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Distributed generation: a definition

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Abstract

Distributed generation (DG) is expected to become more important in the future generation system. The current literature, however, does not use a consistent definition of DG. This paper discusses the relevant issues and aims at providing a general definition for distributed power generation in competitive electricity markets. In general, DG can be defined as electric power generation within distribution networks or on the customer side of the network. In addition, the terms distributed resources, distributed capacity and distributed utility are discussed. Network and connection issues of distributed generation are presented, too. © 2001 Elsevier Science S.A. All rights reserved.

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1. Introduction

A study by the *Electric Power Research Institute* (EPRI) indicates that by 2010, 25% of the new generation will be distributed, a study by the *Natural Gas Foundation* concluded that this figure could be as high as 30% [1]. The *European Renewable Energy Study* (TERES), commissioned by the *European Union* (EU) to examine the feasibility of EU CO_2-reduction goals and the EU renewable energy targets, found that around 60% of the renewable energy potential that can be utilised until 2010 can be categorised as decentralised power sources [2].

The definitions for distributed generation (DG) used in the literature, however, are not consistent. This paper presents a discussion of the relevant aspects of DG and provides the required definitions.

2. Background of definition

Distributed generation is a new approach in the electricity industry and as the analysis of the relevant literature has shown there is no generally accepted definition of distributed generation yet (see particular [35]).

In the literature, a large number of terms and definitions is used in relation to distributed generation.

For example, Anglo-American countries often use the term ‘embedded generation’, North American countries the term ‘dispersed generation’, and in Europe and parts of Asia, the term ‘decentralised generation’ is applied for the same type of generation.

In addition, in regards to the rating of distributed generation power units, the following different definitions are currently used:

1. The *Electric Power Research Institute* defines distributed generation as generation from ‘a few kilowatts up to 50 MW’ [4];
2. According to the *Gas Research Institute*, distributed generation is ‘typically [between] 25 and 25 MW’ [5];
3. Preston and Rastler define the size as ‘ranging from a few kilowatts to over 100 MW’ [3];
4. Cardell defines distributed generation as generation ‘between 500 kW and 1 MW’ [6];

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[1] In addition to this paper, a working paper entitled ‘*Distributed power generation in a deregulated market environment*’ is available. The aim of this working paper is to start a discussion regarding different aspects of distributed generation. This working paper can be obtained from one of the authors, Thomas Ackermann.

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5. The *International Conference on Large High Voltage Electric Systems* (CIGRÉ) defines DG as '*smaller than 50–100 MW*' [36];

And because of different government regulations, the definition of the rating of each distributed power station also varies between countries, for example (also [35]):

1. In the English and Welsh market, DG plants with a capacity of less than 100 MW are not centrally dispatched and if the capacity is less than 50 MW, the power output does not have to be traded via the wholesale market [7]. The term distributed generation is, therefore, predominantly used for power units with less than 100 MW capacity;
2. Swedish legislation gives special treatment to small generation with a maximum generation capacity of up to 1500 kW, [8,9,37]. Hence, DG in Sweden is often defined as generation with up to 1500 kW. But under Swedish law, a wind farm with one hundred 1500 kW wind turbines is still considered DG, as the rating of each wind energy unit, and not the total wind farm rating, is relevant for the Swedish law. For hydro units, in comparison, it is the total rating of the power station that is relevant. Some of the proposed offshore wind farms for Sweden have a maximum capacity of up to 1000 MW. This would still be considered DG as they plan to use 1500 kW wind turbines [10].

Due to the large variations in the definitions used in the literature, the following different issues have to be discussed to define distributed generation more precisely:

A. the purpose;
B. the location;
C. the rating of distributed generation;
D. the power delivery area;
E. the technology;
F. the environmental impact;
G. the mode of operation;
H. the ownership, and
I. the penetration of distributed generation.

2.1. Purpose

There is an agreement among different authors and organisations regarding the definition of the purpose of DG.

Definition A1. *The purpose of distributed generation is to provide a source of active electric power.*

According to this definition, distributed generation does not need to be able to provide reactive power.

2.2. Location

The definition of the location of the distributed generation plants varies among different authors. Most authors define the location of DG at the distribution side of the network, some authors also include the customers side, and some even include the transmission side of the network [3]. We think that the following definition is appropriate:

Definition B1. *The location of distributed generation is defined as the installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer site of the meter.*

The motivation for using this definition is that the connection of generation units to the transmission network is done traditionally by the industry. The central idea of distributed generation, however, is to locate generation close to the load, hence on the distribution network or on the customer side of the meter.

Having defined distributed generation now as electric power generation at distribution level or below, the definition requires a more detailed distinction between a transmission and a distribution system.

A distinction based on voltage levels, e.g. 220 kV and higher is considered as transmission and below as distribution, is not very useful as distribution companies sometimes own and operate 220 kV lines and transmission companies operate 110 kV lines.

As the voltage level does not provide any internationally useful distinction between distribution and transmission, another approach is needed. The approach suggested in this paper is based on the legal definition.

Definition B2. *In the context of competitive electricity market regulations, only the legal definition for transmission and distribution systems provides a clear distinction between the two systems* [11].

In a competitive electricity system, the legal regulations define the transmission system, which is usually operated by an independent company that is not involved in power generation, distribution or retail service. In countries without a clear legal definition, however, further discussions will be required.

In some countries, e.g. Sweden, also regional networks are included in the legal definitions. These regional networks are located between the nation-wide transmission network and the local distribution networks. However, usually they are considered to be part of the distribution network system.

Based on the above definition, another question arises: What is a small generation unit, e.g. a wind farm or a CHP system, connected to the transmission network? Theoretically, the two following situations can occur:

1. a CHP system is located on a large industrial site and the industrial customer is directly connected to the transmission network. In this case, the CHP system can be described as distributed generation as it is connected on the customer side of the meter;
2. a medium-sized wind farm is directly connected to the transmission system, due to the capacity limit of the local distribution network. In this case, the wind farm cannot be described as distributed generation.

2.3. Rating of distributed generation

The maximum possible rating of the distributed generation source is often used within the definition of distributed generation in the literature (see beginning of Section 2). Our definition, however, does not include any information regarding the rating of the distributed generation source.

Definition C1. *The rating of the DG power source is not relevant for our proposed definition.*

The motivation for this approach is that:

1. the rating is 'not critical to the definition of what constitutes distributed generation' [3];
2. the maximum rating that can be connected to a distribution system depends on the capacity of the distribution system, which is correlated to the voltage level within the distribution system. The technical design of each distribution system is unique, therefore, no general definition of the maximum generation capacity that can be connected to a distribution system can be given.

Taking into account these initial remarks, general data can be provided, of course. According to Klopfer et al. power units with more than 100–150 MW cannot be connected to 110 kV voltage levels, due to technical constraints [11]. As this is in most cases the maximum voltage level owned and operated by distribution companies, the maximum capacity for distributed power stations seems to be in the 100–150 MW range.

In Berlin, however, the local utility *BEWAG* built a CCGT power station in the centre of the city. The power plant produces both electricity (capacity 300 MW) as well as district heat (capacity 300 MW). The power station actually feeds into various 110 and 33 kV distribution lines, owned and operated by *BEWAG*. The power as well as the heat is predominantly used locally. Hence, this power station can be considered distributed generation, according to definition Definition B1 This case, however, is certainly very special. The above discussion shows that DG can vary between a couple of kilowatts to up to ~ 300 MW.

The technical issues related to distributed generation, however, can vary significantly with the rating. Therefore, it is appropriate to introduce categories of distributed generation. We suggest the following distinction for these categories:

Micro	distributed generation: ~ 1 Watt < 5 kW;
Small	distributed generation: 5 kW $<$ 5 MW;
Medium	distributed generation: 5 MW $<$ 50 MW;
Large	distributed generation: 50 MW $< \sim 300$ MW.

Some authors define generation between 1 kW and 1 MW as dispersed generation. However, this definition is not used consistently in the literature and should therefore not be applied in this way.

2.4. Power delivery area

Some authors also define the power delivery area, e.g. all power generated by DG is used within the distribution network. In certain circumstances, defining the power delivery area is not very helpful, as the following example illustrates:

The New Zealand utility *Wairarapa Electricity* operated a 3.5 MW wind farm within its 11/33 kV southern distribution network (the wind farm is now owned by the *Electricity Cooperation of New Zealand*). The produced energy is almost totally used within its own network, however, during nights with very low demand and high wind speeds the wind farm actually exports energy back into the transmission system [12].

A definition of the area of power delivery restricted to the distribution network would disqualify this project as distributed generation, despite the fact that it is a very typical DG project. Furthermore, any restriction of the power delivery areas in the definition of DG would result in complex analyses of the power flow in the distribution network. Therefore:

Definition D1. *The area of the power delivery is not relevant for our proposed definition of DG.*

The term *embedded distributed generations* seems to be more appropriate to describe that the power output of the distributed generation source is only used locally. Unfortunately, the term *embedded* is not used consistently in the literature.

2.5. Technology

Often the term distributed generation is used in combination with a certain generation technology category, e.g. renewable energy technology. According to our definition, however, the technology that can be used is not limited.

Definition E1. *The technology used for DG is not relevant for the here proposed definition.*

Current praxis also shows that available technology for distributed generation varies widely (seen in Table 1). A detailed technical description and analysis of the current status for each of the technologies presented in Table 1 is beyond the scope of this paper. The paper will limit itself to discussing typical features of some of these technologies, which can be used to further categorise them.

First, many of the technologies utilise renewable energy resources. According to the *International Energy Agency* (IEA), renewable energy resources are defined as resources that are generally not subject to depletion, such as the heat and light from the sun, the force of wind, organic matter (biomass), falling water, ocean energy and geothermal heat [13]. As about 1000 times more energy reaches the earth as fossil fuel is currently consumed, renewable energy resources can be described as abundant. However, availability of the different resources varies significantly between areas and countries, as well as technology efficiency to harvest the renewable energy resources.

Table 1
Technologies for distributed generation[a]

Technology	Typical available size per modul
Combined cycle gas T.	35–400 MW
Internal combustion engines	5 kW–10 MW
Combustion turbine	1–250 MW
Micro-Turbines	35 kW–1 MW
Renewable	
Small hydro	1–100 MW
Micro hydro	25 kW–1 MW
Wind turbine	200 Watt–3 MW
Photovoltaic arrays	20 Watt–100 kW
Solar thermal, central receiver	1–10 MW
Solar thermal, Lutz system	10–80 MW
Biomass, e.g. based on gasification	100 kW–20 MW
Fuel cells, phosacid	200 kW–2 MW
Fuel cells, molten carbonate	250 kW–2 MW
Fuel cells, proton exchange	1 kW–250 kW
Fuel cells, solid oxide	250 kW–5 MW
Geothermal	5–100 MW
Ocean energy	100 kW–1 MW
Stirling engine	2–10 kW
Battery storage	500 kW–5 MW

[a] Source: Linden et al. [19], IEA [20], p. 64, Duffie et al. [21], pp. 638 and author.

Secondly, technologies such as micro-hydro units, PV arrays, wind turbines, diesel engines, solar thermal systems, fuel cells and battery storage consist of a number of small modules, which are assembled in factories. These modules can be installed in a very short time at the final power station location. Manufacturing and construction on site requires significantly less time than for large centralised power stations.

Furthermore, each modular unit can start to operate as soon as it is installed on site, independent of the status of the other modules. In case a module fails, the other modules are not affected by it. As each module is small compared to the unit size of large centralised power stations, the effect of module failures on the total available power output is considerably smaller. And finally, these technologies allow for adding on modules later or move modules to another site, if required [14–16].

Another important aspect is the combined production of heat and power (CHP). Combined cycle gas turbines, internal combustion engines, combustion turbines, biomass gasification, geothermal, sterling engines as well as fuel cells are suitable for a combined production of heat and power. The combined local production of heat and power has the advantage of a high efficiency, if the heat is used locally. In most cases, heat and power output have an almost (positive) fixed correlation, as the heat production utilises the heat losses of the power production. The heat demand usually defines the operation process, unless there is a back-up system for the heat production. The technology of combined heat and power production is already widely used with combined cycle gas turbines, internal combustion engines, combustion turbines and biomass gasification. A commercial version of a 1 kW fuel cell for the combined production of heat and power for houses is expected to be available by 2001 [18].

For the discussion of the technical and economic issues related to distributed generation technologies, technology categories seems useful. We suggest the following categories, others are also possible, though:

Renewable	distributed generation;
Modular	distributed generation;
CHP	distributed generation.

2.6. Environmental impact

Often DG technologies are described as more environmentally friendly than centralised generation. According to our definition, however, the environmental impact of the DG technology is not relevant.

Table 2
Comparison of energy amortisation time and emissions of various energy technologies

Technology	Energy pay back time in months[a]	SO_2 in kg/GWh[a]	NO_x in kg/GWh[a]	CO_2 in t/GWh[a]	CO_2 and CO_2 equivalent for methane in t/GWh[b]
Coal fired (pit)	1.0–1.1	630–1370	630–1560	830–920	1240
Nuclear	N.A	N.A.	N.A.	N.A	28–54
Gas (CCGT)	0.4	45–140	650–810	370–420	450
Large hydro	5–6	18–21	34–40	7–8	5
Renewable distributed generation technologies					
Micohydro	9–11	38–46	71–86	16–20	N.A.
Smallhydro	8–9	24–29	46–56	10–12	2
Windturbine					
4.5 m/s	6–20	18–32	26–43	19–34	N.A.
5.5 m/s	4–13	13–20	18–27	13–22	N.A.
6.5 m/s	2–8	10–16	14–22	10–17	11
Photovoltaic					
Mono-cystalline	72–93	230–295	270–340	200–260	N.A.
Multi–cystalline	58–74	260–330	250–310	190–250	228
Amorphous	51–66	135–175	160–200	170–220	N.A.
Geothermal	N.A.	N.A.	N.A.	N.A	50–70
Tidal	N.A.	N.A.	N.A.	N.A	2

[a] *Source:* Kaltschmitt et al. [22].

[b] *Source:* Lewin [23], Fritsch et al. [24], also Ackermann [25]; All figures include direct and indirect emissions based on average German energy mix, technology efficiency, solar radiation and typical lifetime.

Definition F1. *The environmental impact of DG is not relevant for the here proposed definition.*

The motivation for this approach is that the analysis of the environment impact is too complex, to be included in the here proposed definition.

Table 2, for example, provides an overview of the most important emissions related to electricity production based on different technologies. The data comprises direct emissions and indirect emissions. Indirect emissions are emissions that occur during the manufacturing of the power unit and the exploration and transport of the energy resources. The calculation is based on the average German energy mix and on typical German technology efficiency, [24,25].

Table 2 shows that the emissions from typical DG technologies are significantly lower than that from coal power stations. *Combined cycle gas turbines* (CCGT) and large hydro units, too, have significantly lower SO_2 and CO_2 emissions than coal power stations.

Biomass is not included in the figure, as it is considered CO_2 neutral, as the amount of CO_2 emitted into the atmosphere when biomass is burned is equal to the amount of CO_2 absorbed during its growth. NO_x emissions of combustion of bio-fuels is reported to be 20–40% lower than that of fossil fuel plants, and SO_2 emissions are reported to be insignificant [26].

Battery storage as well as fuel cells have no direct emissions. Beside the emissions occurring during the manufacturing process, however, the fuel mix used for the production of the electricity stored in the batteries must be considered in the calculations of the indirect emissions of battery storage. In the case of fuel cells, the indirect emissions also depend on the energy mix that is required to produce hydrogen, as hydrogen cannot be exploited.

Additional environmental benefits, resulting from e.g. the reduction of transmission line losses, achieved by proper siting in terms of location and unit size, could further improve the environmental balance of DG. Apart from that, some argued that a large amount of DG might force the large units to operate below their optimum efficiency, which will lead to an increase in emissions per produced kWh [27]. Other aspects, which make an environmental comparison very difficult are different perceptions regarding the risk of nuclear power stations or regarding the visual impact, noise impact and land requirements of wind turbines, for example.

Therefore, the technologies that can be used for distributed generation cannot be described in general as environmentally friendly. But regarding the main current environmental issue, the increased greenhouse effect, all DG technologies lead to significantly lower emissions than coal-based technologies.

2.7. Mode of operation

The issue of the mode of operation is based on the wide-spread view that DG is 'relatively unencumbered by the rules of operation of central systems (scheduling, pool pricing, dispatch, etc.)' [3].

According to our definition, however, the mode of operation is not relevant.

Definition G1. *The mode of operation of distributed power generation is not relevant for the here proposed definition.*

The motivation for this approach is based on large variations in the international regulations regarding the operation of electricity network.

Taking the English and Welsh regulations as an example, a power unit connected to the distribution system with a capacity of more than 100 MW would be treated by the market regulations as a centralised power unit, but a unit with less than 100 MW would be less encumbered in the rules of operation [7].

Therefore, it cannot be assumed in general that distributed generation is relatively unencumbered by the rules of operation.

In situations, however, where distributed generation receives a special treatment by the regulations, this can be specially mentioned, for example: *not centrally dispatched distributed generation.*

2.8. Ownership

It is frequently argued that DG has to be owned by independent power producers or by the customers themselves, to qualify as DG. According to our definition, however, the ownership is not relevant.

Definition H1. *The ownership of DG is not relevant for the here proposed definition.*

The motivation for this approach is based on different international experiences regarding the ownership of distributed generation. In Sweden, for example independent generators as well as traditional generators are involved in DG.

However, the current experience in many countries shows that large power generation companies are often too inflexible to develop small DG systems. Furthermore, there is strong evidence that projects developed by local companies and partly financed with regional involvement have more public support than projects of other organisations [2]. Large power generation companies, however, become more and more interested in the topic and there is no obvious reason why distributed generation should be limited to independent ownership.

Nevertheless, it is important to emphasise that ownership issues of DG can be of importance for the development of distributed generation. Therefore, the ownership of DG could be mentioned, for example, *independently-owned distributed generation.*

2.9. Penetration of distributed generation

Regarding the total amount of DG within a distribution network, some authors assume that DG stands for completely decentralised power generation, that does not require any transmission lines or large centralised power plants [17]. Other authors assume that distributed generation will be able to provide only a fraction of the local energy demand.

According to our definition, however, the penetration level of DG is not relevant.

Definition I1. *The penetration level of DG is not relevant for the here proposed definition.*

The motivation for this approach is based on the fact that the definition of the penetration level itself is problematic. This amount of DG must be put into relation to an area, e.g. local distribution system or nation-wide power network. The definition of this area, however, could significantly influence the penetration level.

It is, however, important to emphasise that if the predictions of the *Electric Power Research Institute* (EPRI) and the *Natural Gas Foundation*, which predict that by the year 2010, 25–30% of new generation will be distributed, will become reality, it will be likely that DG satisfies the majority of the energy needs within certain distribution networks. Therefore, the analysis of DG should always take into consideration that the penetration of DG could reach a significant level.

3. Proposed definition for distributed generation

Different definitions regarding *Distributed Generation* (DG) are used in the literature and in practice. These variations in the definition can cause confusion. Therefore, this paper suggests an approach towards a general definition of distributed generation.

The general definition for distributed generation suggested here is:

Definition 1. *Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter.*

The distinction between distribution and transmission networks is based on the legal definition. In most competitive markets, the legal definition for transmission networks is usually part of the electricity market regulation. Anything that is not defined as transmission network in the legislation, can be regarded as distribution network.

The definition of distributed generation does not define the rating of the generation source, as the maximum rating depends on the local distribution network conditions, e.g. voltage level. It is, however, useful to introduce categories of different ratings of distributed generation. The following categories are suggested:

Micro	distributed generation: ~ 1 Watt < 5 kW;
Small	distributed generation: 5 kW < 5 MW;
Medium	distributed generation: 5 MW < 50 MW;
Large	distributed generation: 50 MW < 300 MW

Furthermore, the definition of distributed generation does neither define the area of the power delivery, the penetration, the ownership nor the treatment within the network operation. It cannot be assumed, as it is often done, that distributed generation stands for local power delivery, low system penetration, independent ownership and special treatment within the network operation in general.

If these aspects are of interest, they should be mentioned additionally.

For example, if the power output of distributed generation is used only within the local distribution network, we suggest the term *embedded distributed generation*. And if the distributed generation source is not centrally dispatched, it should be called: *not centrally dispatched distributed generation*.

Also, the definition of distributed generation does not define the technologies, as the technologies that can be used vary widely. However, a categorisation of different technology groups of distributed generation seems possible. We suggest the following categories, but others are also possible:

Renewable	distributed generation;
Modular	distributed generation;
CHP	distributed generation.

4. What are distributed resources?

According to Moskovitz, distributed resources are "*demand- and supply-side resources that can be deployed throughout an electric distribution system* (*as distinguished from the transmission system*) *to meet the energy and reliability needs of the customers served by that system. Distributed resources can be installed on either the customer side or the utility side of the meter*". [28].

Distributed resources consist of two aspects:

1. distributed generation, located within the distribution system or on the customer side of the meter, and
2. demand-side resources, such as load management systems, to move electricity use from peak to off peak periods, and energy efficiency options, e.g. to reduce peak electricity demand, to increase the efficiency of buildings or drives for industrial applications or to reduce the overall electricity demand. An important aspect of the concept of distributed resources is that the demand-side resources are not only based on local generation within the electrical system on the customer's side of the meter, but also on means that reduce customer demand. That will influence the electricity supply from the distribution network.

5. What is distributed capacity?

The term distributed capacity is less known than the terms distributed generation or distributed resources, probably because it is even more difficult to clearly define that term.

Distributed capacity includes all aspects of distributed resources, plus the requirements for transmission/distribution capacity. For a better distinction between distributed capacity and distributed generation, the following example can be used: one aim of installing distributed generation is to reduce the peak demand. However, distributed generation does not include any reserve capacity, hence the transmission/distribution network usually has to be able to cover at least some of the generation usually supplied by distributed generation. Hence, transmission/distribution lines will be overdimensioned and the load factor will be worse than without distributed generation. As transmission/distribution systems are regarded as monopolies, the transmission/distribution operator will usually be able to recover the costs for the overdimensioned system and the poor load factor via higher transmission tariffs.

Distributed capacity now includes all aspects of distributed generation and distributed resources plus reserve capacity, e.g. stand-by generators or load management, to minimize the requirements for overdimensioning of transmission/distribution system.

6. What is a distributed utility

The term distributed utility stands for a future network and utility architecture, based on distributed generation, distributed resources and distributed capacity. The concept for distributed utilities was developed in the US, see [29], where the term is commonly used. A thorough discussion of the concept is not within the scope of this paper. We refer to [41] and [30] for a working definition of distributed utilities.

7. Distribution network issues

The above definitions of distributed generation, resources, capacity and utility do not include a discussion of network or connection issues. These issues, however, are very important from the technical aspects, as there are significant differences in the design of distribution and transmission networks.

Firstly, distribution networks are often designed for a different purpose than transmission networks. The main difference is that distribution systems are usually not designed for the connection of power generation devices, e.g. the connection of distributed generation leads to a change in the fault-current, hence a redesign of local fault protection system might be required.

Furthermore, distribution networks have usually a radial or loop design, and not a meshed design like transmission networks. Therefore, the power flow in distribution networks usually is one-directional and no or little redundancy exists [6].

Secondly, high voltage lines, e.g. transmission lines or urban distribution lines, have a low resistance compared to low voltage lines in distribution networks. In transmission lines or urban distribution networks, the effect of line or cable resistance (R) on voltage drop is small, since its specific magnitude is generally much less than the reactance (X), i.e. $X/R > 5$. Hence, the reactance is the most important parameter in regards to voltage drop and line losses. In rural distribution systems, however, the resistance in the distribution lines is often larger than, or at least similar to, the inductance. Hence, the distribution line resistance causes a significant proportion of the voltage drop along the distribution lines as well as of the line losses [31]. The connection of distributed generation can therefore have a significant influence on the local voltage level.

Thirdly, the low voltage ends of distribution systems are usually not connected to *Supervisory Control and Data Acquisition* (SCADA) systems. The data gathering required for the control of the distribution system as well as the DG units is therefore difficult. The complexity of data gathering for system control in competitive markets increases due to the fact that independent power generators operate their DG units according to the market price signals, which do not necessarily correspond to the system's control requirements in local distribution areas.

8. Connection issues

The electricity generation technology and grid connection of DG technologies can be significantly different from traditional centralised power generation technologies. Large power units use synchronous generators. These are capable of controlling the reactive power output, for example. Large DG units, utilising natural gas for instance, use synchronous generators, too.

Medium-sized and especially small DG technologies often use asynchronous generators (also known as induction generators), as they are significantly cheaper than synchronous generators. Asynchronous generators, however, have different operational characteristics than synchronous generators. For example, a directly grid-connected asynchronous generator is not capable of providing reactive power. It actually requires reactive power from the grid during the start-up process and at operation. Different technical options exist to overcome the disadvantages of grid-connected asynchronous generators. Manufactures of DG technologies have used a large range of options, such as capacitors and power electronic converters [32].

And finally, micro systems such as photovoltaic modules, batteries, fuel cells and micro hydro turbines have to be connected via an interface (converter) to the grid, as these micro-systems produce direct current. Modern power electronic interfaces offer different solutions to convert D.C. current to an A.C. voltage and active/reactive current with the required frequency. Power electronic converters introduce also 'new control issues and new possibilities' to grid integration [1]. Power converters could be used for voltage control in the distribution network, for instance [31]. In some cases, a control problem might emerge if dispersed converters somehow interact via the distribution network. This may lead to power fluctuations or oscillations in the distribution networks. However, such cases seem to be very rare [32].

This large variety of options for grid connection of distributed generation makes the analysis of grid integration issues very complex. Furthermore, local network conditions have an important influence on the relevant integration issues. Hence, each network will require a detailed analysis.

For an overview of the technical issues involved in the analysis of the connection of power generation to distribution networks, see IEE [40] as well as Hadjsaid [39]. For results of a case study, see Stieb [38].

The development of industry standards for the interface design of distributed generation, covering external as well as internal control issues of the interface, will be an important step towards reducing this complexity [33]. Currently, most distribution network operators rely on commonly used interconnection standards regarding the connection of DG resources to achieve a secure network operation. Many of those standards are based on recommendations by ANSI and IEEE. However, most of these standards do not distinguish between medium-sized CCGT power stations and micro PV systems [34]. Owners of the DG unit (s) and the distribution network operator often disagree regarding the appropriate interconnection standards.

9. Conclusion and future work

This paper discusses the relevant issues and aims at providing a general definition for distributed power generation in competitive electricity markets. In general, DG can be defined as electric power generation within distribution networks or on the customer side of the network.

In addition, the terms distributed resources, distributed capacity and distributed utility are discussed. Network and connection issues of distributed generation are presented, too.

Based on the above suggested definition for distributed generation, the next step will be to discuss this definition with all interested parties and to come up with a commonly accepted definition.

Furthermore, the network integration of distributed generation is a very complex issue, which can be significantly different from traditional network integration of power generation into transmission networks. Therefore, further research is required regarding the analysis of the impact of distributed generation on the reliable and economic operation of distribution systems.

Thereby it is important to consider the benefits of distributed generation, e.g. reduction of network losses, as well as additional costs, e.g. the redesign of the protection system.

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