Technical challenges for the optimum penetration of grid-connected photovoltaic systems: Spain as a case study

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Abstract

This research reviews the technical requirements of grid-connected photovoltaic power plants to increase their competitiveness and efficiently integrate into the grid to satisfy future demand requirements and grid management challenges, focusing on Spain as a case study. The integration of distributed resources into the electric network, in particular photovoltaic energy, requires an accurate control of the system. The integration of photovoltaic energy has resulted in significant changes to the regulatory framework to ensure proper integration of distributed generation units in the grid. In this study, the requirements of the system operator for the management and smart control are first analysed and then the technical specifications established by the network operator in reference to the components of the facility are evaluated. This analysis identifies the shortcomings of the current legislation and concludes with a summary of the main technical recommendations and future regulatory challenges that need to be undertaken in the future. It is presented as a reference case that can be adapted worldwide.

Keywords:

Grid code; smart grid; distribution generation; renewable energy; photovoltaic

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Nomenclature

ADSL	Asymmetric Digital Subscriber Line
CECOEL	Electricity Control Centre
CECRE	Control Centre of Renewable Energy
CCG	Generation Control Centre
CNMC	National Markets and Competition Commission
DG	Distributed Generation
EMC	Electromagnetic Compatibility
EN	European Norm
ES	Electrical System
EC	European Commission
EU	European Union
FACTS	Flexible Alternating Current Transmission Systems
GSM	Global System for Mobile Communications
GDP	Gross Domestic Product ()
IEC	International Electrotechnical Commission
IEA	International Energy Agency
ICCP	Inter-Control Centre Communications Protocol
ISDN	Integrated Services Digital Network
LAN	Local Area Network
LV	Low Voltage
M2M	Machine to Machine
MV	Medium Voltage
P_{sc}	Short-Circuit Power
PV	Photovoltaic
P_{out}	Power output
PVVC	Process of verification, validation and certification
RES	Renewable Energy Sources
rms	root-mean-square value
SO	System Operator
TP	Test Point
UNE	Spanish Norm
U_n	Nominal Voltage
U_{res}	Residual Voltage
VPN	Virtual Private Network
WAN	Wide Area Network

1 Introduction

In recent years, the worldwide photovoltaic (PV) market has experienced a significant increase because of technical improvements in component manufacturing and efficiency of the devices, which leads to cost reduction [1]. Furthermore, the development of policies supporting renewable energy sources (RES) has powered the integration of these technologies in electricity networks [2].

The European Union (EU) has promoted the 20/20/20 targets inside the Directive 2009/28/EC of the European Parliament [3], expanding its commitment to 2030. Compared with 1990 levels, a 40% cut in greenhouse emissions, as well as 27% renewable energy consumption and a 27% improvement in energy efficiency [4-6]. Consequently, EU Member States have enhanced the development of incentive policies [7] that allow the penetration of distributed generation (DG) at RES units in the energy mix [8]. Owing to its inherent characteristics, the integration of PV systems in power grids implies significant technical, legislative and economic challenges [9-11]. Furthermore, the geographical dispersion of power plants as well as the production variability owing to the weather conditions and location, and therefore, the uncertainty in its prediction, makes it necessary to establish new strategies to ensure definite control of the system [12], which will allow proper integration of RES in the electricity system (ES) without compromising the safety and the quality of supply [13].

With all this, it can be noticed the expectation in the Spanish ES [14]. One of the main objectives in Spain has been the improvement of grid integration and the establishment of key parameters to obtain adequate performance of the PV plants as well as promotion of the industry-wide competitiveness of the necessary technology [15]. To tackle this challenge, Spain has developed a complex legal framework, which is constantly updated to allow the appropriate regulation and promotion of the satisfactory penetration of PV systems in the ES [16].

From an economical point of view, the retribution mechanism during the last decades has been by a feed-in-tariff system applied to the selling price of energy [17-20]. Because of this mechanism and other promotion politics, in 2017 the PV system installed power (Fig. 1, [21]) reached 4687 MW, generating 8385 GWh, which accounted for 3.1% of the annual energy demand [21]; therefore, PV technologies have a significant potential in the generation mix in Spain [22].

Fig. 1. *Evolution of installed capacity and energy sales of PV sector in Spain [21]*

The main goals in the operation of the ES, managed by the System Operator (SO), *Red Eléctrica de España* [23], are to ensure the security and the continuity of supply. In this sense, the PV systems, which are connected to the distribution network, must accomplish certain technical requirements to guarantee their correct operation in normal and special situations [23]. These requirements are defined within a compendium of rules that are included in a broad range of technical and legal documents, which represents a lack of standardization and updating. Although there are numerous literature reports that refer to established technical requirements [13, 24-29], in the case of PV grid-connected systems, there is a lack of specific and updated documents. A different approach is required to gather singularities and specificities for the management and technical assessment of PV systems.

This article presents a comprehensive analysis of the main technical requirements and legal resources for the connection of PV systems to the Spanish electricity grid, but with the scope to be a reference model that could be extended worldwide. To promote the integration of PV technology in the generation mix, the different technical levels to be achieved are emphasized as well as the challenges that must be addressed in the short and medium term.

In the following figures it can be noticed the main photovoltaic facilities distributed in Spain [30] (Fig. 2 and Fig. 3).

Fig. 2. *Distribution of photovoltaic installations in Spain, Iberian Peninsula [30]*

Fig. 3. *Distribution of photovoltaic installations in Spain, Canary Islands [30]*

To perform this study, the information contained in laws, regulations, technical instructions and other legislation, were compiled and analyzed [16, 31-33]. Court notes as well as reports published by industry associations and energy agencies were also taken into account, at both European [34-38] and national level [39-42]. In addition, circulars, reports, queries and recommendations published by advisory bodies in the field of electricity markets [24, 43] were also analysed. This paper gives an accurate and well-structured analysis focused on facilitating the optimal penetration of PV grid-connected systems in Spain.

This article is organized as follows: in Section 2, the compulsory requirements of the system operator are defined; in Section 3, a summary of the criteria and technical requirements defined by the network operator is provided; Section 4 describes future recommendations at the legislative level. Finally, Section 5 concludes the paper summarizing the main results.

2 PV system management

The fast development of PV systems has introduced new challenges in the management of the ES [44], the costs associated with increased PV participation in system operation will, depending on the measures involved, have an impact on PV competitiveness. The high complexity of this technology requires robust systems with real-time monitoring, analysis and control [45] to operate both the generation systems and transmission lines and match the generation units production scheduled with the consumer demand [46]. In addition, to ensure the proper technical management of the ES and obtain the required data, the regulation and control of the measuring systems as well as the equipment that comprise and their characteristics is required [47].

2.1 Control and monitoring

In Spain, coordinated operation and real-time monitoring of the national ES as well as control of international trade, are functions performed by the SO in the Electricity Control Centre (CECOEL). The services are managed to adjust the requirements for quality, reliability and safety of the system with production schedules resulting from the daily and intraday electricity market [48]. The solution of technical constraints, the allocation of additional services and the deviation management are handled by setting operation points to the elements of the transport network to keep the control variables within the margins established by the operating procedures. To address these issues, in 2006 the SO launched the Control Centre of Renewable Energy (CECRE), whose function is to integrate the maximum energy production from renewable sources inside the ES, in both adequate safety and quality [49]. CECRE allows real-time monitoring and control of the transmission network to optimize its operation and ensure safety, reliability, flexibility and efficiency [48]. In particular, the interaction between PV generation units and CECRE is performed by connecting the units to the Generation Control Centres (CCG) accredited by the SO (Fig. 4). With this powerful tool, Spain became the first country in the world to have all of its wind and solar farms over 10 MW in size connected to a control centre [50]. In the first half of 2014, 37 CCG on the mainland and 6 CCG on islands, including 4 in remote regions, could communicate with CECRE. Of these, over 60% have been tested for production control during their operation.

***Fig. 4**. Interconnection with CECRE [49]*

2.2 Communications

The CECRE receives activity, reactive power, tension, connectivity, temperature and wind speed data from each wind farm every 12 seconds. Based on this information, it calculates wind production that can be integrated into the electrical system at any time, depending on the characteristics of the generators and the state of the system itself. The CECRE needs at least the following information:

- The connection status, indicate connectivity
- Produced active power (MW)
- Produced / Absorbed Reactive Power (MVAr)
- Status of connection with the distribution or transmission network (connectivity)
- Voltage measurement (kV)

To do this, it is necessary to have a technical infrastructure with sufficient capacity to control, command and monitor the generation of electricity connected to it, and to have appropriate training of human resources to ensure a secure dialogue and functionality 24/7 [51]. As an example, Fig. 5 shows the structure of one CCG (Canary Island, Spain). There is a SCADA (Supervisory Control and Data Acquisition) in operation 24/7, covering single failures of equipment or functions, so that its annual availability sets the standard for this type of mission-critical system. Therefore, a problem that affects a critical function can be solved at the maximum within one hour [52].

***Fig. 5**. CCG-ITER in Tenerife, Canary Islands, Spain [51]*

The communication protocol for the real time data exchange is the Inter-Control Centre Communications Protocol (ICCP or IEC 60870-6-503/TASE.2), which provides features for data transfer, monitoring and control. ICCP functionality is specified as "Conformance Blocks" and implementation must support ICCP Block 1 and Block 2 [53]. Point-to-point redundant lines are used with independent paths. They do not share common infrastructure in terms of conduits and transmission equipment. The connection is permanent, bidirectional and dedicated exclusively. The connections are TCP/IP type with n channels of 64 Kbps (4 <n <32) or 2 Mbps unstructured and must ensure full transparency in the transmitted information, without intermediate modification. The interface of the lines at the ends of the circuit must be of type V.35 or G703 / E1 with BNC termination. Protocols and equipment must be GSM (Global System for Mobile Communications) type M2M (Machine to Machine), excluding VPN (Virtual Private Network), Frame Relay, ISDN (Integrated Services Digital Network), ADSL (Asymmetric Digital Subscriber Line) connection type [52]. This latter requirement may cause additional costs to the system and shortcomings in complying with new technologies (software and hardware), as these technologies are obsolete. End routers and SO routers are CISCO1841, CISCO2800, or similar models. The bandwidth must be fixed and committed, ensuring correct exchange of information. Enabled ports for reception and transmission are 102TCP type and IP addresses for ICCP remote servers must have, at minimum, two different and independent routable addresses for disjoint paths and network elements in the WAN (Wide Area Network) and LAN (Local Area Network) networks [52]. CECRE [54] remits to CCG the fundamental aspects for the attached generators, which ensures the compliance and maintenance of the operation points. The operation values of maximum power per node and type of generator, with the indicator code of the cause of restriction, are received within a minimum period of one minute [55]. To ensure the maintenance of the operation points for each CCG, deviations above 10% of the set point may be received in less than 5 minutes if it is permitted by the particular conditions of the operation of the system [56].

2.3 Metering

Remote management required for the PV generation units involves the fulfilment of meteorological controls to ensure the quality and accuracy of the measurements [48]. In this context, PV generation units are classified in Table 1 according to the type of measuring point, establishing a growing number of technical requirements that affect the accuracy class of the measurement equipment, current-voltage transformers, redundant equipment, installation of recording and the obligation to perform telemetry [48]. In general, the measuring equipment consists, separately or integrally, of an active energy meter, a reactive energy meter, transformers and other ancillary equipment such as recorders, elements of power control, modems and schedule watches [57].

***Table 1**. Accuracy class of the measurement equipment [48]*

Multifunctional static meters included in the same housing are used for recording the active energy in both directions of energy flow (buying and selling) and reactive energy in 4 quadrants programmed with current and time discrimination necessary for billing. Furthermore, they are enabled to close automatically all contracts at day 1. The meter has a verification LED indicator for both directions of energy flows. For installations with a capacity exceeding 15 kVA, it is mandatory that the meter registers the reactive power [57]. The accuracy of the electricity meters must be as indicated in Table 1 [48]. The most stringent requirements are set for types 1, 2 and 3. Therefore, these measuring devices enable remote reading and display the power, ensuring reading even in the absence of voltage. The power control is accomplished by maximeters with an integration period of 15 minutes. Furthermore, available recorders are capable to parameterize integration periods of up to 5 minutes as well as record and store the parameters required for the calculation of tariffs of access or supply. Likewise, it incorporates recording parameters related to the quality of service, storing at least the number and duration of each of the supply interruptions lasting less than three minutes and the time when the line voltage is outside the limits allowed by excess and by default [48].

3 PV system grid connection

In addition to the requirements of the PV systems monitoring, their integration in the network must be conducted to ensure that the connection settings are made in compliance with a series of technical and safety requirements [14, 58]. To achieve this, apart from the requirements to withstand voltage dips that may occur in the network, the voltage at which the facility must be connected is defined, together with the requirements to be met by inverters, because of their role as connection interfaces between the PV generation unit and the network [59] and how protection systems should be provided.

3.1 General criteria

Generation units with power under 100 kVA must be connected to the Low Voltage (LV) network. However, the generation unit can connect to the Mid Voltage (MV) network if there are no LV facilities close by or there is not enough capacity on the LV network to support the connection [56]. The rated voltage for PV systems connected at LV is 230 V for single-phase and 400 V for three-phase electricity. If the connection is made to the MV network, the rated voltage is 25 kV. The facility should be designed for a short-circuit current of 10 kA and 20 kA in the LV and MV networks, respectively. Furthermore, the power factor reference range for the energy supplied to the network is set between 0.98 inductive and 0.98 capacitive [60].

3.2 Inverters

Three-phase inverters are used to avoid unbalanced energy generation. As an exception, generation units with a power rating below 5 kVA are allowed to connect with single-phase systems [56].

The inverter can inject into the network the harmonic currents within the limits established by the following standards [56]:

- IEC-EN 61000-3-2:2014: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
- IEC-EN 61000-3-12:2011: Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase

In this sense, UNE 206007-1:2013 IN [64] provides “minimum technical requirements for the connection of inverters to the power system” [61]. Problems related to the quality of supply involve a wide range of electrical disturbances that are critical for system behaviour [62], such as waveshape faults, overvoltage, capacitor switching transients, harmonic distortion, and impulse transients [63]. The technical regulation [64] includes the requirements for DC current injection [65], behaviour under isolation faults [66], detection of fault currents in the PV generator [67], voltage and frequency shutdown [25, 62], automatic reconnection [68], islanding [66, 69], overvoltage [70], power quality and reconnection out of synchronization [71, 72]

3.3 Electrical Protection Systems

Islanding is a condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system. In this respect, the distributed resources supplying the loads within the island are not within the direct control of the power system operator. [73]. Islanding represents a key security parameter, not only for the PV systems but also for the ES, compromising the security as well as the power restoration, degradation of power quality and reliability of equipment [74]. Therefore, it is necessary to provide appropriate security protection systems including a general cut off switch, permanently accessible by the distribution company, a residual current circuit breaker and a circuit breaker for automatic shut-connection of the facility in the event of voltage or grid frequency failure, together with a latching relay. After being disconnected, reconnection should be prevented before 3 minutes at the power recovery, even if disconnection occurred because of the action of a trigger with line reclosing. Also, whenever possible, unwarranted disconnection must be avoided owing to normal variations in the operating parameters of the network and external faults of its connection line [56].

The system must have the following protections [57], whose parameters are defined in Table 2:

- Maximum and minimum voltage protection, by controlling the voltage between phases.
- Maximum and minimum frequency protection, by controlling the frequency.
- Transient overvoltage protection: installing metal oxide lightning protection systems with a 25 kV voltage rating and 10 kA nominal discharge current. Provided it is advisable to install protections by the value of overloads and their frequencies.
- Fault current protection, both the phase currents and the earth fault current by overcurrent protections, being selective with the header line protections located at the substation level.
- Overload protection: regulation of delayed intensity protections, depending on the nominal power capacity of the PV system.
- Anti-islanding protection (LV connections) through passive or active detection methods (phase jump detection, reactive power control, frequency shift) to avoid the operation of this equipment in terms of network loss, according to the UNE-EN 50438:2014 requirements for micro-generating plants to be connected in parallel with public low-voltage distribution networks. The islanding trigger signal will not disappear until their correct reference quantities remain uninterrupted for 3 minutes. During that time, the connections of the PV system to the network is prevented.

***Table 2**. Protections and settings for a PV system with an obligation to meet performance requirements against voltage dips [57]*

The above described protections may act on the main switch or on the switch or switches on the equipment or generating equipment and may be integrated into the inverter. Similarly, they have galvanic isolation through transformers that are integrated or not integrated into the inverter [57].

3.4 Voltage dips control

Voltage dips are one of the most severe failures of PV systems [25], as well as a major concern for SO because they have detrimental effects on the stability of the grid [24]. A voltage dip is defined as a sharp fall in the supply to a value between 90% and 1% of the voltage, followed by a value recovery after a short time [75-77]. Facilities connected to the distribution network must withstand voltage dips without disconnecting, avoiding cascade disconnections that could affect the continuity of electricity supply [22]. In Spain, both facilities and groups of renewable energy installations exceeding 2 MW are required to comply with the operating procedure *PO 12.3 Requisitos de respuesta frente a huecos de tensión* (in English *Response requirements to voltage dips)* [78]. For this, facilities should be able to withstand voltage dips at the point of network connection, produced by three-phase, grounded two-phased or single-phase short-circuits, with profiles of magnitude and duration as indicated in Fig. 6, [78]. That is, the installation disconnection will not occur for voltage dips in the main connection points included in the shaded area of Fig. 6. For simplicity and applicability, this study will focus on three-phase connections. In recent years several simulation models have been developed [25, 26, 79, 80] that serve as a supporting tool for the modification and adaptation of the inverters.

***Fig. 6**. Voltage-time curve for a voltage dip in the connection point to the network in PO 12.3 [78]*

If the inverter does not satisfy the requirements for voltage dips, it must be adapted by changing its hardware or software configuration [81], along with the modification of the output relay parameters to ensure no power falls, or installing additional power electronics devices outside the inverters [82], called flexible alternating current transmission systems (FACTS), to compensate for the effects of voltage dips on the facilities. The stakeholders have collaborated on the development of a particular process for the measurement and evaluation of PV conversion systems, given the complexity of requirements verification. The outcome was the process of verification, validation and certification requirements of PO 12.3 regarding the response of wind and PV installations to voltage dips (PVVC10) [77]. The document presents a verification system based on the compliance with the requirements for PV systems to have an adequate response to the voltage dip. According to PVVC10 [77], the test is performed by applying a 3-phase fault and an isolated 2-phase fault, causing a dip in the affected phases. The voltage waveform should be obtained in three channels (phase-to-ground, phase-to-neutral or phase-to-phase voltages). The one-cycle rms (root-mean-square) voltage is calculated every half-cycle in every channel. The residual voltage (U_{res}) is the lowest rms voltage recorded in any of the channels during the event [83].

The required tests that have to be conducted with 3-phase converters are summarized in Table 3, [77], in which U_{res} is defined as a function of the nominal voltage (U_n) and P_{out} is the power output before an event. During the tests, the active and reactive power, currents and voltages have to be recorded at the testing point (TP). Both in the test and in the process simulation, all registered data "*(voltage and current) for each phase is performed with a sampling frequency of at least 5 kHz*", according to [77]. The moments before the beginning of the dip and 5 seconds after the recovery period are also registered. The instant of the voltage dip is randomly applied.

***Table 3**. Voltage dip features for testing three-phase PV systems [77]*

The criteria for tests validation are the following:

1. Residual voltage and time during no- load test

Voltage dip profile that applies:

- If P_{sc} at TP ≥ 5 times the registered power, the voltage dip can be obtained by uncoupling the PV system at the dip generator (no-load test). Subsequent tests under load (PV system coupled) have to be performed with the same impedance adjustment of the dip generator equipment.
- If P_{sc} at TP < 5 times registered power, it is compulsory to measure the dip profile under load.

2. Operating point

According to Ref. [77], it is required “that the active power recorded prior to the implementation of the voltage dip is within the range that defines a partial load (10% <Pout <30%) and full load (Pout> 80%)”.

3. Guarantee of continuity supply

No PV system disconnection occurs during the application of voltage dip.

4. TP sharing power and energy conditions

According to Ref. [77], the value of the injected current by the PV System “during the failure must meet that specified in PO 12.3 in relation to the values of the reactive current as well as reactive and active power consumption”. Measurements of the required voltage and current have to be registered at the TP.

4 Future technical regulatory aspects

Regarding renewable energy, the Spanish electricity market reform replaced the previous compensation mechanism to ensure a reasonable return for the facilities investments. Currently, this kind of energy receives approximately €7 billion a year in additional specific regulated compensation to perceived by the market, and will receive until the end of his usefull life, approximately €150 billion in premiums [16]. An important aspect of Spain’s energy policy is the growing role of the EU as the source of policy goals and related obligations [84]. Moreover, Spain is still third in Europe with regard to the total cumulative installed capacity, at 5.3 GW [84,85,92]. In the future, the aim of the ES management should focus on updating and redesigning the traditional instruments to adapt to the new requirements for smart grids. Currently, the ES is adapted by using smart grid technologies and intelligent demand side management [23], but it should also evolve to promote the definitive deployment of new innovative mechanisms such as the integration of storage systems [86-89], charging infrastructure [90], electrical mobility [91] and the use of smart meters [92], among others. To achieve these goals, legislation should advance by using new concepts and developments as well as generation and control systems that allow the shift from a centralized power generation model to a distributed electricity generation. It also should learn from the experience of previous research [8, 68, 93-97], identifying barriers and selecting the best mechanisms to ensure their applicability.

Both currently and towards the future, one of the possible avenues for the development of PV generation units lies in this electricity self-consumption model [17] supported by instantaneous consumption into a net metering framework [99-101]. This model is an important technical and legislative challenge that countries such as the US, have already developed and widely applied [98, 102-110]. As recommended by the European Commission (EC) [102], Member States should promote the demand side flexibility, including demand-side response [111-116] and distributed energy storage [117,118], by establishing simplified administrative and authorization procedures for guaranteeing the competiveness. Moreover, EC underlines the need to ensure objective and non-discriminatory criteria, while ensuring sufficient funding for grid and system costs [101].

In this sense, Spain must continue to develop a regulatory system aimed at facilitating a distributed energy system that allows the energy development of the local network. With the approval of *Real Decreto* 244/2019, of April 5 [119], which gives continuity to

Real Decreto-Ley 15/2018 [120], it establishes three types of self-consumption, without surpluses, with surpluses that are subject to compensation and with Surplus not accepted as compensation. This law also indicates the power installed in a photovoltaic installation will be considered the maximum power of the investor or, where appropriate, the sum of the maximum powers of the inverters. On the other hand, this law establishes the measurement equipment to be installed in different considerations:

- Generally speaking, only one bidirectional measuring device is needed at the boundary point.
- Collective self-consumption, with surpluses not covered by compensation with several supply contracts or non-renewable technology, must have 2 teams. One for consumption and another that measures net generation.
- In certain cases, the measurement counter is allowed to be located outside the boundary point.

5 Conclusions

This paper brings together and describes the technical requirements for the control and connection of PV systems to the electricity grid. It establishes a starting point to overcome the obstacles inherent to this technology and achieve greater penetration of PV technology in the energy mix. This is a significant technical and legislative challenge that must be faced, imperatively, by the institutional bodies owing to the future trend in smart grids. This integration involves significant technical considerations owing to the dispersion of the installations, the variability of their production and uncertainty in their forecast, which makes it necessary to establish new strategies to ensure the control of these variables, and for the proper integration of PV systems in the ES without compromising safety and quality of supply. The conversion systems are under constant technological adaptation to ensure their operation without neglecting performance and reliability. The generation control procedures are well structured, in which Spain is a pioneer in this field. However, the required communications systems are obsolete, causing unnecessary additional costs and deficiencies for adjustment to new technologies (software and hardware). The requirement in communication protocols force the use outdated equipment type GSM (Global System for Mobile Communications) that are type M2M (Machine to Machine) voice, then the system is more expensive and does not take advantage of technological advances in this field. Regarding measurement systems, a powerful development within the framework of smart meters is needed to allow the integration of new technologies into the energy mix, such as charging systems, electric vehicles and storage systems; they are essential elements to encourage the development of smart grids.

A self-consumption model based on distributed electricity generation into a net metering framework should be a reliable scenario for the integration of PV systems. The development of a consistent, uniform and transparent regulatory framework is required to ensure proper access to the network at an optimum quality and safety, which evolved and adapts its characteristics to the consumers’ needs including the optimal application of demand management owing to the dispersion of the generation units. After a significant electricity reform, the Spanish energy sector maintains its strengths, such as the quality and security of supply. However, the economic recession has resulted in new challenges to solve the tariff deficit issue. To achieve the targets set by the EC, substantial efforts are needed to continue the deployment and definitive penetration of the most cost-effective technologies, highlighting PV technologies, to boost policy measures (financial or technical), including support schemes, standards, procedures, and administrative rules. Introducing new mechanisms to encourage the successful integration of PV systems in the energy mix is a significant challenge and constant review and updating of information is required in the future.

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Table

Table 1. Accuracy class of the measurement equipment [48]

Point class	Ratted apparent power (S_n)	Accuracy Class				
		Transformers		Meters		
		Voltage	Current	Active	Reactive	Load curve
1	12MVA$\leq S_n$	0.2	0.2s	0.2s	0.5	Required
2	450 kVA $\leq S_n <$12MVA	≤ 0.5	≤ 0.5s	0.5s	1	Required
3	15 kVA $< S_n <$450 kVA	≤ 1	≤ 1	0.5s	1	Required
5	15 kVA $\leq S_n$			1	2	Optional

Table

Table 2. Protections and settings for a PV system with an obligation to meet performance requirements against voltage dips [57]

Type	Adjustment (islands)	Adjustment (mainland)
Minimum voltage protection	Trigger at 0.77 kV phase-phase, 1 s	Trigger at 0.85 kV phase-phase, 1.2 s
Maximum voltage protection	Trigger at 1.1 kV at MV (1.07 kV at LV) phase-phase, 0.5 s	Trigger at 1.1 kV at MV (1.07 kV at LV) phase-phase, 0.5 s
Minimum frequency protection	47 Hz, 3 s	48 Hz, 3 s
Overfrequency protection	51 Hz, 0.2 s	51 Hz, 0.2 s

Table

Table 3. Voltage dip features for testing three-phase PV systems [77]

Voltage Time	Faults	Power before dip
U_{res}<20%U_n>500 ms	3-phase	P_{out}>80%
		10%<P_{out}<30%
U_{res}<60%U_n>500 ms	2-phase (isolated)	P_{out}>80%
		10%<P_{out}<30%

Figure

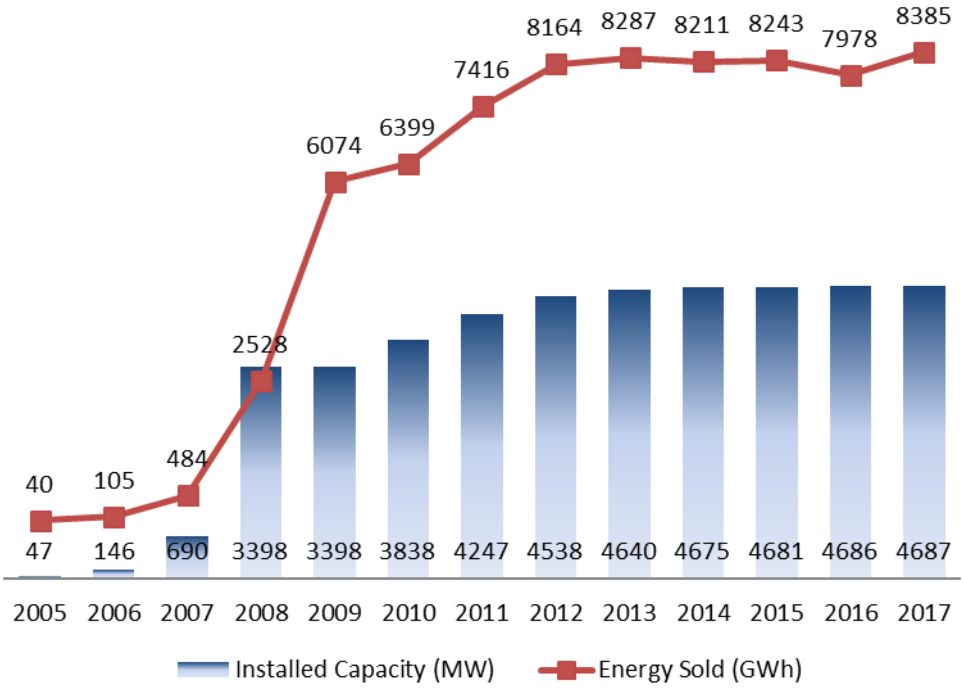

Fig. 1. Evolution of installed capacity and energy sales of PV sector in Spain [21]

Figure

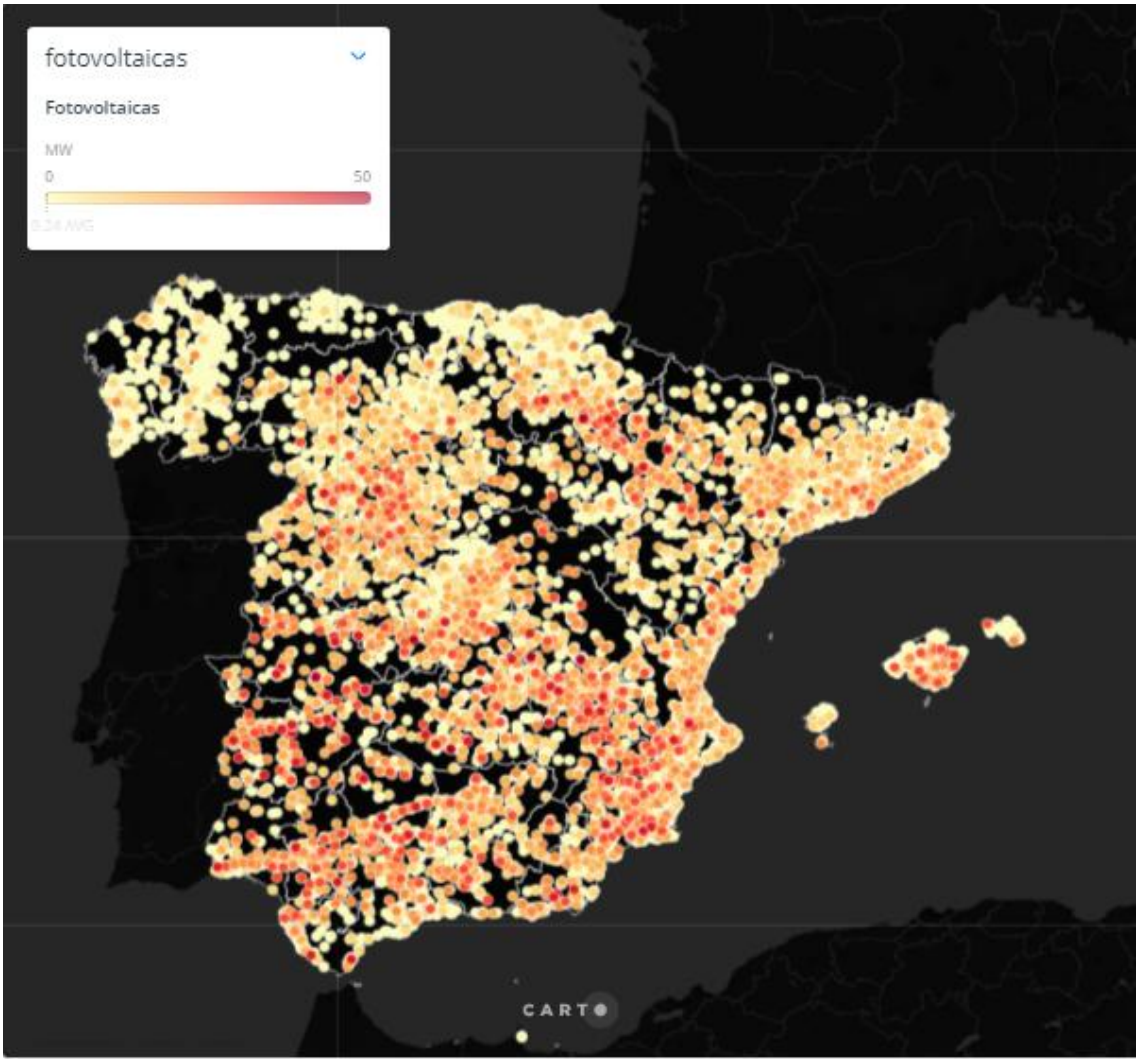

Fig. 2. Distribution of photovoltaic installations in Spain, Iberian Peninsula [30]

Figure

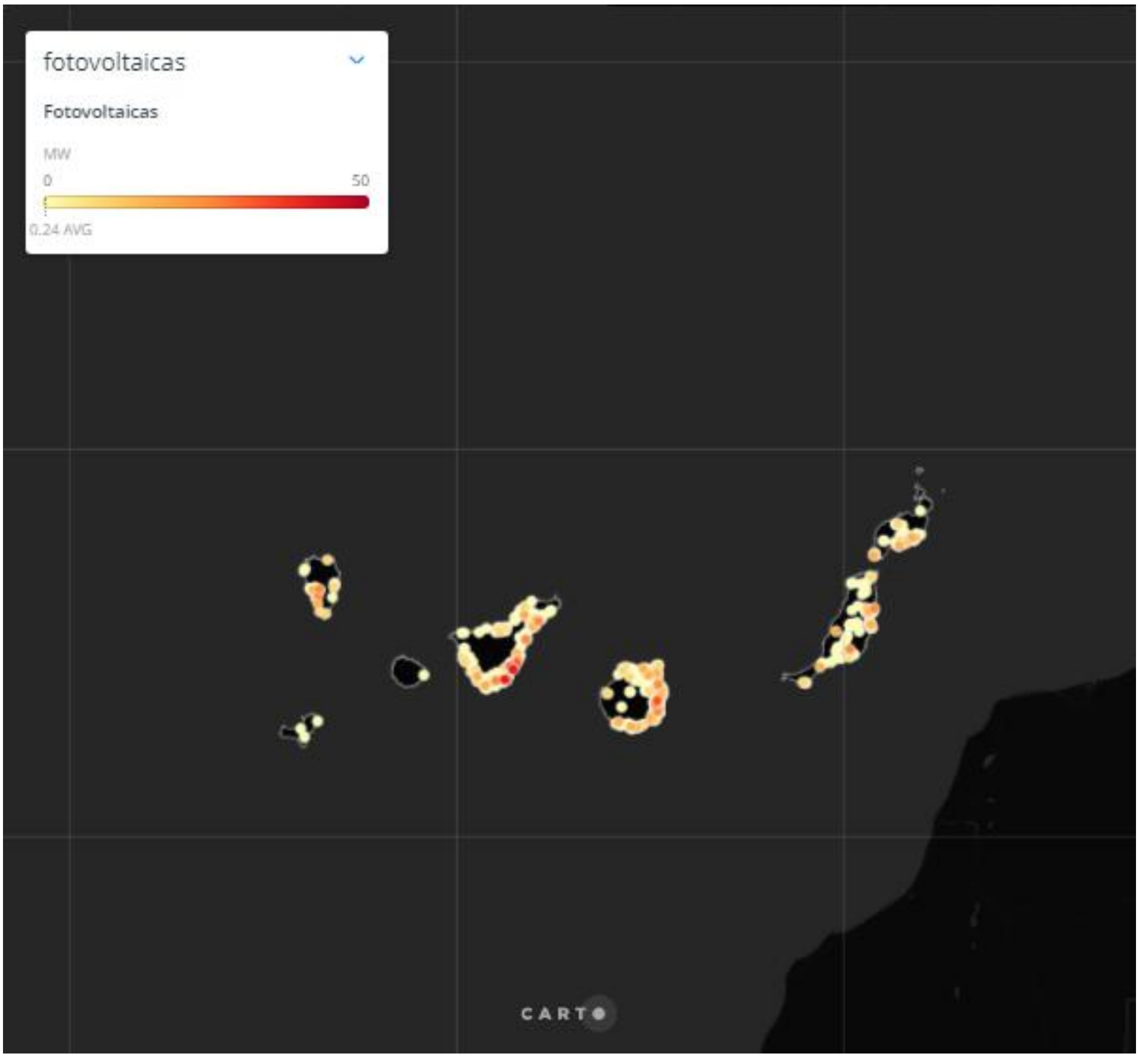

Fig. 3. Distribution of photovoltaic installations in Spain, Canary Islands [30]

Figure

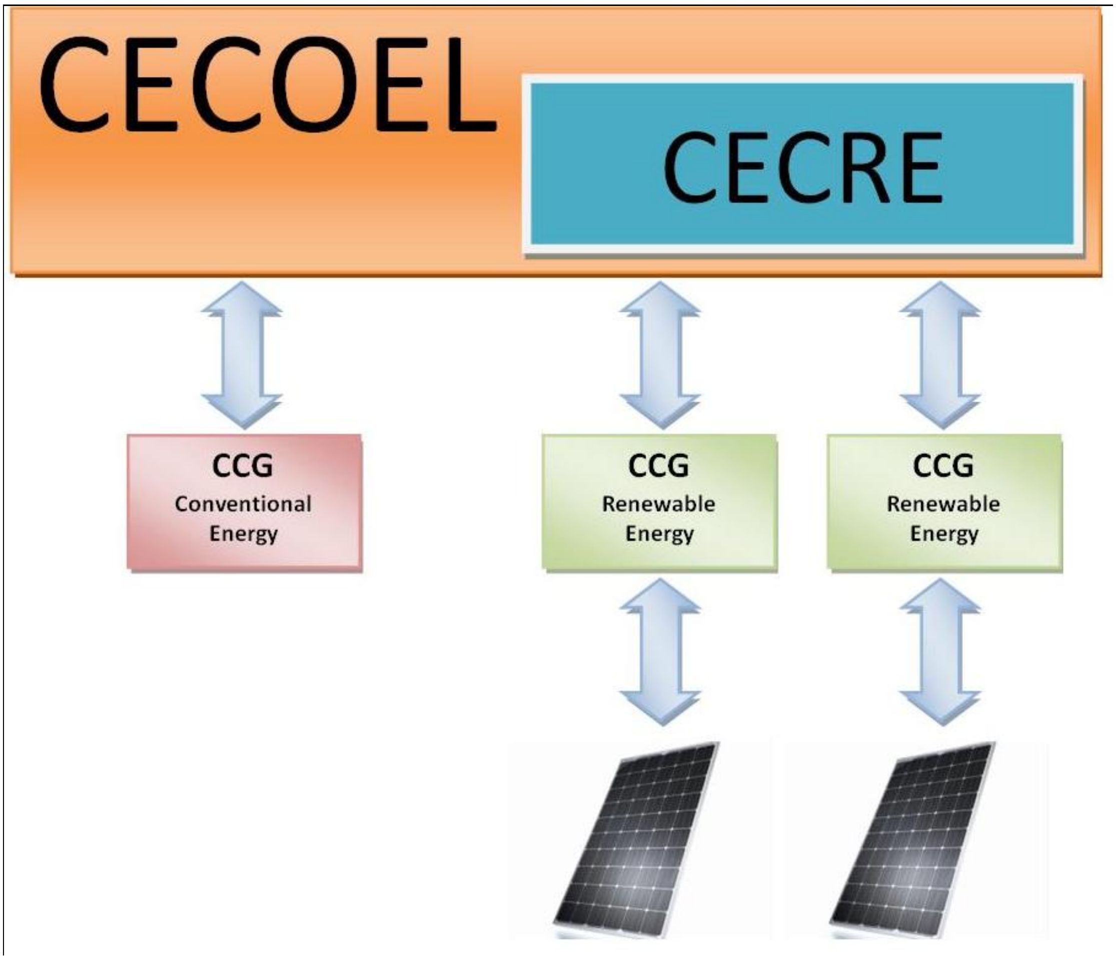

Fig. 4. Interconnection with CECRE [49]

Figure

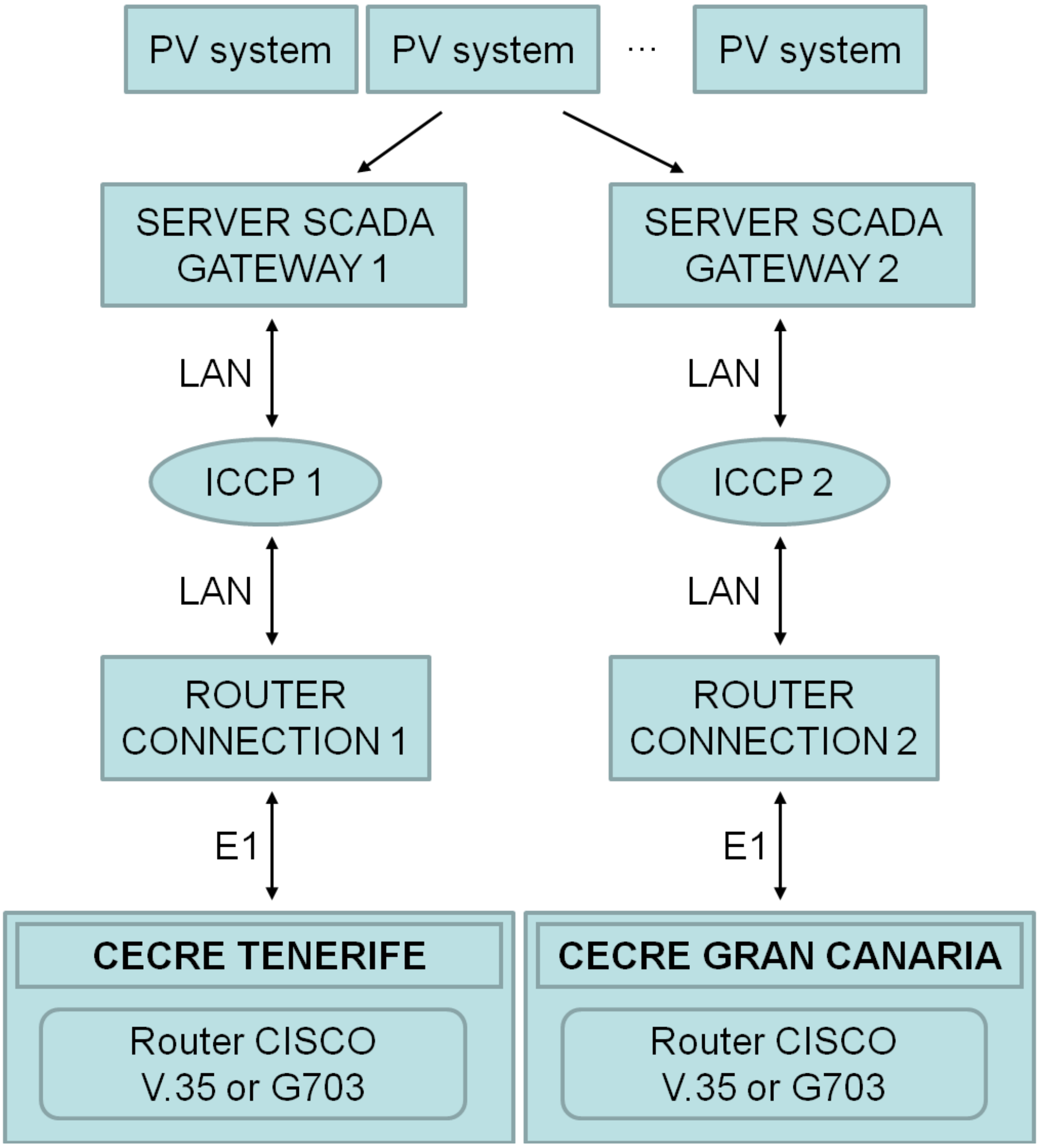

Fig. 5. CCG-ITER in Tenerife, Canary Island, Spain [51]

Figure

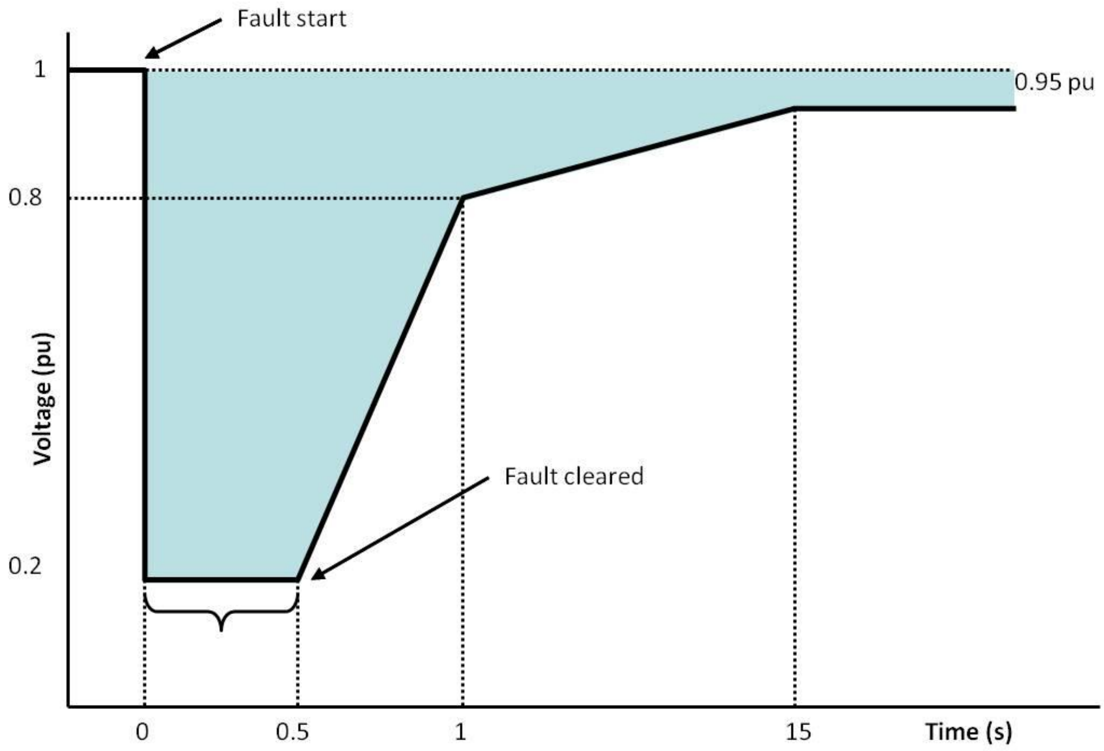

Fig. 6. Voltage-time curve for a voltage dip in the connection point to the network in PO 12.3 [78]