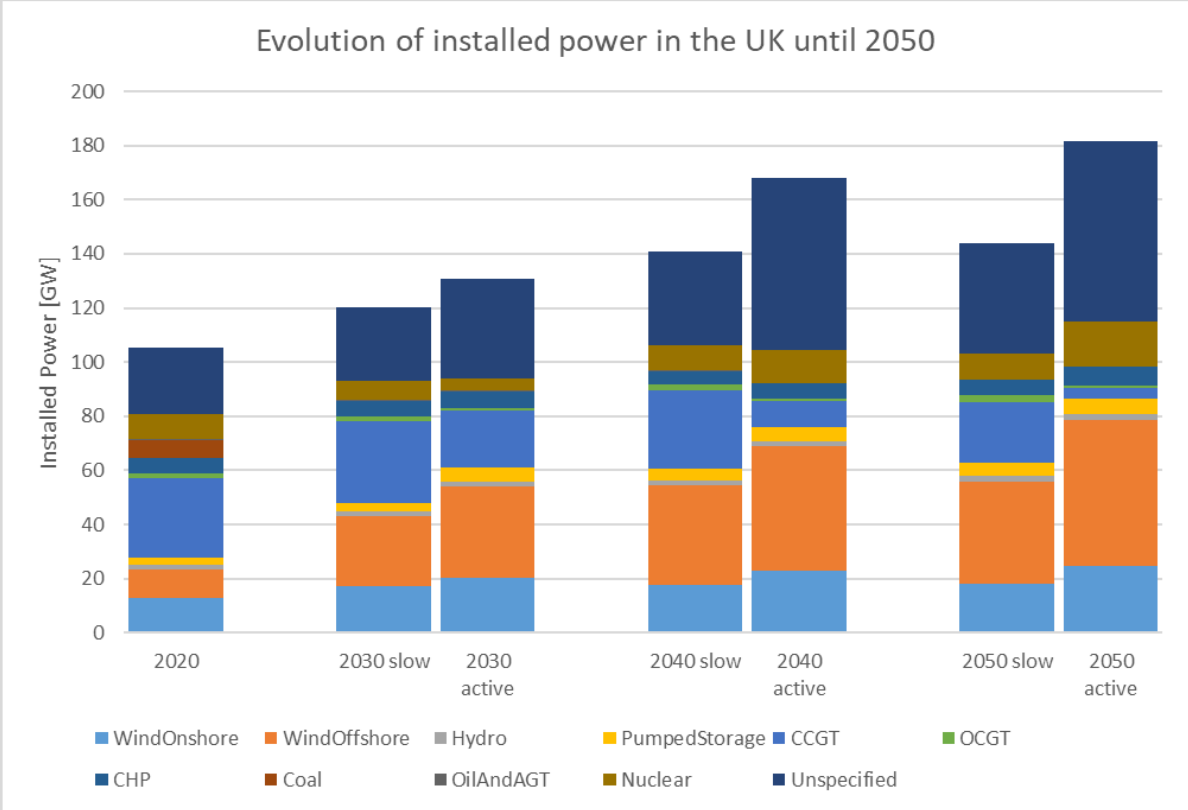



FIGURE 4 - EVOLUTION OF INSTALLED POWER IN THE UK UNTIL 2050 IN TWO SCENARIOS

### 2.2.1 Guidelines for building future test cases

The UK's Future Energy Scenarios (FES) documentation [5] includes the expected location of new installed generation capacity[3]. The power generation technologies that are detailed in the FES include:

- CHP: Dedicated installed capacity data for non-renewable units divided in the following categories: capacities greater than 1 MW, lower than 1 MW, as well as micro-CHP for domestic applications.
- Renewable engines: Dedicated installed capacity data landfill, Gas, Sewage, Gas and Biogas.
- Non-renewable engines (non-CHP): Diesel and gas units, Open Cycle Gas Turbines and Closed Cycle Gas Turbines.
- Fuel Cells.
- Biomass and energy crops.
- Water incineration.
- Solar generation: Dedicated installed capacity data large and small units.
- Wind: Offshore, and onshore with capacities greater than 1 MW and lower than 1 MW.
- Marine: Aggregated installed capacities for tidal stream, wave power and tidal Lagoon.
- Hydroelectricity: Excluding pumped hydro.
- Geothermal.
- Nuclear.

[3] In https://www.nationalgrideso.com/future-energy/future-energy-scenarios the most updated version of this documentation can be consulted. Detailed tables include information for each area and each technology until 2050

The information is provided as annual installed capacities from 2019 to 2050 for all scenarios. The information is provided at the Grid Supply Point levels (i.e., interconnections between Transmission and distribution networks) across different areas of the UK (See Figure 5).

- Each (Distribution Network Operator) DNO area: Western Power Distribution (WPD), Scottish and Southern Electricity Networks (SSEN), United Kingdom Power Network (UKPN), SP Energy Distribution (SPD), Northern Powergrid (NPG) and Electricity North West (ENWL).
- UK Regions: East Midlands, Eastern England, London, Merseyside and Northern Wales, North Eastern England, North Western England, Northern Scotland, South Eastern England, South Western England, Southern England, Southern Scotland, Southern Wales, and West Midlands, and Yorkshire.

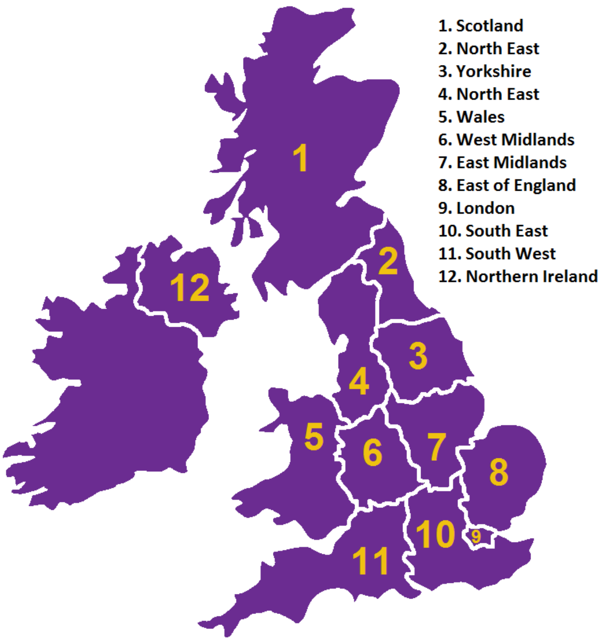



FIGURE 5 - REGIONS IN THE UK.

A few examples of the forecasted annual installed capacities of different generation technologies (I.e., solar and wind) in different UK regions are shown in Figure 6 (Solar – Active Economy scenario), Figure 7 (Solar – Slow Progression scenario), Figure 8 (Offshore wind – Active Economy scenario) and Figure 9 (Offshore wind – Slow Progression scenario).

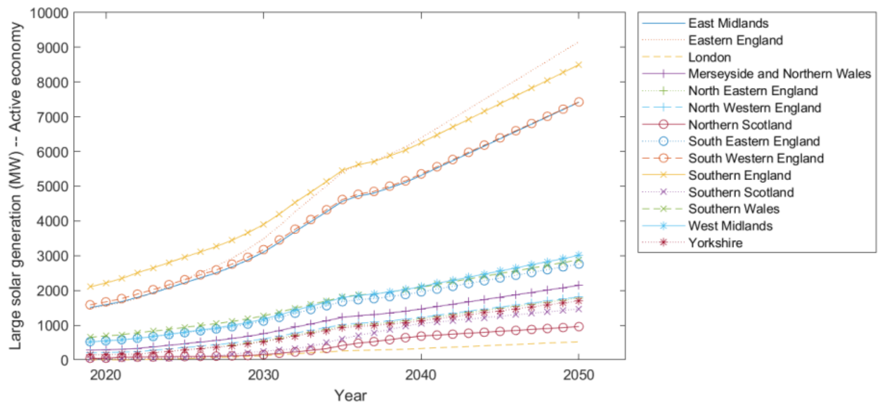



FIGURE 6 - ANNUAL INSTALLED CAPACITIES OF LARGE SOLAR GENERATION UNDER THE ACTIVE ECONOMY SCENARIO IN THE UK.

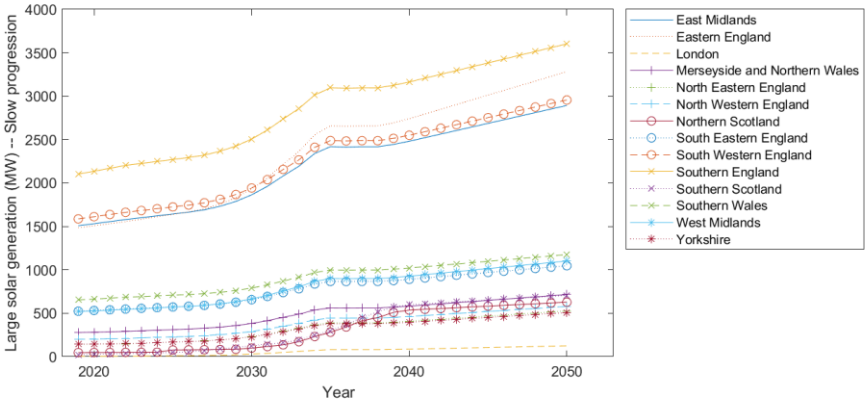



FIGURE 7 - ANNUAL INSTALLED CAPACITIES OF LARGE SOLAR GENERATION UNDER THE SLOW PROGRESSION SCENARIO IN THE UK.

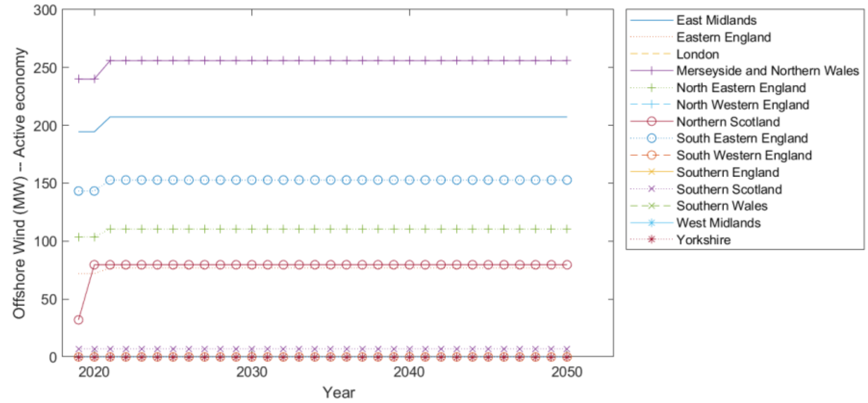



FIGURE 8 - ANNUAL INSTALLED CAPACITIES OF OFFSHORE WIND GENERATION UNDER THE ACTIVE ECONOMY SCENARIO IN THE UK.

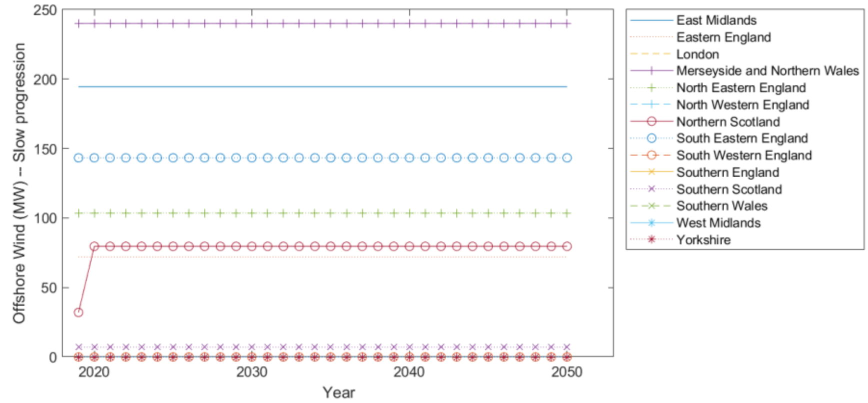



FIGURE 9 - ANNUAL INSTALLED CAPACITIES OF OFFSHORE WIND GENERATION UNDER THE SLOW PROGRESSION SCENARIO IN THE UK.

## 2.3 Croatia

The data collected in this section refers to [6], which concerns data until 2050.

Table 5 and Table 6 address two possible evolutions until 2050: one of "active economy" (called "S1" in [6]), i.e., more trending towards renewables and electrification of the economy, whereas "slow progression" (called "S0" in [6]) represents a lower demand increase and less renewables in the mix.

In this section, "Demand" refers to the sum of generation and exchange (i.e., generation plus import minus export)

TABLE 5 - EVOLUTION OF THE CROATIAN POWER SYSTEM - ACTIVE ECONOMY ("S1") [6], WITH INTERPOLATIONS FOR STORAGE CAPACITY IN 2040

| | Technology | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Generation installed capacity [MW] | Coal | 332 | 192 | 0 | 0 |
| | Natural gas | 743 | 1048 | 1290 | 1970 |
| | Nuclear | 348 | 348 | 348 | 0 |
| | Hydro | 2140 (4% in DG) | 2686 (6% in DG) | 2817 (6% in DG) | 3174 (8% in DG) |
| | Wind (onshore, offshore) | 738 (9% in DG) | 1634 (11% in DG) | 2634 (14% in DG) | 3737 (18% in DG) |
| | Solar (PV, CPV, CSP) | 85 (100% in DG) | 1039 (98% in DG) | 2514 (96% in DG) | 3815 (95% in DG) |
| | Other renewables (biomass, geothermal, others) | 167 (100% in DG) | 165 (80% in DG) | 194 (80% in DG) | 205 (80% in DG) |
| | Oil (including mixed oil and gas) | 937 | 0 | 0 | 0 |
| Storage capacity [MW] | | 0 | 100 | 250 | 400 |
| Demand | | 16.93 TWh | 19.9 TWh; 1.6% annual growth | 22.1 TWh; 1.1% annual growth | 28.5 TWh; 2.6% annual growth |

TABLE 6 - EVOLUTION OF THE CROATIAN POWER SYSTEM – SLOW PROGRESSION ("S0") [6], WITH INTERPOLATIONS FOR STORAGE CAPACITY IN 2040

| | Technology | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Generation installed capacity [MW] | Coal | 332 | 192 | 0 | 0 |
| | Natural gas | 743 | 1048 | 1290 | 1310 |
| | Nuclear | 348 | 348 | 348 | 0 |
| | Hydro | 2140 (4% in DG) | 2546 (6% in DG) | 2676 (7% in DG) | 2807 (8% in DG) |
| | Wind (onshore, offshore) | 738 (9% in DG) | 1184 (11% in DG) | 1684 (15% in DG) | 2162 (18% in DG) |
| | Solar (PV, CPV, CSP) | 85 (100% in DG) | 507 (98% in DG) | 1245 (97% in DG) | 1914 (95% in DG) |
| | Other renewables (biomass, geothermal, others) | 167 (100% in DG) | 174 (80% in DG) | 194 (80% in DG) | 155 (80% in DG) |
| | Oil (including mixed oil and gas) | 937 | 0 | 0 | 0 |
| Storage capacity [MW] | | 0 | 100 | 200 | 300 |
| Demand | | 16.93 TWh | 19,4 TWh; 1.35% annual growth | 20.7 TWh; 0.65% annual growth | 22,1 TWh; 0.7% annual growth |

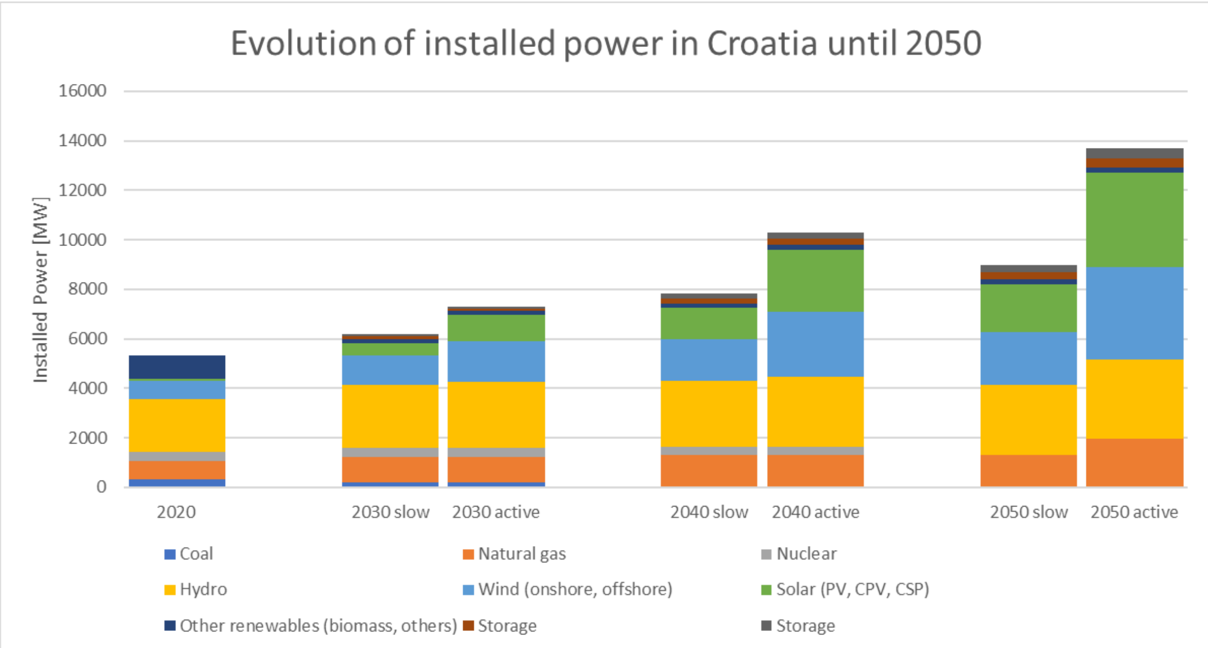



FIGURE 10 – SCENARIOS FOR EVOLUTION OF INSTALLED POWER IN CROATIA UNTIL 2050

Comparing both scenarios, substantial differences exist from 2030 to 2050. For instance, the Demand is 28.5% higher in active economy scenario, which in turn reflects in 65% higher installed power in this scenario in 2050. This difference is largely driven by wind power and solar power: onshore and offshore have more 1575 MW in the "active economy"; for solar power the difference is 1900 MW. Natural gas has more 660 MW in the "active economy" scenario.

### 2.3.1 Guidelines for building future test cases

The ten-year development plan [7], which HEP ODS is obliged to submit to the Croatian Energy Regulatory Agency will serve as the main guideline from which future scenarios for distribution network test cases will be derived. The development plan provides detailed investment list per asset for next three-year period, while providing estimates for investment for the rest of the ten-year period. Figure 11 shows the structure of future investments for HEP ODS. As can be seen the highest amount of investment is related to creating conditions for Distributed Generation (DG) connection to the grid.

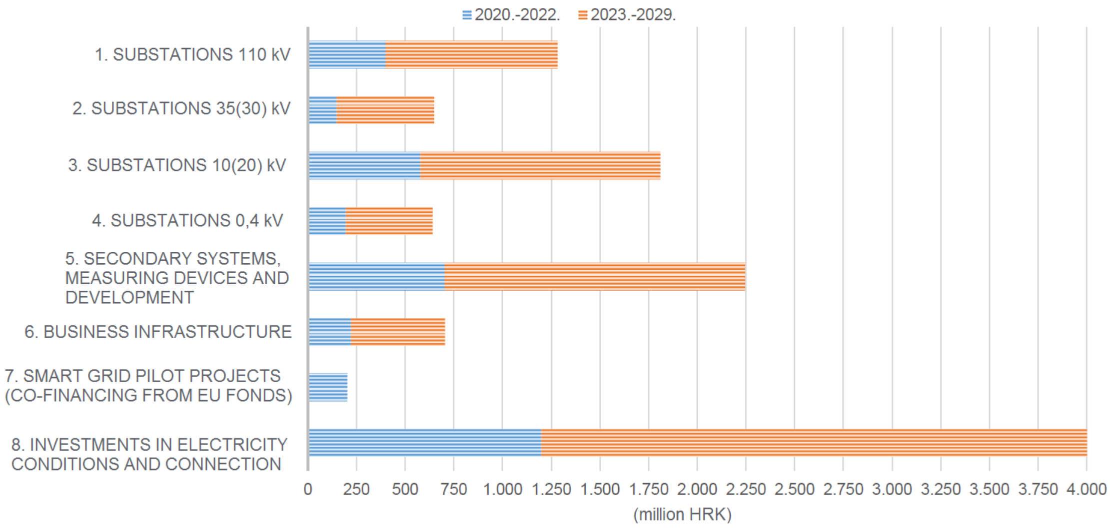



FIGURE 11 - BREAKDOWN OF HEP ODS'S INVESTMENT IN NEXT TEN-YEAR PERIOD

According to the document provided the main drivers that influence the investment planning are:

- Increase/decrease of power consumption;
- Characterization of the power consumption;
- The current state of assets;
- The amount of DG being connected to the grid.

For the next three-year period, the scenarios developed regarding the provided distribution network test cases will be based on development plans as well as connection request for distribution generation connection which will enable specifying detailed and realistic scenarios.

The ten-year development plan [8], which HOPS is obliged to submit to the Croatian Energy Regulatory Agency, will serve as the main guideline from which future scenarios for transmission network test cases will be derived. The development plan provides detailed investment list per asset for next one year and three-year period, while providing estimates for investment for the rest of the ten-year period.

In the ten-year period, there are quite a number of requests for connection of new generation capacities to the transmission network. It is important to emphasize that the number of connected power plants in a ten-year period primarily depends on investors and the preparation of the necessary documentation for the construction of the transmission network connection.

In the next three-year period, it is planned to build and connect a new power plant with a capacity of 150 MW in Zagreb, while in the ten-year period a new 2500 MW can be expected.

As far as wind power plants are concerned, a total of 745 MW can be connected to the transmission network at the end of the next three-year period, while 870 MW of wind farms could be connected to the transmission network by the end of the planned ten-year period. The largest number of wind farms will be connected in the south or northwest of Croatia.

In the next ten years, a significant number of requests were received for the connection of solar power plants to the transmission network with a total capacity of over 800 MW. The largest number of solar power plants will be connected in the south or northwest part of Croatia.

Regarding the revitalization and increase of the approved connection capacity of the existing hydropower plants, 16MW is expected in the next three-year period, while around 60MW is expected in the ten-year period.

Within the planned ten-year period, individual production units as thermal power plants as thermal power plants will become obsolete and / or uneconomical and will go out of operation.

# 3. Inclusion of flexibility providers

Flexibility can be defined as the modification of generation and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system [9]. In general, flexible generation is used to adjust production to consumption. Alternatively, consumers can adjust their load to balance the system through Demand Response (DR). DR could be understood as the change in electric use patterns of end-users by means of price signals or incentive payments.

In this deliverable we refer to “flexibility” in terms of active power. It should be noted that the flexibility bands mentioned in this chapter were calculated disregarding whether the activation of such flexibility would violate grid constraints.

The power systems of the future will have more flexibility providers than the present ones, for many reasons, mostly related with the growing integration of distributed energy resources and the possibility of provision of ancillary services by prosumers that are connected directly to the distribution grid, including on LV. Prosumers can be flexible due to the mix of onsite generation (e.g., PV) and controllable loads such as thermal loads (e.g., HVAC systems), washing machines, electric vehicles (EV), or other loads that can be shifted to periods that are more attractive in terms of electricity pricing [10]. Flexibility can be used to solve problems in distribution networks and, through a certain degree of upscaling, to the transmission network through the provision of ancillary services, as envisioned in WP4. For example, in the tools to be developed in task T4.2, flexibility could be used to solve a voltage problem that occurs in the distribution grid. Although the flexibility is present in the distribution side, it can be made available to the TSO, through the TSO-DSO coordination mechanism defined in task T2.4 and solve for instance a congestion problem using the tools that will be developed in task T4.5.

The inclusion of flexibility providers connected to the grid in LV was addressed in ATTEST taking into account two aspects. On one hand, the project addresses explicitly only voltage levels downstream to Medium Voltage (MV). On the other hand, the main focus of the project is not to define an overly realistic model of the flexibility, but rather how TSOs and DSOs can exploit this resource in order to solve issues on their grids. As a result, it was decided to apply methodologies with proven results that had already been tested by INESC TEC.

The methodology is briefly described in the remainder of this chapter: for a more detailed overview consult the published papers [11] [12].

## 3.1 Methodology to aggregate flexibility

The inclusion of active power flexibility providers from LV has been achieved through a bottom-up approach. Given that in ATTEST the lowest voltage addressed is MV (see Chapter 4), and some flexibility providers are connected to LV, this implies that some form of aggregation is necessary.

In fact, even if one does not consider flexibility, the test cases already possess a form of aggregation: a given (inflexible) MV load in a node results from the aggregation of loads of all consumers from the LV feeders connected to that node. Conversely, the flexibility provided at a given node needs to represent the aggregated flexibility of individual consumers in those feeders. The fact that the flexibility is aggregated per node makes it possible to use the market simulator developed in task T2.6. Task leaders will then be able to use the flexibility present in a given node of the network, or on every node if necessary.

The bottom-up approach follows the principle illustrated in Figure 12. Taking the point of view of one MV node, aggregation of all LV feeders connected to this grid enables the computation of the flexibility of that specific node. In the same way, taking the point of view of one HV node, one aggregates the flexibility of all MV feeders from that HV node and therefore computes the flexibility of that one node.

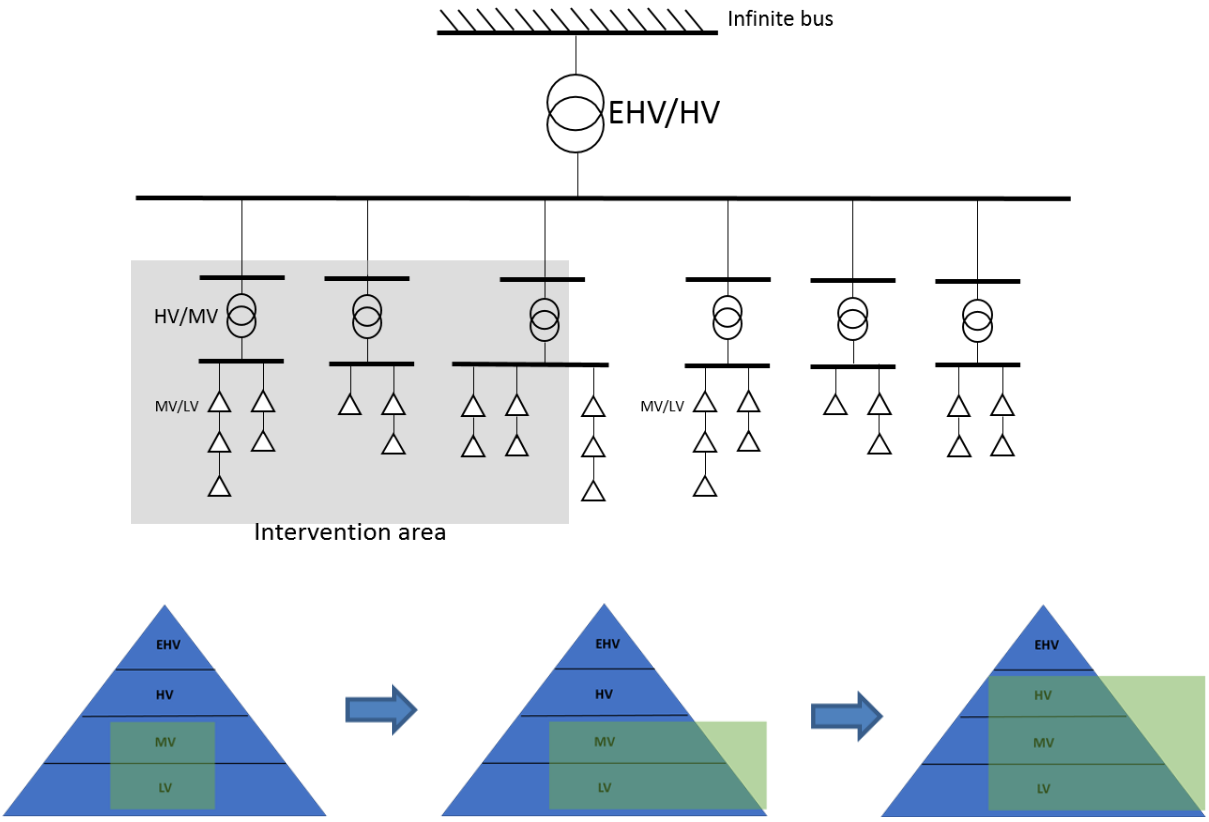



FIGURE 12 - BOTTOM-UP APPROACH FOR FLEXIBILITY COMPUTATION [11]

One of the simplest ways of representing flexibility is through an active power band: at a given time during the day there is a value which is an expected value for load, and at the same time there is a corresponding “upward” and a “downward” value for the load (as in Figure 13). The usefulness of knowing the value of the upward band can be explained with a simple example: consider there is an outage in a part of the grid (e.g., due to a disturbance caused by severe weather), that requires more power to be injected elsewhere in the grid in order to compensate for the loss of generation. For this reason, there is the need to know how much consumption is possible to increase “instantly” in a given part of the grid. The system operator can then activate that flexibility (e.g., using a generator with an upward reserve margin that is therefore able to provide energy to the grid, thus substituting the loss of generation).

A generic load diagram with flexibility band in a grid node for one day is shown in Figure 13.

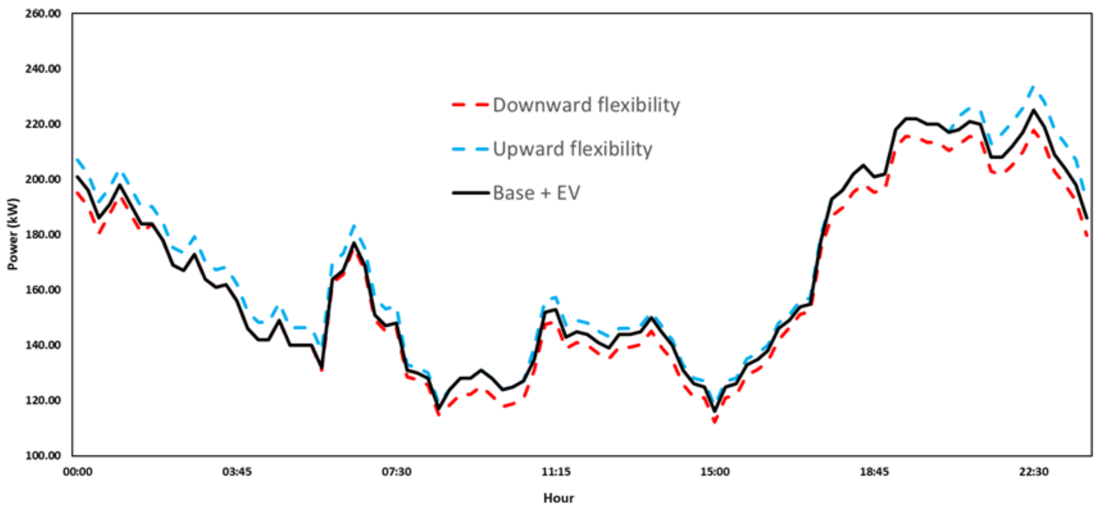



FIGURE 13 - FLEXIBILITY BAND (ADAPTED FROM [11])

An intensive data collection was undertaken in the survey for the Portuguese case [11] regarding aggregation at LV level. The main steps necessary to achieve the flexibility profile of a given node are as follows:

1. Collection of MV/LV secondary substations load diagram;
    a. The data can be obtained from the DSO, which measures load on substations;
    b. It is necessary to estimate the number of residential users vs. service users for a given feeder, given that residential and service loads are from a different nature;
    c. Assumptions regarding number of dual-tariff users;
    d. Assumptions regarding adherence to DR;
    e. Assumptions regarding number of EVs;
2. Creation of annual load profiles for appliances
    a. It is necessary to collect statistics from the country regarding energy use of both residential and service customers;
    b. Necessary assumptions: lighting (according to daylight saving days), electric water heaters and other heaters (according to season), washing and drying machines, dishwashers (according to dual tariffs), HVAC profile, among others;
    c. This step yields load profiles for the appliances as represented in Figure 14 and Figure 15;
3. Disaggregation of secondary substations load per type of device
    a. Taking the data obtained from steps 1 and 2, a match between the total load and daily profiles is performed using the breakdown of electricity consumption according to the percentages presented in Figure 16 and Figure 17;
4. Computation of node flexibility
    a. Assign categories to loads: *controllable* loads, whose power consumption can be increased or decreased by a given percentage (e.g., heating); *shiftable* loads, that can be reduced by a certain percentage in peak hours, being the respective energy shifted to low consumption periods (e.g., washing machine); *non – Controllable* loads, loads with fixed profiles (e.g., oven).

b. Compute flexibility for a given period using the expression:
$T_t = EV_t + R_t + S_t$
where $T_t$ is total flexibility in the period, $EVt$ is EV flexibility, $R_t$ is the residential flexibility and $S_t$ is the services flexibility. We again refer to Figure 13 for a representative result to be obtained.

Figure 14 and Figure 15 show the load profiles of each appliance, after normalization, for the residential and services sectors in a specific day of winter. Figure 16 and Figure 17 present the disaggregation of energy use in Portugal also for residential and services sectors, respectively.

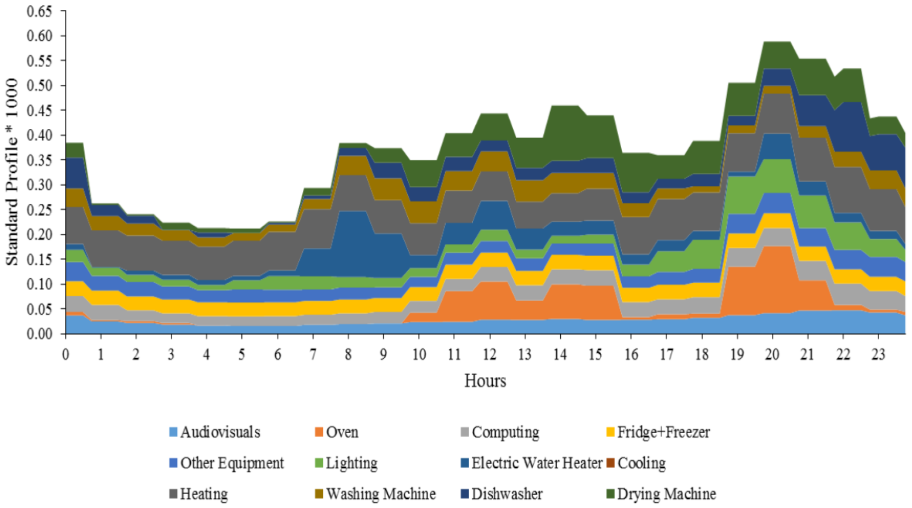



FIGURE 14 - NORMALIZED HOUSEHOLD LOAD DIAGRAM.

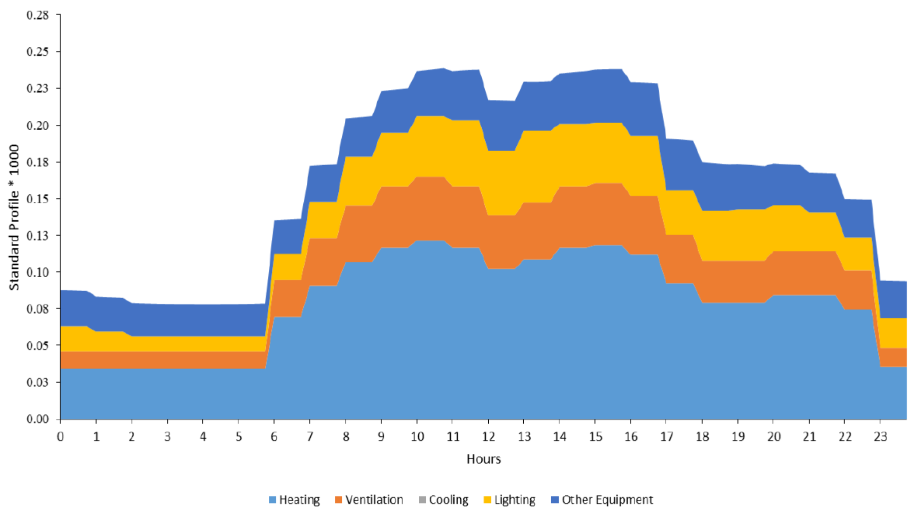



FIGURE 15 - NORMALIZED ENERGY SERVICES LOAD DIAGRAM.

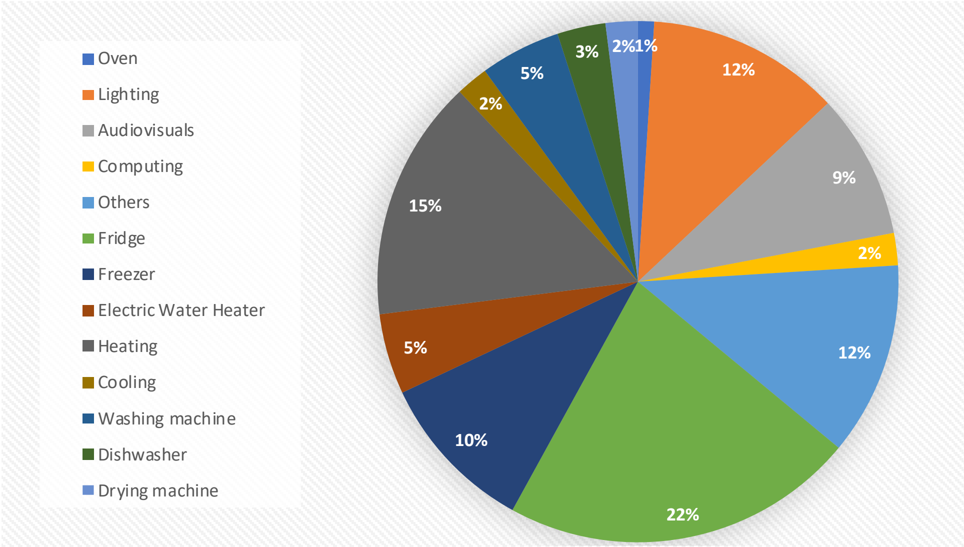



FIGURE 16 - ENERGY USE OF RESIDENTIAL CONSUMERS IN PORTUGAL

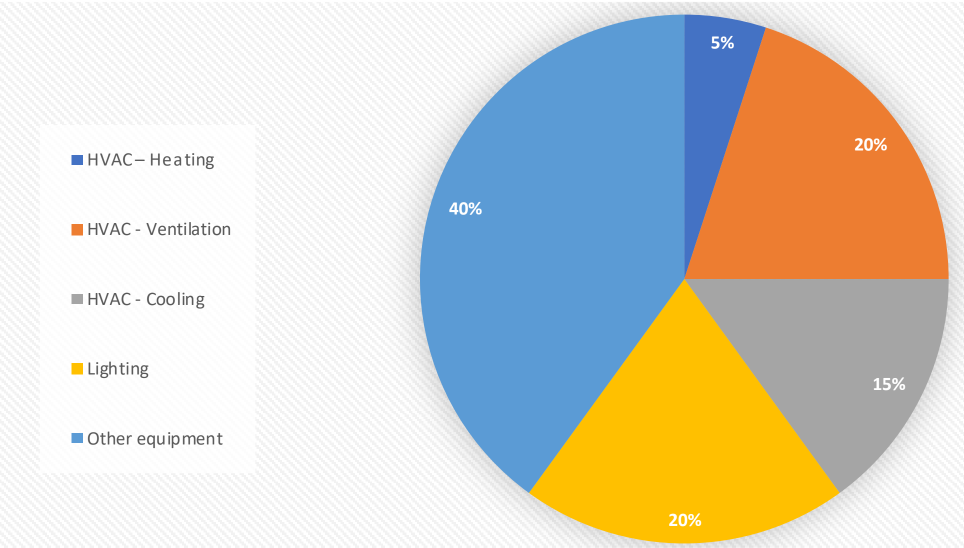



FIGURE 17 - ENERGY USE OF SERVICE CONSUMERS IN PORTUGAL

The methodology is fed by several arguments related with the state of DR adoption in a specific country for a given year. These inputs can be selected from the data collection and can be adapted for the circumstances of each country.

As it will be shown in Section 3.3, a tool capable of estimating automatically the amount of flexibility within these terms, is provided along with the test cases. That way, the volatility of the assumptions used as inputs (especially for distant years) is remedied by the adjustment of these parameters whenever required. As an example, Table 7 provides such parameters stipulated for the purpose of test cases conception of Portugal, UK and Croatia. For the UK case, two scenarios were considered: Slow progression (UK1) and Two degrees (UK2). Also, the number of customers and the peak power of a typical load were considered.

TABLE 7 - INPUTS OF FLEXIBILITY USED FOR PORTUGUESE AND UK CASES UP TO 2050.

| Inputs | 2020 | | | | 2030 | | | | 2040 | | | | 2050 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PT | UK1 | UK2 | CRO | PT | UK1 | UK2 | CRO | PT | UK1 | UK2 | CRO | PT | UK1 | UK2 | CRO |
| EV rate (%) | 0 | 0.7 | 1.2 | 0 | 10 | 6 | 30 | 5 | 22 | 44.9 | 90.2 | 16 | 50 | 88.3 | 96.9 | 40 |
| DR – residential adherence (%) | 3 | 0 | 0 | 0 | 20 | 1.5 | 1.9 | 10 | 40 | 2.9 | 2.7 | 15 | 60 | 3.2 | 2.9 | 25 |
| DR – services adherence (%) | 3 | 5.2 | 5.3 | 0.2 | 25 | 6.9 | 17.6 | 8 | 40 | 10.3 | 28.8 | 15 | 50 | 11.7 | 29.1 | 30 |
| Dual tariff (%) | 25 | 0.4 | 1.3 | 35 | 25 | 6.4 | 34.6 | 60 | 25 | 34.9 | 82.8 | 70 | 25 | 54.3 | 82.8 | 75 |

## 3.2 Numerical results

Some numerical results using the outlined methodology are presented for nodes in a Portuguese distribution grid (introduced in Section 4.11). Figure 18 shows an example of the flexibility expressed in form of bands for a residential load in 2050 in a winter day, while Figure 19 presents the analogous result for a services load. In this particular year and considering the Portuguese case, it was assumed that the rate of EVs corresponds to 50 % of the total fleet. Besides, the share of DR from residential side is 60% while this value for the case of DR adherence by services is 50%. The number of clients from households that represent a typical LV load is 178 while the same number from services is 48.

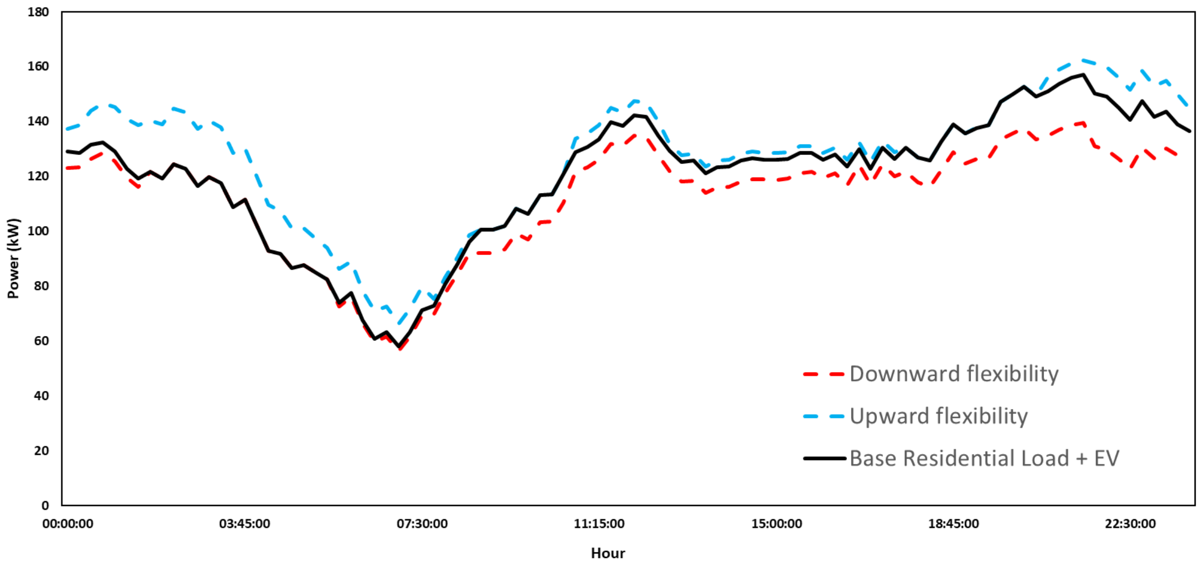



FIGURE 18 - FLEXIBILITY IN RESIDENTIAL NODE IN PORTUGUESE DISTRIBUTION GRID IN 2050.

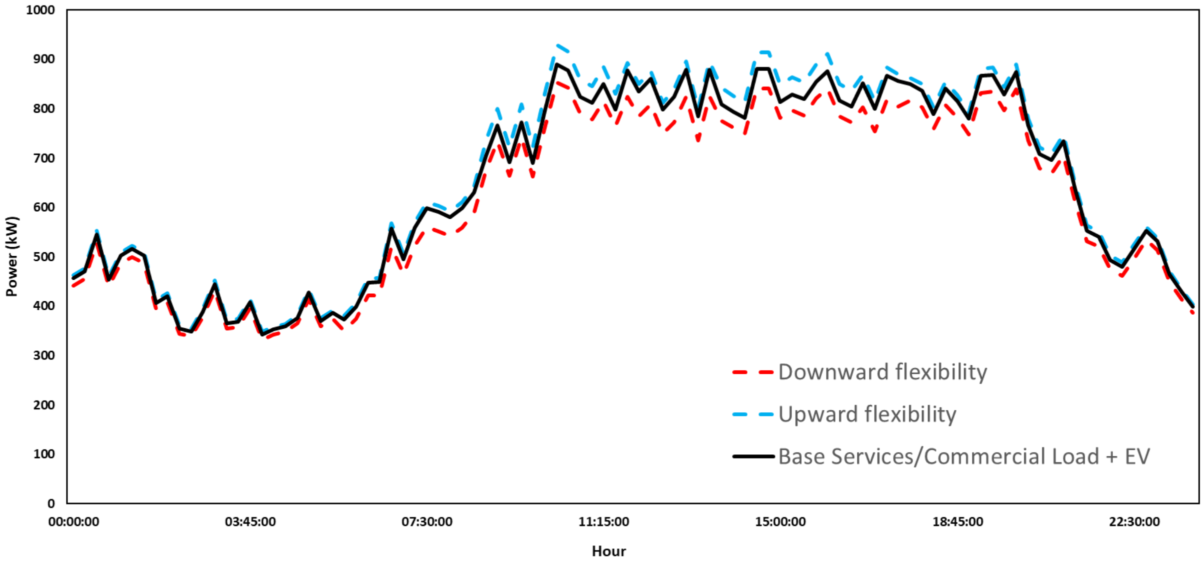



FIGURE 19 - FLEXIBILITY IN SERVICES NODE IN PORTUGUESE DISTRIBUTION GRID IN 2050.

## 3.3 Flexibility calculation tool

The process of flexibility aggregation through a bottom-up approach involves a detailed knowledge of the distribution network, namely the topology of adjacent networks that are connected to the same upstream transmission node. For this reason, while the methodology described in Section 3.1 yields the results presented in Section 3.2, in order to allow a more expedite and higher-level aggregation, it was necessary to define a simple set of rules to improve the computation time of flexibility bands in a given node, while still retaining the possibility of differentiating between nodes. This is useful because, for instance, a rural node will have a distinct flexibility profile from an urban node.

Therefore, the flexibility, as seen from the transmission nodes, was calculated considering four main steps:

- Aggregate the total amount of flexibility that LV loads of three types of distribution networks (Urban, semi-urban and rural) can provide;
- Calculate the hourly percentages of flexible load;
- Assume that 40% of distribution networks connected to each substation are of an urban type, 40% are of a semi-urban type and the remaining 20% are of a rural type;
- Obtain the flexibility for transmission nodes through a proportion between the load of the transmission node and the combination of the three types of distribution networks consumption.

Either LV flexibility or flexibility aggregated at higher voltage levels are calculated independently from the consequences of its mobilization on the grid constraints. This means that the results express the availability of the flexible resources to provide flexibility, but do not examine the impact of its activation.

The defined flexibility bands in Figure 20 and Figure 21 are valid for the Portuguese Transmission network (PT_Tx_2020 in Section 4.1). It should be noted that the values are expressed in percentage of load in the node, and are as follows:

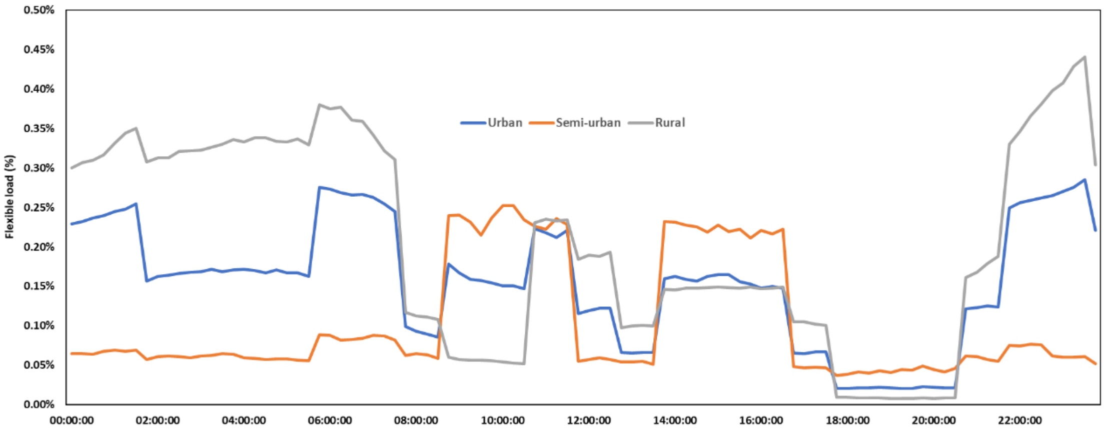



FIGURE 20 - UPWARD FLEXIBILITY BAND AT TRANSMISSION LEVEL ACCORDING TO NODE CLASSIFICATION.

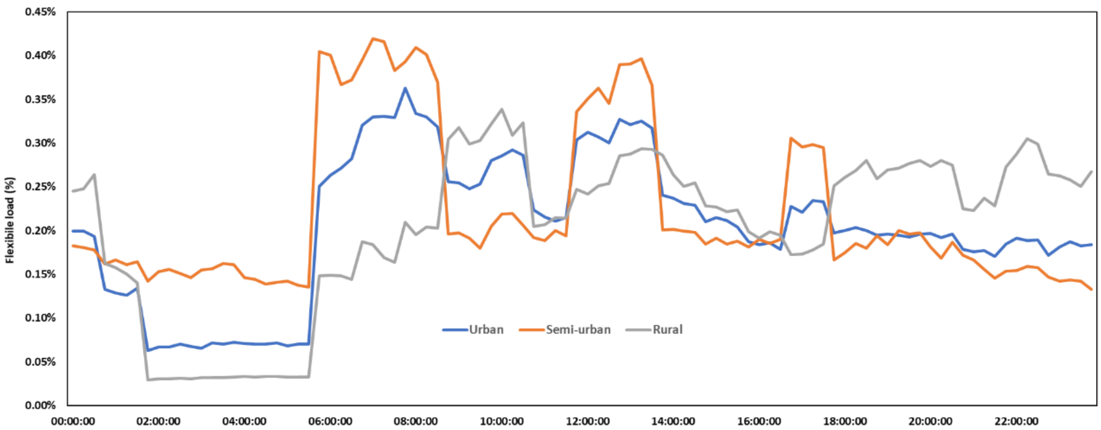



FIGURE 21 - DOWNWARD FLEXIBILITY AT TRANSMISSION LEVEL ACCORDING TO NODE CLASSIFICATION.

In order to support the calculation of the flexibility band for the different test cases, a basic tool was developed in a spreadsheet that allows computing the flexibility at LV nodes automatically by changing some external parameters. The conceptual idea for this is described in the previous sections and the outcomes obtained through it help to produce the illustrative results presented in Figure 18, Figure 19, Figure 20 and Figure 21. The key features of the tool are described in the following paragraphs.

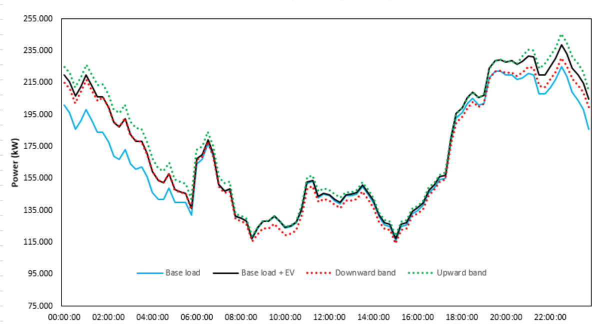
The file has three spreadsheets, one to introduce the necessary inputs and two to present the results. In the first spreadsheet (*Inputs*), the user should choose the external parameters related with the assumptions associated to the study case, namely:

- EV rate (%);
- Share of DR adherence (residential) (%);
- Share of DR adherence (Commerce and services) (%);
- Share of clients with dual tariffs (%);
- Average consumption per EV (kWh);
- Number of household customers connected to public secondary substations;
- Number of services clients connected to public secondary substations;

- Number of services customers connected to private (dedicated) secondary substations.

In addition, in the same spreadsheet, the user should put the values of the typical load(s) for each interval of 15 minutes of a day. Some internal rules linked with the methodology differentiates seasons of the year (Autumn, Winter, Spring and Summer), types of day (Business day, Saturday, Sunday) and typical load categories (residential or services). Therefore, there are specific columns where to place the respective values in order to carry an adequate calculation. Figure 22 illustrates part of the first spreadsheet.

| | Inputs (assumptions) | |
|---|---|---|
| 2 | EV rate (%) | 25% |
| 3 | Share of Demand response adherence (residential) % | 25% |
| 4 | Share of Demand response adherence (services) % | 25% |
| 5 | Share of dual tariff (residential) | 20% |
| 6 | Consumption per EV (kWh) | 15 |
| 7 | | |
| 8 | Typical load (residential) | |
| 9 | Number of clients (households) | 181 |
| 10 | Number of clients (Services) | 1 |
| 11 | Typical load (Dedicated to private services) | |
| 12 | Number of clients | 48 |




| | Residential typical loads (kW) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Winter | | | Spring | | | Summer | | |
| Period | Bus. Day | Saturday | Sunday | Bus. Day | Saturday | Sunday | Bus. Day | Saturday | Sunday |
| 00:00:00 | 201 | 200 | 59.73336 | 73 | 69 | 70 | 65 | 70 | 28.51062 |
| 00:15:00 | 196 | 197 | 60.88114 | 68 | 64 | 68 | 62 | 71 | 26.67927 |
| 00:30:00 | 186 | 197 | 57.23901 | 67 | 64 | 66 | 61 | 70 | 27.76487 |
| 00:45:00 | 191 | 183 | 58.65208 | 63 | 59 | 61 | 62 | 64 | 29.67794 |
| 01:00:00 | 198 | 182 | 58.20843 | 59 | 61 | 59 | 61 | 65 | 27.63265 |
| 01:15:00 | 191 | 177 | 58.30101 | 59 | 64 | 59 | 59 | 63 | 26.82421 |
| 01:30:00 | 184 | 170 | 55.06074 | 56 | 61 | 61 | 57 | 64 | 26.6514 |
| 01:45:00 | 184 | 166 | 57.47903 | 57 | 60 | 59 | 55 | 60 | 26.77062 |
| 02:00:00 | 178 | 159 | 58.6056 | 55 | 62 | 55 | 54 | 63 | 26.87565 |
| 02:15:00 | 169 | 153 | 56.16269 | 55 | 61 | 54 | 56 | 59 | 28.46454 |
| 02:30:00 | 167 | 154 | 55.38956 | 54 | 58 | 55 | 53 | 58 | 27.30793 |
| 02:45:00 | 173 | 153 | 55.71351 | 54 | 57 | 54 | 57 | 59 | 28.97037 |
| 03:00:00 | 164 | 150 | 55.00767 | 56 | 61 | 53 | 55 | 57 | 29.5476 |
| 03:15:00 | 161 | 142 | 58.14759 | 53 | 57 | 53 | 52 | 57 | 27.1149 |
| 03:30:00 | 162 | 142 | 58.7174 | 52 | 58 | 54 | 53 | 55 | 27.80894 |
| 03:45:00 | 156 | 144 | 54.50344 | 51 | 53 | 54 | 51 | 53 | 26.93754 |
| 04:00:00 | 146 | 145 | 52.19697 | 51 | 54 | 53 | 50 | 53 | 27.89334 |
| 04:15:00 | 142 | 138 | 53.12167 | 53 | 53 | 51 | 54 | 54 | 31.86067 |
| 04:30:00 | 142 | 137 | 51.17192 | 54 | 52 | 51 | 52 | 52 | 32.14908 |
| 04:45:00 | 149 | 138 | 52.03591 | 49 | 52 | 49 | 55 | 51 | 34.9866 |
| 05:00:00 | 140 | 132 | 53.87293 | 50 | 51 | 50 | 85 | 53 | 39.02789 |
| 05:15:00 | 140 | 132 | 51.49284 | 49 | 51 | 48 | 52 | 58 | 42.06339 |
| 05:30:00 | 140 | 123 | 54.18095 | 49 | 50 | 47 | 72 | 58 | 40.72729 |
| 05:45:00 | 132 | 123 | 50.76765 | 51 | 52 | 48 | 53 | 57 | 40.55528 |
| 06:00:00 | 164 | 116 | 51.4104 | 52 | 54 | 47 | 73 | 56 | 42.65456 |
| 06:15:00 | 167 | 117 | 53.06728 | 49 | 51 | 46 | 64 | 54 | 40.06365 |
| 06:30:00 | 177 | 122 | 50.93159 | 50 | 52 | 48 | 72 | 53 | 41.379 |
| 06:45:00 | 169 | 124 | 50.63267 | 51 | 56 | 52 | 68 | 55 | 42.01329 |
| 07:00:00 | 151 | 127 | 51.99075 | 50 | 57 | 48 | 94 | 58 | 41.14069 |
| 07:15:00 | 147 | 119 | 54.28077 | 55 | 58 | 49 | 86 | 58 | 41.01557 |
| 07:30:00 | 148 | 124 | 51.45031 | 59 | 55 | 48 | 91 | 62 | 44.35969 |
| 07:45:00 | 131 | 103 | 50.47543 | 55 | 52 | 49 | 81 | 66 | 47.51218 |
| 08:00:00 | 130 | 110 | 54.65858 | 53 | 52 | 58 | 98 | 112 | 48.44654 |
| 08:15:00 | 128 | 110 | 55.96846 | 51 | 51 | 55 | 86 | 64 | 44.12225 |

FIGURE 22 - PART OF THE FIRST WORKSHEET OF THE FLEXIBILITY TOOL.

The second and third spreadsheets (*Output – Residential* and *Output - Services*) refer to the flexibility results. For each type of typical day, there are reserved columns to save six type of outcomes:

- Downward flexibility (kW);
- Upward flexibility (kW);
- Base load, original values of load put in the first worksheet (kW);
- Base load + EV, original load values plus the EV charging consumption (kW);
- Downward band, on the basis of 'Base load + EV' outcome (kW);
- Upward band, on the basis of 'Base load + EV' outcome (kW).

Figure 23 shows how one of these identical spreadsheets are organized.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | Winter | | | | | | | | | |
| 2 | | | Business day | | | | | | Saturday | | | |
| 3 | | Period | Downward | Upward | Base load | Base load + EV | Downward band | Upward band | Downward | Upward | Base load | Base load + EV |
| 4 | | 00:00:00 | 4.800 | 4.739 | 201.000 | 219.850 | 215.050 | 224.589 | 4.754 | 4.945 | 200.000 | 214.186 |
| 5 | | 00:15:00 | 4.545 | 5.174 | 196.000 | 215.807 | 211.262 | 220.981 | 4.568 | 5.256 | 197.000 | 211.915 |
| 6 | | 00:30:00 | 4.313 | 5.698 | 186.000 | 206.535 | 202.222 | 212.233 | 4.568 | 5.648 | 197.000 | 212.466 |
| 7 | | 00:45:00 | 2.692 | 6.217 | 191.000 | 212.293 | 209.601 | 218.510 | 2.579 | 6.049 | 183.000 | 198.989 |
| 8 | | 01:00:00 | 2.791 | 6.719 | 198.000 | 219.729 | 216.939 | 226.448 | 2.565 | 6.405 | 182.000 | 198.395 |
| 9 | | 01:15:00 | 2.692 | 7.167 | 191.000 | 212.959 | 210.267 | 220.126 | 2.495 | 6.724 | 177.000 | 193.637 |
| 10 | | 01:30:00 | 2.593 | 7.521 | 184.000 | 206.074 | 203.480 | 213.595 | 2.396 | 6.981 | 170.000 | 186.758 |
| 11 | | 01:45:00 | 0.009 | 8.001 | 184.000 | 205.965 | 205.956 | 213.966 | 0.008 | 7.226 | 166.000 | 182.617 |
| 12 | | 02:00:00 | 0.009 | 8.228 | 178.000 | 199.609 | 199.600 | 207.837 | 0.008 | 7.385 | 159.000 | 175.394 |
| 13 | | 02:15:00 | 0.009 | 8.367 | 169.000 | 190.124 | 190.115 | 198.491 | 0.008 | 7.488 | 153.000 | 169.036 |
| 14 | | 02:30:00 | 0.008 | 8.451 | 167.000 | 187.423 | 187.414 | 195.874 | 0.008 | 7.562 | 154.000 | 169.468 |
| 15 | | 02:45:00 | 0.009 | 8.468 | 173.000 | 192.570 | 192.562 | 201.039 | 0.008 | 7.590 | 153.000 | 167.764 |
| 16 | | 03:00:00 | 0.008 | 8.437 | 164.000 | 182.481 | 182.473 | 190.919 | 0.008 | 7.555 | 150.000 | 163.998 |
| 17 | | 03:15:00 | 0.008 | 8.336 | 161.000 | 178.298 | 178.290 | 186.633 | 0.007 | 7.478 | 142.000 | 155.113 |
| 18 | | 03:30:00 | 0.008 | 8.174 | 162.000 | 178.035 | 178.027 | 186.209 | 0.007 | 7.354 | 142.000 | 154.176 |
| 19 | | 03:45:00 | 0.008 | 7.975 | 156.000 | 170.657 | 170.649 | 178.632 | 0.007 | 7.213 | 144.000 | 155.108 |
| 20 | | 04:00:00 | 0.007 | 7.742 | 146.000 | 159.215 | 159.207 | 166.957 | 0.007 | 7.035 | 145.000 | 155.043 |
| 21 | | 04:15:00 | 0.007 | 7.480 | 142.000 | 153.811 | 153.804 | 161.291 | 0.007 | 6.841 | 138.000 | 146.976 |

FIGURE 23 - PART OF THE SECOND WORKSHEET OF THE FLEXIBILITY TOOL.

Note that these values are calculated for the typical loads defined earlier in this process. In order to obtain analogous results for other loads, a proportion between peak loads as presented in the next equation should be performed for each period $i$.

$$Flex_{new}^{i} = Flex_{typical}^{i} \cdot \frac{PeakLoad_{new}}{PeakLoad_{typical}}$$

As an important final remark, the tool has internal parameters, associated with consumers profiles and rules, that were adapted to each country.

# 4. Overview of test cases

An overview of the twenty-eight delivered test cases can be consulted in Table 8. As noted in Chapter 1, all test cases are suitable for power systems steady-state studies, except for HR_Tx_dyn_2020, which also includes data for dynamic simulations.

If in the remainder of the ATTEST project other WPs will require further details not present in these test cases, future test cases may be created after the end of T2.3 and the submission of the present deliverable.

In the remainder of this chapter, each test case is seen in more detail in the corresponding dedicated subsection. Repetitions within the descriptions of some test cases may exist and are intentional in order to meke them self sufficient and allow readers to fully understand the one they are interested in, without the need to read all similar test cases previously described.

TABLE 8 - OVERVIEW OF TEST CASES

| NR. | TEST CASE NAME | DESCRIPTION | SOURCE |
|---|---|---|---|
| 1 | PT_Tx_2020 | Real (anonymized) Portuguese Transmission System as in 2020. Includes the full grid. | [4] [3] |
| 2 | PT_Tx_2030_Active | Real (anonymized) Portuguese Transmission System in 2030. Includes the full grid. Using *PT_Tx_2020* as base, with the expected expansion in [3]. | [2] [3] |
| 3 | PT_Tx_2030_Slow | Real (anonymized) Portuguese Transmission System in 2030. Includes the full grid. Using *PT_Tx_2020* as base, with the expected expansion in [3]. | [2] [3] |
| 4 | PT_Tx_2040_Active | Real (anonymized) Portuguese Transmission System in 2040. Includes the full grid. The network model is the same as in *PT_Tx_2030*. | [2] [3] |
| 5 | PT_Tx_2040_Slow | Real (anonymized) Portuguese Transmission System in 2040. Includes the full grid. The network model is the same as in *PT_Tx_2030*. | [2] [3] |
| 6 | PT_Tx_2050_Active | Real (anonymized) Portuguese Transmission System in 2050. Includes the full grid. The network model is the same as in *PT_Tx_2030*. | [2] [3] |
| 7 | PT_Tx_2050_Slow | Real (anonymized) Portuguese Transmission System in 2050. Includes the full grid. The network model is the same as in *PT_Tx_2030*. | [2] [3] |
| 8 | PT_Dx_01_2020 | Semi-urban real (anonymized) Portuguese Distribution network as in 2020. | EDPD, the Portuguese DSO |
| 9 | PT_Dx_02_2020 | Semi-urban real (anonymized) Portuguese Distribution network as in 2020. | EDPD, the Portuguese DSO |
| 10 | PT_Dx_03_2020 | Urban real (anonymized) Portuguese Distribution network as in 2020. | EDPD, the Portuguese DSO |
| 11 | PT_Dx_04_2020 | Urban real (anonymized) Portuguese Distribution network as in 2020. | EDPD, the Portuguese DSO |
| 12 | PT_Dx_05_2020 | Rural real (anonymized) Portuguese Distribution network as in 2020. | EDPD, the Portuguese DSO |
| 13 | UK_Tx_2020 | Real (simplified) UK transmission grid as in 2020 | [13] |

| | | | |
|---|---|---|---|
| 14 | UK_Dx_01_2020 | Urban synthetic UK Distribution (Green Lane - Altrincham.) | [14] |
| 15 | UK_Dx_02_2020 | Semi-urban synthetic UK Distribution (Clover Hill) | [14] |
| 16 | UK_Dx_03_2020 | Rural synthetic UK Distribution (Exchange St.) | [14] |
| 17 | HR_Tx_01_2020 | Part of the Transmission grid around Koprivnica substation with possible congestion and voltage problems. To be used together with HR_Dx_01_2020 especially in WP4. Network data is real and anonymized. | HOPS |
| 18 | HR_Tx_02_2020 | Part of NW Transmission grid of Croatia with congestion problems. Network data is real and anonymized. To be used especially in WP3, coupled with HR_Dx_05_2020 | HOPS |
| 19 | HR_Tx_03_2020 | Part of Zagreb Transmission Network, to be used together with HR_Dx_03_2020 especially in WP4. Network data is real and anonymized. | HOPS |
| 20 | HR_Tx_dyn_2020 | Dynamic model of Croatian Transmission grid to be used especially in T4.6. Network data is real and anonymized. | HOPS |
| 21 | HR_Dx_01_2020 | Koprivnica 35kV demo grid: real (anonymize) distribution grid. To be used coupled with HR_Tx_01_2020, especially in WP4 | HEP ODS |
| 22 | HR_Dx_02_2020 | Bjelovar 35kV demo grid: real (anonymized) distribution grid. To be used coupled with HR_Tx_01_2020, especially in WP4 | HEP ODS |
| 23 | HR_Dx_03_2020 | Zagreb demo grid: real (anonymized) distribution grid including FER and HEP building. To be used coupled with HR_Tx_03_2020, especially in WP4 | HEP ODS |
| 24 | HR_Dx_04_2020 | Koprivnica 10kV demo - grid: real (anonymized) distribution grid, especially for use in WP4 State Estimation and WP5 Asset Management tools | HEP ODS |
| 25 | HR_Dx_05_2020 | NW Croatia demo – grid: (anonymized) distribution grid, to be used coupled with HR_Tx_02_2020 especially for use in WP3 Planning tools | HEP ODS |
| 26 | ES_Dx_01_2020 | Semi-urban real (anonymized) distribution grid in Spain | COMILLAS |
| 27 | ES_Dx_02_2020 | Semi-urban real (anonymized) distribution grid in Spain | COMILLAS |
| 28 | ES_Dx_03_2020 | Synthetic distribution network from an urban area in Spain. Contains three high to medium voltage substations, 387 distribution transformers and high and medium voltage power lines. | [15] [16] |

## 4.1 PT_Tx_2020

The PT_Tx_2020 case refers to the transmission grid of Portugal as in 2020. The grid topology has been anonymized and contains 304 nodes, 557 branches and 7 interconnections with Spain. There are 270 generators, and a label classifies each of them according to the generation technology type (e.g., Fossil Gas, Wind Onshore, etc.) as detailed in Chapter 2.

The network model was built from scratch taking into account the available public data released by the Portuguese TSO, which can be found in [4]. Aside from allowing the inference of the network topology, this document contains the main electrical parameters of power lines/cables and transformers as well as the net load measured in each network substation (for one time instant) regarding the day when peak load occurred in each season. Furthermore, the installed power of each generation group of large hydro and thermal power plants as well as the installed power capacity of the power plants connected to the EHV is also included in the document. Regarding other types of generation, this document also contains the power capacity installed at the High Voltage (HV) level of each network substation.

Nevertheless, some assumptions were made to build a realistic network model. A minimum load ratio for generators from large hydro and thermal power plants was defined, as a percentage of their maximum power. The defined ratios are shown in Table 9.

TABLE 9 - GENERATORS MINIMUM LOAD RATIO

| GENERATION TECHNOLOGY TYPE | GENERATOR MINIMUM LOAD RATIO (PMIN/PMAX) [%] |
|---|---|
| Large hydro (hydro water reservoir, hydro pumped storage and hydro run-of-river and poundage) | 0.5 |
| Fossil Gas | 0.6 |
| Fossil Hard Coal | 0.4 |

Different ratios between reactive power and maximum active power ($tg\ \varphi$) were also assumed for each generation technology type, which are presented in Table 10.

TABLE 10 - TG Φ ASSUMED FOR EACH GENERATION TECHNOLOGY TYPE

| GENERATION TECHNOLOGY TYPE | | TG Φ |
|---|---|---|
| Large Hydro | | +0.5 / -0.4 |
| Large thermal (fossil gas and hard coal) | | +0.6 / -0.3 |
| Generators at EHV level | | ± 0.4 |
| Generators at HV level | Small hydro (P ≤ 10 MW) and Marine | 0 |
| | Other | ± 0.4 |

It should be mentioned that all power transformers were considered to be equipped with On-Load Tap Changers (OLTC) with a total of 25 tap positions, since no information was available in this regard.

Hourly data from ENTSO-E database regarding power generation, consumption and cross-border flows was used to build this test case. Such data is related to the day when the 2019 winter peak load occurred (2019-01-15). Aside from representing a stressful situation in terms of network operation, this day was chosen because the net load measured in each network substation (for one time instant) is available in [4], which allows determining the participation factor of each substation in the total consumption.

### 4.1.1 Generation mix

There are 270 generators installed, with a total power amount of 20.7 GW. The number and type of generators in operation may change during the day, according to the unit commitment exercise. For instance, at the time instant corresponding to peak load there are 202 generators in service. The types of generators considered and respective installed power are as follows in Table 11.

TABLE 11 - GENERATION MIX IN THE TEST CASE PT_TX_2020

| GENERATOR TYPE | NUMBER OF GENERATORS (IN OPERATION AT PEAK LOAD) | INSTALLED POWER [MW] |
|---|---|---|
| Fossil Gas | 10 (8) | 3829 |
| Fossil Hard Coal | 6 (6) | 1756 |
| Hydro Water Reservoir | 25 (10) | 1465 |
| Hydro Pumped Storage* | 21 (13) | 2603 |
| Hydro Run-of-river and poundage | 38 (30) | 2516 |
| Small Hydro (P ≤ 10 MW) | 32 (32) | 506 |
| Small Hydro (10 MW < P ≤ 30 MW) | 5 (5) | 176 |
| Photovoltaic power plant | 33 (0) | 490 |
| Wind onshore | 50 (50) | 5312 |
| Wind offshore | 1 (0) | 25 |
| Marine | 1 (0) | 1 |
| Other thermal, such as geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable | 48 (48) | 2077 |

* A power of 390 MW (out of 2603 MW) is related to a variable speed pump, which corresponds to the second generator connected to the network node 229

Interconnections are modelled as seven additional generators with infinite installed power. For each hour of the selected day, the cross-border flow values gathered from the ENTSO-E database were distributed among these generators, according to the total energy exchanged through each interconnection in that day, whose values are available in the Portuguese TSO database [17].

Regarding the generators from large hydro and thermal power plants, a unit commitment and active power dispatch exercises were performed for each hour of the day, taking into account the power limits of each generation group.

The generation data related to other generator types, namely “small hydro”, “photovoltaic”, “wind onshore” and “other thermal” ones, was distributed among them according to the respective installed power. In the case of PV generation, the value assigned to the DG units (connected to the distribution network) was proportionally reduced to the load value of each substation. According to [4], in 2019 the total installed power of distributed solar PV was 262 MVA.

In Figure 24 the total generation diagram is presented for the selected day.

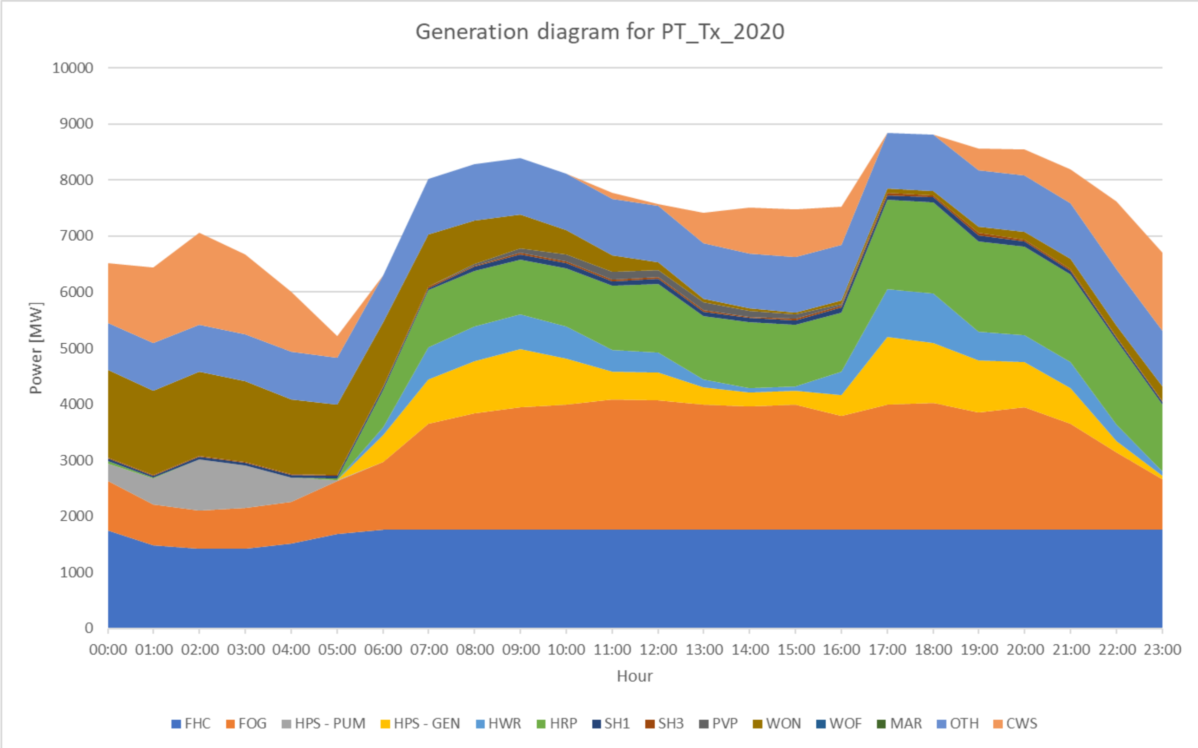



FIGURE 24 – GENERATION DIAGRAM FOR PT_TX_2020 IN 2019-01-15. LABELS ARE AS FOLLOWS: 'CWS': CONNECTION WITH SPAIN, 'OTH': OTHER THERMAL, SUCH AS BIOMASS, GEOTHERMAL, BIOGAS, MUNICIPAL SOLID WASTE AND COMBINED HEAT AND POWER RENEWABLE AND NON-RENEWABLE, 'MAR': MARINE, 'WOF': WIND OFFSHORE, 'WON': WIND ONSHORE, 'PVP': PHOTOVOLTAIC POWER PLANT, 'SH1': SMALL HYDRO P ≤ 10 MW, 'SH3': SMALL HYDRO 10 MW < P ≤ 30 MW, 'HRP': HYDRO RUN-OF-RIVER AND POUNDAGE, 'HWR': HYDRO WATER RESERVOIR, 'HPS – GEN': HYDRO POWER WORKING AS GENERATOR, 'HPS-PUM': HYDRO POWER WORKING AS PUMP, 'FOG': FOSSIL GAS, 'FHC': FOSSIL HARD COAL.

Finally, the reactive power dispatch of all generators was performed by means of an optimal power flow tool with the aim of reducing the active power losses of the network. It is important to state that the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within this dispatch exercise, in order to prevent them from reaching their reactive power limits. Thus, generators will be able to provide voltage control through reactive power support.

### 4.1.2 Load

As mentioned in the beginning of the Section 4.1, in [4] the net load measured in each network substation is available for one time instant of the selected day. After determining the power generation of the generators connected at the LV side of each substation, for the same time instant, the participation factor of each substation in the total consumption was obtained. This participation factor was then applied to the data gathered from the ENTSO-E database to calculate the consumption of each substation at each hour of the day. The peak load was about 8482 MW and occurred between 19h and 20h.

### 4.1.3 Flexibility

Flexibility was calculated using the bottom-up approach introduced in Chapter 3, starting from LV and aggregating it at the MV level, defining the maximum downward and upward available flexibility.

At the transmission network, flexibility bands were determined as aggregated at the LV side of each network substation, considering that:

- 40% of the distribution networks connected to each substation are urban;
- 40% of the distribution networks connected to each substation are semi-urban;
- 20% of the distribution networks connected to each substation are rural.

Moreover, the assumptions shown in Table 7 were considered. However, some substations are customers' facilities, for which no flexibility was determined. The network nodes representing these substations and the respective voltage level are presented in Table 12.

TABLE 12 - SUBSTATIONS FOR WHICH NO FLEXIBILITY WAS DETERMINED IN 2020

| NETWORK NODE | VOLTAGE LEVEL (KV) |
|---|---|
| 11 | 150 |
| 13 | 150 |
| 26 | 150 |
| 27 | 150 |
| 28 | 150 |
| 67 | 220 |
| 245 | 150 |
| 246 | 150 |
| 247 | 150 |
| 248 | 150 |
| 249 | 150 |
| 250 | 150 |
| 255 | 150 |
| 256 | 220 |
| 257 | 220 |
| 258 | 220 |
| 259 | 220 |
| 260 | 220 |
| 261 | 220 |

Those calculated flexibilities are part of the provided spreadsheet auxiliary file (see Section 4.1.4). Other possible sources of flexibility not explicitly addressed but allowed by the test case (and can be exploited by partners in charge of tasks) are, for example, deloading (i.e., operating below the maximum power extraction point) of wind farms and large PV power plants.

### 4.1.4 Auxiliary file

The auxiliary spreadsheet contains the following hourly data, regarding the day when peak load occurred in 2019 (15 of January) [4]:

- Load data (P and Q);
- Generator status obtained from unit commitment (as well as corresponding P and Q values);
- Regulated voltage magnitude setpoint of each generator;
- Transformer tap ratio;
- Power transformer data: year of manufacture and commissioning;

- Power lines/cables data: length and type of installation (overhead, underground or submarine);
- Flexibility calculated per consumption node.

## 4.2 PT_Tx_2030_Active

The PT_Tx_2030_Active test case refers to the Portuguese transmission network in 2030, considering the "active economy" scenario described in Section 2.1. This test case was built from the PT_Tx_2020 one, through the update of the installed power and number of generators as well as the network infrastructure, according to the defined guidelines.

This test case encompasses 312 nodes, 592 branches and 8 interconnections with Spain. There are also 299 generators whose generation technology type and corresponding installed power are detailed in Section 4.2.1.

Data related to power generation, consumption and cross-border flows is based on the PT_Tx_2020 test case, as described in the following sections.

### 4.2.1 Generation mix

There are 299 generators installed, with a total power amount of 26.9 GW. Even though the number and type of generators in operation may change during the day, according to the unit commitment exercise, at the time instant corresponding to peak load there are 217 generators in service. The types of generators considered, and respective installed power are shown in Table 13.

TABLE 13 - GENERATION MIX IN THE TEST CASE PT_TX_2030_ACTIVE

| GENERATOR TYPE | NUMBER OF GENERATORS (IN OPERATION AT PEAK LOAD) | INSTALLED POWER [MW] |
|---|---|---|
| FOSSIL GAS | 7 (7) | 2839 |
| FOSSIL HARD COAL | 0 | 0 |
| HYDRO WATER RESERVOIR | 29 (14) | 1739 |
| HYDRO PUMPED STORAGE* | 27 (18) | 4038 |
| HYDRO RUN-OF-RIVER AND POUNDAGE | 38 (36) | 2516 |
| SMALL HYDRO (P ≤ 10 MW) | 32 (32) | 519 |
| SMALL HYDRO (10 MW < P ≤ 30 MW) | 5 (5) | 181 |
| PHOTOVOLTAIC POWER PLANT | 56 (0) | 3774 |
| WIND ONSHORE | 54 (54) | 8808 |
| WIND OFFSHORE | 1 (1) | 260 |
| MARINE | 1 (1) | 70 |
| OTHER THERMAL, SUCH AS GEOTHERMAL, BIOMASS, BIOGAS, MUNICIPAL SOLID WASTE AND CHP RENEWABLE AND NON-RENEWABLE | 49 (49) | 2208 |

* A power of 390 MW (out of 4038 MW) is related to a variable speed pump, which corresponds to the second generator connected to the network node 229

After determining the consumption of each substation at each $i$ hour of the day (see Section 4.2.2), the pumping, power generation and cross-border flows were calculated. Pumping was obtained from the calculated consumption as follows:

$$Pumping^{i}_{\text{PT\_Tx\_2030\_Active}} = Consumption^{i}_{\text{PT\_Tx\_2030\_Active}} \times \left(\frac{Pumping^{i}}{Consumption^{i}}\right)_{\text{PT\_Tx\_2020}}$$

From the calculated consumption and pumping, the power production of each $t$ generation technology type was determined for each $i$ hour of the day:

$$Generation^{i,t}_{\text{PT\_Tx\_2030\_Active}} = \left(Consumption^{i} + Pumping^{i}\right)_{\text{PT\_Tx\_2030\_Active}} \times \left(\frac{Generation^{i,t}}{Consumption^{i} + Pumping^{i}}\right)_{\text{PT\_Tx\_2020}}$$

The cross-border flow (CBF) values were obtained as the balance between the calculated consumption (plus pumping) and generation:

$$CBF^{i}_{\text{PT\_Tx\_2030\_Active}} = \left(Consumption^{i} + Pumping^{i} - \sum_{t} Generation^{i}\right)_{\text{PT\_Tx\_2030\_Active}}$$

As mentioned in Section 2.1, coal is totally decommissioned before 2030. Thus, the power production that would be assigned to this generation technology through the procedure described above was distributed by the remaining technologies (with the exception of fossil gas), according to the respective installed power.

Since wind offshore and marine technologies were not yet producing in the PT_Tx_2020 test case, realistic profiles were determined:

- Wind offshore: its profile stemmed from ENTSO-E database considering the day 2020-07-15, since wind onshore generation on this day was similar to the verified in PT_Tx_2020 test case;
- Marine: its profile was obtained from wave data from [18] considering the closest available date to the one the PT_Tx_2020 test case is based on 2019-01-28. The power profile was normalized considering the maximum power available on waves on that day [19] as well as efficiency mean values of the elements of a wave power plant [20].

After obtaining the power production of each generation technology type at each hour of the day, the production of each individual generator was determined.

Regarding the generators from large hydro and thermal power plants, both a unit commitment and active power dispatch exercises were performed for each hour of the day, taking into account the power limits of each generation group.

The generation data related to other generator types (namely “small hydro”, “photovoltaic”, “wind onshore” and “other thermal” ones) was distributed among them according to the respective installed power. In the particular case of PV generation, the value assigned to the DG units (connected to the distribution network) was proportionally reduced to the load value of each substation. According to the percentual evolution obtained from Table 1, in the present test case the total installed power of distributed solar PV is 763 MVA.

Similarly to what was performed for the PT_Tx_2020 test case, the calculated cross-border flow values were distributed among the interconnections (modelled as additional generators), according to the total energy exchanged through each one in 2019-01-15. However, a new interconnection is considered in the present test case. In this sense, the previously determined distribution was updated, namely for flows from Spain to Portugal, as this new interconnection will be more important for such flows [4].

In Figure 25 the total generation diagram is presented for this test case.

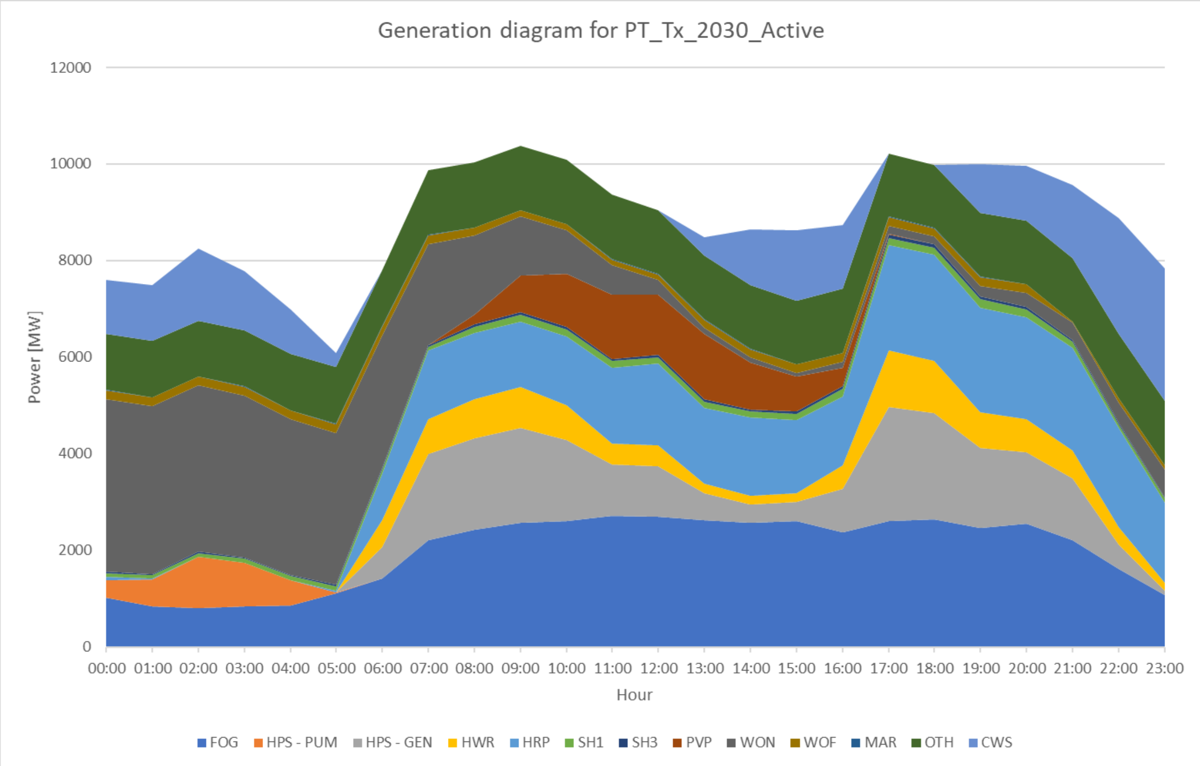



FIGURE 25 - GENERATION DIAGRAM FOR PT_Tx_2030_ACTIVE LABELS ARE AS FOLLOWS: 'CWS': CONNECTION WITH SPAIN, 'OTH': OTHER THERMAL, SUCH AS BIOMASS, GEOTHERMAL, BIOGAS, MUNICIPAL SOLID WASTE AND COMBINED HEAT AND POWER RENEWABLE AND NON-RENEWABLE, 'MAR': MARINE, 'WOF': WIND OFFSHORE, 'WON': WIND ONSHORE, 'PVP': PHOTOVOLTAIC POWER PLANT, 'SH1': SMALL HYDRO P ≤ 10 MW, 'SH3': SMALL HYDRO 10 MW < P ≤ 30 MW, 'HRP': HYDRO RUN-OF-RIVER AND POUNDAGE, 'HWR': HYDRO WATER RESERVOIR, 'HPS – GEN': HYDRO POWER WORKING AS GENERATOR, 'HPS-PUM': HYDRO POWER WORKING AS PUMP, 'FOG': FOSSIL GAS.

Finally, the reactive power dispatch of all generators was performed by means of an optimal power flow tool with the aim of reducing the active power losses of the network. It is important to state that the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within this dispatch exercise, in order to prevent them from reaching their reactive power limits. Thus, generators will be able to provide voltage control through reactive power support.

### 4.2.2 Load

The consumption of this test case was obtained from the PT_Tx_2020 one through the demand evolution shown in Table 1.

According to [3], seven new substations (four of them being customers' facilities) were considered in this test case, in comparison with the PT_Tx_2020 one. In [3] a prediction of the consumption of each network substation for the 2029 horizon can be found for two-time instants (corresponding to peak and valley load periods) of the winter season. The participation factors of each substation in the total consumption obtained from this information were applied to the calculated consumption to determine the consumption of each substation at each hour of the day, considering both peak (between 8h and 21h) and valley (between 22h and 7h) load periods. The peak load was about 9849 MW and occurred between 19h and 20h.

### 4.2.3 Flexibility

Similarly to what was performed to PT_Tx_2020 test case, flexibility was calculated using the bottom-up approach introduced in Chapter 3. At the transmission network, flexibility bands were determined as aggregated at the LV side of each network substation, considering that:

- 40% of the distribution networks connected to each substation are urban;
- 40% of the distribution networks connected to each substation are semi-urban;
- 20% of the distribution networks connected to each substation are rural.

Moreover, the assumptions shown in Table 7 (regarding 2030) were considered.

However, some substations are customers' facilities, for which no flexibility was determined. Four new substations of this type are considered in this test case, in comparison with the PT_Tx_2020 one. The network nodes representing these substations and the respective voltage level are presented in Table 14.

TABLE 14 - SUBSTATIONS FOR WHICH NO FLEXIBILITY WAS DETERMINED IN 2030

| NETWORK NODE | VOLTAGE LEVEL (KV) |
|---|---|
| 11 | 150 |
| 13 | 150 |
| 18 | 150 |
| 26 | 150 |
| 27 | 150 |
| 28 | 150 |
| 48 | 220 |
| 67 | 220 |
| 245 | 150 |
| 246 | 150 |
| 247 | 150 |
| 248 | 150 |
| 249 | 150 |
| 250 | 150 |
| 255 | 150 |
| 256 | 220 |
| 257 | 220 |
| 258 | 220 |
| 259 | 220 |
| 260 | 220 |
| 261 | 220 |
| 308 | 220 |
| 316 | 400 |

Those calculated flexibilities are part of the provided spreadsheet auxiliary file (see Section 4.2.4). Other possible sources of flexibility not explicitly addressed, but allowed by the test case (and can be exploited by partners in charge of tasks) are, for instance, deloading (i.e., operating below the maximum power extraction point) of wind farms and large PV power plants.

### 4.2.4 Auxiliary file

The auxiliary spreadsheet contains the following hourly data:

- Load data (P and Q);
- Generator status obtained from unit commitment (as well as corresponding P and Q values);

- Regulated voltage magnitude setpoint of each generator;
- Transformer tap ratio;
- Flexibility calculated per consumption node.

## 4.3 PT_Tx_2030_Slow

The PT_Tx_2030_Slow test case refers to the Portuguese transmission network in 2030, considering the "slow progression" scenario described in Section 2.1. This test case was built from the PT_Tx_2020 one, through the update of the installed power and number of generators as well as the network infrastructure, according to the defined guidelines.

This test case encompasses 312 nodes, 592 branches and 8 interconnections with Spain. There are also 299 generators whose generation technology type and corresponding installed power are detailed in Section 4.3.1.

Data related to power generation, consumption and cross-border flows is based on the PT_Tx_2020 test case, as described in the following sections. The spreadsheet auxiliary file contains the same data as described in 4.2.4.

### 4.3.1 Generation mix

There are 299 generators installed, with a total power amount of 22.7 GW. Even though the number and type of generators in operation may change during the day, according to the unit commitment exercise, at the time instant corresponding to peak load there are 214 generators in service. The types of generators considered and respective installed power are shown in Table 15.

TABLE 15 - GENERATION MIX IN THE TEST CASE PT_TX_2030_SLOW

| GENERATOR TYPE | NUMBER OF GENERATORS (IN OPERATION AT PEAK LOAD) | INSTALLED POWER [MW] |
|---|---|---|
| Fossil Gas | 7 (7) | 2839 |
| Fossil Hard Coal | 0 | 0 |
| Hydro Water Reservoir | 29 (14) | 1739 |
| Hydro Pumped Storage* | 27 (17) | 4038 |
| Hydro Run-of-river and poundage | 38 (34) | 2516 |
| Small Hydro (P ≤ 10 MW) | 32 (32) | 519 |
| Small Hydro (10 MW < P ≤ 30 MW) | 5 (5) | 181 |
| Photovoltaic power plant | 56 (0) | 2819 |
| Wind onshore | 54 (54) | 5727 |
| Wind offshore | 1 (1) | 150 |
| Marine | 1 (1) | 50 |
| Other thermal, such as geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable | 49 (49) | 2137 |

* A power of 390 MW (out of 4038 MW) is related to a variable speed pump, which corresponds to the second generator connected to the network node 229

After determining the consumption of each substation at each $i$ hour of the day (see Section 4.3.2), the pumping, power generation and cross-border flows were similarly calculated as in the PT_Tx_2030_Active test case. Pumping was obtained from the calculated consumption as follows:

$$Pumping^{i}_{\text{PT\_Tx\_2030\_Slow}} = Consumption^{i}_{\text{PT\_Tx\_2030\_Slow}} \times \left(\frac{Pumping^{i}}{Consumption^{i}}\right)_{\text{PT\_Tx\_2020}}$$

From the calculated consumption and pumping, the power production of each $t$ generation technology type was determined for each $i$ hour of the day:

$$Generation^{i,t}_{\text{PT\_Tx\_2030\_Slow}} = \left(Consumption^{i} + Pumping^{i}\right)_{\text{PT\_Tx\_2030\_Slow}} \times \left(\frac{Generation^{i,t}}{Consumption^{i} + Pumping^{i}}\right)_{\text{PT\_Tx\_2020}}$$

The cross-border flow (CBF) values were obtained as the balance between the calculated consumption (plus pumping) and generation:

$$CBF^{i}_{\text{PT\_Tx\_2030\_Slow}} = \left(Consumption^{i} + Pumping^{i} - \sum_{t} Generation^{i}\right)_{\text{PT\_Tx\_2030\_Slow}}$$

After obtaining the power production of each generation technology type at each hour of the day, the production of each individual generator (including the interconnections related ones) was determined as described for the PT_Tx_2030_Active test case (see Section 4.2.1).

In Figure 26 the total generation diagram is presented for this test case.

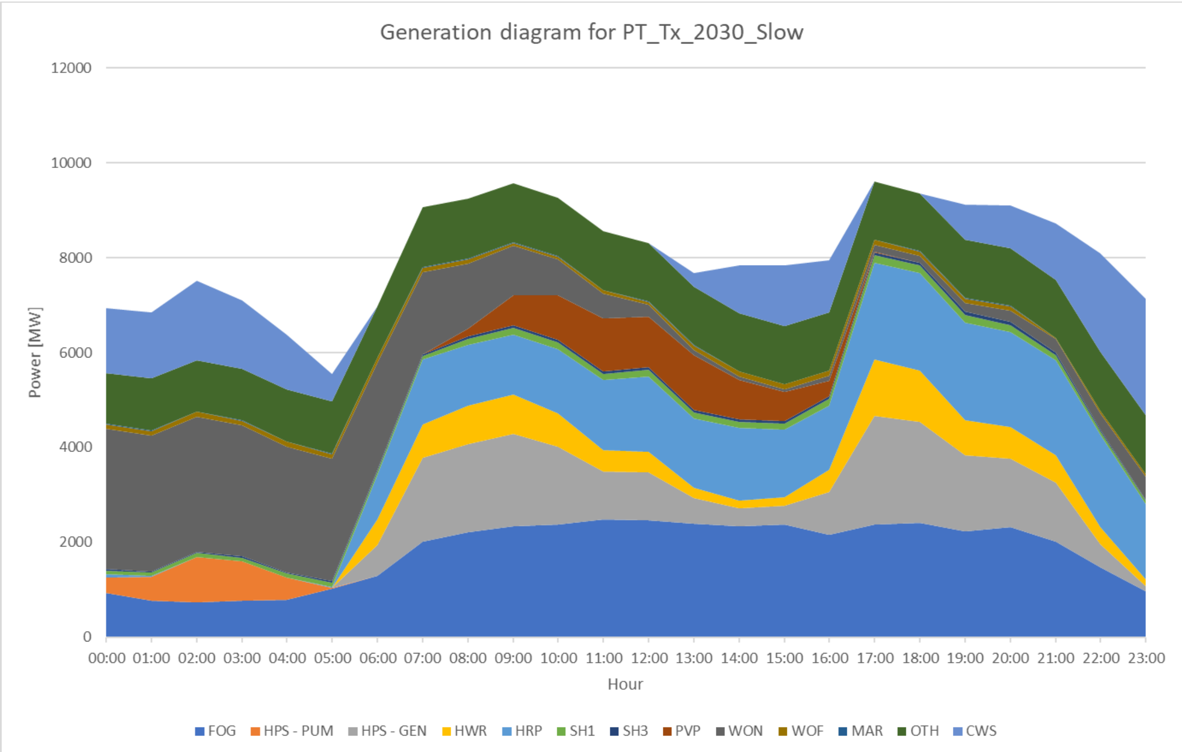



FIGURE 26 - GENERATION DIAGRAM FOR PT_TX_2030_SLOW. LABELS ARE AS FOLLOWS: 'CWS': CONNECTION WITH SPAIN, 'OTH': OTHER THERMAL, SUCH AS BIOMASS, GEOTHERMAL, BIOGAS, MUNICIPAL SOLID WASTE AND COMBINED HEAT AND POWER RENEWABLE AND NON-RENEWABLE, 'MAR': MARINE, 'WOF': WIND OFFSHORE, 'WON': WIND ONSHORE, 'PVP': PHOTOVOLTAIC POWER PLANT, 'SH1': SMALL HYDRO P ≤ 10 MW, 'SH3': SMALL HYDRO 10 MW < P ≤ 30 MW, 'HRP': HYDRO RUN-OF-RIVER AND POUNDAGE, 'HWR': HYDRO WATER RESERVOIR, 'HPS – GEN': HYDRO POWER WORKING AS GENERATOR, 'HPS-PUM': HYDRO POWER WORKING AS PUMP, 'FOG': FOSSIL GAS.

Finally, the reactive power dispatch of all generators was performed by means of an optimal power flow tool with the aim of reducing the active power losses of the network. Similarly to the other test cases, the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within this dispatch exercise, in order to prevent them from reaching their reactive power limits. Thus, generators will be able to provide voltage control through reactive power support.

### 4.3.2 Load

The consumption of this test case was obtained from the PT_Tx_2020 one through the demand evolution shown in Table 2.

Then, the consumption of each substation at each hour of the day was determined as described in the PT_Tx_2030_Active test case (see Section 4.2.2). The peak load was about 8995 MW and occurred between 19h and 20h.

### 4.3.3 Flexibility

In this test case, flexibility was similarly calculated as in the PT_Tx_2030_Active one, but considering different assumptions:

- EV rate: 5%;
- Share of DR adherence at the residential level: 10%;
- Share of DR adherence at the commerce and services levels: 12.5%.

The substations corresponding to customers' facilities are the same as in the PT_Tx_2030_Active test case. The network nodes representing these substations and the respective voltage level are presented in Table 14.

The calculated flexibilities are part of the provided spreadsheet auxiliary file (see Section 4.2.4).

## 4.4 PT_Tx_2040_Active

The PT_Tx_2040_Active test case refers to the Portuguese transmission network in 2040, considering the "active economy" scenario described in Section 2.1. This test case was built from the PT_Tx_2030_Active one, through the update of the generators' installed capacity according to the defined guidelines, i.e., the network topology is the same as in PT_Tx_2030_Active.

Similarly to the PT_Tx_2030_Active test case, this one encompasses 312 nodes, 592 branches and 8 interconnections with Spain. There are also 299 generators whose generation technology type and corresponding installed power are detailed in Section 4.4.1.

Data related to power generation, consumption and cross-border flows is based on the PT_Tx_2030_Active test case, as described in the following subsections. Contrarily to what was performed for the PT_Tx_2030_Active test case, in this one the consumption of each substation as well as the production of each individual generator were only determined for the time instant corresponding to peak load, since this seems to be the most interesting time instant regarding operational problems (see Section 4.6.3). For this reason, this test case is provided with only this snapshot built-in and no spreadsheet auxiliary file was developed.

### 4.4.1 Generation mix

There are 299 generators installed, with a total power amount of 33.7 GW. The number and type of generators in operation may change during the day, according to the unit commitment exercise. For instance, at the time instant corresponding to peak load there are 223 generators in service. The types of generators considered and respective installed power are shown in Table 16.

TABLE 16 - GENERATION MIX IN THE TEST CASE PT_TX_2040_ACTIVE

| GENERATOR TYPE | NUMBER OF GENERATORS (IN OPERATION AT PEAK LOAD) | INSTALLED POWER [MW] |
|---|---|---|
| Fossil Gas | 7 (7) | 2839 |
| Fossil Hard Coal | 0 | 0 |
| Hydro Water Reservoir | 29 (16) | 1739 |
| Hydro Pumped Storage* | 27 (20) | 4038 |
| Hydro Run-of-river and poundage | 38 (38) | 2516 |
| Small Hydro (P ≤ 10 MW) | 32 (32) | 519 |
| Small Hydro (10 MW < P ≤ 30 MW) | 5 (5) | 181 |
| Photovoltaic power plant | 56 (0) | 6250 |
| Wind onshore | 54 (54) | 12789 |
| Wind offshore | 1 (1) | 528 |
| Marine | 1 (1) | 147 |
| Other thermal, such as geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable | 49 (49) | 2243 |

* A power of 390 MW (out of 4038 MW) is related to a variable speed pump, which corresponds to the second generator connected to the network node 229

After determining the consumption of each substation at each $i$ hour of the day (see Section 4.4.2), the pumping, power generation and cross-border flows were similarly calculated as in the PT_Tx_2030_Active test case. Pumping was obtained from the calculated consumption as follows:

$$Pumping^{i}_{\mathrm{PT\_Tx\_2040\_Active}} = Consumption^{i}_{\mathrm{PT\_Tx\_2040\_Active}} \times \left(\frac{Pumping^{i}}{Consumption^{i}}\right)_{\mathrm{PT\_Tx\_2020}}$$

From the calculated consumption and pumping, the power production of each $t$ generation technology type was determined for each $i$ hour of the day:

$$Generation^{i,t}_{\mathrm{PT\_Tx\_2040\_Active}} = \left(Consumption^{i} + Pumping^{i}\right)_{\mathrm{PT\_Tx\_2040\_Active}} \times \left(\frac{Generation^{i,t}}{Consumption^{i} + Pumping^{i}}\right)_{\mathrm{PT\_Tx\_2030\_Active}}$$

The cross-border flow (CBF) values were obtained as the balance between the calculated consumption (plus pumping) and generation:

$$CBF^{i}_{\mathrm{PT\_Tx\_2040\_Active}} = \left(Consumption^{i} + Pumping^{i} - \sum_{t} Generation^{i}\right)_{\mathrm{PT\_Tx\_2040\_Active}}$$

According to the procedure described above, the power production assigned to the “fossil gas” and “hydro run-of-river and poundage” technologies is higher than the respective installed power in several hours of the day. To overcome this issue, the surplus power was distributed by the remaining technologies, according to the corresponding installed power. In the particular case of the “fossil gas” technology, a maximum power production of about 85% of its installed capacity was established.

After obtaining the power production of each generation technology type, the production of each individual generator was determined for the time instant corresponding to peak load as described for the PT_Tx_2030_Active test case (see Section 4.2.1). It is worth mentioning that the total installed power of distributed solar PV is 1022 MVA in the present test case, which is in accordance with the percentual evolution obtained from Table 1.

In terms of cross-border flows, the calculated values were distributed among the interconnections as described for the PT_Tx_2030_Active test case (see Section 4.2.1).

In Figure 27 the total generation diagram is presented for this test case.

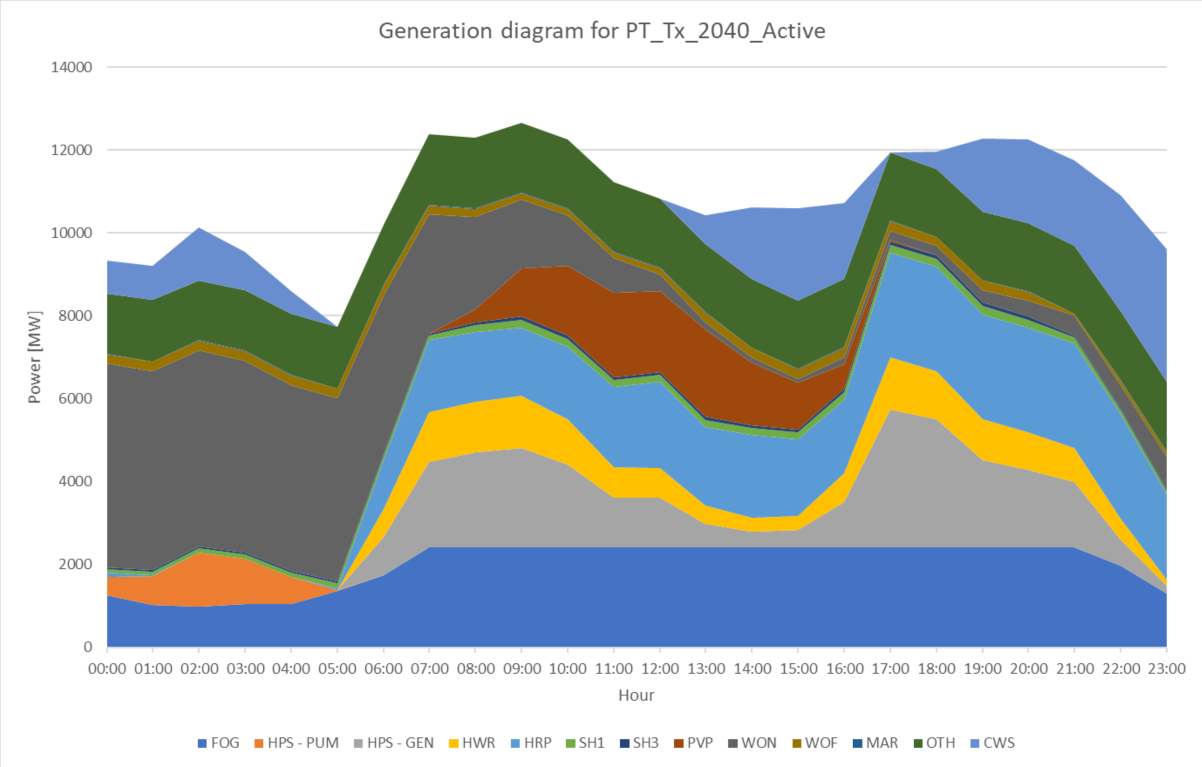



FIGURE 27 - GENERATION DIAGRAM FOR PT_TX_2040_ACTIVE. LABELS ARE AS FOLLOWS: 'CWS': CONNECTION WITH SPAIN, 'OTH': OTHER THERMAL, SUCH AS BIOMASS, GEOTHERMAL, BIOGAS, MUNICIPAL SOLID WASTE AND COMBINED HEAT AND POWER RENEWABLE AND NON-RENEWABLE, 'MAR': MARINE, 'WOF': WIND OFFSHORE, 'WON': WIND ONSHORE, 'PVP': PHOTOVOLTAIC POWER PLANT, 'SH1': SMALL HYDRO P ≤ 10 MW, 'SH3': SMALL HYDRO 10 MW < P ≤ 30 MW, 'HRP': HYDRO RUN-OF-RIVER AND POUNDAGE, 'HWR': HYDRO WATER RESERVOIR, 'HPS – GEN': HYDRO POWER WORKING AS GENERATOR, 'HPS-PUM': HYDRO POWER WORKING AS PUMP, 'FOG': FOSSIL GAS.

Finally, the reactive power dispatch of all generators was performed by means of an optimal power flow tool with the aim of reducing the active power losses of the network. Similarly to the other test cases, the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within this dispatch exercise, in order to prevent them from reaching their reactive power limits. Thus, generators will be able to provide voltage control through reactive power support.

### 4.4.2 Load

The consumption of this test case was obtained from the PT_Tx_2030_Active one through the demand evolution shown in Table 1.

Then, the consumption of each substation was determined for the time instant corresponding to peak load as described in the PT_Tx_2030_Active test case (see Section 4.2.2). The peak load was about 12032 MW and occurred between 19h and 20h.

### 4.4.3 Problems assessment

The purpose of this test case consisted of assessing the occurrence of overloads and under/overvoltages for the time instant corresponding to peak load, since this seems to be the most interesting time instant regarding operational problems (see Section 4.6.3). Nevertheless, only an overload of about 12.1% in the cable connected to nodes 292 and 293 occurred at this time instant.

Partners in charge of other WPs (especially WP4) may adapt the data set and change the generation and consumption profiles afterwards in order to make the test case more relevant to the evaluation of their tools.

## 4.5 PT_Tx_2040_Slow

The PT_Tx_2040_Slow test case refers to the Portuguese transmission network in 2040, considering the "slow progression" scenario described in Section 2.1. This test case was built from the PT_Tx_2030_Slow one, through the update of the generators' installed capacity according to the defined guidelines, i.e., the network topology is the same as in PT_Tx_2030_Active/PT_Tx_2030_Slow.

Thus, this test case encompasses 312 nodes, 592 branches and 8 interconnections with Spain. There are also 299 generators whose generation technology type and corresponding installed power are detailed in Section 4.5.1.

Data related to power generation, consumption and cross-border flows is based on the PT_Tx_2030_Slow test case, as described in the following sections. Contrarily to what was performed for the PT_Tx_2030_Slow test case, in this one the consumption of each substation as well as the production of each individual generator were only determined for the time instant corresponding to peak load, since this seems to be the most interesting time instant regarding operational problems (see Section 4.6.3). For this reason, this test case is provided with only this snapshot built-in and no spreadsheet auxiliary file was developed.

### 4.5.1 Generation mix

There are 299 generators installed, with a total power amount of 23.6 GW. Even though the number and type of generators in operation may change during the day, according to the unit commitment exercise, at the time instant corresponding to peak load there are 218 generators in service. The types of generators considered and respective installed power are shown in Table 17.

TABLE 17 - GENERATION MIX IN THE TEST CASE PT_TX_2040_SLOW

| GENERATOR TYPE | NUMBER OF GENERATORS (IN OPERATION AT PEAK LOAD) | INSTALLED POWER [MW] |
|---|---|---|
| Fossil Gas | 7 (7) | 2839 |
| Fossil Hard Coal | 0 | 0 |
| Hydro Water Reservoir | 29 (15) | 1739 |
| Hydro Pumped Storage* | 27 (18) | 4038 |
| Hydro Run-of-river and poundage | 38 (36) | 2516 |
| Small Hydro (P ≤ 10 MW) | 32 (32) | 519 |
| Small Hydro (10 MW < P ≤ 30 MW) | 5 (5) | 181 |
| Photovoltaic power plant | 56 (0) | 3433 |
| Wind onshore | 54 (54) | 5984 |
| Wind offshore | 1 (1) | 200 |
| Marine | 1 (1) | 105 |
| Other thermal, such as geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable | 49 (49) | 2137 |

* A power of 390 MW (out of 4038 MW) is related to a variable speed pump, which corresponds to the second generator connected to the network node 229

After determining the consumption of each substation at each $i$ hour of the day (see Section 4.5.2), the pumping, power generation and cross-border flows were similarly calculated as in the PT_Tx_2030_Slow test case. Pumping was obtained from the calculated consumption as follows:

$$Pumping^{i}_{\text{PT\_Tx\_2040\_Slow}} = Consumption^{i}_{\text{PT\_Tx\_2040\_Slow}} \times \left(\frac{Pumping^{i}}{Consumption^{i}}\right)_{\text{PT\_Tx\_2020}}$$

From the calculated consumption and pumping, the power production of each *t* generation technology type was determined for each *i* hour of the day:

$$Generation^{i,t}_{\text{PT\_Tx\_2040\_Slow}} = \left(Consumption^{i} + Pumping^{i}\right)_{\text{PT\_Tx\_2040\_Slow}} \times \left(\frac{Generation^{i,t}}{Consumption^{i} + Pumping^{i}}\right)_{\text{PT\_Tx\_2030\_Slow}}$$

The cross-border flow (CBF) values were obtained as the balance between the calculated consumption (plus pumping) and generation:

$$CBF^{i}_{\text{PT\_Tx\_2040\_Slow}} = \left(Consumption^{i} + Pumping^{i} - \sum_{t} Generation^{i}\right)_{\text{PT\_Tx\_2040\_Slow}}$$

According to the procedure described above, the power production assigned to “fossil gas” technology is close to its installed capacity during several hours of the day. Similarly to what was performed in the PT_Tx_2040_Active test case, a maximum power production of about 85% of its installed capacity was established and the surplus power distributed by the remaining technologies, according to the corresponding installed power.

After obtaining the power production of each generation technology type, the production of each individual generator (including the interconnections related ones) was determined for the time instant corresponding to peak load as described for the PT_Tx_2040_Active test case (see Section 4.4.1).

In Figure 28 the total generation diagram is presented for this test case.

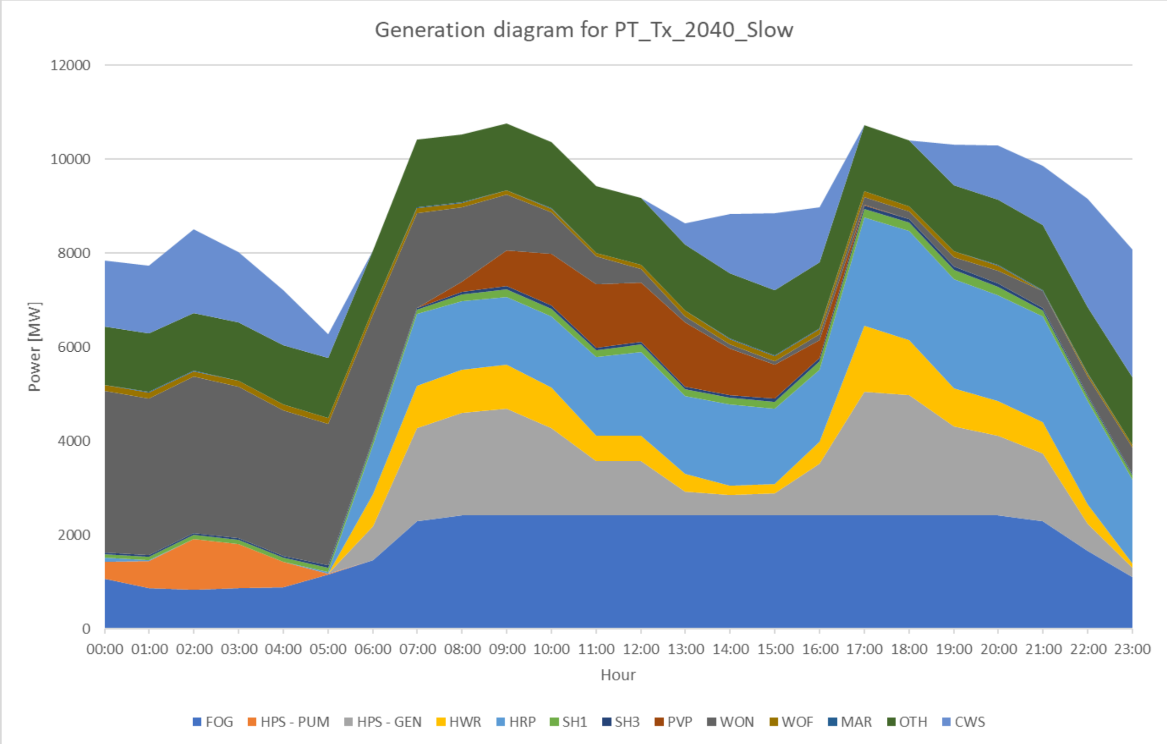



FIGURE 28 - GENERATION DIAGRAM FOR PT_TX_2040_SLOW. LABELS ARE AS FOLLOWS: 'CWS': CONNECTION WITH SPAIN, 'OTH': OTHER THERMAL, SUCH AS BIOMASS, GEOTHERMAL, BIOGAS, MUNICIPAL SOLID WASTE AND COMBINED HEAT AND POWER RENEWABLE AND NON-RENEWABLE, 'MAR': MARINE, 'WOF': WIND OFFSHORE, 'WON': WIND ONSHORE, 'PVP': PHOTOVOLTAIC POWER PLANT, 'SH1': SMALL HYDRO $P \leq 10$ MW, 'SH3': SMALL HYDRO $10 \text{ MW} < P \leq 30$ MW, 'HRP': HYDRO RUN-OF-RIVER AND POUNDAGE, 'HWR': HYDRO WATER RESERVOIR, 'HPS – GEN': HYDRO POWER WORKING AS GENERATOR, 'HPS-PUM': HYDRO POWER WORKING AS PUMP, 'FOG': FOSSIL GAS.

Finally, the reactive power dispatch of all generators was performed by means of an optimal power flow tool with the aim of reducing the active power losses of the network. Similarly to the other test cases, the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within this dispatch exercise, in order to prevent them from reaching their reactive power limits. Thus, generators will be able to provide voltage control through reactive power support.

### 4.5.2 Load

The consumption of this test case was obtained from the PT_Tx_2030_Slow one through the demand evolution shown in Table 2.

Then, the consumption of each substation was determined for the time instant corresponding to peak load as described in the PT_Tx_2030_Active test case (see Section 4.2.2). The peak load was about 10150 MW and occurred between 19h and 20h.

### 4.5.3 Problems assessment

In this test case, no operational issues were observed at the time instant corresponding to peak load. Nevertheless, partners in charge of other WPs (especially WP4) may adapt the data set and change the generation and consumption profiles afterwards in order to make the test case more relevant to the evaluation of their tools.

## 4.6 PT_Tx_2050_Active

The PT_Tx_2050_Active test case refers to the Portuguese transmission network in 2050, considering the “active economy” scenario described in Section 2.1. This test case was built from the PT_Tx_2040_Active one, through the update of the generators’ installed capacity according to the defined guidelines, i.e., the network topology is the same as in PT_Tx_2030_Active.

Thus, this test case encompasses 312 nodes, 592 branches and 8 interconnections with Spain. There are also 299 generators whose generation technology type and corresponding installed power are detailed in Section 4.6.1.

Data related to power generation, consumption and cross-border flows is based on the PT_Tx_2040_Active and PT_Tx_2030_Active test cases, as described in the following sections. Contrarily to what was performed for the PT_Tx_2030_Active test case, in this one the consumption of each substation as well as the production of each individual generator were only determined for a few time instants, since the main purpose of this test case consisted of assessing the occurrence of overloads and under/overvoltages. For this reason, no spreadsheet auxiliary file was developed.

### 4.6.1 Generation mix

There are 299 generators installed, with a total power amount of 40.7 GW. The number and type of generators in operation may change during the day, according to the unit commitment exercise. For instance, at the time instant corresponding to peak load there are 227 generators in service. The types of generators considered and respective installed power are shown in Table 18.

TABLE 18 - GENERATION MIX IN THE TEST CASE PT_TX_2050_ACTIVE

| GENERATOR TYPE | NUMBER OF GENERATORS (IN OPERATION AT PEAK LOAD) | INSTALLED POWER [MW] |
|---|---|---|
| Fossil Gas | 7 (7) | 2839 |
| Fossil Hard Coal | 0 | 0 |
| Hydro Water Reservoir | 29 (17) | 1739 |
| Hydro Pumped Storage* | 27 (23) | 4038 |
| Hydro Run-of-river and poundage | 38 (38) | 2516 |
| Small Hydro (P ≤ 10 MW) | 32 (32) | 519 |
| Small Hydro (10 MW < P ≤ 30 MW) | 5 (5) | 181 |
| Photovoltaic power plant | 56 (0) | 9212 |
| Wind onshore | 54 (54) | 16473 |
| Wind offshore | 1 (1) | 776 |
| Marine | 1 (1) | 220 |
| Other thermal, such as geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable | 49 (49) | 2277 |

* A power of 390 MW (out of 4038 MW) is related to a variable speed pump, which corresponds to the second generator connected to the network node 229

After determining the consumption of each substation at each $i$ hour of the day (see Section 4.6.2), the pumping, power generation and cross-border flows were similarly calculated as in the PT_Tx_2040_Active and PT_Tx_2030_Active test cases. Pumping was obtained from the calculated consumption as follows:

$$Pumping^{i}_{\mathrm{PT\_Tx\_2050\_Active}} = Consumption^{i}_{\mathrm{PT\_Tx\_2050\_Active}} \times \left(\frac{Pumping^{i}}{Consumption^{i}}\right)_{\mathrm{PT\_Tx\_2020}}$$

From the calculated consumption and pumping, the power production of each $t$ generation technology type was determined for each $i$ hour of the day:

$$Generation^{i,t}_{\mathrm{PT\_Tx\_2050\_Active}} = \left(Consumption^{i} + Pumping^{i}\right)_{\mathrm{PT\_Tx\_2050\_Active}} \times \left(\frac{Generation^{i,t}}{Consumption^{i} + Pumping^{i}}\right)_{\mathrm{PT\_Tx\_2030\_Active}}$$

The cross-border flow (CBF) values were obtained as the balance between the calculated consumption (plus pumping) and generation:

$$CBF^{i}_{\mathrm{PT\_Tx\_2050\_Active}} = \left(Consumption^{i} + Pumping^{i} - \sum_{t} Generation^{i}\right)_{\mathrm{PT\_Tx\_2050\_Active}}$$

According to the procedure described above, the power production assigned to the “fossil gas” and “hydro run-of-river and poundage” technologies is higher than the respective installed power in several hours of the day. To overcome this issue, the surplus power was distributed by the remaining technologies, according to the corresponding installed power. In the particular case of the “fossil gas” technology, a maximum power of about 85% of its installed capacity was established.

After obtaining the power production of each generation technology type, the production of each individual generator was determined for a few time instants, as described for the PT_Tx_2030_Active test case (see Section 4.2.1). It is worth mentioning that the total installed power of distributed solar PV is 1427 MVA in the present test case, which is in accordance with the percentual evolution obtained from Table 1.

In terms of cross-border flows, the calculated values were distributed among the interconnections as described for the PT_Tx_2030_Active test case (see Section 4.2.1).

In Figure 29 the total generation diagram is presented for this test case.

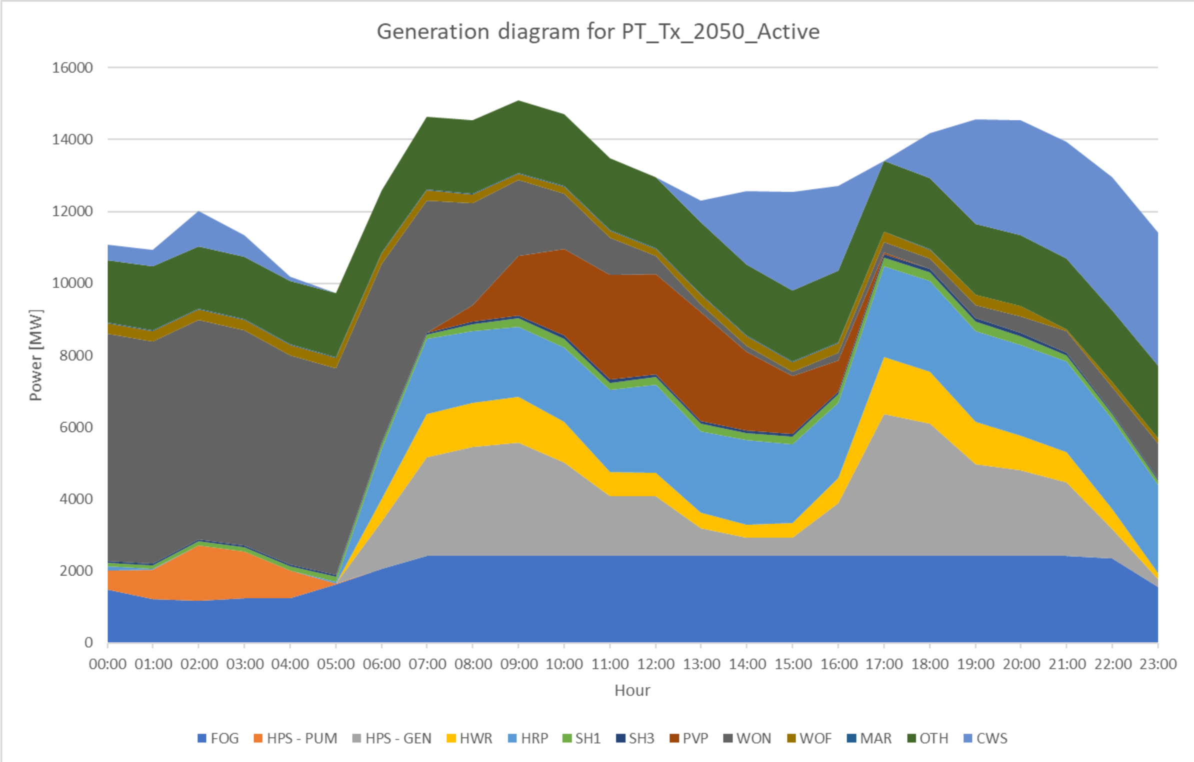



FIGURE 29 - GENERATION DIAGRAM FOR PT_TX_2050_ACTIVE. LABELS ARE AS FOLLOWS: 'CWS': CONNECTION WITH SPAIN, 'OTH': OTHER THERMAL, SUCH AS BIOMASS, GEOTHERMAL, BIOGAS, MUNICIPAL SOLID WASTE AND COMBINED HEAT AND POWER RENEWABLE AND NON-RENEWABLE, 'MAR': MARINE, 'WOF': WIND OFFSHORE, 'WON': WIND ONSHORE, 'PVP': PHOTOVOLTAIC POWER PLANT, 'SH1': SMALL HYDRO P ≤ 10 MW, 'SH3': SMALL HYDRO 10 MW < P ≤ 30 MW, 'HRP': HYDRO RUN-OF-RIVER AND POUNDAGE, 'HWR': HYDRO WATER RESERVOIR, 'HPS – GEN': HYDRO POWER WORKING AS GENERATOR, 'HPS-PUM': HYDRO POWER WORKING AS PUMP, 'FOG': FOSSIL GAS.

Finally, the reactive power dispatch of all generators was performed by means of an optimal power flow tool with the aim of reducing the active power losses of the network. Similarly to the other test cases, the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within this dispatch exercise, in order to prevent them from reaching their reactive power limits. Thus, generators will be able to provide voltage control through reactive power support.

### 4.6.2 Load

The consumption of this test case was obtained from the PT_Tx_2040_Active one through the demand evolution shown in Table 1.

Then, the consumption of each substation was determined for a few time instants as described in the PT_Tx_2030_Active test case (see Section 4.2.2). The peak load was about 14187 MW and occurred between 19h and 20h.

### 4.6.3 Problems assessment

As mentioned in the beginning of the test case's description, the consumption of each substation as well as the production of each individual generator were only determined for a few time instants in order to assess the occurrence of overloads and under/overvoltages. However, only overloads occurred.

An overload in the cable connected to nodes 292 and 293 occurred in several time instants. In addition, during the peak load (between 19h and 20h) an overload in the third transformer connected to nodes 76 and 168 also occurred. Thus, this was the most interesting time instant in terms of operational problems (overloads of about 38.1% and 6.4% in the referred cable and transformer, respectively). For this reason, this test case is provided with only this snapshot built-in.

Afterwards, partners in charge of other WPs (especially WP4) may adapt the data set and change the generation and consumption profiles in order to make the test case more relevant to the evaluation of their tools.

## 4.7 PT_Tx_2050_Slow

The PT_Tx_2050_Slow test case refers to the Portuguese transmission network in 2050, considering the "slow progression" scenario described in Section 2.1. This test case was built from the PT_Tx_2040_Slow one, through the update of the generators' installed capacity according to the defined guidelines, i.e., the network topology is the same as in PT_Tx_2030_Active/PT_Tx_2030_Slow.

Thus, this test case encompasses 312 nodes, 592 branches and 8 interconnections with Spain. There are also 299 generators whose generation technology type and corresponding installed power are detailed in Section 4.7.1.

Data related to power generation, consumption and cross-border flows is based on the PT_Tx_2040_Slow and PT_Tx_2030_Slow test cases, as described in the following sections. Contrarily to what was performed for the PT_Tx_2030_Slow test case, in this one the consumption of each substation as well as the production of each individual generator were only determined for the time instant corresponding to peak load, since this seems to be the most interesting time instant regarding operational problems (see Section 4.6.3). For this reason, this test case is provided with only this snapshot built-in and no spreadsheet auxiliary file was developed.

### 4.7.1 Generation mix

There are 299 generators installed, with a total power amount of 24.7 GW. Even though the number and type of generators in operation may change during the day, according to the unit commitment exercise, at the time instant corresponding to peak load there are 223 generators in service. The types of generators considered and respective installed power are shown in Table 19.

TABLE 19 - GENERATION MIX IN THE TEST CASE PT_TX_2050_SLOW

| GENERATOR TYPE | NUMBER OF GENERATORS (IN OPERATION AT PEAK LOAD) | INSTALLED POWER [MW] |
|---|---|---|
| Fossil Gas | 7 (7) | 2839 |
| Fossil Hard Coal | 0 | 0 |
| Hydro Water Reservoir | 29 (16) | 1739 |
| Hydro Pumped Storage* | 27 (20) | 4038 |
| Hydro Run-of-river and poundage | 38 (38) | 2516 |
| Small Hydro (P ≤ 10 MW) | 32 (32) | 519 |
| Small Hydro (10 MW < P ≤ 30 MW) | 5 (5) | 181 |
| Photovoltaic power plant | 56 (0) | 4004 |
| Wind onshore | 54 (54) | 6343 |
| Wind offshore | 1 (1) | 300 |
| Marine | 1 (1) | 156 |
| Other thermal, such as geothermal, biomass, biogas, Municipal solid waste and CHP renewable and non-renewable | 49 (49) | 2137 |

* A power of 390 MW (out of 4038 MW) is related to a variable speed pump, which corresponds to the second generator connected to the network node 229

After determining the consumption of each substation at each $i$ hour of the day (see Section 4.7.2), the pumping, power generation and cross-border flows were similarly calculated as in the PT_Tx_2040_Slow and PT_Tx_2030_Slow test cases. Pumping was obtained from the calculated consumption as follows:

$$Pumping^{i}_{\text{PT\_Tx\_2050\_Slow}} = Consumption^{i}_{\text{PT\_Tx\_2050\_Slow}} \times \left(\frac{Pumping^{i}}{Consumption^{i}}\right)_{\text{PT\_Tx\_2020}}$$

From the calculated consumption and pumping, the power production of each $t$ generation technology type was determined for each $i$ hour of the day:

$$Generation^{i,t}_{\text{PT\_Tx\_2050\_Slow}} = \left(Consumption^{i} + Pumping^{i}\right)_{\text{PT\_Tx\_2050\_Slow}} \times \left(\frac{Generation^{i,t}}{Consumption^{i} + Pumping^{i}}\right)_{\text{PT\_Tx\_2030\_Slow}}$$

The cross-border flow (CBF) values were obtained as the balance between the calculated consumption (plus pumping) and generation:

$$CBF^{i}_{\text{PT\_Tx\_2050\_Slow}} = \left(Consumption^{i} + Pumping^{i} - \sum_{t} Generation^{i}\right)_{\text{PT\_Tx\_2050\_Slow}}$$

According to the procedure described above, the power production assigned to the “fossil gas” and “hydro run-of-river and poundage” technologies is higher than the respective installed power in several hours of the day. To overcome this issue, the surplus power was distributed by the remaining technologies, according to the corresponding installed power. In the case of the “fossil gas” technology, a maximum power of about 85% of its installed capacity was established.

After obtaining the power production of each generation technology type, the production of each individual generator (including the interconnections related ones) was determined for the time instant corresponding to peak load as described for the PT_Tx_2050_Active test case (see Section 4.6.1).

In Figure 30 the total generation diagram is presented for this test case.

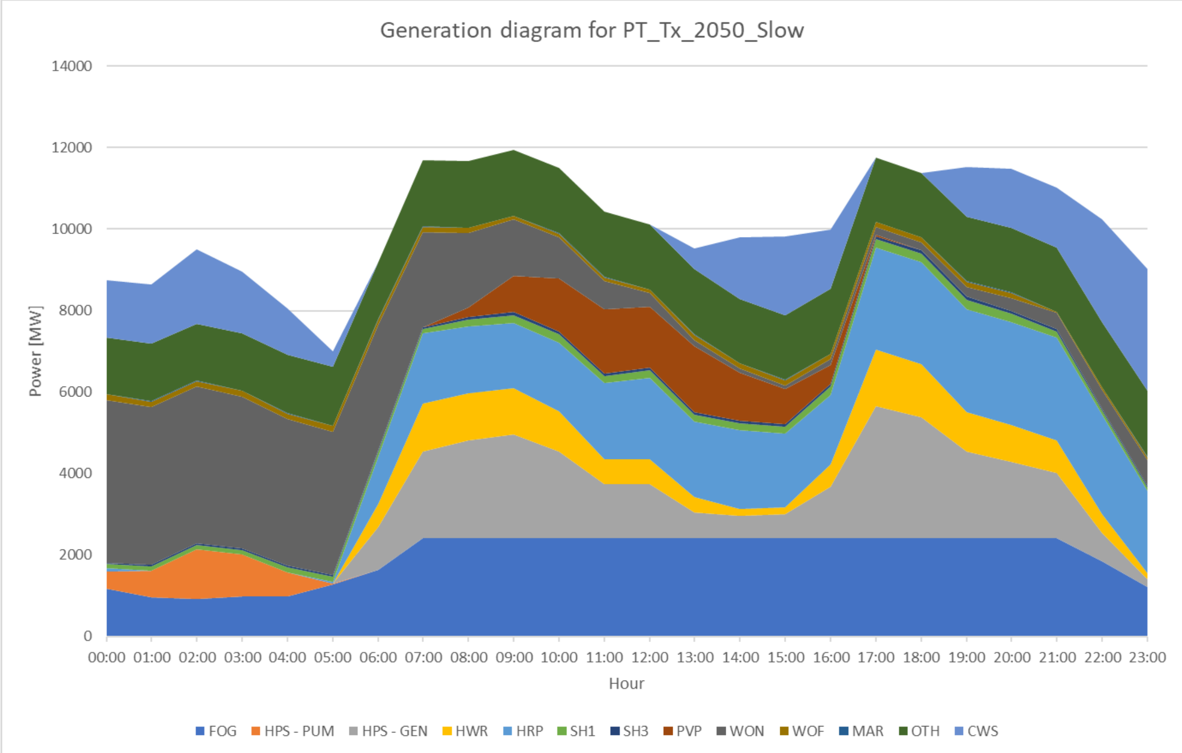



FIGURE 30 - GENERATION DIAGRAM FOR PT_TX_2050_SLOW. LABELS ARE AS FOLLOWS: 'CWS': CONNECTION WITH SPAIN, 'OTH': OTHER THERMAL, SUCH AS BIOMASS, GEOTHERMAL, BIOGAS, MUNICIPAL SOLID WASTE AND COMBINED HEAT AND POWER RENEWABLE AND NON-RENEWABLE, 'MAR': MARINE, 'WOF': WIND OFFSHORE, 'WON': WIND ONSHORE, 'PVP': PHOTOVOLTAIC POWER PLANT, 'SH1': SMALL HYDRO P ≤ 10 MW, 'SH3': SMALL HYDRO 10 MW < P ≤ 30 MW, 'HRP': HYDRO RUN-OF-RIVER AND POUNDAGE, 'HWR': HYDRO WATER RESERVOIR, 'HPS – GEN': HYDRO POWER WORKING AS GENERATOR, 'HPS-PUM': HYDRO POWER WORKING AS PUMP, 'FOG': FOSSIL GAS.

Finally, the reactive power dispatch of all generators was performed by means of an optimal power flow tool with the aim of reducing the active power losses of the network. Similarly to the other test cases, the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within this dispatch exercise, in order to prevent them from reaching their reactive power limits. Thus, generators will be able to provide voltage control through reactive power support.

### 4.7.2 Load

The consumption of this test case was obtained from the PT_Tx_2040_Slow one through the demand evolution shown in Table 2.

Then, the consumption of each substation was determined for the time instant corresponding to peak load as described in the PT_Tx_2030_Active test case (see Section 4.2.2). The peak load was about 11303 MW and occurred between 19h and 20h.

### 4.7.3 Problems assessment

In this test case, no operational problems were noticed at the time instant corresponding to peak load. Nevertheless, partners in charge of other WPs (especially WP4) may adapt the data set and change the generation and consumption profiles afterwards in order to make the test case more relevant to the evaluation of their tools.

## 4.8 PT_Dx_01_2020

This case presents a weakly meshed part of the real Portuguese Distribution network as in 2020. It corresponds to a segment of two contiguous networks located in the same semi-urban area (see the next case). The grid, which is operated at 30 kV and 60 kV, has 191 nodes (100 with consumption) and 190 branches. There is no generation in the grid, apart from the slack bus with infinite capacity. There is one capacitor bank with nominal reactive power Q = 3.43 Mvar. The point of connection of this network with the Portuguese transmission system is stablished at 60 kV level, more precisely at bus 2 of the distribution network or bus 122 of the transmission network (see Section 4.1 about the Portuguese transmission test case PT_Tx_2020).

This information can be seen in the anonymized snapshot that comes with the network MATPOWER file of this test case. Along with this file, this test case delivers also the load profiles in terms of active and reactive power within 15 minutes timeframe for 12 typical days in the year: Business day, Saturday and Sunday for each season of the year. As an example, Figure 31 shows the active power load for the typical days of Spring referring this case.

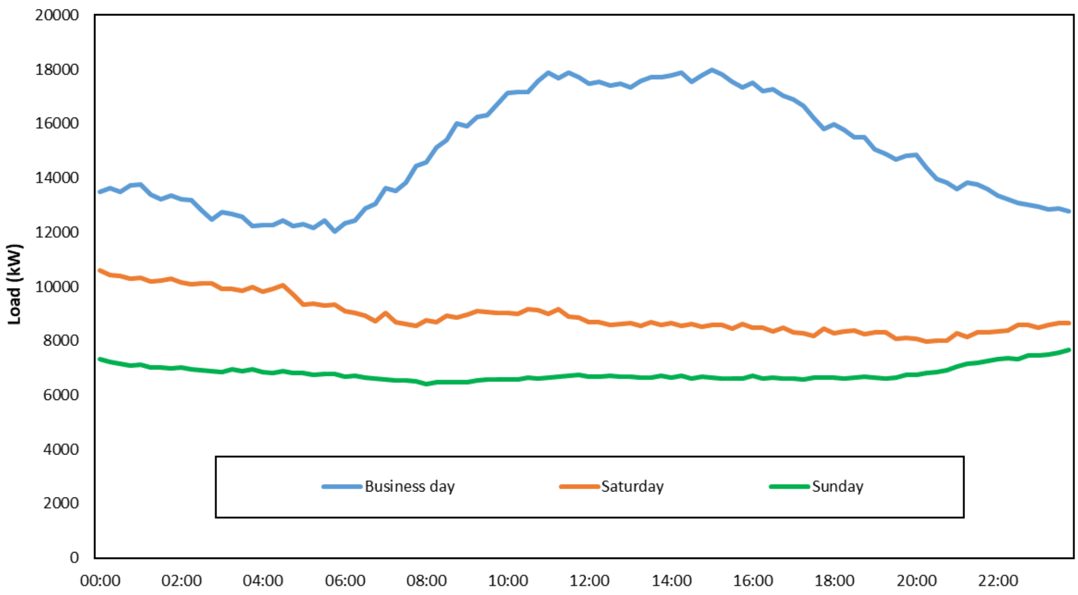



FIGURE 31 - LOAD PROFILES FOR THE CASE PT_DX_01_2020 CONSIDERING THREE TYPICAL DAYS OF SPRING.

Additionally, for each load node at each instant, upward and downward flexibility values are provided considering the scenarios Winter/Summer and Business days/Sundays. These results were calculated using the assumptions explained in Chapter 3 for each year in analysis: 2020, 2030, 2040 and 2050.

Each of the Portuguese Distribution networks presented contains the so-called equivalent nodes that represent the nodes responsible for the connection to other parts of the network and generally englobes the slack bus. It should be important to differentiate them because the load profiles of these nodes can be quite different from the average. In this case, there is only one equivalent node corresponding to bus 1, besides the slack node (bus 2).

Regarding the rest of the nodes, they are associated to normal MV/LV secondary substations (public) or dedicated MV/LV substations (private). The first ones usually supply residential load while private substations are usually associated to commerce or other services. Table 20 distinguishes these networks nodes between the two types.

TABLE 20 - LIST OF NODES SUPPLIED BY EACH TYPE OF SUBSTATION FOR THE CASE PT_DX_01_2020

| MV/LV substations | Nodes |
|---|---|
| Public | 13; 21; 22; 24; 25; 37; 40; 41; 51; 54; 59; 60; 69; 73; 86; 96; 98; 101; 103; 104 |
| Private | 6-12; 14-20; 23; 26-36; 38-39; 42-44; 46-50; 52-53; 55-58; 61-68; 70-79; 81-85; 87-95; 97;99-100; 102; 105 |

Along with all the information mentioned so far, this test case also delivers the load profiles adjusted to 2030, 2040 and 2050. Moreover, the flexibility bands obtained from the consumption is also computed considering the assumptions cited in Chapter 3. In this case, comparing to the base consumption for 2020, the load for 2030, 2040 and 2050 corresponds to 121%, 139% and 170% respectively based on the information referred in Section 2.1.

## 4.9 PT_Dx_02_2020

This case presents a weakly meshed part of the real Portuguese Distribution network as in 2020. It corresponds to the other segment of two contiguous networks located in the same semi-urban area (see the previous case in Section 4.8). The grid, which is operated at 15 kV, 30 kV and 60 kV, has 229 nodes (118 with consumption) and 229 branches. Besides the slack bus with infinite capacity (bus 6), there is another node in the grid where power can be injected (bus 4). There is one capacitor bank with nominal reactive power Q = 3.43 Mvar. The point of connection of this network with the Portuguese transmission system is stablished at 60 kV level, more precisely at bus 6 of the distribution network or bus 122 of the transmission network (see Section 4.1 about the Portuguese transmission test case PT_Tx_2020).

This information can be seen in the anonymized snapshot that comes with the MATPOWER file. Along with this file, this test case also delivers the load profiles in terms of active and reactive power within 15 minutes timeframe for 12 typical days in the year: Business day, Saturday and Sunday for each season of the year. As an example, Figure 32 shows the active power load for the typical days of Spring referring this case.

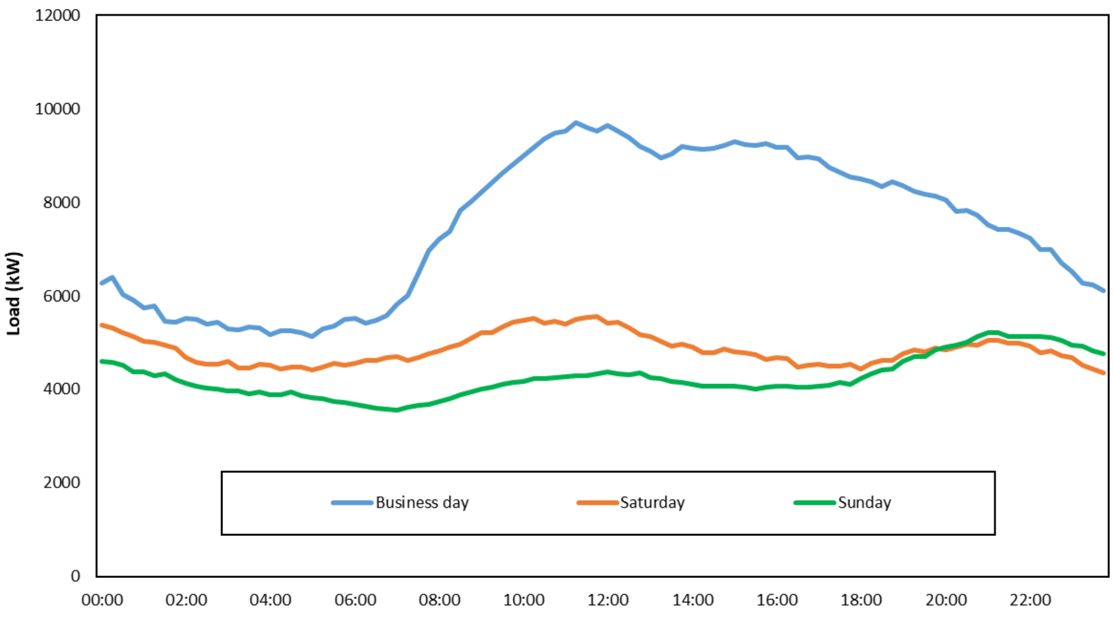



FIGURE 32 - LOAD PROFILES FOR THE CASE PT_Dx_02_2020 CONSIDERING THREE TYPICAL DAYS OF SPRING.

Likewise, this test case delivers the generation profiles in terms of active and reactive power for the same intervals of the typical days. Figure 33 shows an illustrative example of the generation in the typical business day of each season of the year.

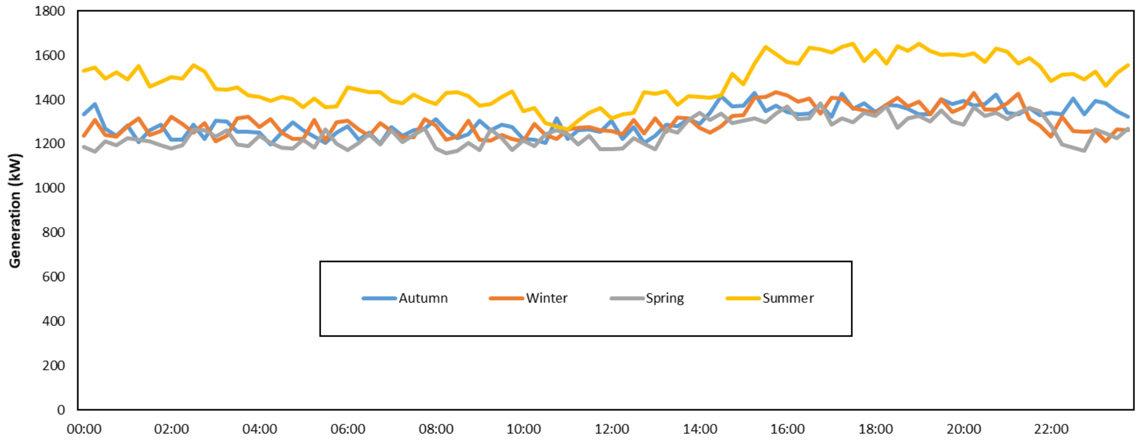



FIGURE 33 - GENERATION PROFILES FOR THE CASE PT_DX_02_2020 CONSIDERING BUSINESS DAYS OF ALL SEASONS.

In this case, there are four equivalent nodes besides the slack node (bus 6), namely the buses 1, 2, 3 and 4.

Regarding the rest of the nodes, they are associated to normal MV/LV secondary substations (public) or dedicated MV/LV substations (private). Table 21 distinguishes these networks nodes between the two types.

TABLE 21 - LIST OF NODES SUPPLIED BY EACH TYPE OF SUBSTATION FOR THE CASE PT_DX_02_2020

| MV/LV substations | Nodes |
|---|---|
| Public | 10; 11; 13; 18; 21; 23; 26; 28; 30; 32; 34; 36-38; 40; 43-48; 51; 57; 62; 64; 65; 70; 71; 74; 75; 84-86; 88; 89; 92; 93; 95; 97-102; 104; 106; 108; 110; 113; 115; 121-123 |
| Private | 12; 14-17; 19; 20; 22; 24; 25; 27; 29; 31; 33; 35; 39; 41; 42; 46; 49; 50; 52-56; 58-61; 63; 66-69; 72; 73; 76-83; 87; 90; 91; 94; 96; 103; 105; 107; 109; 111; 112; 116; 120 |

Again, along with all the information mentioned so far, this test case also delivers the load profiles and flexibility bands adjusted to 2030, 2040 and 2050. Like the previous case, comparing to the base consumption for 2020, the load for 2030, 2040 and 2050 correspond to 121%, 139% and 170% respectively based on the information referred in Section 2.1.

## 4.10 PT_Dx_03_2020

This case presents a weakly meshed part of the real Portuguese Distribution network as in 2020. It corresponds to segment of two contiguous networks located in the same urban area (see the next case PT_Dx_04_2020 in Section 4.11). The grid, which is operated at 10 KV and 60 kV, has 207 nodes (99 with consumption) and 206 branches. There is no generation in the grid, apart from the slack bus with infinite capacity. The point of connection of this network with the Portuguese transmission system is stablished at 60 kV level, more precisely at bus 2 of the distribution network or bus 110 of the transmission network (see Section 4.1 about the Portuguese transmission test case PT_Tx_2020).

This information can be seen in the anonymized snapshot that comes with the MATPOWER file. Along with this file, this test case also delivers the load profiles in terms of active and reactive power within 15 minutes timeframe for 12 typical days in the year: Business day, Saturday and Sunday for each season of the year. As an example, Figure 34 shows the active power load for the typical days of Spring referring to this case.

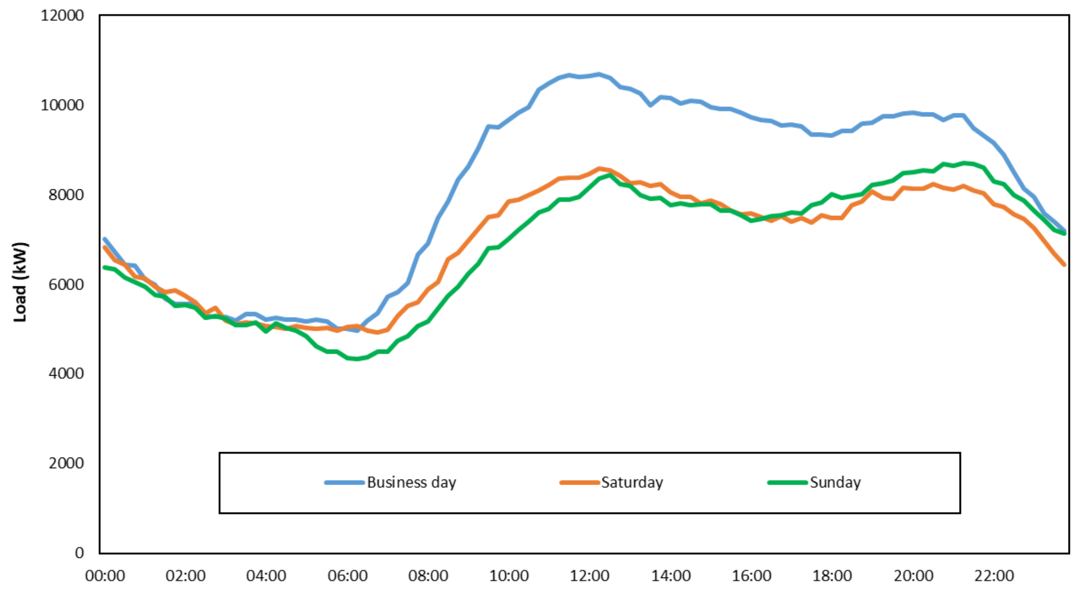



FIGURE 34 - LOAD PROFILES FOR THE CASE PT_DX_03_2020 CONSIDERING THREE TYPICAL DAYS OF SPRING.

In this case, there are one equivalent node besides the slack bus (bus 2), namely the bus 1. Regarding the rest of the nodes, they are associated to normal MV/LV secondary substations (public) or dedicated MV/LV substations (private). Table 22 distinguishes these networks nodes between the two types.

TABLE 22 - LIST OF NODES SUPPLIED BY EACH TYPE OF SUBSTATION FOR THE CASE PT_DX_03_2020

| MV/LV substations | Nodes |
|---|---|
| Public | 3-10; 14-17; 19; 21; 22; 25-27; 29; 30; 32-42; 47; 49-59; 63-70; 72-78; 81-90; 93; 94; 96-105 |
| Private | 11; 12; 20; 23; 28; 31; 43-46; 48; 48; 60-62; 71; 79; 80; 91; 103 |

Again, along with all the information mentioned so far, this test case also delivers the load profiles and flexibility bands adjusted to 2030, 2040 and 2050. Comparing to the base consumption for 2020, the load for 2030, 2040 and 2050 correspond to 139%, 178% and 205% respectively based on the information referred in Section 2.1.

## 4.11 PT_Dx_04_2020

This case presents a weakly meshed part of the real Portuguese Distribution network as in 2020. It corresponds to segment of two contiguous networks located in the same urban area (see the previous case PT_Dx_03_2020 in Section 4.10). The grid, which is operated at 10 kV and 60 kV, has 221 nodes (104 with consumption) and 220 branches. There is no generation in the grid, apart from the slack bus with infinite capacity. The point of connection of this network with the Portuguese transmission system is stablished at 60 kV level, more precisely at bus 2 of the distribution network or bus 110 of the transmission network (see Section 4.1 about the Portuguese transmission test case PT_Tx_2020).

This information can be seen in the anonymized snapshot that comes with the MATPOWER file. Along with this file, this test case also delivers the load profiles in terms of active and reactive power within 15 minutes timeframe for 12 typical days in the year: Business day, Saturday and Sunday for each season of the year. As an example, Figure 35 shows the active power load for the typical days of Spring referring to this case.

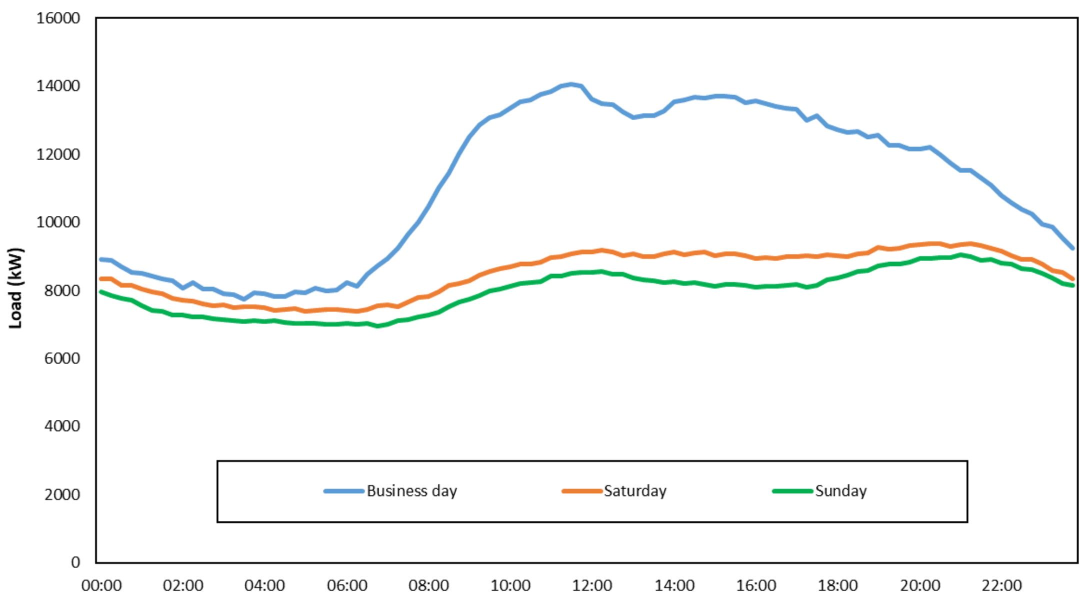



FIGURE 35 - LOAD PROFILES FOR THE CASE PT_DX_04_2020 CONSIDERING THREE TYPICAL DAYS OF SPRING.

Additionally, for each load node at each instant, upward and downward flexibility values are provided considering the scenarios Winter/Summer and Business days/Sundays. These results were calculated admitting the assumptions explained in Chapter 3 for each year in analysis: 2020, 2030, 2040 and 2050.

In this case, there is one equivalent node besides the slack bus (bus 2), namely the bus 1. Regarding the rest of the nodes, they are associated to normal MV/LV secondary substations (public) or dedicated MV/LV substations (private). Table 23 distinguishes these networks nodes between the two types.

TABLE 23 - LIST OF NODES SUPPLIED BY EACH TYPE OF SUBSTATION FOR THE CASE PT_DX_04_2020

| MV/LV substations | Nodes |
|---|---|
| Public | 6-11; 13-15; 18-22; 24; 25; 27-33; 35; 36; 39-44; 46; 47; 50-52; 54-57; 69; 71-73; 79-113 |
| Private | 16; 17; 23; 26; 34; 37; 38; 45; 48; 49; 53; 59; 63-68; 74; 76-78; 114 |

Again, along with all the information mentioned so far, this test case also delivers the load profiles and flexibility bands adjusted to 2030, 2040 and 2050. Comparing to the base consumption for 2020, the load for 2030, 2040 and 2050 is 139%, 178% and 205% respectively based on the information referred in Section 2.1.

## 4.12 PT_Dx_05_2020

This case presents a weakly meshed part of the real Portuguese Distribution network as in 2020. It corresponds to a network located in a rural area. The grid, which is operated at 10 kV,30 kV and 60 kV, has 103 nodes (46 with consumption) and 102 branches. Besides the slack bus with infinite capacity (bus 11), there are four generators (buses 6,7,8 and 10). The point of connection of this network with the Portuguese transmission system is stablished at 60 kV level, more precisely at bus 11 of the distribution network or bus 166 of the transmission network (see Section about the Portuguese transmission test case).

This information can be seen in the anonymized snapshot that comes with the MATPOWER file. Along with this file, this test case also delivers the load profiles in terms of active and reactive power within 15 minutes timeframe for 12 typical days in the year: Business day, Saturday and Sunday for each season of the year. As an example, Figure 36 shows the active power load for the typical days of Spring referring to this case.

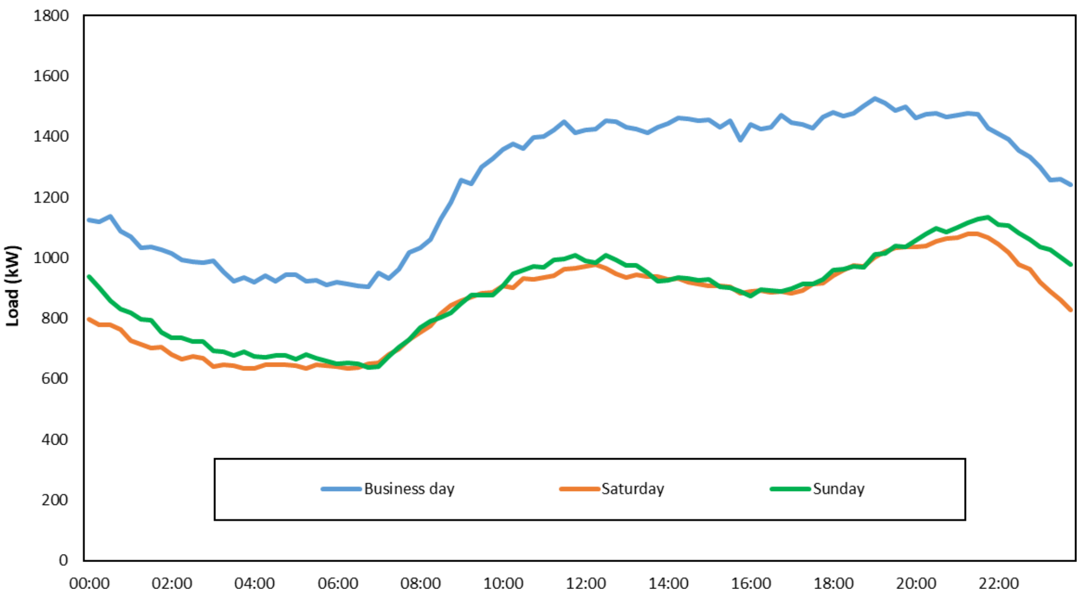



FIGURE 36 - LOAD PROFILES FOR THE CASE PT_DX_05_2020 CONSIDERING THREE TYPICAL DAYS OF SPRING.

Additionally, for each load node at each instant, upward and downward flexibility values are provided considering the scenarios Winter/Summer and Business days/Sundays. These results were calculated admitting the assumptions explained in Chapter 3 for each year in analysis: 2020, 2030, 2040 and 2050.

Likewise, this test case delivers the total generation profiles in terms of active and reactive power for the same intervals of the typical days. Figure 37 shows an illustrative example of the total generation in the typical business day of each season of the year.

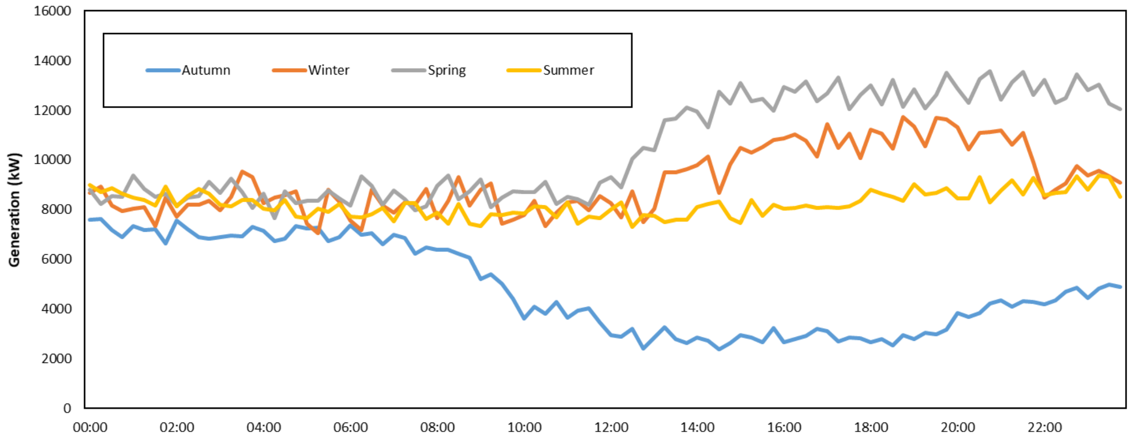



FIGURE 37 - GENERATION PROFILES FOR THE CASE PT_DX_05_2020 CONSIDERING BUSINESS DAYS OF ALL SEASONS.

In this case, there are one equivalent node besides the slack bus (bus 11), namely the bus 1, 4 and 9. Regarding the rest of the nodes, they are associated to normal MV/LV secondary substations (public) or dedicated MV/LV substations (private). Table 24 distinguishes these networks nodes between the two types.

TABLE 24 - LIST OF NODES SUPPLIED BY EACH TYPE OF SUBSTATION FOR THE CASE PT_DX_05_2020

| MV/LV substations | Nodes |
|---|---|
| Public | 18-21; 23; 24; 26-28; 30; 33; 34; 36-42; 45; 46; 49; 50; 52-54 |
| Private | 6; 7; 8; 10; 17; 22; 29; 32; 35; 43; 44; 51; 55 |

Again, along with all the information mentioned so far, this test case also delivers the load profiles and flexibility bands adjusted to 2030, 2040 and 2050. It was considered that the load growth occurs in a homothetic manner, equally distributed along the nodes. Like the previous case, comparing to the base consumption for 2020, the load for 2030, 2040 and 2050 is 100%, 100% and 120% respectively based on the information referred in Section 2.1.

## 4.13 UK_Tx_2020

This case presents a simplification of the real UK transmission grid using 30 nodes, obtained in [13]. Voltage levels are 275 and 400kV; there are 100 branches and 98 generators.

Delivered with this test case there is one auxiliary file: demand (P and Q) for a typical winter day (peak day in the UK) with hourly data [13] .

The network topology can be seen in Figure 38.

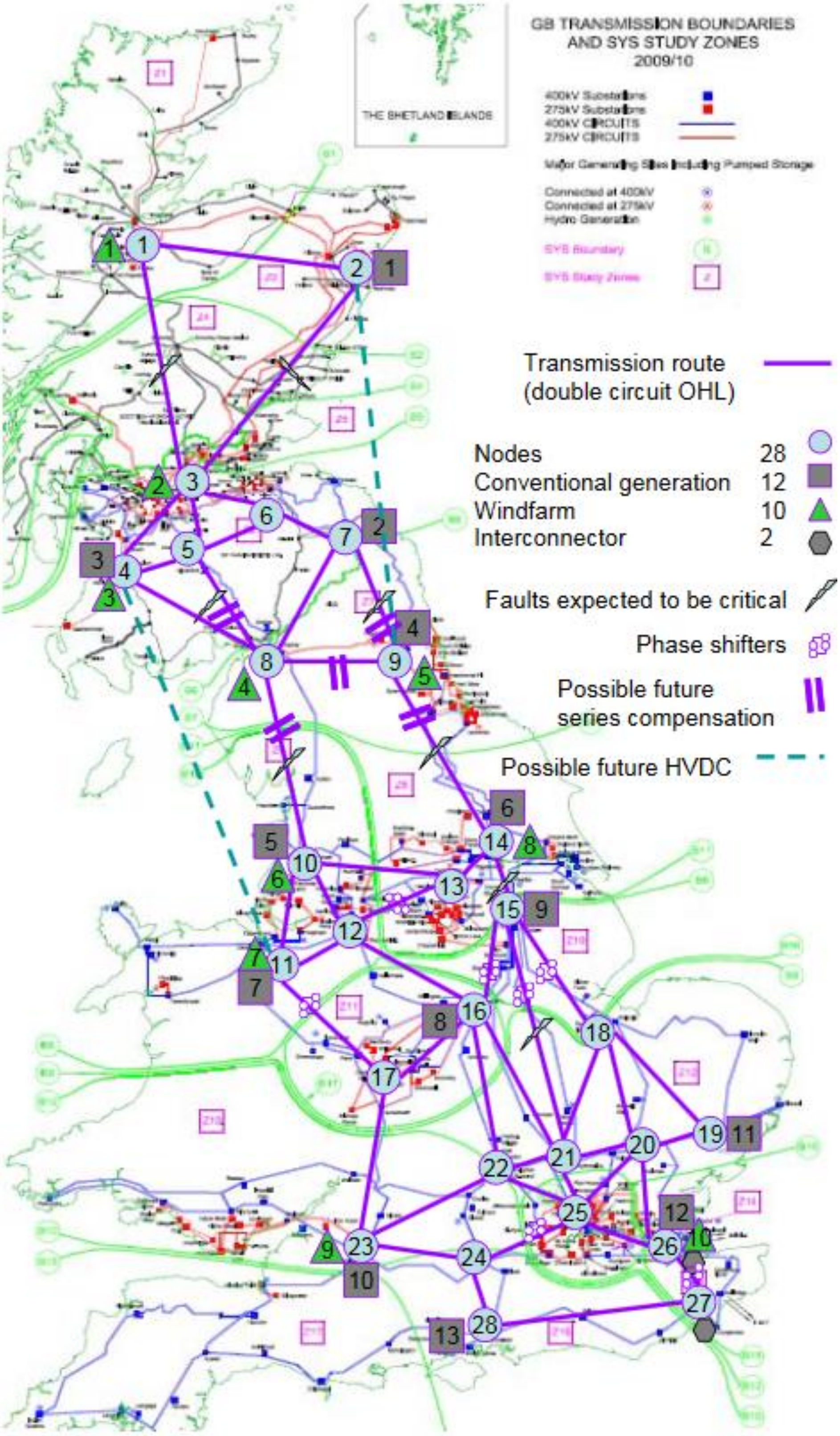



FIGURE 38 - UK 30 NODES TEST SYSTEM [13]

## 4.14 UK_Dx_01_2020

This case presents a part of a synthetic UK Distribution network located in an urban area (Green Lane - Altrincham) as in 2020 [14]. The grid, which is operated at 11 kV, has 30 nodes and 30 branches. There is no generation in the grid, apart from the slack bus with infinite capacity (bus7).

This information can be seen in the snapshot that comes with the MATPOWER file. Along with this file, this test case also delivers the hourly data of load profiles in terms of active and reactive power for typical winter day (the extreme case in UK). Figure 39 shows the active (P) and reactive (Q) power load of this specific day.

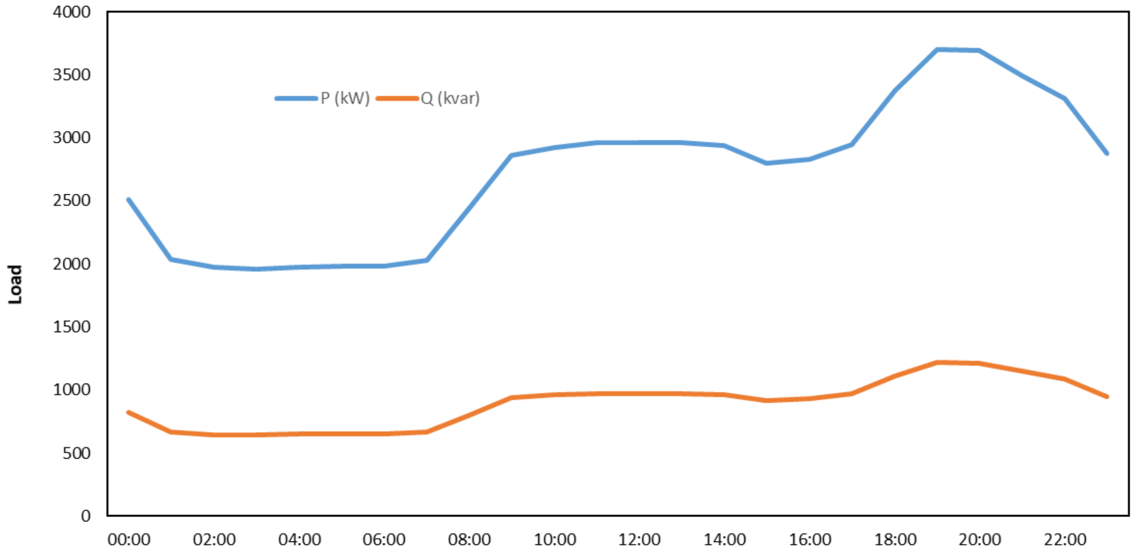



FIGURE 39 - ACTIVE AND REACTIVE LOAD POWER OF UK URBAN NETWORK.

## 4.15 UK_Dx_02_2020

This case presents a part of a synthetic UK Distribution network located in a semi-urban area (Clover Hill) as in 2020 [14]. The grid, which is operated at 6.6 kV, has 38 nodes and 39 branches. There is no generation in the grid, apart from the slack bus with infinite capacity (bus 5).

This information can be seen in the snapshot that comes with the MATPOWER file. Along with this file, this test case also delivers the hourly data of load profiles in terms of active and reactive power for typical winter day (the extreme case in UK). Figure 40 shows the active (P) and reactive (Q) power load of this specific day.

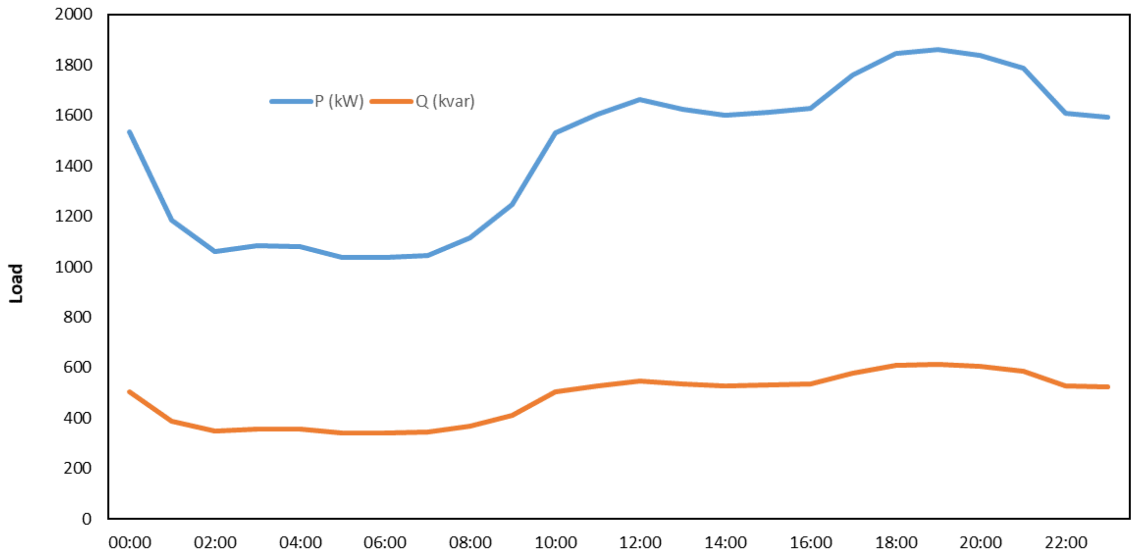



FIGURE 40 - ACTIVE AND REACTIVE LOAD POWER OF UK SEMI-URBAN NETWORK.

## 4.16 UK_Dx_03_2020

This case presents a part of a synthetic UK Distribution network located in a rural area (Exchange St.) Green Lane - Altrincham) as in 2020 [14]. The grid, which is operated at 6.6 kV, has 66 nodes and 66 branches. There is no generation in the grid, apart from the slack bus with infinite capacity (bus 3).

This information can be seen in the snapshot that comes with the MATPOWER file. Along with this file, this test case delivers also the hourly data of load profiles in terms of active and reactive power for typical winter day (the extreme case in UK). Figure 41 shows the active (P) and reactive (Q) power load of this specific day.

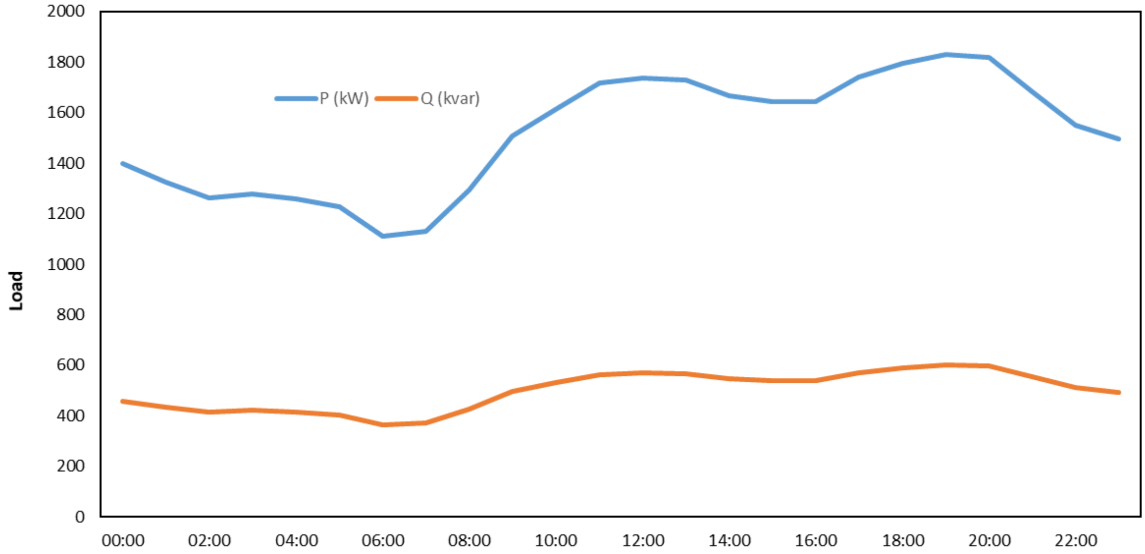



FIGURE 41 - ACTIVE AND REACTIVE LOAD POWER OF UK RURAL NETWORK.

## 4.17 HR_Tx_01_2020

This case presents part of the real Croatian Transmission grid that has been anonymized for the project. It is located around Koprivnica substation according to the demonstration of the project, and possible congestion and voltage problems arise, especially interesting for WP4.

Voltage levels are 35 kV, 110 kV, 220 kV and 400 kV; there are 31 nodes; 45 branches and 11 generators (one of which is a geothermal power plant on the distribution side).

In the remaining of the ATTEST project a new test case, based on HR_Tx_01_2020 herein described will be produced especially for WP5. This reduced network will have 21 nodes, 10 branches and 4 generators; asset data will be related to power transformers and transmission lines and circuit breakers.

Figure 42 shows a part of the transmission grid. Dashed lines represent out of service branches.

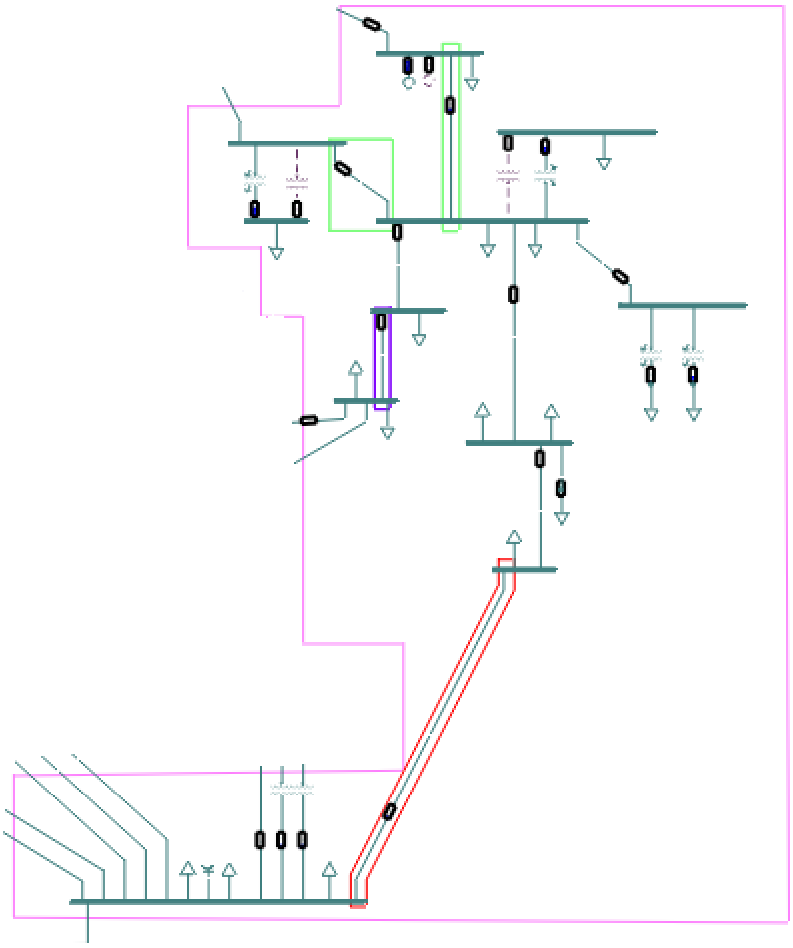


FIGURE 42 - HR_TX_01_2020 SINGLE LINE DIAGRAM

Assuming HV line SUBST1-SUBST29 is disconnected due to maintenance and HV line SUBST1-SUBST36 tripped due to failure (green solid area). Tripping of the transmission line SUBST26-SUBST55 (purple solid area) leads to congestion on HV line between buses SUBST42-SUBST72 (Figure 43).

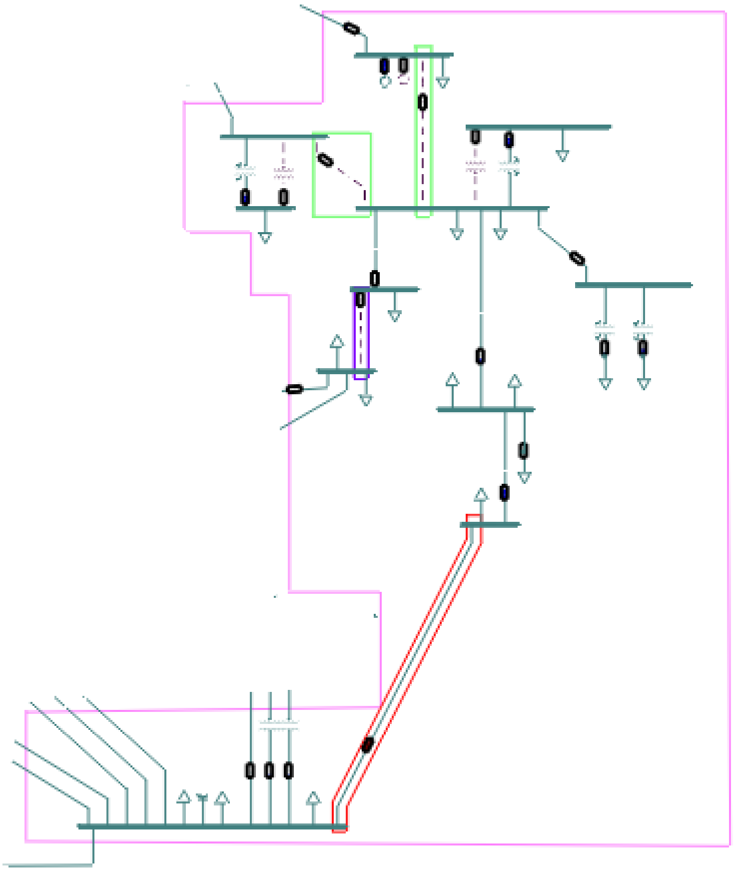


FIGURE 43 - HR_TX_01_2020 CONGESTION

Figure 44 shows congestion on HV line between buses SUBST42-SUBST72.

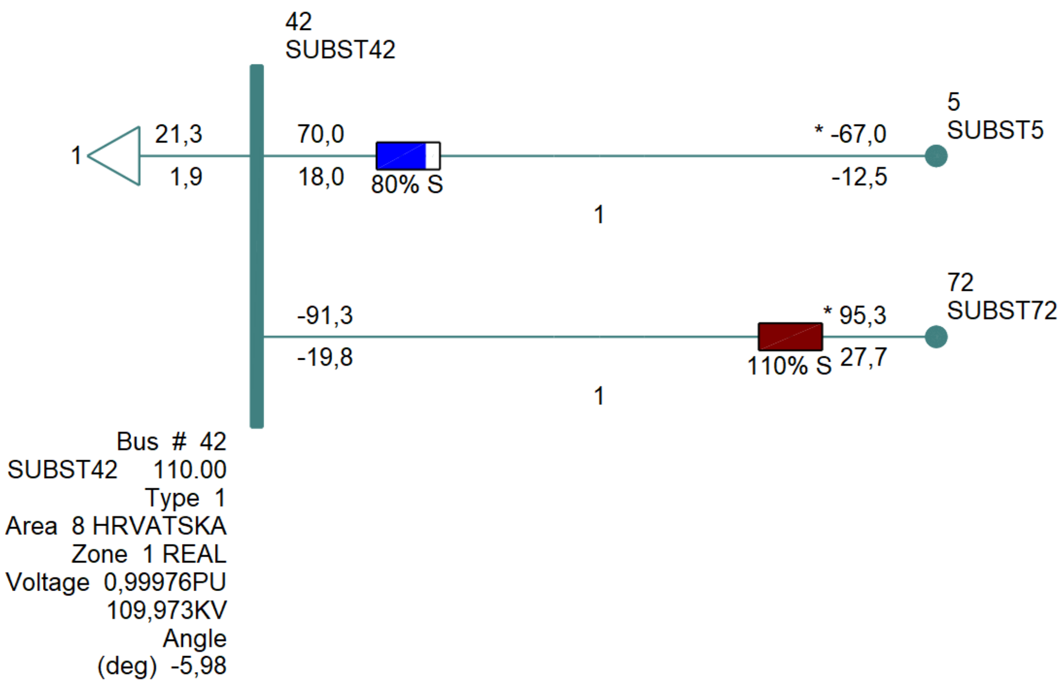



FIGURE 44 - HR_TX_01_2020 CONGESTION RESULTS

In case of tripping of a line SUBST26-SUBST55, overload is 110%. In this case HOPS has no available sources on transmission grid to mitigate congestion.

In addition to congestion problems, there are also problems with voltages in the observed part of the network at a given moment. The reason is that the entire observed part of the network is supplied radially, which causes large voltage drops at the edge nodes of the radially supplied network.

In case of large voltage drops caused by already mentioned congestion on HV line between buses SUBST42-SUBST72, HOPS does not use corrective measures.

HOPS' suggestion is to take in consideration TSO-DSO coordination mechanisms developed in ATTEST deliverable D2.4 [21] to resolve mentioned congestion and voltages problems. In case of tripping of a line SUBST26-SUBST55, overload is 110%.

## 4.18 HR_Tx_02_2020

Test case HR_Tx_02_2020 represents part of the real (anonymized) NW Transmission grid of Croatia with congestion problems. Voltage levels: 110, 220 and 400kV. There are 29 nodes, 44 branches and 13 generators. This test case is especially interesting for WP3 regarding network expansion.

Dashed lines in Figure 45 represent out of service branches.

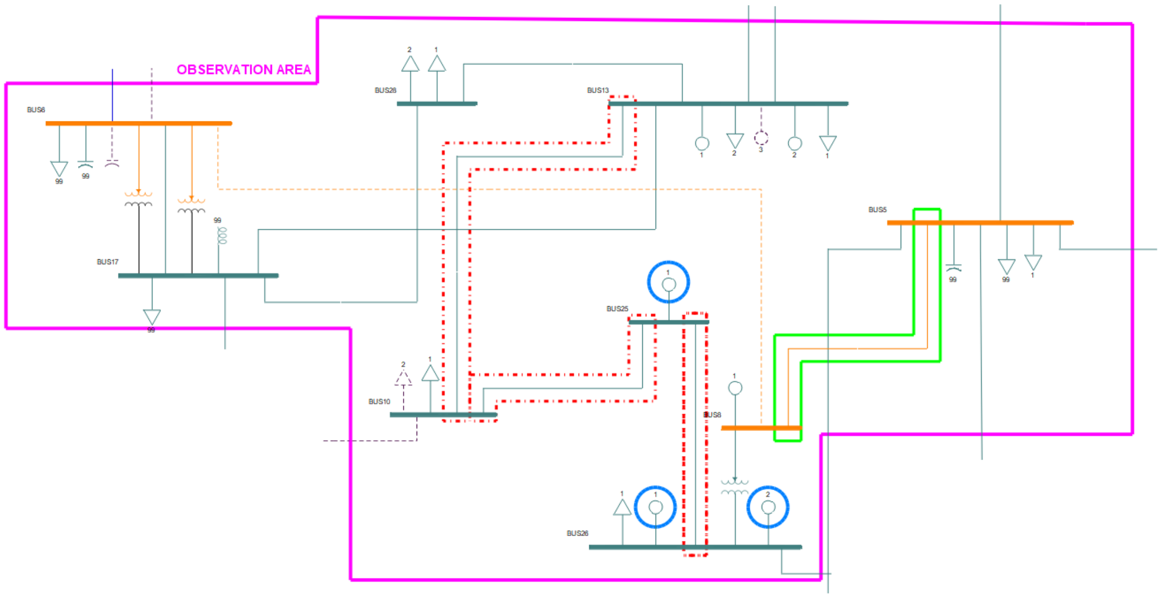



FIGURE 45 - HR_TX_02_2020 TEST CASE

Tripping of the transmission line between buses BUS5 and BUS8 (green solid area) leads to congestion on lines between buses: BUS25 – BUS26, BUS10 – BUS25, BUS10 – BUS13 (red dash-dot line).

Figure 46 shows congestions after tripping of the line between BUS5 and BUS8.

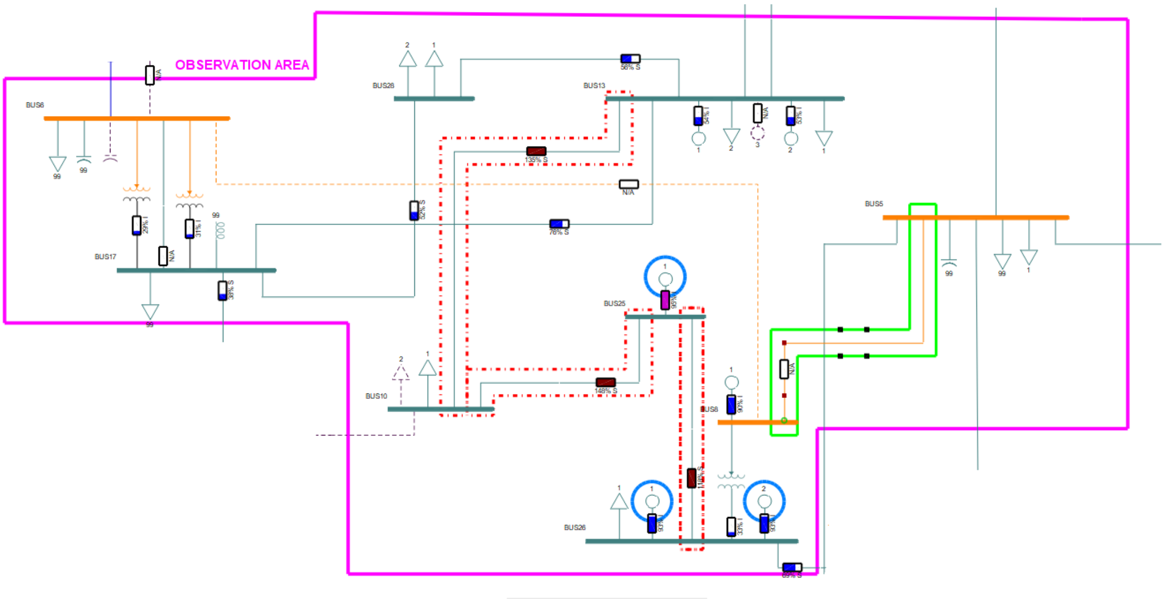



FIGURE 46 - HR_TX_02_2020 TEST CASE AFTER TRIPPING OF LINE

The overloads are as follows in the branches that connect the following buses:

- BUS25 – BUS26: 118%
- BUS10 – BUS25: 148%
- BUS10 – BUS13: 135%

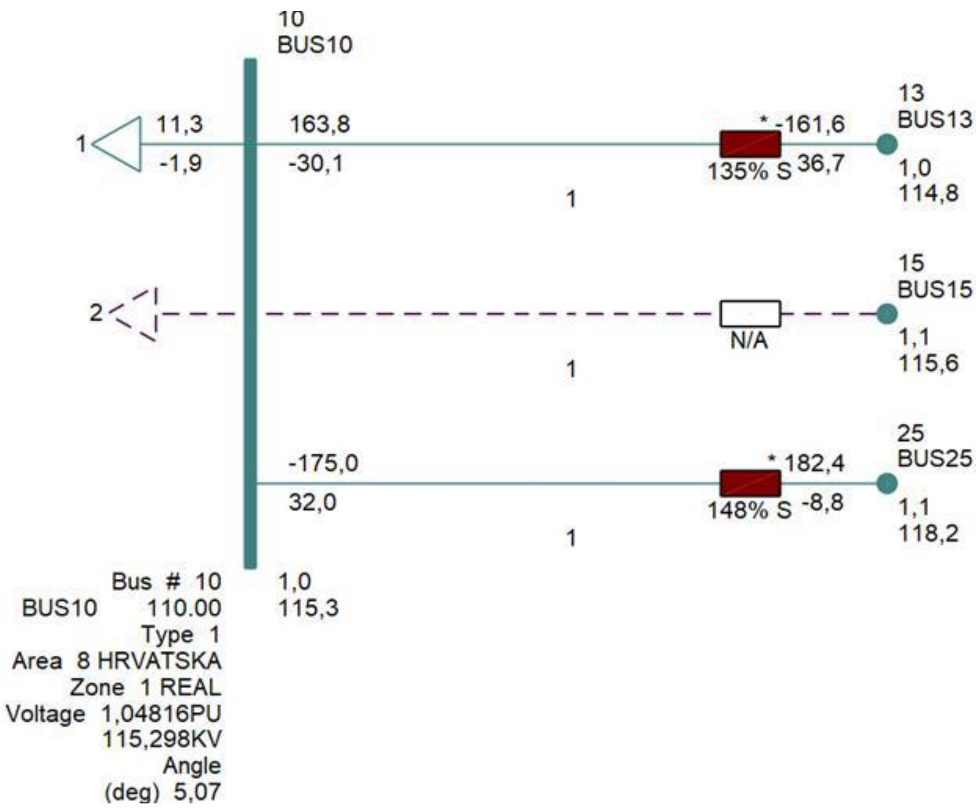



FIGURE 47 - HR_TX_02_2020 TEST CASE RESULTS AFTER TRIPPING OF LINE

## 4.19 HR_Tx_03_2020

Test case HR_Tx_03_2020 represent part of the real (anonymized) Zagreb Transmission Network, to be used together with HR_Dx_03_2020. It should be noted that in this part of the transmission network there are no significant problems with congestion and voltages, but the model is provided due to the existence of DR providers (FER and HEP buildings) in the distribution grid. This test case is particularly interesting for the tools developed in WP4. The voltage levels are 110, 220 and 400kV, there are 10 nodes, 22 branches and 4 generators.

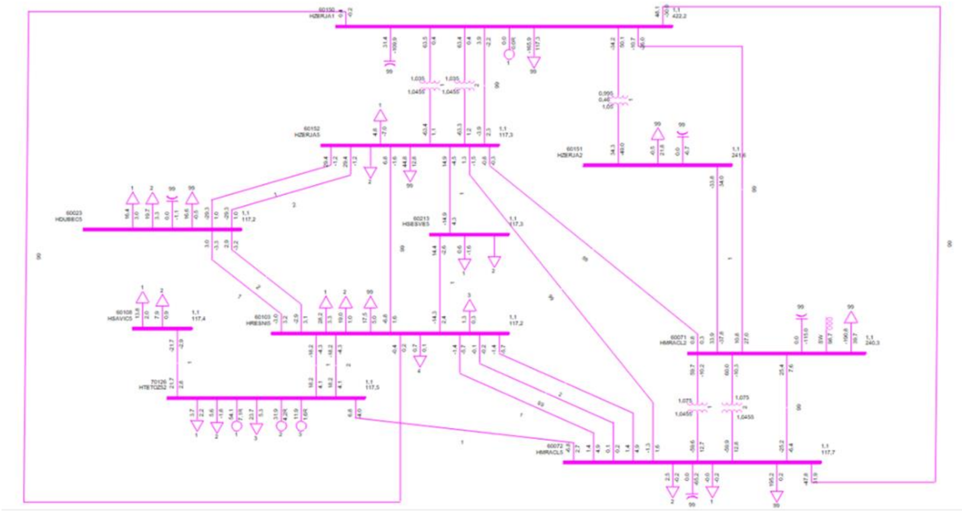


FIGURE 48 - HR_TX_03_2020 TEST CASE

## 4.20 HR_Tx_dyn_2020

This test case was developed due to the dynamic simulations necessary in task 4.6. It represents the real (anonymized) Croatian Transmission grid, simplified to 42 nodes, 27 branches and 12 generators. The voltage ranges from 0.7 to 110 kV. The test case is particularly interesting for T4.6.

There are two scenarios:

- low consumption, high wind generation and low hydro generation;

- high consumption, high hydro generation and low wind generation.

Figure 49 shows the single line diagram of the grid.

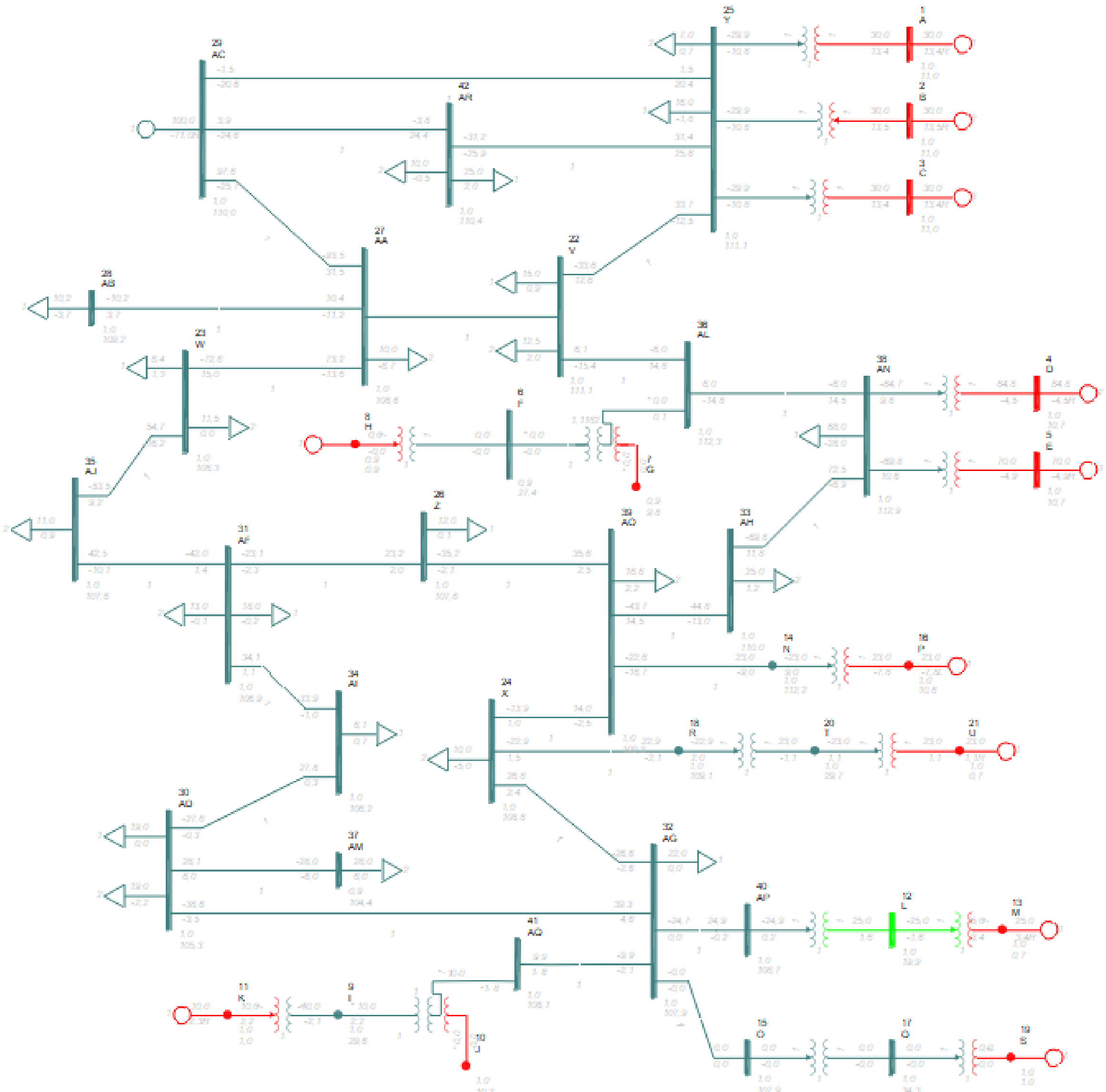


FIGURE 49 - SINGLE LINE DIAGRAM OF HR_TX_DYN_2020

The auxiliary files presented in the test case are intended for dynamic simulation. Each scenario contains one .SLD file, one .RAW file and one .DYN file[4].Two scenarios are presented, with different combination of load, wind power generation and hydro power generation.

[4] File format compatible with Power System Simulation for Engineering, widely known as PSS/E

## 4.21 HR_Dx_01_2020

This test case concerns the Koprivnica demo from the distribution grid side. The real grid has been modeled and anonymized. This grid can be coupled with HR_Tx_01_2020 in three nodes, detailed in an annex text file. The voltage level is 400V / 35kV / 20 kV /10kV, there are 40 nodes, 59 branches and 14 generators modelled as negative loads. This test case is particularly interesting for WP4.

Figure 50 presents the overview of the single line diagram.

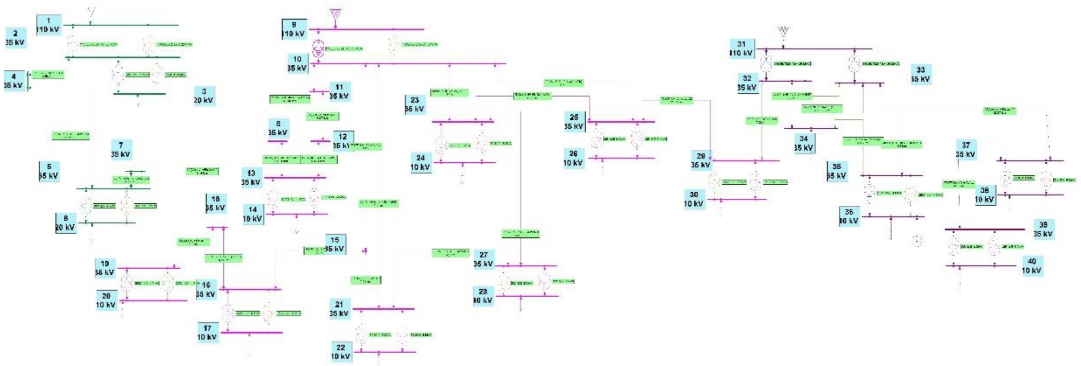


FIGURE 50 - HR_DX_01_2020 SINGLE LINE DIAGRAM

Auxiliary files are as follows:

- One file with three connection nodes to R_Tx_01_2020
- 12 auxiliary files for specific feeders: for each typical day of the season (autumn, winter, spring, summer) and weekday (business day, Saturday, Sunday), 1 file per load (containing P and Q load per node)
- One single line diagram

## 4.22 HR_Dx_02_2020

This test case concerns the area of Bjelovar from the distribution grid side. This area is a city near Koprivnica and has potential for managing DG and therefore to be used as a demo in WP7 with the tools developed in WP4. The real grid has been modeled and anonymized. This grid can be coupled with HR_Tx_01_2020 in three nodes, detailed in an annex text file. The voltage level is 110 kV / 35 kV / 10 kV / 20 kV, there are 25 nodes, 34 branches and 107 generators modelled as negative loads.

Figure 51 presents the overview of the single line diagram.

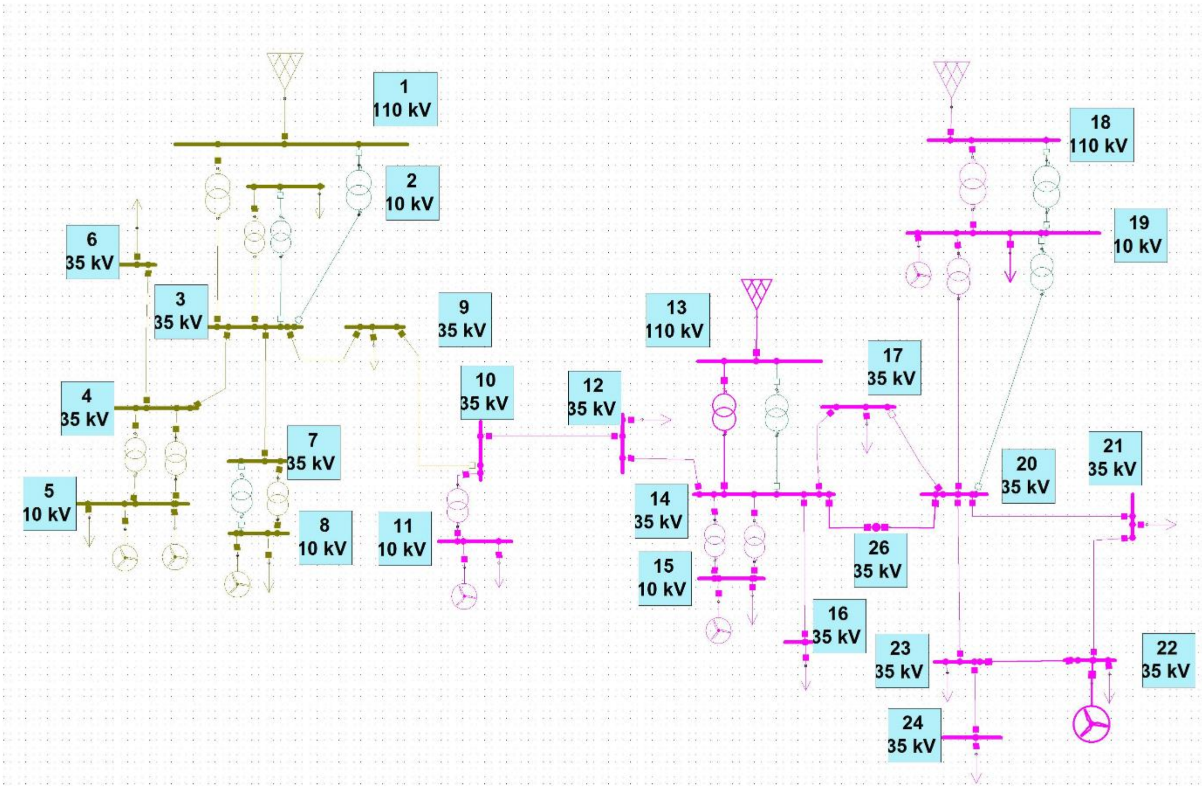



FIGURE 51 - SINGLE LINE DIAGRAM FOR HR_DX_02_2020

The list of auxiliary files is as follows:

- Loads; 12auxiliary files: for each typical day of the season (autumn, winter, spring, summer) and weekday (business day, Saturday, Sunday), 1 file per load (containing P and Q load per node). The time-step for these datasets is 1 hour.
- One text file stating the connection of nodes between TSO and DSO grids
- One single-line diagram

## 4.23 HR_Dx_03_2020

This test case concerns the area of Zagreb demo from the distribution grid side, where HEP and FER buildings are present and will provide DR in WP7 with the tools developed in WP4. The real grid has been modeled and anonymized. This grid can be coupled with HR_Tx_03_2020 in two nodes, detailed in an annex text file. The voltage level is 110 kV / 35 kV / 10 kV / 400 V, there are 24 nodes, 32 branches and 2 generators modelled as negative loads.

Figure 52 presents the single line diagram.

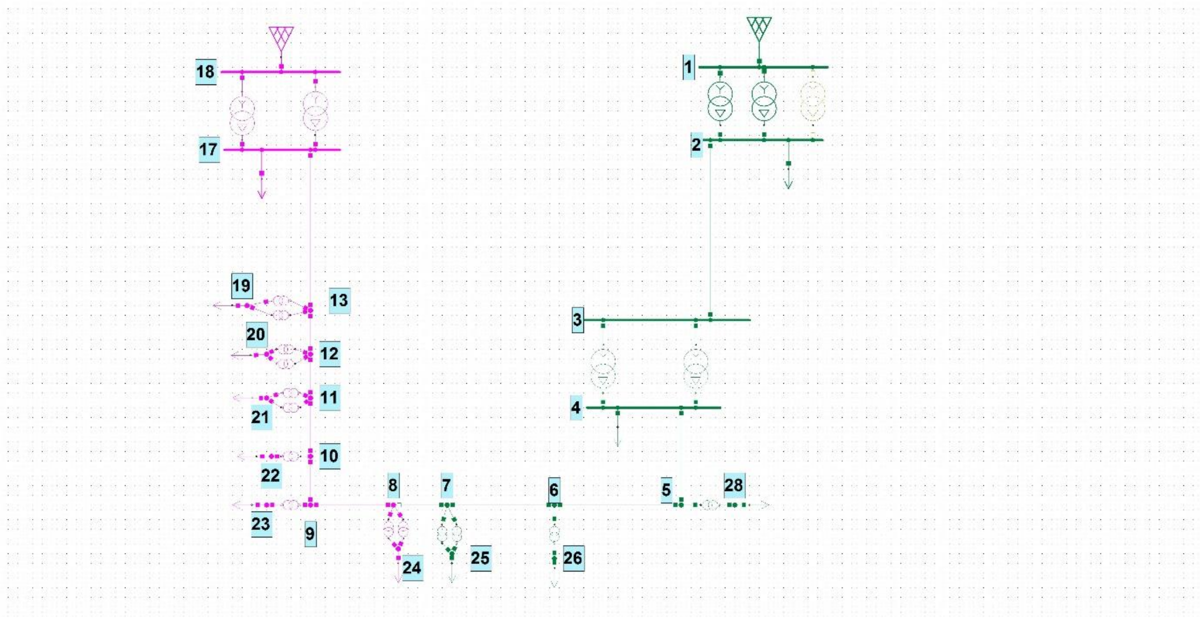



FIGURE 52 - SINGLE LINE DIAGRAM FOR HR_DX_04_2020

HEP building, as well as UNIZGFER building are supplied from transmission system substations and are operated as radial networks. Both buildings are connected to low voltage level 0.4 kV through their own 10/0.4 kV transformers (only users connected to those substations). Buildings are supplied from different MV feeders. In a one-line diagram of distribution network feeders supplying the two buildings shown below, UNIZGFER (node 24) is supplied from 110/10 kV substation (node 18), while HEP building (node 28) is supplied by 35/10 kV substation (node 3) which is connected to 110/35 kV substation (node 1) that is connected to the transmission network. There is a possibility of switching and having both supplied from a single feeder.

The list of auxiliary files is as follows:

- Loads; 12auxiliary files: for each typical day of the season (autumn, winter, spring, summer) and weekday (business day, Saturday, Sunday), 1 file per load (containing P and Q load per node). The time-step for these datasets is 1 hour.
- One text file stating the connection of nodes between TSO and DSO grids
- One single-line diagram
- One text file with a full description of the network

## 4.24 HR_Dx_04_2020

This test case concerns the Koprivnica demo from the distribution grid side, in a distinct area from the test case HR_Tx_01_2020. The real grid has been modeled and anonymized. The voltage level is 10kV, there are 86 nodes, 87 branches and 4 generators (solar PV from 5 to 55 kW installed power) modelled as negative loads. This case is particularly interesting for WP4 and WP5.

Figure 53 presents the single line diagram.

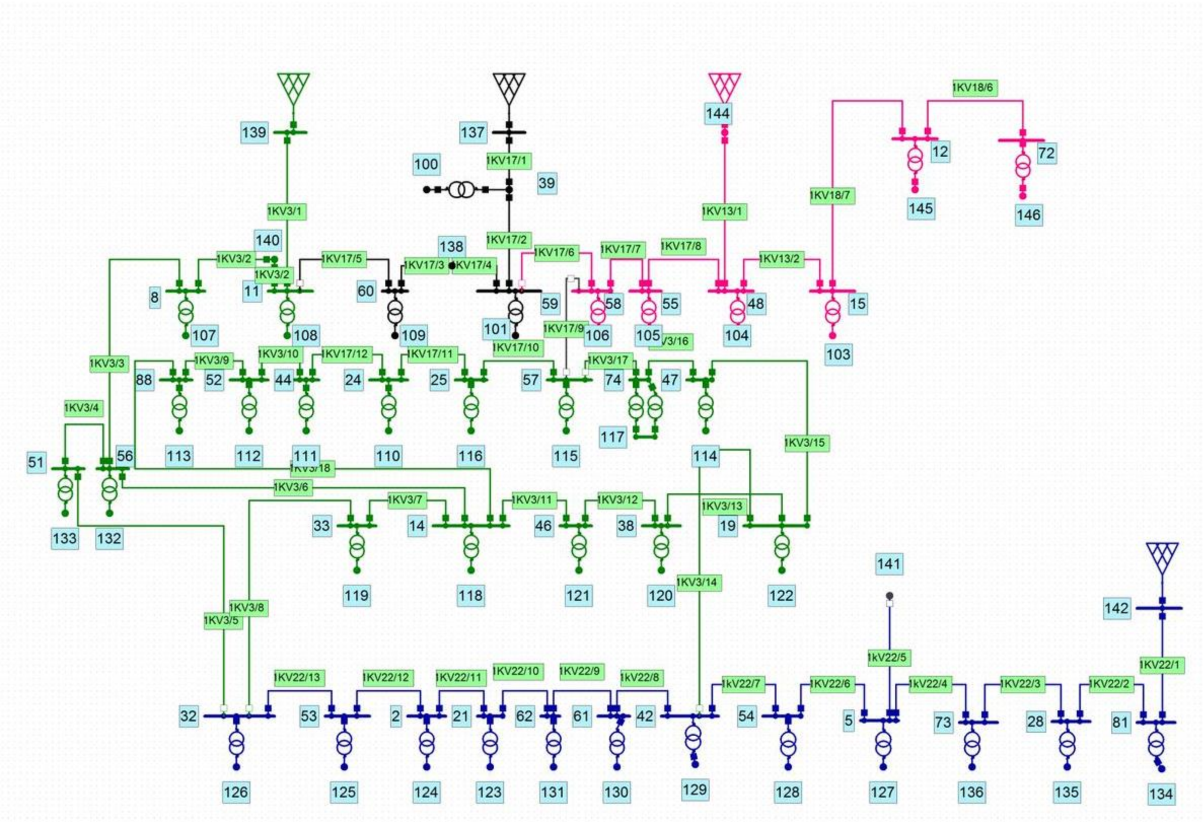



FIGURE 53 - HR_DX_04_2020 SINGLE LINE DIAGRAM

- Auxiliary files are as follows: 12 auxiliary files for specific feeders: for each typical day of the season (autumn, winter, spring, summer) and weekday (business day, Saturday, Sunday), 1 file per load (containing P and Q load per node)
- Single line diagram

## 4.25 HR_Dx_05_2020

This test case concerns the NW Croatia demo from the distribution grid side, which will be useful especially in WP3. It is meant to be used together with HR_Tx_02_2020, via two connection nodes. The real grid has been modeled and anonymized. The voltage levels are 220kV / 110kV / 35kV / 10kV / 400V, there are 26 nodes, 32 branches and 97 generators.

Figure 54 presents an overview of the single line diagram.

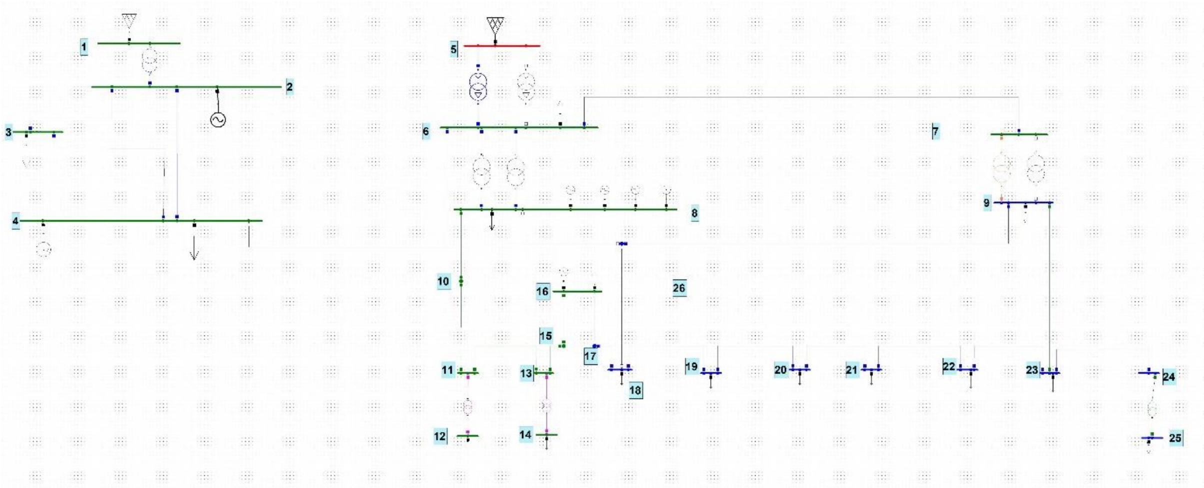



FIGURE 54 - HR_DX_05_2020 – NW CROATIA DEMO

Auxiliary files are as follows:

- 12 auxiliary files for specific feeders: for each typical day of the season (autumn, winter, spring, summer) and weekday (business day, Saturday, Sunday), 1 file per load (containing P and Q load per node)
- Single line diagram

## 4.26 ES_Dx_01_2020

This case represents a Spanish semi-urban real (anonymized) radial distribution grid. The voltage level is 15kV; there are 192 nodes and 193 branches. There are no DG units.

The accompanying asset management file is useful for WP5. The assets being currently addressed are:

- Segments (lines / cables): each including length, type (overhead, underground), model, conductors and date of commissioning;
- Distribution transformers: each including power, remote supervision or not, date of service, contracted power, number of outputs to low voltage, number of customers, number of qualified customers;
- Feeder supports (e.g. pole, tube): each including type of support, function of support, isolation type, support material, manufacturer, date of last supervision.

The auxiliary file contains operational characteristics as follows:

- Hourly load and current for the last 3 years
- Number of incidents in the feeders. Each one includes as more relevant data: power not supplied, duration, cause, customers affected, maintenance action carried out.

Finally, risk conditions are included in the file as follows:

- Evaluation of risk for each feeder, segment, support and power transformer according to the location and conditions of each asset.

Additionally, there is information about the telecontrol operation in the power transformers and feeders and incidences of this.  This data is still under evaluation before inclusion.

## 4.27 ES_Dx_02_2020

This case represents a Spanish semi-urban real (anonymized) distribution grid. The voltage level is 15kV; there are 232 nodes, 232 branches and 1 generator.

The accompanying asset management file is useful for WP5. The assets being currently addressed are:

- Segments (lines / cables): each including length, type (overhead, underground), model, conductors and date of commissioning;
- Distribution transformers: each including power, remote supervision or not, date of service, contracted power, number of outputs to low voltage, number of customers, number of qualified customers;
- Feeder supports (e.g., pole, tube): each including type of support, function of support, isolation type, support material, manufacturer, date of last supervision.

The auxiliary file contains operational characteristics as follows:

- Hourly load and current for the last 3 years
- Number of incidents in the feeders. Each one includes as more relevant data: power not supplied, duration, cause, customers affected, maintenance action carried out.

Finally, risk conditions are included in the file as follows:

- Evaluation of risk for each feeder, segment, support and power transformer according to the location and conditions of each asset.

## 4.28 ES_Dx_03_2020

This synthetic distribution network is modelling an urban area in Spain. It has been built using a Reference Network Model [16] [15]]. It models three high to medium voltage substations, 387 distribution transformers and HV, MV and LV power lines. This test case is particularly interesting for WP5 but a version without low voltage power lines has been also developed for WP3 and WP4. The network is described in MATLAB/MATPOWER format. Figure 55 illustrates the layout of the network.

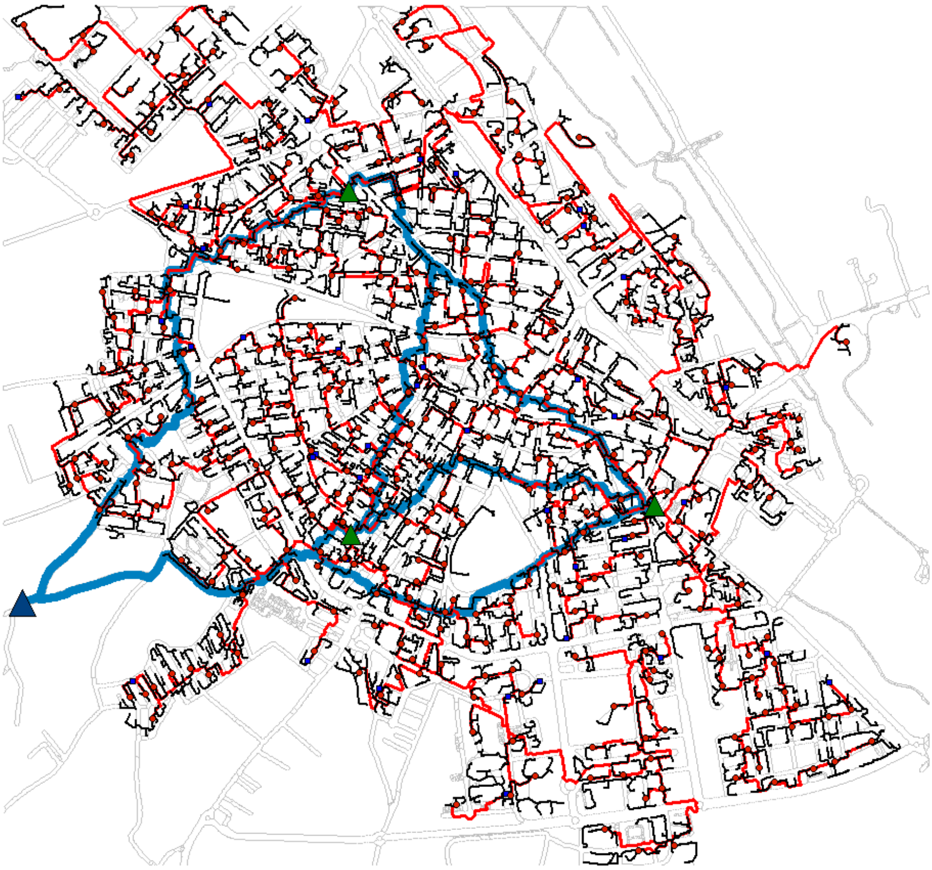


FIGURE 55 - ES_DX_03_2020 GRID TOPOLOGY

The voltage levels are 400kV / 20kV/ 400V, the network has 824 nodes and 841 branches.

# ANNEX 1 | ATTEST FORMAT CASE PT_TX_2020: NETWORK FILE

The text of the case format is presented here with more detail (although truncated for the purpose of saving space). It can be read as a MATPOWER file.

```
function mpc = Transmission_Network_PT_2020

%% MATPOWER Case Format : Version 2
mpc.version = '2';

%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 100;

%% bus data
%   bus_i   type    Pd  Qd  Gs  Bs  area    Vm  Va  baseKV  zone    Vmax
Vmin
mpc.bus = [
    1   2   0.000   0.000   0   0   1   1   0   400 1   1.05    0.95    ;
    2   2   0.000   0.000   0   0   1   1   0   400 1   1.05    0.95    ;
    …
    303 1   0.000   0.000   0   0   1   1   0   63  2   1.05    0.95    ;
    304 1   0.000   0.000   0   0   1   1   0   63  2   1.05    0.95    ;
];

%% generator data
%   bus Pg  Qg  Qmax    Qmin    Vg  mBase   status  Pmax    Pmin    Pc1 Pc2
Qc1min  Qc1max  Qc2min  Qc2max  ramp_agc    ramp_10 ramp_30 ramp_q  apf
mpc.gen = [
    1   253.567 -38.483 9999.000    -9999.000   1.0431  100.00  1
9999.000    -9999.000   0   0   0   0   0   0   0   0   0   0   0   ;
…
0   0   0   0   0   0   0   0   0   0   0   ;
    22  0.000   0.000   23.063  -23.063 1.0307  62.10   0   57.658  0.000
0   0   0   0   0   0   0   0   0   0   0   ;
    30  31.000  1.512   15.500  -12.400 1.0349  34.66   1   31.000  15.500
0   0   0   0   0   0   0   0   0   0   0   ;
…
0   0   0   0   0   0   0   0   0   0   0   ;
    293 0.000   0.000   10.000  -10.000 1.0122  26.93   0   25.000  0.000
0   0   0   0   0   0   0   0   0   0   0   ;
];

%% gen tags
% Generation Technology Type:
%  CWS (Connection with Spain),
%  FOG (Fossil Gas),
%  FHC (Fossil Hard Coal),
%  HWR (Hydro Water Reservoir),
%  HPS (Hydro Pumped Storage),
%  HRP (Hydro Run-of-river and poundage),
%  SH1 (Small Hydro - P ≤ 10 MW),
%  SH3 (Small Hydro - 10 MW < P ≤ 30 MW),
%  PVP (Photovoltaic power plant),
%  WON (Wind onshore),
%  WOF (Wind offshore),
%  MAR (Marine),
```

```
%  OTH (Other thermal, such as geothermal, biomass, biogas, Municipal solid
waste and CHP renewable and non-renewable)
%   genType
mpc.gen_tags = {
    'CWS';  'CWS';  'CWS';  'CWS';  'CWS';  'CWS';  'CWS';  'PVP';  'PVP';
'HWR';  'HWR';  'HRP';  'HRP';  'HRP';  'WON';  'SH3';  'HRP';  'HRP';
'OTH';  'WON';  'SH1';  'PVP';  'OTH';  'OTH';  'OTH';  'PVP';  'OTH';
'SH1';  'PVP';  'OTH';  'WON';  'SH1';  'SH3';  'PVP';  'HPS';  'HPS';
 …
'HRP';  'HRP';  'HRP';  'HRP';  'HRP';  'HRP';  'HRP';  'HRP';  'FOG';
'FOG';  'FOG';  'FOG';  'HRP';  'HPS';  'HPS';  'HPS';  'HPS';  'HPS';
'HPS';  'HPS';  'HPS';  'HPS';  'HWR';  'HWR';  'FHC';  'FHC';  'FHC';
'FHC';  'FHC';  'FOG';  'FOG';  'FOG';  'FOG';  'FOG';  'FOG';  'OTH';
'WON';  'WON';  'WON';  'WON';  'OTH';  'WON';  'WON';  'WON';  'WON';
'WON';  'WON';  'WON';  'HRP';  'HRP';  'HRP';  'WOF';
};

%% branch data
% If the 'step_size', 'actTap', 'minTap', 'maxTap' and 'normalTap' fields
are equal to "-1", it means that the transformer does not have tap changing
capability
% If the length is equal to "0", it means that the correspondent branch
represents a transformer
%   fbus    tbus    r   x   b   rateA (summer)  rateB (spring)  rateC
(winter)  tap ratio   shift angle     status  angmin  angmax  step_size
actTap  minTap  maxTap  normalTap   length (km)
mpc.branch = [
    8   24   0.02945 0.09879 0.03302 91   123 130 0    0    0    -360    360  0
0   0    0    0    54.0     ;
    8   176  0.02007 0.06867 0.02205 96   104 104 0    0    1    -360    360  0
…
    101 158  0.00153 0.09299 0.00000 170  170 170 1.008333333 0   1   -360
360 0.0042  15  1   25  13  0   ;
    103 160  0.00153 0.09299 0.00000 170  170 170 1.012500000 0   1   -360
360 0.0042  16  1   25  13  0   ;
    103 160  0.00151 0.09267 0.00000 170  170 170 1.012500000 0   1   -360
360 0.0042  16  1   25  13  0   ;
    105 164  0.00182 0.08988 0.00000 170  170 170 1.016666667 0   1   -360
360 0.0042  17  1   25  13  0   ;
    105 164  0.00184 0.09109 0.00000 170  170 170 1.016666667 0   1   -360
360 0.0042  17  1   25  13  0   ;
];
```

# ANNEX 2 | ATTEST FORMAT FOR CASE PT_TX_2020: AUXILIARY FILE

This annex illustrates the auxiliary file for the PT_Tx_2020 test case. Figure 56 shows a screenshot of the spreadsheet that describes all spreadsheets encompassed in this file.

| | A |
|---|---|
| 1 | A description of the spreadsheets of this file is provided below. |
| 2 | |
| 3 | **"Load P (MW)" and "Load Q (Mvar)" spreadsheets** |
| 4 | Column A: refers to the network bus where the load is connected to. |
| 5 | Columns B to Y: contain the loads' power values for each hour of the day. |
| 6 | |
| 7 | **"Gen Status" spreadsheet** |
| 8 | Column A: refers to the network bus where the generator is connected to. It is worth mentioning that the generators are presented in the same order as in the network file. |
| 9 | Columns B to Y: contain the generators' status (as a result of the unit commitment exercise) for each hour of the day. |
| 10 | |
| 11 | **"Gen P (MW)" and "Gen Q (Mvar)" spreadsheets** |
| 12 | Column A: refers to the network bus where the generator is connected to. It is worth mentioning that the generators are presented in the same order as in the network file. |
| 13 | Columns B to Y: contain the generators' power quantities (as a result of the dispatch exercises) for each hour of the day. It is important to state that the reactive power limits of the generators were artificially reduced to only 75% of their physical limits within the reactive power dispatch exercise, in order to prevent them from reaching their reactive power limits – thus, generators will be able to provide voltage control through reactive power support. |
| 14 | |
| 15 | **"Gen Vg (pu)" spreadsheet** |
| 16 | Column A: refers to the network bus where the generator is connected to. It is worth mentioning that the generators are presented in the same order as in the network file. |
| 17 | Columns B to Y: contain the regulated voltage magnitude setpoint (in pu) for each hour of the day. |
| 18 | |
| 19 | **"Transf Tap Ratio" spreadsheet** |
| 20 | Columns A and B: refer to the network buses where the transformer is connected to. It is worth mentioning that the transformers are presented in the same order as in the network file. |
| 21 | Columns C to Z: contain the transformers' winding 1 off-nominal turns ratio (in pu of winding 1 bus base voltage) for each hour of the day. |
| 22 | |
| 23 | **"Transf Data" spreadsheet** |
| 24 | Columns A and B: refer to the network buses where the transformer is connected to. It is worth mentioning that the transformers are presented in the same order as in the network file. |
| 25 | Column C: contains the transformer's manufacture year. |
| 26 | Column D: contains the transformer's commissioning year. |
| 27 | |
| 28 | **"Lines_Cables Data" spreadsheet** |
| 29 | Columns A and B: refer to the network buses where the line/cable is connected to. It is worth mentioning that the lines/cables are presented in the same order as in the network file. |
| 30 | Column C: contains the length (in km) of the line/cable. |
| 31 | Column D: contains the type of installation (overhead, underground or submarine) of the line/cable. |
| 32 | |
| 33 | **"Auxiliary Data" spreadsheet** |
| 34 | Column A : refers to the type of distribution network (urban, semi-urban, rural). |
| 35 | Columns B to Y: contain the typical percentages of downward and upward flexible load for each type of distribution network and for each hour of the day. |
| 36 | |
| 37 | **"Downward Flexibility" spreadsheet** |
| 38 | Column A : refers to the network bus where the load is connected to. |
| 39 | Columns B to Y: contain the downward flexible load values for each hour of the day. |
| 40 | |
| 41 | **"Upward Flexibility" spreadsheet** |
| 42 | Column A : refers to the network bus where the load is connected to. |
| 43 | Columns B to Y: contain the upward flexible load values for each hour of the day. |

FIGURE 56 - SCREENSHOT FROM THE AUXILIARY FILE OF THE PT_TX_2020 TEST CASE – SPREADSHEET "FILE DESCRIPTION"

In Figure 57, a screenshot of the spreadsheet that contains the active power values of the loads for each hour of the day is presented.

D11 103.853

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Bus \ Hour** | **00:00 - 01:00** | **01:00 - 02:00** | **02:00 - 03:00** | **03:00 - 04:00** | **04:00 - 05:00** | **05:00 - 06:00** | **06:00 - 07:00** | **07:00 - 08:00** | **08:00 - 09:00** | **09:00 - 10:00** | **10:00 - 11:00** |
| 2 | 11 | 0.661 | 0.613 | 0.586 | 0.573 | 0.572 | 0.58 | 0.625 | 0.719 | 0.825 | 0.874 | 0.876 |
| 3 | 13 | 2.642 | 2.451 | 2.345 | 2.291 | 2.286 | 2.321 | 2.502 | 2.875 | 3.301 | 3.496 | 3.503 |
| 4 | 26 | 2.246 | 2.083 | 1.993 | 1.947 | 1.943 | 1.973 | 2.127 | 2.443 | 2.806 | 2.972 | 2.978 |
| 5 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 28 | 0.132 | 0.123 | 0.117 | 0.115 | 0.114 | 0.116 | 0.125 | 0.144 | 0.165 | 0.175 | 0.175 |
| 7 | 67 | 0.793 | 0.735 | 0.703 | 0.687 | 0.686 | 0.696 | 0.751 | 0.862 | 0.99 | 1.049 | 1.051 |
| 8 | 108 | 11.277 | 10.458 | 10.006 | 9.776 | 9.756 | 9.906 | 10.676 | 12.267 | 14.089 | 14.92 | 14.951 |
| 9 | 109 | 196.678 | 182.401 | 174.519 | 170.506 | 170.163 | 172.778 | 186.207 | 213.955 | 245.727 | 260.221 | 260.757 |
| 10 | 110 | 123.296 | 114.346 | 109.405 | 106.889 | 106.674 | 108.313 | 116.732 | 134.127 | 154.045 | 163.131 | 163.467 |
| 11 | 111 | 117.039 | 108.544 | 103.853 | 101.465 | 101.261 | 102.817 | 110.809 | 127.321 | 146.228 | 154.853 | 155.172 |
| 12 | 112 | 155.297 | 144.024 | 137.801 | 134.632 | 134.362 | 136.426 | 147.03 | 168.94 | 194.027 | 205.472 | 205.894 |
| 13 | 113 | 53.762 | 49.859 | 47.705 | 46.608 | 46.514 | 47.229 | 50.9 | 58.485 | 67.17 | 71.132 | 71.278 |
| 14 | 114 | 120.106 | 111.387 | 106.574 | 104.123 | 103.914 | 105.511 | 113.712 | 130.657 | 150.059 | 158.91 | 159.237 |
| 15 | 115 | 44.094 | 40.893 | 39.126 | 38.227 | 38.15 | 38.736 | 41.747 | 47.968 | 55.091 | 58.34 | 58.46 |
| 16 | 116 | 237.619 | 220.37 | 210.847 | 205.999 | 205.585 | 208.744 | 224.969 | 258.493 | 296.879 | 314.39 | 315.037 |
| 17 | 117 | 39.571 | 36.698 | 35.112 | 34.305 | 34.236 | 34.762 | 37.464 | 43.047 | 49.439 | 52.356 | 52.463 |
| 18 | 118 | 89.062 | 82.598 | 79.028 | 77.211 | 77.056 | 78.24 | 84.321 | 96.886 | 111.274 | 117.837 | 118.08 |
| 19 | 119 | 179.838 | 166.784 | 159.577 | 155.907 | 155.594 | 157.985 | 170.265 | 195.637 | 224.689 | 237.942 | 238.431 |
| 20 | 120 | 103.054 | 95.573 | 91.443 | 89.341 | 89.161 | 90.531 | 97.568 | 112.107 | 128.755 | 136.349 | 136.63 |
| 21 | 121 | 87.959 | 81.574 | 78.049 | 76.254 | 76.101 | 77.27 | 83.277 | 95.686 | 109.895 | 116.377 | 116.617 |
| 22 | 122 | 164.165 | 152.248 | 145.669 | 142.319 | 142.034 | 144.216 | 155.426 | 178.586 | 205.106 | 217.204 | 217.651 |
| 23 | 123 | 142.231 | 131.907 | 126.206 | 123.304 | 123.057 | 124.947 | 134.659 | 154.726 | 177.702 | 188.184 | 188.571 |
| 24 | 124 | 96.948 | 89.911 | 86.025 | 84.047 | 83.878 | 85.167 | 91.787 | 105.465 | 121.126 | 128.271 | 128.534 |
| 25 | 125 | 92.699 | 85.97 | 82.255 | 80.364 | 80.202 | 81.434 | 87.764 | 100.842 | 115.817 | 122.649 | 122.901 |
| 26 | 126 | 68.74 | 63.751 | 60.996 | 59.593 | 59.473 | 60.387 | 65.081 | 74.779 | 85.884 | 90.95 | 91.137 |
| 27 | 127 | 60.761 | 56.35 | 53.915 | 52.675 | 52.57 | 53.377 | 57.526 | 66.099 | 75.914 | 80.392 | 80.557 |
| 28 | 128 | 230.493 | 213.762 | 204.524 | 199.821 | 199.42 | 202.484 | 218.223 | 250.741 | 287.976 | 304.962 | 305.59 |
| 29 | 129 | 208.42 | 193.291 | 184.938 | 180.686 | 180.323 | 183.093 | 197.325 | 226.73 | 260.399 | 275.758 | 276.325 |
| 30 | 130 | 251.544 | 233.285 | 223.204 | 218.071 | 217.633 | 220.977 | 238.153 | 273.642 | 314.278 | 332.815 | 333.5 |
| 31 | 131 | 108.757 | 100.863 | 96.504 | 94.285 | 94.095 | 95.541 | 102.967 | 118.311 | 135.88 | 143.895 | 144.191 |
| 32 | 132 | 8.034 | 7.451 | 7.129 | 6.965 | 6.951 | 7.058 | 7.607 | 8.74 | 10.038 | 10.63 | 10.652 |
| 33 | 133 | 96.335 | 89.342 | 85.482 | 83.516 | 83.348 | 84.629 | 91.207 | 104.798 | 120.361 | 127.46 | 127.722 |
| 34 | 134 | 133.913 | 124.192 | 118.825 | 116.093 | 115.86 | 117.64 | 126.784 | 145.677 | 167.309 | 177.178 | 177.542 |

FIGURE 57 - SCREENSHOT FROM THE AUXILIARY FILE OF THE PT_TX_2020 TEST CASE – SPREADSHEET: "LOAD P (MW)"

# ANNEX 3 | POWER FLOW RESULTS WITH MATPOWER - CASE PT_TX_2020

By using the function *runpf* to run a power flow in MATPOWER [1], the following results were obtained. Note that results were truncated to save space. A summary of the main variables is obtained, together with the data of buses (voltage magnitudes, voltage angles, etc.) and branches (active and reactive power bus injections, losses, etc.).

MATPOWER Version 7.0, 20-Jun-2019 -- AC Power Flow (Newton)

Newton's method power flow (power balance, polar) converged in 5 iterations.

Converged in 0.24 seconds

================================================================================

| System Summary |

================================================================================

| How many? | | How much? | P (MW) | Q (MVAr) |
|---|---|---|---|---|
| Buses | 266 | Total Gen Capacity | 90405.4 | -77398.8 to 79732.8 |
| Generators | 270 | On-line Capacity | 79619.6 | -73479.7 to 74956.7 |
| Committed Gens | 70 | Generation (actual) | 6477.0 | 405.5 |
| Loads | 82 | Load | 6384.7 | 961.5 |
| Fixed | 82 | Fixed | 6384.7 | 961.5 |
| Dispatchable | 0 | Dispatchable | -0.0 of -0.0 | -0.0 |
| Shunts | 12 | Shunt (inj) | -0.0 | -1147.2 |
| Branches | 509 | Losses (I^2 * Z) | 92.26 | 1069.84 |
| Transformers | 203 | Branch Charging (inj) | - | 2773.0 |
| Inter-ties | 0 | Total Inter-tie Flow | 0.0 | 0.0 |
| Areas | 1 | | | |

| | Minimum | Maximum |
|---|---|---|
| Voltage Magnitude | 1.006 p.u. @ bus 23 | 1.049 p.u. @ bus 234 |
| Voltage Angle | -14.47 deg @ bus 147 | 13.82 deg @ bus 161 |
| P Losses (I^2*R) - | 3.95 MW @ line 83-100 | |

Q Losses (I^2*X) - 44.89 MVAr @ line 83-100

================================================================================

| Bus Data |

================================================================================

```
 Bus    Voltage      Generation          Load
  #  Mag(pu) Ang(deg)  P (MW)  Q (MVAr)  P (MW)  Q (MVAr)
----- ------- --------  --------  --------  --------  --------
    1    1.044   0.000*  -251.86    -8.03      -       -
    2    1.047   9.377     0.00   -48.83      -       -
    3    1.046   8.276  -136.52   -51.46      -       -
    4    1.039  -3.975  -203.94   -28.24      -       -
    5    1.030   3.586    -6.87   -11.15      -       -
....
262  1.034   5.751    43.00     1.60      -       -
 263  1.024  -0.113     8.00    16.71      -       -
 264  1.026   1.671    32.00     0.95      -       -
 265  1.036   7.914    68.00   -10.66      -       -
 266  1.046   6.014    63.00    27.08      -       -
                    --------  --------  --------  --------
             Total:  6476.96   405.49  6384.70   961.50
```

================================================================================

| Branch Data |

================================================================================

```
Brnch   From   To    From Bus Injection   To Bus Injection     Loss (I^2 * Z)
  #     Bus    Bus   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
-----  -----  -----  --------  --------  --------  --------  --------  --------
   1     8     24   -76.83     9.97    78.55    -7.66    1.720     5.77
   2     8    174     0.00    -2.62    -0.00     0.33    0.000     0.00
   3     8    174    -0.00    -2.63     0.00     0.32    0.000     0.00
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4 | 9 | 14 | -39.41 | -2.20 | 39.43 | 2.03 | 0.021 | 0.11 |
| 5 | 9 | 14 | -40.30 | -2.07 | 40.33 | 1.91 | 0.022 | 0.12 |
| … | | | | | | | | |
| 506 | 105 | 162 | 18.08 | 0.13 | -18.08 | 0.15 | 0.006 | 0.28 |
| 507 | 253 | 254 | 2.98 | 1.69 | -2.98 | -1.68 | 0.000 | 0.01 |
| 508 | 253 | 254 | 2.99 | 1.69 | -2.99 | -1.68 | 0.000 | 0.01 |
| 509 | 253 | 254 | 2.04 | 1.15 | -2.04 | -1.14 | 0.000 | 0.01 |
| | | | | | | | -------- | -------- |
| | | | | | | Total: | 92.258 | 1069.84 |

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