Europe: Impact of Dispersed and Renewable Generation on Power System Structure

8.1 Introduction

In Europe the dependency on imported primary energy is increasing annually. As a countermeasure against this growing dependency, national programs inside the European Community are directed at increasing the share of renewable energy sources and the efficiency of power generation by cogeneration of heat and power (CHP). Targets have been set by the European Commission for each country to gain a sustainable electricity supply in the future.

Generally, the share of renewable energy sources has to be increased by 2010 from 14% to 22% and the share of CHP has to be doubled from 9% to 18%.

Today approximately 50 GW of wind power are operated in Europe, and about 50 % of it is located in Germany. Assuming that wind power production will grow primarily in the form of large wind farms feeding into the transmission grids with an additional 35 GW installed power by 2010, the dispersed generation based on CHP and small renewable sources shall achieve an additional growth to meet the mentioned goals.

The output of most of the renewable energy sources depends on meteorological conditions and the CHP output is driven by the demand for heat. The question arises, how can the power system be operated with such a large share of mostly non-dispatched power sources? How can the reserve power be limited, which is required for compensation of power fluctuations and ensuring a safe network operation?
Thus, it has become clear that advanced planning and energy management approaches have to be introduced to ensure that the existing high level of power quality will exist in the future as well.

In this context, the power system of the future might consist of a number of self-balancing distribution network areas. In each of these areas a significant share of the power demand will be covered by renewable and CHP generation. However, the power balance of these areas should be planable and dispatch able in such a way that the import or export of power from or into the higher-level network has to follow a schedule, which can be predicted with a high level of accuracy in advance.

As the result of this future set-up, the distribution networks will become active and have to provide contributions to such system services like active power balancing, reactive power control, islanded operation and black-start capability. These services have to be coordinated with the transmission system operators where the responsibility for system stability will be allocated in the future as well. On the other hand, large-scale integration of wind power at the transmission level combined with an international area for trading energy will lead to higher utilization of the transmission grids. Consequently, the transmission capability has to be strengthened and short-term congestions have to be managed in an efficient and innovative way.

8.1.1 New Challenges

Each of these trends creates new challenges for power system operation on all of its levels and requires the introduction of advanced and economic solutions concerning:

- Supervisory control for congestion management
- Real-time security assessment
- Coordinated centralized and decentralized energy management including the unit commitment based on predictions of fluctuating power sources, demand side and storage management
- Coordinated trade of energy and transmission capacity.

The new tasks require a significant growth of information exchange. Communication networks using the existing infrastructure with different communication technologies like radio channels, power line carrier, fiber optics or traditional telecommunication cables will be the means of exchange. International communication standards shall be applied to simplify the engineering and operation of these new types of communication networks.

Under these mentioned circumstances the interplay of transmission and distribution will reach a new quality.

8.2 Distributed Generation: Challenges and Possible Solutions

Distributed generation (DG), for the moment loosely defined as small-scale electricity generation, is a fairly new concept in electric energy markets, but the idea behind it is not new at all. In the early days of electricity generation, distributed generation was the rule, not the exception. The first power plants only supplied electric energy to customers connected to the '*microgrid*' in their vicinity. The first grids were DC based, and therefore, the supply voltage was limited, as was the distance covered between generator and consumer. Balancing supply and demand was partially done using local storage, i.e. batteries, directly coupled to the DC grid. Today, along with small-scale generation, local storage is also returning to the scene.

Later, technological evolutions, such as transformers, led to the emergence of AC grids, allowing for electric energy to be transported over longer distances, and economies of scale in electricity generation led to an increase in the power output of the generation units. All this resulted in increased convenience and lower per-unit costs. Large-scale interconnected electricity systems were constructed, consisting of meshed transmission and radially operated distribution grids, supplied by large central generation plants. Balancing supply and demand was done by the averaging effect of the combination of large amounts of instantaneously varying loads. The security of supply was guaranteed by the built-in redundancy. In fact, this interconnected high-voltage system made the economy of scale in generation possible, with the present 1.5 GW nuclear power plants as a final stage in the development. Storage is still present, with the best-known technology being pumped hydro plants.

In the last decade, technological innovations and a changing economic and regulatory environment resulted in a renewed interest for DG. This is confirmed by the IEA [1]. This chapter presents the technical challenges and possible solutions when large amounts of distributed generation are introduced.

8.2.1 Drivers for DG

The IEA identifies five major factors that contribute to the renewed interest in DG. These five factors can be grouped under two major driving forces, i.e. electricity market liberalization and environmental concerns. The developments in small-scale generation technologies have been around for a long time, but were as such not capable of pushing the ''*economy of scale*'' out of the system. Although it is sometimes indicated, it may be doubted that DG is capable of postponing, and is certainly not capable of avoiding, the development of new transmission lines, as, at the minimum, the grid has to be available as backup supply.

8.2.1.1 Liberalization of electricity markets

There is an increased interest from electricity suppliers in DG, because they see it as a tool that can help them fill in niches in the market, in which customers look for the best-suited electricity service. DG allows players in the electricity sector to respond in a flexible way to changing market conditions. In liberalized markets, it is important to adapt to the changing economic environment in the most flexible way. DG technologies in many cases provide flexibility because of their small sizes and assumed short construction lead times compared to most types of larger central power plants. However, the lead-time reduction is not always that evident. For instance, public resistance to wind energy and use of landfill gasses may be very high.

Many DG technologies are flexible in several respects: operation, size and expandability. Making use of DG allows a flexible reaction to electricity price evolutions. DG then serves as a hedge against these price fluctuations. Apparently, this is the major driver for the US demand for DG, i.e. using DG for continuous or peaking use (peak shaving). The energy efficiency is sometimes very debatable. In Europe, market demand for DG is, for the moment, driven by heating applications (through CHP), the introduction of renewable energies and potential efficiency improvements.

The second major driver of US demand for DG is quality of supply or reliability considerations. Reliability problems refer to sustained interruptions, being voltage drops to near zero (usually called outages). The liberalization of energy markets makes customers more aware of the value of a reliable electricity supply. In many European countries, the reliability level has been very high, although blackouts have occurred in recent years.

Customers do not really care about supply interruptions, as they do not feel it as a great risk. However, this may change in liberalized markets. A high reliability level implies high investment and maintenance costs for the network and generation infrastructure. Because of the incentives for cost-effectiveness that come from the introduction of competition in generation and actions from regulators aiming at short-term tariff reductions for network companies, it might be that reliability levels decrease. However, having a reliable power supply is very important for society as a whole, and industry specifically (chemicals, petroleum, refining, paper, metal, telecommunications, …). Companies may find the grid reliability to be of an insufficient level and decide to invest in DG units in order to increase overall reliability of supply to the desired level.

Apart from 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 [2]. Thus, strictly speaking, power quality encompasses reliability.

Insufficient power quality can be caused by failures and switching operations in the grid, mainly resulting in voltage dips, interruptions, and transients and by network disturbances from loads yielding flicker (fast voltage variations), harmonics, and phase imbalance. The nature of these disturbances is related to the 'short-circuit capacity', being a measure for the internal impedance in the grid, depending on its internal configuration (e.g. length of the lines, short-circuit capacity of generators and transformers) [3].

DG could partially serve as a substitute for investments in transmission and distribution capacity (demand for DG from T&D companies) or as a bypass for transmission and distribution costs (demand for DG from electricity customers). This is only possible to the extent that alternative primary fuels are locally available in sufficient quantities. For example, increased use of DG could result in new congestion problems in other networks, such as the natural gas distribution network.

Finally, DG can also contribute in the provision of ancillary services, including those necessary to maintain a sustained and stable grid operation of the customers. This may be the capability of the grid operator to generate active power on demand, for instance to stabilize a dropping frequency due to a sudden under capacity in generation or excess demand, or reactive power to support the voltage.

8.2.1.2 Environmental Concerns

At present, environmental policies are probably the major driving force for the demand for DG in Europe. Environmental regulations force players in the electricity market to look for cleaner energy solutions. Here, DG can also play a role, as it allows optimizing energy consumption of firms that have a large and constant demand for heat. Furthermore, most government policies aiming to promote the use of renewables also results in an increased impact of DG technologies, as renewables, except for large hydro and wind parks (certainly off-shore), have a decentralized nature.

8.2.2 Grid Protection and DG

Power can flow in a bi-directional way within a certain voltage level, but it usually flows uni-directionally from higher to lower voltage levels, i.e. from transmission to distribution grid. An increased share of DG units may induce power flows from low into medium-voltage grid. Thus, different protection schemes at both voltage levels may be required [4].

Safe operation and protection are to be guaranteed at all times. In addition, the protection system has to be sufficiently selective; in order to optimize reliability and availability of supplied power. This is less simple than it seems, since the fault current not only comes from the main power system grid in a unidirectional way, but also from the DG units, making detection far more complicated and the conventional hierarchy (selective) protection methods might fail. Therefore, a more 'active' protection system with some form of communication is required to keep up the required level of safety in the future.

The protection problems are illustrated by using a distribution system with five feeders in Figure 8.1. If a short circuit occurs at F2 or F3, the short-circuit current is supplied by the generators connected to this Feeder (G1 and G2), other DG units in adjacent feeders, and the main grid. If the contribution to the short-circuit current of G1 and G2 is large compared to that of the grid and the other Feeders, the current through the circuit breaker and fuse CB1 might be too low to operate in order to eliminate the short circuit in the feeder. On the other hand, if the contribution to the short-circuit current from generators in adjacent feeders is significant, healthy feeders (Feeder 4) might be disconnected before the faulty feeder is disconnected.

As long as islanding is not intended to backup a loss of mains, it should be avoided [5]. According to technical standards (e.g. IEEE 1547), DG must be automatically disconnected when faults or abnormal conditions occur, with the assumption that interconnection systems detect such conditions.

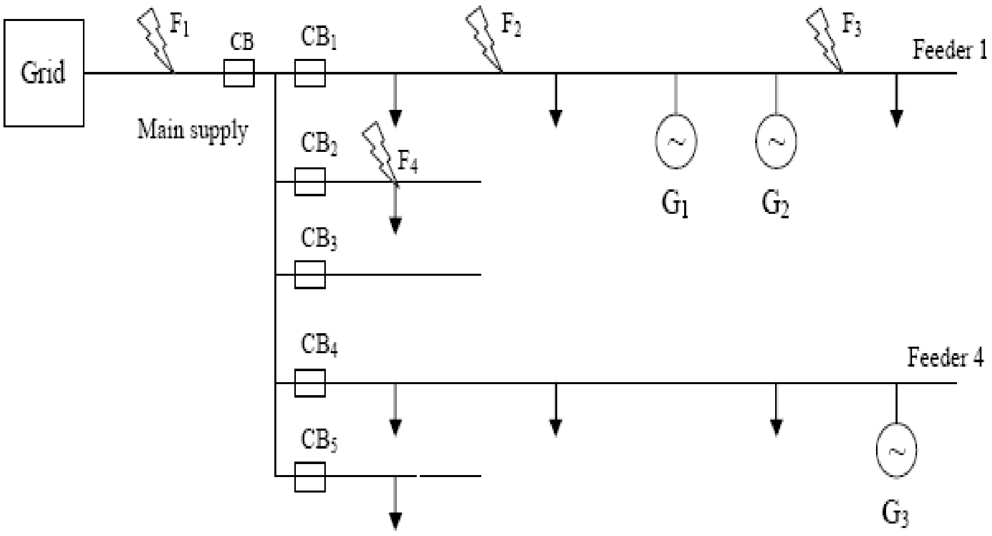


Fig. 8.1. Grid with Safety Problems due to High DG Penetration

In this way, conventional protection selectivity can be restored, guaranteeing person and equipment safety. In the future, when more DG is used, this requirement would reduce expected benefits of DG. To make optimal use of DG, unnecessary disconnection of DG should be avoided. Generators should be able to ride through minor disturbances [6].

DG flows can reduce the effectiveness of protection equipment. Customers wanting to operate in 'islanding' mode during an outage must take into account important technical (e.g. the capability to provide their own ancillary services) and safety considerations, such that no power is supplied to the grid during the time of the outage. Once the distribution grid is back in operation, the DG unit must be resynchronized with the grid voltage.

8.2.3 Voltage Quality and DG

Imbalances between demand and supply of electricity cause the system frequency to deviate from its rated 50/60 Hz value. These deviations should be kept within very narrow margins, since the proper functioning of many industrial and household applications depends on it. In economic terms, system frequency can be considered as a public good. As a consequence, the transmission grid operator is appointed to take care of the system frequency as well as of other services with a public good character that need to be provided.

The installation and connection of DG units are also likely to affect the system frequency. These units will free ride on the efforts of the transmission grid operator or the regulatory body to maintain system frequency. They will probably have to increase their efforts and have an impact on plants efficiency and emissions. Therefore, the connection of an increasing number of DG units should be carefully evaluated and planned upfront.

The relation between DG and power quality is an ambiguous one. On the one hand, many authors stress the beneficial effects of DG for power quality problems [1], including the potential positive effects of DG for voltage support and power factor corrections [4].

On the other hand, large-scale introduction of decentralized power generating units may lead to instability of the voltage profile: due to the bi-directional power flows and the complicated reactive power equilibrium arising when insufficient control is introduced, the voltage throughout the grid may fluctuate. Eventually an '*islanding*' situation may occur in which a local generator keeps a part of a disconnected grid energized leading to dangerous situations for the repair personnel coming in.

Others also stress the potential negative externalities on power quality, caused by the installation of DG capacity. According to [7], the impact on the local voltage level of DG connected to the distribution grid can be significant. The same reaction was noted through the CIRED questionnaire [8], where, next to the general impact on power quality, a rise in the voltage level in radial distribution systems is mentioned as one of the main technical connection issues of DG. The IEA [1] also mentions voltage control as an issue when DG is connected to the distribution grid. This does not need to be a problem when the grid operator faces difficulties with low voltages, since in that case the DG unit can contribute to the voltage support. But in other situations it can result in additional problems.

Small and medium-sized DG units often use asynchronous generators that are not capable of providing reactive power. Several options are available to solve this problem. On the other hand, DG-units with a power electronic interface are sometimes capable of delivering reactive power.

Some DG technologies (PV, fuel cells) produce direct current. Thus, these units must be connected to the grid via a DC–AC interface, which may contribute to higher harmonics. Special technologies are also required for systems producing a variable frequency AC voltage. Such power electronic interfaces have the disadvantage that they have virtually no 'inertia', which can be regarded as a small energy buffer capable to match fast changes in the power balance. Similar problems arise with variable wind speed machines [7].

8.2.4 Practical Distribution Network

An existing Belgian medium voltage distribution system segment has been used to study the power quality and voltage stability with different DG units (Figure 8.2). The system includes one transformer of 14 MVA, 70/10 kV and four cable feeders. The primary winding of the transformer is connected to the transmission grid and can be considered as an infinite node. Normal operation of the distribution system is in radial mode and the connections at node 111 with feeders 2, 3 and 4 are normally open.

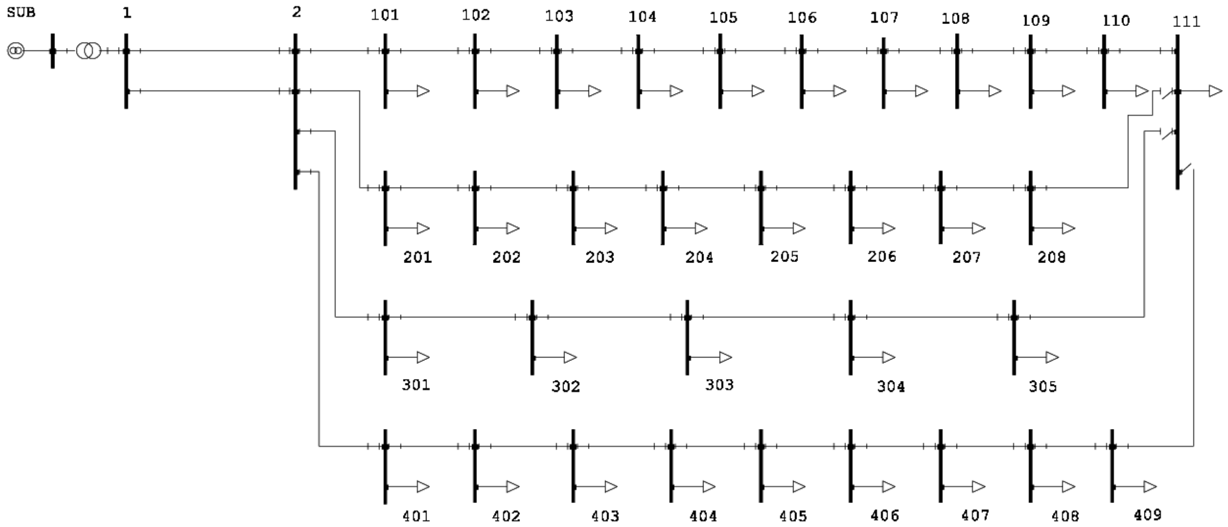


Fig. 8.2. Practical Distribution System

A DG unit is connected at node 406 of Feeder 4. The total load in the system is 9.92 MW, 4.9 MVAr. A synchronous and an induction generator are simulated with different power output. The synchronous generator is simulated at power factor 0.98 leading at 3 and 6 MW. The induction generator is simulated at power factor 0.95 lagging also at 3 and 6 MW. The power of the DG for both synchronous and induction generators raises the voltages of Feeder 4, compared to the base case without DG (Figure 8.3). For higher active and reactive power generation (synchronous 6 MW), an over voltage occurs at node 406 and its neighbors.

Figure 8.4 illustrates the voltage at node 406 with different power generation levels and power factors. Compared to the case where DG only injects active power or operates at the unity power factor, synchronous generators raise the voltage of the system faster due to reactive support. For induction generators, the voltage rise is slower and at a certain level of power generation, the voltage starts to decrease. This is due to the fact that induction generators need reactive power, yielding in a reduction of the voltage rise.

Through this study, it can be seen that the impact of induction generators is less than that of synchronous ones in terms of voltage rise (Figure 8.5). If an over voltage occurs with a synchronous generator, it has to operate under-excited and to absorb reactive power instead of injecting it.

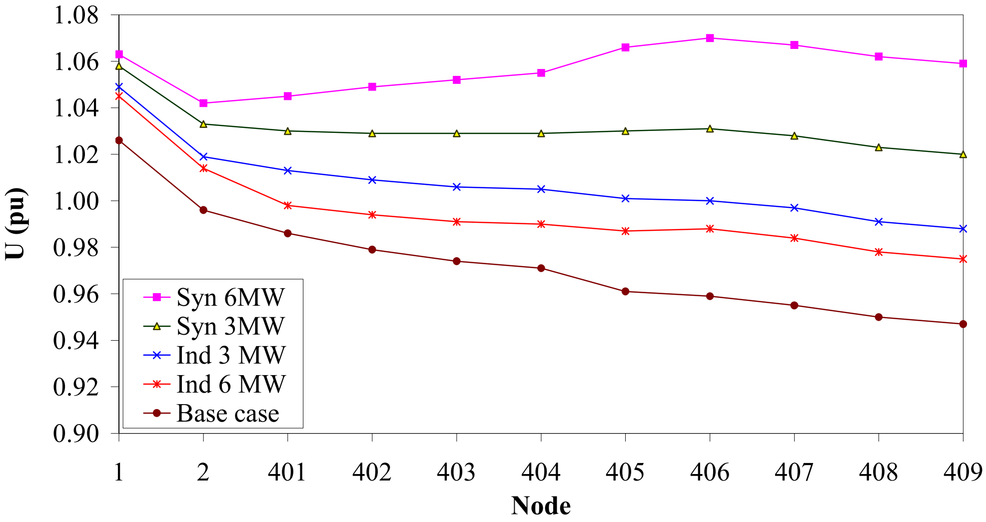


Fig. 8.3. Voltage Profile of Feeder 4 with DG Connected at Node 406

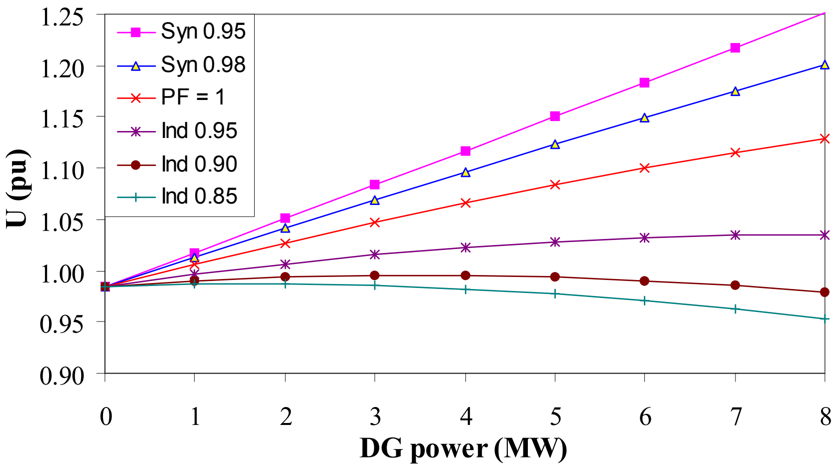


Fig. 8.4. Voltage at Node 406 with Different Power Factors

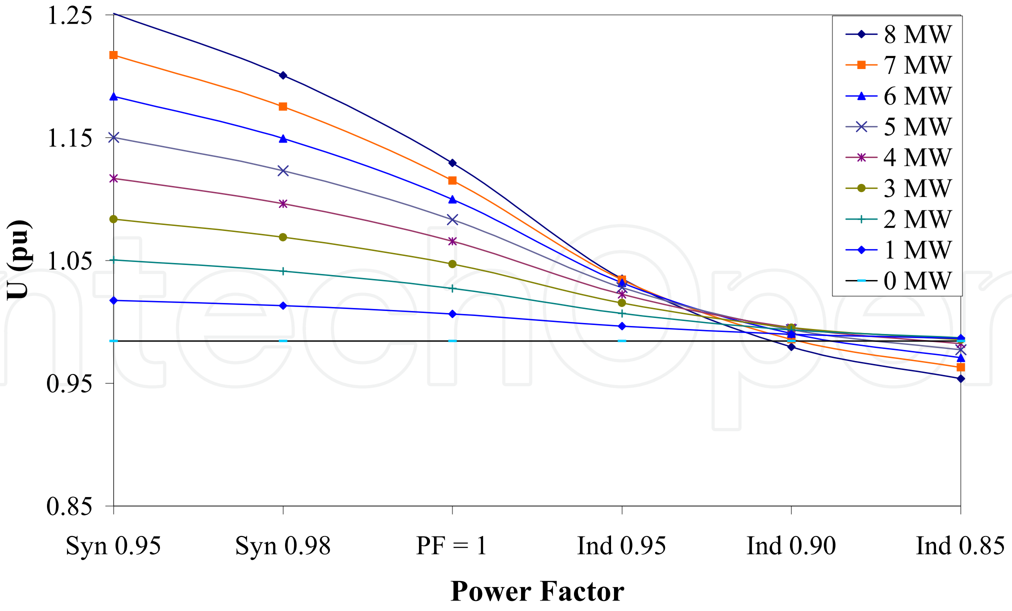


Fig. 8.5. Voltage at Node 406 with Different Power Generation Levels

In order to see the voltage fluctuation problem with DG, a photovoltaic (PV) system is used. The reactive power is produced by a capacitor of the inverter's grid filter and is almost constant. The PV system is treated as a PQ node with negative active power. The PV power is calculated from 5-s average irradiance data measured during one year in Leuven, Belgium. In this study, a PV array with 50 kW rated peak power is connected at node 304. Figure 8.6 shows the one-hour power output of the PV system at noon of a slightly cloudy summer day. In order to isolate the voltage fluctuation impact of PV from short-time load variation at individual nodes, the loads are assumed constant during the calculation. The total load in the system is 4.4 MW, 1.9 MVAr. In Figure 8.6, the voltage fluctuations correspond to the variations of injected active power of the PV system. At times when clouds cover the sun, the power generated can quickly drop by 60%, causing sudden variations in node voltages in the range of 0.1%. The installed capacity of PV in this study is rather low compared to the capacity of the distribution system and the loads, so the value of voltage fluctuation is limited. However, with a high connection density or the connection of a large PV system, the voltage fluctuation problem might become more severe.

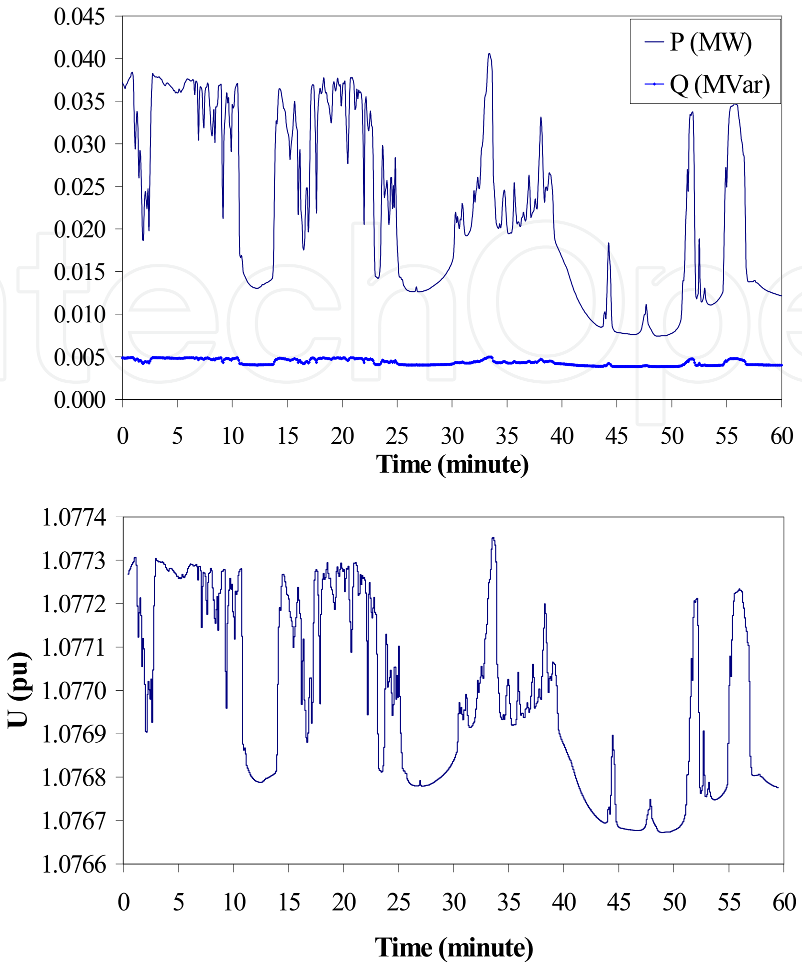


Fig. 8.6. Injected Power and Voltage at Node 304

A total DG capacity of 30% of the total system load is distributed equally over nodes 108, 204, and 406. The simulations have been carried out for induction and for synchronous generators. All operate at power factor 0.98 lagging. One of the 1-2 lines is opened during dynamic simulations at time t = 100 s. The distributed generators are connected at node 108, 204 and 406 with rated power 1 MW for both synchronous and induction generators.

The voltage dips are highest with constant power load characteristic and lowest with impedance load characteristic for both synchronous and induction generators (Figure 8.7 and Figure 8.8). With synchronous generators, after a short voltage dip, the voltage recovers close to the voltage level before the disturbance. For induction generators, the voltage does not recover due to the lack of reactive power support. There is not a big difference between a voltage dip in the base case and with DG connection, being around 1%. So the connection of DG in the distribution system does not affect dynamic voltage stability significantly. In most cases it reduces the voltage dip value.

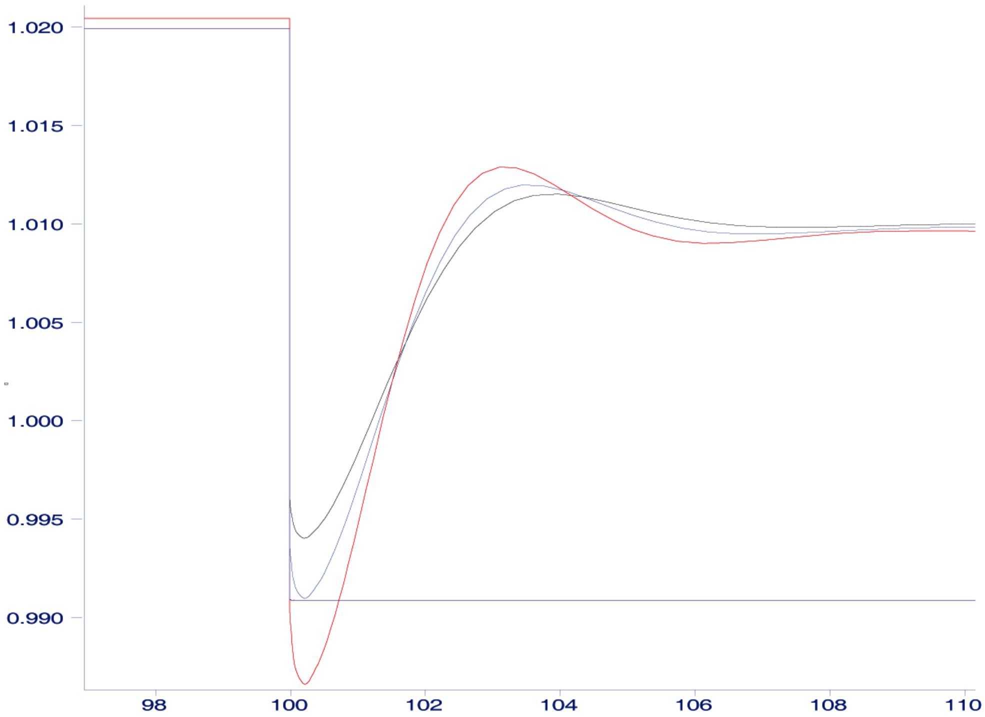


Fig. 8.7. Voltage Dip at Bus 2 with Synchronous Generator

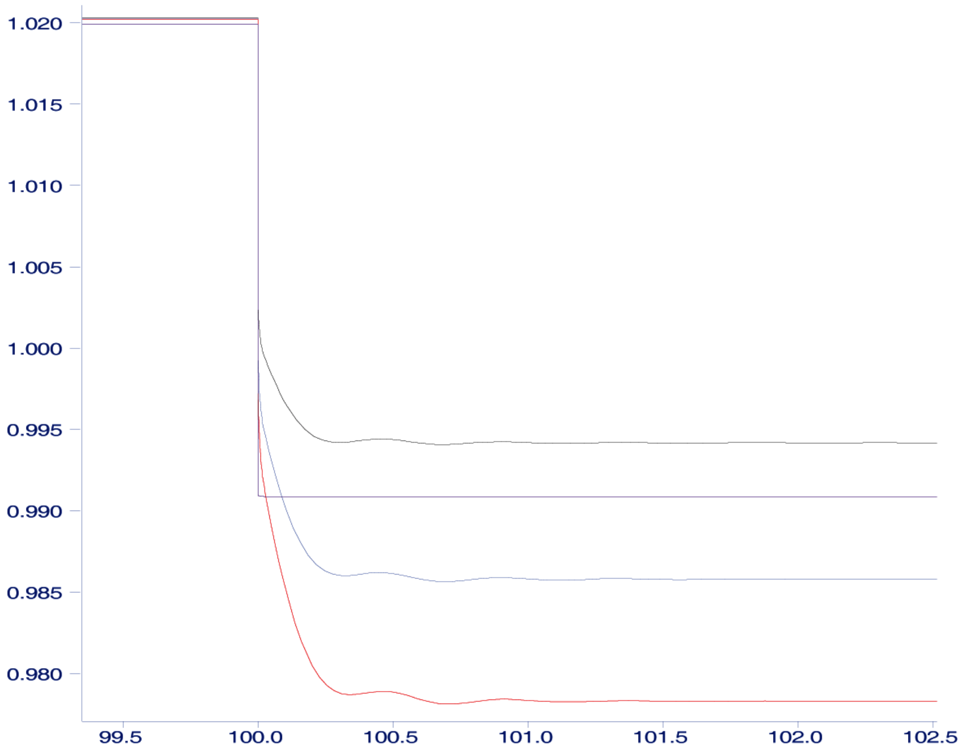


Fig. 8.8. Voltage Dip at Bus 2 with Induction Generator

In order to see the voltage dip problem when a DG starts up, an induction generator connected at node 108 with rated power of 3 MW is tested at lagging power factor of 0.9. When the induction generator starts up, it causes a transient and a voltage dip of up to 40%

in the system and lasts for several seconds (Figure 8.9). It is due to an initial magnetizing inrush transient and power transfer to bring the generator to its operating speed [9]. This results in a major problem for sensitive loads connected near the DG. If the distribution system is equipped with an under-voltage relay and the DG unit has islanding protection, the voltage dip may lead to an action of the protection relay resulting in an outage of the system. A soft-start circuit is required for large connected induction DG.

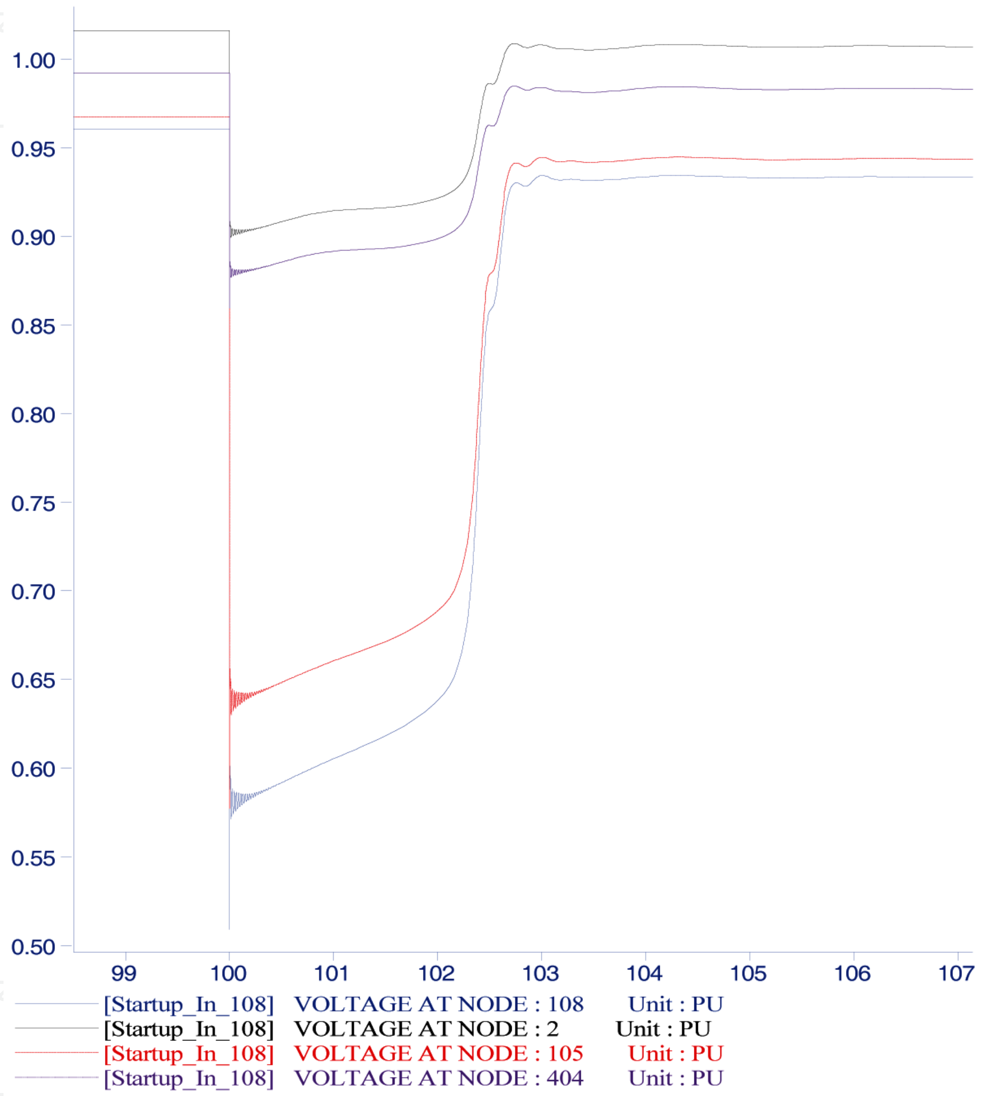


Fig. 8.9. Voltage Dip when an Induction Generator Starts Up

The voltage stability was studied for synchronous and induction generators with three cases of DG connection: a) one DG unit connected at node 108, b) one at node 2, c) DG units distributed in the system at nodes 108, 204, 406. The total load of the system is 9.92 MW, 4.9 MVAr, all impedances. The total installed capacity of the DG units in all cases is 3 MW. The voltage stability at node 111, at the end of feeder 1, was studied. DG units generally increase the voltage and support stability in the system (Figure 8.10 and Figure 8.11), however the connection point of the DG influences the voltage stability in the system. DG strongly supports the voltage at nearby nodes and has less impact on distant ones. This is also true for the other load characteristics. Compared to induction DG, the synchronous generator has a larger impact on the voltage stability because of its capability of reactive power injection. On the other hand, the influence of induction DG on voltage stability is not so different from the base case (without DG).

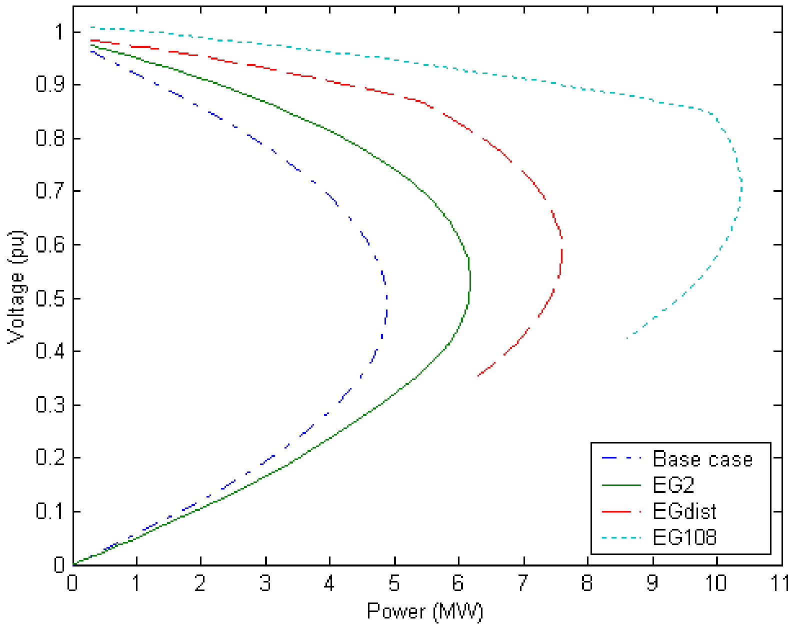


Fig. 8.10. Static Voltage Stability at Node 111 with a Synchronous Generator

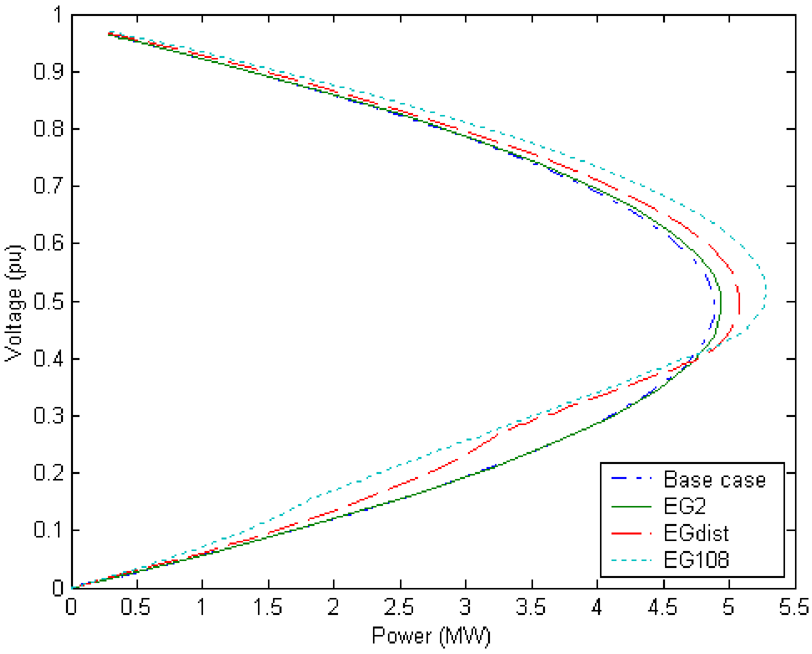


Fig. 8.11. Static Voltage Stability at Node 111 with an Induction Generator

8.2.5 Energy Security

In some discussions, energy security is linked to the diversification of primary energy supplies, while in others it is interpreted as the reliability of the electricity system. Under the first interpretation, energy security improves as the diversification of primary energy supplies increases. In this case, the advantages of DG are limited, as most technologies are directly or indirectly dependent on natural gas – with the exception of systems based on renewables.

Under the second interpretation, many authors think [1] that DG can contribute to reduce the risks and costs of blackouts. Here, DG is seen as an instrument that helps to reduce the private costs and risks of system failures for electricity customers. Others, like [8], claim that DG does not contribute to system security. On the contrary, it would have a negative effect. Such a negative impact on the system security occurs when the share of non-dispatch able generation capacity increases. Examples of such units are wind turbines, photovoltaic systems and cogeneration units closely tied to heat demand. The latter units cannot be centrally controlled because of the natural variability of their power supply. As a consequence, there is an increased need for regulating (backup) power.

8.2.6 General Summary

Section 8.2 began with the observed renewed interest in small-scale electricity generation. General elements of the drivers for this development are discussed both from the economic and environmental point of view. Small-scale generation is commonly called DG and we have tried to derive a consensus definition for this latter concept. It appears that there is no agreement on a precise definition as the concept encompasses many technologies and many applications in different environments. In our view, the best definition of DG that generally applies seems to be 'an electric power generation source that is connected directly to the distribution network or on the customer side of the meter'. Depending on the interest or background of the one confronted with this technology, additional limiting aspects might be considered. A further narrowing of this 'common denominator' definition might be necessary depending on the research questions that are being investigated. However, a general and broadly understandable description as proposed here, is required to allow communicating on this concept.

From a technical viewpoint, Section 8.2 discusses the impact on the protection and the safety of the grid. A lot of attention has been paid to the interaction of the DG units with the quality of the grid voltage. Both static and dynamic voltage analyses are used to demonstrate the interactions. The choice of generator type has a major influence: two types are distinguished, synchronous and induction; the impact of the power electronic converter that may be used was discussed. An actual grid was used for supporting the results obtained by simulations.

8.3 New Tasks Create New Solutions for Communication in Distribution Systems

8.3.1 Basic Principles and Tasks

In the environment of a growing share of dispersed and renewable generation the distribution networks will change from passive to active systems. In the power systems of the future distribution networks will also have to contribute to the system services in coordination with the transmission system. The idea of virtual power plants (VPP) will become reality where a number of dispersed and renewable generation units (partially with intermittent power output), storage units and controllable loads will be clustered and managed in such a way that the power exchange with the outer world can be scheduled and dispatched with a high level of accuracy. The decentralized energy management inside VPPs requires communication facilities that are mostly not applied in today's practice of the distribution system operation.

The efficiency of future communication networks at the distribution level requires some basic principles.

In contrast to the existing practice, where power generation is located on a rather concentrated area and, therefore, information and data is transferred on local networks or field busses, the supervisory control and dispatching of dispersed generation will be spread over a wide area. For economical reasons the pre-existing infrastructure has to be used; that also means the utilization of different communication channels like radio, fiber optics, power line carrier and telecommunication cables will be applied within one network as long as they are available in the environment.

The communication over the different physical layers has to be compliant to a common standard regarding data modeling and communication services. The main requirements for such a standard are:

- plug and play ability,
- possibilities for mapping to different physical layers,
- expandability of the data models and introduction of new models in accordance with the new and enhanced communication tasks.

Thus, if the communication network for dispatching the VPP covers a whole distribution network additional system services can be provided by the same network. Therefore, communication tasks for distribution networks of the future include:

- the contribution to the active power balancing through dispatch of power generation, storage and controllable loads in the framework of a VPP,
- the transfer of metered values as a support for the decentralized energy management and for billing,
- the provision of further system services like congestion management, reactive power and voltage control, fault location, network recovery after faults, islanded operation, black start capability etc.

The application of these ideas is investigated in the framework of the German "Network for Energy and Communication", a project sponsored by the German Ministry for Education and Research.

8.3.2 Case Study

The design of the communication network was investigated for a typical distribution network shown in Figure 8.12.

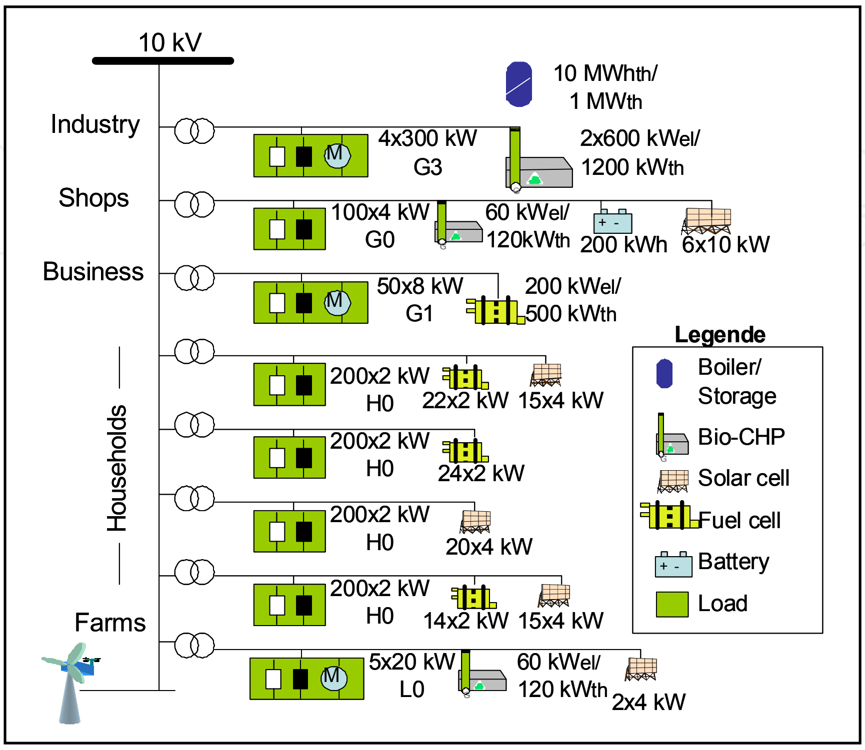


Fig. 8.12. Considered Distribution Network

Along a 10 kV feeder 8 ring main units supplying different types of low voltage consumers are connected. At the end of the feeder there is a further wind power plant.

The low voltage lines supply consumers with different load profiles in accordance with the German standard load profile types defined by the German Network Society (VDN): G3 - industry, G0 - shopping center, G1 - business center, H0 - households, L0 - rural farm. Various D&RES and storage units are located in the low voltage networks as shown in Figure 8.12. They provide their specific generation profile partially depending on weather conditions. Demand side management is planned with 12 x 20 kW in the industrial network, 10 x 2 kW in the shopping area and 40 x 2 kW in the business center.

For the distribution network described, the optimum communication network has to be designed in accordance with the following criteria:

- A maximum latency time is assigned to each class of information, e.g.

- Control with return information	2 s
- Alarm	1 s
- Event message	5 s
- Metered or measured value	2 s
- Power schedule (96 target values)	20 s

- The content and the classes of information exchange have to be defined for each active component of the network - loads, generators, storage units, substation equipment. The amount of data for communication varies by type. For example, only the metered value will be communicated every 15 minutes for non-controllable loads or photovoltaic units. On the other hand, the larger CHP plants provide 6 alarms, 24 event messages, 12 measured and 2 metered values, 6 controls, 2 target values as well as target profiles for active and reactive power.
- The volume of data transfer has to be defined in accordance with operational needs for worst case and normal scenarios. In the normal case the metered values of all components will be transferred in a 15 minutes interval. One time per day the target profiles of the generation units above 100 kW will be communicated. Furthermore, 40 target values, 20 event messages, and 10 controls will be communicated. In the worst-case scenario (e.g. voltage dip) each component will send a report with alarms and measured values, and this has to be performed within 5 s.
- The selection of the communication protocol defines the data volume for each data class. Chapter IV discusses special features of available IEC standards, in particular the application of IEC 61850.
- The selection of communication channels is based on their availability, a cost comparison of different alternatives and the baud rates providing the performance in worst case and normal scenarios.

The experience gained in initial pilot projects with VPPs [10], [11] underlined the need to apply communication protocols based on common standards for all channels used. Otherwise the engineering expenses will grow and the operation of the communication network will become inconvenient.

8.3.3 Communication Standards

The first international standards for digital communication in power systems were developed in the 1990s. These standards were limited regarding their ‘plug and play’ ability. Figure 8.13 gives an overview of the IEC standards for supervisory control in electric networks.

Only the latest standard IEC 61850 for communication in substations (published as standard in 2004) responds to the requirements of chapter II, topic 2.

The ‘plug and play’ - ability is reached by the detailed object modeling based on logical nodes (objects like circuit breaker or transformer etc.) and data (information like “status ON” or “Buchholz alarm” etc.) with the supplement of different attributes (like time stamps, validity information etc.) [12].

The mapping to different application layers was foreseen in the reference model of the standard in accordance with Figure 8.14.

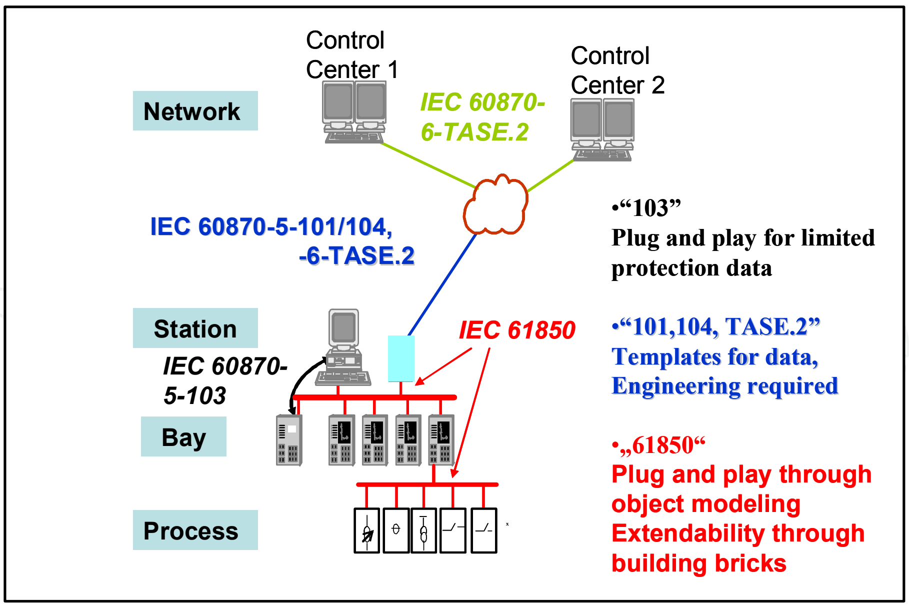


Fig. 8.13. IEC Standards for Communication in Electric Networks

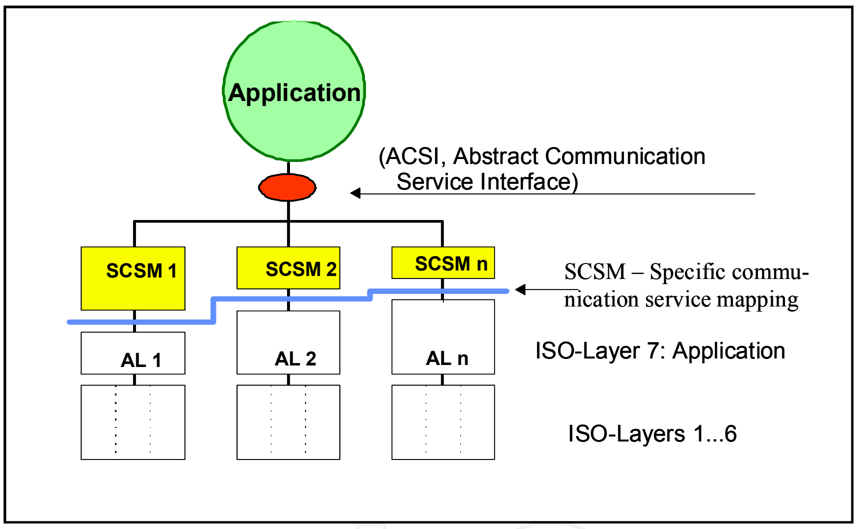


Fig. 8.14. Reference Model of IEC 61850

The abstract communication service model describes the data models and the services in an abstract form. The protocol requires the definition of all layers of the ISO/OSI model. IEC 61850 defines in Part 8.1 the 'Manufacturing Message System' (MMS) as the base for the first standard conform application layer (AL1) and Ethernet for the lower layers. The specific communication system mapping SCSM ensures the adaptation of the services and models to the layers selected. This way, IEC 61850 allows the adaptation of future communication methods to the core elements of the standard - the ACSI (described in the parts 7.1-7.4). Consequently, through the SCSM different link and physical layers can be applied.

Last but not least, the object models can be extended on demand. IEC 61850 defines the rules for building such extensions.

As a result of these features the standard IEC 61850 is suitable to serve as a general standard for all communication tasks in power systems. Therefore, the basic rules and models of IEC 61850 are inherited in the following subsequent standards:

- IEC 61400-25 for communication of wind power plants [13],
- IEC 62350 for communication of dispersed generation [14].

As a goal of the new standards it was declared that all existing services and models of IEC 61850 would be taken over, as defined and only necessary extensions will be added.

In accordance with Figure 8.12 there will be a need to communicate information from wind power plants, other D&RES and substation equipment over a common communication network. Consequently, the consistency of the data models used is mandatory.

The relevant IEC working groups of TC 57 (62350) and TC 88 (61400-25) are requested to ensure the consistency of all subsequent standards with IEC 61850. Otherwise there will be no acceptance of the new standards from both the power automation industry and the utilities.

8.3.4 Design of the Communication Network

IEC 61850 was analyzed regarding the size of telegrams for each data class. The results in Table 8.1 present the worst case, which means the maximum possible number of bytes. In practice the services of IEC 61850 create reports within a given time interval in which all changed information is to be embedded. Therefore, the net bytes will be much lower then stated. However, these figures build a good base for the communication network design. The design task consists of the distribution of the communication clients over the possible communication channels with minimum expenses and under the condition that the baud rates of the selected channels ensure the required performance in worst case and normal scenarios. A possible design of the communication network which meets the performance requirements and combines different physical channels is shown in Figure 8.15. The large CHP- plants of the industrial network play a significant role in the power balance of the distribution network and impact the energy tariff of the industrial plant. They are connected by a dedicated ISDN line that was available. The other generation and storage units in the shopping and business area as well as the access to weather forecast data (for load and renewable generation prediction) need only a dial up line. The wind power plant is connected via a radio channel with the aim to combine this kind of communication with the others.

The main load of communication is assigned to the ’Distribution Line Carrier‘ (DLC), which can reach baud rates higher than 300 kBd [15]. Over this channel the dispersed generation units in the household and rural networks communicate, the metered values of all loads are reported, the control commands for demand side management are sent out and the equipment in the substations is incorporated to provide a new class of distribution system management. For this network the installation of new communication lines was avoided.

Data class	Raw data array	Overhead Layer 7 (MMS)	Overhead Other layers	Overall
Status inform.	11	161	64	236
Control	14	1245	384	1643
Measured value	15	161	64	240
Metered value	15	161	64	240
Array (96 metered values)	1440	1320	128	2888
Target value	15	693	192	900
Schedule (96 target values)	480	388	128	996

Table 8.1. Telegram Size for Different Data Classes (Byte)

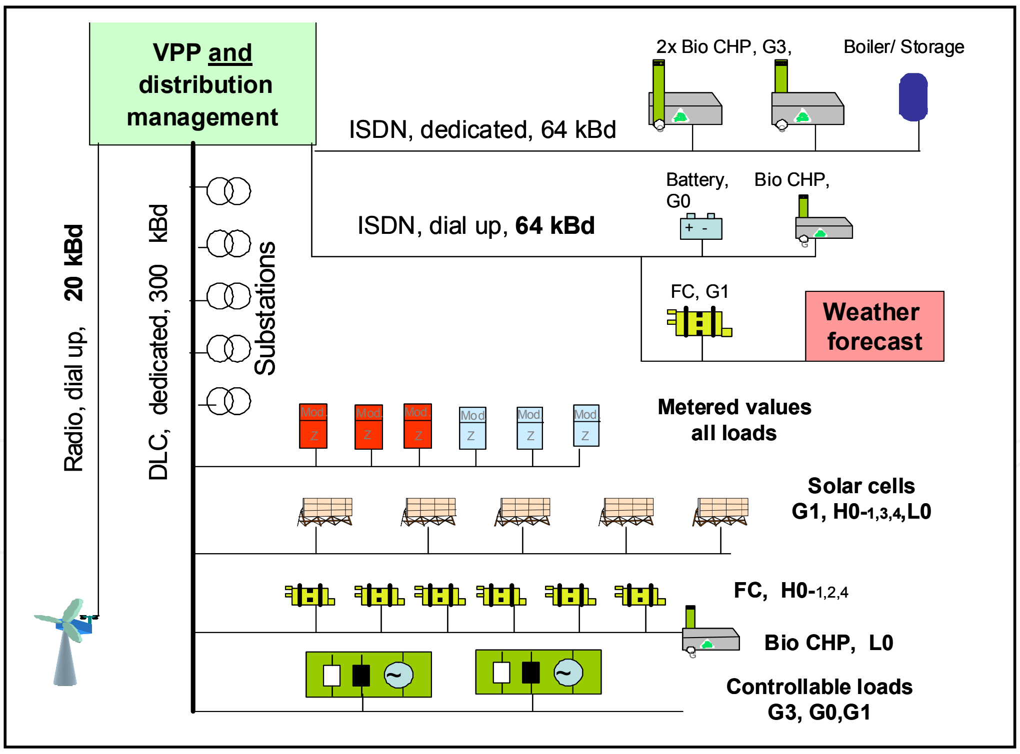


Fig. 8.15. Scheme of the Communication Network

8.3.5 Benefits for Other System Services

The availability of communication channels in the distribution level allows for the improvement of various system services. The example of a supply restoration after faults is demonstrated in Figure 8.16.

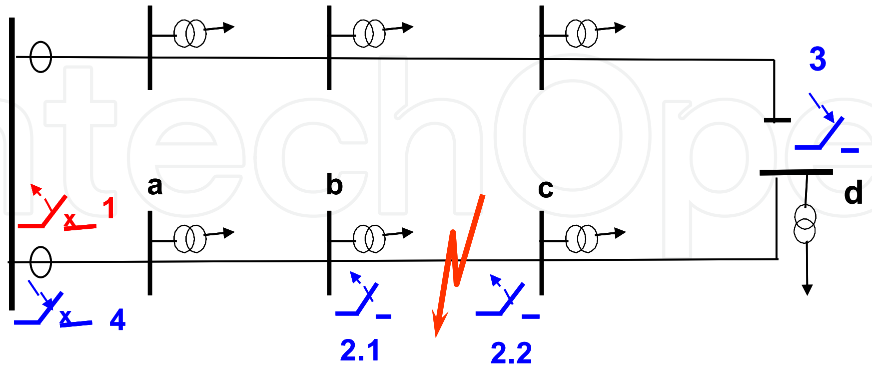


Fig. 8.16. Supply Restoration after Faults in an Open Loop

Preferably, distribution networks are operated with open loops. The loop in Figure 8.16 is disconnected in the ring main unit "d". In the event of a fault the protection of the feeding substation trips and the faulted feeder will be switched off. All ring main units (a-d) lose their supply (operation 1). Now, the maintenance staff allocates the faulted feeder part through driving along the feeder and reading the fault indicators in the ring main units. After localization the faulted part is disconnected by the switching operations 2. The restoration of supply is provided after that by the switching operations 3 and 4. The whole restoration procedure takes more than one hour on average. But, if communication channels are available in the ring main units the restoration procedure can be performed remotely. The restoration time will be shortened up to only a matter of minutes. Similar benefits can be demonstrated for other system services as well. Therefore, communication is a key to improve power quality.

In summary, the expected large-scale penetration of D&RES requires a new sharing of system services between the transmission and distribution levels. The distribution networks will become more active and communication networks have to be established for that purpose.

Setting up a cost efficient communication requires the use of existing communication channels and of standardized protocols. With the help of an example of a distribution system with different characteristics for load and generation, the design of the communication network was investigated. It was shown that IEC 61850 provides the required features to serve as a communication standard. However, the consistency of the subsequent standards IEC 61400-25 and IEC 62355 should be reached as a prerequisite for a broad acceptance in practice. Examples of actual deviations and inconsistencies are given. Furthermore, it was shown that the communication tasks of the example system can be performed by a combined communication network with dedicated and dial up communication channels on different physical media like ISDN, Distribution Line Carrier and radio transmission. The availability of communication channels in the distribution level benefits the management of system services and helps to improve the power quality.

8.4 Integrating Dispersed Generation into the Danish Power System

Denmark is electrically divided into two parts - western Denmark forms the northern part of the continental European synchronous area - and eastern Denmark constitutes the southern part of the Nordel synchronous area (Figure 8.17). The eastern and western Danish networks are planned to be connected by a High Voltage Direct Current (HVDC) link by the year 2009. As a link between the two synchronous areas, Denmark faces high-energy transits.

Since the early 1980s a huge amount of dispersed generation has been implemented into the grid - mainly in the continental European synchronous area part of Denmark, where today 23 % of the energy consumption is produced by wind turbines and about 32 % by CHP units. More than 50% of the total production capacity is implemented within local distribution grids, making control and forecasting of system operation very challenging.

Thus the transmission system operation requires careful planning as well as intelligent utilization of possibilities offered by the liberalized electricity market.

Energinet.dk is responsible for the secure and reliable operation of the power system (and natural gas), a well functioning energy market and for owning, operating and expanding the transmission infrastructure for electricity (and natural gas). Daily operation of a system with massive infeed from uncontrolled generation units is a challenging task and depends strongly on interconnections to neighboring countries and a well functioning international electricity market. The further - also international - growth of wind power capacity may lead to increasing demand for national security of supply as well as the implementation of an international market for ancillary services for the efficient utilization of the available resources.

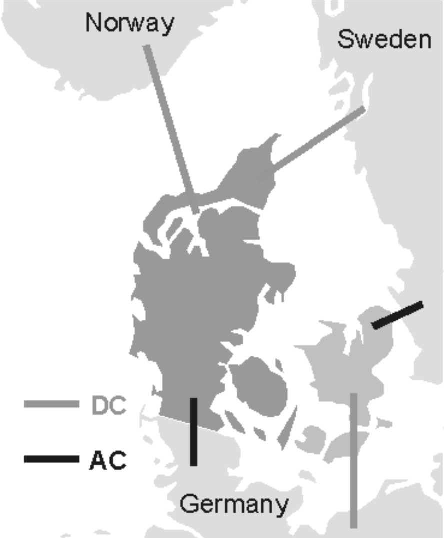


Fig. 8.17. Denmark between Two Synchronous Areas

8.4.1 System Overview

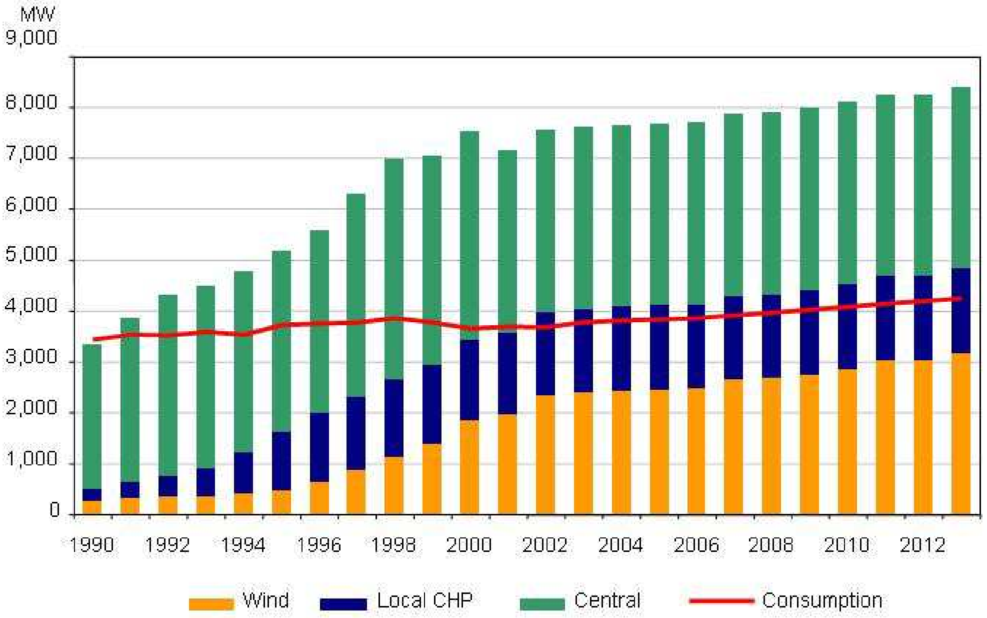
The transmission system in western Denmark is operated at 400 kV and 150 kV. To the south, it is connected to the continental European synchronous area via 400 kV, 220 kV and

150 kV AC-lines to Germany. To the north, it is connected to the Nordel synchronous area via HVDC links to Norway (1,000 MW) and Sweden (600 MW). The eastern Danish system is operated at 400 kV and 132 kV, respectively, as a meshed transmission system with AC connection to Sweden and HVDC connection to Germany.

Figure 8.17 and Figure 8.18 give the key figures of the Danish power system. The primary power plants are thermal units, fired by coal or gas. A significant part of today's installed capacity in the Danish system are decentralized units, such as wind turbines and combined heat and power (CHP) units, mostly connected to the distribution grid. This combination has resulted in a change of the classical hierarchical load flow structure - former passive networks have become active networks due to the changed load flow direction, especially on windy days.

In the western system the offshore wind farm Horns Rev A (HRA) with a rated power of 160 MW is connected to the 150 kV transmission system. The construction of the second offshore wind farm, Horns Rev B (HRB), with a rated power of 215 MW should be finished by the year 2009 [16].

In the eastern system another new big offshore wind plant with a rated power of 215 MW is planned to be operating in 2009 -2010.



Top to bottom: Central, Local CHP, Wind. Line: Consumption

Fig. 8.18. Development of the Power Balance in Western Denmark

The significant share of wind power and CHP units has introduced several technical tasks to the system operator regarding the stable, safe and reliable operation of the transmission system, such as:

- Development of technical specifications for the grid connection of wind turbines that are based on prior experience; e.g. requirements like fault-ride-through capability of large offshore wind farms [17].
- Constant improvement of wind power forecasts.
- Long- and short-term balance for the Danish power system.
- Responsibility for voltage stability and power quality.
- Wind turbine modeling as part of the Danish power system model.
- Preparation of the system for the implementation of more wind power.

8.4.2 Wind Energy

Large offshore turbines usually are located close to each other and show significant correlation between their output powers. Experience from the operation of Horns Rev A (HRA) shows that power fluctuations within 10-min intervals can be remarkable high due to the concentration of wind power in a small area of about 20 km^2 [16]. The power gradients may reach values of 15 MW/min for this 160 MW wind farm resulting in changes of generated power from none up to the rated power within 10 to 15 minutes. Without control such power fluctuations may be introduced into the transmission system and even distributed to the neighboring transmission systems.

A control system has been developed which reduces this effect [16]. This is achieved by applying power gradient limits of the wind farm and by using secondary control of the primary power plants and, additionally, using fast power control of HVCD. The main target of keeping the power balance is to adjust power generation including power import and power consumption, including power export, as well as keeping the power exchange between western Denmark and the UCTE synchronous area at the planned level.

The high share of wind power within the system results sometimes in extreme requirements for system operation due to the power fluctuations mentioned above.

An impressing example is the hurricane on the 8th of January 2005 that crossed the whole area of Denmark resulting in a disconnection of nearly the total wind production (Figure 8.19). In this case, the system operator had to handle a record high imbalance between schedule and production of more than 1,700 MW. Until now a sufficient amount of regulating power has been available in the western Danish power system to compensate for the intense power fluctuations from HRA by applying the load-frequency controller (LFC) accessing the secondary control on the central power plants.

The second offshore wind farm HRB will be located very close to the existing wind farm HRA. An analysis showed that it might be critical to compensate for the additional power fluctuations using only the domestic regulating power 16]. A part of the power fluctuations will be reduced by the offshore wind farms` control themselves. In the analysis HRB was obliged to comply with the power gradient limit of +5 MW/min. Additionally, the use of the fast power control of the HVDC- connections will be necessary to keep the power balance in the western Danish power system. This requires applying the capacity of some of the HVDC- links to the regulating power to compensate for the wind farms` fast power fluctuations.

However, the LFC control is not capable of handling the power regulation that is required for the case shown in Figure 8.19.

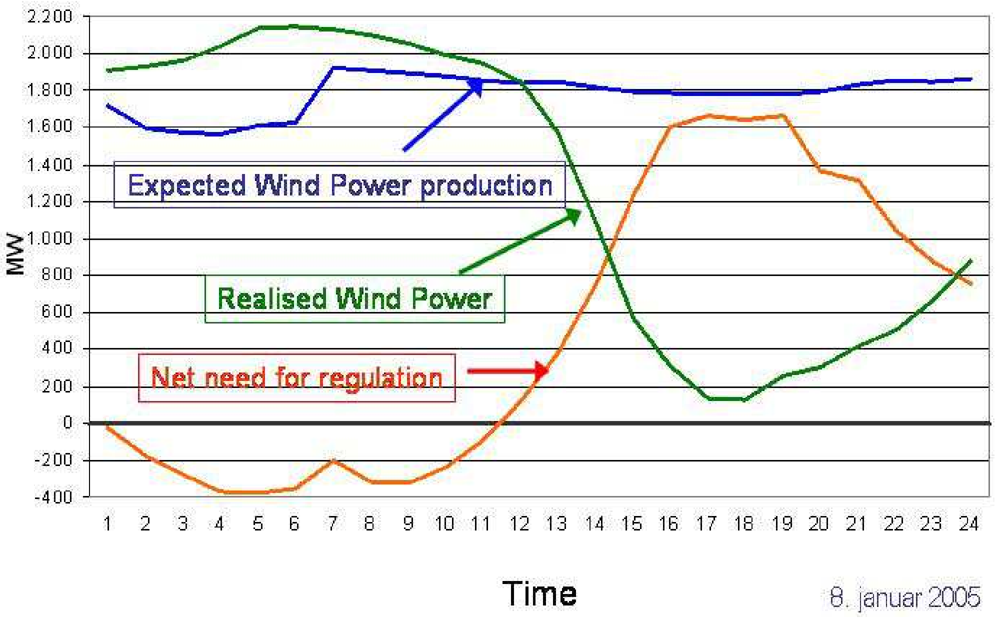


Fig. 8.19. Need for Regulation in Western Danish System during the Passing of a Wind Front

Improving forecasting systems is one of the possibilities to improve the power balance. Reliable wind forecasts are essential for power system operation in Denmark.

The planned active power from a wind farm is based on wind forecasts that are transferred to active power forecasts. The first active power forecast is made a day ahead, but can be updated during the day. The active power produced by wind farms is part of the power supplied from a group of power plants available to the Power Balance Responsible Player (PBRP). The PBRP controls the active power from this group of the power plants according to the latest power forecast in a way that complies with the planned total power production. Deviations between power forecast and the delivered total active power are injected into the transmission system and should therefore be minimized.

The aggregated western Danish wind power curve (Figure 8.20) has a very high power slope, resulting in a deviation of +320 MW for a +1 m/s wind velocity prediction fault appearing between wind speeds of 5 and 15 m/s. A relieving factor is the regional distribution of the wind turbines over the whole western Danish area.

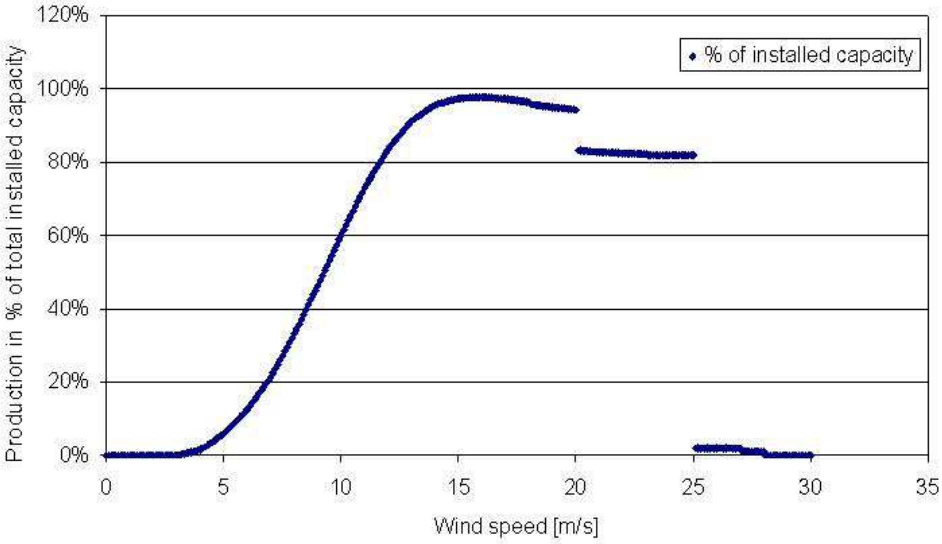


Fig. 8.20. Aggregated Wind Power Production Curve for Western Denmark

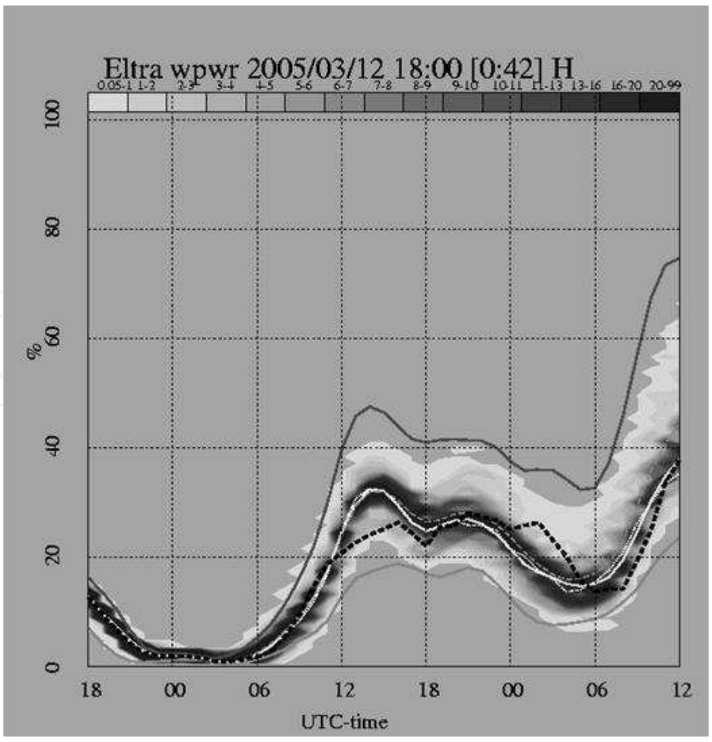
The wind forecast models have to be improved in several ways:

- Improvement of day-to-day forecasts because the amount of grid incorporated wind power is significant and still increasing (work in progress).
- Improvement of hour-by-hour forecasts: they have to comply with the power balances and planned operation of the power plants, planned power transits and consumption (work in progress).

8.4.2.1 MELTRA

In 2002, Energinet.dk funded a research project on ensemble forecasting at University College Cork (UCC), Ireland. In this context a real-time forecasting system called MELTRA was designed to meet specifically set requirements in Energinet.dk. It consists of 75 ensemble members and a graphics package for visualization of the forecasts (Figure 8.21).

MELTRA has undergone many changes since its first implementation. The upgraded 2005 system generates 3-day forecasts every hour and consists of around 6000 forecasts per day. Half of the forecasts are carried out as nested forecasts in higher resolution. The forecasts are converted into probabilities and, in combination with observations, provide the best possible forecasts of wind power. The MELTRA ensemble system is run on a 92 processor Linux cluster, which is believed to be a very cost-effective hardware solution. The resolution in the meteorological model is 45 km with a finer 5 km nested grid covering Denmark.



Grey Colors: Probability Distribution; White Curve: Average Prediction; Black Dotted Curve: Measured Production

Fig. 8.21. 48-hour Power Prediction for the Western Danish Area

The major benefits of the first year's real-time experience with the MELTRA system can be summarized as:

- Averaged over one year, the implemented ensemble technique has a potential of at least 20 % better forecasts of wind power compared to a single forecast.
- The ensemble technique is also better in predicting wind power for single sites or smaller areas than a single forecast [16].

8.4.2.2 Future requirements for further expansion of wind power

An increase of the share of wind energy up to 35 per cent of the Danish electricity demand by 2015 has been suggested and will probably be given serious consideration [18]. This requires focusing on regulation power that is available within the present frames. Several issues are under study at this time.

Utilization of domestic regulation power could be applied to further the development of price response mechanisms and better utilization of local scale CHP units introducing them to market terms.

The establishment of the planned Great-Belt connection between both Danish systems will allow for utilizing the regulating power control of both systems.

Further, the establishment of an offshore transmission system connecting the large offshore wind farms with the grids of Norway, Denmark, Germany and Holland may reduce the impact onto the Danish transmission system.

8.4.3 CHP Units

Since the energy crisis of the 1970s, small-scale CHP power plants have been established to supply local heating systems of small cities. Simultaneously industrial CHP units have been installed. This concept has been followed until today resulting in a high share of dispersed installed capacity, which is not as a matter of course available for power regulation and thus, does not contribute to system balance.

The distributed CHP-units' range in size is from a few kW up to 100 MW. Most of these units are gas turbines or gas engines. Traditionally the power production from these units depends on the heat demand, thus heat and electricity are strongly coupled. To eliminate this dependence, these units are equipped with heat storage tanks.

Most of the large thermal units are coal-fired CHP units that can extract steam for heat production. These units have an operating domain between 20 % and full power load without heat production. However, the operating domain for the power depends on the heat production - with higher heat production the minimum power load increases and the maximum power load decreases. According to the power station specifications [19], these thermal units have a regulating capability of 4 % of full load/minute in the operating domain from 50-90% and 2 % of full load/minute below 50 % and above 90 % load. Besides the normal regulating capabilities these units can disconnect the heat production and, for a short period, utilize the extracted steam for electricity generation.

Increasing security problems have led to a reconsideration of the traditional high degree of independence between TSOs and DSOs (distribution system operators).

A new control strategy shall include all local grids with DG into new responsibilities, such as control of reactive power, provision of data for security analyses, supervision of protection schemes at local CHP plants, updating under-frequency load shedding schemes and new restoration plans, including controlling dead start of local plants in emergency cases.

The implementation of such new responsibilities will require development of new control, communication and information systems. During normal operation all functions should be automatic. For emergency situations restoration plans have to be carefully prepared and trained. The targets concerning the systems redesign are:

- balance between supply and demand shall be ensured by sufficient available domestic resources
- operators need to have access to an improved knowledge of the actual system conditions, both locally and centrally
- efficient system control shall be available, especially during emergencies
- Black start capabilities using local generators shall be provided.

Presently, Energinet.dk is executing a cell controller pilot project (CCPP) defining a demonstration area of a real distribution network ("cell"), where a new concept implementing new communication systems and a new controller shall be implemented and tested according to the following ambitions[20]:

- in case of a regional emergency situation reaching the point of no return, the cell shall disconnect itself from the high voltage grid and transfer to island operation
- after a total system collapse, the cell has black-start ability to a state of island operation.

The CCPP aims to:

- gather information about feasibility and approaches to utility-scale microgrids
- develop requirements, specifications and preliminary solutions for a pilot implementation of the cell concept
- implement measurement and monitoring systems to gather and analyze data from the pilot area
- perform detailed design, development, implementation and testing of a selected pilot cell.

8.4.4 Aspects Concerning the Energy Market

The Nordic electricity market consists of several markets: the physical day-ahead market (Elspot), the hour-ahead (Elbas) trade and the real-time market for balance power (Figure 8.22).

The power plants find a Production Balance Responsible (PBR) to sell their energy production. The PBR sells the production either directly to the Nord Pool spot market or announces the capacity to Energinet.dk`s regulation power market. Energinet.dk transfers the regulation power bids to the Nordic TSOs Nordic Operational Information System (NOIS). In the NOIS a merit order list of the bids, visible to all TSOs, is composed. The present regulation measures are based on this list. Regulating power prices can differ in the event of network congestions, when several price areas have to be defined.

The residual market is a market for the production of energy that is not supplied by prioritized renewable generation. The commercial suppliers face a decreasing power demand leading to a decrease in the commercial production capacity’s utilization and thereby a reduction in profit making opportunities.

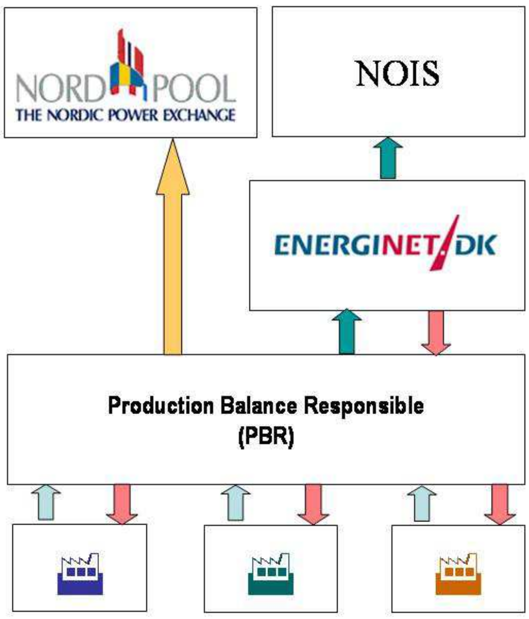


Fig. 8.22. Electricity Market Overview

8.4.4.1 SivaEl

The approach of defining the volume of the residual market is based on a fictitious west Danish 100 % thermal system with base-load and peak-load units [21]. The system is modeled in the simulation tool SIVAEL (simulation of heat and electricity), and the consequences of increased installation of wind power are analyzed by means of model simulations. The share of wind power is gradually increased from 0 % to 100 % coverage of the annual energy consumption. Two types of units are used: coal-fired base-load units and natural gas-fired gas turbines as peak-load units. Two assumptions are made; namely, base-load units are preferable when utilization times exceed 2,000 hours, whereas peak-load units are more profitable when utilization times are less than 2,000 hours. As for the calculations, the number of units and their distribution on base load or peak load are adjusted exogenously in the model in such a way that this criterion is observed.

A 100 % thermal west Danish system in 2025 with an annual consumption of about 26 TWh has been chosen as a basis in order to be able to relate the calculation results to something well known. Combined heat and power and international connections have been disregarded to maintain simplicity and generality – this means that the system must be able to make adjustments for variations in consumption and wind-power production.

The expansion of wind power is assumed to increase onshore and offshore in parallel. A maximum production of some 6 TWh onshore is assumed. Offshore, wind power production is some 20 TWh in the case of 100% share of wind power. Wind power production is included in the model as a time series based on wind-speed measurements offshore near Horns Rev and the island of Læsø and on wind-power production measurements from onshore wind turbines in Jutland and on Funen as well as from the offshore wind farm at Horns Rev.

SIVAEL solves the week-plan problem on an hourly basis and finds the optimum load dispatch with regard to start-stop, overhauls and outages. The optimum load occurs when the total variable costs are at a minimum.
Figure 8.23 shows the wind energy production, the share that can be sold immediately and the surplus electricity. It shows that the system can absorb about 30% of the wind power with no surplus electricity. On the other hand, the surplus grows substantially when the share of wind power is more than approximately 50%.

Following this idea, there will be two different residual markets: one for demand and one for overflow. The SIVAEL-Model is calculated for a share of 100 % wind power with a residual energy consumption of 8 TWh / year and a surplus energy of 8 TWh / year, thus the resulting residual market has an energy volume of 16 TWh and a capacity differential of about 9,000 MW. (Comparison: For a pure thermal system the volume of the electric energy market equals 26 TWh and the demand for capacity about 4,500 MW.)

In the future this business area can be cultivated by market players, e.g. by means of developing new products.

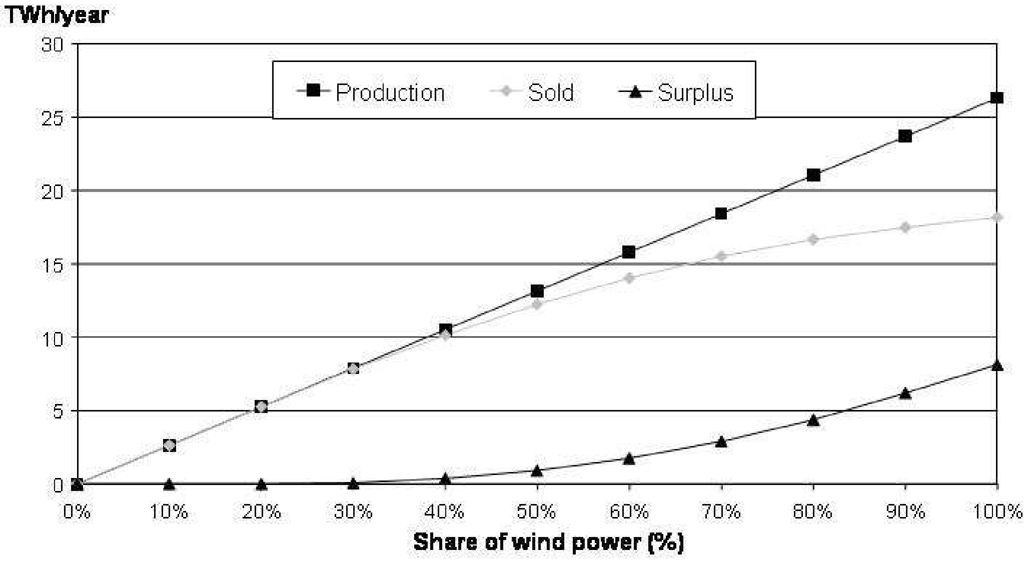


Fig. 8.23. Wind Power Production on an Annual Basis (TWh/year), the Share of Wind Power that Can Be Sold for the Assumed Consumption (TWh/year) and the Remaining Surplus

8.4.4.2 Demand response

The increasing share of wind energy has resulted in an increasing need for balance tools, which also may be located on the demand side. Demand response is defined as a short-term change in electricity consumption as a reaction to a market price signal [22]. The Nordel study [23].identifies demand response as both an alternative and a prerequisite for investments into new production capacity and recommends that all Nordic TSOs prepare action plans for developing demand response.

The TSO is responsible for maintaining the instantaneous balance between supply and demand for each control area. The TSO agrees with the supplier on the amount of power that has to be available at a certain time. If the reserve is activated it is financially compensated for according to the supplier's bid. Sometimes energy is very cheap - even free (Figure 8.24). It would be valuable to use this cheap energy rather than activating reserve energy that has to be paid for and simultaneously exporting the wind energy.

A further expansion of wind power capacity makes only sense if consumption is increased accordingly or thermal production can be reduced. Demand response manual reserves can be activated by suppliers or consumers, whereas up regulation means interrupted consumption and down regulation means extra consumption. If there is an unbalance in the system, either the production can be increased or the consumption decreased or vice versa - depending on the kind of unbalance. The smallest bid is 10 MW, and the price for being available as reserve power for the system operator can be between 27,000 EUR/MW/year and 67,000 EUR/MW/year for up regulation power and up to 20,000 EUR/MW/year for down regulation power. Thus, not only supply, but also electricity consumption should follow price signals. The former philosophy of influencing consumer behavior by means of time-tariffs or campaigns is substituted by new market products, which illustrate the market value of consumers` reaction and capitalize market gains. The system operator acts as a catalyst promoting the consumers` price flexibility. By this means utilization of cheap wind energy instead of valuable coal or oil shall be achieved. During Energinet.dk`s demonstration projects, for some big customers like such as an iron foundry, it has turned out to be economically efficient to install a parallel electricity based consumption system which is used during times of extremely low prices for wind energy.

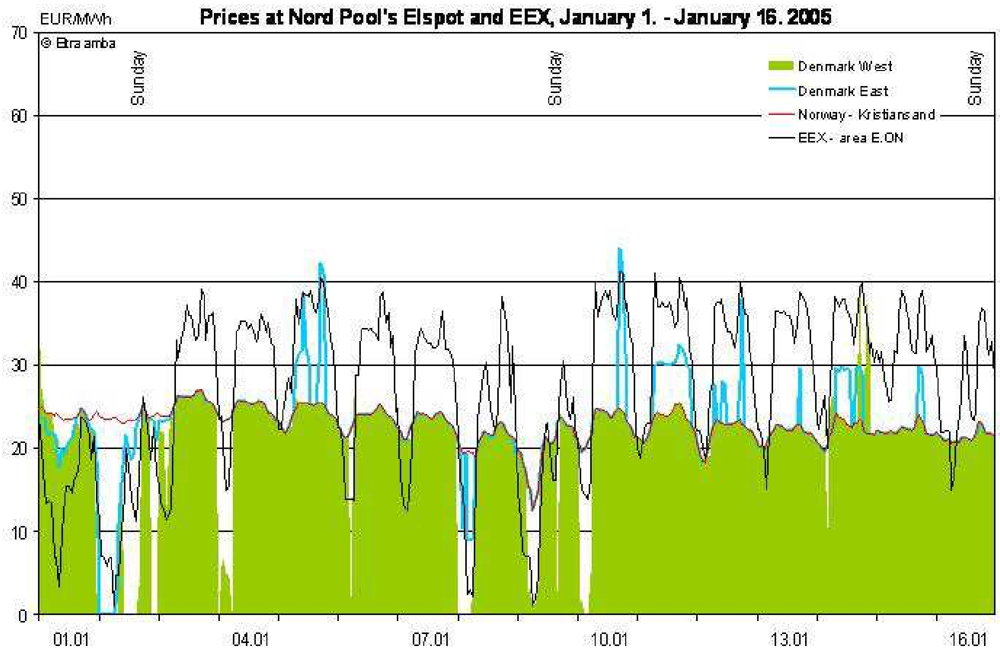


Fig. 8.24. Energy Prices in Denmark, Norway and at the EEX

In Denmark there is also a large technical potential for increased electricity consumption in district heating systems to substitute fossil fuels during periods of heavy wind production. Consequently, the substitution of primary resources is obtained and investments in non-economic peak load units can be avoided. The respective change of consumer behavior can be: moving the time of consumption to periods with lower prices; reducing or stopping consumption during periods when consumer benefit from using electricity does not exceed the price (possibly by means of substitution to another energy source); or increasing the consumption during times when the electricity price is lower than the marginal utility and the price of another energy source, e.g. during times of high wind production. This measure results in a smaller slope of the demand curve where, due to limited demand response, there may sometimes be no market clearing point found (Figure 8.25). An action plan has been made including 22 specific initiatives aiming at the development of demand response in the electricity market and all Nordic TSOs are cooperating on this topic [24].

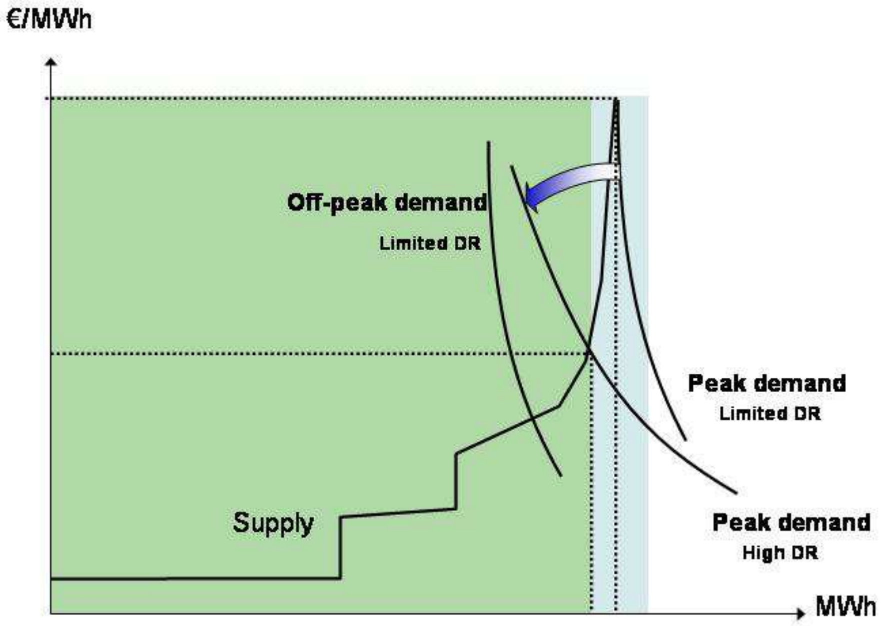


Fig. 8.25. Supply and Demand Curve for Different Elasticity Coefficients due to Grade of Demand Response

In summary, Section 8.4 has highlighted that the Danish system is facing various difficulties on several levels: Technically, a high share of dispersed generation challenges the transmission system operator who is responsible for reliability and security of supply and constantly has to balance supply and demand. This is additionally complicated by high transits passing through the system. Interconnections to neighboring countries are essential for the functioning of the system, and a further expansion of the network as well as the interconnections has to be planned carefully.

Referring to market requirements the Danish transmission system operator, being situated in two synchronous areas operating with different schedules, has to adapt to both systems and use the opportunities of the market to improve the national power balance situation by means of the real time market.

In Denmark a further wind energy expansion is expected, but it has been decided, that there will be a maximum limit for the price at which energy can be sold. Consequently, the future role of small-scale CHP units has to be newly defined aiming at better utilization through operation on market terms.

Also, the use of electricity is being re-discussed. A demand response project illustrated the potential of integrating the consumer into the well functioning of the market. For example, in times of high wind production it can be economically efficient to use electricity for district heating systems by using heat pumps or heat boilers.

8.5 Further Reading

Further reading on integrating dispersed renewable generation sources into European Grids is given in References [25].

8.6 Acknowledgement

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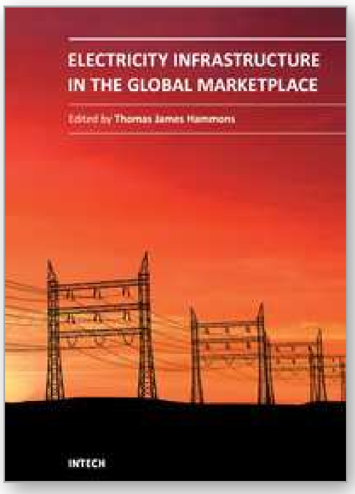

Electricity Infrastructures in the Global Marketplace
Edited by

ISBN 978-953-307-155-8
Hard cover, 802 pages
Publisher InTech

Published in print edition June, 2011

This book discusses trends in the energy industries of emerging economies in all continents. It provides the forum for dissemination and exchange of scientific and engineering information on the theoretical generic and applied areas of scientific and engineering knowledge relating to electrical power infrastructure in the global marketplace. It is a timely reference to modern deregulated energy infrastructure: challenges of restructuring electricity markets in emerging economies. The topics deal with nuclear and hydropower worldwide; biomass; energy potential of the oceans; geothermal energy; reliability; wind power; integrating renewable and dispersed electricity into the grid; electricity markets in Africa, Asia, China, Europe, India, Russia, and in South America. In addition the merits of GHG programs and markets on the electrical power industry, market mechanisms and supply adequacy in hydro-dominated countries in Latin America, energy issues under deregulated environments (including insurance issues) and the African Union and new partnerships for Africa's development is considered.

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How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

T. J. Hammons (2011). Europe: Impact of Dispersed and Renewable Generation on Power System Structure, Electricity Infrastructures in the Global Marketplace, (Ed.), ISBN: 978-953-307-155-8, InTech, Available from: http://www.intechopen.com/books/electricity-infrastructures-in-the-global-marketplace/europe-impact-of-dispersed-and-renewable-generation-on-power-system-structure

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