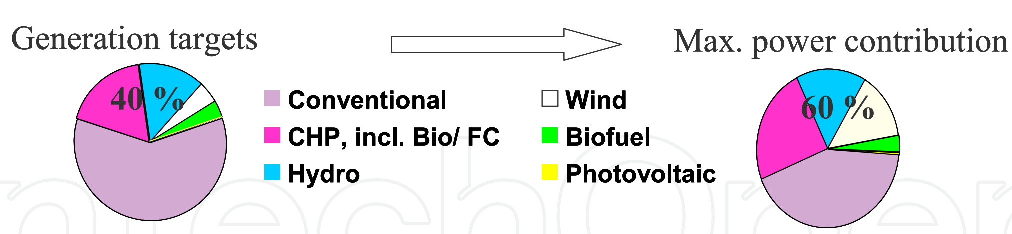
7

Europe: Status of Integrating Renewable Electricity Production into the Grid

The visionary targets of the European Community were to increase the share of renewable energy resources between 1997 and 2010 from 14 to 22 % as well as to double the contribution of cogeneration plants for heat and power (CHP) on total electricity production from 9 to 18 %. Consequently, the share of dispersed and renewable energy resources (DER) would cover 40 % of the whole electricity production in 2010. All countries have set their own targets to reach the common goal.

The DER in distribution systems will achieve an additional growth of more than 300 TWh/a to meet the challenging European targets. Additionally, wind power will grow primarily in the form of large wind farms that centrally feed into the transmission grids with 20-30 GW installed power by 2010. Large offshore wind farm sites with rated power up to 1,000 MW are currently under investigation to be installed in the North and in the Baltic Seas.

However, the output of most of the renewable energy sources depends on meteorological conditions and the CHP output is normally driven by the demand for heat that is higher in winter and lower in summer periods. The full load hours of the installed wind power capacity, for example, are approximately 1,400-1,600 h/a at onshore locations and between 800 and 1,000 h/a for photovoltaic plants.



Conventional (bottom), CHP, incl. Bio/FC, Hydro, Wind, Biofuel, Photovoltaic (clockwise)

Figure 7.1. Generation Targets of the European Communities for 2010 and the Related Maximum Power Contribution of Renewable and CHP Generation

Thus, if the contribution of DER in electric energy generation shall achieve 40 %, their maximum possible contribution in the power balance must achieve 60 % of the European system peak load. A possible scenario is shown in Figure 7.1.

Such a large-scale penetration of DER in the power balance requires a sustainable restructuring of the present operation practice in power systems. A large number of different dispersed generation units in the range of some kW up to large centrally feeding wind farms of some 100 MW partially with an intermitting power output will be connected to all levels of the power system as shown in Figure 7.2. The question arises, how can the existing high level of power quality be maintained under these fundamental changing circumstances?

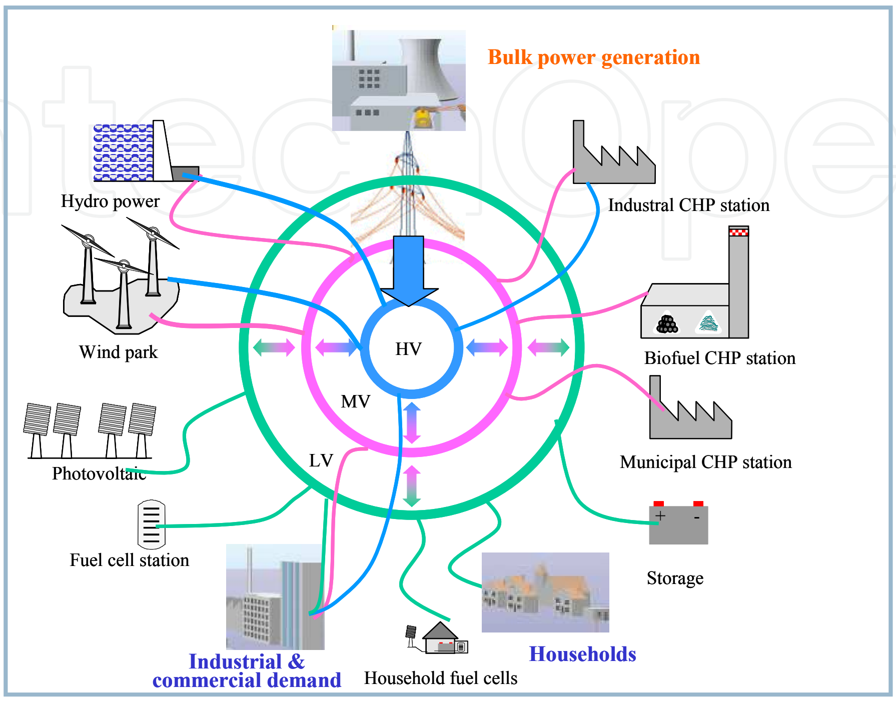


Figure 7.2. Power System Structure with Integration of Dispersed and Renewable Generation

To answer this question the experience of different countries with a large share of renewable and dispersed power generation is analyzed.

Based on the experience in these countries new recommendations and rules regarding grid conformity, reliability including the “fault ride through behavior” and dispatching of renewable and dispersed generation units are necessary. In some countries new guidelines are in development or already exist, for example in Germany.

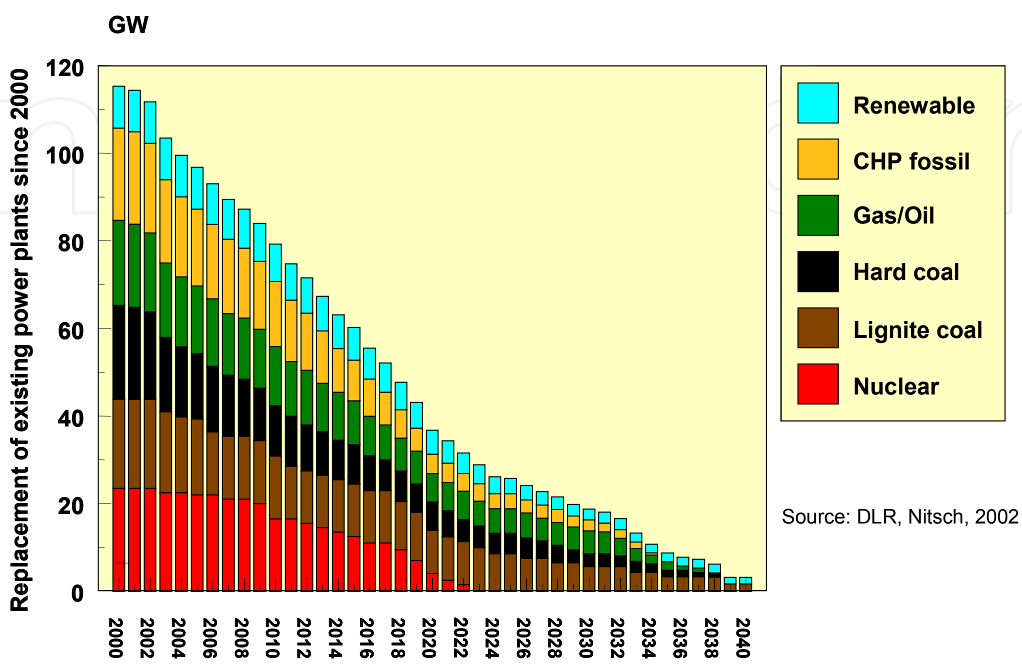
7.1. The German Experience Of The Grid Integration Of Renewable Energy Sources

7.1.1 Prospective Development of Renewable Energy Generation in Germany

In Germany today, annual energy generation of the order of 520 TWh/a comes from approximately

- 56 % coal fired power plants,
- 28 % nuclear power plants,
- 8.5 % renewable energy sources,
- 7.5 % gas and oil fired power plants.

In the coming decades a fundamental change in generation structure will occur as the result of the political decision to shut down all nuclear power stations and, further, the need to replace most of the present power stations for reasons of aging. In Figure 7.3 the expected decommissioning of generation capability is presented.



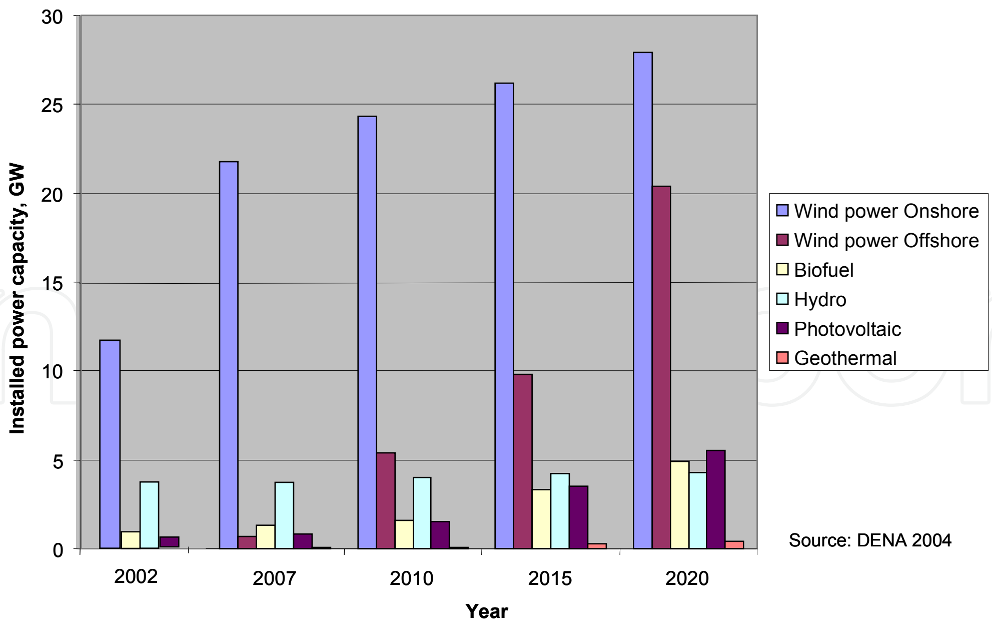
Top to Bottom: Renewable, CHP fossil, Gas/Oil, Hard coal, Lignite coal, Nuclear

Figure 7.3. Need for Replacement of Existing Power Plants

It is a political goal that only a portion of the traditional power stations will be replaced by fossil fired generation plants. In this situation the targeted growth of renewable and dispersed generation plays a significant role. In the field of renewable energy the official goals are to achieve shares of 12.5% in 2010 and 20% in 2020 of the overall electric energy generation.

However, this process seems to be ahead of schedule and the above targets were and will be gained in 2007 and 2015, respectively [1]. In Figure 7.4 the actual development scenario of the installed renewable power capability in Germany is shown.

As presented, the share of hydropower will be kept at the present level because of the lack of possible locations for new large hydropower stations. But all other renewable sources will grow significantly.



Left to right: Wind power Onshore, Wind power offshore, Biofuel, Hydro, Photovoltaic, Geothermal

Figure 7.4. Development of Renewable Generation Capability in Germany

A special high growth is expected in the wind power sector where Germany currently has a share of approximately 50 % of whole European capacity. Beginning in 2007, further growth was focused primarily on offshore locations where large wind farms with some hundred Megawatt installed power is being erected. Taking into account the achievable full load hours of the different generation technologies, the contribution of renewable energy sources in the whole energy balance of Germany will achieve about 30 % in 2020. However, their maximum contribution in strong wind situations may achieve:

- 70 % for peak load, and
- 100 % for weak load coverage,

where 58% and 83 % of the shares, respectively, come from fluctuating sources with an intermitting output depending on meteorological conditions (wind, solar). Such a large share of fluctuating power contribution requires advanced solutions to maintain power system security.

7.1.2 Economic Incentives

The generation of renewable energy is co-financed by fixed prices at high levels for the different renewable power sources and with subsidies for heat and power cogeneration.

The fixed prices are:

- wind energy - 8.7 €Ct/ kWh
- solar energy - 54 €Ct/ kWh
- biofuel energy - 6.6-10.2 €Ct/kWh (depending on the plant size)

independent of network level where the connection is provided. These much higher prices for renewable energy are paid by an additional charge of 0.54 €Ct/ kWh (level 2003/04) from all customers in accordance with Figure 7.5. Additionally, investors benefit from tax incentives for all capital expenses into renewable energy generation plants. Consequently, high profitability is the driver for the fast growth of renewable energy generation in Germany.

On the other hand, the network operators are obliged by law to ensure unlimited renewable power in-feed. This obligation incurs additional costs for:

- network enhancement from 2 Mil € in 2003 up to 40 Mil.€ in 2010
- spinning reserve to compensate power fluctuations from 130 Mil.€ in 2003 up to ~400 Mil.€ in 2010

in the case of one of the four transmission operators [2].

Figure 7.5 demonstrates the mean household price structure for electric energy in Germany.

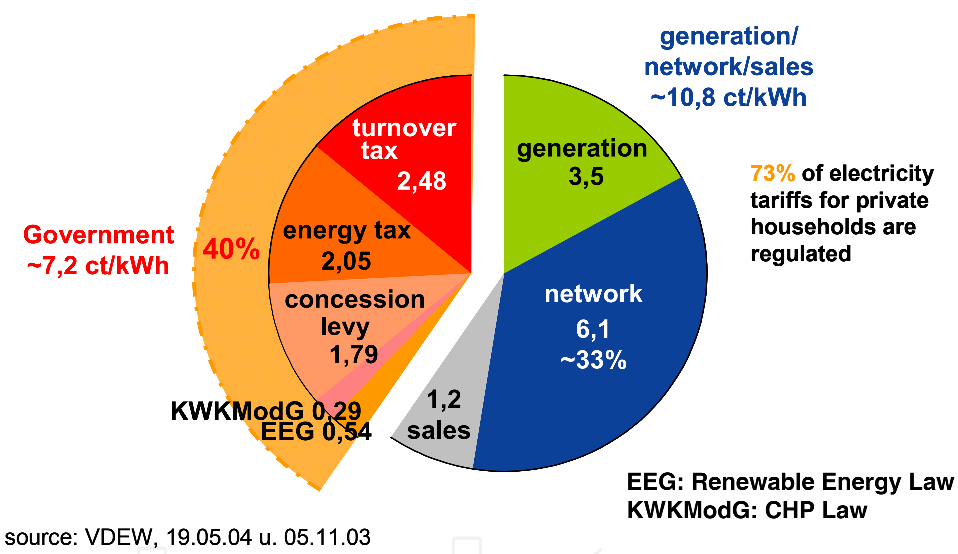


Figure 7.5. Shares of the Energy Price for Household Customers

7.1.3 Grid Integration of Large Scale Wind Power at the Transmission Level

In-feed of power by large wind farms is fundamentally subject to different patterns as is the case with conventional power sources such as thermal, gas turbine or hydroelectric generating plants. Three major problems need to be solved as the first priority:

Wind power output depends on meteorological conditions and may be intermittent. In addition to application of prediction tools for power schedule planning, a higher level of reserve power than before should be provided.

As wind power in-feed increases, the transmission capacity of the network becomes a further problem. Wind farms are mostly constructed in relatively underdeveloped regions in the north of Germany. The transmission networks in these regions have been expanded to only a limited extent.

Appropriate transmission capacities must be created in order for the power to reach the load centers.

The fault ride through of wind power plants should be adapted in such a way that wind generators contribute during short circuit currents and during network recovery after fault clearing.

In most cases, the wind velocities in northern Germany, as well as over the Baltic and North Seas, are mostly within the range of 3 to 12 m/s. Within this range, the power produced by a wind generator depends greatly on the wind velocity. Wind power producers basically feed in the maximum possible power obtainable from the wind and they receive a statutory payment.

Thus, planning the power balance of a transmission system depends substantially on the precision of weather forecasts, quite particularly if the share of wind power generation accounts for a significant portion of the network load. Special prediction tools for wind power generation have been developed and applied. However, their accuracy is limited as shown in Figure 7.6 and additional reserve power, significantly over the level, which is required for primary reserve to compensate outages in the UCTE grid (German share 750 MW), shall be provided for ensuring reliable system operation. Ongoing work towards improving the prediction accuracy is directed at minimizing the reserve power.

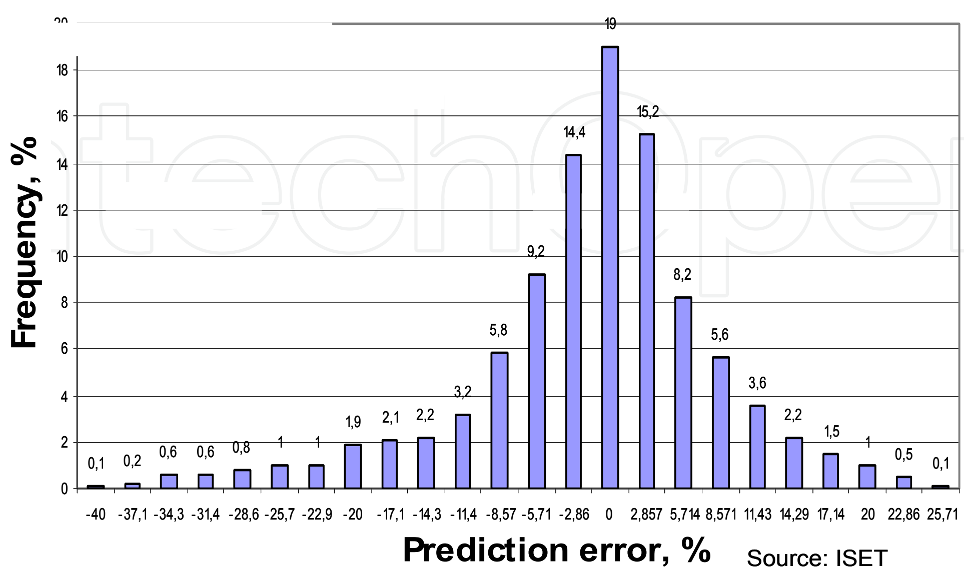


Figure 7.6. Distribution of Prediction Errors for Next Day Wind Power Forecasts

The solution to the second problem, grid enhancement, is restricted by legal difficulties and the long-term permission process for installation of new transmission lines. Moreover, existing conventional power stations will offer their generating capacity on the free market, selling it throughout Germany or Europe. Consequently, free energy trading is suffering increasing constriction owing to a lack of transmission capacity, and the installation of new transmission capacity will become mandatory. But, from an economic viewpoint, it is just the time to rethink the situation and to consider whether the network ought to be expanded for about 60 strong wind days per year, or whether generation management for wind power installations ought to be approved for this relatively short time.

Thirdly, apart from local impacts wind power also has a number of system-wide impacts because it affects

- power system dynamic and stability,
- reactive power control and voltage control,
- frequency control and load following/dispatch of conventional units.

The wind generators should fulfill three main aspects:

- no excitation of power oscillations after grid disturbances,
- in-feed of reactive power during and after system faults,
- maintaining system stability, minimize grid disruption.

Wind turbines installed in the German power system before 2003 had a single response to fault situations on the grid that resulted in instantaneous voltage drops: they were tripped off to protect their function until the grid recovered. The immediate loss of generation can impact on system stability and lead to cascaded tripping of some thousand MW of wind power. Reference [3] shows that faults in some grid locations can cause power tripping that is much higher than the whole spinning (primary) reserve of the European Network of Transmission System Operators for Electricity (ENTSO-E) grid of 3000 MW. For this reason, new rules for grid connection of wind power plants were established [4]. These rules describe the requirements regarding *Fault-Ride-Through* capability of wind turbines.

In Figure 7.7, rules regarding behavior of wind turbines connected to the German Power System during and after faults are illustrated.

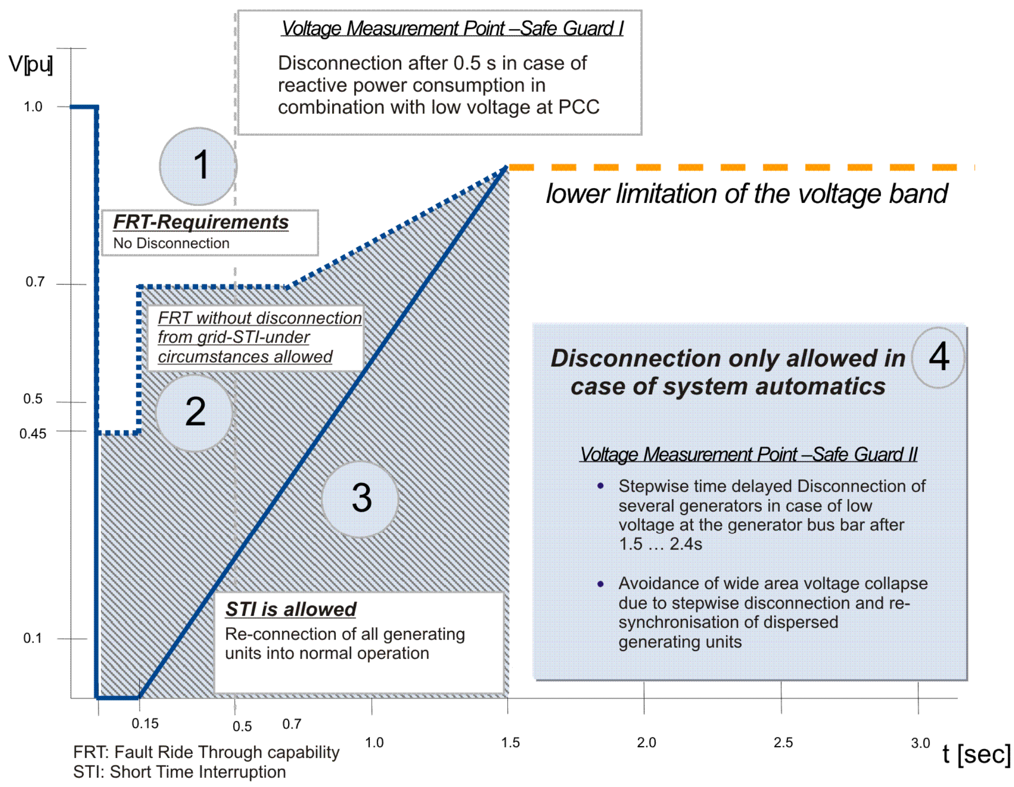


Figure 7.7. Requirements for the Fault Ride Through Capability of Wind Turbines Connected to the German Power System [5, 6]

According to the new German Grid Code [6], wind turbines must not disconnect from the grid and must not lead to instability in the event of three-phase faults even if the residual voltage is equal to zero at the grid connection point and for the time period of 150 ms, which corresponds to Region 1 in Figure 7.7.

In Region 2 of Figure 7.7, a short disconnection of the wind turbine (STI) is allowed if the generation unit becomes unstable during the fault. However, from the time point at which the disconnection occurred, the unit has to be resynchronized with the grid within 2 seconds maximum. Furthermore, the value of the generated active power by the wind turbine has to be restored to the pre-fault value with gradient of at least 10% of the generator rated power per second. In Region 3 the disconnection is allowed. However, in some special cases the grid operator can require the fulfilling of the resynchronization conditions for Region 3, which is similar to the case of Region 2.

Generally, all units that remain connected to the grid during a fault have to restore the value of the produced active power to their pre-fault value with a gradient of at least 20% of the rated power per second. Moreover, according to the new Grid Code, wind turbines have to support the voltage level of the grid during a voltage drop by in-feed of the reactive current.

7.1.4 Dispersed Generation in Distribution Systems

In addition to connection of large onshore and offshore wind farms to the transmission grid, a fast growth of dispersed energy resources (DER) in distribution systems is expected.

The problems to be solved at distribution level are:

- Ensuring network conformity in accordance with special rules of DER connection in medium and low voltage networks [7], e.g. regarding voltage quality, avoidance of equipment overloads, ability to withstand short circuits, influence on ripple control etc.
- Contribution for reliability of supply through provision of high availability and support of network recovery after faults.
- Compensation of power fluctuations and dispatch of a stable power balance in clusters of different DER, storage units and controllable loads.

These main requirements are presented in Figure 7.8.

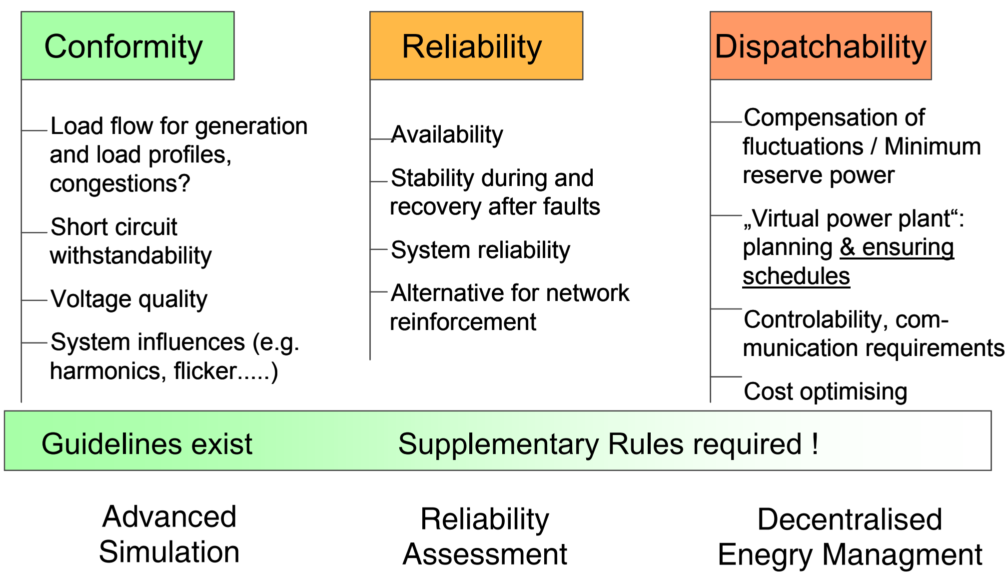


Figure 7.8. Requirements and Provision Means for a Large Scale Penetration of DER

The response regarding the first two requirements has to be analyzed by typical network planning methods. The simulation and assessment tools are available and have been approved in pilot projects [8].

The dispatch-ability requires more:

At present DER units are operated without higher-level control, feeding in maximum power as supported by current political and regulatory framework conditions. The transmission system operator is obliged to ensure power balance. This task will become more and more difficult under conditions of a growing contribution of uncertain and intermitting power output of DER. In the future, stable grid operation, economical considerations and environmental benefits will require intelligent energy management to be able to plan generation profiles at the distribution level as well. Those decentralized energy management systems have to balance required and available power in particular supply areas based on offline schedules for DER, storage units, demand side management capabilities and contractual power exchange.

The central dispatching of power balance will be supported by one of the decentralized dispatching systems as shown in Figure 7.9.

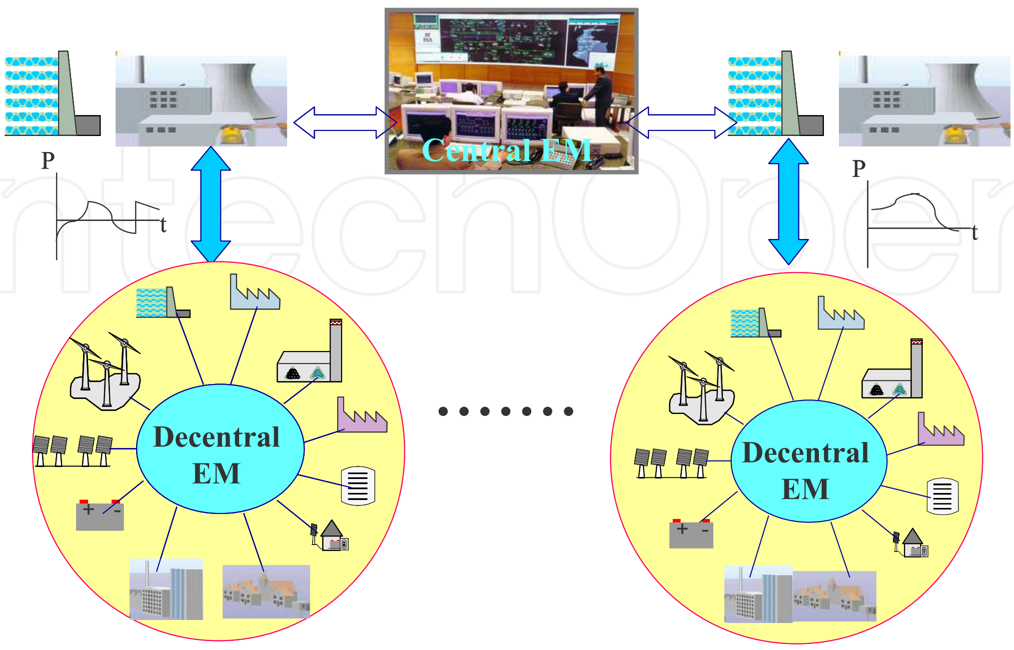


Figure 7.9. Future Task Splitting between Centralized and Decentralized Energy Management

Online monitoring and control of the units based on the schedules form balanced supply areas for different supply scenarios, i.e. different combinations of DER, storage, and load units. For higher-level management systems these balanced *"self sufficient cells"* appear as *"virtual power plants"* which show similar reliable, plan able, and controllable behavior like traditional power plants. There are various possibilities for vertical and horizontal integration of these locally optimized cells into central control centers.

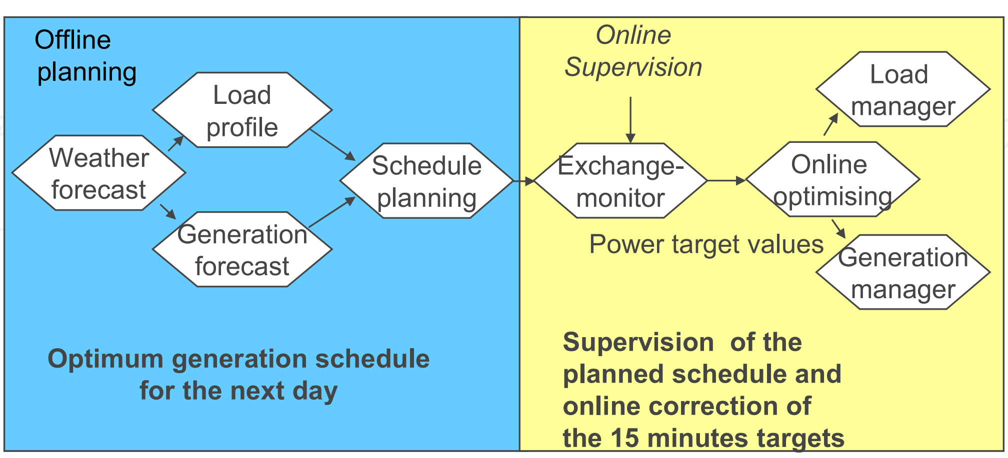


Figure 7.10. Principle of the Decentralized Power Management of DER

Adherence to the schedules has to be guaranteed online in operation to enable exactly defined contractual power exchange in the balanced supply areas. Unplanned power fluctuations and deviations from the schedules require fast adjustment of the real power flow within the individual period by dispatching controllable generation, storage units and demand in a one-minute time interval. The principle of the considered decentralized power management is presented in Figure 7.10.

To cope with unavoidable prediction errors for generation and demand, unit commitment accounts for the determined reserve power locally, while meeting all technical constraints. Thus, central power reserves can be reduced.

From the technical point of view, all of the means needed for operation with large-scale integration of DER are available and have been proven in practice [9].

However, the actual legal and incentive situation acts against an introduction of "virtual power plants". The legal and incentive frameworks have to be adapted so that the idea of the "virtual power plants" can become reality.

In summary, the increasing share of renewable and dispersed generation has no technical limits if *Conformity and Reliability* in context of the new guidelines [4], [7] is ensured and if their *Dispatch-ability* can be reached by technical means within an adapted legal and incentive framework.

7.2. Options for Large Scale Integration of Wind Power

The worldwide development of wind power installations now includes the planning of large-scale wind farms ranging in the magnitude of 100 MW, and is considered to constitute a significant part of the renewable power production planned in Europe and in the world. This is a challenging development that will have an impact on the power system stability and operation as outlined in section 7.2. The development is sound however; wind power is a cost-effective renewable source that can smoothly be integrated into the power system by applying adequate control technologies and market based solutions. Two cases are applied to demonstrate this. One considers the connection of a large wind farm to a fairly week regional grid (section 7.3), and the other considers the power system balancing of large magnitudes of wind power (section 7.4). It is demonstrated that local control actions enable quite large wind farms to be operated on fairly week grids, and that market based balancing tackles large magnitudes of wind power.

7.2.1 Impact of Wind Power on Power System Stability and Operation

Voltage control – reactive power compensation:

A main challenge related to voltage control is to maintain acceptable steady-state voltage levels and voltage profiles in all operating conditions, ranging from minimum load and maximum wind power production to maximum load and zero wind power. Capacitor banks and transformer tap changers represent the most common means to control voltage profiles. Another challenge in this context is related to the control (or limitation) of the exchange of reactive power between the main transmission grid and the regional distribution grid.

Voltage stability:

The output power from wind farms may vary significantly within a few seconds and, depending on the applied wind turbine technology, the reactive demand will also vary significantly. If the power system cannot supply this demand, a voltage instability or collapse may occur. Sufficient and fast control of reactive compensation is required to relax such possible voltage stability constraints related to wind farms, which can be provided through the use of wind turbines with active voltage control, or by using external compensators, such as Static Var Compensators (SVCs).

Transient stability:

Traditionally, the protection systems of wind turbines have been designed to disconnect and stop the units whenever a grid fault (temporary or permanent) is detected. With increasing integration of wind power there are and will be system requirements implying that wind turbines must be able to “ride through” temporary faults, and contribute to the provision of important system services, such as momentary reserves and short circuit capacity. This puts emphasis on transient stability performance, power oscillations and system damping. Control equipment within wind farms enabling both power and voltage control becomes increasingly important in this context.

Thermal transmission capacity constraints:

Thermal transmission capacity problems associated with wind power integration may typically be of concern in only a small fraction of the total operating time. Applying control systems to limit the wind power generation during critical hours may be a possible solution, or if other controllable power plants are available within the congested area, coordinated automatic generation control (AGC) may be applied. The latter alternative may be beneficial as energy dissipation may then be avoided.

Power fluctuations – frequency control:

Wind energy is by nature a fluctuating source of power. In a system where a significant part of the power generation comes from wind, system operational issues, such as frequency regulation and congestion management become a challenge due to the normal variations in the available wind power. Systems with substantial supply from wind farms thus call for flexible and improved solutions with respect to secondary generation control.

Adverse impact from interaction of power electronic converters:

Modern wind turbines utilizing power electronic converters provide enhanced performance and controllability compared to traditional fixed speed solutions. With increasing use of power electronics, however, there may be uncertainties with respect to possible adverse control interactions within the wind farm itself. Converter modulation principles and filter design are important issues that must be addressed and analyzed as part of the wind farm design and installation.

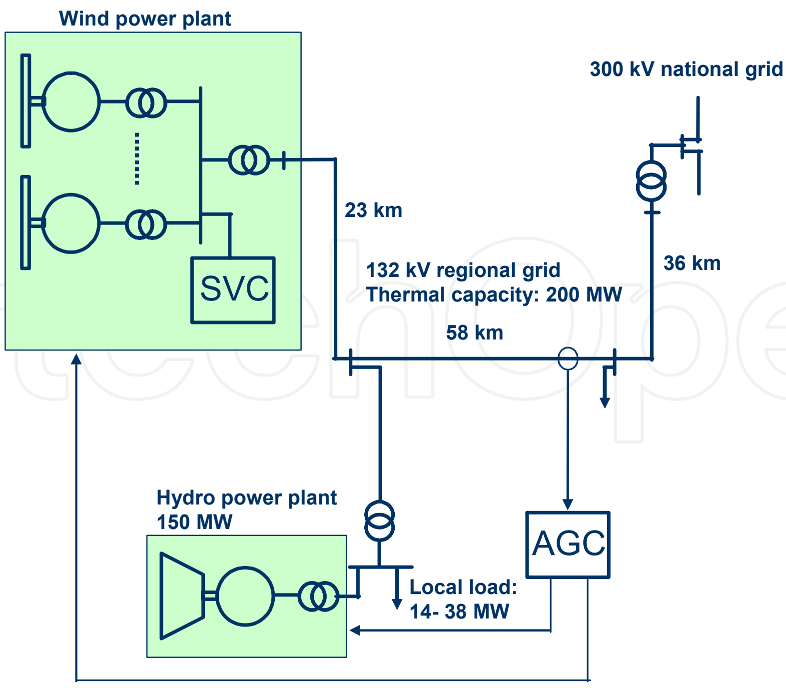
In summary, most of the challenges described above may result in operational conditions that adversely affect the quality of the voltage and power supplied to customers. Additionally, there may be system operational problems, such as congestion management and secondary control that not only affect the wind farm in question but the entire network. Thus, the problems suggest coordinated control solutions that maintain secure operation of the network, and at the same time allow for maximized and profitable integration of wind power. Indeed, large scale integration of wind power does not only set requirements on the power system, but also the wind power technology must be developed according to the system needs. The development of IEC 61400-21 [10] specifying procedures for characterizing the power quality of wind turbines and the various grid codes setting system requirements on wind farms, e.g. Eltra [11], are examples of such development.

7.2.2 Case – Local Control

The case study considers the connection in Norway of a large 200 MW wind farm to a typical regional distribution grid (see Figure 7.11. The study is based on an actual system, though slightly modified to serve the purpose of this Chapter. The regional distribution grid is connected to the main transmission grid via a long 132 kV line with a thermal power capacity limit of about 200 MW. Considering that the hydropower plant that is already connected is rated 150 MW and that the local load may be as small as 14 MW, a conservative approach would suggest that the wind farm capacity should not exceed 64 MW (i.e. 200 – 150 +14), or indeed 50 MW (i.e. 200-150) to ensure operation if the local load disconnects. However, contrary to such conservative planning, this case demonstrates that installation of a much larger wind farm is viable.

Due to environmental constraints, it is not an option in this instance to upgrade the 132 kV line for higher thermal power capacity. Hence, power electronics and control systems are applied to allow connection of the large wind farm.

Reference [12] shows that as long as the thermal capacity of the 132 kV line is respected, voltage control and stability is ensured by the application of a Static Var Compensator (SVC) and/or the utilization of the reactive control capabilities of modern wind turbines with frequency converters.



Operation of a 200 MW wind farm is viable using the Static Var Compensator or built in reactive control capabilities of modern wind turbines for securing voltage stability, and using Automatic Generation Control (AGC) for controlling that the thermal capacity of regional grid is respected.

Figure 7.11. Outline of Case Study Regional Grid.

Figure 7.12 illustrates that reactive support enables a stable voltage for feed-in of 0 to 200 MW of wind power, whereas without reactive support, the wind farm size would have to be restricted to about 50 MW.

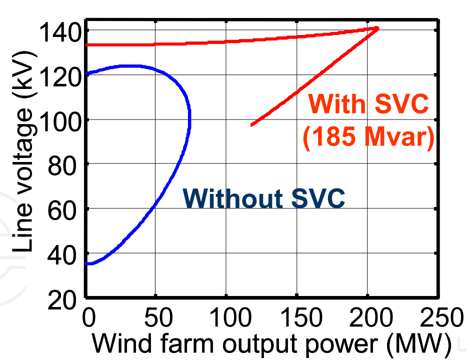


Figure 7.12. Result of Dynamic Simulations of Power System with 0-200 MW of Wind Power [12]

Ref [13] demonstrates that Automatic Generation Control (AGC) of the hydropower plant can be used to avoid overloading the 132 kV line. This is illustrated in Figure 7.13, showing a result of a dynamic simulation verifying the performance of the AGC.

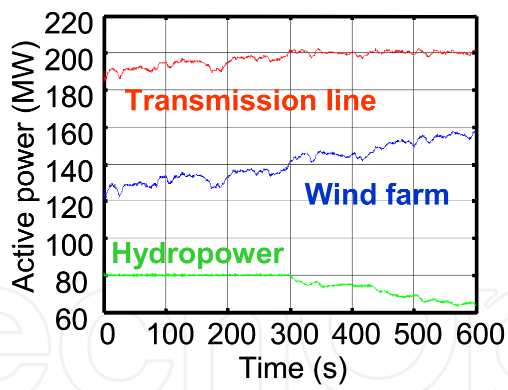


Figure 7.13. Result of Dynamic Simulation of Power System with 200 MW Wind Farm and AGC Control of Hydropower Plant [12]

The AGC operation influences the annual output and energy sales from the hydro and wind power plants. As found in [14] however, the impact on the energy sales is (surprisingly) moderate (see Table 7.1).

	Control hydro	**Control wind**	**Non-congested**
Wind power (GWh/y)	609	551	609
Hydropower (GWh/y)	646	657	657
Local load (GWh/y)	219	219	219
Line load (GWh/y)	1036	989	1047

Table 7.1. Case Study Results of 200 MW Wind Farm for Two Cases of AGC Control, i.e. Control Hydro (Reschedule Production) or Control Wind (Reduce Production), and for the Case of Unlimited Grid Capacity (Non-Congested Case) [14]

7.2.3 Case – Market Based Power Balancing

EU regulation requires that market based principles should be used for congestion management. In the Nordic power system the real time frequency control is also handled through a joint balancing market.

This case considers real operational data from the Nordic power system (see Figures 7.14 and 7.15). On January 8, 2005 there was a storm affecting southern Scandinavia initially causing high wind power production in Denmark. At a certain time however, the wind turbines started to cutout due to excessive wind speeds and the wind power production was reduced from 1800 MW to 100 MW during the afternoon hours. The loss of wind power production amounted to more than half of the consumer loads in western Denmark. Figure 7.15 shows how this situation was handled in operation. The loss of generation was compensated through the balancing power market (mostly activated in southern Norway) and by regulating the HVDC link between Norway and Denmark from full export to full import in the same hours. The example illustrates clearly that the Nordic power system can handle large amounts of wind power through the existing marked based mechanisms.

Secure operation requires that sufficient reserves and transmission capacity are available in such situations. In a future system with high penetration of wind power throughout Europe, the operational challenges with respect to operating reserves, frequency control and transmission capacity are expected to become increasingly important.

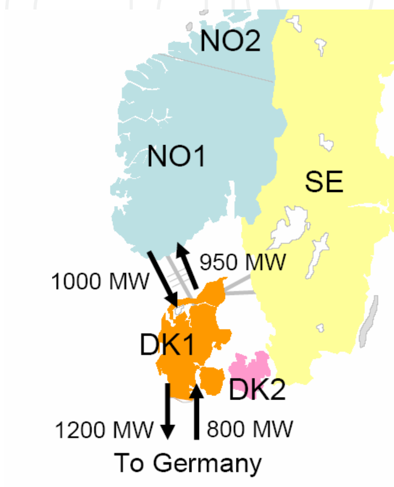


Figure 7.14. Map Showing Parts of Nordic Market (Elspot) Areas and Normal Transmission Capacities between western Denmark and Germany and between Denmark and Norway

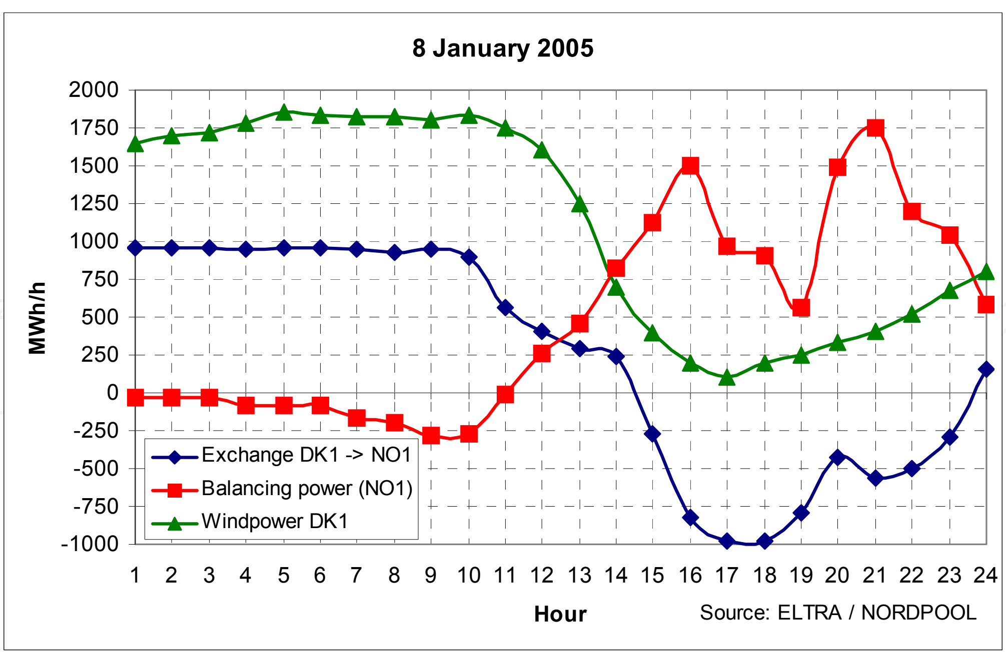
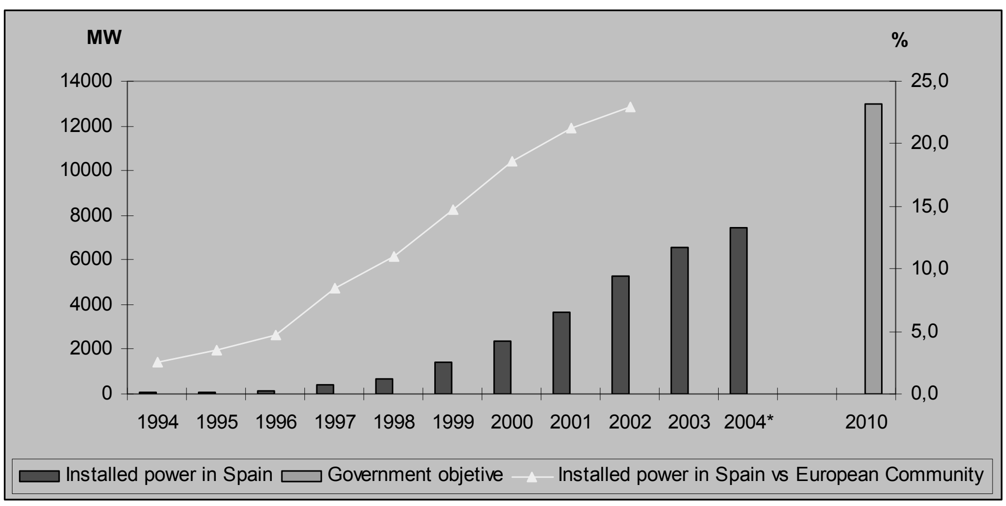


Figure 7.15. Actual Hour-by-Hour Data of Wind Power in western Denmark (DK1), Balancing Power in southern Norway (NO1) and Power Exchange over the HVDC Line between southern Norway and western Denmark

Section 7.2 has demonstrated options for large-scale integration of wind power. Local control enables the operation of a large wind farm on a fairly weak regional grid, and market based balancing tackles large magnitudes of wind power. Thus, a future with a high penetration of wind power throughout Europe seems viable, though the operational challenges with respect to operating reserves, frequency control and transmission capacity are expected to become increasingly important.

7.3. Spanish Experience of Grid Integration of Wind Energy Sources

Until recently, installed wind power was anecdotic, and its influence on the system insignificant. Over the last few years, however, the installation of wind power generation connected to the Spanish electric power system has expanded fast. This growth has proven more rapid than average growth within the European Community, as illustrated in Figure 7.16.



* up to 20th July

Figure 7.16. Evolution of Wind Power Generation Connected to the Spanish Electric Power System and Comparison with Growth in the European Community

By relating wind-installed power with other figures, we can demonstrate that the importance of wind generation in Spain is not less than in other countries like Germany or Denmark (Figure 7.17). When wind-installed power is compared with population (indirect way of comparing installed power with the size of the electric system), Spain appears to have a size comparable to Germany. If wind installed power is compared with import exchange capability, Spain fares well above other countries. This means that the transient support that Spain can receive from other countries, due to the *Principle of Joint Action*, is small compared with the wind-installed power.

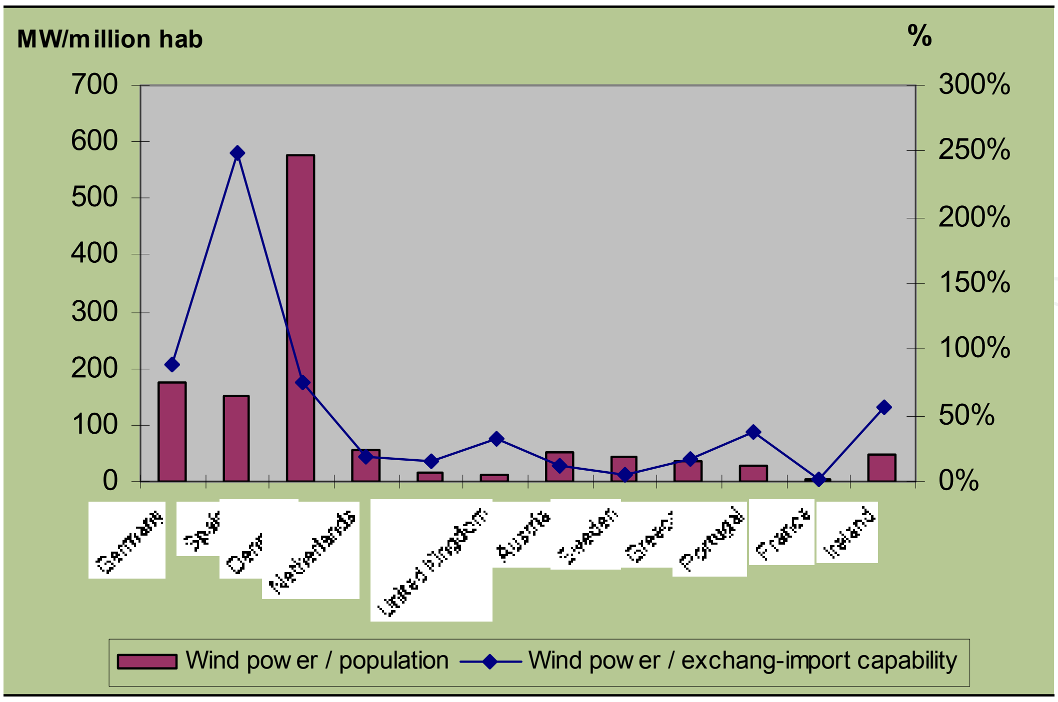


Figure 7.17. Relation of Wind Power Installed vs. Population and vs. Exchange Capability

7.3.1 Present Economic Incentives for Wind Energy in Spain [15]

Wind power producers are entitled to transfer their production to the system through the electricity distribution or transmission company whenever the absorption of the energy by the network is "technically possible". Wind power producers may chose from two different options in order to incorporate their production into the system. They can opt to participate directly in the wholesale electricity market or to sell the energy to distributors.

The first option of participating directly in the Spanish Wholesale Electricity Market involves either presenting bids or establishing bilateral contracts. In both cases wind power producers have the same treatment as the "ordinary regime" as far as ancillary services are concerned. If they opt to participate directly in the Spanish Wholesale Electricity Market presenting bids, their production has the following treatment concerning congestion management:

- Their production cannot be withdrawn on the grounds of network congestion problems (except for real time management) if they bid as price takers (bids at a price of 0 € / MWh).
- Their production shall be incorporated for solving technical constraints, provided their bid price is less than 70% of the reference tariff as defined in [15] article 2 (except for real time management). The producers shall be connected to a distribution company that in turn is connected to a point of the transmission network in which the System Operator (REE) has identified a constraint problem.

The second option is to sell the energy to the distributors. Wind power producers are entitled to sell their production to the distribution companies, which are obliged to buy this energy. The distribution companies deduct this production from the buying bids that they have to present to the Spanish Wholesale Electricity Market in order to supply their captive customers. The above is also what currently applies to production from all renewable and high efficiency plants, integrated in the so-called "*special regime*", as opposed to the "*ordinary regime*".

Depending on the option chosen, wind power producers are recompensed as follows (Table 7.3):

Participating directly in the Spanish Wholesale Electricity Market: Hourly marginal price of the wholesale market or price negotiated in bilateral contracts + subsidy + incentive + complement for reactive power + complement for fault ride through capability--deviation from production programs (see "Treatment of deviations from production programs"):

- Subsidy: percentage (40%) of the yearly electricity average tariff or reference tariff as defined in [15] article 2.
- Incentive: percentage (10%) of the yearly electricity average tariff or reference tariff as defined in [15] article 2.
- Complement for reactive power: percentage of the yearly electricity average tariff or reference tariff as defined in [15] article 2, (Table 7.2). Producers can also renounce to this complement and participate in the reactive power market (not in place yet).
- Complement for fault ride through capability (withstanding voltage sags): for 4 years, 5% of the yearly electricity average tariff or reference tariff as defined in [15] article 2.

Selling the energy to the distributors: Regulated tariff + complement for reactive power + complement for fault ride through capability - deviation from production programs (see "Treatment of deviations from production programs"):

- Regulated tariff: percentage of the yearly electricity average tariff or reference tariff as defined in [15] article 2. Irrespective of onshore or offshore installations, the above percentage is established as follows:
    - For installed capacities < 5 MW: 90% of the tariff during the first 15 years after commissioning, and 80% thereafter;
    - For installed capacities > 5 MW: 90 % of the tariff during the first 5 years, 85% during the following 10 years and 80% thereafter.
- Complement for reactive power: Percentage of the yearly electricity average tariff or reference tariff as defined in Table 7.2.
- Complement for withstanding voltage sags: Same as above.

Power factor	Active & reactive energy	%		
	Power factor	Peak	Plain	Off-peak
Inductive (lag)	< 0.95	-4	-4	8
	< 0.96 & ≥ 0.95	-3	0	6
	< 0.97 & ≥ 0.96	-2	0	4
	< 0.98 & ≥ 0.97	-1	0	2
	< 1 & ≥ 0.98	0	2	0
	1	0	4	0
Capacitive (lead)	< 1 & ≥ 0.98	0	2	0
	< 0.98 & ≥ 0.97	2	0	-1
	< 0.97 & ≥ 0.96	4	0	-2
	< 0.96 & ≥ 0.95	6	0	-3
	< 0.95	8	-4	-4

Table 7.2. Complement for Reactive Power

The reported tariffs, subsidies, incentives and complements were reviewed in 2006 and then again every 4 years. Irrespective of this, prices will also be reviewed when wind power generation reaches 13 000 MW of total installed capacity.

The treatment given to deviations differs, depending on the option chosen to incorporate the production in the system, as follows (Table 7.3):

Participating directly in the Spanish Wholesale Electricity Market: Same treatment as ordinary regime, which basically follows the principle that those installations that deviate from their programs pay the overall cost of solving the deviation of the whole system, in proportion to its own deviation. Selling the energy to the distributors: Wind power producers exceeding 10 MW of installed capacity are permitted a deviation of 20% from their forecast (they are obliged to give this forecast to the distribution company to which they are connected). Deviations exceeding that range are paid at a price consisting of a percentage (10%) of the yearly electricity average tariff or reference tariff as defined in [15] article 2.

	Participating directly in the Spanish Wholesale Electricity Market	Selling the energy to the distributors
Hourly marginal price or price negotiated bilaterally	Depends on the market	--------------------------------
Regulated tariff	--------------------------------	5.76576-6.48648 c€/kWh
Subsidy	2.88288 c€/kWh	--------------------------------
Incentive	0.72072 c€/kWh	--------------------------------
Complement for reactive power	Depends on power factor and time of the day	Depends on power factor and time of the day
Complement for withstanding voltage sags	0.36036 c€/kWh during first 4 years	0.36036 c€/kWh during first 4 years
Deviation from programs	Depending on deviations	Depending on deviations
TOTAL (not including complement for withstanding voltage sags)	3.60360 c€/kWh + market or negotiated price + complement for reactive power - cost of deviations	From 5.76576 to 6.48648 c€/kWh + complement for reactive power - cost of deviations

Table 7.3. Summary of the Retribution Schemes for Wind Energy

7.3.2 The Spanish Experience

The minimum voltage protection systems in Spanish wind farms must comply with the specifications of the Ministerial Order of 5th September 1985 [16]. In accordance with this Order, it is mandatory to install three instantaneous minimum voltage relays between phases in the connection point of wind farms. The relays must provoke instantaneous disconnection of the wind farm when voltage drops below 85% of the average value between phases.

In order to integrate as much generation as possible, a delay in the disconnection of wind parks during disturbances has been considered. However, it has been confirmed that some technologies cannot stand such a delay.

Wind penetration levels are currently being reached in Spain, so that in the event of a short-circuit in the transmission network –even if it is correctly cleared, the minimum voltage protection system may cause instantaneous disconnection of a significant number of wind farms, with the consequent loss of power generation. Studies that have been carried out [17] show the importance of minimum voltage protection systems in wind farms and system stability. Figure 7.18 (real experience, not theoretical or simulation) presents the total wind production in the Spanish Peninsular Electrical System during the 18th of January of 2004.

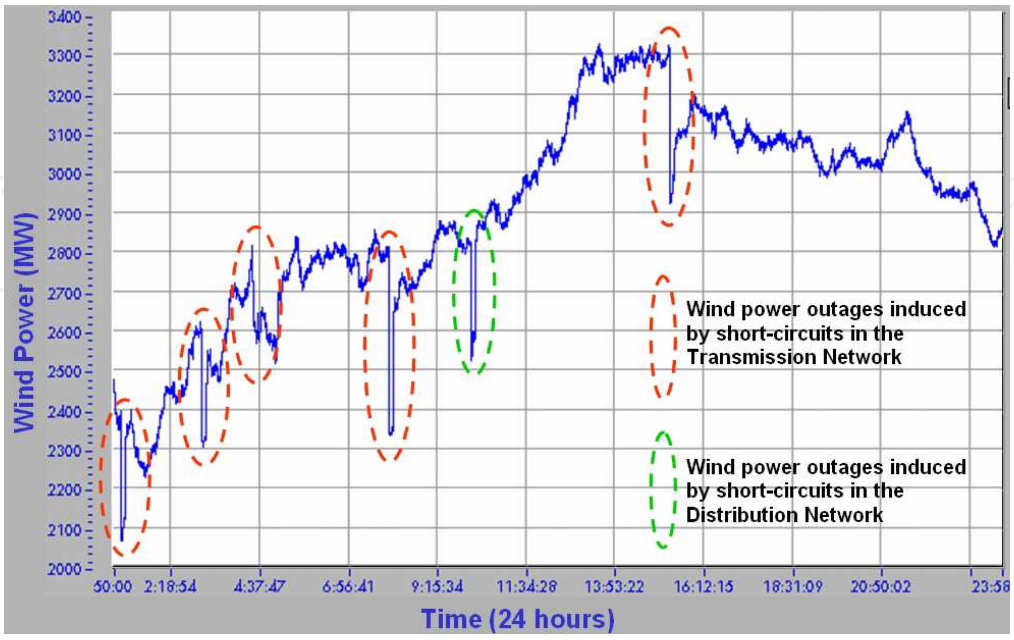


Figure 7.18. Wind Power Trips induced by Faults on the Network (MW)

The curve shows the wind production in peninsular Spain, with some sudden trips of production coincident with correctly cleared short-circuits in the transmission network. In this case, the interrupted production does not exceed 500 MW, but should the short-circuit occur on a day with more wind, or if the wind installed power increases, the amount of production disconnected will also increase.

In order to evaluate the influence of these trips in system security, the amount of connected ordinary regime plants is very important because they help contain the disturbance and recover the system parameters after the disturbance. For this reason, the same amount of wind production loss would be more severe in low demand conditions than in peak demand conditions.

Being aware of this drawback, REE has proposed new technical requirements to the regulator [18] in order to integrate a large amount of wind generation in the Spanish electric system, maintaining the actual security and quality standards. Of course, for this purpose it is necessary that wind generators meet some requirements for improving the fault ride through capability.

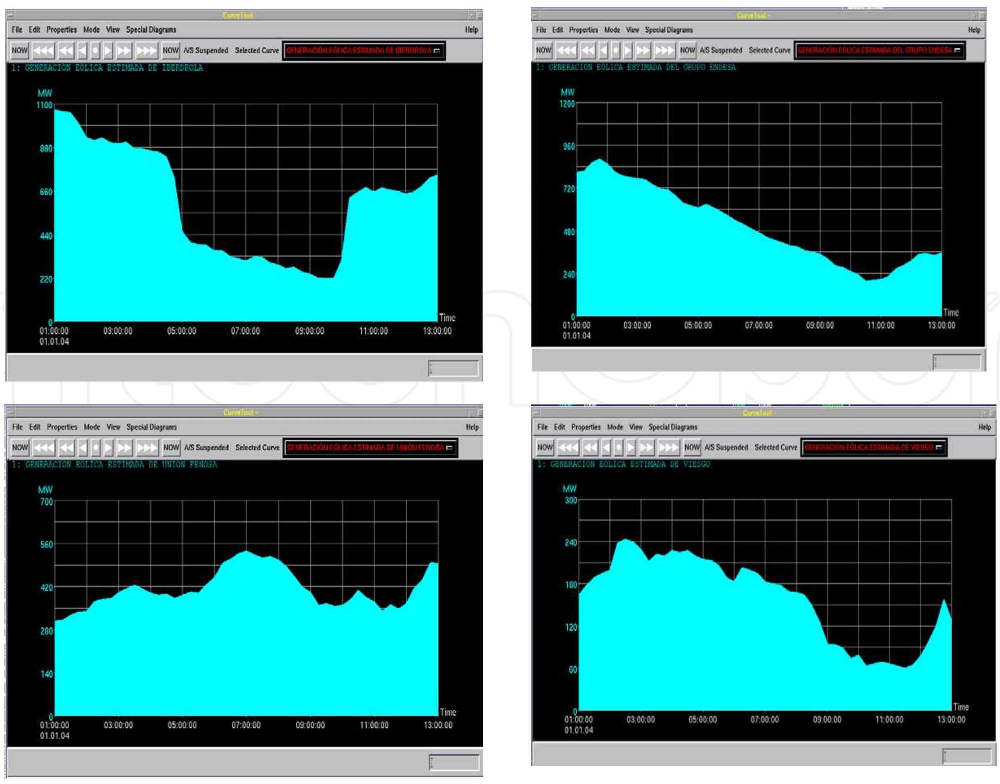


Figure 7.19. Wind Production in Four Different Distribution Areas

REE regularly evaluates the maximum wind power penetration that is compatible with system security according to transient stability analysis in different situations. According to this evaluation, it was sometimes required to reduce wind generation, for example on January 1 2004.

Figure 7.19 shows the different responses of wind generators in four distribution areas in Spain to a request for limiting the production.

These graphs display the aggregated production of the distribution zones. The first of the four graphs shows the production of a zone that has a control center, with a very good response. Conversely, the request to limit the production has not been correctly followed in the other zones.

These case studies confirm the importance of connecting all wind generation plants to a control center to effectively inter-act with the system operator.

In summary, **w**ind power differs from conventional sources of energy in three main ways: the prime mover is wind, the location of resources, and the electrical machines. Controllability and availability of wind power significantly differs from thermal or hydro generation because the primary energy source cannot be stored and is uncontrollable. Wind power does not complicate very much short term balancing and all wind turbine types can be used for it, although variable speed wind turbines have better capabilities. Long term balancing is problematic. The power generated by wind turbines depends on actual value of the wind speed. When there is no wind, no power from wind turbines is available. Wind turbines complicate the long term balancing task, particularly at high wind power penetrations.

More than 7900 MW in wind mills were connected (2005) to the Spanish peninsular power system networks, this "*enormous*" amount requires advanced solutions in order to maintain the actual level of power quality, such as the development of dispatching centers (under the ownership of the TSO or others) which transmit with accuracy the orders given by the TSO to the wind farms. Integration of wind power is possible, but it requires the development of adequate procedures that harmonize and make compatible the technical requirements with the market rules.

Considering the reduced contribution of wind generators to short-circuit power and the high meshed level of the European networks, a short-circuit on the transmission network can lead to widespread voltage dips to neighboring TSOs. Therefore, the "*fault ride through capability*" of wind generators is a useful requirement to prevent large outages of wind power dependent on the given regional potential gradient area.

7.4. From the Kyoto Protocol to the Future Power Grid

The decision of the Russian Parliament (or Duma) to ratify the 1997 Kyoto Protocol on climate change has re-energized international cooperation on cutting greenhouse gas emissions.

Russian ratification ensured that the Protocol is legally binding on its 128 Parties on 16 February 2005 and launches an exciting new phase in the global campaign to reduce the risks of climate change. All must get down to the serious business of reducing emissions of carbon dioxide and other greenhouse gases, by giving industry, local authorities and consumers incentives to take action on climate change. Russia and the 29 other industrialized countries that have joined the Protocol will set themselves on a path to greater economic efficiency. Accelerating the development of the clean technologies that will dominate the global economy of the 21st century will earn them a competitive edge in global markets. What various countries in Europe are doing in this respect will be examined.

The Protocol contains legally binding emissions targets for 36 industrialized countries. These countries are to reduce their collective emissions of six key greenhouse gases by at least 5% by 2008-2012, compared to 1990 levels. This first five-year target period is only a first step. While developing countries do not now have specific emissions targets, they too are committed under the 1992 Climate Change Convention to taking measures to limit emissions; the Protocol will open up new avenues for assisting them to do so. In addition to inspiring national action to cut emissions, the Protocol's entry into force will strengthen international cooperation through the early start-up of an international "emissions trading" regime enabling industrialized countries to buy and sell emissions credits amongst themselves; this market-based approach will improve the efficiency and cost-effectiveness of emissions cuts. the "*clean development mechanism*" (CDM), through which industrialized countries can promote sustainable development by financing emissions-reduction projects in developing countries in return for credit against their Kyoto targets cooperative projects under the system for "*joint implementation*", whereby one developed country can finance emission reductions in another developed country.

Developments in the power industry in Europe depend on expectations for future political, financial and technical conditions. Embedding of renewable energy sources is a quite challenging task, based on conditions defined by the Kyoto Protocol.

The trend in European power industry developments will be influenced by:

- Liberalization and globalization with the goal to open markets, not only for delivery of equipment but also to include new market players in the generation and transmission of the energy.
- Increasing environmental constraints (e.g. CO_2 reduction, regenerative power generation, and difficulties to get right of way for overhead lines) will influence the type and location of new generation and changes in the structure of power systems.
- Continuous increase of price for oil and gas can speed up the use of new generation technologies if they would be technically available.

In the deregulated environment, responsibilities for generation, transmission and distribution are separated. However, from technical point of view there are strong interdependencies among all the parts of power systems. Generation locations depend on the available primary energy sources (water, wind, etc.), mostly not close to the centers of power demand. The transmission system then has to transmit power over long distances. In case primary energy as gas or coal is available close to the load centers or it can be transported by other means (e.g. pipelines, shipping), generation can be placed close to the load, even in sub-transmission or distribution systems.

Financing of power plants plays an important role in the deregulated environment. Therefore payback times are an important factor in the decision for new power stations. Technologies with the shorter payback have economic advantages.

In the decades to come it can be expected that the main primary energy will still be gas, with declining use of coal. Studies show that the gas exploitation will increase for more than 4 times in the next 30 years. The renewable power generation (wind, solar and biomass) will increase considerably in some countries, especially in Europe; however, because of still high costs and the need for additional generation as running reserve, there are many on-going discussions on the feasibility of embedding large amounts of renewable energies within the existing grids.

New technologies as fuel cells are still in the early phase of the development. To be economical, the production costs have to be reduced considerably. This depends, however, on the progress in the development of new materials. The expectations for the economic break-through are therefore uncertain. In the next 30 years fuel cells will be used only for small ratings in distribution networks and will not play a major role in the power industry.

Development in the field of fusion to produce electric energy is just at the beginning with problems in the field of materials that have to resist very high temperatures. Its realization in the near future cannot be expected. It can, however, be possible that fusion generation will be built in 50 years or even later.

According to the expectation for increasing power demand in the next decades the existing systems in many industrialized countries, also in Europe, will be loaded by additional power of at least 60%, without the possibility to build a larger number of new overhead lines. The existing lines, in Europe with a relatively low voltage level of only 400 kV will therefore be loaded up to their thermal limits. The solution in densely populated areas will be to introduce more underground cables and preferably to use GIL (Gas insulated Lines) for bulk power transmission corridors, as GIL technology can transmit large amounts of power at reasonable costs through narrow rights of way. FACTS (Flexible AC Transmission Systems) technology could also help to improve the loading of power corridors. With the increasing load the short-circuit current will also further increase. Short-circuit current limiter solutions will be needed.

However, with the increasing complexity of power systems, the reliability of power supply will diminish as already shown by a number of large blackouts in Europe and America. Studies show that the probability for large blackouts is much higher than theoretically expected. The reason is that fault sequences leading to blackout do not result only from statistical failures. An essential role is played by human errors, insufficient maintenance and systematic errors in planning and operation, leading to cascading of the faults. These systematic errors cannot be completely avoided, because of too high complexity of the systems. Improvements can be made also by the use of HVDC. Back-to-back HVDC could separate parts of the interconnected systems to avoid widening of large disturbances throughout the system.

HVDC will further be increasingly used to transmit large power blocks from remote locations to the load centers.

The effective operation of large and complex power systems in many countries of Europe will ask for new modern control systems combined with new protection strategies. The goal of new control and protection will be to assure economic and reliable operation even under emerging conditions.

Power output of wind generation can vary fast in a wide range, depending on weather conditions. Hence, a sufficiently large amount of controlling power from the network is required to substitute the positive or negative deviation of actual wind power in feed to the scheduled wind power amount.

One possible solution is to use HVDC long distance transmission, integrated into a synchronous AC network to reinforce the interconnection of different parts of the system, when an increase of power exchange is requested without overloading weak links or bottlenecks in the existing grid. Such a situation is expected in the German network, when large amounts of renewable energy sources, e.g. wind parks, are connected to the northern parts of the grid. At present, a total amount of about 12 GW wind power has already been installed in Germany (out of 120 GW totally installed generation capacity). A further increase of up to 50 GW wind power capacities can be expected in the next decades, from which about 50% will be generated by off-shore wind parks in the north- and east-sea areas.

Both tasks, to transmit surplus power out of the northern wind generation area and to provide the controlling power from the generation in central and southern grid parts, would additionally load the existing network, thus leading to bottlenecks in the transmission system.

Loading in distribution systems will also increase leading to high current networks. In addition, decentralized power generation will be in larger extent connected to the distribution networks. The structure of distribution networks will therefore change from vertical oriented power in-feed to the mixed structure with part of power in-feed from the superposed power system and part delivered by own generation.

Distribution systems will operate in similar way as high voltage systems.

Because of high short-circuit currents and reliability reasons they will be separated into smaller systems interconnected by current limiters or DC back-to-back stations.

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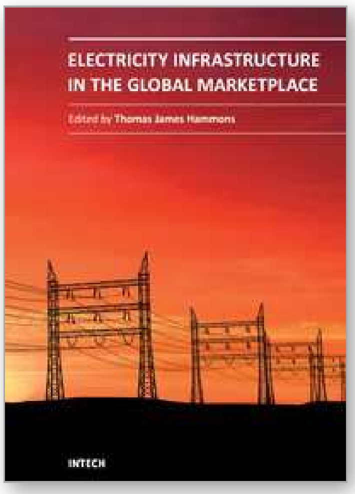

Electricity Infrastructures in the Global Marketplace

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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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