



Power Quality and Utilisation Guide

Section 8 – Distributed Generation

Integration & Interconnection*

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1 Introduction

Traditionally electricity networks were built to transport electrical energy generated by large, central placed, power production units. The new, relatively small, distributed generation (DG) units are usually connected to distribution networks, not designed to host power generators. Most studies confirm that 10 –15 % penetration of DG can easily be absorbed in the electricity network without major structural changes.

Distributed Generation (DG) is emerging as a promising electricity generating technology for a number of reasons. Three independent trends are currently laying the groundwork for the possible widespread adoption of DG:

- Utility industry restructuring.
- The political will to increase the use of RES (Renewable Energy Sources).
- And technology advancements.

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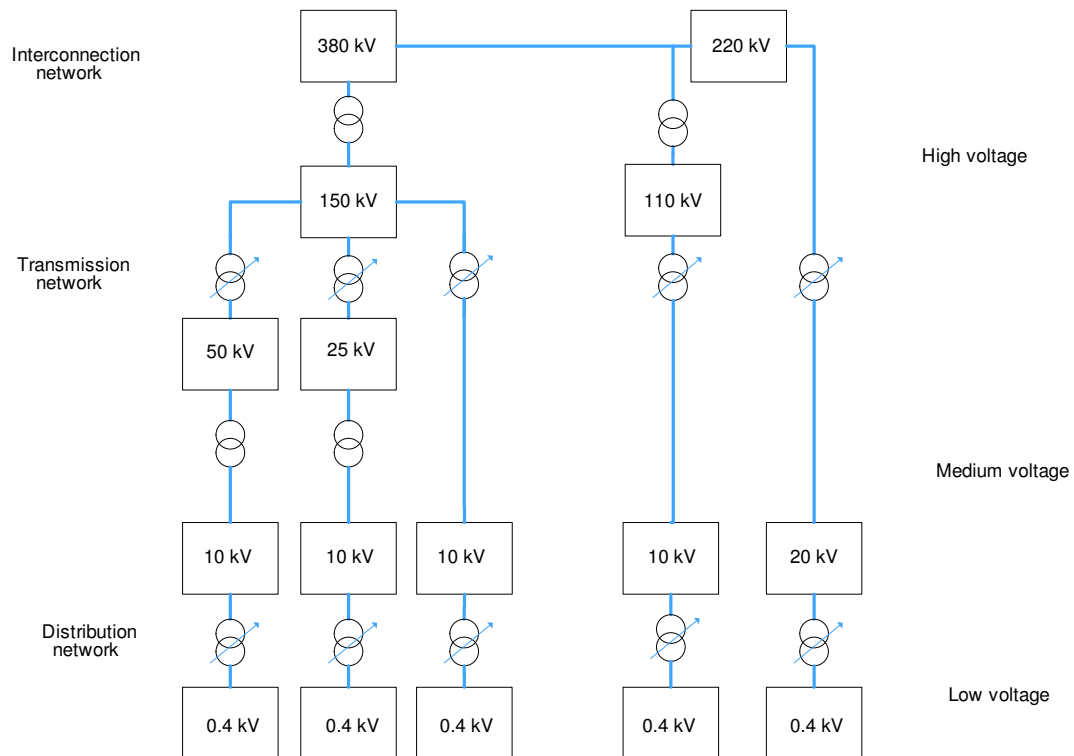


Figure 1: An example of a typical electricity network, in this case of the Netherlands whereby large power production units are central placed to feed in on the 380kV transmission network

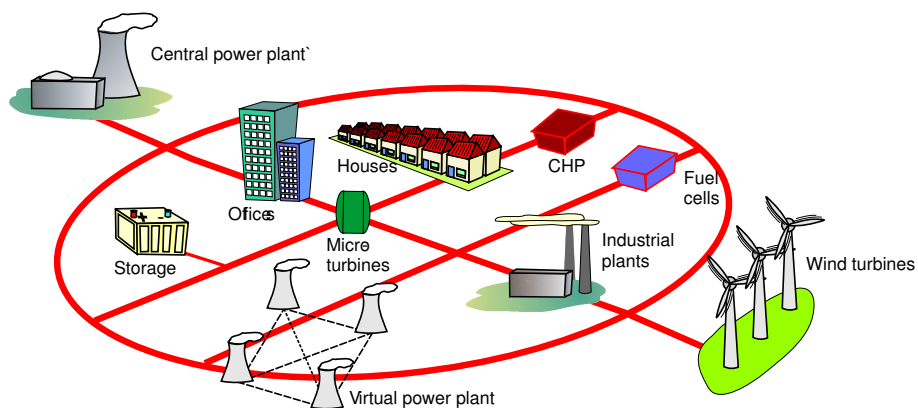


Figure 2: The electricity network of the future; "Energy Web Concept" whereby different DG feed in on the electricity web, mainly on distribution voltage level

1.1 Definition of integration & interconnection

Integration is the system level addition of DG to the power grid. Important integration issues are:

- Protection systems
- Power electronics
- Reliability modeling
- Power quality issues
- Connection standards
- Simulation and computer modeling

Interconnection DG units can be grid independent or grid parallel as well as a combination of both. In the latter case a grid failure means that the DG unit is disconnected from the grid and continues to operate independently from the grid and thus creates an 'island' (islanding, island mode operation).

A typical arrangement for the DG interconnection to the medium voltage network is depicted in Figure 1. Connection and disconnection of the generator is made by the circuit breaker at the generator side of the main power transformer (main breaker). Depending on the size of the plant the disconnector on the grid side of the transformer may be replaced by circuit breaker.

The general scheme presented in Figure 3 illustrates interconnection of DG technologies based on synchronous (or asynchronous) generator. Other DG technologies apply slightly different interconnection arrangements. In all cases the voltage level at the interconnection point determines the need for a transformer. Smaller units can be directly connected to the low voltage network.

Considering only the electrical characteristic there are three different DG types:

- Synchronous generator
- Asynchronous generator
- Inverter

The first two types represent traditional technology based on rotating electrical machines. The last type refers here various arrangements applying modern power electronic converters. From the interconnection point of view these three types have different impacts on the distribution network.

Interconnection requirements: requirements from utilities to ensure reliability, safety and power quality. These may include: protective relays requirements, power quality requirements, power flow studies and engineering analysis.

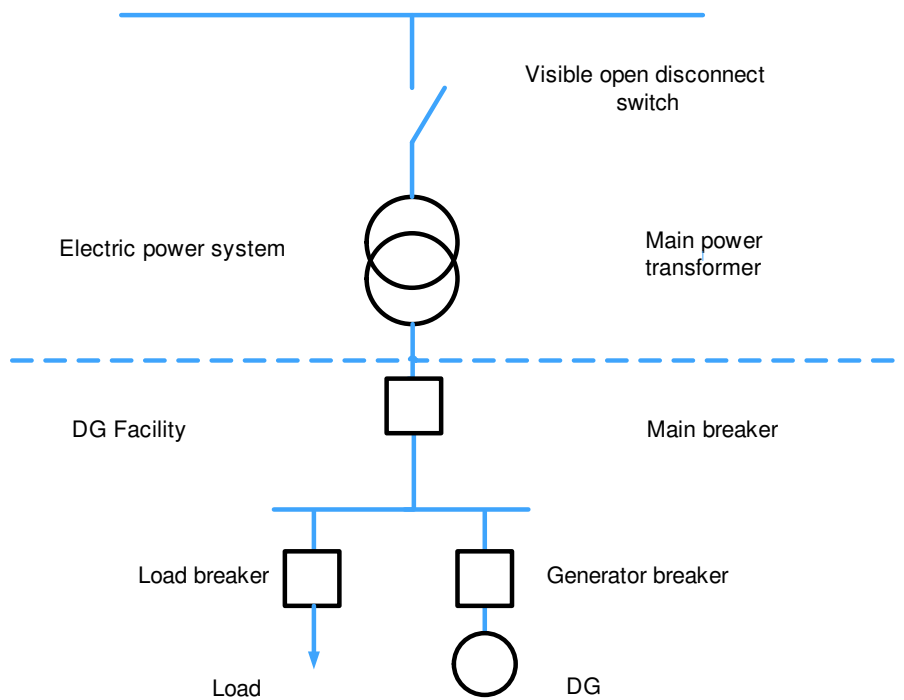


Figure 3: Interconnection of DG technologies based on synchronous (or asynchronous) generator

1.2 Application of integration & interconnection:

1.2.1 Client

Interconnection requirements are requirements from utilities to ensure reliability, safety and power quality. These may include: protective relays requirements, power quality requirements, power flow studies and engineering analysis.

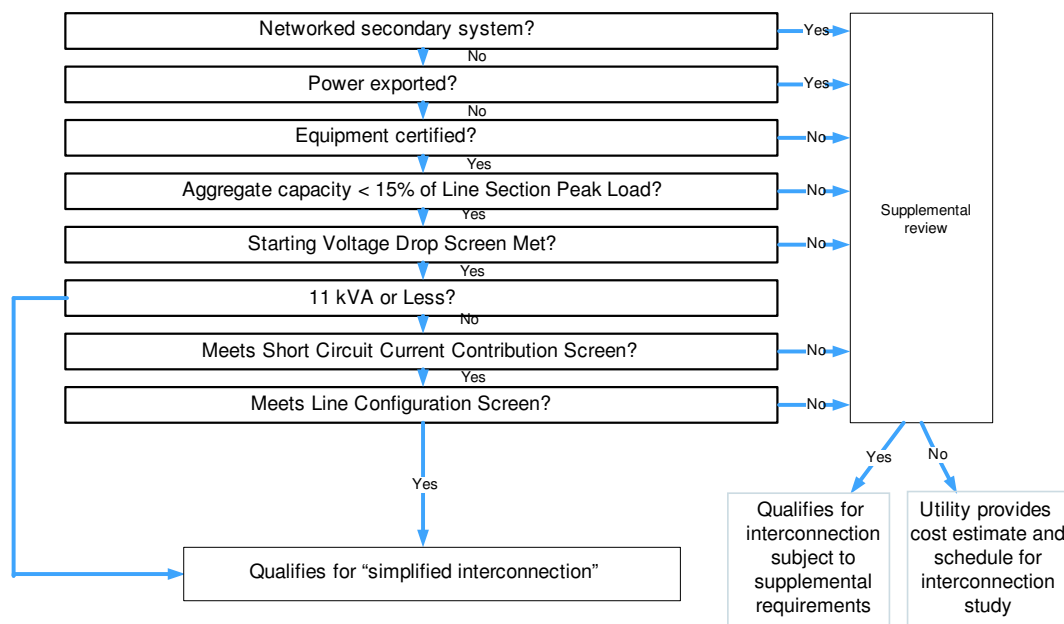


Figure 4: Example of flowchart with requirements for interconnecting DG resources

1.2.2 Networks

For many years the electric power industry has been driven by a paradigm where most of the electricity was generated by large, central power plants, sent to the consumption areas through the transmission lines, and delivered to the consumers through passive distribution infrastructure at lower voltage levels. In this system, power flows were only in one-direction, from higher to lower voltage levels (see figure 5 left). Nowadays this model is changing from one-directional central delivered power generation to bi-directional distributed generation network, as shown in Figure 5 right.

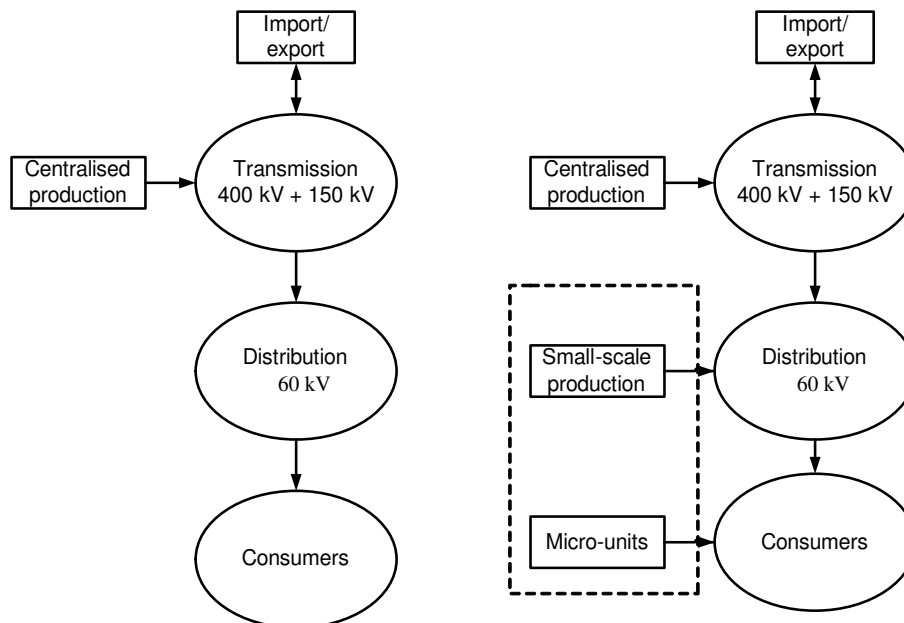


Figure 5: One-directional central delivered power generation and a bi-directional distributed generation network

Several main impacts can be identified in the operation of a distribution system with a large amount of distributed generation:

- Voltage profiles change along the network, depending on the power produced on the consumption levels, leading to a behavior different from the typical one
- Voltage transients will appear as a result of connection and disconnection of generators or even as a result of their operation
- Short circuit levels increase
- Losses changes as a function of the production and load levels
- Congestion in system branches is a function of the production load levels
- Power quality and reliability may be affected
- Utility protection need to be coordinated with the ones installed in the generator's side

In solving these problems it is important to keep in mind, that the existing network design standards and regulatory framework is based on the old one-directional model. A power system requires several system services in order to be reliable. Apart from generating power, the central power stations supply are normally used for supplying the following services:

- Power control
- Frequency control
- Load following
- Voltage control
- Power availability

1.2.3 Conditions (generation)

DG strategically applies relatively small generating units (typically less than 20 MWe) at, or near, consumer sites to meet specific customer needs, to support economic operation of the existing power distribution grid, or both. The convergence of competition in the electric industry with the arrival of environmental friendly micro-turbines, fuel cells, photo-voltaics, small wind turbines and other advanced distributed power technologies, has sparked strong interest in distributed power, particularly in on-site generation. Reliability of service and power quality are enhanced by proximity to the customer, and efficiency is improved in on-site CHP applications by using the heat from power generation.

Distributed generation complements central power by providing a relatively low capital cost response to incremental increases in power demand, by avoiding transmission & distribution capacity upgrades, by locating power where it is most needed and by having the flexibility to put power back into the grid at user sites. On the other hand, there are social needs for cheaper, less polluting, safer and more reliable and sustainable energy for all stakeholders: consumers, suppliers, generators and policy makers. The distributed generation, including RES integration, is a promising solution to solve those needs.

1.3 Current status in EU

The European Commission's White Paper for a Community Strategy sets out a strategy to double the share of renewable energies in gross domestic energy consumption in the European Union by 2010 (from the present 6% to 12%) including a timetable of actions to achieve this objective in the form of an Action Plan.

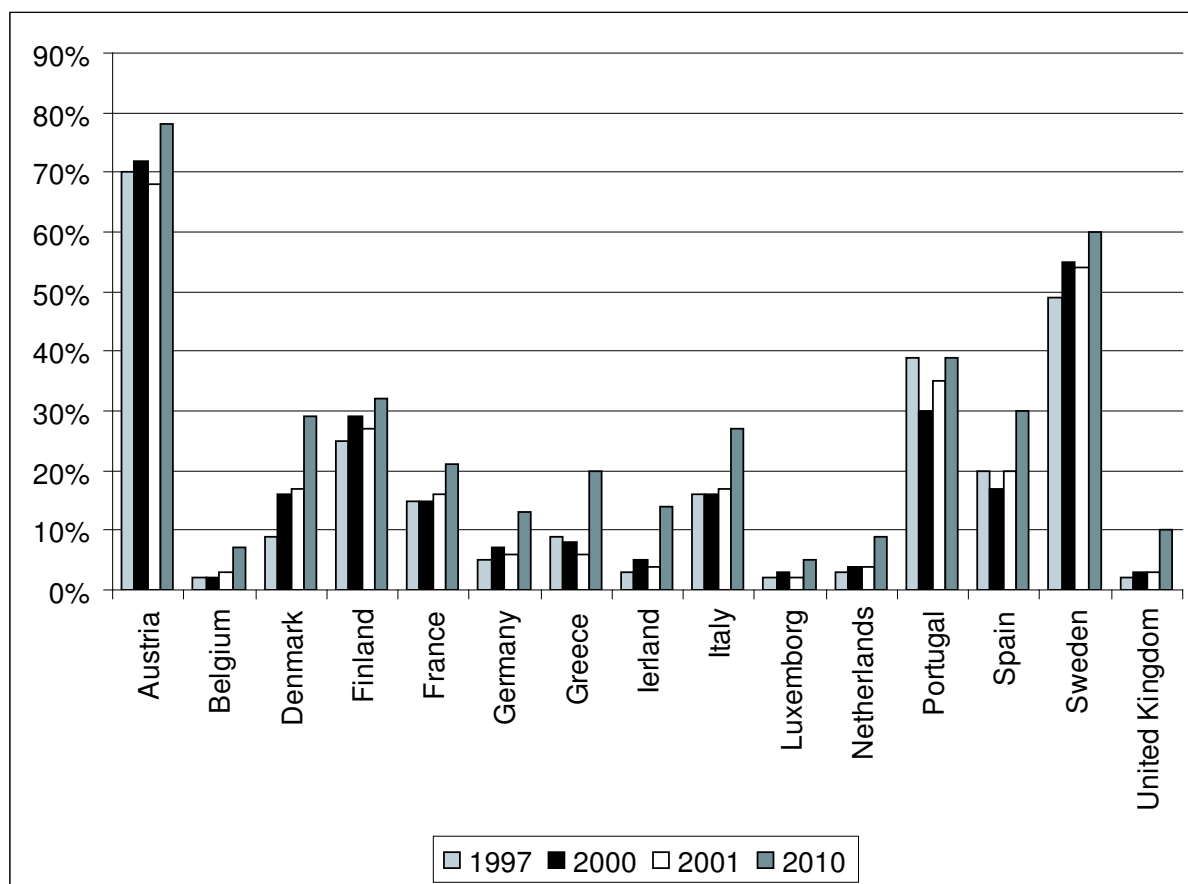


Figure 6: The share of RES-E in total electricity consumption (Eurostat) compared to 2010 targets (RES-E Directive)

1.4 Trends

Looking forward to the future, fast growth of RES and DG is to be expected.

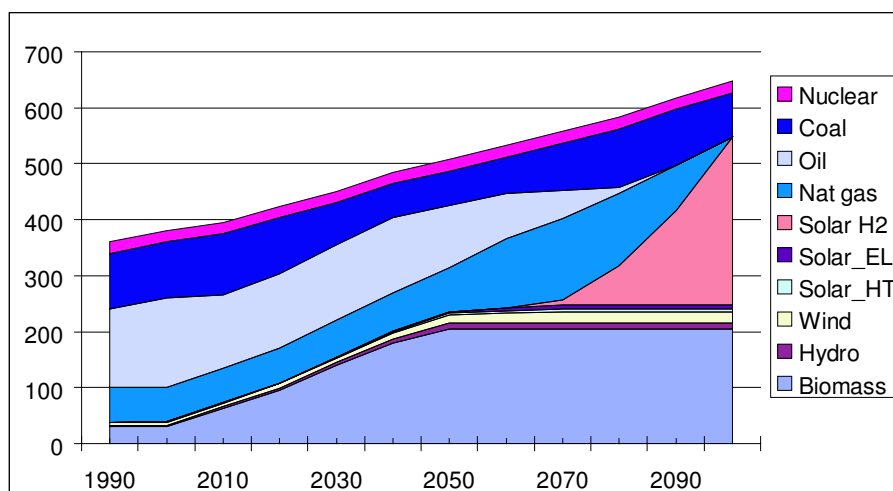


Figure 7: The required energy resources required if atmospheric CO₂ concentrations are stabilized at 400 ppm

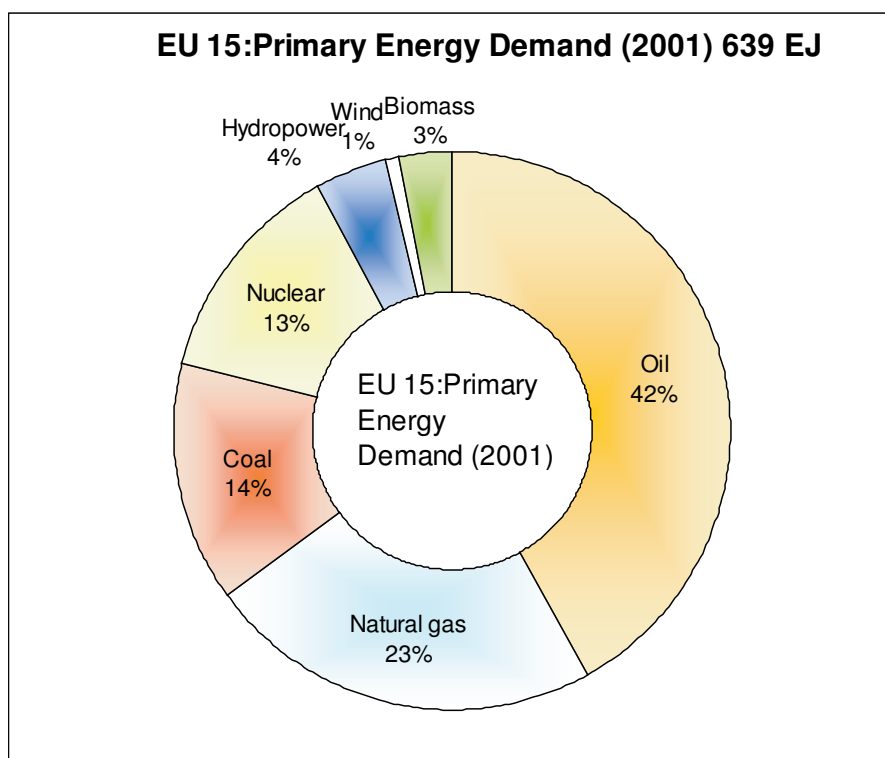


Figure 8: The primary energy demand and energy resources in EU-15 in 2001

2 Configuration & Characteristics

2.1 Scale of integration & interconnection of application

Table 1 shows the typical available size per module for various DG technologies.

Technology	Typical available size per module
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
<i>Renewable_</i>	
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

Table 1: Technologies for Distributed Generation

Table 2 shows the characteristics of Distributed Generation.

	Combined Heat and Power (CHP)	Renewable Energy Sources (RES)
Large scale generation	<ul style="list-style-type: none"> • Large district heating* • Large industrial CHP 	<ul style="list-style-type: none"> • Large hydro** • Off-shore wind • Co-firing biomass in coal power plants • Geothermal energy
Distributed generation (DG)	<ul style="list-style-type: none"> • Medium district heating • Medium industrial CHP • Commercial CHP • Micro CHP 	<ul style="list-style-type: none"> • Medium and small hydro • On-shore wind • Tidal energy • Biomass and waste incineration/gasification

Table 2: DG Characteristics

* typically > 50 MW ** typically < 10 MW

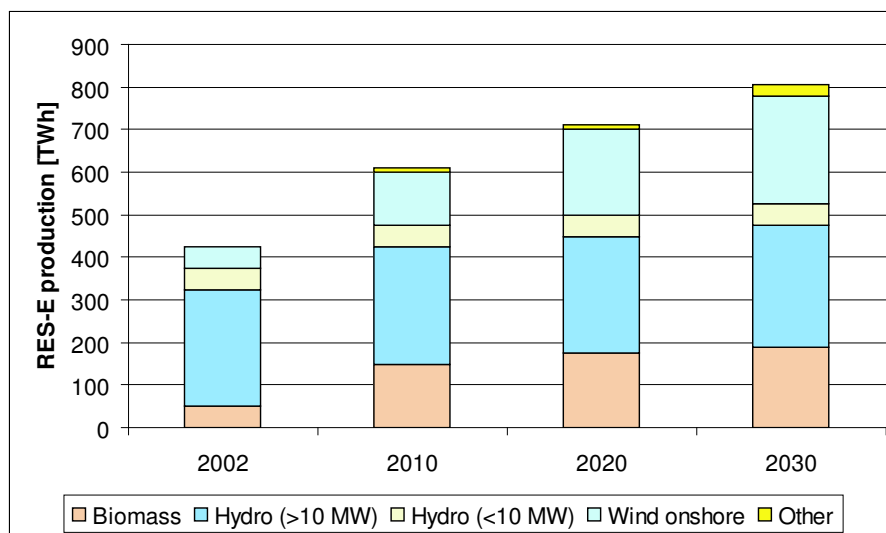


Figure 9: Total RES-E production in EU for different groups

2.2 Voltage level of integration & interconnection

Voltage quality problems may also arise during normal operation of DG when considering the voltage level. When a distribution feeder is designed to carry a certain power flow from the primary substations to the loads a generation unit along the feeder may cause a reversed power flow and a voltage rise. This is schematically illustrated in figure 10.

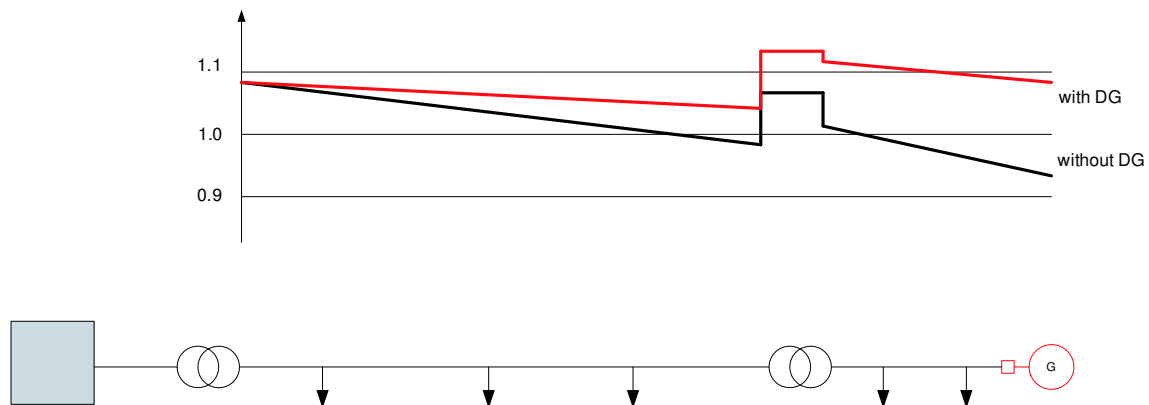


Figure 10: Voltage rise due to reversed powerflow due to Distributed Generation

2.3 Quality of integration & interconnection

Next to short circuit power level, load flow, flicker and harmonics, protection also is an essential subject for integration and interconnection of DG.

The proper protection of distribution networks containing DG requires several new concepts and methods to be developed. These are related to the following topics:

- Loss-of-mains protection
- Auto-reclosing functions
- Changes in fault levels
- Protection coordination
- Earth-fault indication
- Fault location

There is a need for totally new solutions, but obviously some solutions may be adopted from the high voltage (HV) systems. An interesting topic will also be the protection of low voltage (LV) networks which is traditionally based on fuses. In case of low power inverter based generation there might not be enough fault current to blow the fuses.

2.3.1 Short circuit power level

The short circuit power is determined by the properties of the grid.

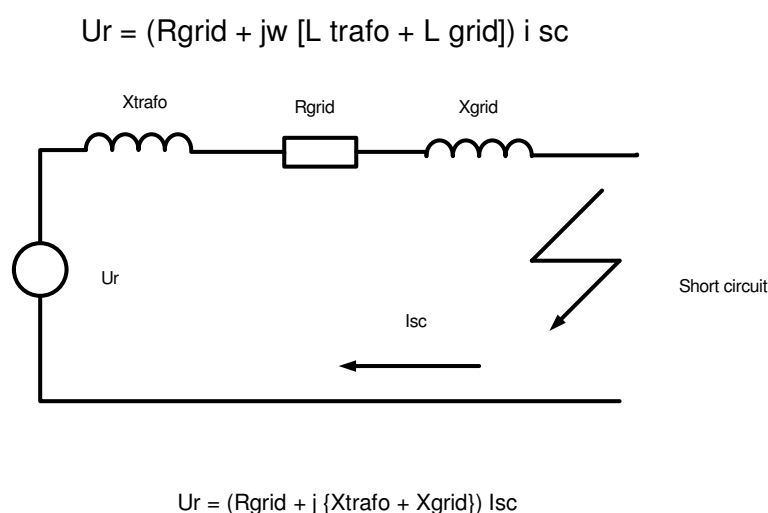


Figure 11: Example of a grid lay-out and short circuit

Since the value of the grid impedance will increase with the length of the line or cable, the short circuit current and power will generally decrease with the length.

For a desired steady state voltage deviation of less than 2%, a "rule of Thumb" is often applied which states that the short circuit power should be at least 50 times the rated power. This is a approximation only since it does not take into account any effects by other producers or consumers.

2.3.2 Steady state voltage deviations: load flow

A more accurate determination of the steady state voltage deviation is found in a load flow calculation. In this calculation the steady state voltages, currents and phase relations are determined in a section of the electrical grid. Consumers and decentralized producers are specified with their power and reactive power. The voltage and current phasors are determined from the voltage equations for all transmission lines or cables in the grid section. Generally this will be an iterative process. By applying the principle of superposition (voltage and current are added vectorally since the system is considered to be linear) the iterative proces can be simplified considerably. The result of a load flow calculation is demonstrated for a wind farm consisting of six turbines arranged in a string in figure 12.

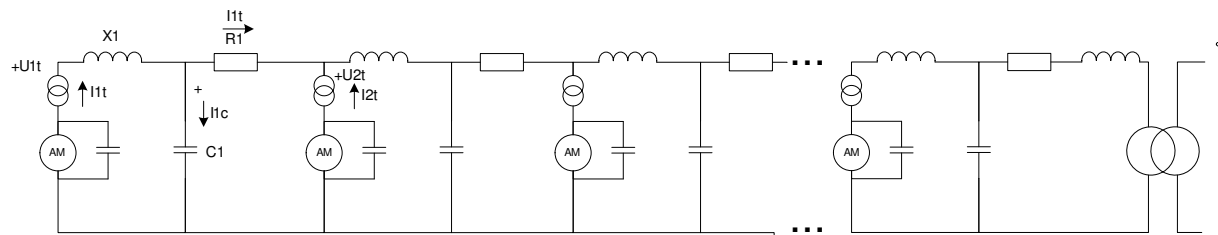


Figure 12: Example of a wind farm consisting of six turbines arranged in a string

The turbines are represented by an induction generator, reactive power compensation and a transformer from the 600V level at the turbine to 6kV of the cable. Each cable section is represented by an inductance resistance and capacitance. The cable is connected to a 6-150kV transformer station through a choke. The purpose of the choke is to reduce the short circuit power of the branch to prevent overload in the transformer station.

2.3.3 Dynamic voltage deviations: flicker

The load or capacity factor of DG is much less than one, typically 0.25-0.35 for wind farms and 0.10 for photovoltaic systems. The peaks in the generated power can cause large voltage variations.

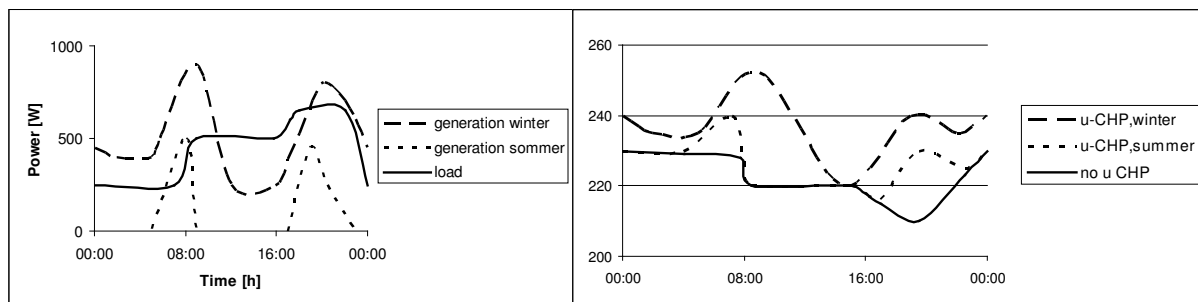


Figure 13: Voltage fluctuations due to micro CHP installation

When these power fluctuations are fast, they may cause fast voltage changes, so called flicker. But depending in the connection technology, DG can also contribute to short circuit level, thus reducing flicker caused by intermitting loads.

2.3.4 Voltage wave form deviations: harmonics

As far as DG is concerned, the issue of harmonics is determined by connection technology. Different technologies are used to connect distributed generation units to the electricity system. DG can either be connected through a rotating machine or through a power electronics converter. Power electronics interfaces offer advanced system support possibilities, but will also inject harmonic currents, possibly causing excessive harmonic voltage levels elsewhere in the grid. But rotating generators can also inject harmonics due to the winding design or core non-linearities. The relevance of this aspect depends on the grid layout and specific DG details.

2.4 Planning

Operational planning

The task of operational planning involves many activity areas to achieve the primary objective, securing the system at minimum possible costs. Involved areas are, demand forecasting, availability forecasting and outage planning. Overall, planning consists of strategic planning, net planning and net design.

3 RELIABILITY

3.1 Description of network reliability in EU

The constant increase of electric power demand, together with the international shift towards competitive electricity markets and the difficulties in building new transmission and central generation facilities due to environmental constraints force modern power systems to operate closer to their stability limits. At the same time, pressing needs for higher security, reliability and power quality impose demanding requirements for power system planning, operation and control.

The interconnection of distributed power resources to the distribution network brings challenges of its own. These challenges include power quality issues, network stability, power balancing considerations, voltage regulation, protection and controls, unwanted islanding, losses, reliability of DG and infrastructure capacity. Important in the perceived technical barriers are the low fluctuating power output and the non-existence of standards for connecting to the utility.

4 POLICY & REGULATION

4.1 Relevant regulations (general and common in EU, not country specific)

The regulatory framework aimed at DSO activities. Managing the electricity network is a monopoly activity and as such this activity has to be regulated. Regulation can be purely based on cost-efficiency of network management or also include performance-based criteria. In case of this performance regulation, DG can be taken into account when DSOs plan extensions and upgrades of their network.

Market presence	Market participation	Description
Low	Protected niche	DG develops outside the regular energy market. Penetration levels are low and priority access and obligatory purchase schemes such as feed-in tariffs are the most efficient way to integrate DG.
Medium	Wholesale market	Penetration levels of DG are growing and DG can sell its energy on the wholesale market. Market conform pricing mechanisms are required, such as green certificates or premium tariffs based on the environmental benefits of DG.
High	Level playing field	Penetration levels of DG are high and dispatch problems can occur. DG should start playing a role in balancing the electricity system and contributing to power quality.

Table 3: Market Access for DG

EN50160	DG in general	Wind Power	PV	Fuel Cells	Biomass	Small Hydro	Microturbines	Small CHP	Batteries	Inverter & interfaces	Grid Integration	Island	UPS	PQ in general	Voltage Sags & interruptions	Harmonics	Flicker	EMC	Network Stability	Protection	Control	Ancillary network services	FACTS	Market	Management and Operations	Measurements & monitoring
	3-2, 3-3, 3-11, 4-7, 4-11, 4-13, 4-14, 4-15, 4-27, 4-30																									
EN561000/ IEC61000																										
EN61400/ IEC61400	21																									
EN50373		x																								
EN60868																										
IEC/TR 61000-2-8																										
IEC/TR 61000-3-4																										
IEC/TR2 61000-3-5/																										
IEC/TR3 61000-3-6/																										
IEC/TR3 61000-3-7																										
IEEE 1547																										
prEN50438																										
IEC/SC22G, IEC61800-3																										
IEC/SC22H,																										
prEN62310-2																										
IEEE P1547.1																										
IEEE P1547.2																										
IEEE P1547.3																										
IEEE P1547.4																										
IEEE P1547.5																										

Figure 14: An overview of relevant regulations for DG

The IEEE 1547 is believed to be the most general interconnection standard available.

4.2 Current policies and policy goals

The widespread integration of RES and DG will contribute significantly to achieving a wide range of EU policy objectives:

- Sustainable development, combating climate change and reducing air pollution – e.g. a shift from the large-scale combustion of fossil fuels to a more sustainable, decentralised energy supply will help the EU to meet its Kyoto commitments regarding the emission of greenhouse gases (particularly CO₂) – 8% reduction by 2008-2012.
- Security and diversity of energy supply – reducing the EU's external energy dependence is crucial for the development of a dynamic and sustainable economy in Europe. If nothing is done, external dependence (on coal, oil and gas) will reach 70% in 20-30 years time, against the current 50%.
- Increasing the penetration of Renewable Energy Sources – doubling their share in the energy supply quota from 6 to 12 % and raising their part in electricity production from 14 to 22 % is an objective to be attained between now and 2010.
- Energy market liberalisation – the Single EU energy markets will change the production, distribution and supply of energy to the benefit of society.
- Industrial competitiveness – developing and improving solutions for the integration of renewables and distributed generation will create new markets and business opportunities, especially for SMEs. The export potential for such technologies is particularly high in a rapidly growing world energy market, the largest geographical portion of which is devoid of transmission and distribution networks.
- Economic and social cohesion – remote regions and island communities will benefit greatly from the possibilities offered by the development of decentralised energy technologies. Employment, for example in the agricultural biomass sector, will also be stimulated.

Quite apart from all of these political drivers, there are also sound technical and economic reasons for promoting the integration of RES and distributed generation (DG). For example :

- Local generation reduces energy transmission losses, helps to avoid congested areas in the existing transmission grids and enables the use of by-product heat, thus improving overall system efficiencies. Power quality and reliability can also be enhanced.

- RES and DG can be brought on-line much more quickly. Capital exposure and risk is reduced and unnecessary capital expenditure avoided by closely matching capacity increases to local demand growth.

4.3 EU directives regarding integration & interconnection

The support of renewable energy sources is one of the key issues in European energy policy. One of the most relevant milestones was established in September 2001 with the adoption of the Directive on the promotion of electricity produced from renewable energy sources in the Internal Electricity Market (RES Directive). Included in this Directive are indicative targets, which have resulted in the distribution of the global EU goal (22% renewable electricity supply in 2010) over the individual Member States, as well as the recommendation to Member States to take appropriate measures to achieve them. The most relevant milestone was established in September 2001 with the adoption of the Directive on the promotion of electricity produced from renewable energy sources in the Internal Electricity Market (RES Directive). Included in this Directive are indicative targets, which have resulted in the distribution of the global EU goal (22% renewable electricity supply in 2010) over the individual Member States, as well as the recommendation to Member States to take appropriate measures to achieve them.

5 Costs and Charges

5.1 Description of investment costs of integration & interconnection:

The main cost elements for the production of RES are investment costs, operational costs, balancing costs and grid costs. For RES, the owner of the production device has traditionally only been accountable for the investment cost, the operational cost and perhaps part of the costs of connecting the device to the grid. Balancing costs, which are particularly significant when it comes to wind energy, have been borne by "the system". The costs borne by the RES owner have traditionally been compensated with a subsidy and a fixed electricity price (feed-in-tariff), independent of the market value of physical electricity. Therefore, the investment decisions of a RES investor are not related to the actual value of electricity in the given location.

	Wind generators Landbased	Wind generators offshore	PV	Microturbines	Fuel cells	Stirling engines	Reciprocating engines	Steam cycle
Size, kW	10-3000	3000-6000	< 1-100	25-500	5-3000	2-500	50-25000+	10000
Installed costs, /kW	950-1500	1100-1650	6000-10000	1000-1800	1000-2000	- 1800	250-1500	1000-2000
Operation and maintenance costs, /kW	No	No	No	Low	Almost no	Low	Fairly low	Fairly low
Availability on demand	Low	Low	Low	High	High	High	High	High
Commercial status	Available well established	Available well established	Available	Available coming into commercial application	2005	Available newly introduced	Available well established	Available well established
Application	Green power remote locations	Green power remote locations	Green power base load	Co-generation back-up peak reduction Natural gas	Power quality base load	Co-generation back-up peak reduction	Back-up co-generation peak reduction	Co-generation
Fuel	-	-	-	Natural gas	Natural gas	Any heat source	Natural gas, diesel, biofuel	Natural gas, diesel, biofuel

Low availability of these technologies can be explained by uncertainty in energy source

Figure 15: An overview of different DG technologies

5.2 Tariffs

The main barrier for the Distributed Generation projects development is the price/profitability, compared both to other business barriers and to the whole of the analyzed barriers. The other business barrier practices have a minor impact. It is a fact that most of the barriers, no matter its type (technical, regulatory, monopoly), can be translated to money.

High costs: especially for small plants due to the fact that most of the times no difference is made in interconnection requirements between big and small plants. In some regions the connection fees are too high in proportion to produced electricity. There is also a need of low cost standardized equipment, for example, islanding protection can cost 350€/kW or more. Moreover, grid operators often charge excessive measurement and accounting (metering) prices.

Uplifts tariffs: The rate to be charged by the distribution utility to the DG producer for transmitting his energy

5.3 Taxes and incentives (General and common in EU, not country specific)

Fiscal measures

Fiscal measures can be used in different ways for supporting renewable energy. First the investment can be stimulated by some special fiscal measures. (i.e. subsidy, VAT reduction). Secondly producers or consumers can get a tax exemption if they produce or use renewable energy. This is normally based on an exemption per kWh.

Green pricing

If enough consumers are willing to pay an extra price for renewables, a support scheme is not necessary. This extra is called Green pricing. It is an option provided by electricity providers (utilities, brokers and stand-alone producers) that allows their customers to support investment in renewable energy technologies. Through green pricing, participating customers pay a premium on their electricity bill to cover the extra cost of the renewable energy.

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