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A Review and Discussion of the Grid-Code Requirements for Renewable Energy Sources in Spain

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Abstract

During the last years, the rate of renewable energy sources in the current electricity production mix has been increasing more and more. In parallel, a significant development of regulations have been proposed by most developed countries, where the integration of these alternatives resources has been mainly focused on wind and PV power plants. Under this scenario, this paper discusses the current and upcoming Spanish grid code requirements concerning renewable energy resources. Specifically, the operating procedures P.O.12.2 and P.O.12.3 are described in detail. These procedures involve non-interrupted generation submitted to disturbances, extending characteristics such as low voltage ride through or reactive and active power capabilities. Additionally, the last draft proposed by the Spanish transmission system operator is included as well, comparing the current specifications facing other European requirements for renewable energy sources.

Key words
Grid code requirements, PV power plants, Wind farms

1. Introduction

The traditional fossil fuels have been remarkable sources of primary energy in the world, and they still continue to dominate growth in power generation. Indeed, fossil fuels accounted for 81% of the global Total Primary Energy Supply (TPES) in 2010 [1]. This important world energy demand dependence from fossil fuels is playing a relevant role in the increasing CO_2 emissions. In fact, developed countries are called to participate on the efforts of reducing CO_2 emissions in order to avoid dangerous climate change.

These reductions can be achieved by promoting potential changes in primary energy sources, as well as system/life cycle improvements in sectors such as industrial or tertiary customers. With regard to the possibilities of fuel choices and the inclusion of renewable energy technologies as alternative sources, electricity provides a much more flexibility than other energy-uses. In fact, the electric power can be generated by a wide range of diverse technologies (nuclear, hydro, wind, solar…) [2]. This characteristic of flexibility offers remarkable opportunities to include energy efficient solutions in the primary energy source mix of electricity generation, being also able to reduce greenhouse-gas emissions. In addition, this sector has a notable role in the current developed countries: 75% of the energy required by residential and commercial end-users is provided by electricity, and 35% of the energy demanded by industrial customers comes from electricity [3]. Moreover, from a global point of view, electricity has been played an increasing share of total final consumption during these last decades, increasing from 9.4% in 1973 up to 17.7% in 2010 [4]. Consequently, displacing fossil-fired generation with renewable energy generation has many desirable outcomes, mainly significant reductions in pollution and CO_2 emissions. In addition, a significant challenge emerges as desirable target, the reliable delivery of electrical power of acceptable quality nearly 100% of the time [5]. The combination of all these factors has led to increasing electricity generation by Renewable Energy Sources (RES), being supported by sustainable energy policies promoted by most developed country governments. In this new and upcoming policy scenario, electricity generation from renewables should nearly triple from 2010 to 2035, reaching 31% of total generation [6].

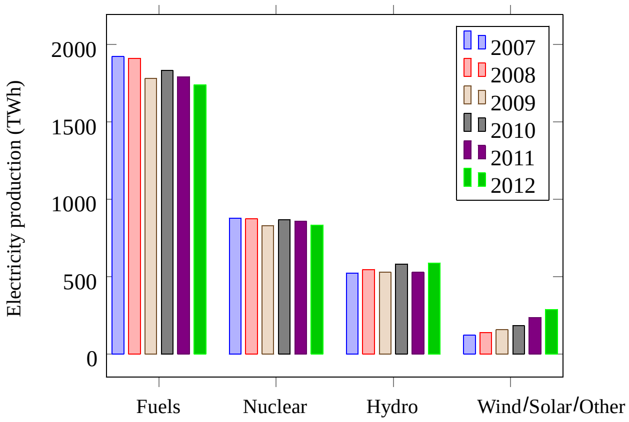

Fig 1. Electricity production by fuel type in Europe

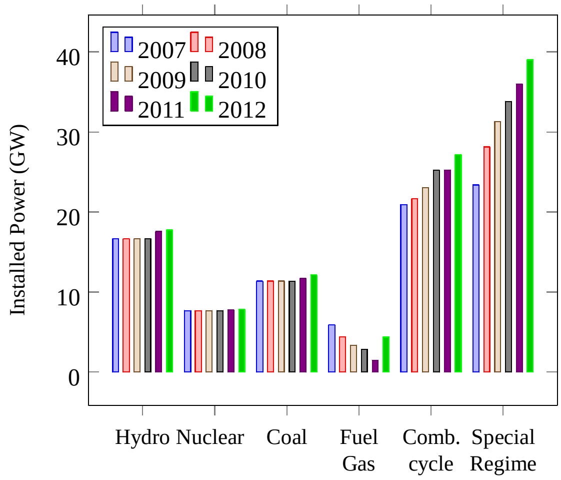

Fig 2. Installed power by technology in Spain

During the last decade, there has been a large increase in RES generation in Europe. In this way, the power capacity installation of RES was 3.5 GW in 2000, representing 20.7% of new power capacity installations. In 2012, the RES capacity has been increased by over 30 GW, being wind and Photovoltaic (PV) resources the most widespread technologies, with more than 97 and 69 GW capacity installed respectively. The rest of renewable energy technologies (hydro, biomass, waste, CSP, geothermal and ocean energies) have also increased their installed capacity over the past decade, but to a lesser extent than wind and PV resources. Figure 1 summarizes the electricity production in Europe by fuel type for the period 2000-2012, [7].

In the case of Spain, the RES is playing an active role in the electricity generation, becoming a significant percentage of the current installed capacity and accounting over 20% of the generated power. Figure 2 depicts the global installed power by technologies in Spain, [8]. In 2012, the Spanish wind farms supplied around 48.519 GWh, representing the third electricity generation source in terms of energy produced. Within RES resources, PV power plants generated 8.257 GWh in 2012, being the second RES [9]. Figure 3 shows the evolution of RES power installed in Spain along the last years.

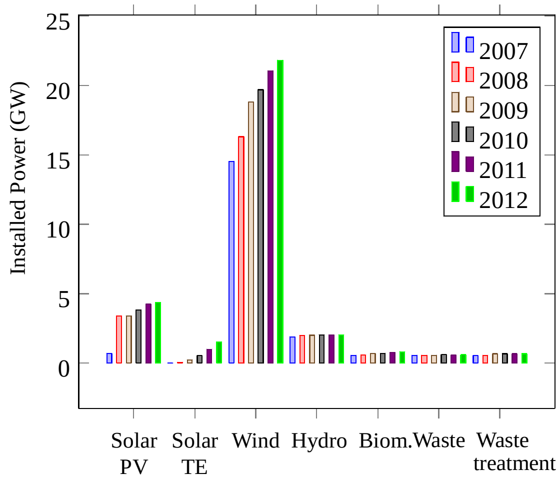

Fig 3. RES power installed by year and by technology in Spain

As can be seen, wind farms and PV power plants represent the most implemented technologies, with significant contributions to the generated electricity power in Spain in comparison with other renewable sources, [10]. However, and in the light of the recent financial crisis, some countries are developing ambitious renewable energy policies and even suspending entirely all-new renewable energy projects. This scenario is expected to be clarified in a short-term, proposing policies and measures to attract private investments as well as promoting the stability of investors.

Considering the significant penetration of RES technologies in some developed countries, and their influence of current power grids, an increasing attention of their potential impacts on both electrical distribution and transmission systems have been grown along the last decade [11]. In fact, and with the aim of maintaining power supply continuity and security, some countries have developed specific grid code requirements for the connection of wind farms and PV power plants to the power grid [12]. For example, in the case of Spain and due to significant penetration rate of RES installations, the National Grid-Code is requiring uninterrupted generation for RES installations submitted to power system disturbances. These requirements involve an extension of characteristics for wind farms and PV power plants, such as low voltage ride through, or reactive and active power capabilities [13].

Under this framework, where the integration of RES technologies into the power grids is promoted as a way of reducing the dependence on external sources for energy supply as well as an alternative to decrease the green-house effects, this paper is focused on describing recent proposals and technical requirements for RES installations proposed and developed by the Spanish Transmission System Operator (TSO), Red Eléctrica de España (REE). Requirements for the integration of distributed generation in Spanish distribution networks to ensure continuity of supply under the presence of voltage dips will be discussed in detail.

2. Spanish Grid Connection Requirements for Renewable Energy Sources

The promotion of RES technologies and green energy solutions involves not only governmental mechanism to incentive these installations, but also a regulatory environment where technical requirements have to be described in detail. Along the last decade, Spanish governments have promoted a sort of legal frameworks regarding grid connection and technical requirements. In this way, the 54/97 Law and the Royal Decree (RD) 1955/2000 firstly defined the Spanish legal framework for grid connection. Later, in 2004, the Spanish government published the RD 436/2004, which were mainly focused on renewable energy sources [14]. This RD allowed the operator system to send power curtailments and operational set-points to the wind farms. In some cases, the addition of suitable technical equipment to maintain the continuity of supply under the presence of voltage dips has been necessary to fulfil the current Spanish grid-code requirements. The Spanish TSO (REE), as system operator of the national grid, developed the Operation Procedure "*Requirements for response to voltage dips of production facilities under the special regime*" (P.O.12.3) [15]. These requirements were approved and issued in October 2006. In this case, only wind farms were called to fulfil the specific requisites under the presence of such disturbances. Recently, in November 2010, the RD 1565/2010 was proposed and issued, [16], supposing an extension towards PV power plants of the previous continuity requirements in response to voltage dips. Additionally, power factor requirements and modifications must be fulfilled for energy sources under the Spanish special regime generation.

As was previously discussed, the current Spanish grid code specifies that installations submitted to special regime production must support voltage dips at the point of interconnection with the transmission/distribution network, without tripping. The RSM voltage-time curve characterizing the magnitude and duration of maximum supported voltage dips is shown in Figure 4. These disturbances include both balanced and non-balanced faults; mainly due to single-phase-to-ground, two-phase-to-ground and three-phase short-circuits.

According to Figure 4, the current Spanish P.O.12.3 does not allow disconnections within the blue area. This voltage dip-time curve has been established according to stability simulations from REE and protection criteria [13]:

- The minimum 0.2 pu comes from REE stability simulations and the maximum generated active power that the Spanish power grid can loose when a short-circuit is suffered by the transmission system.

- The 500 ms time interval of the voltage dip derives from the maximum activation time of the distance protection, following general protection criteria of the Spanish electrical system.

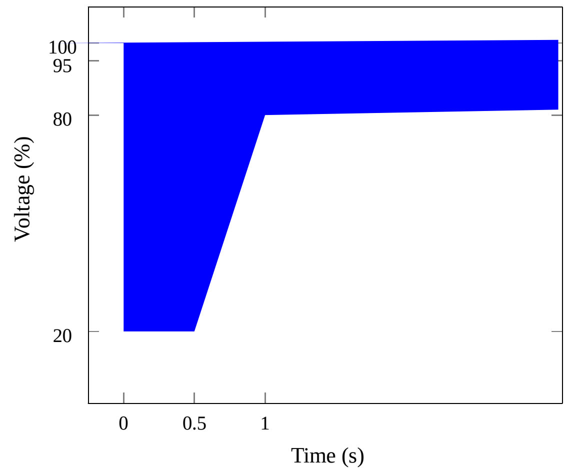

Fig 5. Spanish voltage-dip requirements at the grid connection point

- The voltage dip recovery time of up to 1 s results from the under-voltage protection of conventional generation units, which is activated when the voltage is below 0.8 pu during a time interval higher than 1 second.

This Operation Procedure also provide characteristics related to reactive and active power capabilities. Indeed, it is not allowed the demand of active and/or reactive power during periods of system failure and recovery. The global time interval ranges from the occurrence of the failure (and the voltage drops below 0.85 pu) until the voltage on the grid is within the limits of operation.

During the fault and later, including the voltage recovery period after the clearance of the fault, wind farms and PV power plants at the grid connection point, must provide the maximum generation of current. In any case, this current must be located in the shaded area of Figure 6. Both wind farms and PV power plants must supply reactive current with voltage levels under 0.85 pu, and they must not demand reactive power between 0.85 pu and the minimum allowed voltage level for the normal operation of the grid. With these premises, it is then desirable to maintain an active power generation similar to the pre-fault conditions.

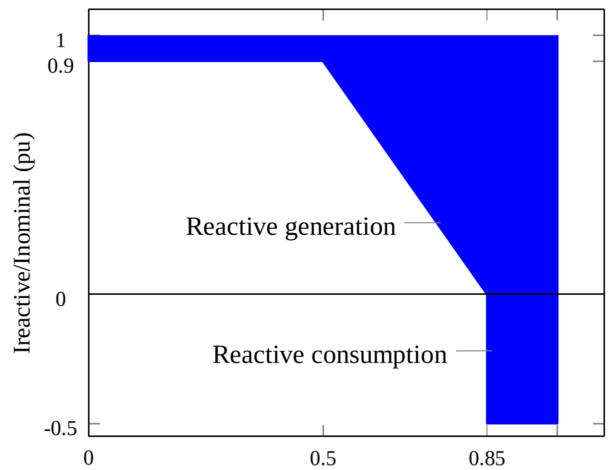

Fig 5. Allowed reactive current ranges (generated or consumed) as a function of the voltage level.

3. New Proposals of Spanish Requirements for Renewable Energy Sources

In accordance with the evolution of the Spanish Grid Code requirements and the increasing presence of wind farms and PV power plants in the power grid, the Spanish TSO (REE) published in 2008 a draft of the P.O.12.2 under the title "*Technical requirements for wind power and photovoltaic installations and any generating facilities whose technology does not consist on a synchronous generator directly connected to the grid*" [17]. The main difference of this draft in comparison with previous characteristics is focused on the voltage-time curve profile, which presents different proposals depending on the nature of the fault. In this way, an alternative voltage–time curve characteristic limiting the magnitude and duration of the voltage dips for single-phase, two-phase-to-ground and three-phase short-circuits is proposed and shown in Figure 6. In the particular case of a two-phase to ground fault, the P.O.12.2 gives another voltage–time curve to characterize the magnitude and duration of the allowed voltage dips, as can be seen in Figure 7.

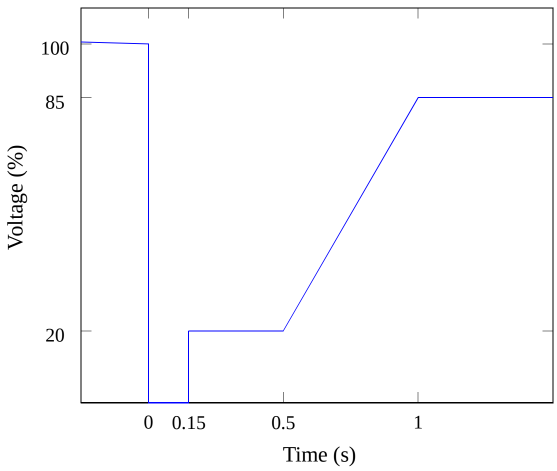

Fig 6. New proposal for Spanish voltage dip requirements at the grid connection point (excluding two-phase-to-ground faults)

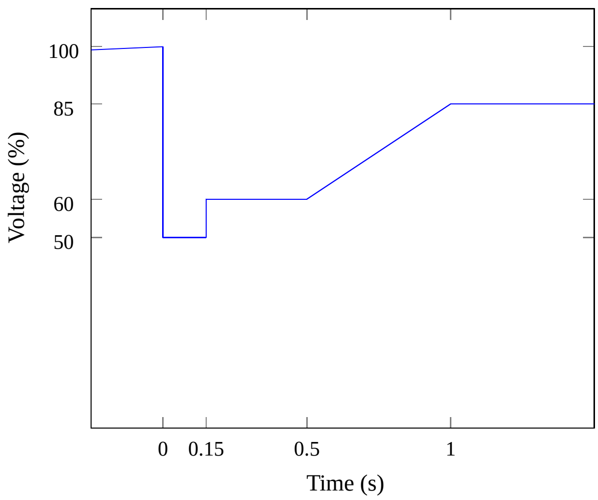

Fig 7. New proposal for Spanish voltage dip requirements at the grid connection point (only for two-phase-to-ground fault)

From the new proposals, and in line with the current Spanish grid-code requirements, the facility might not demand reactive and active power at the grid connection point during the fault and along the voltage recovery period (after the clearance of the fault). Nevertheless, and according to the last draft, momentary demand of reactive and active power is also allowed during the first 40 ms for balanced faults (three-phase), and 80 ms in the case of unbalance faults (single-phase and two-phase). In both cases, the active and reactive power demand is also allowed during the first 80 ms following the clearance of the fault. With regard to reactive power consumption, this is allowed only when the following conditions are met:

a) For balanced faults:
   - For the first 40 ms after the beginning of the fault, the net reactive power consumption of the facility for each cycle (20 ms) must be lower than 60% of the registered nominal power.
   - For the first 80 ms after the fault clearance, the net reactive energy consumption of the facility must be lower than the equivalent reactive power to 60% of the registered nominal power of the facility for an 80 ms time period.

b) For unbalanced faults:
   - The net reactive energy consumption (referred to the accumulated total of the three phases) of the facility must be lower than the equivalent reactive power to 40% of the registered nominal power of the facility for a 100 ms time period.
   - The net reactive power consumption of the facility for each cycle (20 ms) must be lower than 40% of the registered nominal power.

In the case of unbalanced faults, the demand of active power is only allowed outside those intervals if the following conditions are met:
   - The net active energy consumption (referred to the accumulated total of the three phases) of the facility must be lower than the equivalent active power to 45% of the registered nominal power of the facility for a 100 ms period.
   - The net active power consumption of the facility for each cycle (20 ms) must be lower than 30% of the registered nominal power.

During the whole transient regime, the facility must be able to inject to the grid at least the nominal apparent current. This draft of the P.O.12.2 gives the characteristics of the contribution of current during the disturbance, when the fault is balanced.

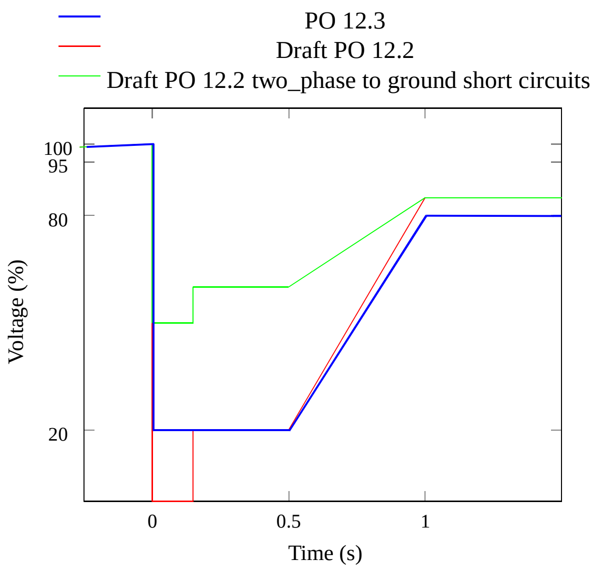

Fig 8. Spanish grid-code perspectives: comparison of voltage limiting curves at the grid connection point.

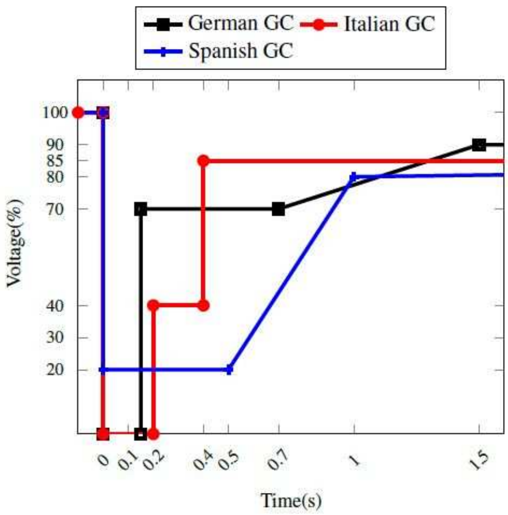

Fig. 9. Comparative of limiting curves of voltage at the grid connection point for PV.

Figure 8 compares the voltage-time characteristic profiles from the last published P.O.12.2 draft and the current Spanish special regime requirements. After a preliminary comparison of both regulations, it can be deduces that the final P.O.12.2 draft involves more demanding technical requirements. Indeed, this new draft proposes that both wind and PV installations must support voltage dips deeper and longer without disconnecting from the grid. In contrast, this last draft is more relaxing in the particular case of two-phase faults to ground short circuits.

4. European Requirements for PV Power Plants

With the aim of providing reliability and stability system operators in many countries have enforced stringent technical requirements on wind power plants. However only a few countries (like Spain, Germany and Italy) have elaborated specific technical requirements for PV power plants. This section compares the Spanish, German and Italian grid code requirements whit the specifications for the disconnection of wind and PV plants under abnormal voltage levels.

In Germany, the first Grid Code for wind turbines was introduced in 2003. However, and due to the experiences acquired in the recent years, it has become necessary to update the current Grid Code. The new grid connection requirements, has been developed by bdew (energie. Wasser. Leben). In 2008, the bdew published the "Technical Guideline Generating Plants Connected to the Medium-Voltage Network Guideline for generating plants connection to and parallel operation with the medium-voltage network". The German grid code made a distinction between type-1 and type-2 generating plants with regard to their behaviour in the event of network disturbances: A type-1 is for generating plants in which a synchronous generator is directly (only through the generator transformer) connected to the network. All other plants are type-2 generating units.

The general rules for connecting to the transmission system in Italy are given by different reports and rules. The main technical standards for the connection of electrical generators to the Italian grid are the CEI 0-16 (reference technical rules for the connection of active and passive consumers to the high-voltage (HV) and medium-voltage (MV) electrical networks of distribution companies), the CEI 11-20 (electrical energy production system and uninterruptable power systems connected to low-voltage (LV) and MV networks), and the CEI 11-32 (electrical energy production system connected to HV network). The technical requirement for the PV plant connection is the CEI 0-21.

To compare the different grid codes, the different limiting curves of voltage at the grid connection point for PV are overlapped as shown in Figure 9. After a preliminary comparison of the grid requirements for PV power plants, it can be deduces that the German and Italian Grid-Codes involve more demanding technical requirements. Indeed, they propose that PV installations must support voltage dips deeper and shorter without disconnecting from the grid. In contrast, at this moment, the Spanish GC seems to be more relaxing.

5. Conclusion

Both current requirements and proposals provided by the Spanish Transmission System Operator (TSO) for renewable energy sources have been discussed in the present paper. These regulations are aimed to ensure continuity of supply under the presence of disturbances, mainly voltage dips. Our description has been focused on the operation procedure for wind and PV power plant installations, accounting most renewable energy integration into power grids.

A comparison among different voltage dip requirements and voltage-time characteristics is also included in the paper. From the current drafts, the last version of these operation procedures are demanding more stringent requirements for wind and PV installations, which must support deeper and longer voltage dips without disconnecting from the grid. Additionally, different European requirements have been also included in the paper.

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