OPTIGRID

D2.1 - Validation of transmission network and MIBEL data

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Executive Summary

The work presented in this deliverable was developed by LNEG and R&D NESTER as part of the R&D activities of the project *OPTIGRID - Methodology for the dynamic line rating analysis and optimal management of power networks*. According to the plan activities of Tasks 2.2 and 2.3, the main objective of this deliverable is to present the transmission network and the Iberian electricity market (MIBEL) data gathered and validated to use in each case study.

According to the work plan, and as detailed reported in the deliverables from Task 4, three case studies were defined: 1) a region with large distributed wind capacity; 2) a region with large photovoltaic (PV) potential and limited grid capacity.; and 3) market splitting occurrence in MIBEL due to congestion in the interconnections - Figure 1. For these regions, during this project, the high voltage network topology and its electrical characteristics (e.g., cables, resistance, reactance, and susceptance) were collected. The power generation, the loads in the regions under analysis were also obtained. Finally, to address the third case study, the interchange capacity (import and export) available and the bids of the day-ahead and intra-day markets at those hours are also gathered and analysed.

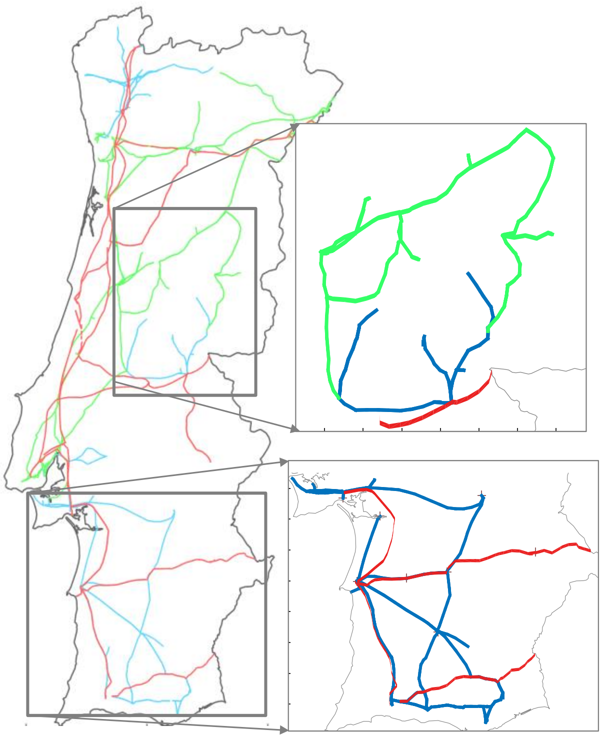

Figure 1 - Identification of the regions and the overhead power lines used in each case study. The blue, green and red lines represent the line voltage: 150, 220, and 400 kV, respectively.

The meteorological data from the year 2018 was selected to use in the mathematical models for all case studies under development. This choice mainly occurs due to the extreme weather conditions observed during this year and the consequent number of hours with electricity market split that enables assessing the DLR potential to reduce *i)* congestion problems and increase the renewable energy sources share into the power system, and *ii)* the MIBEL price in Portugal. Moreover, after this year, no substantial changes in the topology and electrical characteristics of the transmission network in the regions of the case studies under analysis were observed. Thus, the period considered can provide a significant insight regarding the future expansion/uprating of the national transmission electrical grid.

For confidentiality reasons, only the non-confidential data are presented in this report. Nevertheless, within the scope of this project, all the data need to apply the mathematical models under development were attained.

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1. Introduction

The present deliverable was developed by the Laboratório Nacional de Energia e Geologia (LNEG) and R&D NESTER as part of the R&D activities of the OptiGRID project - *Task 2: Meteorological, network and market data* - that deal with the data gathering and validation for conducting the research activities foreseen in this project. Specifically, this report describes the *i)* Portuguese transmission network data and *ii)* market data related to the Iberian Electricity Market (MIBEL) that will feed the methodology under development in this project for the dynamic line rating (DLR) analysis and optimal management of power networks.

The main limiting factor for the transmission capacity of overhead lines (OHLs) is usually defined by a thermal constraint [1],[2]. The static seasonal line rating (SLR) methodology, traditionally used by the system operators to ensure that the grid does not operate over the maximum pre-defined conductor temperature, determines the line's ampacity using: *i)* seasonal weather basis information or *ii)* conservative weather conditions. These conditions usually underestimate the real transmission capacity of OHLs. For this reason, several authors argue that the DLR analysis models can represent a safe and cost-efficient way to deal with potentially congested electrical networks allowing the optimal integration of distributed renewable power generation [2]–[6]. In fact, the use of DLR analysis may postpone the upgrade of congested power lines or avoid the building of new power lines to cope with the national renewable generation targets foreseen for the coming years.

To evaluate the DLR methodology proposed in this project, namely, the additional power line capacity obtained by using this technique when compared with the traditional SLR methodology, a mathematical model to optimize the power flow (OPF) [7] for the electric grids of a general power system and a graphical user interface (GUI) to assemble all intervening modules [4], [5] are also being developed, as schematically depicted in Figure 2. As detailed in deliverables from Task 4, the methodology will be applied to three different case studies in Portugal: 1) a region of the Portuguese power system with a large amount of distributed wind generation; 2) a region of the network with high distributed solar photovoltaic (PV) potential, but grid capacity limitation to allow its embedment; and 3) market splitting occurrence in the Iberian Electricity

Market (MIBEL) due to congestion in the interconnections - Figure 2. Therefore, to properly identify the benefits of DLR, accurate data concerning the Portuguese transmission network (grid topology and properties) and the MIBEL operation (*e.g.*, load and generation) are crucial. The first step comprised the collection of all public data needed and their validation. Then, the remaining data required to achieve the goals of the project were complemented by R&D NESTER based on their databases.

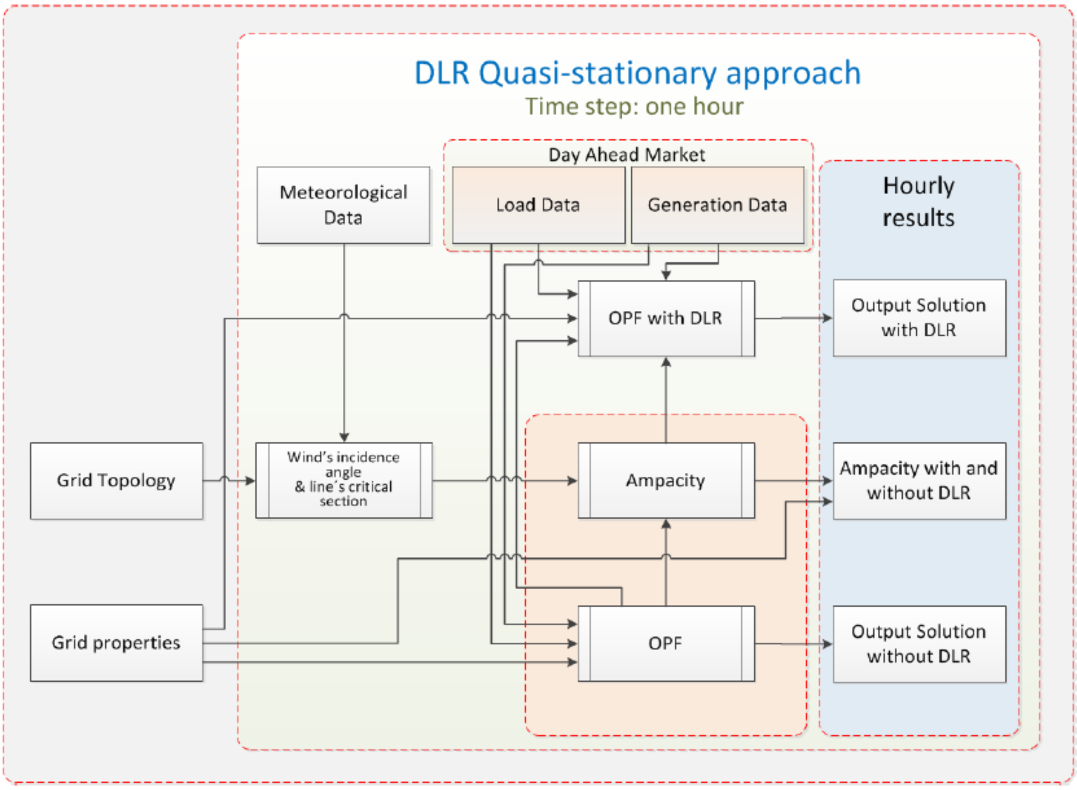


Figure 2 - Schematic representation of the approach for DLR analysis under development in the OptiGRID project.

Section 2 presents the data needed to conduct the research activities of the OptiGRID project as well as the data control and quality procedures implemented. In Section 3, the transversal and specific data for each case study are presented. Lastly, in section 4 some final remarks are provided.

2. Identification of the data needed for the DLR analysis

A dataset will be defined to cover all the regions of the network to be analyzed in each case study. Several days of operation of the Portuguese power system will be selected to highlight the added value of the DLR methodology, including under windy, sunshiny and MIBEL constraints conditions. Apart from the meteorological conditions (that will be explored in Task 2.1: Meteorological forecast data - Coupling NWP and CFD Modeling), the necessary data to conduct the OptiGRID research activities can be split into two essential types of data:

1) Portuguese transmission and distribution networks: georeferenced layout and topology of the national transmission network (identification of all buses/substations, wind, solar PV and hydropower plants) and its electrical characteristics (e.g., cables, resistance, reactance and susceptance) and the different load and generation hourly profiles. Additionally, the following information was also collected and validated: the location of the vertex towers with the indication of the connections busbar (when more than one bus/substation in the same place); the technical characteristics of transformers and the respective connecting specifications; the location, connections and technical characteristics of reactive power compensation systems (*e.g.*, shunts, and capacitor banks); and nominal loads and generation capacities associated with each busbar.

The network data gathered during this project comprises the current topology of the Portuguese transmission network (RNT), but also for future topologies of network expansion already planned by the transmission system operator (TSO) to accommodate additional levels of energy from renewable power sources. It covers the voltage levels of 400, 220 and 150 kV, including the interconnection with Spain and the interface with the distribution network at the 60 kV level.

2) Historical operation of day-ahead and intraday electricity markets in MIBEL: identification of hours in which the market splitting mechanism has been activated. This comprises public information from market agents and their participation in MIBEL, including their supply and demand bids (quantity and price), as well as from MIBEL itself, namely the day-ahead and intra-day market-clearing prices, interconnection capacities, among others [8].

2-1. Data validation

The main steps of data validation are depicted in Figure 3. The procedure consists of an internal peer revision with the data collecting task assigned to one person of *partner A*. Then, a second person of this partner performs a control and quality (C&Q) check of the data before sending it to partner B. P*artner B* is also responsible for carefully reviewing the data received and requesting additional information if any problem is detected.

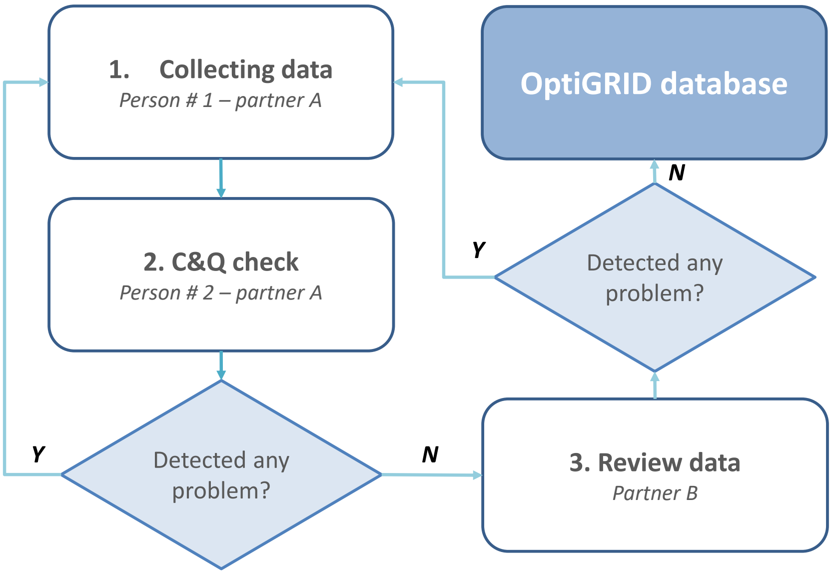


Figure 3 – Data validation procedure.

For temporal data further steps were considered using a rigorous data quality control check. This step is performed in two stages:

1. ***Automatically report*** (using in-house scripts) that performs**:**
   - General system checks (number of data records and time and date of each data record);
   - Measurement range tests (for each parameter and according to partners experience range limits are defined);
   - Trends and step-change tests;
   - Physical and statistical relationships between various measured parameters (e.g., correlations among power production of neighbour wind parks);
   - Each suspect or invalid data is flagged and carefully analysed resorting to manual inspection.

2. ***Manually inspection*** using time series graphics that allows complementing the automatic approach to detect flaws and erroneous records. When faults, anomalies or errors are detected in the data collected, they are flagged and deep analysis is performed using statistical-based tools. The flagged data are then validated, repeating the process of automatic inspection and/or manual. Figure 4 represents briefly this process.

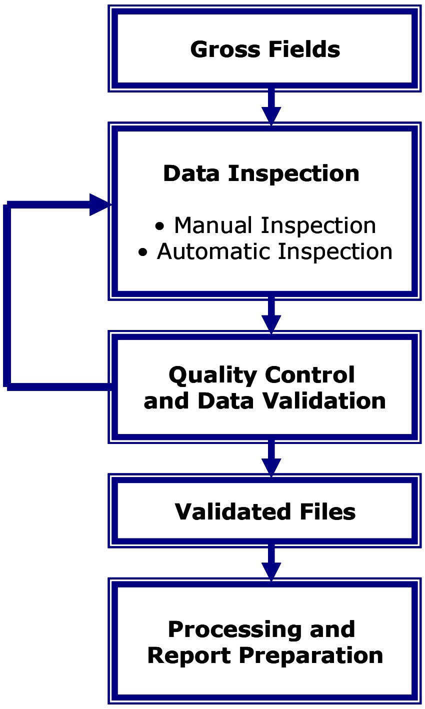


Figure 4 – Measured data C&Q control procedures.

All temporal data are in Coordinated Universal Time (UTC).

2-2. Period under analysis

A typical meteorological year with extreme weather conditions representative of wet/dry and windy/calm periods was selected to assess the benefits of the methodology proposed in this project, Figure 5. This approach enables to have a good spectrum of the different weather conditions. In this sense, the year 2018 was selected [9]. Moreover, the number of hours with market splitting within the MIBEL market during 2018 is very close to the average value between 2014 and 2018, Figure 6. Since no substantial changes were observed in the topology and electrical characteristics of the transmission network in the regions of the case studies under analysis, this option also enables to use up-to-date information regarding the transmission and distribution networks, being representative of the current situation.

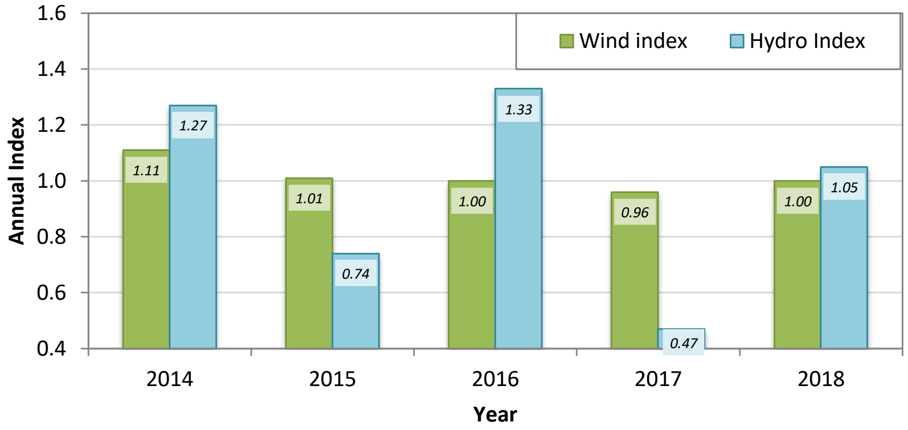


Figure 5 – Annual wind and hydropower production index.

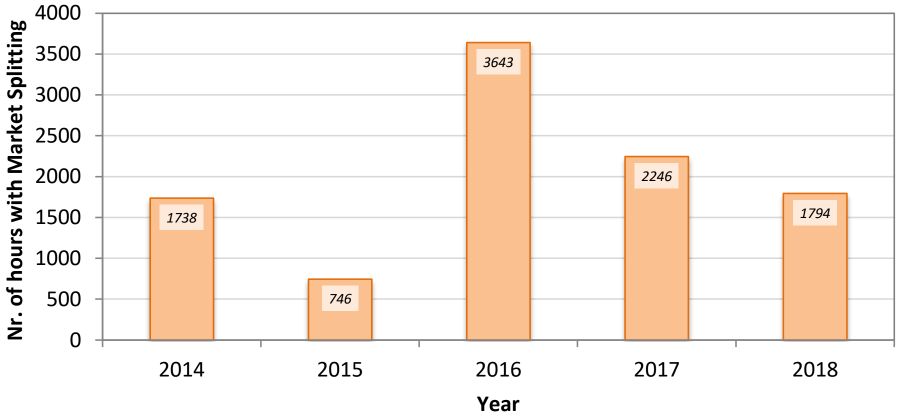


Figure 6 – Annual number of hours with market splitting in the MIBEL.

3. Data collected during the OPTIGRID project

In this section, the data collected and the sources are presented. First, the overhead conductors’ characteristics, which are transversal to every case study, are presented, and after, the main transmission network features of each case study are provided.

For disclosure reasons, only non-confidential data are presented in this report. Nevertheless, within the scope of this project, it was possible to obtain all the data needed to apply and validate the mathematical models under development.

3-1. Overhead conductors’ characteristics

For the regions under analysis, five different aerial conductors were identified. The characteristics of each conductor were obtained through manufacturers and distributors catalogues [10]–[12]. In Table 1, the overhead conductors' characteristics considered in this project are shown.

Table 1. Detailed characteristics of all aerial conductors identified in the regions under analysis. *Numeration applied by the project partners to identify the different cables used.

Parameter [units]		Cable designation				
		Zebra	Bear	Aster 570	Zambezi	Rail
Cable Number*		1	2	3	4	5
External diameter (D)	[m]	0.0286	0.02345	0.03105	0.0318	0.02959
Conductor diameter (d)	[m]	0.00318	0.00335	0.00345	0.00414	0.0037
Area	[m^2]	4.85E-04	3.26E-04	5.70E-04	0.00059497	0.00048384
cp aluminium (at 20ºC)	[J/kg/K]	897	897	897	897	897
cp steel (at 20ºC)	[J/kg/K]	481	481	0	481	481
Resistance (at 20ºC)	[ohm/m]	0.0000674	0.0001093	0.0000583	0.000051	0.0000596
Aluminium cable mass	[kg/m]	1.16	0.714738	1.574	1.528	1.334
Steel cable mass	[kg/m]	0.43	0.480018	0	0.235	0.263
β aluminium	[1/K]	0.00038	0.00038	0.00038	0.00038	0.00038
β stel	[1/K]	0.0001	0.0001	0	0.0001	0.0001
α aluminium	[1/K]	0.00403	0.00403	0.00403	0.00403	0.00403
Absortance	[adim.]	0.5	0.5	0.5	0.5	0.5
Emissivity	[adim.]	0.456	0.5	0.456	0.5	0.5

3-2. Case study A - Region predominantly with wind distributed generation

Due to the orographic conditions and resource availability, wind power is mainly distributed in the North and Centre of Portugal. In particular, most of the Centre region is covered by a region known as Pinhal Interior where 49 wind parks (with a total capacity of 1766 MW) and 15 hydropower plants (with a total capacity of 1113 MW) are installed which makes it a strong candidate to be used as a case-study, Figure 7. Moreover, the localization of industries from that region inducing a shift in local energy consumption considerably modifies power flow conditions enriching, even more, this region as an excellent case study for the application of the proposed. Thus, this case study will enable to understand the DLR impact in a region with a high level of wind power capacity.

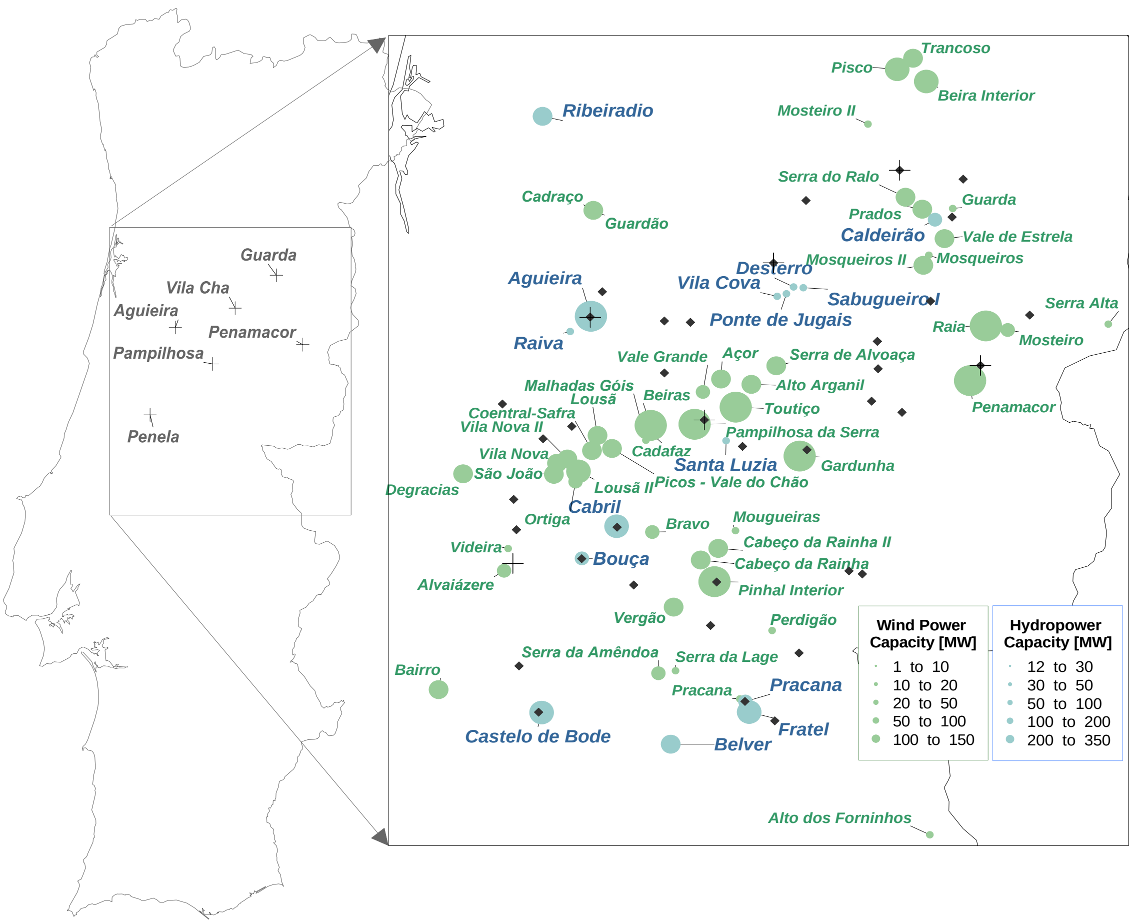


Figure 7 - Location and nominal capacity of the wind and hydropower parks for case study A. Squares represent the substations while the "+" represents some geographic points to be used as a reference.

For the wind and hydropower plants depict in Figure 7, no missing or abnormal data were identified.

The region comprises 37 substations and 22 high-voltage lines, Figure 8. In this figure, the seasonal line power capacity is also shown.

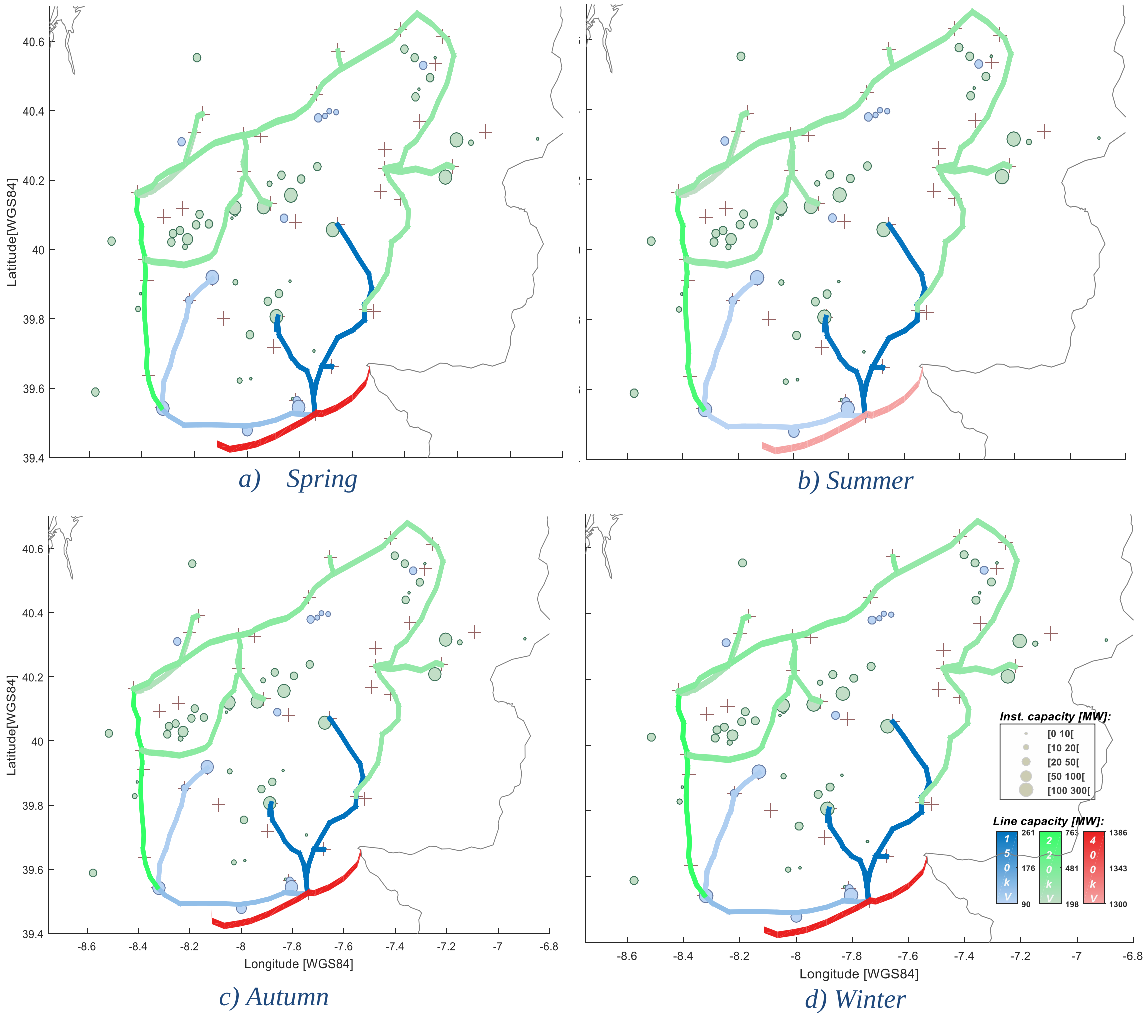


Figure 8 – Lines' saturation represents the seasonal line capacity for case study A. Location and nominal capacity of the wind and hydropower parks for case study A. Black squares represent the substations while the "+" represents some geographic points to be used as a reference.

As expected, due to the weather conditions considered by the TSO, the highest power capacity values are observed during the Autumn and Winter periods. The maximum seasonal difference identified was 98 MVA (in a 220 kV line).

In Figure 9 the type of cable used in each line are presented. The cable *ZEBRA* (#1) is the most common in this region. The cable Rail (#5) is not applied in any overhead power line in this region.

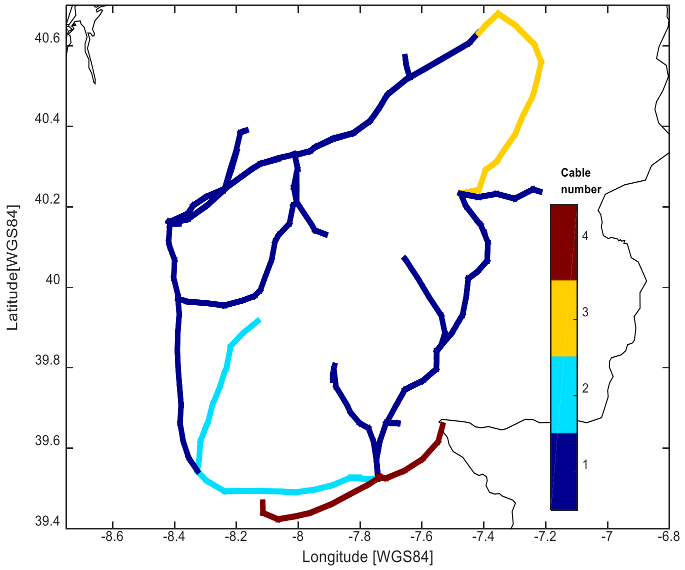


Figure 9 – Type of cable for case study A using the references presented in Table 1.

Table 2 summarizes the previous information *per* line, namely, the topology and properties of the transmission and distribution networks analysed in this case study.

Table 2 - Grid topology and properties for case study A.

Voltage Level (kV)	Start Bus	End Bus	LINE Code	Type of Cable	Capacity Limit [MVA]			
					Spring	Summer	Autumn	Winter
150	Cabril	Bouça	1010	2	104	96	104	104
	Bouça	Zêzere	1015	2	104	96	104	104
	Falagueira	Subs. Rodão (Refer)	1616	1	260	255	260	260
	Corgas	Falagueira	1114	1	260	253	260	260
	Falagueira	Zêzere	1089	2	123	91	130	130
	Falagueira	Castelo Branco	1108	1	260	260	260	260
	Gardunha	Castelo Branco	1115	1	260	253	260	260
220	Aguieira	Pereiros	2054	1	237	199	269	297
	Chafariz	Vila Chã	2135	1	381	381	381	381
	Pereiros	Mortágua (Refer)	2615	1	400	382	418	435
	Chafariz	Gouveia (Refer)	2617	1	400	382	418	435
	Vila Chã	Gouveia (Refer)	1	1	400	382	418	435
	Castelo Branco	Ferro	2160	1	381	370	381	381
	Chafariz	Ferro	2124	3	381	376	381	381
	Penamacor	Ferro	2155	1	381	374	381	381
	Penela	Zêzere	2164	1	727	667	762	762
	Pereiros	Penela	2163	1	727	684	762	762
	Pampilhosa da Serra	Tábua	2169	1	364	342	383	402
	Vila Chã	Tábua	2170	1	400	382	418	435
	Pereiros	Tábua	2173	1	400	382	418	435
	Penela	Tábua	2168	1	400	382	418	435
400	Pego	Falagueira	4055	4	1386	1300	1386	1386
	Falagueira	Cedillo	4056	4	1386	1300	1386	1386

In Table 3 the substations considered for case study A and its operational voltage level are presented. For each substation, the load with a 15-minute time resolution was collected. After applying control and quality checks to these data, no missing or abnormal values were identified.

Table 3 – Substations used in case study A.

Designation	Voltage Level
Chafariz	220/60
Vila Chã	220/60
Tábua	220/60
Pereiros	220/60
Penela	220/60
Zêzere	220/60
Ferro	220/60
Castelo Branco	220/60
Falagueira	220/60
Pego	400

3-3. Case study B - Region predominantly with solar photovoltaic distributed generation

The orographic conditions and resource availability makes the south of Portugal ideal for solar PV generation. Despite the current PV installed capacity in this region being still limited, a sharp short-term increase is expected given the recent public calls for tenders and bilaterally contracted grid access to PV power plants. Therefore, this case study focuses on assessing the DLR impact in a region with very high solar potential and limited grid capacity – south of Portugal, Figure 10. Supported by previous studies conducted by LNEG, this large-scale integration of solar PV will likely create challenges for the TSO, thus making it a promising area for the application of the DLR. This region also comprises a large and a small hydropower plant (Alqueva and Pedrógão with a nominal capacity above 500 MW and 10 MW, respectively), and 17 wind parks (with a total capacity above 300 MW).

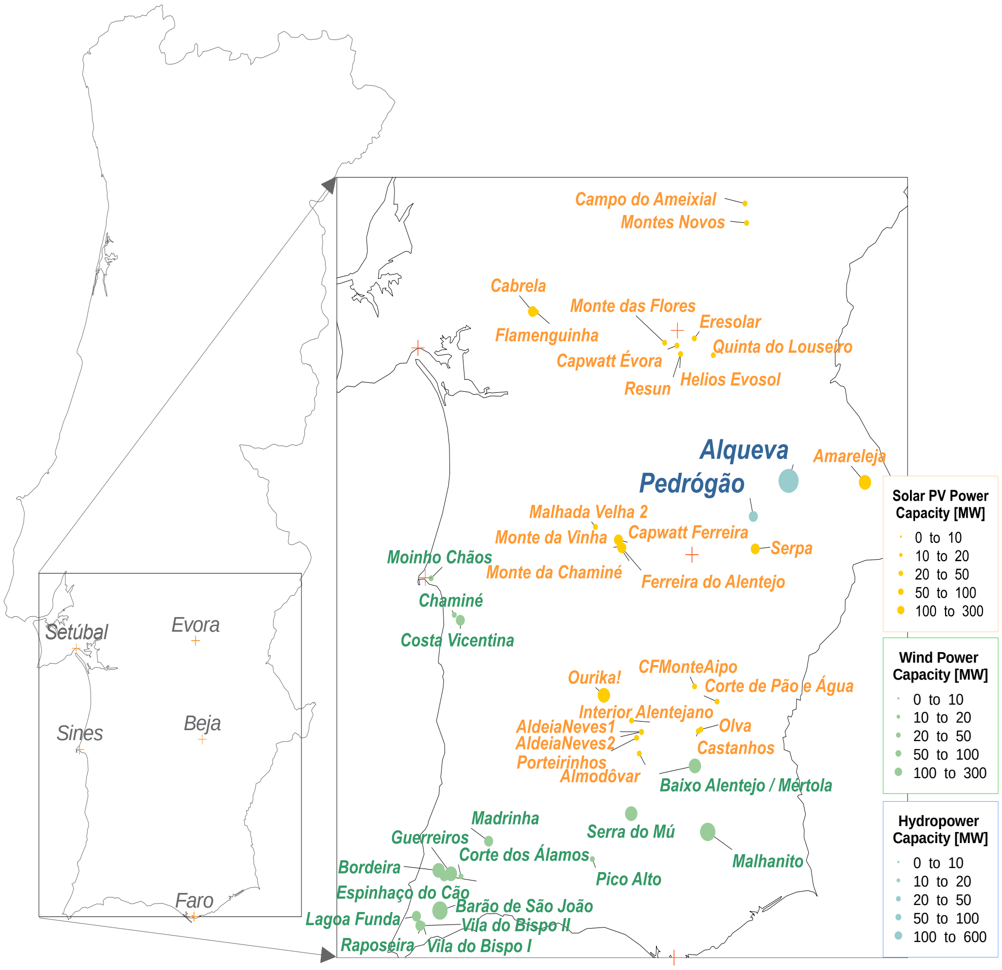
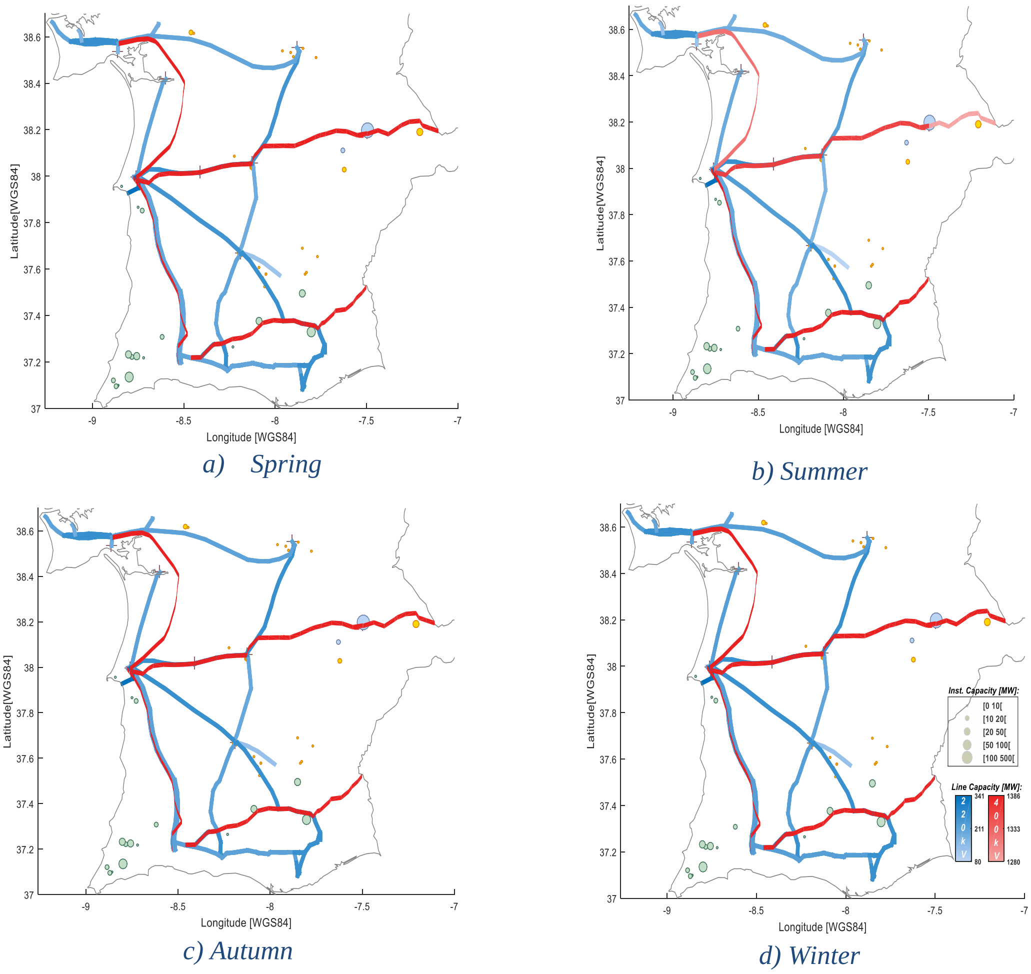


Figure 10 - Location and nominal capacity of the wind, solar and hydropower parks for case study B. Black squares represent the substations while the "+" represents some geographic points to be used as a reference.

For the solar, wind and hydropower plants depict in Figure 10, no missing or abnormal data were identified.

The region comprises 9 substations and 43 high-voltage lines, Figure 11. In this figure, the seasonal line power capacity is also shown. As expected the highest power capacity values are observed during the Autumn and Winter periods. The maximum seasonal difference identified was 98 MVA (in a 220 kV line).

In Figure 12 the type of cables used in each line are presented. The cable *ZEBRA* (#1), and *BEAR (1x3x1 AA 325)* (#2) are the most common in the region under analysis.



a) Spring b) Summer c) Autumn d) Winter

Figure 11 – Lines' saturation represents the seasonal line capacity for case study B. Location and nominal capacity of the wind, solar and hydropower parks for case study B. "+" represent the substations.

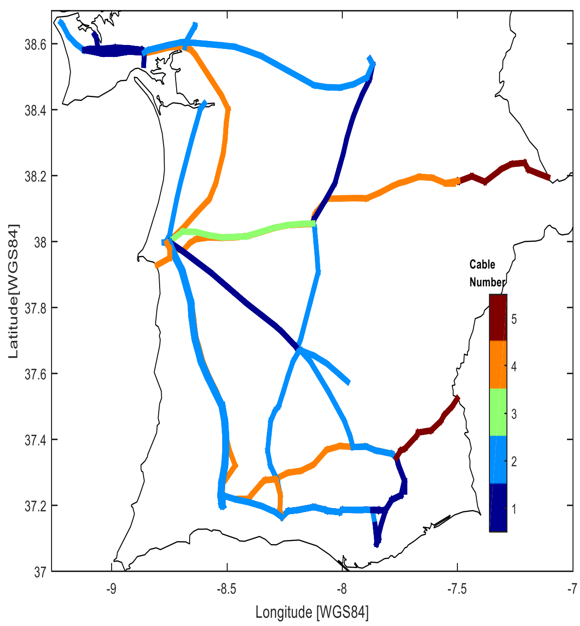


Figure 12 – Type of cable for case study B using the cable number references presented in Table 1.

Table 4 summarizes the previous information *per* line, namely, the topology and properties of the transmission and distribution networks analysed in this case study.

Table 4 - Grid topology and properties for case study B.

Voltage Level (kV)	Start Bus	End Bus	LINE Code	Type of Cable	Capacity Limit [MVA]			
					Spring	Summer	Autumn	Winter
400	Ferreira do Alentejo	Sines	0	4	1386	1361	1386	1386
	Palmela	Sines 3	4018	4	1386	1321	1386	1386
	Palmela	Sines 2	4010	4	1386	1321	1386	1386
	Alqueva	Brovales	4037	5	1386	1280	1386	1386
	Alqueva	Ferreira do Alentejo	1	4	1386	1361	1386	1386
	Sines	Portimão 3	4063	4	1386	1386	1386	1386
	Portimão	Tavira	4064	4	1386	1386	1386	1386
	Tavira	Puebla de Guzmán	4065	5	1386	1386	1386	1386
150	Palmela	Fernão Ferro 1	1041	1	260	255	260	260
	Palmela	Fernão Ferro 2	1042	1	260	255	260	260
	Palmela	Setúbal 2	1045	1	260	255	260	260
	Palmela	Setúbal 3	1046	1	162	124	183	203
	Ferreira do Alentejo	Évora	1078	1	248	218	260	260
	Ferreira do Alentejo	Ourique	1085	2	186	164	196	206
	Ourique	Neves Corvo	1087	2	123	81	130	130
	Monte da Pedra	Sines	2	2	204	191	214	222
	Ermidas Sado	Ferreira do Alentejo	3	3	260	260	260	260
	Sines	Ermidas Sado	4	3	260	260	260	260
	Sines	Ourique 1	1079	1	248	224	260	260
	Sines	Ourique 2	1105	1	248	224	260	260
	Ourique	Tunes	1086	2	204	189	214	222
	Fernão Ferro	Trafaria 1	1097	2	204	195	214	221
	Ourique	Tavira	1143	2	260	260	260	260
	Tunes	Tavira 1	1131	1	260	255	260	260
	Tunes	Estoi	1147	2	204	195	214	222
	Estoi	Tavira 2	1139	1	260	255	260	260
	Estoi	Tavira 1	1132	1	260	255	260	260
	Estoi	Tavira 3	1148	1	260	255	260	260
	Portimão	Tunes 3	1130	4	260	260	260	260
	Portimão	Tunes 2	1124	2	204	195	214	222
	Portimão	Tunes 1	1123	2	204	195	214	222
	Saboia	Portimão	1122	2	204	195	214	222
	Sines	Portimão 2	1125	2	204	195	214	222
	Sines	Saboia	1113	2	204	195	214	222
	Palmela	Quinta do Anjo	1093	1	260	255	260	260
	Fernão Ferro	Quinta do Anjo	1094	1	273	260	285	296
	Palmela	Fernão Ferro 4	1063	1	260	255	260	260
	Ramal Palmela - Évora	Pegões (Refer)	1611	2	186	171	196	206
	Ramal Palmela - Monte da Pedra	Pegões (Refer)	1612	2	186	171	196	206
	Ramal Palmela - Fernão Ferro 4	Seixal	1619	1	162	136	183	203
	Central Sines 1	Sines 1	1065	4	340	340	340	340
	Central Sines 2,3,4	Sines 2,3	5	4	1020	1020	1020	1020
	Palmela	Évora	1067	2	204	185	214	222

In Table 5 the substations considered for case study B and its operational voltage level are presented. For each substation, the load with a 15-minute time resolution was collected. After applying control and quality checks to these data, no missing or abnormal values were identified.

Table 5 – Substations used in case study B.

Designation	Voltage Level
Sines	400/150/60
Setúbal	150/60
Ferreira do Alentejo	400/150/60
Alqueva	400/60
Portimão	400/150/60
Tavira	400/150/60
Ourique	150/60
Central de Sines 1	150
Central de Sines 2,3,4	400
Tunes	150/60
Estoi	150/60
Évora	150/60

3-4. Case study C - Market splitting scenarios in MIBEL

This case study is related to the occurrence of market splitting scenarios in MIBEL that can be reduced through the use of OptiGRID tools. Specifically, the competitiveness of MIBEL is highly dependent on available thermal capacity in transmission lines connecting the Portuguese and Spanish power systems due to a less cost-effective use of generation units. The frequent activation of market splitting mechanisms in MIBEL, which can represent a significant number of hours - Figure 13, makes it a strong case study for the application of DRL to assess the potential of such techniques in reducing the number of hours with market splitting.

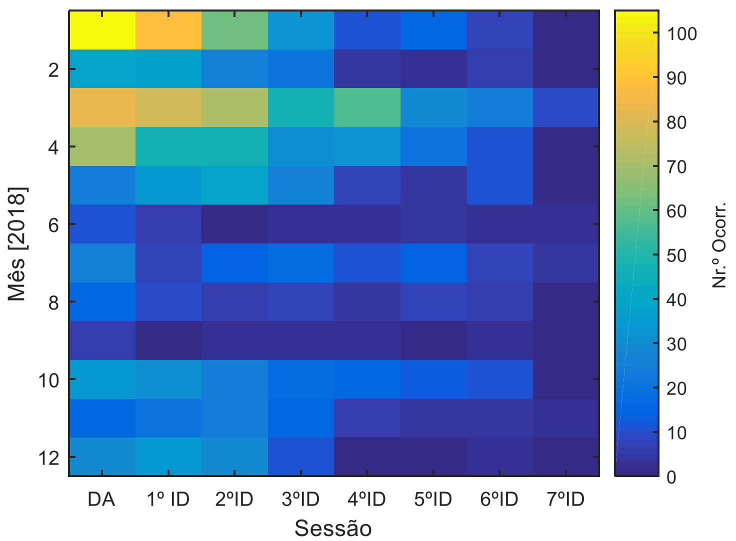


Figure 13 – Number of hours with market splitting in the MIBEL during 2018.

The Iberian interconnection lines are depicted in Figure 14. From this figure, it is possible to understand that the Cedillo, Brovales and Puebla de Gúzman interconnections are the ones located within the two regions previously identified and under analysis in this project (case study A and B). Therefore, these three interconnection lines will be analyzed in case study C.

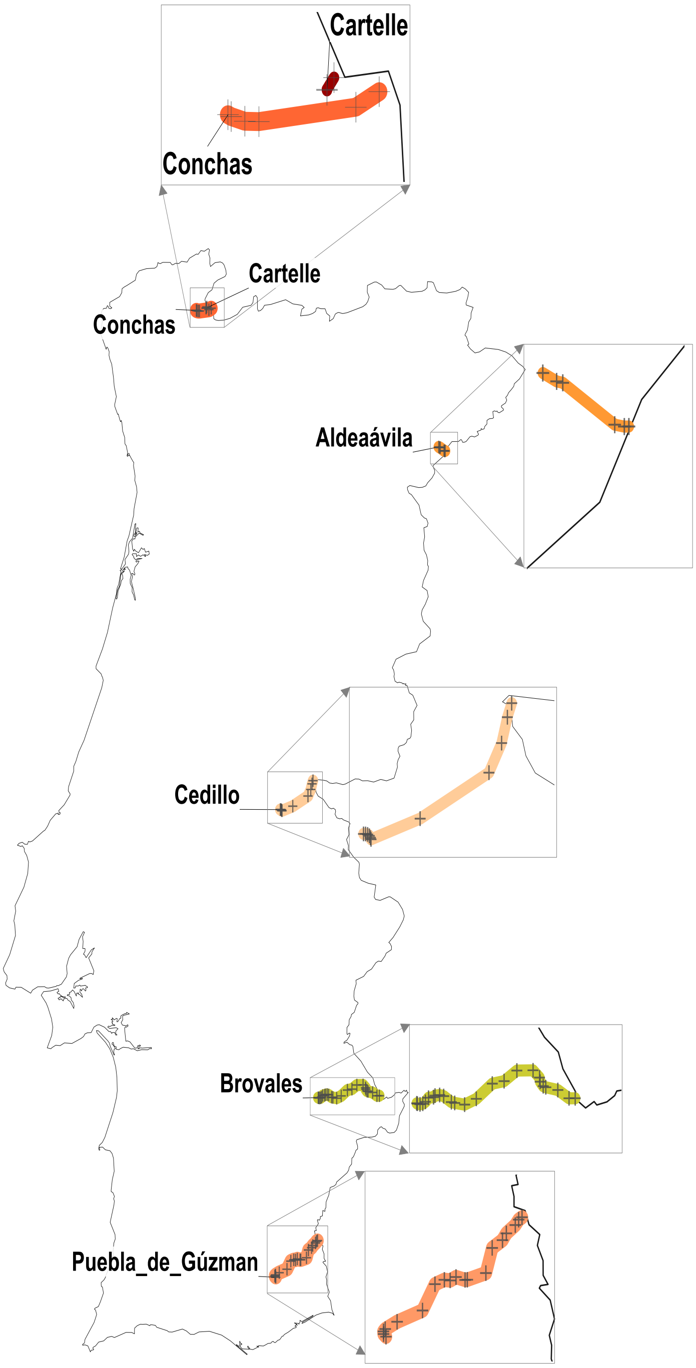


Figure 14 – Identification of the Iberian interconnection. The "+" symbols represent the vertex towers.

4. Final remarks

This report describes and validates the i) Portuguese transmission network and ii) Iberian Electricity Market (MIBEL) data collected to conduct the research activities of the OptiGRID project.

The data were collected for 2018. Firstly, all the necessary data were identified based on public information. The remaining data were obtained through the partners' confidential databases. In this sense, only non-confidential data were presented in great detail throughout this report.

The data were validated by crossing different databases and using an internal peer-review process. For temporal time-series data, automatic and manual control and quality checks were applied.

Within the scope of this project, all the data need to realize the case studies defined in Task 4 and evaluated these case studies in Task 5 were attained.

References

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