Wind power goes large-scale

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Spurred by new technologies, the harnessing of wind power to generate electric energy has exceeded all forecasts, with about 13.4 gigawatts of plant capacity – the equivalent of more than 20 large fossil-fuelled power stations – currently in place. Now an even newer technology promises more: an integrated system named Windformer™, designed to generate wind power offshore and in coastal areas and to transmit the power to the utility grid. Windformer increases the power output by up to 20 percent and cuts lifetime maintenance costs in half. Using advanced cable technology originally developed for ABB's Powerformer™ generator, ABB engineers have created a wind generator that requires neither a gearbox nor a transformer, making wind farms more reliable and reducing electrical losses.

1 Mean wind speeds offshore translate into higher energy production and reduce the impact on the local environment

Wind power is the fastest growing energy source in the world, having registered an annual 40 percent increase over the last five years. New installations in 1999, at almost 4 gigawatts, were up 51 percent compared with the previous year. By the end of 1999, the total installed wind power had reached 13,932 MW, with approximately 30 TWh of electrical power generated during the year [1].

It is predicted that world electricity demand will increase from 13,000 TWh to 23,000 TWh between 2000 and 2020. This extra electricity will be required primarily in the developing countries, while in the industrialized nations growth is estimated at 1.8 percent per annum, equating to about 3,500 TWh over the same period. Demand for new production capacity to cover the world's electricity requirement is expected to be up to 10,000 TWh or thereabouts by the year 2020 [2].

If the influence of ecological issues on newly installed production capacity remains strong, demand for renewable energy sources can be expected to grow faster than if economics were the sole factor. The Kyoto Protocol, with its focus on CO_2 and other greenhouse gases, serves to underline worldwide environmental concern and emphasizes the importance of renewable energy. Those areas of the world in which environmental aspects exert the strongest influence on energy markets, eg North America, Western Europe, Japan, Australia and New Zealand [1], are expected to see the fastest growth in renewable energy.

3922 MW of new wind power capacity was installed in 1999, and trends point to this figure doubling within three to four years. World market turnover was US$3 billion in 1999, and is growing by approximately 20% per annum [1].

The growth potential for wind power is considerable. Much of the generating capacity is placed offshore 1, where high mean wind speeds translate into higher energy production. Offshore locations also reduce the impact on the local environment, since the turbines are largely out of sight and out of hearing range. Development work continues to produce larger units and wind power can now be seen as a major source of energy, with large wind farms capable of delivering hundreds of MW. Accompanying this is the realization that the wind power industry has now reached a stage where the equipment vendor has to look beyond the straightforward supply of small, individual wind turbine generators (WTGs) to the supply of total solutions that span the complete wind power system. To be successful in this market, suppliers must understand the energy chain in its entirety, and demonstrate that its expertise and know-how extend from the energy source right through to the end-consumer.

Windformer™ is a new wind power system, developed by ABB for wind farms situated offshore and in coastal areas. WTGs with Windformer have a high output of typically 3 to 5 MW. This generator power rating has a number of advantages. In the first place it reduces the required site area, since fewer machines are needed for a given station output. This in turn diminishes the visual impact 2 and noise emissions of the WTGs. Based on Powerformer™

2 Because of the higher power rating of Windformer™, fewer wind turbine generators are needed (left) than for a comparable wind farm with conventional WTGs (right). (Photomontage)

technology [3, 4, 5], the Windformer generator has a variable-speed rotor with permanent magnets and is connected directly to the turbine. The voltage (over 20 kV) produced by the generator is converted to DC by means of diodes. The WTGs are connected in groups, the power being transmitted by cable to a network station with inverter, linked directly to the utility grid **3**.

The 'simple' technology

Windformer was conceived as a 'simple' technology, incorporating stable systems that supply energy with high reliability and low losses. Its simplicity can be summed up as follows:

Primary energy	Wind, freely available
Rotor	Iron, permanent magnets
Stator	Iron, cables
Rectifier	Diodes
Transmission	Cables
Inverter	Transistors

Windformer electric power system

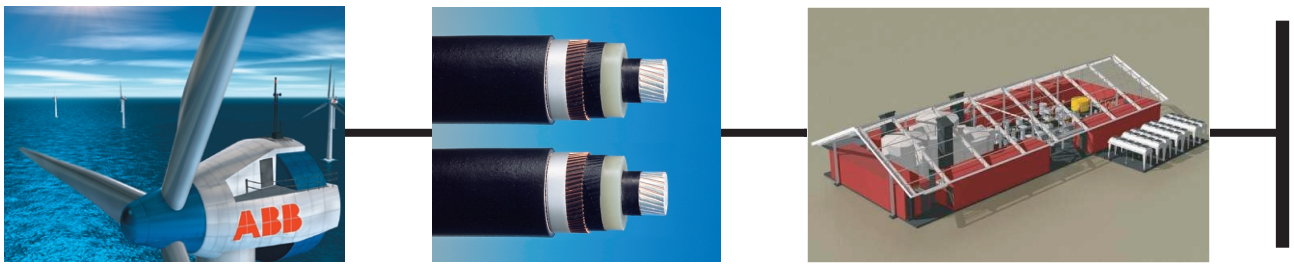
As the development of commercial wind farms gets under way, the need for equipment suppliers to take overall responsibility for the electric power system will also grow. Complete systems have to be optimized, not only individual components. This calls for a comprehensive approach, with solutions that cover everything from the system converting the wind's energy into electrical power to its transmission to the utility grid.

ABB's Windformer electric power system is based on a total wind farm solution in which the best systems for the prevailing conditions are chosen.

Clusters for wind power farms

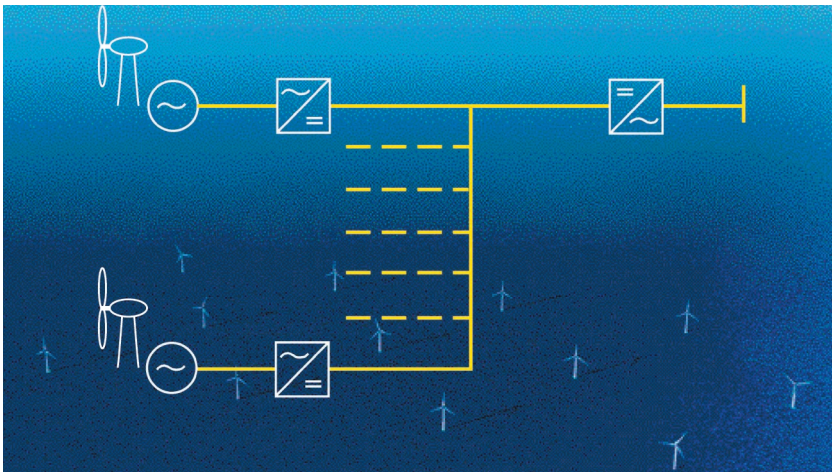
4 shows a Windformer cluster, comprising multiple WTGs, capable of supplying up to 40 MW.

The cluster is connected to a high-voltage utility grid through an inverter located in a network station. Offshore wind farms use land-based network stations, which are easily accessible for maintenance and service work. The network station controls the real and reactive power output individually, making it possible to connect the wind farms to even a weak network. With Windformer technology, variations in wind speed or



3 Schematic of the Windformer system. DC power from the wind farm is transmitted by cable to a network station with inverter, which is connected directly to the utility grid.

4 Windformer cluster comprising several WTGs. Capable of supplying up to 40 MW, the cluster is linked through an inverter to the HV grid.



tower shadow due to other WTGs will not cause fluctuations in grid voltage, which could affect nearby consumers. This is an important consideration, particularly for weak electrical networks.

By using an inverter to control the DC voltage, the generator speed is indirectly regulated, optimizing the energy production in the process. The turbine blades are pitch-regulated; the main use of regulation, however, is to adjust the input power to prevent turbine overspeed. A permanent-magnet rotor converts the kinetic energy to electrical power. The generator is connected directly to the turbine and operates at a frequency in the range of 5 to 10 Hz. The choice of voltage, which is at least 20 kV, depends on the optimization of the Windformer system. A diode rectifier converts the low-frequency AC voltage to DC.

A Windformer wind farm comprises several clusters. In the present configuration, the clusters have a rating of up to 40 MW and are connected via DC cables to an inverter in a land-based network station.

The voltage configuration for the wind farm is chosen on the basis of, among other

Table: Comparison of Windformer and a conventional wind farm based on an asynchronous generator

	Windformer	*Wind farm based on asynchronous generator*	
	Turbine	Turbine	
		Gearbox	
	Powerformer generator	Asynchronous generator	
	Permanent magnet rotor	Power factor correction equipment	
	Diode rectifier	Soft starter	
		Turbine transformer	
	DC cluster cable	AC cluster cable	
	↓	↓	↓
Offshore	**<100 km**	**<40 km**	**>40 km**
		Transmission transformer	Transmission transformer
			HVDC Light station
		Offshore platform for transmission transformer	Offshore platform for HVDC Light and transmission transformer
	DC transmission cable	AC transmission cable	DC transmission cable
Onshore	Inverter	SVC station	HVDC Light station
	System transformer	System transformer	System transformer

things, the existing network connection and the local regulations which govern it, the output of the wind farm, the maximum energy output per surface unit, the distance to the network connection, and its environmental (especially visual) impact.

As an example, a conventional utility-scale wind farm currently consists of 10 to 100 WTGs delivering 500 kW to 2 MW each with asynchronous generators rated at 0.7 kV. The generators are connected in series with a step-up transformer. In a large wind farm, a substation transformer steps the voltage level up to 130–230 kV. The differences between Windformer and a conventional wind farm are shown in the *Table*.

The ABB Windformer power system has several distinct advantages: it exhibits low losses, the power electronics in each WTG are reduced to a minimum, thereby increasing availability, AC flicker in the network is reduced, and the real and reactive powers are controlled separately.

To sum up, the land-based regulating system optimizes the energy output for an entire wind farm. This is in stark contrast to systems that regulate the power output of each individual WTG.

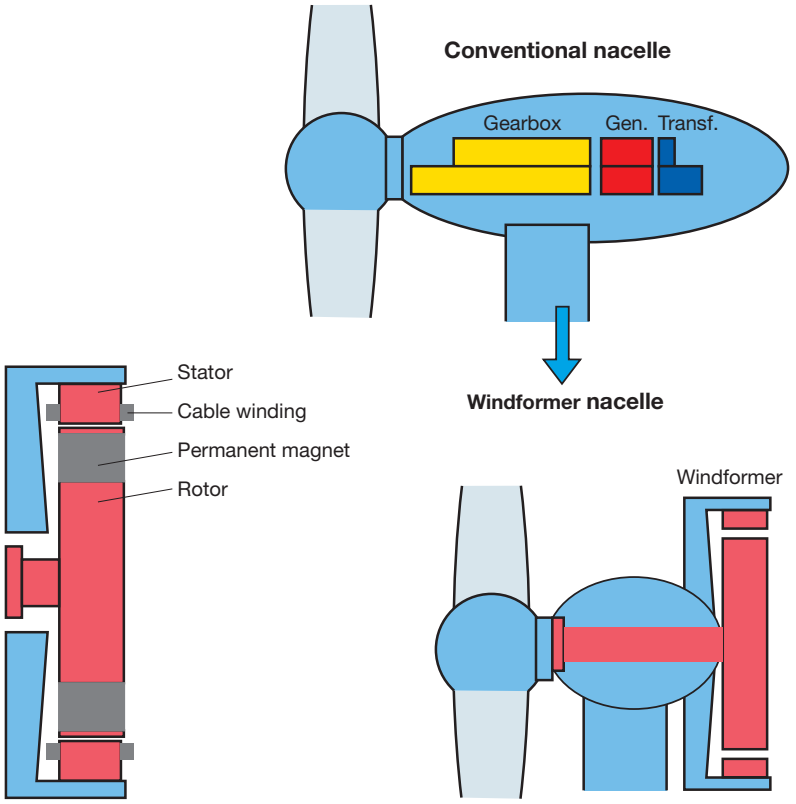
Pilot installation due soon

A pilot Windformer installation is to be installed soon at Näsudden in Sweden. The participants in this pilot project are ABB, Scanwind, Vattenfall AB and the Swedish National Energy Administration. Although an offshore version, it will be land-based to facilitate the comprehensive evaluation and testing programs that are needed. The WTG has a rated output of 3.0 MW, which will be increased for offshore applications. Able to work within a wind speed range of 5 to 28 m/s at variable speed, the WTG's rated output is reached at a wind velocity of 13 m/s. Below the rated turbine speed, the blade angle is kept in the most efficient position, whereas at rated speed the blade is turned towards the 'feathered' pitch position to limit the power output.

The output power is gradually reduced from 3 MW to 500 kW for wind speeds between 18 and 27 m/s. This has only a marginal effect on the annual energy production, but helps significantly to optimize the lifetime of the WTG. Annual energy production with the WTG placed offshore is calculated to be around 11 GWh, based on an annual mean wind speed of 8.0 m/s.

The turbine has three 90-meter diameter blades made of glassfiber-epoxy. The hub height of the Näsudden plant is 70 meters.

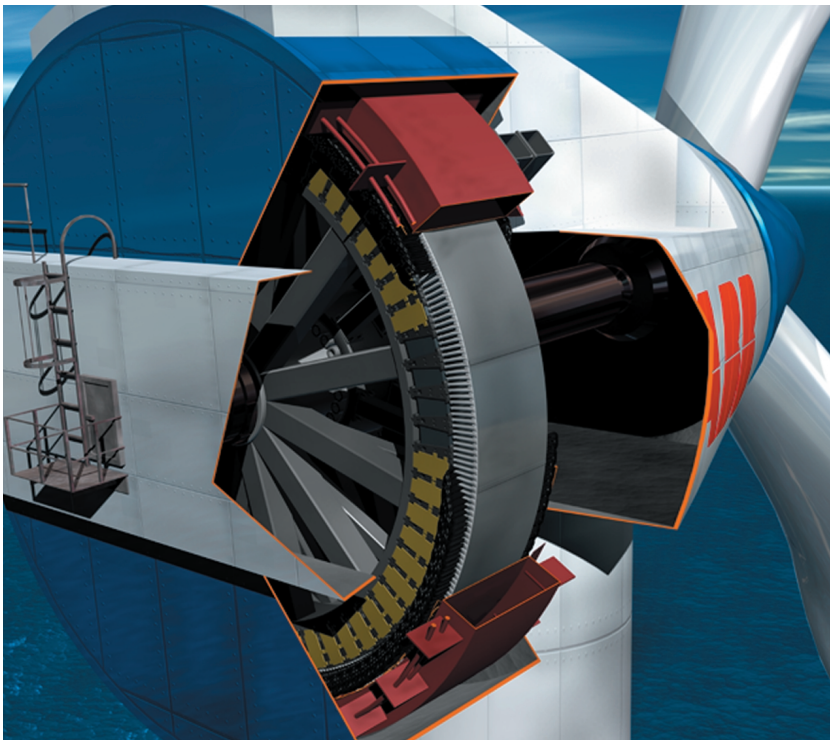
5 Comparison of a Windformer WTG nacelle with the nacelle of a conventional WTG



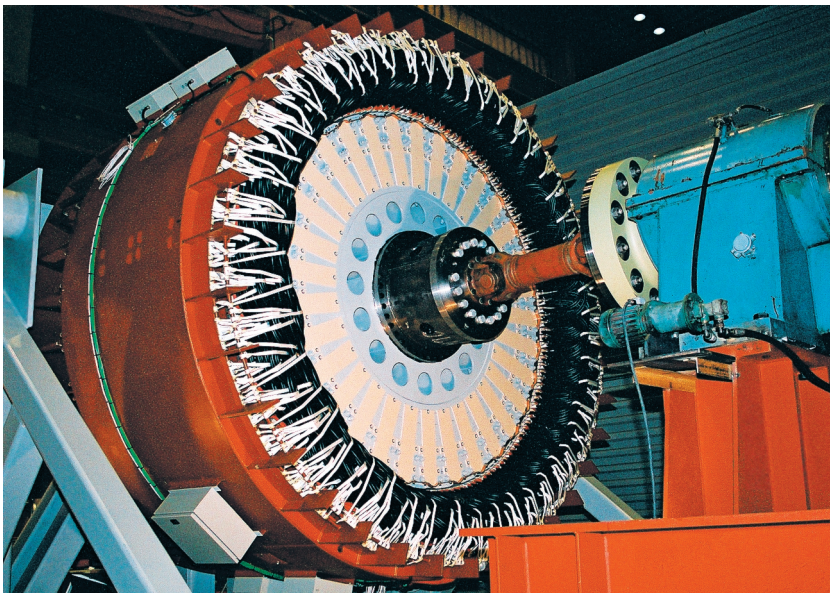
Based on Powerformer

The Windformer concept includes a cable-wound generator (Powerformer), connected directly to the turbine. The variable speed of around 18 rev/min reduces stresses as well as noise emissions at low wind speeds.

Windformer does not have a gearbox **5**, **6**, thereby reducing both losses and



6 Cutaway view of the Windformer generator, showing the rotor and cable-wound stator



7 Windformer WTG prototype during initial production tests. The cable-wound stator and the rotor with permanent magnets are clearly visible.

maintenance. It is worth noting that a conventional gearbox-driven 1500 rev/min fixed-speed generator rotates the same number of times in one month as the direct-driven Windformer WTG does in ten years.

Windformer's smaller number of vulnerable components contributes to its extremely high reliability and availability. These characteristics and the reduced maintenance are vital for offshore applications, where access to the WTGs is limited.

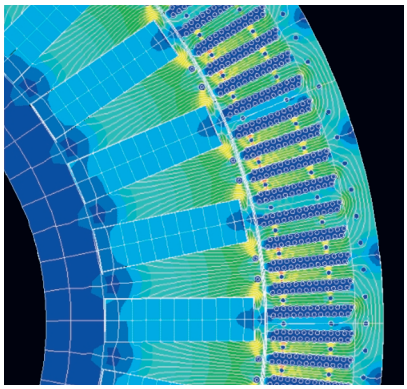
Special measures have been taken to ensure that the generator withstands severe climatic conditions, such as constant dampness and salt air.

Stator

The stator is based on Powerformer technology [3, 4, 5]. Therefore, round cables 7 are used instead of square, insulated copper conductors, as in a conventional generator.

Since the electrical field is totally confined within the cable, there are none of the usual problems with discharges at the end windings and connections, as in conventional generators. Losses in the windings are lower due to the higher voltage level. The use of cables also reduces the risk of phase-to-phase faults. The concept in itself reduces the short-circuit currents. And there are fewer safety issues involving the generator because of the smaller number of electrical components. Summing up all of these features, it can be said that a generator based on Powerformer technology offers higher availability, improved efficiency,

8 Calculated magnetic flux generated in the permanent magnets of the Windformer WTG



and, since fewer components are used in the installation, lower operating and maintenance costs.

Further improvements were made to Powerformer technology in the course of developing Windformer. For example, the entire Windformer generator winding is constructed without cable joints.

Rotor

In all previous Powerformer applications the magnetic flux is induced in the rotor by coils on the pole cores. The magnetizing current and the slip rings that are required are a direct cause of electrical losses.

In Windformer, the stator's magnetic field is produced by permanent magnets, and auxiliary equipment for inducing the magnetic flux in the rotor circuit is not necessary 8. A rotor with permanent magnets does not need to be cooled since the losses are low. In addition to improved efficiency, the permanent-magnet rotor offers other advantages, such as better availability, higher reliability, and reduced maintenance.

During development of the Windformer generator special attention was given to optimization of the magnetic circuit. This included dimensioning the circuit so as to avoid demagnetization of the permanent magnets.

The rotor is multipolar with a large air-gap diameter of over 6 m, making it what is probably the largest permanently magnetized rotor ever to have been manufactured.

Windformer is adapted for offshore operation. For example, a corrosion-resistant material is used for the permanent magnets that will withstand the harsh environment and minimize maintenance. Also, the Powerformer stator cable windings are designed to resist the harsh marine climate, so there is no risk of electrical flashover.

Life cycle assessments carried out for other installations using Powerformer show clear ecological advantages for the generator. These include its contribution to reduced environmental impact through improved overall efficiency, and the use of environmentally friendly materials.

The cables used for the stator windings are cross-linked polyethylene (XLPE) insulated and contain no oil. Distribution transformers, with their oil and epoxy insulation, are not needed, eliminating the risk of fire and high-risk oil handling. Also, virtually all parts of the generator can be recycled at the end of its useful life. The use of permanent magnets also has a positive effect on the environment.

Outlook

Wind power is fully renewable and the fastest growing source of electricity production in the world. Continuing to exceed all forecasts, installed capacity has grown from practically nothing in 1990 to about 13.4 gigawatts today, and it is estimated that the installation rate could reach 10 gigawatts per year by 2005. With its many advantages, primarily its high output and efficiency and the simplicity of its design, Windformer is destined to lead the way as wind power captures an even greater share of the renewable energy market.

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