Distributed generation and the grid integration issues

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1 What is distributed generation?

The term distributed generation is often used to depict a small-scale electricity generation. But what exactly is small-scale electricity generation? Currently, there is no consensus on how the distributed generation should be exactly defined. As shown by the survey conducted by CIRED [1], there is no consensus on the definition of this term [2]. Some countries define distributed generation on the basis of the voltage level, whereas others start from the principle that distributed generation is connected to circuits from which consumer loads are supplied directly. Other countries define distributed generation as having some basic characteristic (for example, using renewables, cogeneration, being non-dispatchable, etc.).

International organizations from the industry try to come up with a definition. The working group of CIGRE [3] devoted to distributed generation defines distributed generation as all generation units with a maximum capacity of 50MW to 100MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched. The IEEE [4], on the other hand, defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system. International Energy Agency, in turn, sees the distributed generation as units producing power on a customer's site or within local distribution utilities, and supplying power directly to the local distribution network. IEA, as opposed to the previous, makes no reference to the generation capacity level.

The task of defining the scope of distributed generation has also been taken by many academics. [6] defines distributed generation as a small source of electric power generation or storage (typically ranging from less than a kW to tens of MW) that is not a part of a large central power system and is located close to the load. [7] in turn defines distributed generation as relatively small generation units of 30MW or less, which are sited at or near customer sites to meet specific customer needs, to support economic operation of the distribution grid, or both.

A very good overview of the different definitions proposed in the literature is given in [8], where the authors conclude that they prefer the definition proposed by [9], which is defining the distributed generation in terms of connection and location rather than in terms of generation capacity. Everyone seems to agree on at least the small-scale generation units connected to the distribution grid to be considered as part of distributed generation. Moreover, generation units installed close to the load or at the customer side of the meter are also commonly identified as distributed generation. This latter criterion partially overlaps with the first, as most of the generation units on customer sites are also connected to the distribution grid. However, the latter might also include somewhat larger generation units, installed on customer sites, but connected to the transmission grid[1]. As these views are also shared by the authors of this report, the term *distributed generation* will be further used to depict an electric power generation source connected directly to the distribution network or on the customer side of the meter.

2 What are the benefits?

In the last decade, the concept of many small scale energy sources dispersed over the grid gain a considerable interest. Most of all, technological innovations and a changing economic and regulatory environment were that main triggers for this interest. International Energy Agency IEA [10] lists five major factors that contribute to this evolution, such as developments in distributed generation technologies, constraints on the construction of new transmission lines, increased customer demand for highly reliable electricity, the electricity market liberalization and concerns about climate change. Especially the last two points seem to offer the most significant benefits, as it is unlikely that distributed generation would be capable of avoiding the development of new transmission lines. At minimum, the grid has to be available as backup supply.

In the liberalized market environment, the distributed generation offers a number of benefits to the market participants. As a rule, customers look for the electricity services best suited for them. Different customers attach different weights to features of electrical energy supply, and distributed generation technologies can help electricity suppliers to supply the type of electricity service they prefer. One of the most interesting features is the flexibility of DG that could allow market participants to respond to changing market conditions, i.e. due to their small sizes and the short construction lead times compared to most types of larger central power plants[2].

2.1. Flexibility in price response

Important aspects of the abovementioned flexibility of distributed generation technologies are operation, size and expandability. Flexible reaction to electrical energy price evolutions can be one of the examples, allowing a DG to serve as a hedge against these price fluctuations. Apparently, using distributed generation for continuous use or for peak shaving is the major driver for the US demand for distributed generation. In Europe, market demand for distributed generation is driven by heat applications, the introduction of renewables and by potential efficiency improvements.

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[1] Large generation units connected on the customer's side are however difficult to classify in view of this definition.

[2] The value of their flexibility is probably understated when economic assessments of distributed generation are made. Recent work based on option value theory suggests that flexible power plants operating during peak periods may be much more profitable than conventional evaluations suggest [11].

2.2. Flexibility in reliability needs

Reliability considerations of the second major driver of US demand for distributed generation is quality of supply or reliability considerations. Reliability problems refer to sustained interruptions in electrical energy supply (outages). The liberalization of energy markets makes customers more aware of the value of reliable electricity supply. In many European countries, the reliability level has been very high, mainly because of high engineering standards. High reliability level implies high investment and maintenance costs for the network and generation infrastructure. Due to the incentives for cost-effectiveness that come from the introduction of competition in generation and from the re-regulation of the network companies, it might be that reliability levels will decrease. However, for some industries, such as chemical, petroleum, refining, paper, metal, telecommunication, a reliable power supply is very important. Such companies may find the reliability of the grid supplied electricity too low and thus be willing to invest in distributed generation units in order to increase their overall reliability of supply.

The IEA recognizes the provision of reliable power as the most important future market niche for distributed generation. Fuel cells and backup systems combined with an UPS (Uninterruptible Power Supply) are identified as the technologies that could provide protection against power interruptions, though it has to be noted that the fuel cell technology is currently not easily commercially available.

2.3. Flexibility in power quality needs

Apart from large voltage drops to near zero (reliability problems), one can also have smaller voltage deviations. The latter deviations are aspects of power quality. Power quality refers to the degree to which power characteristics align with the ideal sinusoidal voltage and current waveform, with current and voltage in balance [11]. Thus, strictly speaking, power quality encompasses reliability. Insufficient power quality can be caused by failures and switching operations in the network (voltage dips and transients) and by network disturbances from loads (flickers, harmonics and phase imbalance).

2.4. Environmental friendliness

Environmental policies or concerns are probably the major driving force for the demand for distributed generation in Europe. Environmental regulations force players in the electricity market to look for cleaner energy- and cost-efficient solutions. Many of the distributed generation technologies are recognized environmentally friendly. Combined Heat and Power (CHP) technology, allowing for portfolio optimization of companies needing both heat and electrical energy, is one of the examples. Compared to separate fossil-fired generation of heat and electricity, CHP generation may result in a primary energy conservation, varying from 10% to 30%, depending on the size (and efficiency) of the cogeneration units. The avoided emissions are in a first approximation similar to the amount of energy saving [12],[13].

Furthermore, as renewable energy sources are by nature small-scale and dispersed over the grid. Installing distributed generation allows the exploitation of cheap fuel opportunities. For example, DG units could burn landfill gasses in the proximity of landfills, or other locally available biomass resources. Most government policies that aim to promote the use of renewables will also result in an increased impact of distributed generation.

2.5. Substitute for grid investments

Distributed generation could serve to bypass for transmission and distribution costs (customers investing in DG) or as a substitute for investments in transmission and distribution capacity. Of course, this is possible only to the extent that alternative primary fuels are locally sufficiently available. Otherwise increased use of distributed generation could result in congestion in other networks, such as the gas transport network.

On-site production could result in cost savings in transmission and distribution of about 30% of electrical energy costs. The smaller the customer size, the larger the share of transmission and distribution costs in the electricity bill (above 40% for households). As such, it is seen as one of the biggest potential drivers for the distributed generation demand.

From the viewpoint of the system operators, distributed generation units can substitute for investments in transmission and distribution capacity. In some cases even, it can even be used as an alternative to connecting a customer to the grid in a 'stand alone' application. Furthermore, locating the generation close to the loads could also contribute to reduced grid losses. The IEA estimates the grid losses reduction potential for 6.8% in the OECD countries leading to cost savings of about 10–15% [6].

3 What are the difficulties?

The question of power quality and distributed generation is not straightforward. On one hand, distributed generation contributes to the improvement of power quality. In the areas where voltage support is difficult, distributed generation offers significant benefits for the voltage profile and power factor corrections. On the other hand, large-scale introduction of decentralized power generating units may lead to instability of the voltage profile. The bi-directional power flows and the complex reactive power management can be problematic and lead to voltage profile fluctuation. Additionally, short-circuits and overloads are supplied by multiple sources, each independently not detecting the anomaly.

3.1. Financial cost

One of the major difficulties in the wide-spread success of DG is the relatively high capital costs per kW installed power compared to large central plants. Moreover, different DG technologies differ from each other in that respect quite significantly, ranging from 1000 €/kW[3] for combustion turbines to over 20,000 €/kW for fuel cells. If these numbers are compare with the capital costs of large centrally managed power plants, 750 €/kW for gas-fired, 1300 €/kW for Integrated Gasification Combined Cycle (IGCC) and 1600 €/kW for nuclear, it can be noticed that the DG technology is quite expensive.

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[3] The prices mentioned are current prices of the commercially available technologies on the existent market and are subject to change with the technological developments.

3.2. Less choice between different (costly) primary fuels

According to the IEA, an increasing share of distributed generation in the installed generation capacity is likely to imply less choice between primary fuels, leading to diversification of primary energy supplies. As the most distributed generation technologies are based on gas, given the current tendency is retained gas-based generation will replace coal-based generation leading the increase of gas dependency. Depending on the share of distributed generation in the total generation capacity, and the extent of the cogeneration, the negative effect of gas dependency could be compensated by the fuel-savings resulting from increased fuel efficiencies and possibly and a lower overall fuel use of the CHP. The sign and size of the total effect is however difficult to estimate.

In general, the primary fuel supply for distributed generation applications will usually be more costly than that for central generation. This is possibly related to economies of scale and market power in the demand for primary energy sources that can be used to obtain lower primary fuel prices.

3.3. Predictability of power output

In liberalized electricity market, each party that wants to get an access to the transmission grid needs to sign a contract with the System Operator. This entity becomes then Access Responsible Party (ARP) or Programme Responsible Party (PRP). Next to the right to access the grid, the ARP is obliged to follow certain rules grouped under the grid code. Next to a number of technical requirements, an ARP is among other obliged to keep the overall equilibrium between generation and the contracted supply by balancing his own injections and withdrawals in the grid. In other words, the power injected in the grid by an ARP needs to be equal to the power withdrawn[4]. Market participants unable to maintain the balance between their injections and withdrawals are penalized. These penalties are not included in the transmission tariffs. On the contrary, each market participant has to bear the consequences of its inability to balance its portfolio.

Clearly, as distributed generators have often difficulties to forecast their power output (heat driven electrical energy generation, or renewables), they are adversely affected by this evolution

3.4. Impacts on power quality

As mentioned in 2.3, the installation and connection of distributed generation units can positively affect the power quality. However, a converse effect could also be noted. DG units are likely to affect the system frequency. As they are often not equipped with a load-frequency control, they will free ride on the efforts of the transmission grid operator or the regulatory body to maintain system frequency. Therefore, connecting a large number of DG units to the grid should be carefully evaluated and planned.

Moreover, the impact on the local voltage level of distributed generation connected to the distribution grid can be significant [2],[9]. Especially raising voltage levels in radial

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[4] Sometimes the power injections need to be corrected for the transmission losses, meaning that an ARP should inject some 3÷4% more than it withdraws.

distribution systems can be seen as one of the main technical connection issues of distributed generation. As this does not have to be a problem in systems facing difficulties of low voltages (DG can have a healing effect on voltage profile), it might lead to an unwanted voltage increase in weakly loaded systems

3.5. Connection issues

In the way the power grid is currently managed, it can be taken as given that the electric power flows from the higher voltage grid to the lower voltage grid. Increased share of distributed generation units may lead to inducing power flows from the low voltage into the medium-voltage grid. This bi-directional power flows asks for different protection schemes at both voltage levels.

Moreover, the added flexibility of DG asks for extra efforts on the grid operation side. As some customers might want to switch to the “island” mode during an outage, they should also meet the requirements for such operation mode. Next to guarantying no power supplied to the grid, they must be able to provide the ancillary services needed. Moreover, once the distribution grid is back into operation, the DG unit must be able to be re-synchronized.

4 Distributed Generation Trends in EU-15

Distributed generation (DG) in Europe consists mainly of wind power and combined heat and power (CHP). The largest installed wind power generation capacities are in Germany, Denmark and Spain. Denmark, Finland and Netherlands have the highest installed CHP capacity (Tuerkucar and Gailey 2003). However, as discussed in the previous section there is no precise definition of DG, and therefore the inclusion of large wind farms in published figures is questionable, especially where they are connected to the network at transmission level voltages or do not serve an onsite load.

Turbines and reciprocating engines fuelled by natural gas and oil are the dominant technologies for distributed generation applications. Microturbines are increasing their shares and fuel cells may have good prospects in the field if cost reductions can be achieved (IEA 2002).

In the EU-15, the percentage of electrical energy produced by CHP-based DG is listed in Figure 1. For the year 2000 CHP accounted for almost 10% of electricity generation in the EU-15 (almost 250 000 GWh from a total of 2 600 998 GWh) (Eurostat). Denmark, followed by the Netherlands, were the leaders in CHP-based electricity production, with almost 53% and 38% respectively, while Greece and Ireland display the smallest figures with a little more than 2% of the total electricity generation. Germany’s CHP electrical output in absolute figures (60.8 TWh) is the highest in Europe.

More than half of the EU-15 CHP-based electricity (145.3 TWh) originated from units installed on industrial sites. Figure 1 shows CHP electricity generation for all EU-15 member states.

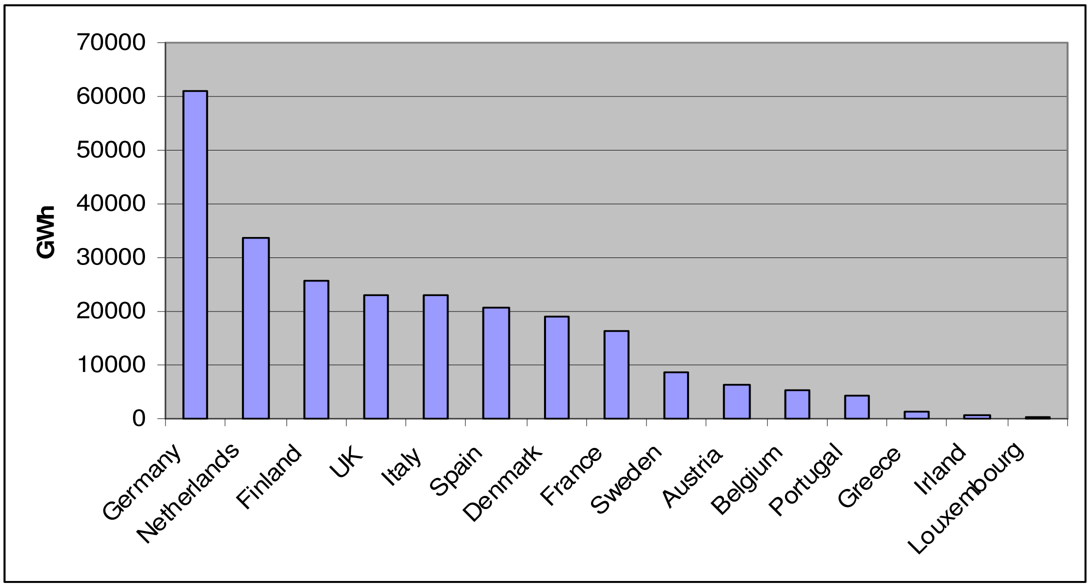

Figure 1. CHP electricity generation for the EU-15 member states in year 2000

Source: Loesoenen 2003, Eurostat

EU-15	Belgium	Denmark	Germany	Greece	Spain	France	Ireland	Italy	Luxembourg	Netherlands	Austria	Portugal	Finland	Sweden	United Kingdom
9.6	6.5	52.6	10.6	2.1	9.2	3.0	2.4	8.3	17.7	37.6	10.4	10.0	36.4	5.9	6.1

Figure 2. CHP generation in year 2000 - % of gross electricity generation

Source: Eurostat

Renewable electricity sources including photovoltaics, wind and small scale hydro (0-10 MW of installed capacity) can often be considered as distributed generation. In Figure 2, electrical energy generated by renewables excluding large scale hydro, are displayed for the years from 2000 to 2003.

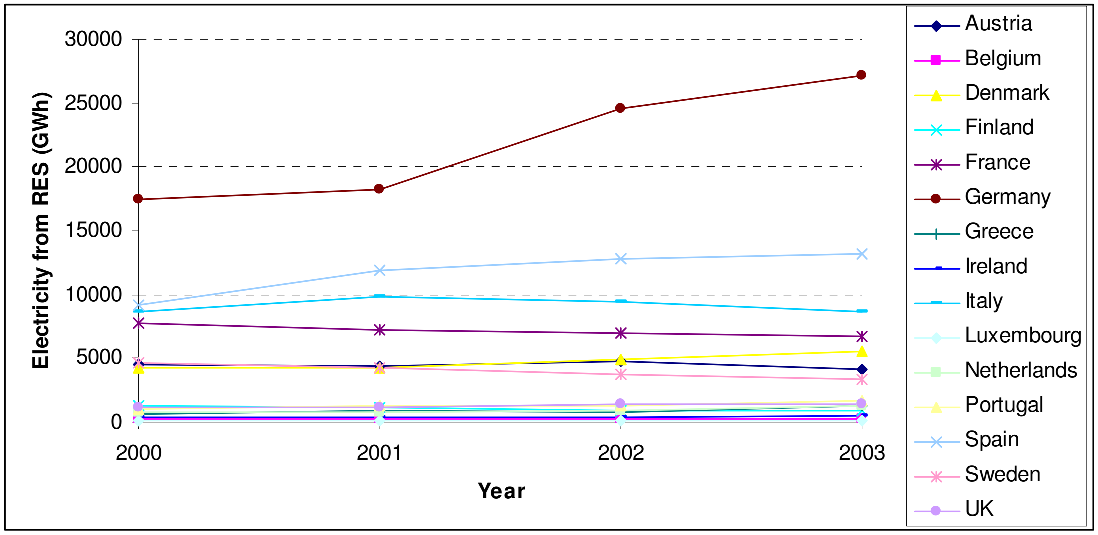

Figure 2. Electricity generated by Renewable Sources, excluding large-scale hydro, in the EU-15 from 2000 to 2003

Source: Eurostat 2005

Distributed generation is generally perceived to be technology that can help to meet environmental goals of the EU, whilst simultaneously being able to provide an economic benefit in many cases and often energy security benefits through primary fuel diversification and improvements in supply reliability. As discussed in this document, a number of issues including market rules, regulation, high gas prices (for CHP) and technical issues continue to impede increased penetration in many States.

Possibly the most important recent changes in EU legislation that affect DG (and particularly CHP) are the co-generation directive and the EU Emissions Trading System (EU-ETS). The co-generation directive seeks to promote co-generation through systematic identification and progressive realisation of the national potential for high efficiency co-generation by creating a common definition and removing barriers. It suggests that national targets be set for co-generation, and ensures Member States analyse their potential for high efficiency generation, apply consistent definitions and report on progress. The EU-ETS could provide more direct financial assistance for CHP and renewables; where installations achieve emissions reduction over their allowance in the various national allocation plans, thus potentially improving the financial motivation for new installations.

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