Distributed Generation in Europe: the European Regulatory Framework and the Evolution of the Distribution Grids towards Smart Grids

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***Abstract* – The European Union (EU) Regulatory Framework concerning Distributed Generation (DG) may have a decisive impact on the development of European distribution systems towards Smart Grids. To address this issue, the present paper firstly reviews this Regulatory Framework. Secondly, focus is on the current state of penetration of DG technologies deployed in the EU Member States, comparing then the level of penetration of distributed generation with the existing number of Distribution System Operators (DSO). Finally, considering that different elements can be included when referring to Smart Grids as a concept, several architectures do exist, having some discrepancies between themselves. Two representative case studies of two different Smart Grid architectures, INOVGRID (Portugal) and Amsterdam Smart City (Netherlands) are presented to show the potential impact that Smart Grids can have in the distribution systems.**

***Index Terms*—Distributed Generation, Distribution Networks, European Energy Regulatory Framework, Smart Grids.**

I. Introduction

The European electric power sector is undergoing several important developments in generation, transmission, distribution and utilization, responding to the objectives set by the European Union (EU) to guide its energy policy: environmental sustainability, security of supply and competitiveness [1]-[9].

Given the average growth of electric consumption in the EU of about 1.7% per year since 1990, forecasted to continue at 1.5% until the year of 2020 [10], it is reasonable that the characteristics of the electric European system are bound to be subject to profound changes.

Some of those changes are already apparent. This is the case, particularly, for power distribution systems, where several EU countries report a steady increase in the installation of small and medium generation systems (with capacities achieving some tenths of MW), usually placed close to the final user , i.e. Distributed Generation (DG).

In the absence of a global recognized definition of DG, the present article considers it as electric power generation connected to the distribution networks, according to the relevant European legislation [1]. In general, DG comprises units based on Renewable Energy Sources (RES) like wind turbines, photovoltaic panels, hydraulic micro turbines and also generators of non-renewable sources like gas micro turbines, diesel engines and fuel cells, which are used for the combined production of electricity and heating (cogeneration or combined heat and power, CHP).

A large penetration of DG technologies within the distribution networks, on one hand, has the potential to reshape the lower voltage grids towards new architectures displaying reduced power losses and improved system operation features. On the other hand, the various stages leading to a pervasive deployment of DG technologies have to be carefully monitored and evaluated to understand the types and levels of impact on the distribution grids.

The DG dissemination in the EU is driven by the EU's targets of attaining a 20% share of the energy consumed, produced by RES, and reducing by 20% (compared to 1990 values) the emissions of greenhouse gas and the energy consumption by the year of 2020 [5]-[7]. The DG penetration is also indirectly encouraged by the social and environmental opposition to the construction of large-sized power plants and high-capacity transmission infrastructures.

Nevertheless, the expansion of the penetration of DG in the European distribution networks raises several questions at both the technical and the regulatory level. Distribution systems were usually, not designed to operate in the presence of several types of generation connected to them. To obtain a

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successful integration of DG units, it is fundamental to maintain the reliability and the continuity of the system, given the growing influence of this technology.

Also large-scale power plants based on renewables are entering the system, like large wind farms and solar installations. This has especially a large impact on the transmission grids. In the nowadays context of change and evolution, the realization of an integrated European electric grid, flexible and with the capacity of absorbing a large amount of RES and DG, constitutes then a crucial challenge for the EU.

II. REGULATORY ISSUES

The DG is considered in several European Directives that are either concentrated on the technical, economic, and regulatory issues of the electric market (whose main ones are described in Fig. 1) or on the European Strategic Energy Technology Plan (SET-Plan) that promotes the up-take of low-carbon energy technologies.

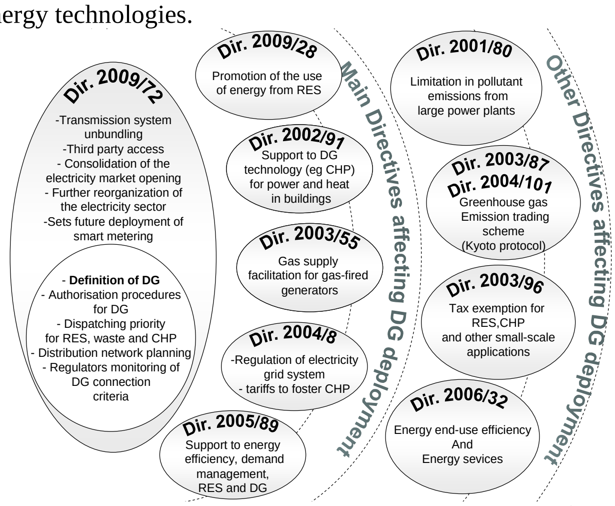


Fig 1 –European Directives with direct impact in the development of DG

A stepping stone of this regulatory framework is the Directive 2009/72/EC [1], part of the Third Electricity and Gas Package, and focusing upon the common rules for the internal market in electricity. It may be considered the principal act of the EU concerning DG, presenting a definition of DG as “generation plants connected to the distribution system”, and sets the application of the principle of proportionality in the authorization procedures for its connection.

Furthermore, it regulates a securing priority in the deployment of DG based on renewable sources and cogeneration systems, draws the attention to the need of an optimal development of the distribution network, and for the DSO to operate, to maintain and to develop a “secure, reliable and efficient electricity distribution system”.

This Directive introduces a number of new aspects when compared to the one repealed by it. In particular, in the transmission networks, a higher grade of separation is achieved between the different players, as it proposes the separation of the ownership (or the subordination to the management) of the activity of transmission and the ones of production, distribution and supply.

Finally, it sets that, in the Member States (MS) where a positive assessment of the smart metering is made by 2012, 80% of the consumers should be equipped with this technology by 2020.

The Directives 2004/8/EC [2] and 2009/28/EC [3] address, respectively, the promotion of CHP and of RES, with evident reflexes in the diffusion of the respective DG technologies.

Both concerning electric grids and addressing RES electricity generation, the first one fosters the access to the grid system of electricity produced from high-efficiency CHP from small scale and micro units.

The second one, reinforces the concepts of integration in the network, discriminatory connections and priority access, whereas setting mandatory (the 20/20/20) objectives to the shares of RES in the energetic consumption and on transport (10 %).

Setting differentiated targets per MS for the RES shares, some of them quite ambitious, defines also the need of the MS to elaborate National Renewable energy action plans.

Moreover, this Directive 2009/28/EC considers the need of developing the transmission and the distribution grid infrastructure, the energy efficiency, the intelligent networks, the storage facilities and the overall electricity system. This is made in order to allow a secure operation of the electricity system, as it welcomes the further development of RES electricity production, particularly from renewable DG, and the development of international connections.

The Directive 2006/32/EC [4] is focused on energy efficiency, and drives the MS to include measures, in its public sector, to improve and promote energy efficiency and energy services. Furthermore, it calls for achieving an indicative energy saving target, initially set to 9% (by 2016) and then raised to 20% (by 2020) by a subsequent Communication [9].

To achieve the goal of moving “Towards a low carbon future”, the EU delineated a strategy in the SET-Plan [5] [6]. This plan, defined as the technology pillar of the EU energy and climate policy, will be implemented via the European Industrial Initiatives (European wind initiative, solar Europe initiative, European electricity grid initiative, sustainable bio-energy Europe initiative, European CO2 capture, transport and storage initiative, sustainable nuclear fission initiative, and Joint Technology Initiative (JTI) on fuel cells and hydrogen), the Initiative on Energy Efficiency/Smart Cities and the European Energy Research Alliance.

Among the key technologic challenges set for the next ten years, some of them have a higher impact in the current context. One of those is the creation of a European grid integrated and flexible, capable of assimilating a high penetration of RES and DG. Within this Industrial Initiative it is anticipated the deployment of up to 20 projects concerning the ability to respond to three interrelated challenges – creating a real internal market, integrating a massive increase of intermittent energy sources, and managing complex interactions between suppliers and customers. It sets a goal that, by 2020, 50% of networks in Europe would enable the seamless integration of renewables and operate along 'smart' principles, effectively matching supply and demand and supporting the internal market for the benefit of citizens.

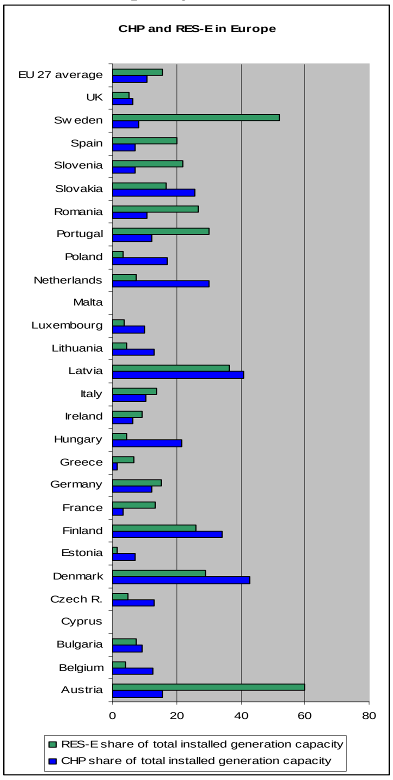
Another challenge that will affect the DG evolution roadmap is an increased availability on the market systems and equipment for more efficient energy conversion for use in buildings, transport and industry, this mostly due to the Smart Cities Initiative.

III. DISTRIBUTED GENERATION IN THE EU-27

In Europe, the increasing tendency for a greater share from RES follows a trend started in 1990, which meant that in the period from 1990 until 2006, the energy dependency from this kind of technologies almost doubled in the EU-27 [11].

However, the impact of both RES and CHP in the EU-27 MS is not uniform as one can see from Fig. 2, where are displayed the CHP and RES for electricity (RES-E) capacity shares in 2007. The averages for the EU-27 are of 15.6% and 10.9%, respectively.

Note, however, that the RES-E figures include large hydro and wind plants, which cannot generally be considered as DG. Likewise, not all CHP capacity refers to distributed CHP.



(Data source: Eurostat)

Fig 2 – CHP and RES-E percentages for the EU-27 Member States in 2007

Nevertheless, some of the DG technologies are in strong expansion at EU level. This is the case of photovoltaic, a technology that is mostly connected at distribution level.

Table 1 displays the photovoltaic capacity installed in some EU MS during the years of 2007 and 2008[12].

Table 1
Photovoltaic capacity installed in some of the EU-27 MS during 2007 and 2008 (in MWp).

	2007	2008
Spain	590.846	2670.916
Germany	1103.000	1505.000
Italy	70.200	197.300
Czech Republic	3.118	50.329
Portugal	14.454	50.082
Belgium	17.363	49.667
France	12.794	44.496
Total EU-27	1825.553	4592.289

(Data source: Eurobserv-er)

IV. DISTRIBUTED GENERATION AND DISTRIBUTION GRIDS

Gathering accurate and consistent data on DG units installed in networks, unlike for large central generation plants, is very complex. The reasons are multiple and vary throughout the EU: different definitions of DG (e.g. according to the size and type of the network connection), lack of a centralized database and of a communication structure between the DSO and the Transmission System Operators (TSO), the nature geographically dispersed of the DSO and the current limited access of DG to the electric markets [13], [14], [15].

The actual values of the capacity of DG in the several MS of the EU – estimated in relation to the total capacity of installed generation – are reported in the Fig. 3 inside the several bands [16], [17], [18], [19].

Based on the definition of the distributed generation adopted, the decentralized production units linked to the sub transmission or transmission grid are not considered as DG.

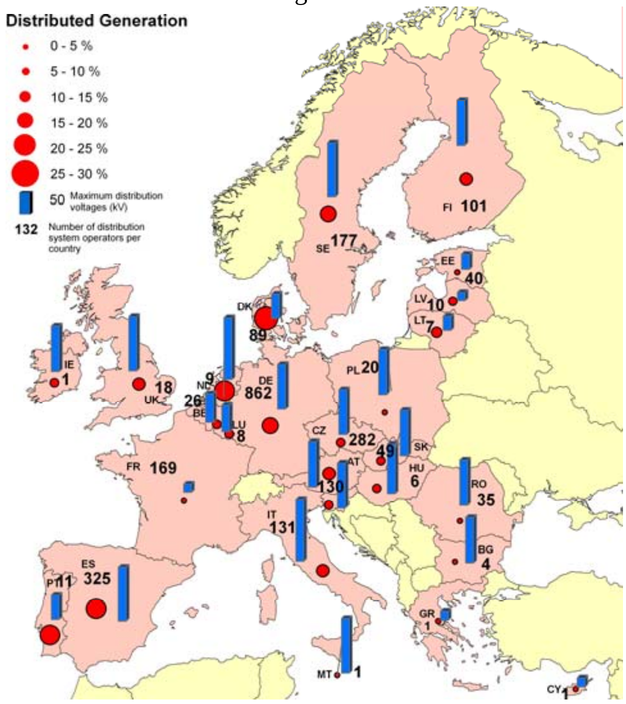


Fig 3 – Number of DSOs and penetration of DG in the EU-27 in 2008

It may be observed that the share of installed DG is, on average, higher in the older Member States of the EU (EU-15) comparably to the new ones (EU-12) [20].

In Fig. 3 it is equally reported the number of DSO operating in the territory of the EU-27 states. It may be noted that in some cases a dominant DSO exists that controls the entire distribution grid, whereas in other states, there are tens or hundreds of DSO, which run their networks on a regional or municipal basis. Those differences are due to historic, geographical, socio-politic and economic reasons. The number of network operators in the distribution is, anyway, in continuous evolution, following the restructuring of the European electricity markets [14].

The unbundling level in most EU-27 MS is still at a quite formal level, but progresses have been made during the year of 2008. The usage of different logos and websites is now more common, some interest exists in developing a corporate culture that goes beyond the legal obligation, and the national regulators have been fostering the functional unbundling [18].

Analyzing the data displayed in Fig 3, it is possible to identify several MS groups that share common characteristics in the context of DG, regrouping them by the share of penetration of DG and classifying them by the maximum level of voltage in the respective distribution networks [21], starting by the lowest.

A. Member States with a low penetration of DG (<10%)

(France, Latvia, Cyprus, Greece, Estonia, Lithuania, Luxembourg, Belgium, Bulgaria, Poland, Romania, Czech Republic, Ireland, Slovakia, Slovenia, Hungary, Malta)

In this group it is inferred a possible direct correlation between the DG penetration rate and the number of DSOs. Indeed, with the exception of France, Czech Republic and Slovakia (where in each case only a few DSOs control large part of the distribution system), all these nations have a low number of DSOs in their territory. This could also be correlated to the incomplete procedure of separation of the electric companies vertically integrated.

B. Member States with an average penetration of DG (10-20%)

(Austria, Germany, Finland, United Kingdom, Sweden, Italy)

This group is the most homogeneous in terms of voltage levels, with a maximum varying between 100 and 150 kV. All these nations – with the exception of the United Kingdom – present a high level of DSOs. However, almost all these countries have dominant distribution operators, excluding again the United Kingdom where the process of liberalization and unbundling has long been effectively completed. The DG share results are more consisting if compared with the previous group, which may be due to more mature solutions concerning the technical and regulatory challenges for DG promotion.

C. Member States with a high penetration of DG (20-30%)

(Portugal, Denmark, Spain, Netherlands)

This forerunner group is quite diversified in terms of geographic dispositions. It seems to prove that, in nations where the technologies of DG have reached a good level of integration in the distribution system, their high percentage is not necessarily the legacy of a high number of DSO. In fact, The Netherlands and Portugal present a reduced number of DSOs in their territory.

V. EVOLUTION OF THE DISTRIBUTION SYSTEMS

Traditionally, the distribution networks have been designed to transfer passively the power from the generation to the load. In this situation, with the power flow that is usually one-way passing through the distribution networks until it reaches the final consumer, the DSO would have neither the possibility nor the need of actively controlling the power flow, differently from the TSO.

However, with the nowadays increasing amount of generators connected to the distribution network, it can be verified that the power may be transferred in the reverse way, from the distribution network to the transmission network.

In general, most of the distribution grids have the ability of connecting a growing number of DG in a short term perspective. Nevertheless, in the medium-long term and with the increasing penetration of DG, these grids must necessarily be subjected to several (sometimes radical) changes, regarding the development and the operation of the network.

The distribution networks traditionally prefer the simplicity of management to the redundancy and are generally characterized by a radial structure (especially at medium-low voltages level) or by a meshed structure with radial operation (especially at medium-high voltages level). The latter structure differ from the first one by the fact that some of the existing connections are normally left open, so that the grids present a radial operation, but have power reserve available quickly in the event of disruption.

The DG increasing penetration may lead to a further meshing of distribution grids – in the structure and/or in the operation – which, equipped of opportunely located protection and control technologies, shall allow a full bidirectional power flow. This would then guarantee a better continuity of service in the event of unavailability of one of the distribution links.

Several aspects must be taken carefully in consideration to evaluate the impact of DG on the distribution networks. Those aspects are related to: network capacity and congestion, losses, short circuit currents, selectivity of the protections, network robustness, voltage profiles, stability of the system, island operation, system reserves and balance, and power quality.

The integration of DG in the electric systems depends also on the effects that its implementation may have, not only in the distribution grid, but also in the upstream transmission grid. In that regard, the effects on steady state and transient operation, on the protections, and on the static security analysis (contingency analysis) must be taken into consideration.

The transition process from the traditional distribution system to architectures similar to those ones of transmission is, as a rule, gradual and might involve several intermediate steps. This process could therefore lead to a traditional approach of simply connected of DG (“fit and forget”), the introduction of several changes/improvements in the systems concerned (grid protection systems, network reinforcement), up to the development of new advanced control strategies

[15].

A. Perspectives of evolution towards Smart Grids

A Smart Grid may be defined as an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies [22].

In the following, some possible developments of the distribution systems are introduced, in the context of the evolution towards smart distribution grids. It must be stressed that these categories (predominantly recalled from [23]) are not universally shared and present also areas of overlap.

1) Active Networks

These networks are considered as the first probable evolution of the nowadays passive distribution systems, stimulated by the connection of an increasing number of micro and small generation units, towards structured systems with an operation similar to the transmission grids. Such transformation implies an appropriate shift of the protection schemes, together with the introduction at different levels of new soft and hard technologies: these can be respectively based on systems of Information and Communication Technology (ICT) and on power electronics controllers such as the distribution-like FACTS (Flexible Alternating Current Transmission System) devices, for a more flexible management of the system.

2) Microgrids

They are a portion of the distribution network (generally LV grids) containing not only microgeneration units, but also energy storage devices and controllable loads. These networks, typically with a total installed capacity ranging near the hundreds of kW to the hundreds of MW, can be managed like a single generator or load equivalent, having the possibility of providing support and services to the networks.

A microgrid, even though it operates predominantly connected to the distribution network, has the ability of automatically disconnect itself (through intentional island operation), in case of faults affecting the upstream network. With sufficient resources of generation and storage it can assure the supply of power to some of the local clients. After the elimination of the fault and restoration of the normal operation of the upstream network, it can be reconnected to the remaining system. In the event of widespread disruption in the upstream network, a series of microgrids could not only feed the local loads, but also actively contribute to the restoration of normal operation conditions (black start) of the main system.

3) Virtual Power Plants

A Virtual Power Plant (VPP) consists of a decentralized management system of the energy produced by small generators and devices of energy storage – not necessarily physically connected to each other – aggregated in order to participate in the energy market and to provide support services to the system. This aggregation is accomplished through an ICT system that create the so-called virtual power plant, that can also be multi-combustible, multi-site and with multi-property.

B. Case studies of evolution towards Smart Grids

However it may appear contrary, the evolution towards Smart Grids is not a future event, as it is already in practice.

In Portugal, the INOVGRID project intends to take advantage of advanced smart metering with bidirectional communication, allowing virtually every consumer equipped with this technology to be a producer of energy, using micro generation, and expecting not only to reduce client energy bills, but also losses and maintenance costs on the grid. It is expected to reach 600.000 consumers in the end of 2011 and the entire continental part of the country by 2017 [24].

Being at the beginning of the first phase of implementation of the Automated Meter Reading, in which in a customer-centric approach, the INOVGRID project intends to promote energy efficiency, providing an added set of tools and services for the liberalized market [25] [26].

In its second phase, Advanced Meter Management, it is foreseen the expansion of its abilities, allowing a further integration of distributed energy resources (DG, storage and demand side management).

In the last phase, it will become a fully operational Smart Grid, with Active Network Management, incorporating intelligence in the network, and upgrading operational efficiency and effectiveness.

In this way the smart metering platform will leverage the Smart Grid concept, namely by exploiting the metering communication infrastructure to support the technical management of the system.

The EU Smart City Initiative, integrated in the SET-Plan, will be taken to 25-30 European cities [5]. This is the case of Amsterdam, in the Netherlands, who intends to connect 200.000 households, one third of the city, in its smart grid by the end of 2011, having as objective cutting 40% of the city GHG emissions by 2025 [27].

For now this initiative has 5 pilot projects addressing 4 different aspects. The first one, Sustainable Living, shall reach a total of 1200 households and implement two systems based on smart metering technologies. One of those systems goes even further using energy control to increase the energy efficiency of 500 households.

The second aspect, Sustainable Mobility, will allow anchored ships to be powered by green energy instead of the boat’s internal diesel generator.

The Sustainable Public Space is focused in a normal commercial street, intending to use electric vehicles for the day to day needs, energy saving lamps for the street lighting system, and smart metering and a glimpse of domotics (through smart plugs) in the establishments.

The Sustainable Working will use an office building to show how the energy efficiency of a sustainable building can be further improved within a smart building, without decreasing both the quality and comfort available.

VI. Conclusions

The impact that the European Regulatory Framework will have on electric grids, particularly on distribution, is of major importance for the future deployment of Smart Grids and in all that may be accomplished through them.

On the European level, the SET-Plan plan has set as targets, by 2020-2025, the increase of the penetration of wind, solar and bio-energy, large scale deployment of smart grids, the maturing of the Generation-IV nuclear and carbon capture and storage technologies with several cities as forerunners towards the evolution to a low carbon technology [6].

The trend of increased DG present in the European distribution systems put the EU MS facing different technical and regulatory challenges, which are mainly linked to factors such as the DG penetration level already reached, the regulatory, technical and operational aspects that characterize the distribution grids and the degree of maturity of the liberalization of the electric sector.

However, with the growing DG penetration, both planning and development of new distribution networks architectures (as Active Network, Microgrid, and Virtual Power Plant) constitute measures of medium-long term necessary for a full integration of DG.

The realization of European electric grids, integrated and flexible, able of promoting a large penetration of the RES and of DG represents one of the most important challenges that the EU will face in the coming years. It is fundamental, to this end, that the development of the DG can be carefully monitored and coordinated in Europe, allowing a gradual evolution of the existing energetic infrastructure and therefore mitigating the risk and critical issues to the security of supply.

Furthermore, a closer and more coordinated interaction between the DSO and the TSO involved is becoming more and more important in the operation and planning of those networks that have an increasing share of DG. Also, some MS that today present a higher penetration of DG may have to address technical and regulatory challenges, due to the saturation of the infrastructure (in terms of congestion and constraints of the network).

On the contrary, the EU MS where there is a low level of penetration of DG possess a remarkable potential for development in this direction. This is due to the fact that these nations have the possibility to plan in advance the future distribution grids, taking advantage of the technical and regulatory experience accumulated by the more forerunner nations and of the infrastructure less engaged by previous DG technologies.

Very important is the need to improve in the future the regulatory framework such that investments costs in the development of the Smart Grids concept can be accepted by the regulators.

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