Harnessing the wind

How the wind is leading to a paradigm change in electrical power supply.

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In the face of the anthropogenic greenhouse effect and concerns over future fuel shortages, the nature of the energy market is changing. Alternative sources such as wind energy have gained substantial and rapidly expanding market shares. To cite a much used cliché, the “wind of change” has truly come. Unfortunately, the expression is true in another sense also: Generation stops when the wind stops. As most consumers are not prepared to accept blackouts every time the weather changes, backup generating capacity is needed that can compensate the fluctuations at very short notice.

But this is not the only challenge. Thermal power plants were built where they were most convenient from the point of view of the transmission network – and this often meant close to major cities. Wind power, however, has to be generated where the wind blows. The transmission network is having to adapt to generation rather than vice-versa.

The electrical power supply system of the future must become a flexible mediator between unplannable generation and high expectations of the supply quality.

Energy efficient grids

One of the major advantages of the electrical power supply in industrial nations is the availability of electrical power in a standardized quality at any time and at practically any location. This has been achieved through systematic consumption-oriented structuring of the system since its beginnings at the start of the 20th century. Systems were frequently planned and constructed around consumption centers (the origins of electrical power supply were mainly decentralized and local), and thermal power stations, which predominate in most countries, follow the requirements of consumption in their operational patterns.

The energy storage required to compensate for fluctuations in consumption basically takes place on the primary energy side, where it can usually be implemented cost-effectively (for example, by stock-piling fuel). However, this basic principle has been increasingly called into question in the past 15 years. Essentially there are two reasons:

- The liberalization of electrical power supply which has been enforced in many parts of the world since the early 90s has led to the breakdown of the principle of local generation. Competition without the possibility of being able to supply from different power stations is not good policy.
- Climate change caused by anthropogenic greenhouse gas emissions, which is becoming more and more apparent, and the growing shortage of fossil primary energy carriers have led to a growing interest in renewable energy sources. After hydroelectric power, which has been used since the earliest days of electrical supplies, wind power has become the second most important renewable source in the world.

Wind power has been experiencing extremely strong growth around the world for the past 15 years.

The wind and the sun are almost ideal sources of sustainable energy supply: clean, available in the long-term and with high potential for growth in comparison to all other forms of renewable energy. However, their exploitation means a departure from a purely load-driven system operation. Since neither wind nor solar energy can be stored on the primary side, the electrical power supply systems of the future must be considerably more flexible than those of today. They must be able to balance between an unplannable and erratic generation side and the unchanged requirements for a high quality and reliable supply on the consumption side.

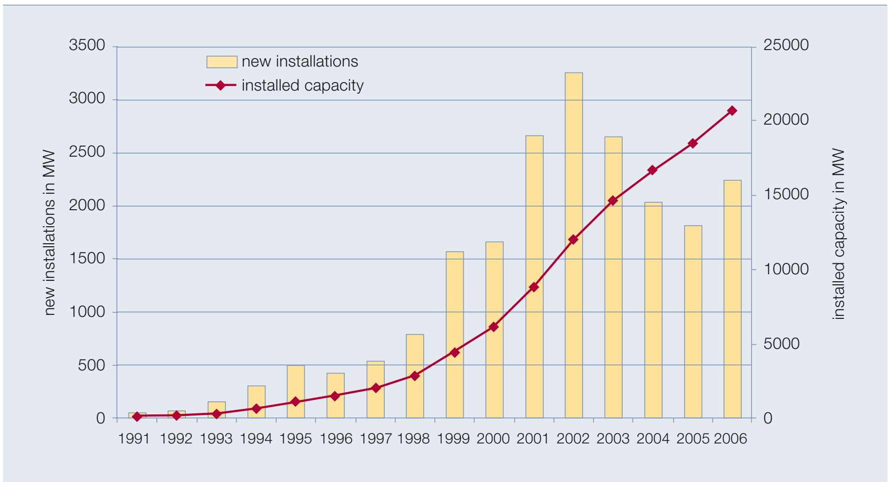
Basic structural changes in the electrical power supply sector

Two important trends have led to far-reaching change in the electrical power supply sector since the beginning of the 1990s. The first of these is the liberalization of the electricity supply, which can be observed throughout the world. This has led to the separation of generation, wholesale supply and energy marketing on the one hand and supply systems and system operation on the other. As a consequence, the planning of new power stations is no longer coordinated with the planning of grid expansion. In addition, system operators must react to the requirements of the power generators for unit commitment and load distribution. Only in the event of the system stability being endangered do system operators have the power of decision. Finally, system operators also have only very limited information about the power stations of independent power generators.

The second major trend is the effort to increase energy efficiency and to reduce the use of non-renewable primary energy carriers. In this respect, decentralized generating units with combined heat and power generation and renewable energy sources play a central role within the electrical energy supply sector. The latter are without doubt one of the most important fundamentals for a sustainable coverage of international energy requirements that is securable in the long-term. As a result, they have a firm place in the energy policy of many countries, and their development is often strongly promoted.

Wind power has been experiencing extremely strong growth around the world for the past 15 years.[1] Its advantages lie in the considerable amount of primary energy available (at least in coastal areas) and the fact that its generation costs are closer to competitive levels than is the case for other forms of renewable energy. It had previously remained largely unharnessed because its economic efficiency was as yet insufficient. The promotion of wind power in many countries has, however, resulted in a worldwide installed wind power output of more than 74,000 MW by the end of 2006. In Germany alone, the

1 Expansion of wind energy in Germany (source: Bundesverband Windenergie e. V.)



Footnote

1) See also "Clean power from the sea" on page 69 of this edition of ABB Review.

country with the biggest expansion so far, more than 20,000 MW 1 has been installed to date (Germany's total peak load was 77,000 MW in the winter of 2005/2006). As a result, 30.5 TWh of electrical power was produced in Germany in 2006, corresponding to 5.1 percent of total production.

It is common to both these trends that, in addition to load fluctuations, further unplannable processes have to be increasingly considered by system operators in the electricity supply sector.

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Consequences of a high proportion of unplannable generating capacity

The essential characteristic features of wind power are that it is location-bound – good wind conditions are frequently found outside the areas of concentration of power consumption – and it is volatile.

The selection of a suitable location for the generation of any type of renewable energy is guided by the availability of the primary energy supply – particularly if the costs for the use of the grid are independent of the infeed location. In Germany, wind energy converters are concentrated in the northern federal states 2. These are areas in which grid infrastructure is typically least developed and consequently not well suited for handling high throughput. Such infrastructure must therefore be expanded. In addition to the around 20,000 MW installed on land in Germany, there are offshore windfarms with an overall output of around 30,000 MW. 3 shows the current estimate of the further expansion. The dena[2)] grid study on the effects of the expansion of wind power on the German transmission network has calculated an additional transmission route requirement of more than 800 km by the year 2015 [1].

However, a high proportion of wind energy in generation not only results in new requirements for the transmission network but also for the rest of the generating system. First of all, installed capacity should be considered: Wind energy converters located in land areas with typical wind conditions can only provide between 10 and 15 percent of their installed output at the availability that is usual for thermal power stations [3]. This figure improves to almost 50 percent for offshore turbines. The power shortfall must be sourced from so-called "shadow power stations": These are back-up (non-wind) power plants.

Because of this back-up, the installed generating capacity in networks in which wind power is incrementally built-up will not initially cause any problems in supply systems. However, the guarantee of short and medium-term reserve capacity must be adapted. Basically, just as in any other supply system, load and generation must be kept balanced at all times. In all generating systems, a certain part of the load, the so-called balancing band, is covered by power stations that are run in partial-load operation and can thus adjust their power output up as well as down at short notice Factbox. Since these balancing power plants require additional control engineering equipment and their installed capacity is not fully used, the balancing band should be kept as small as

Factbox Reserve to keep the power flowing

Seconds reserve is the generation reserve that can be accessed within seconds. It usually consists of generators running at partial load and whose output can be easily increased or decreased. Seconds reserve is used mainly for frequency control.

Minutes reserve (also known as warm or spinning reserve) is the next level of reserve. An unplanned generation or transmission outage or load fluctuation is initially absorbed by the seconds reserve control band. To free this reserve, generation is switched to other sources within minutes (UCTE rules, for example, demand that minutes reserve relieves seconds reserve in under 15 minutes). Minutes reserve usually takes the form of storage stations and gas turbines (started for the purpose) and thermal stations running at less than full power.

Hours reserve (also known as cold or stand-by reserve) is the next level of reserve and usually consists of power plants that have to be started for the purpose.

2 Landscape in Mecklenburg-Vorpommern, Germany: Low density of population and industry in such regions mean that the power grid is traditionally weak

Footnote

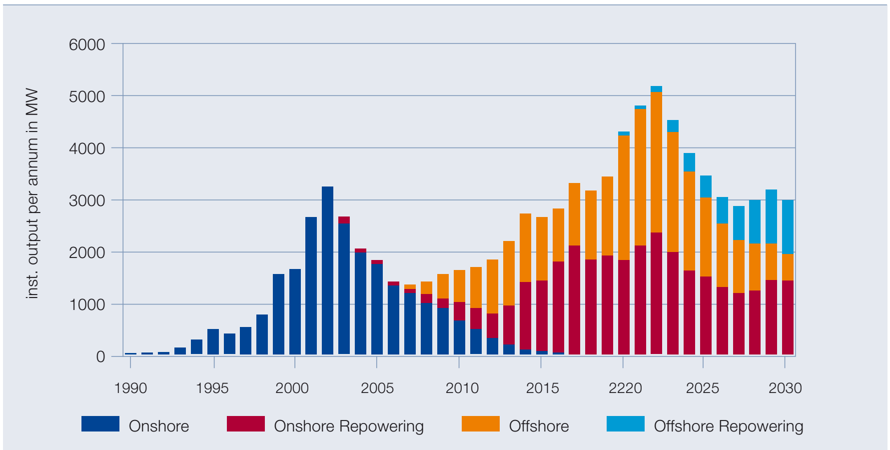
[2)] dena: Deutsche Energie Agentur, the German agency for energy efficiency possible. The band's size depends on the amount of unplannable load fluctuations in the system; this is determined both by the load itself and by the size of the largest generating unit (whose failure the system must be able to compensate at any time). Within a network system, e.g. the European UCTE[3] system, there are binding requirements for the size of the balancing band and for the rate of output change that the balancing power plants must be able to deliver.

The spatial concentration of wind power generation off the coast will in many situations result in a permanent large-scale transport requirement.

A system in which wind power generation can fluctuate for a short time between zero and almost complete load coverage (as is the case in northern Germany or Denmark) will have substantially higher reserve requirements than a purely thermal system, in which the largest unit accounts for at most a few percent of the peak load and the load itself is quite well-known and predictable. The initial experience in northern Germany, using prediction methods for wind power generation that are doubtlessly capable of improvement, resulted in an average minutes reserve requirement of 25 percent of the installed wind power output [2]. Against such a background, the UCTE requirements for system balancing will doubtlessly have to be adapted. This is supported by investigations of the dena grid study [1]. According to this, a short circuit in the north German supergrid under strong winds conditions can lead to a generation failure that is an order of magnitude greater than the rotating reserve capacity prescribed in the UCTE.

The major failure in the UCTE of 4th November 2006 shows that the European network system already has a considerable unplannable generation capacity with influence on the system management. The report of the UCTE on this failure [4], in which the UCTE network was initially split into three asynchronous islands, firstly records that following the failure, wind energy converters in northern Germany automatically disconnected without any coordination with the system operators. Although in case of this particular major failure this behavior had a system-stabilizing effect (since the wind energy converters were located in a region with overfrequency, ie, excess generation) the opposite could also have been the case. Secondly, the report points out that the recovery of the synchronous network was impeded as a result of decentralized generation, of whose nature the system operator had inadequate knowledge and which he could not influence. This shows that the basic requirements of system management have changed significantly, but that the associated tools have yet to follow suite.

3 Expected further expansion of the wind power capacity in Germany (source: http://www.deutsche-windindustrie.de)



Technical solutions for the design of future supply systems

New options for transmission networks

A high proportion of renewable energy sources and changes in the electricity business give rise to different tasks for the transmission network than is the case in systems with local balancing of load and generation. Transport and reactive-power demand are above those of conventional systems. There are various alternatives for grid reinforcement:

First of all, the option of adding new supply lines should be mentioned. However, this is frequently time-consuming and can only be implemented with difficulty. The higher capacity utilization of existing lines and routes is therefore an interesting alternative. In addition, the operating voltage, cross-section of the line or operating temperature of existing three-phase lines can be increased[4].

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In particular, the spatial concentration of wind power generation off the coast will in many situations result in a permanent large-scale transport requirement. This situation is already foreseeable in Germany. The question arises as to whether a reinforcement of the 400 kV network, which was built for another purpose, ie, essentially reserve pooling, is really the right method – or would it be better to build an overlay network for this

Footnotes

[3] UCTE: Union for the Co-ordination of Transmission of Electricity, the association of transmission system operators in continental Europe

[4] See also "Power to be efficient" on page 14 of this issue of ABB Review

transport task. Such an overlay network is conceivable either at a higher voltage level using three-phase current technology, or using high-voltage DC transmission (HVDC). The latter permits the transfer of higher power outputs with identical space requirement and has the advantage that it has no reactive-power demand. If self-commutated IGBT-based HVDC converters are provided, these can, in addition to their transport functionality, provide fast and continuous reactive power support for the local network 4. This option is particularly attractive in areas with high wind power generation – as explained above, the networks in these areas are often structurally weak. ABB has supplied installations using this technology under the name HVDC Light™ since 1997 and can now realize system power ratings up to 1,100 MW.

The capability of the self-commutated HVDC to instantaneously perform in any point of the PQ-diagram and, in particular, also the zero point 4b, combined with the fundamental advantage of transport without reactive power mean that this technology is ideally suited for the connection of the planned offshore wind farms. In this respect, it will often be appropriate not to establish the connection directly at the coast, but to extend the HVDC lines to suitable high-performance nodes of the transmission network. This could be easily reconciled with the concept of an overlay network for bulk transport.

More transparency for the system management

Power transmission and rapid changes in load flow during supply fluctuations from renewable sources place increased demands on the transmission networks. The more detailed and timely availability of information on the grid status, as can be provided by innovative wide-range monitoring systems [5], can support grid management in this respect. Decentralized vector measuring instruments can record current and voltage vectors in a high time-resolution. A highly accurate image of the dynamic system status is available to the grid management system through the system-wide time synchronization via GPS 5.

The fields of application of this new quality of information extend from the more exact observation of adjacent network areas – particularly when they contain elements that influence load flow such as phase-shifting transformers, FACTS or HVDC lines – to the continuous monitoring of the system for critical states and the identification of parts of the network that are no longer frequency synchronous. During the major failure on 4th November 2006, in which the UCTE network split into three sub-networks, this islanding was initially not detected in the control stations. Basically, it can be assumed that the probability of critical situations such as occurred on 4th November 2006, will increase in a transmission network that is more heavily loaded by transport. Better information availability for network control stations will be appropriate and necessary.

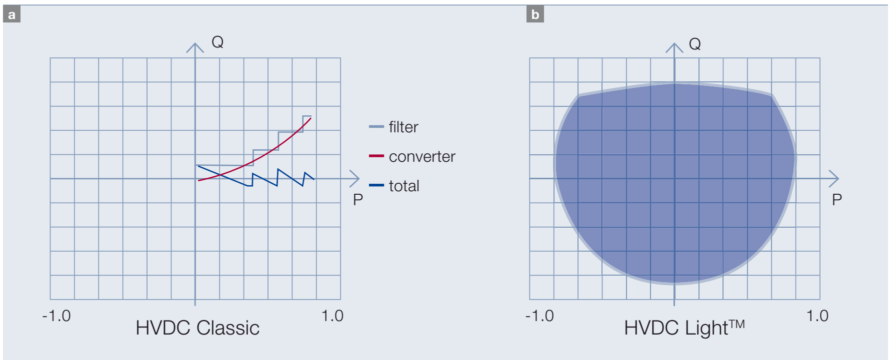
The electrical power supply systems of the future will be characterized by a high proportion of renewable energy sources, by decentralized, externally determined generation and frequently by a strongly developed electricity business.

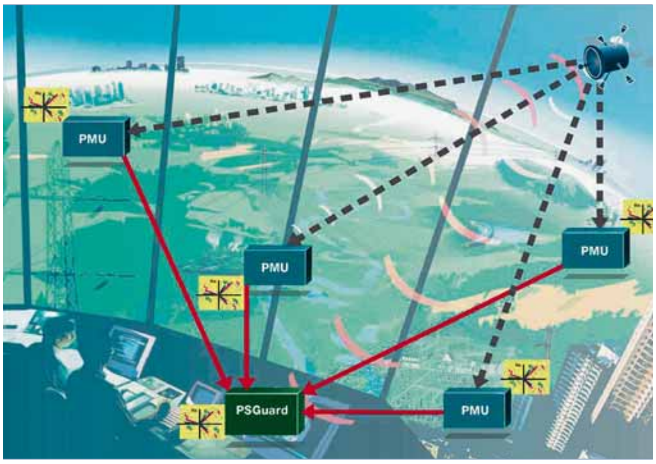
Challenge for thermal power stations

A high proportion of wind power generation leads to increased control engineering demands for the supply-independent generating subsystem. This concerns both primary and secondary reserve capacity such as minutes reserve Factbox and is especially relevant in systems in which coal-fired power stations are used for balancing. The use of modern instrumentation and control in the existing thermal power stations offers a considerable potential for improvement and can be realized with a low effort. The implementation of model-supported and comprehensively optimized operating characteristics for the turbine and boiler of steam power stations, as is provided in ABB's systems MODAN and MODAKOND, leads to a smoother, low-fatigue operation and a reduction in auxiliary demand in the percent range. During throttled operation, which is important for the provision of seconds reserve, efficiency increases of up to 0.48 percent could be verified. This increase is basically attributable to the fact that the output change rate required for balancing the system is obtained by minimum turbine throttling. Such improvements, which enable results significantly above the present UCTE requirements, become even more important in systems with a high proportion of renewable sources and a correspondingly unstable operation of the remaining generating system.

In view of the forecasting uncertainties in wind power, the provision of minutes reserve is of particular importance. The upgrading of existing power stations can be a technical necessity for reliable system operation but equally a commercial opportunity for the power plant operators – reserve capacity is a high-quality product in

4 PQ-diagram of a traditional HVDC installation a and of self-commutated HVDC Light™ b – HVDC Light™ can continuously and quickly control each point of the four quadrants





5 Wide-area monitoring system with synchronized Phasor Measuring Units (PMU) [5]

The wind is a freely available but volatile source of energy

liberalized electricity markets. Systematic modernization of the instrumentation and control often offers considerable potential. In one case, an increase in the output change rate from 2 MW/min to 50 MW/min and an increase in the control accuracy of ± 5 to ± 0.5 percent could be achieved through the coordinated modernization of the turbine, boiler and unit control. In addition to this, the power station concerned is able to participate in primary and secondary balancing since the modernization.

A high proportion of wind power generation leads to increased control engineering demands for the supply-independent generating subsystem.

Outlook

The electrical power supply systems of the future will be characterized by a high proportion of renewable energy sources, by decentralized, externally determined generation and frequently by a strongly developed electricity business. This calls for new requirements for conventional generating subsystems and transmission networks, because the generating plants are location-bound, because the primary energy supply is often unstable and difficult to forecast, because there is a lack of information about the behavior of decentralized generating units and because of the influence of the electricity business. In this respect, the increase in the number of processes in the electrical energy supply system which cannot be planned or influenced by the system operator is of central importance. In the past, the load basically had this characteristic, and the system management took into account that the load was the guiding variable for the system operation. In the future, a significantly larger number of such processes must be considered and coordinated with each other, so that a safe, reliable and economic supply of electrical power, an important mainstay of industrial societies, continues to be available.

Solutions are already available for many of the consequential aspects. The increased control engineering requirements of the conventional power stations, the increase in the transport capacity of the transmission networks and improved information about the system status are examples of this. The main challenge in the coming years will therefore be to select the right solutions on the basis of a comprehensive understanding of the system and to integrate them in the supply systems in good time.

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