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Requirements for New Grid Codes: A Review in Spain & Portugal

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Abstract. To continue to make successful progress towards the achievement of net zero emissions by 2050, a significant number of new facilities based on renewable technologies must continue to be deployed at large scale. However, the integration of large capacities of renewable generation sources into power systems leads to a series of challenges that must be urgently addressed. On the one hand, the intermittent character of renewable resources may lead to imbalances between generation and demand curves, and on the other hand, transmission and distribution system operators will have to carefully consider the impact of reduced power system inertia due to the increase in the number of renewable power plants. Under this framework, stricter technical requirements will be demanded to new power plants that will be integrated into the grid to guarantee quality of electricity supply. These requirements are included within increasingly modern and up-to-date network connection -or grid-codes. Thus, grid codes have a significant role to play in the years to come towards the transition of a more sustainable future, and therefore this paper presents an overview of two grid codes for connecting new generation units across Europe, focusing on the current situation of Iberia. A special emphasis is given on the detailing of certain grid code requirements based on a comparison between the Portuguese and the Spanish grid codes, together with few highlights on the operational procedures for connecting new generation units on both regions.

Key words. Grid code, Network code, Portugal, Regulation EU 2016/631, Spain.

1. Introduction

According to [1], despite how challenging it was, the year 2020 positioned as a very positive period for the global wind industry, since more than 93 GW of wind power were installed, which brought the total cumulative capacity up to 743 GW. In the case of solar Photovoltaic (PV) power, the total capacity worldwide was more than 760 GW at the end of 2020 [2]. In 2021, the electricity generation from renewables reached a record high in countries such as Spain, since it accounted for 46.6% of the country's total electricity generation.

The increase in the installation of renewable energy capacity is one of the main lines of actions to pursue zero-carbon economies, although it is not the only one, since bold actions in other sectors, such as the building industry or the transportation sector, are also urgently required. Research and development must be supported as well, so that the transition towards a more sustainable future can be achieved.

Returning to the matter of the installation of renewables, the retirement of fossil fuel power plants and the commission of new renewable facilities will ease the transition to emission-free energy models. Large-scale Wind Power Plants (WPP) and solar PV power plants will have to be deployed, and this will be also accompanied by the expansion of other renewable energy technologies, such as solar thermal power. It is therefore doubtless that in this new scenario in which the penetration of renewable energy into the electricity mixes of countries is increasing, the way power systems operate is also changing.

Within this framework, one of the main challenges that must be faced is the intermittent character of renewable resources. Variability in the generation of electricity from renewables may lead to large imbalances between generation and demand, and hence large energy storage systems will be needed to act as balancing systems between periods of high electricity generation and low demand, and vice versa. Besides, the increase in the number of renewable power plants -and the consequent reduction of conventional generation power plants- may significantly decrease inertia in power systems. This means that frequency dynamics are faster in the areas of the power system where there are low levels of rotational inertia. Therefore, control issues become more complex and the time to respond to frequency changes and fault events -such as large-scale set-point changes or power plant outages- decreases.

Thus, the new scenario that will rise from the massive integration of renewables inevitably leads to a deep transformation of power systems. This implies, among other things, demanding stricter technical requirements to new power plants that are going to be integrated into the grid, so that stability and quality of electricity supply can be guaranteed. In this context, countries have developed technical documents, commonly known as *grid codes*. Grid codes are normative documents that define the technical specifications that a facility that is going to be connected to the grid must comply with. Hence, grid codes define not only the technical requirements renewable facilities must meet, but also usually the compliance process for the compliance assessment of the requisites.

In view of the great importance that grid codes play in the deployment of renewables at large scale, the present contribution performs a comparison between certain technical requirements established in the grid codes of Spain and Portugal. The review work carried out serves to highlight the differences between the most demanding technical requirements established in the normative documents of the two main peripheral European countries that form part of the Iberian Peninsula. The similarities and points in common of these requirements will be highlighted as well, and, finally, a brief summary of the main challenges modern power systems must face is included.

2. Grid Codes in Spain & Portugal

Before reviewing some of the main aspects of the Spanish and Portuguese grid codes, it is worth making a brief review of grid codes at European level. The European Commission began developing, in 2010 and through the European Network of Transmission System Operators for Electricity (ENTSO-E), a new network code formulating two types of requirements: mandatory requirements for all countries, and optional technical requirements, adaptable by each country based on the characteristics of its national electricity network. Moreover, the European network code is divided into three families: i) connection; ii) operations; and iii) market. Each of these network code families is in turn divided into different specific grid codes. The document that specifically addresses the requirements set for generators, known as "Requirements for Generators" (RfG), was established in the Commission Regulation (EU) 2016/631 [3].

The RfG document aims to harmonise, at European level, the connection requirements demanded to generators of any kind -wind, solar PV, etc. The regulation also offers a global structure that may be followed for compliance assessment of the requirements. Thus, it is the national application of Commission Regulation (EU) 2016/631 that has led to the development of the Spanish and Portuguese network codes.

A. Grid Code in Spain

Based on the European regulation EU 2016/631, in July 2020, a new grid code was released in Spain, formed by Ministerial Order (MO) TED/749/2020 [4] and Royal Decree (RD) 647/2020 [5], as well as a guidelines document that has the objective of monitoring compliance with the technical requirements established. The second edition was published in November 2020. The guidelines document, called Technical Supervision Standard, '*Norma Técnica de Supervisión*' (NTS) [6], develops the aspects set out in the Spanish normative documents that form the new grid code -those requiring a greater level of detail-aimed at verifying the compliance of the electricity generation modules that are going to be connected to the national grid [7].

B. Grid Code in Portugal

Like Spain, Portugal also began developing a new grid code based on the European regulation EU 2016/631. In particular, Portugal launched an ordinance, '*Portaria n.º 73/2020*', in March 2020 [8]. As was indicated previously, the RfG document defines specific technical requirements for implementation by the member states, but also defines non-mandatory or non-exhaustive requirements, the specification of which depends on the decisions of each European country. Thus, regulation or ordinance '*Portaria n.º 73/2020*' defines the non-exhaustive technical requirements for the connection of generation modules to the Public Electricity Supply Network, '*Rede Elétrica de Serviço Público'*, and identifies the facilities subject to the fulfilment of these requirements.

3. Comparative Analysis

Regulation EU 2016/631 establishes specific requirements of common application to all member states, although it also establishes other requirements, known as non-exhaustive requirements, the specification of which is left to the decision of each member state.

Therefore, the present contribution focuses on highlighting the main differences between a number of non-exhaustive -or non-mandatory- requirements included in the grid codes of Spain and Portugal. In particular, the work focuses on those requirements related to network frequency, such as the frequency sensitive modes, which shall be activated by the generation units under compliance to provide active power under certain frequency changes conditions. Moreover, the work also addresses the fault-ride through capability requirements demanded by both grid codes to the power plants.

Before going on to list the main differences between the non-mandatory technical requirements of the Spanish and Portuguese grid codes, it should be noted that the Power-Generating Modules (PGM) that must comply with the requirements established are divided into different types: i) synchronous PGMs, which are those having an inherent capability to resist or slow down frequency deviations; ii) power park modules, which are those generating units that are either connected to the network through power electronics or non-synchronously connected; and iii) offshore power park modules, which are power park modules located offshore, i.e., situated at sea some distance from the shore. However, as mentioned previously, the present contribution focuses on the requirements that renewable energy power plants must comply with, which are facilities encompassed within the type 'power park modules'. It should be noted at this point that if no specific distinction is made between 'power park modules' and 'PGMs', and only 'PGMs' are mentioned, this means that the renewable units are already included within this term.

There are, in turn, different types of PGMs, depending on the voltage level of their connection points -or Point of Common Coupling (PCC)- and their maximum capacity. In the case of Spain, the types of modules are divided as follows:

- Type A: PGMs with PCC of which voltage is below 110 kV and its maximum capacity is between 0.8 kW and 100 kW.
- Type B: PGMs with PCC of which voltage is below 110 kV and its maximum capacity is between 100 kW and 5 MW.
- Type C: PGMs with PCC of which voltage below 110 kV and its maximum capacity is between 5 MW and 50 MW.
- Type D: PGMs with PCC of which voltage equal to or greater than 110 kV or its maximum capacity is above 50 MW.

In the case of Portugal, these are divided according to the following classification [9]:

- Type A: PGMs with PCC of which voltage is below 110 kV and its maximum capacity is equal to or above 0.8 kW and below 1 MW.
- Type B: PGMs with PCC of which voltage is below 110 kV and its maximum capacity is equal to or above 1 MW and below 10 MW.
- Type C: PGMs with PCC of which voltage is below 110 kV and its maximum capacity is equal to or above 10 MW and below 45 MW.
- Type D: PGMs with PCC of which voltage is equal to or greater than 110 kV or its maximum capacity is above 45 MW.

It can be observed that there are certain differences in the classification of the PGMs depending on the grid code. Although the voltage threshold that is used to classify the PGMs into the different types is the same (110 kV), the capacity values considered vary. In the case of Spain, Types A PGMs only include those PGMs up to 100 kW, while Types A in Portugal cover PGMs of a significantly greater capacity (up to 1 MW). In the case of Types B PGMs, Portugal continues along the same path, covering PGMs up to 10 MW, a capacity that is double the capacity of the PGMs covered by Types B in Spain (up to 5 MW). In the case of Types C, the range of PGMs covered by the Spanish grid code is wider, from 5 MW to 50 MW, while in Portugal this range goes from 10 MW to 45 MW. Finally, regarding Types D, a similar classification is made, since this category includes, in both cases, PGMs of a very significant capacity.

When either of the two normative documents analysed, in any of the technical requirements addressed, leaves out of its scope of application any of the types of PGMs shown in the previous classification, we could quickly deduce how demanding the relevant grid code is in requiring compliance with this requirement by the generating units depending on its capacity. Therefore, these classifications should be born in mind when discussing each of the technical requirements and its scope of application.

A. *Frequency Stability*

In the case of frequency stability, both countries establish the same requisites, and require all types of power park modules to remain connected to the network and operate within the time periods and frequency ranges defined in Table I.

Table I. – Frequency Stability Requirements

Country	Frequency Range (Hz)	Time period for operation
Spain & Portugal	47.5 – 48.5	30 minutes
	48.5 – 49.0	Unlimited
	49.0 – 51.0	Unlimited
	51.0 – 51.5	30 minutes

It should be noted that Regulation EU 2016/631 establishes that, for the frequency range between 48.5 Hz and 49.0 Hz, the time period for operation must be not less than the period set for the range between 47.5 Hz and 48.5 Hz, i.e., not less than 30 minutes in this case. It is set as ‘unlimited’, which means that it is stricter than it could be according to the European regulation. Moreover, it should also be noted that, in the Spanish case, the limits established in Table I are modified for combined frequency and voltage deviations, while this scenario is not covered in the Portuguese grid code.

The normative documents of both countries also contemplate the rate of change of frequency withstand capability of PGMs. The European regulation does not include specific values in this case, since they are left to the discretion of each Transmission System Operator (TSO), and both grid codes establish the same values: all types of PGMs must remain connected to the network for rates of frequency variation equal to or less than 2 Hz/s, measured in a moving time interval of 500 ms.

B. *Limited Frequency Sensitive Mode – Overfrequency (LFSM-O)*

All types of PGMs shall be capable of activating the provision of active power frequency response according to Figure 1 included in Article 13.2 of Regulation EU 2016/631 [3]. Moreover, the Portuguese grid code specifies that this applies at the expense of the information included in section b) of that same article. In any case, the parameters to be set to allow an adequate response under the LFSM-O mode, namely the frequency threshold and the droop -or statism, are specified in Table II. As stated before, these parameters are defined, for both cases, according to Figure 1 included in Article 13.2 of Regulation EU 2016/631 [3].

It should be noted that ‘droop’ is defined as the ratio of a steady-state change of frequency to the resulting steady-state change in active power output, and as observed in Table II, is expressed in percentage. On the other hand, the frequency threshold is the value of frequency above which, or below which -depending on the particular case, the sensitive modes shall be activated.

In this regard, the Spanish grid code, based on what is included in the regulation at the European level, makes a further request, and states that, if the PGM is of Type C or D, the static characteristic must be accumulated over the corresponding static characteristic of the frequency sensitive mode, detailed in Section 3-D of the present work. With respect to the response speed of the PGM to activate the provision of active power frequency response, the Portuguese grid does not make any specification, while the Spanish grid code defines a number of parameters with which to characterize the response, gathered in Section 1.3 of Annex I, in MO TED/749/2020 [4].

Table II. – Setting of Parameters under the LFSM-O Mode

Country	Frequency Threshold (Hz)	Droop (%)
Spain	50.2	5
Portugal	50.2	4 - 6

C. Limited Frequency Sensitive Mode – Underfrequency (LFSM-U)

In the case of the LFSM-U mode, the parameters to be set to allow an adequate response of the PGMs (including both power park modules and synchronous PGMs), are specified in Table III. These parameters are represented graphically in Figure 4 included in Article 15.2 of Regulation EU 2016/631 [3]. Both grid codes demand these requirements to be complied with only by Types C and D PGMs. This means that, in this case, the Spanish grid code is a bit more stringent, since this requisite is required to be complied with by PGMs from 5 MW, while the Portuguese grid codes demand this requisite to be complied with by PGMs of greater capacity, from 10 MW.

Table III. – Setting of Parameters under the LFSM-U Mode

Country	Frequency Threshold (Hz)	Droop (%)
Spain	49.8	5
Portugal	49.8	4 - 6

As in the case of the LFSM-O mode, the grid codes state that the static characteristic must be accumulated over the corresponding static characteristic of the frequency sensitive mode (although in this case the LFSM-U mode only applies to Types C and D), described in Section 3-D of the present work, and it also states the response speed of the PGM to activate the LFSM-U mode, included in Section 1.7 of Annex I, in MO TED/749/2020 [4].

D. Frequency Sensitive Mode (FSM)

In the case of the FSM mode, Regulation EU 2016/631 [3] states that, in addition to fulfil the requirements established with regard to the LFSM-O and LFSM-U modes, the PGMs of Types C and D shall be capable of providing active power frequency response in accordance with the parameters that each TSO must specify within the ranges shown in Table 4 included in Article 15.2 of Regulation EU 2016/631 [3].

Specifically, Table IV shows the parameters chosen by Spain and Portugal, included in their grid codes. All these parameters are represented graphically in Figure 5, included in Article 15.2 of Regulation EU 2016/631.

As in the case of the LFSM-U mode, the Spanish grid code is more stringent than the Portuguese one in relation to the requirement for compliance of PGMs with this requisite, as it applies to PGMs from 5 MW.

Table IV. – Setting of Parameters under the FSM Mode

Parameters		Spain	Portugal
Active Power Range Related to Maximum Capacity ($\|\Delta P_1\|/P_{max}$)		8%	5%
Frequency Response Insensitivity	$\|\Delta f_i\|$	10 mHz	10 mHz
	$\|\Delta f_i\|/f_n$	-	0.02%
Frequency Response Deadband		0 mHz	0 mHz
Droop (s_1)		5%	4% - 6%

Furthermore, Regulation EU 2016/631 establishes that, in the event of a frequency step change, the PGM shall be capable of activating full active power frequency response, at or above the line shown in Fig. 1 in accordance with the parameters that each grid code specifies.

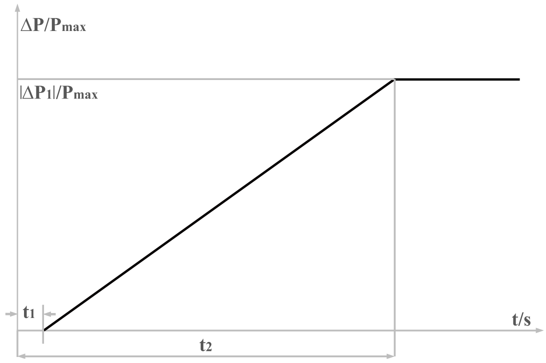

Fig. 1. Active Power Frequency Response Capability

The values of these parameters are shown in Table V for both normative documents.

Table V. – Setting of Parameters under the FSM Mode

Parameters		Spain	Portugal
Active Power Range Related to Maximum Capacity ($\|\Delta P_1\|/P_{max}$)		8%	5%
Initial Delay (t_1)	PGMs with inertia	2 s	2 s
	PGMs without inertia	500 ms	500 ms
Time for Full Activation (t_2)		30 s	30 s

The parameters that appear in Table IV and Table V are defined as follows. P_{max} is defined as the maximum capacity to which the change in active power output from the PGM (i.e., ΔP) relates. ΔP_1 is the point up to which the PGM has to provide active power output ΔP, and the PGM has to do it according with the time periods t_1 and t_2, specified further on in Table V. t_1 is the initial delay, and t_2 is the full activation time. On the other hand, f_n is the nominal frequency in the network; 'frequency response intensitivity' ($|\Delta f_i|$) is specified as the minimum magnitude of change in the frequency that results in a change of output power. Finally, Δf refers to, in general, the frequency deviation in the network.

Regulation EU 2016/631 also states that the PGMs shall be capable of providing full active power frequency response for a period between 15 and 30 minutes. In the case of Spain and Portugal, their grid codes choose the same values: 15 minutes. Another important point to note, which can be observed in Table V, is that a shorter delay to activate full active power frequency response is allowed to those PGMs without inertia, which are typically those corresponding to renewable energy power plants. I.e., a stricter requirement is established for the PGMs connected through power electronics to the network.

E. Maximum Power Capability Reduction with Falling Frequency

With respect to the admissible active power reduction from maximum output with falling frequency, it should be noted that the Portuguese grid code specifies that, below 49 Hz, a reduction rate of 2% of the maximum capacity at 50 Hz per 1 Hz frequency drop is allowed, and it applies to both power park modules and synchronous PGMs. However, in the case of the Spanish grid code, this requirement only applies to synchronous PGMs, and not to renewable energy power plants.

F. Capability of connecting automatically to the network

Regulation EU 2016/631 establishes that the relevant TSO shall specify the conditions under which a PGM is capable of connecting automatically to the network, and these conditions shall include the frequency ranges within which an automatic connection is admissible, a delay time, and the maximum admissible gradient of increase in active power output. In that regard, the grid codes of both countries define the frequency range between 47.5 Hz and 51.5 Hz, and state that the maximum admissible gradients must be defined, in each case, in coordination with the corresponding TSO.

However, this requisite is only required to Types A, B, and C in Spain, while it is required to all types of PGMs in Portugal. Moreover, the Spanish grid code demands these conditions to be complied with by those PGMs which have the capability of connecting automatically -and does not require all of them to have it, while the Portuguese grid code demands all the types of PGMs to have the capability of automatically connecting to the network. Finally, it is important to note that this 'automatic connection' capability must not be confused with the 'automatic reconnection' capability after a fault. It can therefore be concluded that the Portuguese grid code is more stringent as to the scope of application of this requirement, as it applies to PGMs of any capacity.

G. Fault-Ride-Through Capability

Each grid code defines different fault-ride through capability characteristics, through the definition of different voltage-against-time-profiles, depending on the type of PGM, its technology (power park modules or synchronous PGMs), and the type of fault -symmetrical or asymmetrical.

Fig. 2. shows the lower limit of voltage at the PCC -i.e., specifies the voltage-against-time-profile at the PCC for fault conditions- in the following cases:

- Spanish grid code: power park modules of Types B, C and D (Types D connected below a voltage level of 110 kV), and for symmetrical faults.

- Portuguese grid code: power park modules of Types A (Types A with a maximum capacity above 15 kW), B, C and D (Types D connected below a voltage level of 110 kV), and for symmetrical and asymmetrical faults.

Fig. 3. Shows the voltage-against-time-profile at the PCC for fault conditions- in the following cases:

- Spanish grid code: power park modules of Type D connected above a voltage level of 110 kV, and for symmetrical faults.

- Portuguese grid code: power park modules of Type D connected above a voltage level of 110 kV, and for symmetrical and asymmetrical faults.

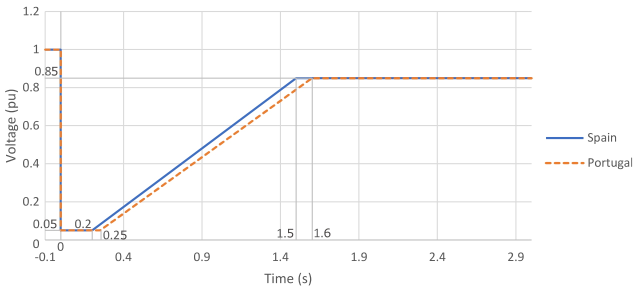

Fig. 2. Profile of the voltage dip withstand capability for different types of power park modules in the Spanish and Portuguese grid codes.

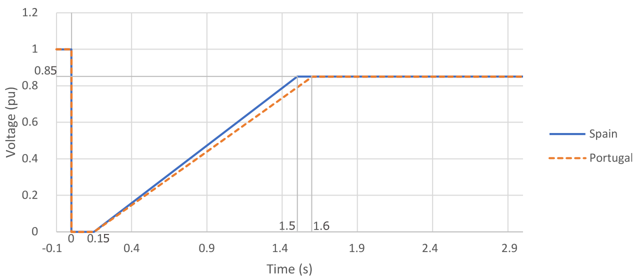

Fig. 3. Profile of the voltage dip withstand capability for Type D power park modules, connected above 110 kV, in the Spanish and Portuguese grid codes

In both cases, it should be noted that voltage is expressed in the per-unit system. Moreover, the following may be deduced from the above several considerations:

- The Spanish grid code does not legislate on the fault-ride through capability of Type A PGMs, which implies that these types of generating units are under no obligation to remain connected to the grid during faults (this involves the PGMs of the lowest capacity, until 100 kW). This means that the fault-ride through capability is demanded by the Portuguese grid code also to PGMs from 15 kW to 100 kW, which is a capacity range in which this requirement is not applied according to the Spanish legislation.

- Regarding the fault-ride through capability of power park modules under asymmetrical faults, the Spanish grid code states that, in the case of 1-phase or 2-phase faults (whether to earth or phase-to-phase), the voltage-against-time profile shown in Fig. 2. and Fig. 3. must be considered taking into account the lower of the phase-to-phase or phase-to-ground voltages, as appropriate.

In view of all the above, it is doubtless that Regulation EU 2016/631, which establish a network code on requirements for grid connection of generators, was updated in line with the new energy scenarios that are arising all over the European Union. The integration of renewables has led grid codes to be more demanding, since generation from conventional power plants is decreasing, and, as a result, power system inertia is also decreasing. This leads to control issues being more complex, since frequency dynamics are faster and the time to respond to those frequency variations changes. This is the main reason why stricter technical requisites are demanded, and also because flexibility, stability and reliability of the power system has to be maintained.

4. Challenges - Future Lines of Action

The Iberian power system is facing a lot of challenges for the upcoming years. The interconnections with other geographies need to be increased, while the installation of more renewable energy sources-based power plants is to be performed. The incremental integration of renewable energy will come from several PV power plant projects, from the retrofit of existing wind power plants, and the development of offshore wind farms, mostly using floating technologies. Considering that these new generation power plants are electronically interfaced, it is important to constantly study the dynamic characteristics of the Iberian systems to identify their scarcities in terms of power-frequency control, voltage regulation and fast power response, namely the possible lack of synchronous inertia.

Grid codes will continue to play an important role for grid operators, since they constitute an important tool that can be upgraded with new response characteristics as well as new services to deal with the predicted necessities of the evolving power systems. Nevertheless, to achieve such fulfilment it is of upmost importance to have accurate dynamic models of the power systems in order to fully address the problems that may arise. Thus, it is crucial that the grid operator have proper and well defined equivalent dynamic models of each new power plant. Here, an additional challenge arises, as several renewable energy sources-based power plants are connected to distribution grids and are not modelled/fully modelled on transmission system studies. There is thus an urgent need to create a common platform that would allow sharing equivalent dynamic models between distribution and transmission system operators so that the participation of distributed generation units is considered on system-wise studies, enabling the most accurate identification of both capacities and future needs.

5. Conclusions

Grid codes are normative documents that constitute an important tool that allows specific performance conditions to be required to the power plants that form part of a power system. Grid codes have significantly evolved over the last years, and they have done so hand in hand with the emergence of renewables, which poses enormous challenges that need to be addressed. As seen, there are still certain differences in the requirements of the grid codes developed by the two main Iberian countries, although they are not very significant. This is something very positive that allows the foundations for a future harmonization of the requirements demanded to be laid, which will also allow to address, in a joint and coordinated manner, the challenges related to the energy transition.

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