OPTIGRID project

Deliverable 4.1 - Development of RES Case studies A and B: regions predominantly with a) wind distributed generation and b) with photovoltaic distributed generation

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Executive Summary

The work presented in this deliverable was developed by R&D NESTER and LNEG as part of the R&D activities of the project OPTIGRID - *Methodology for the dynamic line rating analysis and optimal management of power networks*.

This report presents the deliverable 4.1, which consists on the definition of the two first case-studies of the project: *case study A - a region with large distributed wind capacity (Sub-task 4.1)* and *case study B - a region with large photovoltaic (PV) penetration (sub-task 4.2)*.

Both case studies are very promising, since wind speed have a positive correlation with transmission capacity in overhead lines, but solar radiation have a negative correlation with the transmission capacity. This means that the region of the wind production may require less transmission grid reinforcements, but the region of solar production may require more grid reinforcements.

For each case study, grid topology for transmission grid and distribution grid was identified and catalogued. Time series for the load in each transmission substations and renewable (hydro, wind and solar) generation pattern for the entire 2018 year was also used to create both case studies.

For confidentiality reasons, only non-confidential information is presented in this report. Nevertheless, within the scope of the project, all the data needed to apply (and validate) the mathematical models under development were obtained.

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1. Introduction

The present deliverable was developed by R&D NESTER with the collaboration of LNEG as part of the OPTIGRID project R&D activities *Task 4 - Development of RES Case Studies*. This report presents the deliverable 4.1, which consists on the definition of the two first case-studies of the project: *case study A - a region with large distributed wind capacity (Sub-task 4.1)* and *case study B - a region with large photovoltaic (PV) penetration (sub-task 4.2).*

Power systems are facing an increasing penetration of electricity from renewable energy sources (RES) with low predictability in the operational timescale, namely the wind and solar generation. While this promotes the environmental sustainability of human life on Planet Earth, it presents great challenges for the energy system management and operation, mostly due to the sharp variability and uncertainty of the wind/solar power production.

Line rating has been studied since the beginning because the physical limit is not the current or the power of the line, but the distance on the conductor to the obstacle due to the thermal consequence of the joule effect of the current. Dynamic line rating is used by contrast with the static line rating, since it's adjust to the environmental condition, compared with the pre-define, static condition.

The use of Static Line Rating (SLR) [1] methodology by Transmission System Operators (TSOs) and Distribution System Operators (DSOs), calculates thermal rating using conservative assumptions regarding the overhead transmission lines (OHLs) operating conditions such as static weather conditions, average wind speeds and direction, average ambient temperatures, and solar conditions for summer and winter seasons (*e.g.* based on maximum ambient temperatures, reduced wind speed, or full solar exposure).

Table 1 presents typical environmental parameters used in a SLR methodology [2].

Table 1 - Example of environmental parameters used in a SLR approach.

Ambient temperature	30°C to 35°C[1]
Wind speed	0,6 m/s
Solar irradiation	1000 W/m^2

Overall, SLR establishes a fixed constraint that does not take advantage of dynamic environmental conditions that may allow for greater transmission usage in a significant amount of hours of the year. However, there are some instances when the real ratings based on actual conditions may be lower than SLR, putting the conductor at risk for thermal damage and increased sag (near its design limit).

On the other hand, Dynamic Line Rating (DLR) analysis [1] is an alternative methodology to enhance the transmission capability of an existing network. This methodology offers a smarter, more efficient and a better evaluation of the true real-time ampacity of OHLs. DLR consists in the determination of the real-time maximum current rating in a conductor ensuring the OHLs safe and reliable operation. This real-time capacity evaluation is provided by the monitoring of dynamic weather conditions such as ambient temperature, wind speed and direction and solar irradiation. Therefore, due to the use of weather parameters, the ampacity values estimated with the DLR analysis are usually higher than ones observed with the SLR approach. Figure 1 illustrates the improved OHLs transmission capacity due to the use of DLR, when compared to a SLR approach. It is noteworthy, that for a reduced number of hours in the year, DLR may be below the transmission capacity determined when using SLR assumptions (yellow area in Figure 1) [3]. This fact is particular relevant when considering regions with extreme values of solar irradiation and the absence of wind, as may be the case of case study B.

[1] Adjusted for the Portuguese case

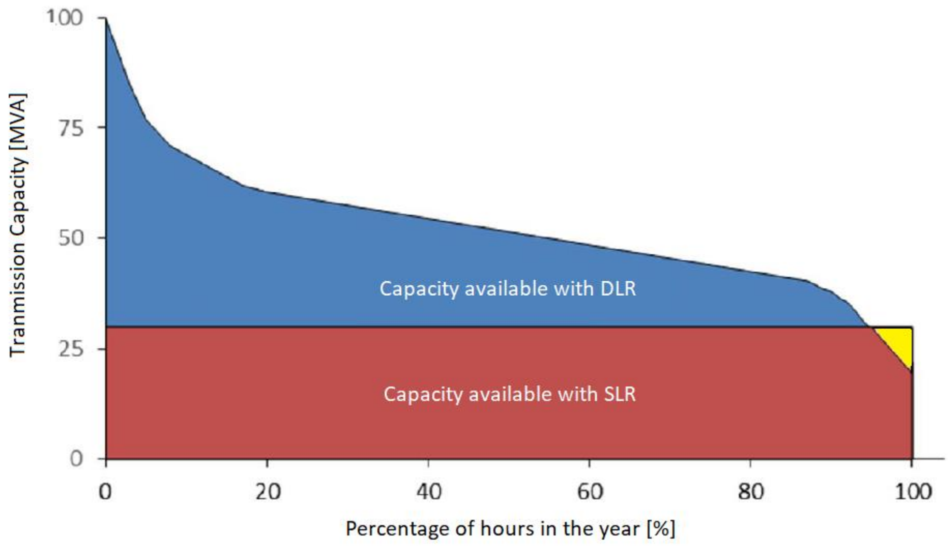


Figure 1 - Example of transmission capacity curve during the year, considering SLR and DLR methodologies.

The application of DLR methodology can effectively alleviate network congestion, lower the operating costs and RES curtailment in the short term, and supporting higher penetration of RES.

Therefore, to properly assess the benefits of the DLR tool developed in this project, three case studies were defined based on their intrinsic features:

- *case study A* - a region with large distributed wind power generation;
- *case study B* - a region with large (foreseen) PV generation;
- *case study C* - market splitting occurrence in Iberian Electricity Market (MIBEL) due to congestion in interconnections.

This deliverable presents the main details of case studies A and B, namely, the motivation beyond the scope of each case study as well as some specifications and data of the National High Voltage Transmission Grid (*RNT – Rede Nacional de Transporte*) gathered for the regions under study. For confidentiality reasons, only non-confidential information is presented in this report. Nevertheless, within the scope of the project, all the data needed to apply (and validate) the mathematical models under development were obtained.

The case study C is part of the sub-task 4.3 activities and it will be presented in D4.2 Case study C - Market splitting scenarios in MIBEL.

In section 2, case studies A and B are presented and the characterization of the regional grid and the identification of wind, solar and hydro resources available in the regions are performed. In addition, the load patterns for 2018 on an hourly basis were gather and are presented for the case study regions.

Section 3 presents the main conclusions based on the information gathered for the purpose of this deliverable.

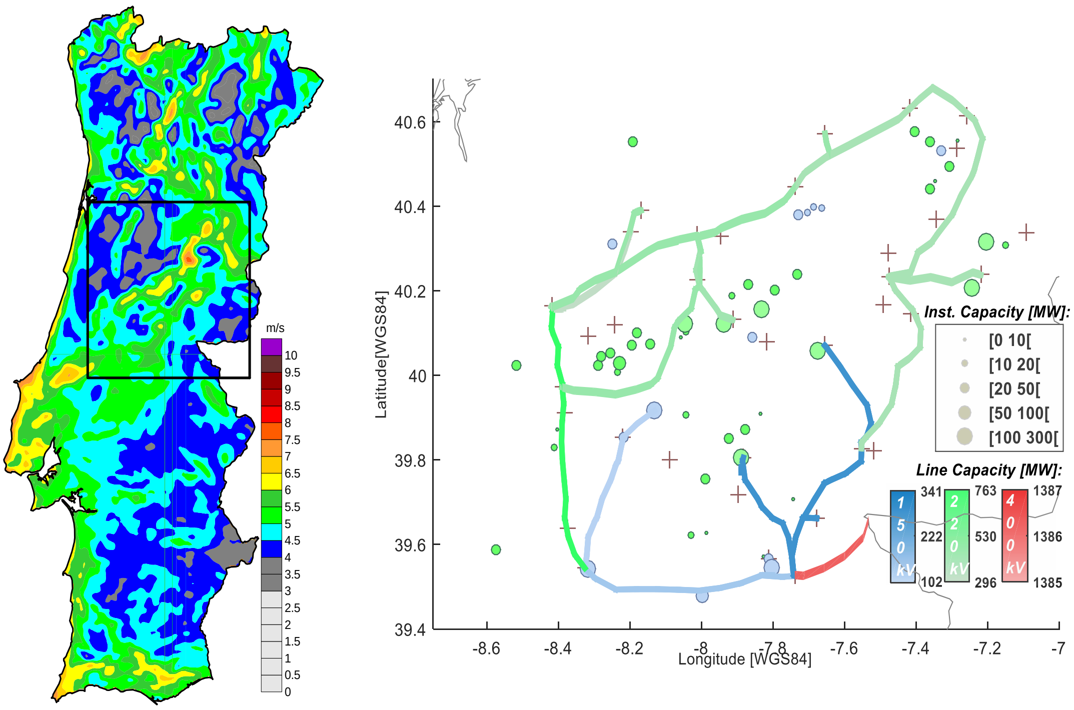
2. Development of RES Case Studies

In this deliverable, two case studies are defined, a region with large distributed wind generation and a region with large distributed photovoltaic generation.

2.1. Case Study A – Region predominantly with wind distributed generation

Portugal has more than 5200 MW of wind power (by the end of 2019) corresponding to approximately 27 % of the total power installed capacity. The *Pinhal Interior* region, situated in the centre of Portugal - Figure 2-a), is an excellent case study due to its orographic conditions and resource availability. Since convective heat transfer (cooling effect) plays a major role in the thermal balance of overhead conductors, wind resource availability is directly related with the transmission lines heat loss, fact that may improve transmission capacity in periods of high wind power generation. As exceptions, particular attention may be payed to valleys within forest areas where OHLs may be protected from wind dissipative effect and to terminal equipment (at substation level) that is not exposed to wind.

Therefore, this case study was selected to assess the DLR impact in a region with a high penetration of wind generation. Figure 2-b) depicts the region under analysis and characterizes the grid and the installed RES power capacity.



a) *b)*

Figure 2 - a) Wind speed Atlas (the box represent the region under analysis in case study A) [4]. b) Case study A: Location and nominal capacity of the RES generation (blue circles represent hydro generation and green circles represent wind generation). The symbol "+" represent the substations. The blue, green and red lines represent the line capacity during the winter for 150 kV, 220 kV, and 400 kV, respectively.

An assessment of all the OHLs in this region was made. The OHLs were separated in 3 different voltage categories: 150 kV, 220 kV and 400 kV, as depicted in Figure 2. For each OHL in the case study region, a characterisation was made regarding the following information [5] [6]:

- Identification of each OHL start and end busbar;
- Identification of the cable type and cable length;
- Calculation of their respective Resistance - R (pu), Reactance - X (pu) and susceptance - B (pu);
- Calculation of the maximum capacity in each season of the year (i.e. spring, summer, autumn and winter);
- Characterization of the transformers in the substations.

A collection of data, regarding the substations situated in *Pinhal Interior* region, was performed to further improve the development of this case study, as well the base load (natural load without RES contribution) of each substation in the year of 2018, as depicted in the table and figures below.

Table 2 - Substations list of *Pinhal Interior* region.

Designation	Voltage Level [kV]	SUB_ID	LONG	LAT
Chafariz	220/60	SCF	-7,41776	40,63315
Vila Chã	220/60	SVC	-7,73855	40,44813
Tábua	220/60	STBA	-8,01217	40,33310
Pereiros	220/60	SPR	-8,41934	40,16543
Penela	220/60	SPNL	-8,39110	39,97330
Zêzere	220/150/60	SZR	-8,32726	39,54503
Ferro	220/60	SFE	-7,47710	40,23540
Castelo Branco	220/150/60	SCC	-7,55200	39,82790
Falagueira	400/150/60	SFR	-7,74076	39,52852

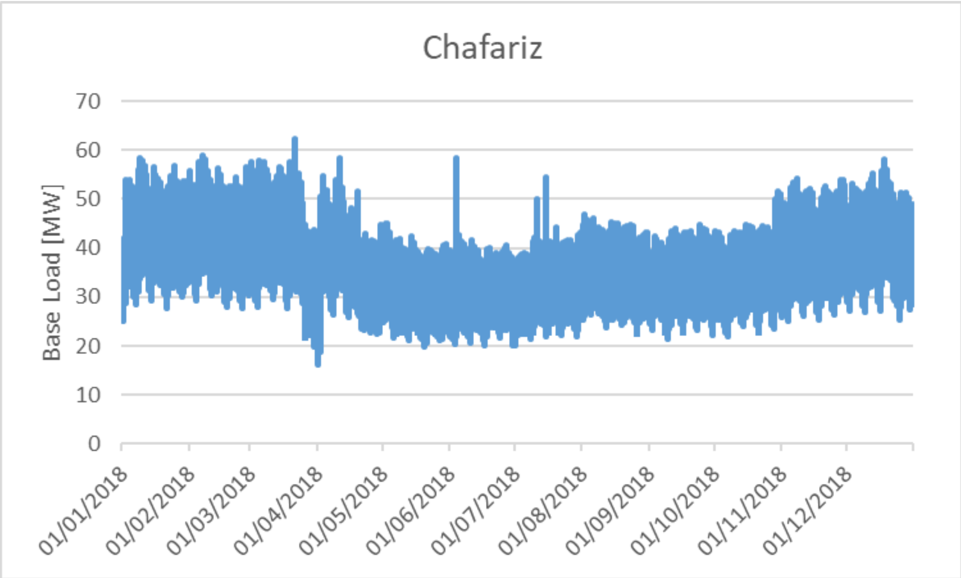


Figure 3 - Base Load of *Chafariz* Substation throughout 2018.

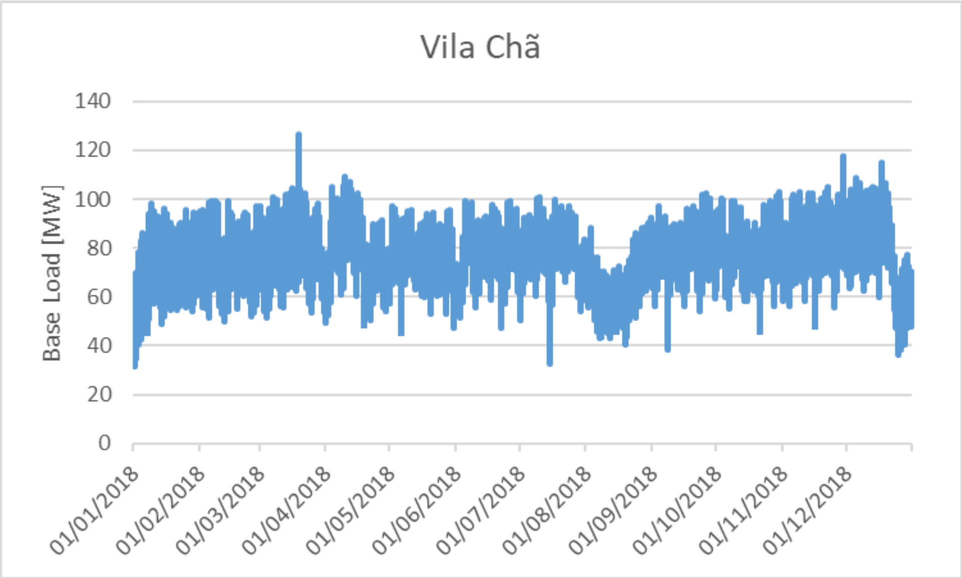


Figure 4 - Base Load of *Vila Chã* Substation throughout 2018.

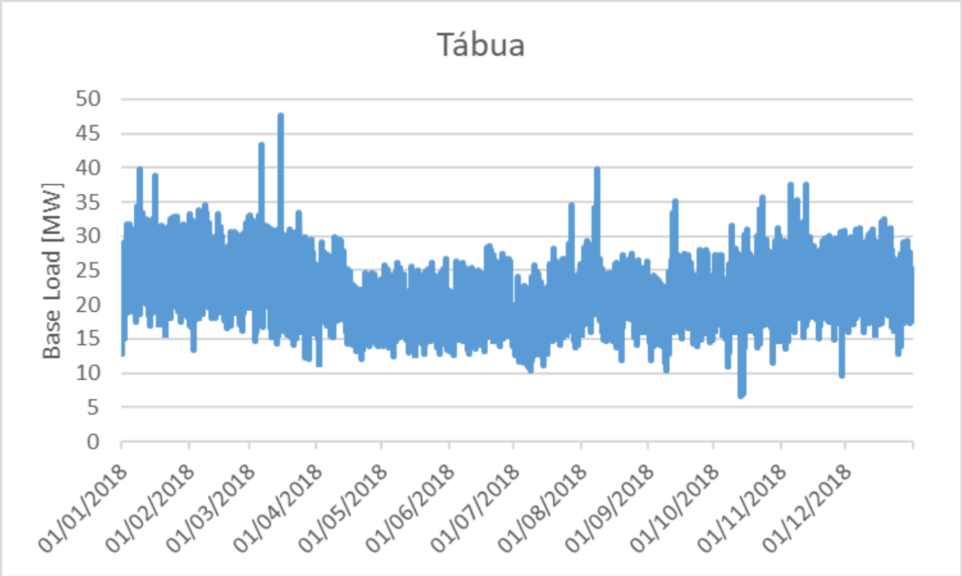


Figure 5 - Base Load of *Tábua* Substation throughout 2018.

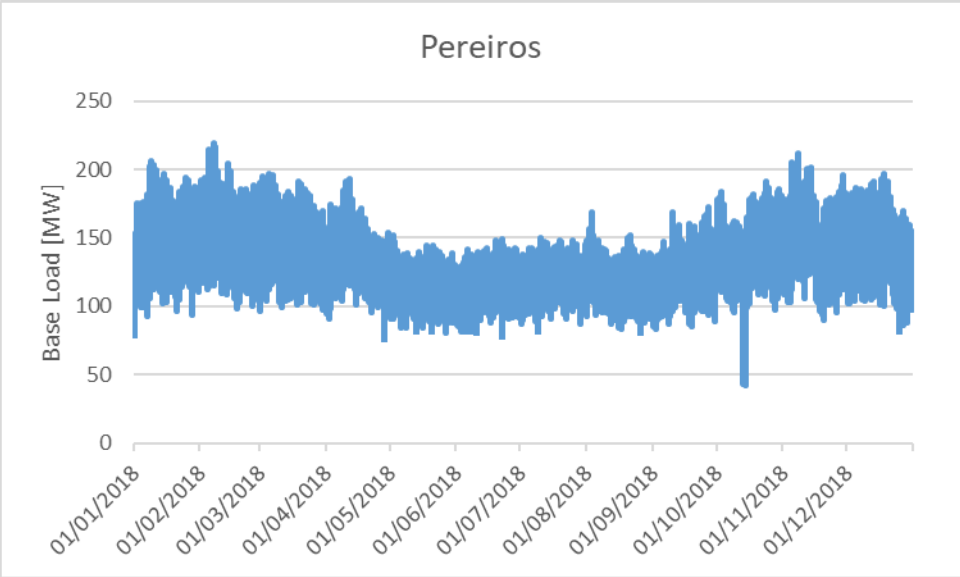


Figure 6 - Base Load of Pereiros Substation throughout 2018.

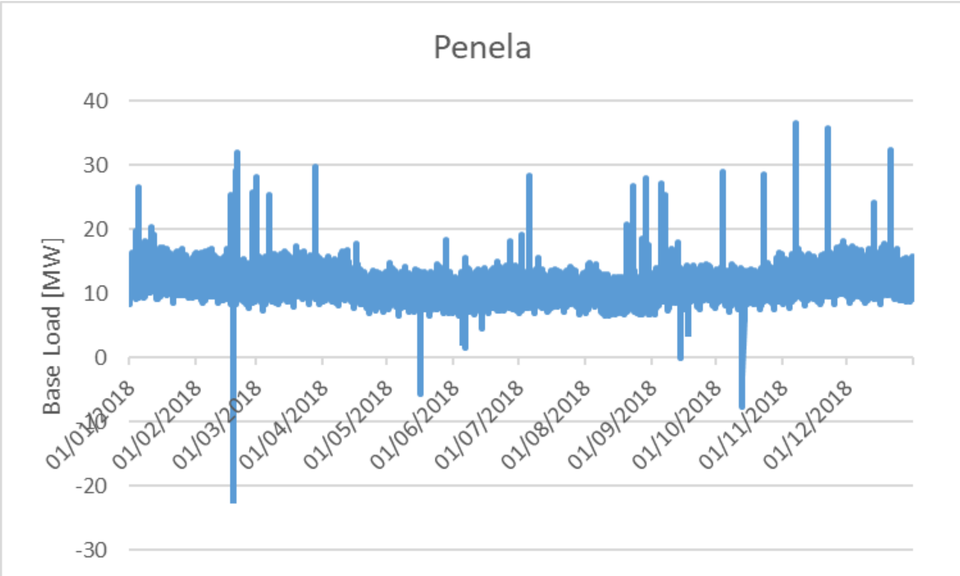


Figure 7 - Base Load of *Penela* Substation throughout 2018.

The positive and negative spikes are due to distribution shift of load between near substations.

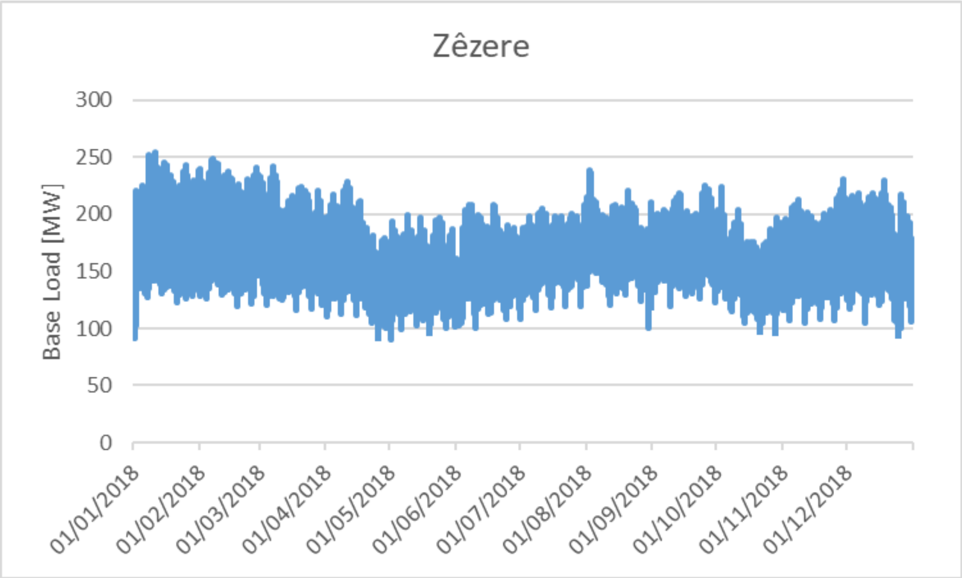


Figure 8 - Base Load of *Zêzere* Substation throughout 2018.

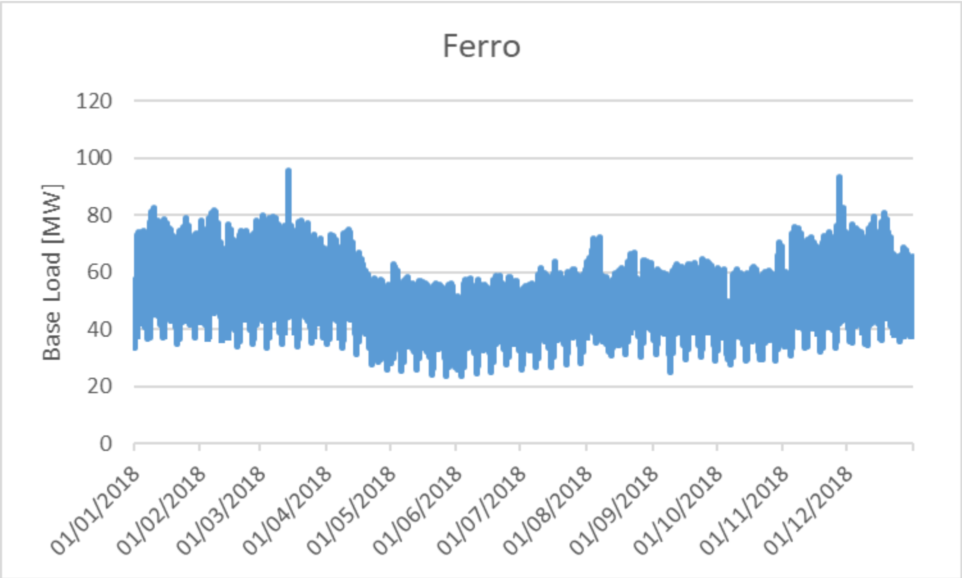


Figure 9 - Base Load of *Ferro* Substation throughout 2018.

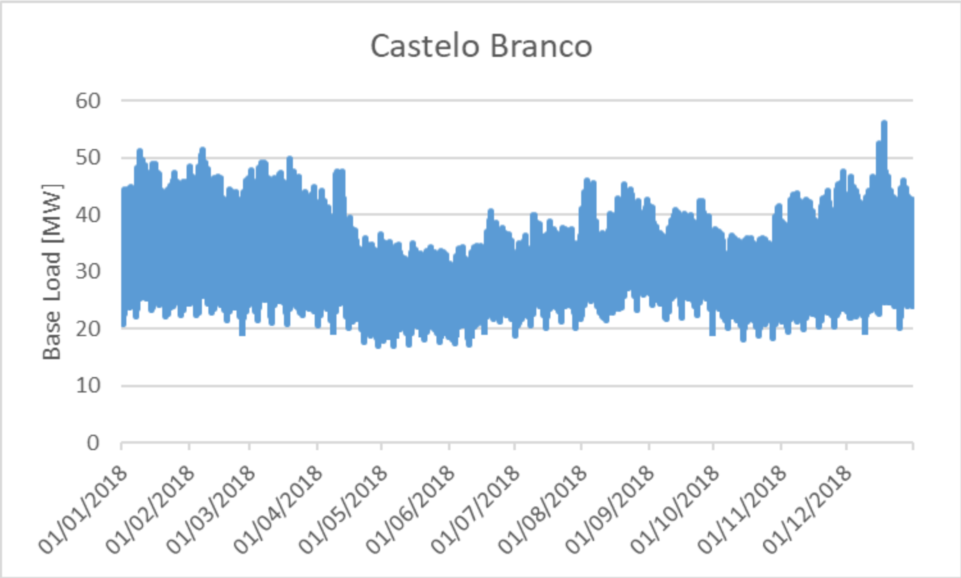


Figure 10 - Base Load of *Castelo Branco* Substation throughout 2018.

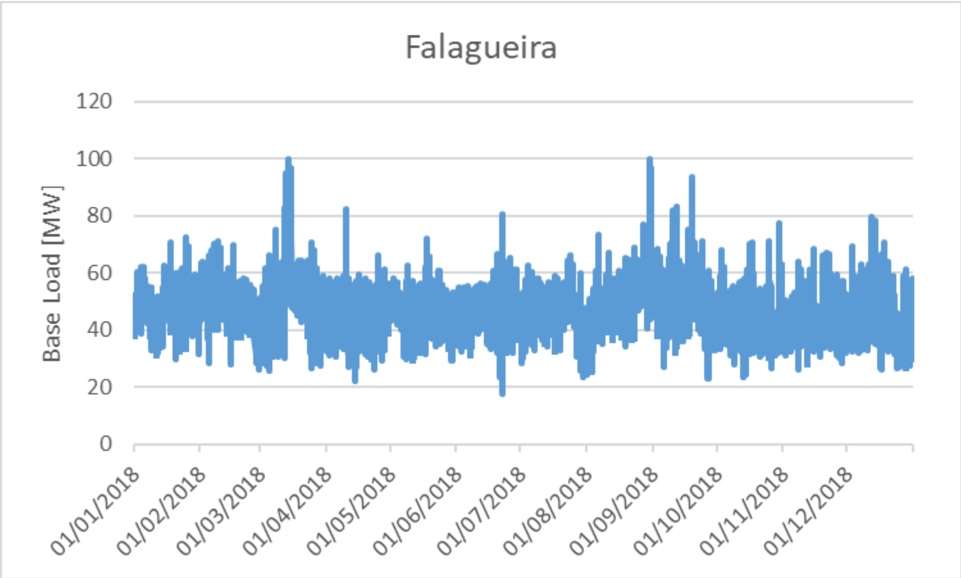


Figure 11 - Base Load of *Falagueira* Substation throughout 2018.

In addition, it was made a characterization of the wind and hydro power plants in each case study region. In this case study (A) since there are no PV power plants in the region, only wind and hydro power plants were identified, as follows (Table 3).

Table 3 - Wind power plants in *Pinhal Interior* region.

Common Name	LAT	LONG	Nº Turbines	Install Power [MW]	Limit Power [MW]	Voltage [kV]	Substation Name	MVA Limit	MW Limit	SUB_ID
Serra do Ralo	40,57740	-7,40340	16	32	32	60	Chafariz	34,4	32	SCF
Beira Interior	40,80977	-7,34828	25	58,75	58,75	60	Chafariz	49,5	49,5	SCF
Prados	40,55304	-7,36134	17	39,95	39,95	60	Chafariz	33,8	33,8	SCF
Trancoso	40,85675	-7,38127	14	28,7	28,7	60	Chafariz	30,1	28	SCF
Pisco	40,83475	-7,42161	25	50	50	60	Chafariz	50	50	SCF
Guarda	40,55392	-7,28459	4	8,6	8,6	MT	Chafariz	8	8	SCF
V. Estrela	40,49346	-7,30606	11	27,5	27,5	60	Chafariz	33,8	33,8	SCF
Cadraço	40,556079	-8,194814	1	1,29	1,29	MT	Vila Chã	1,2	1,2	SVC
Pampilhosa da Serra	40,12290	-7,93670	38	114	114	220	Tábua	96,614	96,614	STBA
Toutiço	40,15714	-7,83357	34	102	102	220	Tábua	107,1	102	STBA
Alto do Arganil	40,20284	-7,79415	18	36,9	36,9	60	Tábua	37	36	STBA
Beiras	40,12087	-8,04673	45	102,65	102,65	220	Tábua	84,8	84,8	STBA
Vale Grande	40,18790	-7,91570	6	12,3	12,3	220	Tábua	12,63	12,3	STBA
Acor	40,21382	-7,87022	12	24,6	24,6	60	Tábua	25,8	24	STBA
Guardão	40,55328	-8,19092	14	28,7	28,7	60	Tábua	25	25	STBA
SQ Guardão	40,55328	-8,19092	1	2	2	60	Tábua	0	0	STBA
Coentral Safra	40,07011	-8,19387	25	41,75	41,75	60	Pereiros	39,618	39,618	SPR
Cadafaz	40,10408	-8,04411	17	10,2	10,2	60	Pereiros	10,2	10,2	SPR
Malhadas	40,09087	-8,05881	15	11,25	11,25	60	Pereiros	10	10	SPR
Degracias	40,02274	-8,51629	10	20,85	20,85	60	Pereiros	17,119	17,119	SPR
Lousã	40,10054	-8,18003	14	38,36	38,36	60	Pereiros	31,967	31,967	SPR
SQ Cadafaz	40,10408	-8,04411	1	2	2	60	Pereiros	0	0	SPR
S. João	40,02231	-8,28917	13	21,71	21,71	60	Penela	22,854	21,71	SPNL
VilaNova2	40,05313	-8,25548	14	29,3	29,3	60	Penela	24,1	24,1	SPNL
LousaII	40,02827	-8,22760	25	60	60	60	Penela	52,64	50	SPNL
Ortiga	40,00769	-8,23501	8	13,36	13,36	60	Penela	12,65	12,65	SPNL
Videira	39,87278	-8,40306	3	6,15	6,15	MT	Penela	6,45	6	SPNL
VilaNova1	40,04463	-8,28135	15	30	30	60	Penela	25,317	25,317	SPNL
Alvaiázere	39,82810	-8,41299	9	18,45	18,45	MT	Penela	19,35	18	SPNL
Picos VC	40,07435	-8,14371	11	22,55	22,55	60	Penela	22,55	22,55	SPNL
SQ LousaII	40,02827	-8,22760	5	10	10	60	Penela	0	0	SPNL
Bairro	39,58848	-8,57485	11	22,55	22,55	60	Zêzere	18,5	18,5	SZR
Vergão	39,75526	-7,99013	10	13	13	60	Zêzere	10	10	SZR

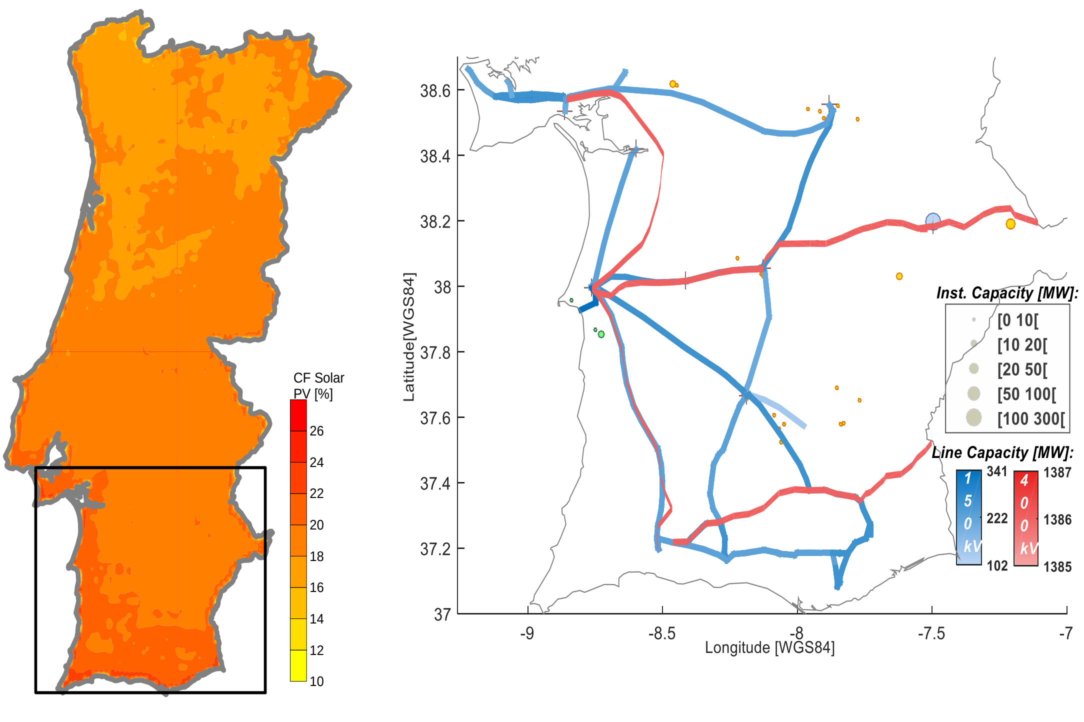
Common Name	LAT	LONG	Nº Turbines	Install Power [MW]	Limit Power [MW]	Voltage [kV]	Substation Name	MVA Limit	MW Limit	SUB_ID
Se. Lage	39,62723	-7,98561	6	4,749	4,749	MV	Zêzere	3,93	3,93	SZR
Penamacor	40,20741	-7,24536	70	143,8	143,8	220	Ferro	129	120	SFE
S. Alvoaca	40,24001	-7,73147	17	36,6	36,6	60	Ferro	34,699	34,699	SFE
Raia	40,31712	-7,20433	56	131,6	131,6	220	Ferro	109,8	109,8	SFE
Mosqueiros2	40,44022	-7,35997	12	25,2	25,2	60	Ferro	20,6	20,6	SFE
Mosteiro	40,30848	-7,14951	8	11,1	11,1	60	Ferro	9	9	SFE
Mosqueiros1	40,46051	-7,34588	4	8,2	8,2	60	Ferro	8,6	8	SFE
Mosteiro2	40,72500	-7,49675	1	2	2	60	Ferro	1,511	1,511	SFE
Se.Alta	40,31790	-6,89664	1	2,15	2,15	60	Ferro	2,15	2	SFE
Gardunha	40,05821	-7,67389	57	116,85	116,85	150	Castelo Branco	121,334	114	SCC
Cabeco da RainhaII	39,87310	-7,87852	15	30,75	30,75	MV	Castelo Branco	28,959	28,959	SCC
Pinhal Interior	39,80620	-7,88800	63	146,25	146,25	150	Falagueira	130	130	SFR
Mougueiras	39,90869	-7,83521	4	8,2	8,2	150	Falagueira	7	7	SFR
Bravo	39,90630	-8,04304	8	16,4	16,4	150	Falagueira	13	13	SFR
CabecodaRainha1	39,84985	-7,92227	23	22,35	22,35	60	Falagueira	23,865	22,2	SFR
Perdigão	39,70758	-7,74490	1	2,05	2,05	MV	Falagueira	2,15	2	SFR
SQ Cabeco Rainha1	39,84985	-7,92227	2	4	4	60	Falagueira	0	0	SFR
Amêndoa	39,62219	-8,02823	14	21,19	21,19	60	Falagueira	19,3	19,3	SFR
Pracana	39,57028	-7,82596	1	1,935	1,936	MV	Falagueira	1,936	1,8	SFR
Alto Fornin	39,29476	-7,35668	4	8,204	8,204	MV	Falagueira	8	8	SFR

Table 4 - Hydropower plants and Dams in *Pinhal Interior* region.

Designation	LAT	LONG
Caldeirão	40,531618	-7,329622
Sabugueiro	40,396638	-7,662179
Desterro	40,398626	-7,686967
Pontes Jugais	40,384792	-7,705056
Vila Cova	40,379731	-7,727932
Aguieira	40,340227	-8,196834
Ribeiradio	40,742890	-8,319974
Raiva	40,309483	-8,248805
Santa Luzia	40,089661	-7,858350
Cabril	39,917880	-8,132184
Bouça	39,853404	-8,218857
Castelo de Bode	39,542931	-8,318695
Pracana	39,564980	-7,812203
Fratel	39,543384	-7,802804
Belver	39,480833	-7,998186

2.2. Case Study B – Region predominantly with PV distributed generation

The current PV installed capacity in the country is still limited (approximately 743 MW, by the end of 2019). However, since short-term changes are expected this case study will simulate the impact of an increase of PV installed capacity in the range of 800-1000 MW connected to the RNT in the south of Portugal. Therefore, this case study aims to assess the DLR impact in a region with very high solar potential[1] and limited grid capacity. As previously mentioned, the extreme environmental conditions expected in this region in some periods of the year, may originate real transmission capacity lower than the one established by SLR methodology. Figure 12 depicts the region under analysis and characterizes the grid and the installed RES power capacity.



a) b)

Figure 12 - a) Solar power PV capacity factor (CF) during 2015-2016 (the box represent the region under analysis in case study B). b) Case study B: Location and nominal capacity of the RES generation (blue circles represent hydro generation, yellow circles represent solar generation and green circles represent wind generation). The symbol "+" represent the substations. The blue, green and red lines represent the line capacity during the winter for 150 kV, 220 kV, and 400 kV, respectively.

[1] Hourly data gathered from the PVGIS web-based tool considering a crystalline silicon panel, the optimal azimuth and inclination angles and the influence of shadows from the terrain.

As presented for the previous case study, a characterization of the OHLs located in the south of Portugal is made, regarding the following information [5] [6]:

- Identification of each overhead line start and end busbar;
- Identification of the cable type and cable length;
- Calculation of their respective Resistance - R (pu), Reactance - X (pu) and susceptance - B (pu);
- Calculation of the maximum capacity in each season of the year (i.e. spring, summer, autumn and winter);
- Characterization of the transformers in the substations.

Also, a characterization of the substations situated in Southern Portugal region was made, as shown in the following table and figures.

Table 5 - Substations list in south of Portugal (Alentejo).

Designation	Voltage Level [kV]	SUB_ID	LONG	LAT
Estremoz	400(150)/60	SETM	-7,52896	38,88960
Évora	150/60	SER	-7,88204	38,55520
Alqueva	400/60	SAV	-7,49700	38,18590
Ferreira do Alentejo	400/150/60	SFA	-8,12570	38,05550
Sines	400/150/60	SSN	-8,76240	37,99728
Ourique	150/60	SOQ	-8,18951	37,66738
Setúbal	150/60	SSB	-8,86194	38,53648
PC Ermidas Sado	150	PCES	-8,41213	38,01704
PC Monte da Pedra	150	PCMP	-8,59873	38,41935

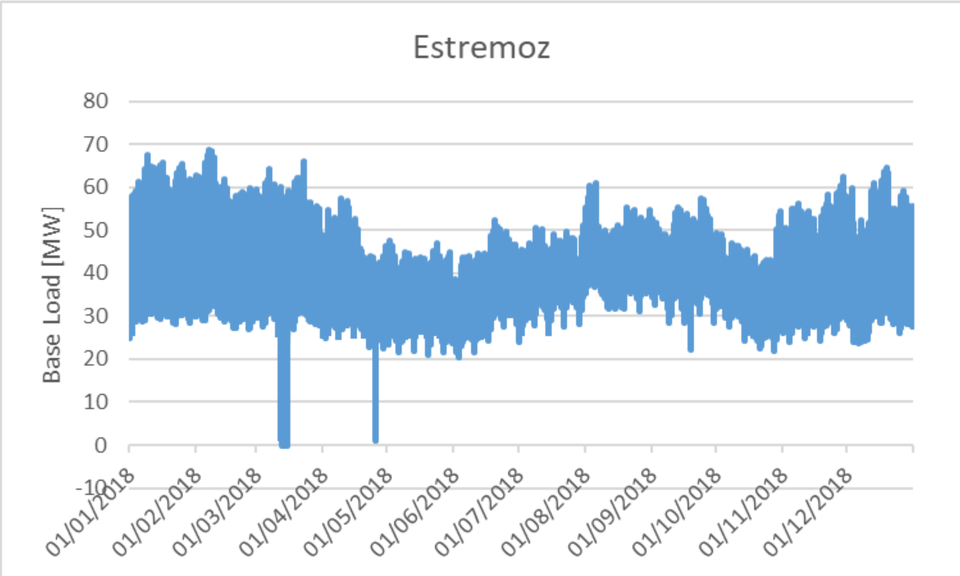


Figure 13 - Base Load of *Estremoz* Substation throughout 2018.

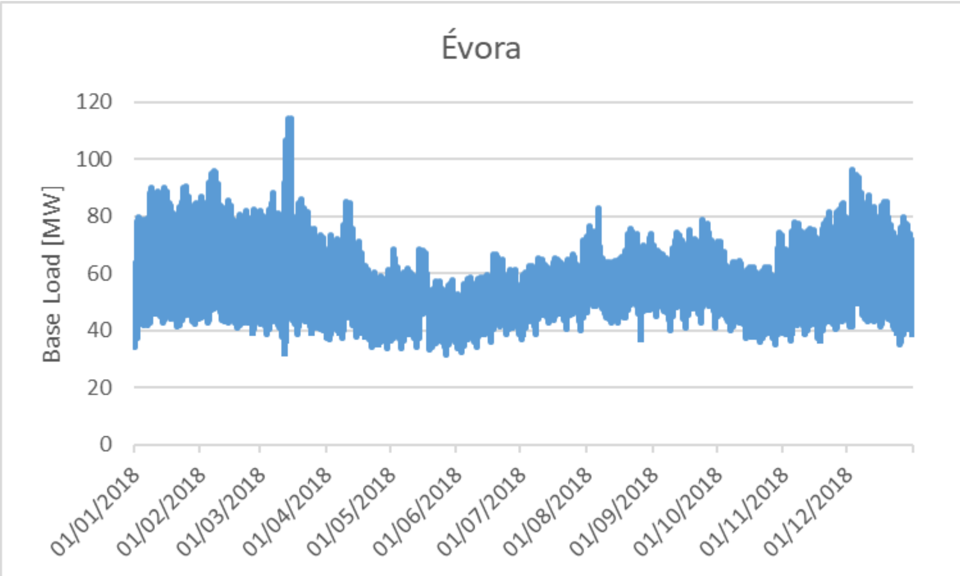


Figure 14 - Base Load of *Évora* Substation throughout 2018.

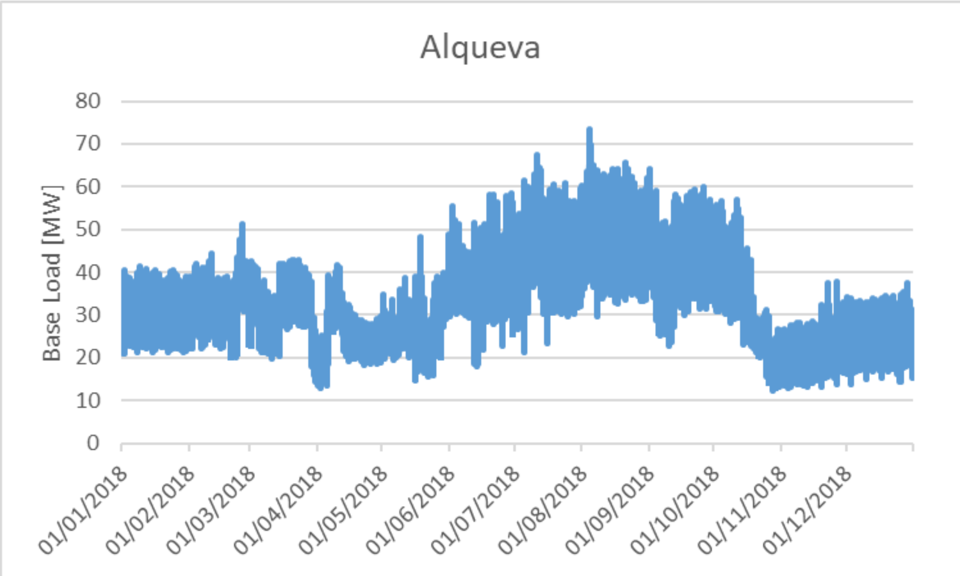


Figure 15 - Base Load of *Alqueva* Substation throughout 2018.

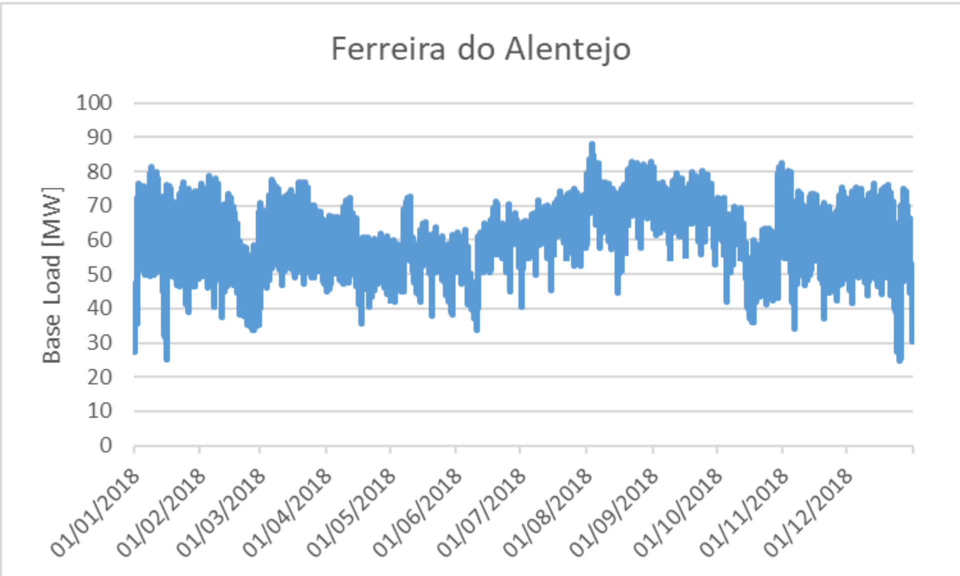


Figure 16 - Base Load of Ferreira do *Alentejo* Substation throughout 2018.

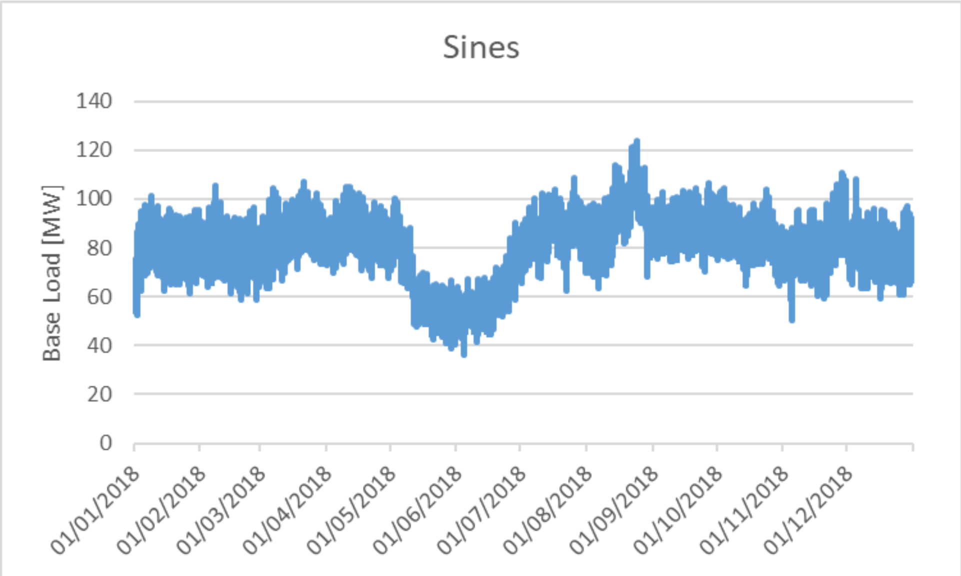


Figure 17 - Base Load of *Sines* Substation throughout 2018.

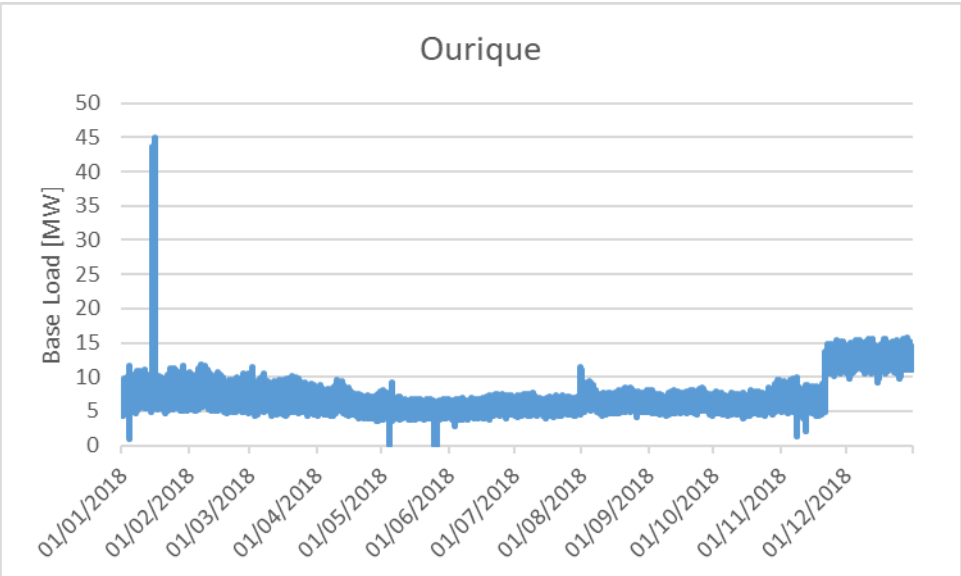


Figure 18 - Base Load of *Ourique* Substation throughout 2018.

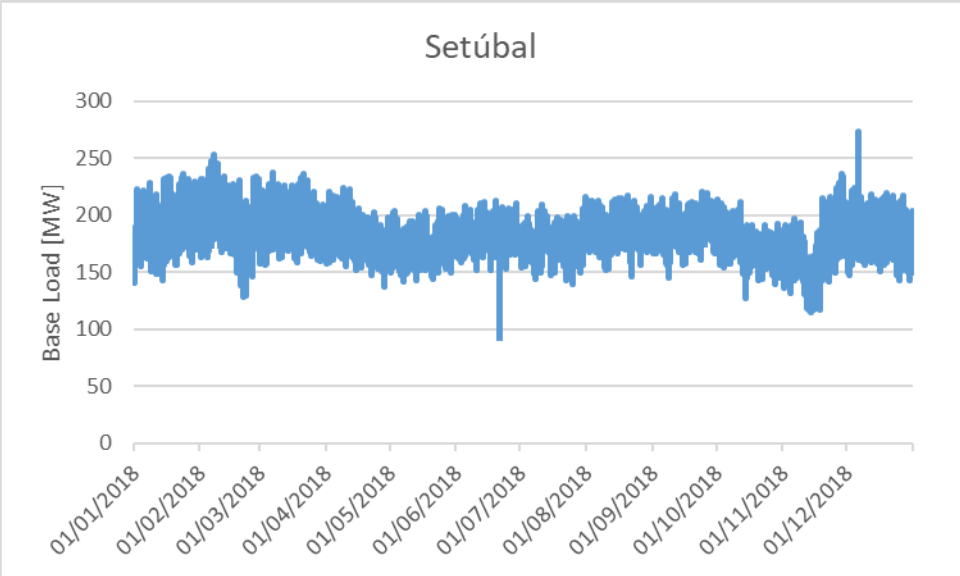


Figure 19 - Base Load of *Setúbal* Substation throughout 2018.

Unlike the case study of *Pinhal Interior*, the Southern Portuguese region has PV power plants as well as some wind and hydro power plants. They are characterized in the tables below.

Table 6 - PV power plants in the south of Portugal.

Name	LAT	LONG	Capacity [MW]
Campo Ameixial	38,8847	-7,6558	5,000
Montes Novos	38,8365	-7,6499	3,300
Cabrela	38,6179	-8,4613	12,000
Flamenguinha	38,6165	-8,4469	2,000
Eresolar	38,5514	-7,8497	5,000
Alcamises	38,5410	-7,9618	2,500
Barbarrala	38,5339	-7,9154	1,000
HeliosEvosol	38,5130	-7,9018	5,000
Resun	38,5130	-7,9018	5,000
Quinta Louseiro	38,5098	-7,7779	1,100
Amareleja	38,1921	-7,2090	35,000
CFMalhadaVelha	38,0853	-8,2228	9,000
FAlentejo2	38,0534	-8,1364	10,000
Chaminé	38,0379	-8,1329	1,400
Monte Vinha	38,0371	-8,1334	0,400
FAlentejo1	38,0339	-8,1238	12,000
Serpa	38,0299	-7,6229	11,000

Name	LAT	LONG	Capacity [MW]
CFMonteAipo	37,6903	-7,8519	0,100
Ourika	37,6688	-8,1908	40,500
CPaoAgua	37,6526	-7,7681	0,600
IntAlent	37,6063	-8,0874	2,200
Olva	37,5838	-7,8287	2,200
Castanhos	37,5797	-7,8383	1,300
AldeiaNeves1	37,5782	-8,0505	0,100
AldeiaNeves2	37,5782	-8,0505	0,100
Porteirinhos	37,5634	-8,0687	6,000
Almodovar	37,5247	-8,0587	1,100

Table 7 - Wind power plants in the south of Portugal.

Common Name	LAT	LONG	Nº Turbines	Install Power [MW]	Limit Power [MW]	Voltage	Substation Name	MVA Limit	MW Limit	SUB_ID
Chaminé	37,86601	-8,75113	3	6,9	6,9	MV	Sines	5,645	5,645	SSN
M. Chãos	37,95628	-8,83890	12	2,112	2,112	MV	Sines	2,112	1,8	SSN
M. Pias	37,85299	-8,72857	5	10,75	10,75	MV	Sines	10	10	SSN

Table 8 - Hydro power plants in the south of Portugal

Designation	LAT	LONG
Alqueva	38,197277	-7,49655
Pedrogão	38,110647	-7,63015

3. Conclusions

In this deliverable the gathered data regarding grid characteristics and available RES in the regions considered as use-cases are presented:

- *case study A* - a region with large distributed wind power generation;
- *case study B* - a region with large (foreseen) PV generation;

The data consists of topology and electrical characteristics of the high voltage network of the Portuguese power transmission system, considering the planned future topology of network expansion that needs to take place to accommodate the expected increased penetration of renewable generation. Since the majority of the wind power resources are at the High Voltage (HV. i.e. 60 kV) in the distribution grid, also HV grid data was gathered and described in this deliverable.

The renewable power generation sources installed capacity and the loads in the regions under analysis were also obtained. Time series for the load in each transmission substations and renewable (hydro, wind and solar) generation pattern for the entire 2018 year was also used to create both case studies. This data collection is aimed to provide all the information needed to enable the application of the mathematical models under development within the project scope.

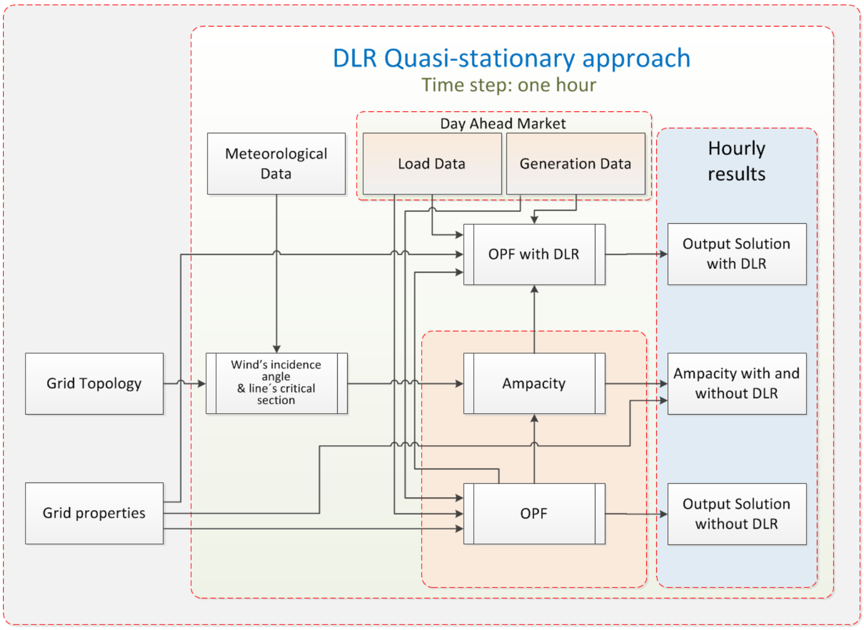


Figure 20 - Block diagram with data interaction.

For confidentiality reasons, only non-confidential information is presented in this report. Nevertheless, within the scope of the project, all the data needed to apply (and validate) the mathematical models under development were obtained.

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