KEMA

memo

To: IEPR Committee (Chair Weisenmiller and Commissioner Douglas)

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Subject: Distributed Generation in Europe – Physical Infrastructure and Distributed Generation Connection

KEMA is pleased to submit the attached memo (Memo #1) on distributed generation applications in Europe. This memo specifically focuses on the physical infrastructure and distributed generation connection. This memo is the first of three memos that will serve as interim deliverables for the European Distributed Generation Infrastructure Study. The three memos will eventually be rolled into one consultant report.

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INTRODUCTION

As reflected in the Energy Commission's previous Integrated Energy Policy Report proceeding, the Energy Commission wants to determine how certain European countries integrate large quantities of intermittent renewable electricity into their electric distribution systems while still maintaining system control and reliability. This memo addresses this issue by providing a comparison between the electric distribution systems in Europe and California with the ultimate goal of capturing key lessons learned to facilitate California's intermittent renewable distributed generation (DG) into its electric distribution system.

This memo describes the physical distribution infrastructure and the requirements and processes for interconnecting DG to the distribution infrastructure in Germany and in Spain. It compares the relevant characteristics in these European countries to the corresponding characteristics in California. The analysis focuses on medium- and low-voltage distribution grids and outlines relevant aspects and impacts of renewable generation at higher voltage levels.

The research focused on addressing the following questions:

- How are the electric transmission and distribution systems configured in Germany and Spain? Does this topology increase opportunities for renewable DG integration?
- Have grid operators changed the configuration of their distribution systems to allow for greater penetration of renewable DG? What are the changes from a qualitative sense (what have they done) and a quantitative sense (how much of it have they done, how are they treating cost allocation, what is the quantitative relationship between changes in infrastructure and DG penetration)?
- Do grid operators use ancillary technologies (i.e., battery storage, flywheel) and policy levers that allow for greater backflows on the distribution system without threatening grid stability (e.g., protection devices, curtailment)? Or do they simply allow greater penetration under some circumstances without concern?
- Is higher penetration of renewable DG likely to cause voltage issues and potential back-feed issues? How does the electric distribution system of Germany and Spain address the back-feed issue in light of active power flow from the medium voltage circuits up to the transmission / sub transmission high voltage circuits?

This memo is organized as follows:

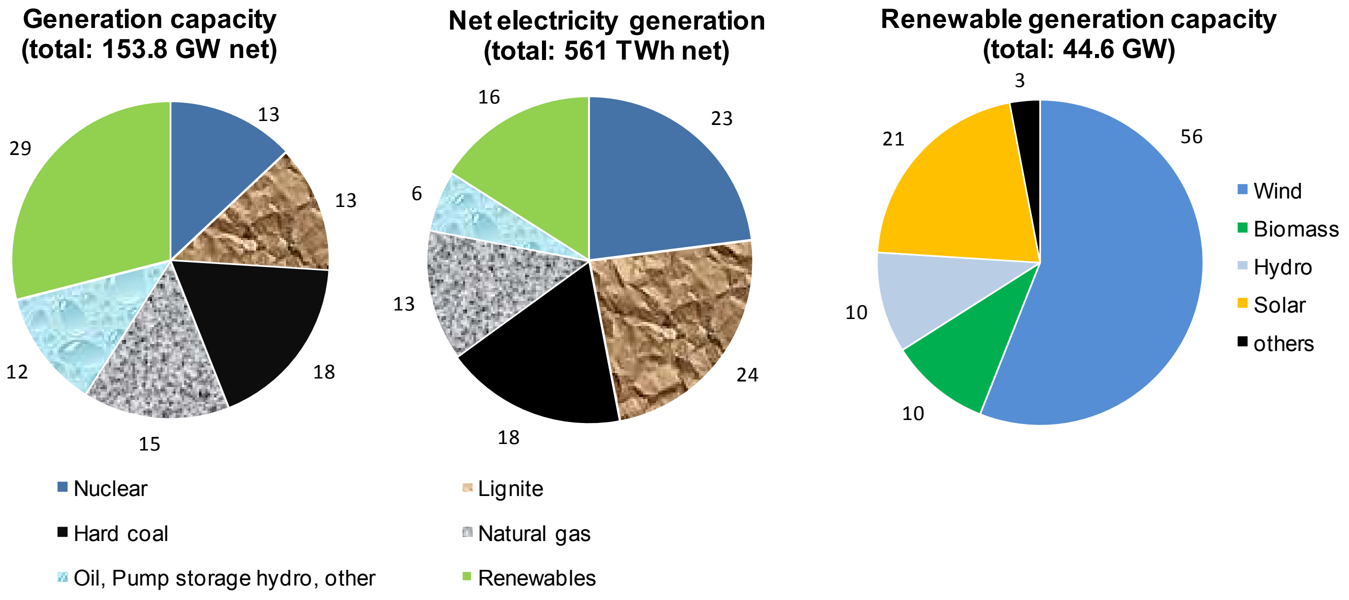
- Section 1 reviews the current state of physical infrastructure in Germany.
- Section 2 reviews the current state of physical infrastructure in Spain.
- Section 3 provides a comparison to grid infrastructure in California.
- Section 4 provides a summary of key lessons learned.

SECTION 1:
Physical Infrastructure in Germany

At of the end of 2009 about 16 percent of the German electrical energy production came from renewable energy sources.[1]The growth of renewable DG in Germany continues unabated. German grid operators have dealt with the challenge of significant renewable integration for the last five to 10 years and have developed technical rules and guidelines to ensure secure network operation. An examination of the German power system is therefore useful for a comparative analysis.

Regional and Quantitative Allocation of Renewable Energy in Germany

The extent of deployment of each type of renewable generation depends on many factors such as local climate conditions, land utilization, and population levels. A comparison of all types of installed generation capacity in Germany, including both renewables and conventional generation is shown in Figure 1.



Generation capacity (total: 153.8 GW net)

Net electricity generation (total: 561 TWh net)

Renewable generation capacity (total: 44.6 GW)

Figure 1: Generation Mix in Germany at End of 2009 (All Data in Percentages)

Source: BDEW: German Energy Market, 2010

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[1] German Statistics of Renewable Energy Sources, December 2010.

The type of renewable energy source often affects the size of the generation plants and thereby the type (voltage level) of the grid connection. As a general rule for the German grid, the voltage level at the point of common coupling for DG plants follows the schema shown in Table 1.

Table 1: General Rules for Selecting the Voltage Level of the Point of Common Coupling, according to the Rated Power of Generation Plants

Rated power of the generation plant	Voltage level of grid connection
Up to 30 kW	Low-voltage grid without verification
30 to 200 kW	Low- or medium-voltage grid
0.15 to 20 MW	Medium-voltage grid
15 to 80 MW	High-voltage grid
80 to 400 MW	Extra-high voltage grid

Source: Potentialermittlung für den Ausbau der Wasserkraftnutzung in Deutschland, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), September 2010 *[Capacity of hydro power in Germany, September 2010]*

In actual practice there can be deviations from the general rule based on the results of specific studies for DG interconnection. Figure 2 shows the breakdown of generation types installed at each voltage level as a percentage of the total generation capacity installed at that voltage. The size of the generator is a key parameter as it requires a corresponding capacity both at the network connection point and for transporting the electricity produced from that point to the system. For instance, solar power installations tend to be rather small (mainly roof-based installations) and are mostly connected to the low voltage network. On the other hand, wind projects are developed over a much wider range of sizes (e.g., wind farms) and therefore are connected at many different voltage levels.

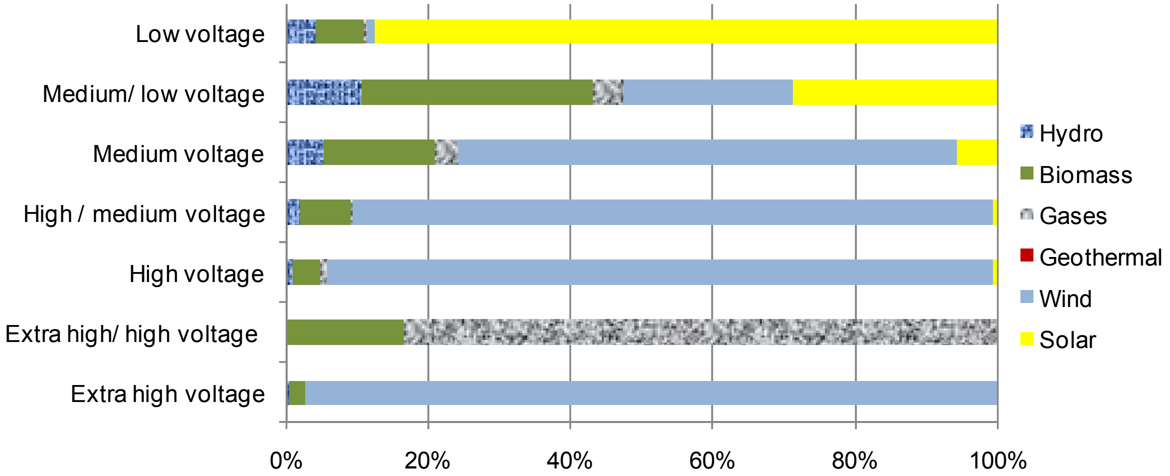

Figure 2: Relationship between Network Connection Level and Technology for Installations Eligible under the 2008 Renewable Energy Act[2]

Source: Bundesnetzagentur EEG-Statistikbericht 2008 (Translated – *Regulator's* EEG Statistical Report, 2008)

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[2] Installed geothermal capacity is negligible. Gases refers to waste gas projects (e.g., mine gas, etc.)

Additional general observations in regard to network integration of DG on the German network are as follows:

Wind Energy

A high concentration of wind energy plants appears in rural, sparsely populated areas in northern Germany. The individual generating units mostly have a rated power from 1 MW to 3 MW. Hence, the point of common coupling is most often located on a medium-voltage grid. However, when individual units are collected into wind farms with rated power from 20 MW to 80 MW, they are usually connected to the high-voltage grid. A few large wind farms generate 80 to 400 MW of electric power apiece and are directly connected to the extra-high voltage grid via separate substations.

Solar Energy

Even though the percentage of electrical energy generated by solar power was only about 7 percent of all renewable energy by the end of 2009, solar power has had the strongest growth rate for the last two years. A significant amount of solar energy generating units has been installed particularly in southern Germany. The installed solar generation capacity increased by 3,800 MW in 2009 and by about 6,500 MW in 2010, bringing the total installed solar capacity to approximately 10 GW.

In urban areas, small solar generation plants (photovoltaic modules and converters) are installed on roofs of residential homes (rated power 3 kW to 5 kW) or commercial and public buildings (100 kW to 1 MW). According to grid code, small units up to 5 kW peak can be connected as a single-phase customer at a service point.[3] Units up to 30 kW are allowed to connect as a three-phase customer at any point on the LV grid without technical verification. However, the presence of multiple DG projects within an individual rural low-voltage grid can cause severe voltage or power quality issues (see Memo #2 for further discussion).

Biomass in Cogeneration Plants

By the end of 2009, the fraction of renewable electrical energy generated from biomass was roughly 30 percent of all renewable energy production. Hence, biomass is the next most important renewable energy source after wind in Germany, and also has high growth rates. Co-generation plants for biomass are installed all over Germany, particularly in rural areas. Small units with electric power up to 150 kW are connected to the low-voltage grid. The majority of units ranges from 500 kW to 5 MW and is connected to the medium-voltage grid. Large units with considerably more than 5 MW exist and are connected to the medium- or high-voltage grid

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3 Eigenerzeugungsanlagen am Niederspannungsnetz – Richtlinie für den Anschluss und Parallelbetrieb von Eigenerzeugungsanlagen am Niederspannungsnetz; VWEW Energieverlag GmbH; September 2005 [German Technical Guideline – Generating Plants Connected to the Low-Voltage Network, September 2005]

according to their rated power. Since biomass is consistently available, it is less critical for network operation than fluctuating resources such as wind and solar power.

Hydro Power

Hydro power resources are considered to be well developed in Germany. Therefore, the amount of hydro power has remained nearly constant over the last few decades since most of the potential locations are already utilized. Hydro power stations of various sizes have been installed in mountainous areas and along rivers in central and southern Germany. Currently, hydro generation is about 25 percent of all German renewable energy generation.

Several large pumped-storage power plants connected to the extra-high voltage grid contribute to the load balancing and frequency control of the transmission system. Table 2 provides an overview of the number of generation plants in several power categories and the installed power.

Table 2: Hydro Power Plants in Germany, Categorized by Number and Installed Power

	Hydro power units with less than 1 MW	Hydro power units with more than 1 MW	Pumped- storage plants
Number of units	~6,500	~400	~30
Installed Power	~600 MW	~3,400 MW	~6,600 MW

Network Structures in Germany

In the next part of the memo, the basic technical layouts and configurations of German transmission and distribution grids, including substations and secondary substations are described. Then the general and technical requirements for the interconnection of DG from a German perspective are then considered. Finally, the most common network upgrade options to manage the integration of renewable energy sources and comply with technical requirements are examined.

Grid and Voltage Levels

The European power grid is a three-phase alternating current grid operated at a frequency of 50 Hertz at all voltage levels.[4] Four common voltage groups (EHV, HV, MV, and LV) have been established in the German power grid per International Electrotechnical Commission definitions. The existing grid voltages for each of these groups in Germany are shown in Table 3.

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[4] The railway power grid is distinguished from the public power grid by frequency and generation. It is a two-phase AC grid operated at 16.7 Hz.

Table 3: Overview of Voltage Levels in Germany

Name(IEC Definition)	Abbreviation	Rated Voltage	Role
Extra-high voltage	EHV	380 kV, 220 kV	Transmission grid
High voltage	HV	110 kV	Distribution grid
Medium voltage	MV	30 kV, 20 kV, 15 kV, 10 kV	
Low voltage	LV	400 V	

Transmission Grid

The European transmission grid is operated primarily at 380 kV and partially at 220 kV, but the latter is on the decline and provides the basis for the electrical energy transport between large-scale power plants, the connected distribution grids, and neighboring countries. The European transmission grid is an integrated network designed to ensure reliable, efficient, and secure electrical energy supply based on the rules of the Operation Handbook of the European Network of Transmission System Operators for Electricity (ENTSO-E).[5] According to the German Transmission Grid Code,[6] the main task of the transmission grid operators is to assume responsibility for the whole system of electrical energy supply, including:

- The balance of load within a control area, especially in case of a resource contingency, and thereby maintaining system frequency stability
- Network security, i.e., the security of supply, secure operation, the compliance with voltage and other operational limits and the (n-1) criterion
- The ongoing evaluation of system operating conditions and initiation of required corrective measures that will involve the associated distribution grid operators as needed

The transmission grid is a meshed system with high standards for system stability (frequency, voltage, dynamic stability) and security of supply. The transmission infrastructure in Germany is predominately overhead construction.

Distribution Grid at the High Voltage Level

The 110 kV high-voltage (HV) grid serves as the transport grid for medium distances and carries the electric energy from exchange points on the transmission grid towards urban or rural medium-voltage grids. The requirements concerning security of supply are again covered by compliance to the (n-1) contingency criterion. The grid is meshed and consists mainly of overhead lines. In urban areas, underground cables are often installed at 110 kV. High loads

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[5] UCTE Operation Handbook (OH), version 2.5, level E, dated 24.06.2004, Union for the Co-ordination of Transmission of Electricity” (UCTE); Brussels.

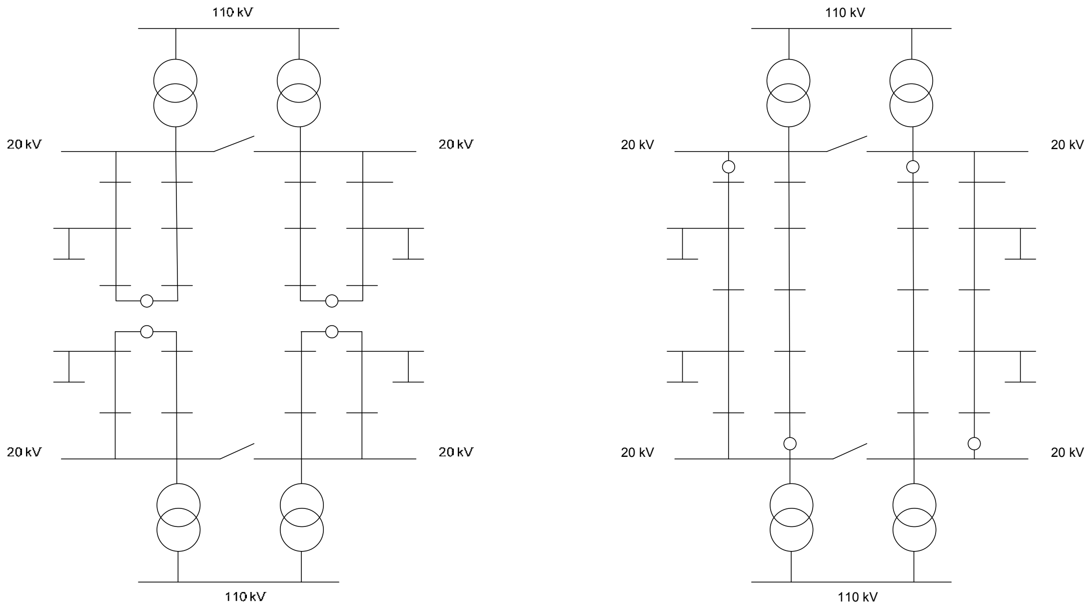
[6] Transmission Code 2007, Netz- und Systemregeln der deutschen Übertragungsnetzbetreiber, Version 1.1, August 2007, Verband der Netzbetreiber – VDN – e.V. beim VDEW, Berlin [Transmission Code 2007, *Network and System Rules of the German Transmission System Operators*, August 2007]

with high demands (e.g., large industrial loads) and generating units exceeding a power limit of about 20 MW are primarily connected to this grid level.

Distribution Grid on Medium Voltage Level

The medium-voltage grid (MV grid) mainly comprises the voltage levels 30 kV, 20 kV, 15 kV, and 10 kV. Urban and rural medium-voltage grids significantly differ in their characteristics.

A high density of loads and relatively high demand that causes high utilization of the equipment (transformers, cables) is typical for urban areas. Appropriate for these requirements, urban medium-voltage grids in Germany consist largely of cables with a typical cable cross-section of 150 to 300 mm² (nominally equivalent to a range of 300 kcmil to 636 kcmil) and with a comparably short cable length. The urban MV grids are generally operated at voltage levels of 10 kV and 20 kV. They are set up as looped networks with open loops under normal operating conditions (see Figure 4), where the smaller circles represent normally open switchgear and the larger circles represent substation transformers.



a) b)

Figure 3: Medium-voltage Grid Layouts
a) Normally-open Loops; b) Circuits with Two Source Stations and Normally-open Contact at One Station

Source: KEMA

The MV grids are connected to the high-voltage grid (110 kV) via substations with two or more HV/MV transformers in a rated power range from 31.5 MVA to 63 MVA. The power transformers are typically equipped with tap changers and automatic voltage control to guarantee a fixed voltage at all medium-voltage bus bars. As link to the low voltage grids, the secondary substations mainly consist of single MV/LV transformers in a rated power range from 400 to 1,000 kVA. For direct customer connections, transformers up to 1,600 kVA can be used. As a result of the high installed power transformer capacity and the relatively short cables with large cross-sections, the network impedance is comparably low throughout the whole urban medium-voltage grid. Hence, voltage drop and power quality issues rarely occur.

Rural Medium-voltage Grids

Rural areas are characterized by larger geography and low load density. This results in long lines, high network impedances, and low utilization of the equipment. In rural medium-voltage grids in Germany, underground cables and overhead lines are installed in nearly equal shares. Typical underground cable cross-sections range from 120 to 240 mm^2 (nominally equivalent to a range of 4/0 AWG to 400 kcmil). The cross-sections of overhead lines range from 70 to 120 mm^2 (nominally equivalent to a range of 2/0 AWG to 4/0 AWG).

Rural MV grids are operated at various voltage levels; most common are 10 kV, 15 kV, 20 kV, and 30 kV. Like urban areas, rural MV grids are set up as looped networks with open loops under normal operating conditions or in some cases, lines are connected between two stations with a normal open contact at one end (see Figure 1). Usually, the grids are connected to the high-voltage grid (110 kV) via substations with two HV/MV transformers in a rated power range from 16 to 40 MVA. The power transformers are typically equipped with tap changers and automatic voltage control to guarantee a fixed voltage at all medium-voltage bus bars. The secondary substations consist of single MV/LV transformers in a rated power range from 100 to 400 kVA.

In a few cases, intermediate 30 kV grids operate to supply remote, lightly loaded areas. These 30 kV distribution grids form closed loops and supply lower-voltage 10 kV grids.

Due to the long lines, small cross-sections and the comparably low installed transformer capacity, the network impedance increases significantly towards the remote line terminal. Voltage drop and power quality issues frequently occur (see further discussion in Memo #2).

Low Voltage (LV) Distribution Grid

The low-voltage grid (LV grid) is a 400 V network and remains a three-phase grid (or three-phase plus neutral phase) up to the service points (end customers). In general, outgoing cable units in secondary substations are fused by a low-voltage, high-load breaking capacity fuse. Service point connections are protected for a maximum permissible current of 63 A (equal to 25 kVA). Similar to medium-voltage grids, urban, and rural low-voltage grids have different grid characteristics.

Urban Low-voltage Grids

According to the high spatial density of urban loads, low-voltage grids in these areas consist of relatively short grid cables with typical cable cross-sections of 150 to 240 mm^2 (nominally equivalent to a range of 300 kcmil to 400 kcmil). From the grid cables, service point cables with a cross-section of 35 – 50 mm² (nominally equivalent to a range of #2 AWG to #1 AWG) branch off to customers.

The urban LV grids are operated as meshed grids connected by means of cable distribution boxes. The LV grids can be fed by a single secondary substation or by one or two MV circuits (see Figure 4). The urban secondary substations contain about 10 outgoing cable units. The meshed grid structure ensures high service reliability, allows for high utilization, and reduces voltage drops and power quality issues. Unfortunately, the grid assembly is unclear and the maintenance effort is relatively high.

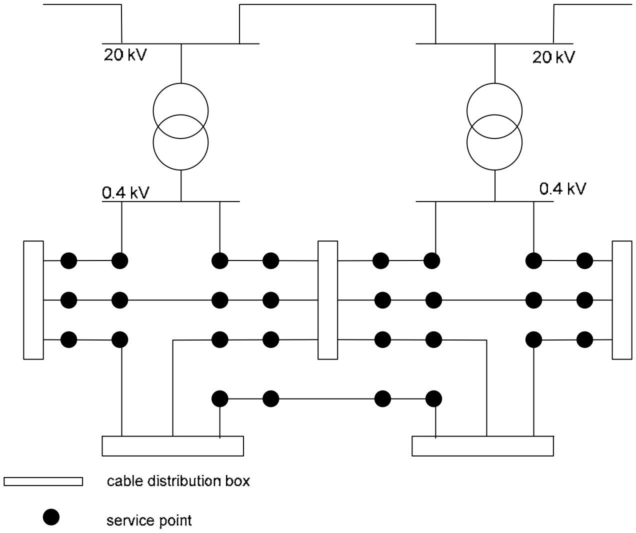


Figure 4: Typical Urban Low-voltage Grid Layout

Source: KEMA

Rural Low-voltage Grids

With respect to the expansion of the supply zone and the low load density, rural low-voltage grids in Germany are mainly radially structured cable or overhead line grids. For the grid lines, typical cable cross-sections range from 95 mm² to 150 mm² (nominally equivalent to a range of 3/0 AWG to 300 kcmil). The cross-sections of overhead grid lines range from 50 to 95 mm² (nominally equivalent to a range of #1 AWG to 3/0 AWG). The service point connections are typically realized through 35 mm² cables (nominally equivalent to #2 AWG). Occasionally, overhead lines with cross-section of 25 to 35 mm² (nominally equivalent to a range of #4 AWG to #2 AWG) are used.

The rural secondary substations contain up to eight outgoing cable units. The rural LV grids are operated as radial grids fed by a single secondary substation (see Figure 5). The long lines and decreasing cross-sections towards the line ends cause high network impedances. Thus, the sensitivity to voltage deviation and system perturbations (power quality issues) significantly rises.

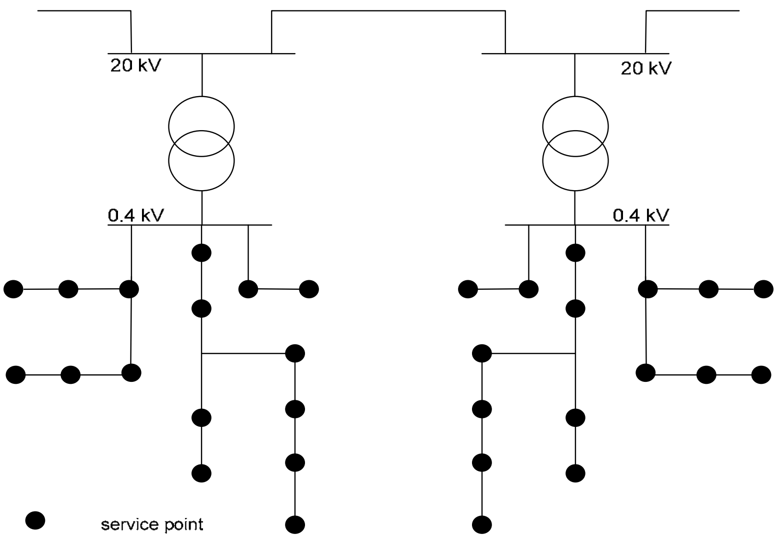


Figure 5: Typical Rural Low-voltage Grid Layout

Source: KEMA

In addition to the standard task of supplying end-use customers the distribution operators (DSO) must connect distributed generating units in the most cost-efficient, technically secure way. Therefore, the DSO first utilizes any existing reserve capacity in the grid for connecting a DG. If these reserves are exhausted, the point of common coupling can either be moved to a higher voltage level grid (depending on the DG size), or the lower voltage grid must be upgraded to accommodate the new DG. In the case of a grid extension or upgrade, the grid planner considers existing grid expansion requirements and network planning directives in conjunction with the technical rules for the grid connection of distributed generation in order to come up with the overall lowest cost grid expansion plan.

Conclusion for Grid Connection of Distributed Generation

Implications of DG on Grid Planning and Operation

Even though the increasing production of renewable energy from distributed generating units affects the grid at all voltage levels, no fundamental changes in the grid structure and planning standards have been made in Germany. However, due to the scale of distributed generation growth in the last decade, the level of DG output on medium- and low-voltage grids now exceeds local load in many places in Germany. Hence, back-feed conditions occur in some regions of the network. In general, back-feeds are permitted in Germany. The metering and protection has to be designed for bi-directional flow. A four-quadrant meter is necessary and the protection system has to allow back-feeds.

Network connections and upgrades are planned, based on the expected level of back-feed, so that this condition causes no overloads. Therefore, a back-feed condition during normal operations should not lead to curtailment or tripping the DG. In fact, under the German rules, TSO's must first exhaust all other available market options before curtailing renewable DG. Rules applying to DG curtailment by DNOs are not as clear, and the DNOs also have fewer options than the TSOs. However, if a renewable DG is curtailed by either a TSO or a DNO, the DG still receives its normal feed-in tariff remuneration for any curtailed energy (i.e., it does not reduce the DG's revenue).

Since the costs of network upgrades in Germany are socialized, network planners seek the lowest cost plan of upgrade to satisfy DG integration needs. Up to now, the planning for DG integration has generally been done as part of the regular grid expansion planning process with normal expansion planning and replacement needs considered first, then DG integration second.

Grid Dimensioning

In the past, medium- and low-voltage grids were designed and dimensioned based on the peak load scenario. The grid dimensioning and operation now have to account for the following four scenarios for load and DG output:

- Peak load / low DG output
- Peak DG output / low load
- Peak load / peak DG output
- Low load / low DG output

The first two scenarios have become the most critical cases for grid planning and operation. The power lines and transformers of each voltage level of the grid must be sized to manage the emerging renewable power production.

Protection aspects The protection devices and settings in German distribution grids generally allow for back-feeds. The overload protection depends on the loading limits of the assets and is independent of the flow direction.

Distributed generation plants have to be equipped with over-voltage and under-voltage protection. The time delay of the protection devices has to be adjusted to allow for the time delay of the automatic tap changers on HV/MV power transformers supplying that part of the network. Additionally, distributed generation plants in medium-voltage grids and above must be equipped with under-frequency and over-frequency protection. Furthermore, a power circuit breaker within the DG plant must guarantee the disconnection of the distributed generation project from the grid in case of a short circuit in the plant.

Grid Operation

Operational issues due to the high concentration of wind and photovoltaic generation plants that are managed mainly at the high-voltage and extra-high voltage level in Germany include:

- The load forecast and generation schedules, defined in the traditional 15-minute scheduling intervals, get perturbed by fluctuating renewable output.

- The considerable back-feeds from low load/high DG areas must be transported to large load centers and can cause congestion in the transmission grid.
- The curtailed utilization of conventional power plants reduces the available frequency control and short-circuit duty and affects the dynamic stability of the system due to a reduction in rotational inertia connected to the system.

According to the German law EnWG, grid operators at all voltage levels can invoke generation curtailment to cope with congestion and other critical operational situations that jeopardize the network security. For this purpose, distributed generation plants with rated power of more than 100 kW must be equipped with remote control capability to communicate their real-time output to the grid operator and allow for the grid operator to send automatic power dispatch control instructions to the generators. While such telecommunication facilities are not high-voltage facilities, they still are an essential component of the infrastructure required for reliable operation and control of the high voltage grid in Germany.

General and Technical Requirements in Germany

General Requirements

The implementation of renewable energy sources is an important political target of the German government. In this context, the federal government has developed legal boundary conditions for the development of distributed generation. As a result, important new laws (EnWG[7] and EEG[8]) were enacted. These laws define a priority of renewable energy sources in contrast to conventional energy sources and obligate the German grid operator to connect distributed generation. The grid operator has to ensure that distributed generating units are able to feed into the grid and that the total installed power can be transmitted under normal conditions. Furthermore, the point of common coupling should be as close as reasonable to the location of the individual distributed generating unit, given technical limitations.

An exception is defined for distributed generating units with an installed power lower than 30 kW. For these units the point of common coupling is simply defined as the low-voltage grid closest to the service connection of the owner of the generating unit.

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[7] EnWG - Zweites Gesetz zur Neuregelung des Energiewirtschaftrechts vom 7. Juli 2005; Bundesgesetzblatt Jahrgang 2005 Teil I Nr. 42, ausgegeben zu Bonn am 12. Juli 2005 *[Second German Law on the Energy Industry, July 2005]*

[8] EEG – Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich und zur Änderung damit zusammenhängender Vorschriften vom 25. Oktober 2008; Bundesgesetzblatt Jahrgang 2008 Teil I Nr. 49, ausgegeben zu Bonn am 31. Oktober 2008 *[German Law on the Renewable Energy Sources, October 2008]*

Regarding the evaluation of the technically reasonable point of common coupling, different technical norms and rules were developed in the past. These rules were developed in consideration of the following targets:

- The point of common coupling should be close to the location of the respective DG.
- A secure grid operation must be maintained under all conditions, including the full output of the distributed generator.
- The operation of DG should have negligible impact on other customers.
- Specific power quality parameters have to be maintained.

Given this context, distributed generation plants are connected at various voltage levels depending on the type of energy source and the installed power. The following summary describes the technical norms and rules regarding distributed generation connected to medium-voltage and low-voltage grids.

Technical Requirements

To ensure a secure operation of the grid under all conditions the following main points should be considered:

- All components used in the interconnection should be properly dimensioned for the size of the renewable project.
- The voltage level at the point of connection should be within an acceptable range.

Utilization and Overload

The utilization of the electrical interconnection components must not exceed the rated current of the electrical components. The rated currents of the components are defined through industry norms. In addition, grid operators in Germany have defined related rules. Distributed generating units that are connected to the medium-voltage or low-voltage grids should not cause overloads, under-voltages, or over-voltages.

Permissible Voltage Range

The permissible voltage range for medium- and low-voltage grids is defined in the norm DIN EN 50160.[9] On the one hand, the maximum voltage should not exceed the insulation level of the electrical components. On the other hand, the minimum voltage at each service connection point must allow an undisturbed operation of all connected devices. In this context, the voltage at each service connection point should be in a range of ± 10 percent of the rated voltage under normal operating conditions.

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[9] DIN EN 50160 – Merkmale der Spannung in öffentlichen Elektrizitätsversorgungsnetzen; April 2008 [German Norm 50160 – *Voltage Characteristics of Electricity Supplied by Public Distribution Networks*, April 2008]

Power Quality

Additionally, distributed generation plants should not interfere with other customers (consumers or generating units). To ensure acceptable power quality parameters, the following system perturbations associated with a DG should be considered:

- Voltage increase at point of connection
- Flicker
- Harmonics

Admissible limits for voltage deviation, non-symmetry, flicker, and harmonic levels are also defined (see Memo #2). Technical rules exist for the grid connection of generating units to the medium-voltage grid[10] and to the low-voltage grid[11], respectively.

The Most Critical Issue: Voltage Increase

Generally, voltage increase is the most critical issue at the point of common connection for distributed generating units. Voltage increases are caused by the injected power of generating units. The power transmission over the network impedance causes a voltage drop from the feeding to the receiving end. The magnitude of the voltage deviation relates to the size of the impedance. As a result, the voltage deviations in the grid vary depending on the DG size. This effect is illustrated in Figure 6.

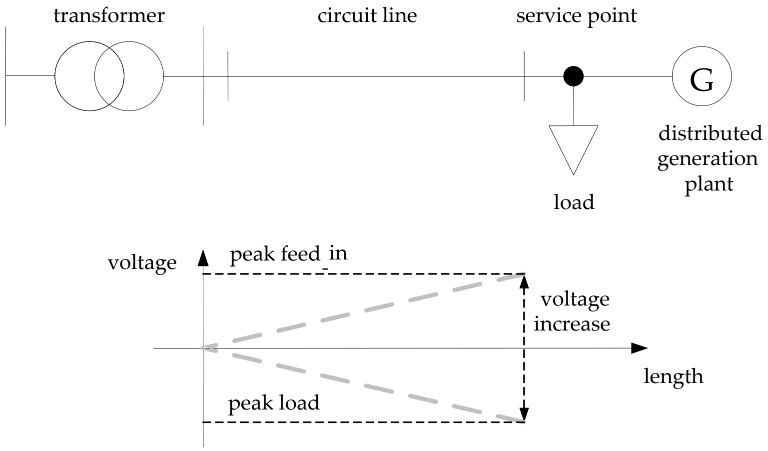

Figure 6: Voltage Increase Caused by Distributed Generation

Source: KEMA

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[10] Erzeugungsanlagen am Mittelspannungsnetz – Richtlinie für den Anschluss und Parallelbetrieb von Erzeugungsanlagen am Mittelspannungsnetz; VWEW Energieverlag GmbH; Juni 2008 *[German Technical Guideline – Generating Plants Connected to the Medium-Voltage Network, June 2008]*

[11] Eigenerzeugungsanlagen am Niederspannungsnetz – Richtlinie für den Anschluss und Parallelbetrieb von Eigenerzeugungsanlagen am Niederspannungsnetz; VWEW Energieverlag GmbH; September 2005 *[German Technical Guideline – Generating Plants Connected to the Low-Voltage Network, September 2005]*

The maximum difference between received voltages with and without DG operation are defined in the German grid rules (see Memo 2). All distributed generating units that are connected on a common section of grid have to be considered.

The short-circuit duty at a point of common coupling serves as a measure for the network impedance. High short-circuit duty reflects a low network impedance and vice versa. Therefore, in areas with low short-circuit power (i.e., rural areas), the occurring voltage increase is higher than in areas with a higher short-circuit power (i.e., urban areas). If the voltage increase exceeds the limit value, either grid upgrades are required to reduce the network impedance, or the distributed generating unit has to be connected to another point of common coupling.

In addition, other types of system perturbations (i.e., flicker, harmonics, etc.) are also evaluated in regard to the short-circuit power at the point of common coupling. All of the performance rules are considered by the respective TSO or DNO during planning studies for each DG connection and appropriate planning options are employed, as discussed in the next section.

Technical Options to Ensure Secure Grid Operation

General

Because of the distinct electrical characteristics of each medium- and low-voltage grid, the maximum acceptable level of DG capacity can be limited at any given point in the network. To ensure secure grid operation different grid planning options can be used to increase the acceptable amount of connected distributed generation in a given part of the network. However, German network planners consider all possibilities in order to determine the minimum level of grid investment. Generally, when the connection point is inadequate, the technical options include:

- Directly connecting the DG into a substation
- Upgrading of the network circuit thermal capability to the DG location
- Upgrading of upstream transformer capacity
- Rerouting the circuit to reduce circuit length
- Relocation of the network loop normally-open disconnect point
- Set point adjustment of automatic voltage control on network transformers
- Using reactive power capabilities of distributed generating units
- Construction of a new substation
- Changes to network topology
- Upgrade of the network's rated voltage level
- Installation of supplemental reactive power compensation equipment
- Implementation of rotating and non-rotating energy storage systems

These possibilities are described in more detail below.

Direct Connection at a Substation

If the voltage increase exceeds the limit value, other points of common coupling should be justified. In this context, the direct connection of a distributed generating unit to a network substation is one of the most commonly used solutions in Germany. This option can also be used if other system perturbation factors exceed the permissible limits. It requires relocation of the planned DG to a site adjacent to the network substation or construction of a gen-tie line from the DG site to the network substation.

Upgrade of Conductor Size

An upgrade of grid underground cable or overhead lines can be used if the connection of the DG to the nearest grid line exceeds critical performance parameters. Depending on the grid load, this approach may allow additional distributed generating units to be integrated into the grid. In Germany, this solution is often used for older grid lines, and conductor replacement needed due to the age of the grid line can sometimes be combined with integration of distributed generation. This solution is also used in order to raise short-circuit duty at the point of common coupling. Therefore, this option can also be used to solve problems regarding critical voltage increases. However, Germany avoids upgrading of the distribution grid solely for integrating distributed generation many. Depending on the amount of DG projects added to a portion of the grid, upgrade of line conductors may only be a short-term option. In all cases, relevant near-term and long-term grid planning factors should be taken into account.

Upgrade of Transformer Capacity

Similar to line upgrades, the upgrade of upstream transformer capacity is also used in Germany for some DG interconnections. This option may be preferable, especially for older transformers and allows more power output by distributed generation.

Reduction of the Circuit Length

This option can be realized by replacing grid line(s) to the DG site with an alternative route that creates a shorter circuit length and lower network impedance. However, the feasibility of this option depends on the geography of the specific grid area. Moreover, the resultant benefits in many cases are relatively low.

Relocation of the Network Normally-Open Disconnect Point

A short-term option to reduce voltage increases on grid lines can be the relocation of the normally open disconnect point of a grid loop.[12]

In Germany this option is only a short-term solution and is used more from the grid operation side. The impact of the relocation of the disconnection point on the ability to integrate distributed generation is comparably low and may increase the network electrical losses. With respect to the dynamic growth of renewable energy generation, there are superior options for medium-term or long-term grid planning.

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[12] The disconnection point defines the normally-open point in a network loop (see Figure 1a).

Adjustment of Automatic Voltage Control Set Point on Transformers

An adjustment of the transformer voltage control set point is also considered a short-term option, but in some cases can be used to keep the voltage level at a downstream DG connection point within the permissible range.

This option can only be used in medium-voltage grids in Germany because only the HV/MV power transformers are equipped with automatic voltage control systems (tap changing under load). Therefore, application is limited to larger DG facilities that need to connect to MV networks. This option is occasionally used in Germany.

Using Reactive Power Production Capabilities of Distributed Generation Plants

Some distributed generators are equipped with automatic voltage regulators that can absorb reactive power from the grid (under-excited operation) or provide reactive power to the grid (over-excited operation) Under-excited DG operation can be used to decrease connection voltage, while over-excited operation causes voltage increase. In Germany, this option is being used with increasing frequency as part of the long-term goal for distributed generating units to contribute to the voltage control of the grid. In the past, numerous DG units were not capable of producing reactive power. Therefore, different technical rules have been developed that include the requirement for DG capability to provide reactive power and to control voltage.

Construction of a New Substation

A new substation can be necessary if several components—transformers and grid lines—reach critical utilization levels due to DG integration. The construction of a new substation implies extensive grid extension measures. It is the most costly option and is therefore avoided in Germany. However, this option may be necessary in areas experiencing a comparably high level of DG installation concentrated in one location. This has been the case in the northern part of Germany where some HV/MV substations have been constructed exclusively for distributed generation (wind farm connection).

Change to the Network Structure

Changes to existing network structures are carried out in Germany only if needed as part of a comprehensive grid expansion plan. While distributed generation alone is not considered the main reason for changing network structure in Germany, it is one of the many factors considered in long-term grid expansion planning.

Upgrade of the Rated Voltage Level

The rated voltage level of medium-voltage grids in Germany has been upgraded in some areas. In most cases, the upgrade was from 10 kV to 20 kV. These upgrades allow for a greater penetration of distributed generation. However, when this option has been used it was selected due to its compatibility with the overall grid expansion planning needs. Distributed generation was not been used as the sole driver for this option in Germany.

Installation of Supplemental Reactive Power Compensation

The implementation of supplemental reactive power compensation systems (e.g., shunt reactors, FACTS), is hardly ever used for medium-voltage and low-voltage grids in Germany. Tests regarding the implementation of reactive power compensation systems are being carried out. Whether the installation of more reactive power compensation systems in medium-voltage and low-voltage grids will take place in Germany is unclear at this time.

Implementation of Rotating and Non-rotating Energy Storage Systems

Energy storage systems can store output from fluctuating renewable energy sources at times when they exceed the needs of the grid, and the stored energy is released back into the grid at a later time when needed. However, storage systems have not been used in medium-voltage and low-voltage grids in Germany for DG integration to date because the costs of such technologies are not economically justified. However, pumped-storage hydro projects have been used extensively on the EHV grid for regulating purposes.

However, implementation of storage systems for renewable integration on HV and MV grids is considered to be a long-term possibility in Germany.

Most Frequent Application of Options in Germany

The most frequently used options are summarized in Table 4 and are categorized according to the most common fields of their application.

Table 4: Most Frequently Used Options to Integrate Distributed Generation in Germany

Option	Grid overload	Critical voltage variation	Power quality issues
Direct connection to a substation		●	●
Upgrade of grid circuit conductors	●	●	●
Upgrade of upstream transformer capacity	●	●	●
Reduction of the grid circuit length		●	●
Relocation of the loop normally-open disconnect point	●	●	
Set point adjustment of transformer automatic voltage control (tap changer)		●	
Using reactive power capabilities of distributed generation plants		●	
Construction of a new substation	●		

Automatic Curtailment Option

In general, the grid operators of medium- and low-voltage grids in Germany have not used automatic curtailment of DG as an option for expansion planning. However, this option has recently been under discussion. In this scenario the distributed generation plant would need to be capable of automatically reducing their output in the event of specific over-voltage or overload condition, even without a remote control signal from the grid operator. Technical rules have not yet been established for this potential option, but it might be implemented in the future as an option.

Recent Network Planning Policies and Studies

Even though the increasing production of renewable energy from distributed generating units affects the grid at all voltage levels, no fundamental changes in the approved grid structure and planning directives have been made to date. Technical guidelines have been developed to ensure a secure operation of the grid under all conditions while connecting distributed generation in an economic, least cost manner from the perspective of grid expansion options. Any large-scale grid expansion and redesign measures in the past have been driven primarily by overall long-term grid planning goals, and not primarily by distributed or renewable generation. However, recent policy initiatives and studies in Germany suggest that a new grid investment paradigm may be developing. This is due perhaps in part to concerns over the level of dependence on nuclear resources in Germany’s long-term energy plan and the possibility of significantly reducing this dependence through integration of even higher levels of renewables.

Most relevant to the current KEMA investigation, recently published German study reports conclude that a major increase in the scope of distributed and renewable generation would require considerable expansion of existing transmission and distribution networks. According to one major wind resource expansion study[13] completed in 2010, in the base renewable expansion scenario studied up to 3,600 km of new transmission lines are needed to accommodate renewable growth, particularly large offshore wind, by 2020. This would require approximately €1 billion/year in additional grid expansion costs for new transmission lines. Another expansion scenario considered increased use of high temperature transmission conductors which would reduce the mileage of new lines to some 1,700 km, but would also require some 5,700 km of existing lines to be modified. This scenario would increase the expansion costs to €1.6 billion/year, which is the highest of all the scenarios analyzed.

These results are complemented by another draft study by a major German industry association (BDEW) which quantifies the network expansion necessary to meet mid-term renewable policy goals and forecast.[14] While the government’s energy strategy published in 2010 envisions a total

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[13] Deutsche Energie-Agentur Network Study II – Planning of the Grid Integration of Wind Energy in German Onshore and Offshore up to the Year 2020 (Dena Grid study), 2010.

[14] Draft report by the Federal Association of the German Energy Industry (BDEW), March 2011.

installed solar power capacity of approximately 33 GW in 2020 (i.e., doubling the current installed solar power capacity), the Federal Ministry of Environment estimates that by 2020 there will be another 52 GW of installed capacity added from solar power and smaller onshore wind parks. Given this forecast, the BDEW draft study concludes that by 2020 they would need to build 195,000 km to 380,000 km of additional lines on the German HV and MV distribution voltage networks. The associated capital cost is estimated to be €13 billion to €27 billion.

Due to the delay and considerable amount of time needed of the permitting procedure for planned and new transmission lines, the German government has also revealed potential legal changes in order to accelerate and simplify the planning and permitting procedure.

SECTION 2:
Physical Infrastructure in Spain

In recent years distributed generation (DG) has received increasing attention as it can contribute to the various goals of EU energy policy. Enhanced diversity of supply, a reduction in greenhouse gas emissions, efficiency gains and more flexibility in investments are some of the major benefits associated with DG. However, when the amount of distributed electricity supply of renewable energy sources (RES) surpasses a particular level, it can no longer be ignored in planning and operation of the electricity supply system. Therefore, improvements of the regulatory framework of the electricity supply systems are required along with the growth of the electricity supply from distributed generation.

Basic principles for achieving sustainable development from an economic, social, and environmental point of view in Spain today include reducing dependence on foreign energy, better use of available energy sources, and a greater awareness of the environment. These goals increasingly demand the deployment of renewable sources of energy, increased efficiency in electric generation and a reduction in greenhouse gases in accordance with the commitments acquired on signing the Kyoto protocol, by means of a search for energy efficient generation of electricity.

Creation of the special regime for the generation of electricity meant an important milestone in Spain's energy policy. Targets for renewable energy and combined heat and power are covered in the Renewable Energy Plan 2005-2010 and in the Strategy for Energy Saving and Efficiency in Spain (E4), respectively. In view of the above, although growth in the special regime for electricity generation has been outstanding, in certain technologies the targets are still far from being reached.

At the end of 2010 Spain had a total installed electric power production capacity of 97.5 GW (peninsular system). The total installed capacity in solar and wind power production was 23.8 GW (24 percent of the total installed capacity). This total includes approximately 9 GW from wind projects and 4 GW from solar PV projects smaller than 20 MW. Continued growth of distributed renewable generation seems unabated.

Therefore, Spanish grid operators in recent years have developed technical rules and guidelines to maintain secure network operation with large amounts of renewables. According to these extensive experiences the Spanish power distribution system is suitable for a comparative analysis.

The Spanish Ministry of Industry through the Institute for Energy Diversification and Saving (IDAE) has developed the website Renovables (Renewables) Made in Spain, http://www.renovablesmadeinspain.com/ with the objective to inform the world about the significant penetration of renewable energies in Spain and the leadership of Spanish companies and organizations that have made this possible.

In the following sections the research team presents the main voltages of the transmission and distribution networks in Spain. Then we describe the relevant types of renewable energy sources by region, along with the characteristics of the generation plants and their implications for the grid. Finally, we address the most frequently used technical options and facilities to manage the integration of renewable energy sources and thereby to comply with technical requirements and guidelines.

Overall System Planning and Development

In May 2008, the Spanish Ministry of Industry, Trade and Tourism passed the 2008-2116 planning document for the gas and electricity sectors to ensure the safety and quality of the energy supply. This plan sets out a substantial program involving the construction of new power installations.

In 2009 Red Eléctrica de España (REE), the Spanish corporation that operates the nation's power transmission system and electricity grid, continued to draw up forecast studies, both for power demand and cover. REE, as operator of the insular and extra-peninsular systems, likewise draws up both the demand and power peak forecasts and the estimates of generating equipment needs for these systems.

REE is carrying out investments aimed at reinforcing the grid mesh in order to cover increases in demand in some areas of the mainland and to facilitate the establishment of the new generation installed, mainly combined cycles and wind-power plants and, to an ever increasing extent, solar thermal plants.

Network Structures in Spain

This part of the report describes the basic technical configurations of Spanish distribution grids including substations and secondary substations. The analysis focuses on medium- and low-voltage distribution grids. It also outlines relevant aspects of distributed generation at higher voltage levels in Spain.

Grid and Voltage Levels

The Spanish power grid at all voltage levels is a three-phase alternating current grid operated at a frequency of 50 Hertz. Four common voltage levels have been established in the Spanish power grid as shown in Table 5. This classification of voltages is according to the IEC definitions.

Table 5: Overview of Voltage Levels in Spain per IEC Definitions

System Name *(IEC Definition)*	Abbreviation	Rated Voltage	Role
Extra-high voltage	EHV	400 kV, 220 kV[15]	Transmission grid
High voltage	HV	132 kV, 110 kV 66 kV, 45 kV	Distribution grid
Medium voltage	MV	30 kV, 20 kV, 15 kV, 13.2 kV, 11 kV	
Low voltage	LV	400 V	

Spanish legislation (Royal Decree 223/2088) gives a similar classification for lines above 1 kV:

- Special category: Lines of nominal voltage above or equal to 220 kV, or the ones of lower voltage that are operated by the TSO.
- First category: Lines of nominal voltage below 220 kV and above 66 kV
- Second category: Lines of nominal voltage equal to or below 66 kV and above 30 kV
- Third category: Lines of nominal voltage equal to or below 30 kV and above 1 kV.

The characteristics and functions of the main voltage levels are discussed below.

The Spanish Transmission System

The typical voltage levels for the transmission grid in Spain are 400 kV and 220 kV. The international connections are also considered as a part of the transmission system. REE is the Transmission System Operator (TSO) and owns about 99.8 percent of the 400 kV power lines and 98.5 percent of the 220 kV power lines. According to current Spanish regulations all 220 kV must be transferred to the TSO.

The Electricity Sector Act 54/1997 confirmed the role of REE as a cornerstone of system operation. This law created a wholesale power market that required an effectively managed transmission grid to work properly and a coordinated operation of the generation-transmission system to ensure that demand would be satisfied at all times.

Act 17/2007 of 4 July in Spain amended the previous law to adapt it to European Directive 2003/54/CE which established the common guidelines for the domestic power market. This law has resulted in the definitive consolidation of the REE's TSO model. In this regard, REE, as the system operator, guarantees the continuity and security of the power supply and the proper

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[15] In the past, the DSO's controlled parts of the 220 kV network, but it has mostly been moved to the TSO.

coordination of the production and transmission system, performing its functions based on the principles of transparency, objectivity, and independence.

REE is not just the manager (operator) of the transmission grid but likewise has exclusive responsibility for development and maintenance of the grid. This is quite different from the German case where several transmission grid owners and operators coexist.

Like Germany, Spain is part of the European Network of Transmission Operators for Electricity (ENTSO-E), and therefore operates according to rules in the Operation Handbook of ENTSO-E. The transmission grid is a meshed system with high standards for system stability (frequency, voltage, dynamic stability) and security of supply. Overhead lines dominate the grid infrastructure. Figure 7 illustrates the Spanish transmission system with 400 kV lines represented in red and 220 kV lines represented in green.

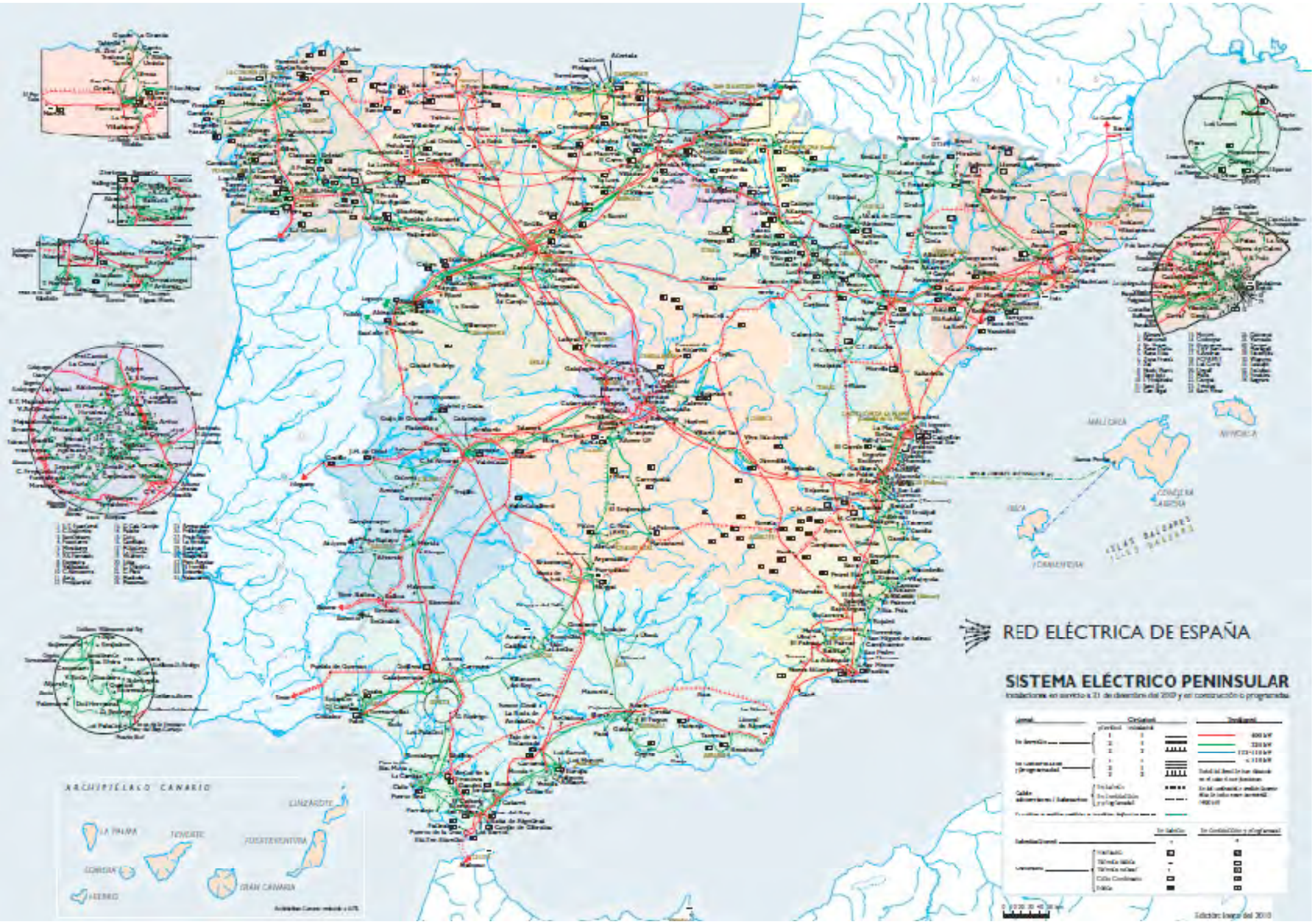

Figure 7: Spanish Transmission System

Source: REE (http://www.ree.es/transporte/mapa_red_transporte.asp)

The Spanish Distribution System

The typical distribution voltage levels in Spain are 132 kV, 110 kV, 66 kV, 45 kV (high voltage), 30 kV, 20 kV, 15 kV, 13.2 kV, 11 kV (medium voltage), and 380 V (400 V in the latest regulation, RD 842/2002, low voltage).

In Spain the main distribution companies are Iberdrola, Endesa, Gas Natural Fenosa, Hidrocantábrico, and E.On with a market share of 40 percent, 39 percent, 15 percent, 2.5 percent, and 2.5 percent each, which combined represent 99 percent of the total distribution activity.

HV Distribution Grid

Spanish HV grids are of meshed topology (more or less complex) and can be operated also in a meshed philosophy (closed loop) or radial (open loop). The exception are a few radial built networks in rural areas, but even in these areas the most common topology is the open loop, so there is possibility of support through a second line. This grid is used to feed the distribution substations that are connected to the MV grid. The layout of the HV bus bar of these distribution stations depends on the area they are built. Most of the HV grid complies with n-1 security criterion (for transformers and lines). Security criteria n-2 can be applied for HV grids associated to urban areas, when there are for example substations fed by critical double circuit lines. Figures 8 through 10 illustrate different network topologies applied at the HV level in Spain.

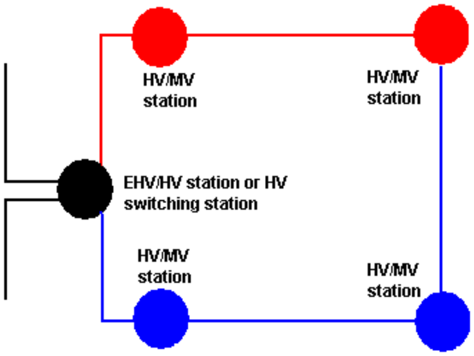

Figure 8: Looped HV Grid (Single Source Point)

Source: KEMA

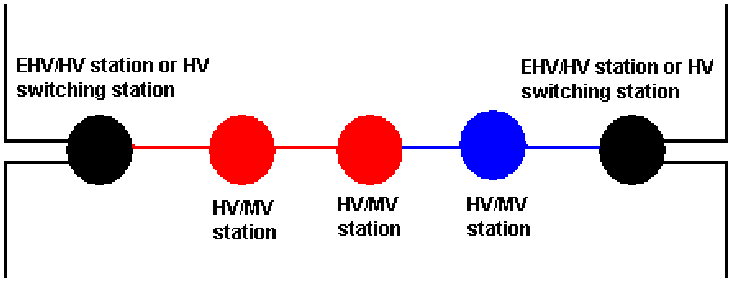

Figure 9: Bridge Configuration (HV Grid Fed from Two Points)

Source: KEMA

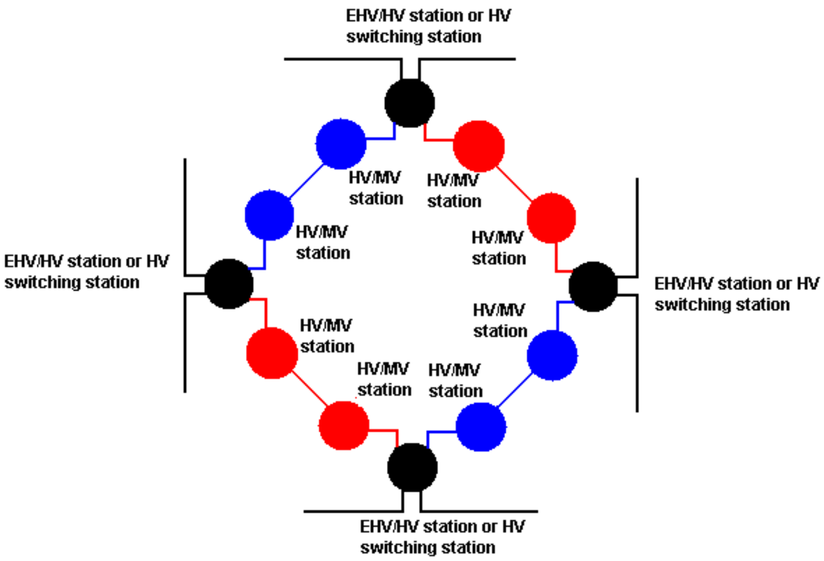

Figure 10: HV Mesh Configuration

Source: KEMA

MV Distribution Grid

The Spanish medium-voltage (MV) grid) in Spain is differentiated by urban, semi-urban, and rural areas that have different power quality, reliability, and continuity of supply requirements.

Urban Medium-voltage Grids

Urban MV grids in Spain serve high-density urban areas fed by underground cables. The typical cable cross section is 240 to 400 mm² (nominally equivalent to a range of 400 kcmil to 750 kcmil), but there is a significant heterogeneity of cross section especially in the large cities due to decades of different planning criteria and network development criteria.

The design philosophy of MV grids in Spain is to serve the MV/LV stations in a way they can always be fed from at least from two different points. There should not be MV/LV stations on single, radial MV sources. This is achieved by applying mainly two standard network designs:

- Reflection point and support circuit
- Distribution point

Figure 11 illustrates the concept behind the reflection point and support circuit design. The idea is to have a normally open backup circuit (Circuito de Apoyo) that in case of fault in one of the main feeders will be able to close into the reflection point and feed the load on the healthy portion of the faulted feeder after the fault has been isolated by remote controlled switches. These switches are associated to RMUs (Ring Main Units) in the MV/LV stations (circles in the figure). In the example shown in Figure 11, a fault (indicated by the lightning bolt) has occurred on the first section of Circuit 1 near the source station (ST), which has been isolated and the remainder of the circuit load picked up from the reflection bus via the backup circuit (green indicates a closed breaker, and white indicates an open breaker).

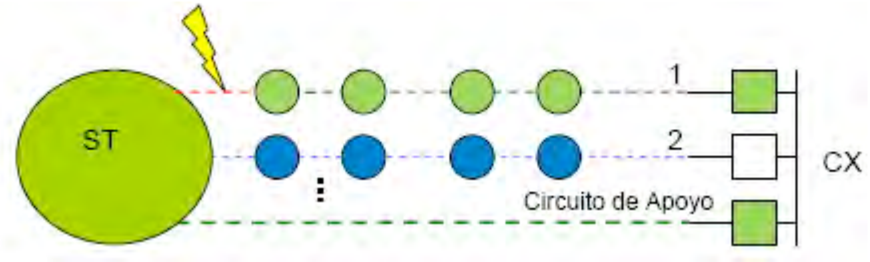

Figure 11: Urban MV Grid: Reflection Point and Support Circuit Design[16]

Source: Universidad Pontificia Comillas: Master Thesis by Trinidade Moya

Figure 12 illustrates the distribution point design that is used mainly in high density load areas. Reliable distribution centers are built as close as possible to the load center and two or more high capacity trunk feeders (circuitos allementadores) are constructed from the remote HV/MV transformation substations to the distribution centers. No load is connected directly to the trunk feeders. Multiple distribution circuits emanate from each distribution center and feed multiple MV/LV stations within the high load density area. Figure 12 illustrates a configuration with two such distribution centers, but other combinations can be used. The MV/LV stations normally consist of transformers above 400 kVA, with one or more transformers per station.

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[16] "ST" means substation. "Circuito de Apoyo" means backup circuit. "CX" means reflection point; a bus with circuit breakers and ground switches used to ground the circuits when the breakers are open.

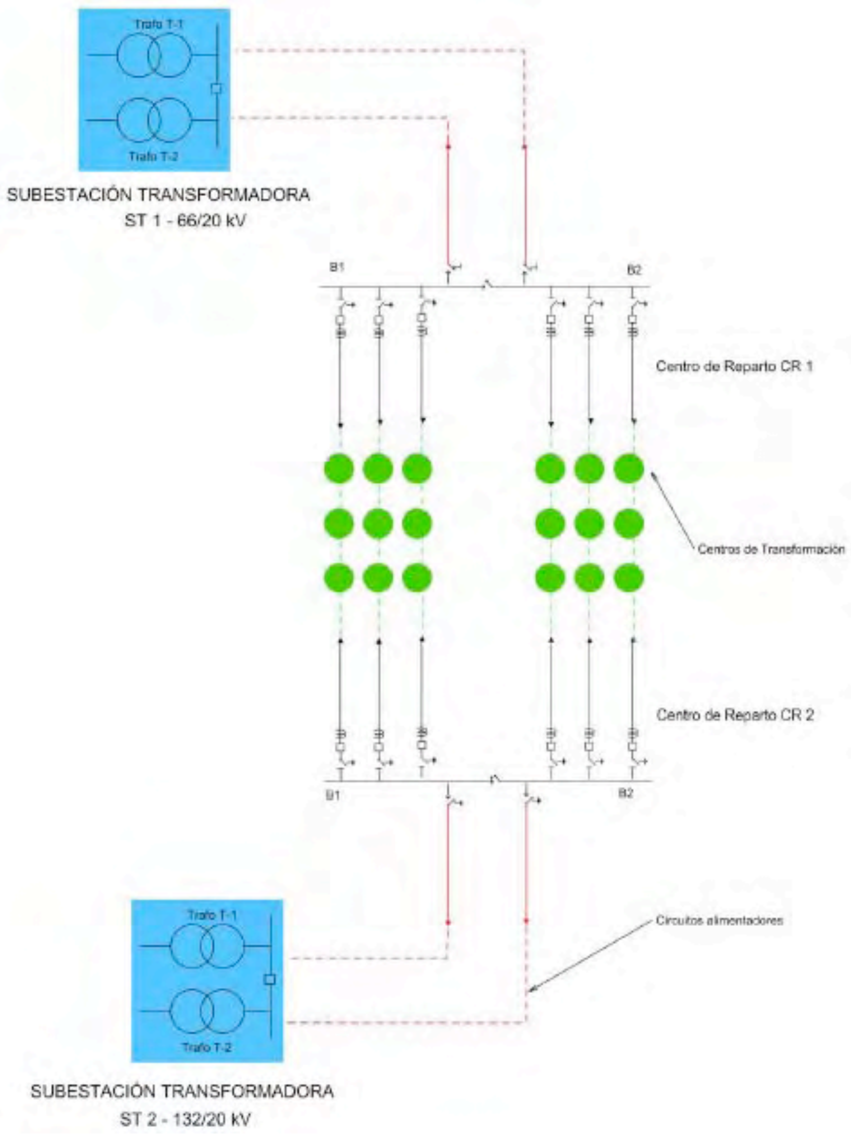

Figure 12: Urban Medium Voltage Grid: Distribution Point design[17]

Source: Universidad Pontificia Comillas: Master Thesis by Trinidade Moya

Rural Medium-voltage Grids

Spain has made a differentiation between concentrated and dispersed rural areas. Both are fed mainly by overhead lines, though dispersed rural areas have longer lines, commonly causing voltage drop problems related to the large impedance of the long overhead lines. The design normally consists of a main feeder with the same conductor cross section over its full length,

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17 "Centro de Reparto CR 1 and 2" means "Distribution Centers No. 1 and 2", "Subestaciaon Tranformadora" means Transformation Substation, "Trafo T-1 and T-1" mean Bank 1 and 2.

from which several derivative feeders (branches) are supplied—typically with smaller conductors.

Similarly to the United States, the rural networks in Spain are equipped with switches along the lines (reclosers and sectionalizers) in order to more efficiently isolate faulty sections and restore the supply to the healthy ones. The main feeders of the rural network can be fed from two alternative substations operating in an open loop manner (making use of a normally open point by means of a switch), resembling the loop connected with normal open contact philosophy that is used in Germany. This allows the use of loop restoration schemes in case of faults. The typical Spanish rural MV grid structure is illustrated in Figure 13. Unlike urban areas, MV/LV stations in rural areas are usually supplied from a single circuit.

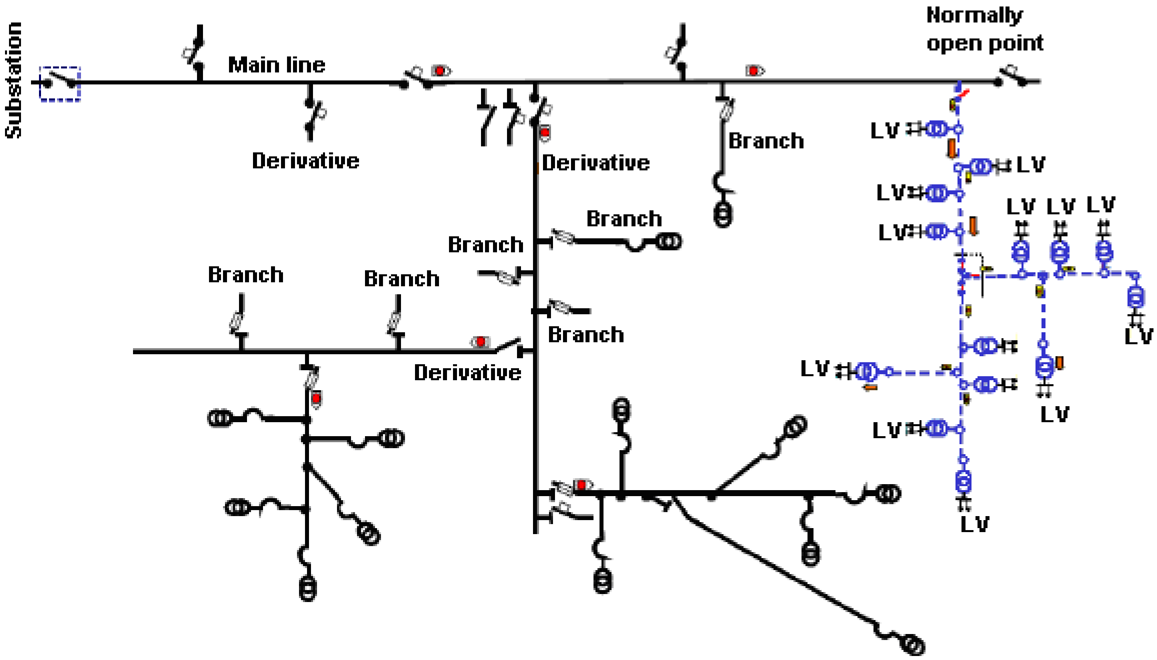

Figure 13: Rural MV Grid Structure

Source: KEMA

LV Distribution Grid

The low-voltage grid (LV grid) is a three-phase 400 V, comprising also a neutral wire. These grids are built and operated in a radial way, regardless of being urban or rural. Urban grids are dominated by underground cables, while rural grids are dominated by overhead lines. Rural grids are more exposed to voltage deviations (drop or rise) due to their higher per unit impedance combined with longer length. The typical Spanish LV grid structure is illustrated in Figure 14.

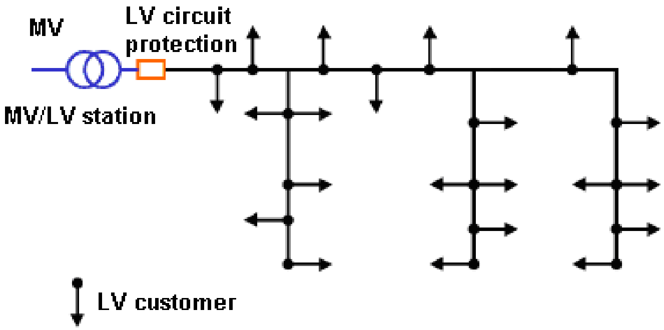

Figure 14: LV Grid Structure

Source: KEMA

Renewable Energy Sources (RES) in Spain

Electricity producers in Spain are subjected to different legislation depending on the technology and energy source used. Producers are classified in two main groups: special regime (ex: renewable energy sources) and ordinary regime (ex: conventional power plants such as nuclear power stations). Figure 15 shows a breakdown of the total installed capacity by technology at the end of 2010. Figure 16 shows the annual evolution of the installed power by technology from 2005 to 2010.

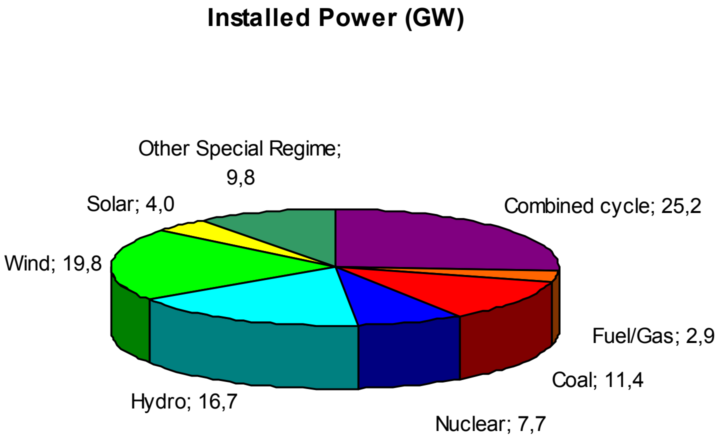

Figure 15: Breakdown of the Total Installed Capacity by Technology at the End of 2010[18]

Source: REE (Red Eléctrica de España)

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[18] The category "Other Special Regime" includes cogeneration and waste-to-energy plants below 50 MW.

Spain had a total installed capacity in electric power production of 97.5 GW (peninsular system) by the end of 2010. The total installed capacity in solar and wind power production was 23.8 GW (24 percent of the total installed capacity) at the end of 2010. Next to combined-cycle plants at 25.2 percent of the total resource capacity, wind was the next largest block at 19.8 percent of total.

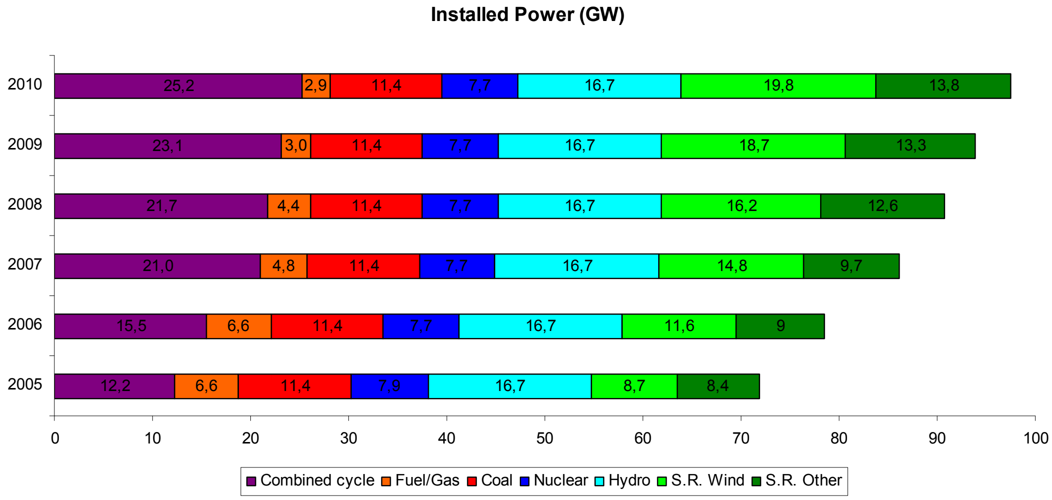


Figure 16: Annual Growth of Spain's Installed Power Generation (GW)

Source: REE (Red Eléctrica de España)

Distributed Generation

Generally, distributed generation comprises generation plants that are connected to low- and medium-voltage distribution grids close to energy consumers and generation plants for self supply. However, this definition as such is not used in practice in Spain. Although there are different remuneration schemes for generators of different size, which therefore will be connected to distinct voltage levels, the main split in Spain is made between the so called ordinary and the special regime. The technologies eligible for special regime are cogeneration, renewable energy sources and waste. According to the Spanish law RD 661/2007, the renewable energy sources group is divided in eight subgroups as follows:

b.1: solar energy

b.2: wind energy

b.3: waves, geothermic, tides

b.4: and b.5: hydropower

b.6, b.7, and b.8: biomass and biogas

Installations with an installed capacity larger than 50 MW are not included in the special regime. However, if these installations produce renewable energy they receive a premium equal to that paid to smaller renewable projects (i.e., those less than 50 MW), but discounted by 20-80 percent. Due to this financial disincentive there are no individual renewable energy projects in Spain with installed capacity over 50 MW.

Point of Common Coupling

The definition of point of common coupling in Spain is similar to Germany, i.e. it is the grid connection point of a generation plant. Its location depends on the rated power of the generation plant and technical and economic aspects of the power grid (voltage level, utilization of assets, network impedance, etc.).

Regional and Quantitative Allocation of Renewable Energy

In 2009, the generators operating in the special regime supplied 32 percent of the gross electrical consumption in Spain. Wind farms alone supplied 14.5 percent of Spain's gross electrical consumption in 2009.

Figure 17 shows the share of the different renewable technologies to the total installed capacity in renewable electricity production for the special regime (S.R.).

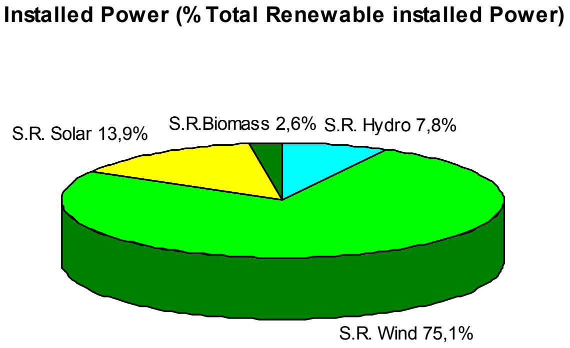


Figure 17: Breakdown of the Total Renewable Installed Capacity by Technology at the End of 2009

Source: REE (Red Eléctrica de España)

Wind Energy

Wind power is the renewable source that has experienced the largest development in Spain. The population density in large areas with good wind resource is much lower than in Germany, which has provided opportunities to build larger wind farms. The development has taken place through large investors such as electricity and construction companies. Recently, the trend is for non-electric companies to sell their installations due to the increasing technical requisites in this sector. The development of the wind power sector goes in the direction of larger wind farms connected directly to the transmission grid due to the technical development of wind turbines technology and the available capacity in the transmission grid to transport more electric power, getting better prices. When the installation capacity is larger than 50 MW, promoters divide into several installations under 50 MW in order to get the highest payment. About 60 percent of the total installed wind power is connected to the transmission grid. Of the remaining 40 percent connected to distribution the large majority is connected to the 132/110/66 kV grids. Only 2-5 percent is connected to the radial operated distribution grids (30 kV and below). Wind power is distributed all over the country, but there is significant incidence of large wind farms in the northern regions of Galicia and to the southeast in Castilla-La Mancha. Figure 18 shows the installed wind capacity density (kW/km^2) in Spain.

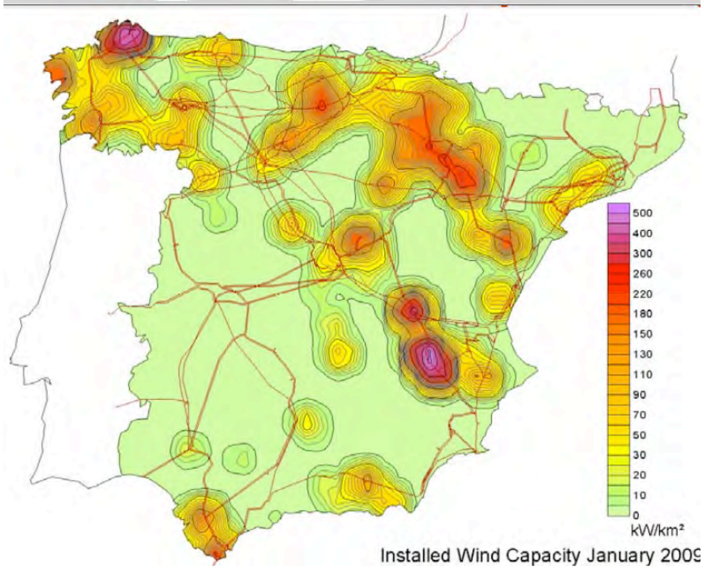


Figure 18: Wind Capacity Geographic Density in Spain

Source: REE (Red Eléctrica de España)

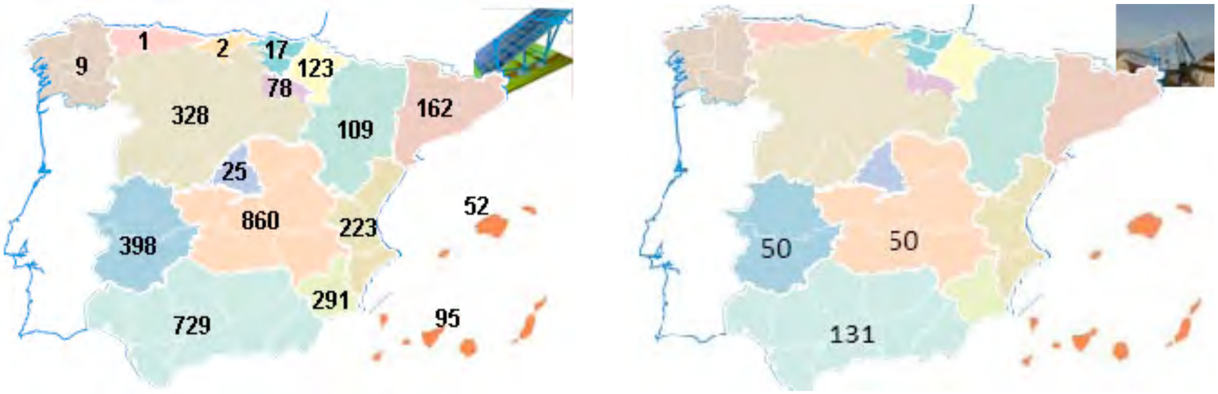
Spain's wind production is highly variable both hour by hour and day to day. For example, Spain's record high wind production was about 11:00am on February 24, 2010 at 12,916 MW, and the record low was on June 3, 2009 at 164 MW in the early afternoon. On most days, wind production peaks at night, and reaches a minimum between noon and 2:00pm. Downward ramps in wind production in the mornings often increase morning ramp-ups of conventional generation in the summer along with dispatch of pumped hydro plants. Some key facts about wind power in Spain:

- Renewable energy plan for Spain (2005-2010): ~ 20,000 MW (accomplished)
- Official network planning for 2016: 29,000 MW
- Further increase expected for 2020 in compliance with proposed EC initiatives
- Production records: 54 percent of demand at 3:50 am on December 30, 2009

Solar Energy

Spain leads the world in the development of solar energy, as it is one of the sunniest countries in Europe. More than 95 percent of the total PV installed capacity is connected to the distribution grid (below 220 kV) as well as about 35 percent of the total thermal (conventional) installed generating capacity.

Figure 19 shows the distribution of solar PV and solar thermal power in the Spanish autonomous communities, by end 2009. At this time there were about 3.3 GW of solar PV were connected to the grid. While solar thermal is present only in the communities of higher solar radiation exposure, such as Andalucia, solar PV is much more uniform along the country, although still dominated by the southern communities.



a) b)

Figure 19: Installed Solar Power (MW) in the Autonomous Communities of Spain by End 2009 a) PV and b) Solar Thermal

Source: REE and ASIF (Associacion Industrial Fotovoltaica)

At present the TSO has no remote monitoring or remote control capability for any of the 3.3 GW of PV power generation because telemetry to the TSO is only required for DG projects of 10 MW or larger, and there are no PV projects of this size in Spain. As the installed MW of solar PV expands, the lack of telemetry on these projects will create greater operating problems for the TSO. Also, Spain's winter peak demand is in the evening when PV makes no contribution. In the winter the use of molten salt energy storage and hybridization with natural gas[19] can enable such systems to produce during the peak demand hours. On the other hand, concentrating solar thermal has a positive correlation with Spain's summer peak demand.

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[19] Hybridization with natural gas is limited by Spanish regulations to 15 percent of solar thermal plant capacity, whereas hybridization with biomass or biogas is allowed up to 50 percent.

RES Compensation Arrangements in Spain

RES revenues can be determined by one of the two following alternatives:

- Feed-in-tariff: the price paid per each kWh produced by a RES installation is regulated and fixed to a constant value, independent of market fluctuations. The annual evolution of this tariff depends on the evolution of the average reference electricity tariff in Spain (RT), as feed-in tariffs (FIT) are set as a percentage of the RT. The tariff is fixed for a certain contract duration (e.g., 15 years). The regulated feed-in-tariff for each RES technology depends on the type of the technology and on the year when the installation is put on service. This alternative is a heritage of the previous regulation. RES facilities greater than 10 MW are committed to give to distribution companies (DISCOs) a production schedule 30 hours in advance, being allowed to adjust such schedule 1 hour ahead of each intra-daily market (six calls during a day). Hourly energy deviations from the production schedule are penalized at a price per kWh deviated equal to 10 percent of the RT. This penalization does not apply in a dead-band of 20 percent of the production scheduled for RES facilities. This rule, which implies a big change in RES regulation from the previous framework, will apply to wind farms only since January 1, 2006. As the government RES targets are reached, the FIT decreases. When the FIT contract period for a given RES project is over, its energy is sold at the market (pool) price.
- Wholesale market: RES are given incentives to join the wholesale market, following in this case practically the same rules as ordinary generators. As the RES will face new technical and economic constraints by doing so, their remuneration scheme provides an additional economic incentive. The total income is the sum of the market selling price, plus a premium that represents the externalities in a similar way to previous regulation, plus the above-mentioned additional incentive to access the market. The premium and the additional incentive are set also as a percentage of the RT. As RES are integrated in the wholesale market, they have access to all the rest of electricity markets (daily, intra-daily, ancillary services, etc.). They can earn money if they are able to participate in such markets or pay if they use such services, being the most important the cost of production deviations from the predictions. In this case, there is no dead-band, and the price is settled through market mechanisms.

RES have an additional income associated to reactive power that depends on the time period (peak, flat, or valley hours) and it can be positive or negative depending on the power factor the unit is providing. This income encourages RES to consume reactive power (lagging power factor) in valley hours and to supply reactive power (leading power factor) in peak hours. In previous regulations there was an incentive to keep the power factor equal to one.

An interesting aspect of current Spanish legislation is the economic incentive that has been fixed for wind farms to be able to cope with voltage dips without tripping. This is one of the main technical problems for wind generation expansion, with high penetration levels of wind generation that can all trip at once if there is a voltage dip in the transmission network, threatening system stability. There is an economic incentive of 5 percent of RT to each kWh sold by each immunized wind park against voltage dips during a period of four years.

Interconnection Technical Requirements in Spain

RES producers that wish to connect at the EHV level must connect a minimum capacity of 100 MW at any one point of interconnection to the 220 kV grid or at least 250 MW at any one point of connection with to the 400 kV grid. It is possible several for smaller project developers to make a joint application to the TSO to fulfill this requirement. RD 436/2004 defines additional criteria and are again stated again in the RD 661/2007 (annex 11) with some modifications:

1. The combined capacity of all special regime generators connected to one line of the distribution grid cannot exceed 50 percent of the capacity of the line.
2. The combined capacity of all special regime generators connected to one substation or substation transformer cannot exceed 50 percent of the capacity of the respective substation or transformer serving that voltage level.
3. For producers without storage capabilities or not able to directly manage their output, such as wind power and PV producers, it is also established that the MW capacity of the producer or group of producers sharing a connection point (point of common coupling), will not exceed 5 percent of the grid short-circuit duty (at that point on the system) expressed in MVA. For dispatchable generators (biomass, solar thermal), the MW capacity shall not exceed 10 percent of the grid short-circuit duty (at that point) expressed in MVA. This is intended to limit the maximum voltage deviation due to DG operation to the range of 5-10 percent of the local grid's nominal voltage.

Because of the above limitations in grid impacts due to DG, very few backfeed situations have developed in Spain. In practice, the criteria above only restrict the connection to the distribution grid and are not the connection to the transmission grid. Based on utility experience regarding connection to the distribution grid, criteria 1 and 2 from the list above limit the capacity that can be connected in about 10 percent of the cases, while criteria 3 is limiting in approximately 90 percent of the cases. DG projects in Spain do not have much experience connecting to the MV distribution grid, so these limitations may need to be reviewed in the coming years as well. Distribution companies generally consider these criteria to be adequate, although there have been suggestions/discussions on the inclusion of local load as a limiting factor for the interconnection of special regime generation due to concern about backfeed into HV and the transmission grid.

Photovoltaic plants smaller than 100 kVA and connected to low voltage networks (below 1 kV) have specific connection requirements enacted in the Royal Decree 1663/2000. The most relevant requirements of this legislation are the obligations to maintain voltage at the interconnection point at ± 5 percent of the nominal voltage and operate at a power factor as close as possible to unity.

Implications on Power Grid Operation

REE (TSO) has, along the years, been experiencing wind generation trips due to voltage dips. As a result, it has been monitoring voltage and generator performance since 2005. An operational procedure has been implemented as part of the Spanish grid code that establishes when generators must remain connected in order to allow ride-through in the event of a fault. Starting January 1, 2008, all new wind facilities had to comply with this voltage ride-through regulation. Most existing plants have made the necessary retrofits to comply, and only some 1,000 MW to1,500 MW plants still need to be adapted. REE now runs real-time simulation to model scenarios of three-phase faults in 70 of its 400 kV substations. These simulations allow the TSO to take actions from a dedicated control centre in order to ensure safe system operation and avoid further generation tripping.

Voltage control for conventional generation is typically done at the substation. That is not sufficient where a large penetration of renewable generation exists. REE has instituted a system to incentive renewable generators to provide reactive power: Generators receive a bonus or suffer a penalty for +8 percent to -4 percent of €78.44 per MWh, depending on the power factor. The system operator issues instructions to modify the power factor settings.

Since April 1, 2009, REE has ordered all DG units above 10 MW to operate at power factors between 0.98 and 0.99 inductive in order to eliminate sudden changes in the voltage profile and avoid high voltages. REE believes that the ultimate solution is to enable voltage scheduling capability for all generators greater than 10 MW. A key issue remains as to when and how to automate DG voltage control and whether this requires a local, regional, or national structure.

Connection Process to Transmission Network in Spain

Connection Application Phase

There are two different stages, according to P.O 12.2 of REE:

- 1 - Request for access to the transmission grid.
- 2 - Request for connection to the transmission grid.

For stage 1, the generator must submit a request for access to a specific network location (node) and supply a variety of technical data about its generating plant from rated power to PSS/E control block models for dynamic analysis. REE also requests the seasonal generation patterns. It is a complete set of data on the generating unit, which is complemented with data on interconnection lines and also with data on step-up transformers. Furthermore there are different requests depending on the generation technology. REE P.O 12.1 annexes list all the necessary data for different generation technologies. After receiving the request for access accompanied by the generator data, the Spanish TSO has two months to determine if the system capacity will support the connection. If so, the generator advances to stage two.

At stage two the generator must submit the basic design of its installation, the construction program and a report showing that the installation fulfills all the connection requirements in "Instalaciones conectadas a la red de transporte: Requisitos minimos de diseño y equipamiento.” This document defines protection requirements, grounding requirements, switchgear arrangements, etc. The generator has one month to deliver these documents after receiving a positive stage 1 approval. In its turn, the TSO has one month to decide if the generator’s documentation is adequate.

The generator does not have to perform any studies itself, since the studies are carried out by the TSO using data supplied by the generator. The generator is free to ask the TSO for information about a particular location or node of the grid if he wishes to perform his own studies to evaluate the feasibility of the interconnection in a given node. The [deciding authority] uses the TSO studies for its decision.

If the state one proposal fails, the generator can propose alternative connection points or request information on the grid reinforcement costs necessary to eliminate the restrictions. If the developer is willing to pay for these reinforcements, while advancing to stage two, he must pay upfront for 20 percent of these costs.

Commissioning Phase

Two months before the planned interconnection date, the generator must provide the TSO with a test program and the dates for first interconnection and start of commercial operation. Generators must conduct specific tests taking into account the expected absorption/supply of active and reactive power. The generator must also provide a single line diagram of the installation, including ancillary services. He must provide updated information on the installation according to P.O. 9 of REE. P.O. 9 asks for information necessary for real time operations, so along with standard generator characteristics it includes information on control systems such as islanding ability. The information to be supplied varies with the generation technology.

The TSO must plan the commissioning date of the interconnection facility, taking into account the necessary outages and their effect on network security. Once a date is established, the TSO is responsible for scheduling a meeting with the generator where the following aspects will be clarified with the relevant stakeholders:

- Necessary outages
- Network situation before commissioning of the generator
- List of tests and actions associated to each phase of the commissioning along with verifications
- Network situation after generator commissioning is finished
- Intermediate configurations during the commissioning stage
- Future generation operating conditions
- Impact of the new generator on network black-start and recovery plans

The relevant studies are made by the TSO so there is no need to validate modeling from the generator. However, in the public documents there is no reference to network model validation methodology. It seems the TSO does not have to prove the validity of his models. If there is non-compliance the generator cannot begin commercial operation and is given the opportunity to correct the problems and repeat the tests. The process will happen as many times as necessary until there is compliance with all aspects demanded by the TSO.

Connection Process to Distribution Network in Spain

The special system's connection process to the installation network has six phases (excluding Project Execution), ending with the invoicing process, as shown in Figure 20:

Figure 20: DG Connection Process

The phases of this process differ depending on whether the installation is photovoltaic or another type (wind, solar thermal, small-scale hydro, cogeneration, biomass, or waste).

RES Installations (Non-solar)

For installations contemplated by the special regime that are not photovoltaic, the phases for connecting to the network are as follows:

Request by the Developer

The developer formalizes a guarantee to the Autonomous Community for €20/kW. The developer must request a connection point from the distributor. The distributor issues a report that includes the connection point requirements. The developer notifies the distributor that it is in compliance with the report and connection point requirements.

Approval of the Project by the Autonomous Community

The developer, when applicable, requests administrative authorization and presents the basic project and execution program. The developer will present a copy of the request for administrative authorization and proof of presentation to the Autonomous Community of the basic project and execution program. The developer grants administrative authorization and approval of the project.

Connection to the Network

The distribution company formalizes a technical contract with the producer and issues a certificate of reading if the installation's power is less than or equal to 450 kW, as well as a certificate of access and connection. If the DG is larger than 450 kW, their meters and interconnection must be certified by the TSO.

Contracting

If the connection occurs at the HV level the developer must formalize the supply contract with an authorized commercialization company. For a LV connection, the developer must contact the distributor to formalize the supply contract. The developer signs the supply contract. The terms of this contract are regulated by the Ministry of Industry and apply for at least five years. The contract has to specify the following:

- Location of metering devices and connection point to the network. It also has to specify the characteristic of control, protection, and metering devices
- Estimations of the expected volume of sold energy and, when applicable, energy consumption, specifying maximum demand and production
- Possible causes for modification and cancellation of the contract
- Technical aspects of the interconnection, such as circumstances in which the Distribution Company will not be able to absorb the energy production
- Economic terms and conditions, which includes the chosen alternative for selling the energy and the agreement on how to remunerate the DG for production of reactive power (if applicable). The distribution company must pay within 30 days of receiving of each bill.

The distribution company must sign the contract in the three months after the agreement on the location and technical conditions, even if the RES generator does not supply energy. The distribution company has to pay RES all the items corresponding to the special regime (premiums, economic incentives, etc.) in the 30 days after it receives the bill. If the distribution company does not pay during this period, it has to pay a penalty of 1.5 percent of the bill.

Installation of Metering Equipment

Metering equipment may be owned by either the developer or the distributor. Some distributors provide the option of renting this equipment (except equipment connected to LV installations with a power exceeding 15kW). Installations having a power greater than 15kW are required to be equipped with remote control metering equipment, but remote control is not required. The distributor inspects and seals the metering equipment. The developer provides a copy of the definitive inscription in the Autonomous Community's Registry of the Special System.

Photovoltaic Installations

Below is summary of the requirements and procedures that must be compliance with by producers of the special system in the event of photovoltaic installations.

Request by the Developer

The developer, when the installation is based on the ground, must formalize a guarantee to the Autonomous Community for€500kW (excluding roof-based installations). The developer asks distributor for a connection point. The distributor issues a report with the connection point requirements. The developer notifies the distributor of its compliance with the report and connection point requirements.

Approval of the Project by the Autonomous Community

The developer, when applicable, will request administrative authorization from the Autonomous Community and present the basic project and execution program. The developer will present the distributor a copy of the request for administrative authorization and proof of the presentation. Lastly, the developer will present the distributor with the administrative authorization and project approval granted by the Autonomous Community.

Connection to the Network

The distribution company will issue a connection contract and certificate of meter reading, if the installation's power is up to 450 kW, and a certificate of access and connection. If the DG is larger than 450 kW, their meters and interconnection must be certified by the TSO.

Contracting

In the case of high-voltage connections, the developer must contact an authorized selling company in order to sign the supply contract. In the case of a LV connection, the developer must contact the distributor to formalize a supply contract. The developer signs the supply contract. The terms and conditions of this contract are similar to the ones applicable for other RES.

Installation of Metering Equipment

Metering equipment may be owned by either the developer or the distributor. Some distributors provide the option of renting this equipment (except equipment connected to LV installations with a larger than 15kW). Installations larger than 15kW are required to be equipped with remote control meter reading equipment (telemetering). The terms and conditions of the contract are similar to the ones applicable to other RES.

Main Reasons for Success of RES in Spain

There have been two steps in the promotion of RES in Spain. The second step has just begun, so it is only possible at this time to judge the first step’s results (RD 2818/1998). In this initial scheme, special regime generators had fewer technical obligations, had the right of selling all their production, and were economically supported through a feed-in-tariff or market price plus a premium. The results depended on the economic support level and on the administrative authorization process.

The results show that expansion of wind has been a success in terms of installed capacity. However, there are some regions of Spain where wind development has been completely blocked until an official wind plan has been developed, while other regions have just begun to give the mandatory authorizations to promoters.

There are around 30,000 MW of additional wind installed capacity in different stages of registration as special regimes. This does not mean that all of them will be built and operated, but it gives an idea of the strength of wind expansion in Spain. It appears that only administrative barriers or technical limits of integration can stop the expansion of wind resources on the Spanish grid.

On the other hand, the level of development to date of other RES technologies is still not considered satisfactory by the government, and it is unlikely that proposed targets for those categories will be reached.

Remaining Barriers to Development of DG in Spain

The main stakeholders (renewable developers and Distribution System Operators) have identified several barriers to full development of renewable technologies in Spain as follows:

- Technical requirements:
  - Connection standards (particularly short circuit limits) are viewed as conservative by promoters, and in many cases require them to connect at a higher voltage than originally planned.
  - Monitoring and communication devices may represent a barrier in case of trying to access the market.
  - In the case of wind generator, its ability to cope with voltage/frequency dips without tripping may become essential.
  - Network capacity for delivery of renewable energy: Renewable resources, especially wind parks, are not always situated near the electrical network and may require construction of high voltage lines., The approval process for line construction can be slow due to environmental issues and delays in construction may be as long as five years.
  - Distribution System Operators (DSOs) perceive DG as an added complexity in their networks that do not provide any economic benefits and bring additional operational and planning problems such as: grid operation and maintenance personnel safety; impact on grid operation regarding short circuit levels, voltage control, and interruptions due to failures; impact on network reinforcements to accommodate new DG connections; unpredictable energy deviations with respect the scheduled program; and the difficulty to maintain certain power factors at consumption points on the transmission grid.
  - A major revision of distribution system regulations is expected in Spain. Under these changes stakeholders expect that DG expansion will need to be considered as a more integrated component of the overall grid planning process. The revised regulation

should provide DSOs with option(s) to recover the cost of network reinforcements due to the connection of DG. Significant connection charges are currently imposed on DG projects in Spain, which creates issues for renewable expansion.

- A distribution congestion management procedure to dispatch DG in case of network congestion should be designed and implemented.
- The definition of DSOs with associated functions should be clarified in Spain, in line with the Directive 2003/54/EC. Operational procedures for DSOs should be clearly stated, as it was done for the TSO.
- Administrative processes: A developer has to negotiate with the state ministry, the regional authority, the municipality, the electrical company and, in case of accessing the market, with the market operator and system operator as well. Due to the complexity of this process, experience shows that building a wind park may take five years.
- Economic support: As the premium is calculated ex-ante and decided by the regulator, not by the market, the fixed amount may be insufficient to recover renewable project costs. Conversely, in the case of wind power, the premium may be too high, which could become a barrier to renewable development in the future if all the economic resources have been dedicated to the first wind parks.

Impact of DG on Spain's Network Infrastructure

The Spanish electric power grid is designed to meet reliability requirements at all voltage levels. This is reflected in the established grid structures at the various grid levels and provides a solid basis for the grid integration of renewable energy sources. Therefore, no fundamental changes in the topology of the Spanish grid have been required to date due to the interconnection of renewable energy sources. Changes have been limited to local/specific reinforcements in the distribution grid, mainly associated to the growing of solar PV and the need to maintain voltage within acceptable boundaries. The way Spanish law (RD 436/2004 and stated again in the RD 661/2007) is written shifts the biggest renewable generators (tenths of a MW) to higher voltage grids where they do not cause problems. The restrictions foreseen in the current Spanish law may be reviewed in the future, as there is more experience with interconnection of renewable generation in MV and LV. This was not an issue in the last decade where most of the renewable energy development was driven by large wind farms connected to high voltage. Although setting up such limits can be seen as too restrictive (it is seen that way by promoters), for a country with ambitious emission reduction targets such as Spain they have produced good results enabling massive integration of renewable energy with minimum disturbance to the grid, at least at the planning level.

From a technical perspective, in order to be able to continue integrating large amounts of DG, Spain is establishing national and regional control centers for renewables with mandatory monitoring and control coupled while establishing incentives for curtailing wind. Providing frequency regulation by spilling wind (and other intermittent resources) provides operational flexibility to maximize renewable energy production while maintaining reliability. These centers include state-of-the-art renewable forecasting technology, including ramp-rate prediction software. Although Spain’s wind forecasting technology is world class, the discipline needs substantially more research and development to optimally operate a power system with substantial penetration of renewables. At the same time Grid Codes are being updated and will require all renewable generators over a certain size to provide zero voltage ride-through capability and mandatory Volt/VAR control capability to support the system. Volt/VAR capability in wind power generation can be provided by the use of power electronic interfaces on wind turbine generators such as doubly-fed induction generators or advanced inverters on PV systems.

SECTION 3:
Comparison to Grid Infrastructure in California

Like the European power grid, the California grid is a three-phase alternating current (AC) grid. The California grid, like most of North America, is operated at a frequency of 60 Hertz at all voltage levels. However, the difference between the 60 Hertz AC system in California and 50 Hertz in Europe has no impact on renewable integration. In addition, the California grid has two major high-voltage direct current (HVDC) 500 kV transmission lines that are closely integrated with the AC system and interconnect California to the Pacific Northwest and Rocky Mountain regions. Likewise, in KEMA's opinion, the presence of these HVDC lines has no direct bearing on integration of renewables internal to California.

Table 6 compares common voltage ranges found in the California electric grid to the corresponding ranges in used in Germany and Spain, and shows that there is a close correlation at all of the network levels.

Table 6: Comparison of AC Voltage Levels in California and Europe (Phase-to-Phase Voltages)

Network Level	Germany	Spain	California
Extra-high voltage	380 kV, 220 kV	400 kV, 220 kV	500 kV, 345 kV, 287 kV, 230 kV, 220 kV
High voltage	110 kV	132 kV, 110 kV 66 kV, 45 kV	138 kV, 115 kV, 69 kV, 66 kV
Medium voltage	30 kV, 20 kV, 15 kV, 10 kV	30 kV, 20 kV, 15 kV, 13.2 kV, 11 kV	34.5 kV, 13.8 kV, 12.47 kV, 4.8 kV, 4 kV
Low voltage	400 V	400 V	480 V, 208 V

This comparison clearly shows much similarity between the network voltage ranges in the three regions. Although California's 230 kV and 220 kV voltages are grouped with the Extra-high voltage (EHV) network classification in Table 7 they are not generally considered EHV voltages by U.S. standards. The functions of the 60 kV through 138 kV systems in California can either be transmission or distribution, depending on the facility owner.[20] Similarly, although 34.5 kV is shown in the MV distribution category, the Los Angeles Department of Water and Power operates an extensive 34.5 kV subtransmission system. Regardless of the nomenclature used by

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20 SDG&E's 138 kV and 69 kV systems, and much of PG&E's 115 kV system, are considered transmission and are under the California ISO's operational control. SCE's 66 kV and 115 kV systems are considered distribution, and not under California ISO control.

California utilities for 34.5 kV to 230 kV systems, their electrical *function* is similar to the European HV and MV categories.

However, one difference worth noting in Table 6 is the apparent skewing of MV distribution voltages the EU toward in the 15-30 kV range as compared to California where the predominate distribution voltages are in the 12-15 kV range, plus a substantial amount of older distribution load in the state which is still served by facilities at 2 kV to5 kV. This could have a direct impact on DG integration, since the power delivery capability of any size electrical conductor varies proportionally with the operating voltage. Therefore, if a conductor is capable of carrying 6 MW at 10 kV, the same conductor could carry 12 MW at 20 kV. However, making such an increase in the operating voltage of an existing distribution grid would entail virtually a complete rebuild of the associated infrastructure (substations, pole lines, underground cables, and primary to secondary transformers, etc.) It can be assumed that the costs of such a wholesale conversion would be prohibitive, except perhaps in the case of an antiquated distribution grid that is experiencing high failure rates and needs to be replaced. In most cases a more cost effective approach to integrating DG on such lower voltage distribution systems would be to use the same planning options discussed in Section 1 relative to the German system. Again, each local system would need to be studied to determine the best planning option.

Another difference that is not obvious from Table 6 is the absence of LV distribution networks in California. While these are commonly used in the EU for supply to residential customers, this topology is not in common use in California.[21] In Germany and Spain, residential and small commercial customers in urban areas are served directly from meshed, three-phase 400V networks. In California it is common practice to use MV circuits operated radially to cover both urban and rural areas. These MV circuits are often connected to adjacent MV circuits via normally open switches to provide alternative sources of supply in the case of faults or maintenance on an MV circuit. In fact, any one MV circuit might have normally-open ties to several adjacent MV circuits in this manner. MV circuits in California serve distribution transformers that step down the voltage from MV to LV. The resulting LV system in California (typically referred to as secondary voltage) only distributes to power to relatively few customers (e.g., one to 20 customers) near the MV to LV transformer – in contrast to many hundreds (or thousands) of customers on a typical LV network in Germany. The same practice is followed in sparsely populated rural areas in California, where an MV circuit is used to cover the longer distance between customers, and the LV (secondary) wiring is present only for a few spans and maybe only for one customer.

Some examples of fully meshed LV networks, like those in Europe, exist in other parts of the U.S.—particularly in large urban settings where the LV supply system originally evolved along

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[21] An exception to this in California is the occasional use of LV spot networks (e.g., 240 volts) for supply of localized customer load centers in urban areas (e.g., selected office complexes and shopping malls), but these are relatively limited in scale compared to the widespread LV networks found in Europe. Larger commercial customers and smaller industrial customers in Europe are typically served from MV distribution systems.

this model (e.g., New York City and Boston). Connecting DG to fully meshed networks can be problematic, partially because such networks are designed to prevent reverse power flow through the MV/LV transformers. Industry experts are engaged in developing standards and practices that would allow for DG connection to these LV networks. Obviously, the general absence of fully meshed LV networks in California renders this a moot point for DG integration in the state.

Another difference between distribution grids in California and Germany is the more predominant use of a three-phase circuit configuration throughout German distribution systems versus California. The common practice in California is to utilize a three-phase configuration on the main trunk lines leaving distribution substations, but switch to a single-phase or double-phase configuration for many smaller downstream branches. A potential impact of this design difference is that if renewable DG projects are added on single-phase or double-phase distribution branches in California, it may be more difficult for utility system planners to balance loading between all three of the phases on the main feeders and substations. This problem seems less likely to occur when all of the distribution system is built with a three-phase configuration. If a significant imbalance in loading exists between phases it could, under worst case conditions, accelerate the need for reconductoring of a feeder. However, a number of other lower cost options such as transferring customer loads between phases can typically be used to rebalance loading on the main feeder. Therefore, KEMA concludes that this difference in distribution system design between California and the EU should have a negligible effect on DG integration.

There also appears to be some minor differences in network facility grounding practices in Europe compared to California. There are a variety of grounding configurations used for three-phase systems in the industry including grounded-wye, ungrounded-wye, delta, and other variations. Each of these has unique operating and protection implications, and to some extent may also bear on the technical performance a DG facility and its impacts on the network under some operating conditions. In general there appears to be a greater tendency in the EU to build distribution networks with ungrounded configurations more so than in the US. However, the affect of this factor on overall DG integration in the EU vs. California is probably negligible.

Typical network topologies and equipment ratings used for HV and MV distribution grids in Germany and Spain are described in Sections 1 and 2 of this memo. While there are nuances to the topologies and equipment ratings in all three regions (Germany, Spain, and California), they have in common:

- Planning and design of EHV and HV networks to withstand at least single contingencies without interruption of service to customers, loss of generation or system instability
- Planning and design of HV to MV substations with either redundant transformer capacity or a spare transformer that can be energized in the event of a transformer failure

- A tendency to plan and operate MV networks as radial systems, but with the capability to restore service following loss of the primary source by closing a normally-open switching device in either a loop configuration or to an adjacent MV network

The similarity of system voltages shown in Table 6 suggests that the DG interconnection capability of individual distribution grids in both the EU and California should be comparable. While a determination of the acceptable interconnection voltage always must be made on a case-by-case basis except for the smallest DG units, general observations can be made by comparing Tables 1 and 6. Based on KEMA's experience, the DG capacity ranges and corresponding interconnection voltage levels shown in Table 1 are generally comparable to California. For example, it is possible to interconnect DG projects up to about 20 MW in California at many 34.5 kV substations or on an individual 69 kV line. Likewise, DG projects in the range of 5 MW to10 MW could be connected into either a typical 30 kV MV line in Germany or a typical 34.5 kV line in California.[22] The maximum DG project size on a typical 10 kV to15 kV distribution line in either Germany or California is likely to be several megawatts. However, this conclusion only applies for distribution circuits of comparable voltage and would not be valid for comparing say a 12 kV circuit in California versus a 20 kV circuit in the EU (this issue of capacity versus voltage was discussed earlier in this section). Finally, renewable project sizes at HV and EHV voltage levels in Table 1 are also comparable to generation plant sizes interconnected on the HV and EHV grid in California.

However, one aspect of the network infrastructure in Germany that clearly bears on successful integration of DG capacity is the requirement that all DG units above 100 kW must have remote observability and dispatchability by the network operator. While this infrastructure requirement doesn't directly affect the maximum DG capacity that can be integrated at a given location in the network, it clearly impacts the ability of the German grid to accept more total DG capability on a macro level than California. This is due to the ability of the German grid operators to observe the output and redispatch these DG units in real-time when needed for system emergencies. This has clear implications on congestion management and frequency regulation, in contrast to California where only DG facilities above 20 MW would typically be observable in real-time to the grid operator and no automatic curtailment provisions exist at this time for congestion or frequency regulation needs. On the macro level this lack of observability and control poses a serious constraint to the total amount of intermittent renewables that can be integrated into California's grid.

Another aspect of the infrastructure that appears to be different is the typical system protection design at HV/MV distribution substations. Because MV feeders in the U.S. are usually a radial configuration, fault detection and/or overload protection (especially on older feeders) is often provided by simple, non-directional over-current relaying. In such cases, if there is a back-feed

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[22] An exception to this may be if a DG connects to a long 34.5 kV distribution circuit in rural area of California, where the point of common coupling is extremely remote from the source substation. However, similar circumstances could also occur in Germany.

condition due to DG and the magnitude of the backflow exceeds the settings of the over-current relays, they will operate and trip the circuit breaker at the substation de-energizing the feeder. In some cases in the U.S., the distribution substation transformers also have reverse power relays that are intended to prevent back-feed into the transmission system that serves the distribution substations. In such locations, a backflow condition could cause an outage of an entire HV/MV transformer bank or substation. There can also be substation protection designed to avoid circulating current between two transformers operating in parallel the same substation, if they are connected to common high-side and low-side buses. Typically, such protective schemes are used to prevent circulation of reactive power due to differences in tap settings between parallel transformers, but they could also operate due to DG back-feed. Therefore, if and when such scenarios develop in California due to increasing DG deployment, affected portions of the existing substation protection equipment might need to be changed to accommodate back-feed. The simplest change is at the feeder level, where it may be possible to reset older electro-mechanical over-current relays to accommodate backflow or to replace them with newer solid-state relaying that is more flexible. Solid-state relays are already in place on many feeders.

Finally, there appears to be a difference between the U.S. approach and those used in Germany and Spain with respect to certain options available to DG developers and associated grid operator study processes. Under existing grid tariffs in the U.S., an independent power producer (IPP) seeking connection to the transmission grid has the option to simply apply for interconnection to the grid, or can also elect to apply for delivery rights over the grid. If the latter is elected, a bifurcated application and study process results. In the first phase, the required interconnection study only needs to show that there is a plausible system load and dispatch condition for which the IPP's full power output can be reliably fed into the grid. This phase does not explicitly address deliverability from the IPP point of interconnection to any other point(s) on the grid. However, if the IPP also seeks assurance of such delivery capability, a second phase of study is required. In this second phase a range of stressed system load and dispatch conditions are typically studied and additional grid upgrade requirements may be determined. An IPP seeking such deliverability rights is responsible for the up-front capital costs of such grid deliverability upgrades, but may be eligible for a refund of such capital contributions from the grid owner after the IPP project achieves commercial operation. The basic interconnection study process used for DG units in the German and Spanish grids seems similar to the two-phase study process that is only used in the U.S. if an IPP applies for interconnection plus deliverability. However, for IPPs that only seek interconnection, it appears the U.S. study process is narrower in scope than the planning process in Germany and Spain. If so, it clearly has implications regarding the likelihood of dispatch constraints for such projects in the U.S.

SECTION 4:
Summary of Key Lessons Learned

The impacts of renewable DG integration on the distribution grid and the choice of appropriate counter-measures depend heavily on regional and locational aspects such as load density, the type and amount of DG capacity per region/substation/circuit/location, the original grid utilization conditions, and other factors. Given these many variables and interdependencies, we must be careful in deriving conclusions regarding the impacts of distribution infrastructure on DG integration in Europe versus California. Even so, based on KEMA's review of the most common DG grid characteristics and integration issues, options and countermeasures in Germany and Spain the following conclusions can be made in regard to infrastructure impacts on DG integration in California versus Germany and Spain:

- Differences in the basic distribution infrastructure design between Germany, Spain, and California do not appear to be a major factor in how much DG can be integrated into the respective systems, with one important exception – the requirement under German grid codes that all DG projects above 100 kW must have telemetry which provides the TSO with both visibility and remote control of these units. In Spain, this type of telemetry is only required on DG units above 10 MW. In California, remote metering and/or telemetry requirements exist for projects that elect to execute a participating generator agreement (PGA) with the California ISO. This PGA requires that all intermittent renewable projects of 1 MW or greater are required to have telemetry that allows the ISO to see unit status and output level. Other types of participating generators that are 10 MW or larger must also have telemetry. However, the California ISO's agreements with DGs normally do not include remote control of DG dispatch, but in some cases aggregators may contract with various DGs to create a resource portfolio for bidding into theCalifornia ISO's ancillary service market.
- Grid operators in Germany and Spain have not changed the basic configurations of their distribution systems to allow for greater penetration of renewable DG. The types of grid upgrades considered by grid planners and operators for integrating DG projects in Germany and Spain are comparable to the options employed by grid planners and operators in California. However, there are differences in how the cost is assigned for such upgrades compared to California. In all three countries the connection option selected may impact the costs borne by the DG developer (e.g., such as the cost to construct a longer gen-tie lead to an upstream substation). Significant connection charges are currently imposed on DG projects in Spain, which creates an impediment to renewable expansion. However, pending changes in Spanish law could socialize more of these costs. Similar cost allocation issues exist in California.
- To date, grid operators in Germany and Spain have not utilized ancillary technologies (i.e. battery storage, flywheels, etc.) to integrate DG on the distribution system. However, there is significant reliance on existing pumped-hydro storage plants on the

EHV grid level in Germany in order to balance the intermittency of wind generation for regulation and frequency control.

- Grid planners and operators in Germany and Spain do not intentionally ignore the consequences of greater penetration of DG in their distribution grids or willingly take additional risks compared to those taken by DG operators in California. The technical performance requirements specified in the German grid codes that apply to connection of DG projects are at least as rigorous as those in California.
- Grid planners in Germany and Spain address back-feed conditions from the MV distribution grids to the HV distribution grids due to DG integration by considering the same range of planning options as used in California. However, they are obligated under current laws in Germany and Spain to identify a reliable service plan to connect any DG project, consistent with the grid-code technical specifications. The cost of the required grid upgrades is then socialized to a large extent, especially in Germany. The DG-connection planning process in California appears to be less compulsory and more subject to negotiation over the scope of the required grid upgrades and the allocation of cost responsibilities between the grid operator and DG provider.
- Once a DG project has been connected to the grid, transmission and distribution operators in Germany and Spain have the authority to re-dispatch DG units to mitigate back-feed issues and various other network security concerns. Such DG re-dispatch authority is not generally available to grid operators in California, unless it has been packaged (e.g., aggregated) by an ancillary service provider and made available through bid/contract mechanisms to the grid operator. Even so, the grid rules in Germany and Spain require grid operators to exhaust other dispatch options before curtailing renewables.
- Though the cost of grid upgrades for DG deliverability are largely subsidized in Germany and Spain, the capital investment strategy in both countries to date has been to minimize the incremental distribution grid upgrades for DG integration. This is similar to the situation in California. However, there is growing pressure in Germany at this time to consider changing this strategy. Draft study results by German industry based on a government forecast of 52 GW of potential renewable generation expansion by 2020 indicates that €13 billion to €27 billion of capital upgrades may be needed on the German HV and MV distribution grids to reliably integrate this level of renewables. This figure excludes EHV grid expansion costs that may also be needed for large scale wind farm integration in Germany. However, it may be some time before the results of national policy debate on these options will be known.
- Accomodating back-flow conditions caused by DG integration does not appear to require sweeping changes to California's basic distribution infrastructure . However, a number of secondary measures will be required such as adding telemetering for all DG units greater than a certain size (e.g., 100 kW), replacing substation relaying to accomodate back-feed, reconfiguring voltage control appartus and controls on distribution feeders, and deploying appropriate smart-grid technologies on California's distribution and transmission grids. As renewable levels continue to increase, the

installation of energy storage devices on the transmission and distribution system—and in some cases at DG sites—may become essential to modulate the affects of the intermittent resources and provide acceptable levels of balancing area frequency control.

- It is possible that selective changes to rate-making design and capital cost allocation policies in California related to integration of DG into the distribution and transmission grids could incentivize a higher rate of DG growth in California.
- Similarly, it would be beneficial to explore the range of DG scheduling/redispatch/curtailment options that could be implemented in DG interconnection agreements, tariffs and market models in California to increase participation by DG producers in supporting the operational reliability needs of the distribution and transmission grids. Regulators can help to steer the direction of such options through policies regarding equitable compensation for curtailments, lost opportunity costs, and so forth.