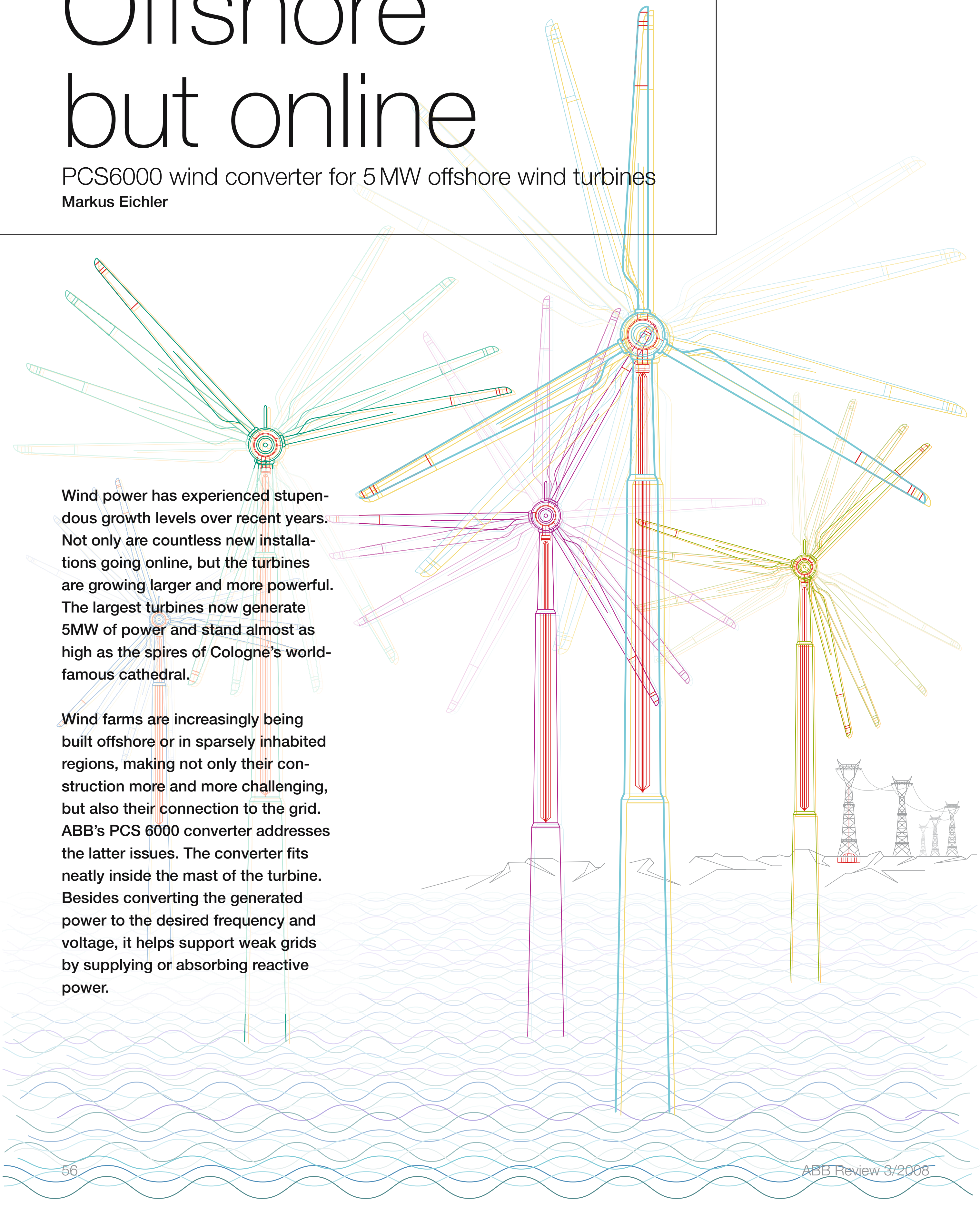
Offshore but online

PCS6000 wind converter for 5 MW offshore wind turbines

Markus Eichler



Wind power has experienced stupendous growth levels over recent years. Not only are countless new installations going online, but the turbines are growing larger and more powerful. The largest turbines now generate 5MW of power and stand almost as high as the spires of Cologne's world-famous cathedral.

Wind farms are increasingly being built offshore or in sparsely inhabited regions, making not only their construction more and more challenging, but also their connection to the grid. ABB's PCS 6000 converter addresses the latter issues. The converter fits neatly inside the mast of the turbine. Besides converting the generated power to the desired frequency and voltage, it helps support weak grids by supplying or absorbing reactive power.

The Alpha Ventus offshore wind farm is a pioneer project undertaken jointly by E.ON Climate and Renewables, EWE and Vattenfall Europe. Situated some 45 kilometers north of the German North Sea island of Borkum, in water about 30 meters deep, Alpha Ventus is the first German wind farm to be erected at sea under genuine offshore conditions. The design, construction, operation and grid integration of the Alpha Ventus research project as a test field will help build up fundamental experience with a view to future commercial use of offshore wind farms.

The plan is to erect six Multibrid M5000 and six Repower 5M wind turbines. An offshore transformer station will be located at the south-eastern corner of the wind farm. An on-shore control room will be set up to supervise the operation of the turbines. The feeding of power into the German grid will be handled by the transmission system operator E.ON Netz GmbH.

The total capacity of offshore wind energy is estimated to be between 20 and 40 GW. This will be harnessed in the European Union by 2020.

The first six wind turbines will be erected on an area of four square kilometers. They will be arranged in a rectangle with four north-south parallel rows of three turbines each. In the resulting grid-like formation, the wind turbines will stand approximately 800 meters apart.

Including its rotor, each wind turbine is about 150 meters tall, almost as high as Cologne Cathedral. The six wind turbines supplied by Multibrid will be anchored to the seabed by a tripod structure. The depth of the water at this site is around 30 meters. It would take 56 men to surround the triangular area of 255 m² on which the tripod stands. The amount of steel in each unit (around 1,000 tons) weighs as much as 200 adult elephants or 22 railcars. The rotor receives the wind over an area about one and a half times the size of a football pitch. When the rotor is turning at maximum speed, the tips of the blades cut through the air at around 300 kilometers per hour.

Technology from ABB

Wind turbines whose synchronous generator is excited by a permanent magnet need to be connected to the utility grid via a full-scale converter.

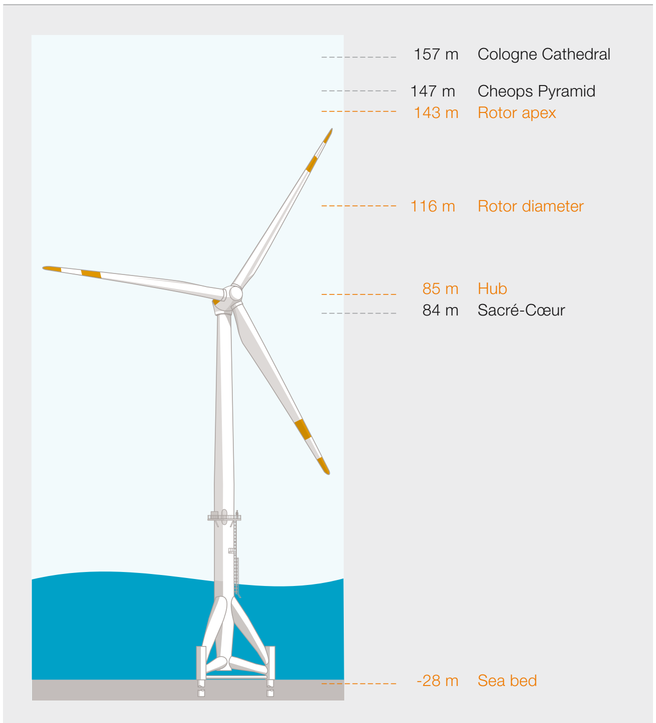
Factbox 1 Key data Alpha Ventus

- Number of units: 12
- Total capacity: 60 MW
- Expected energy yield per annum: approx. 180–200 GWh (equivalent to the annual consumption of about 50,000 three-person households)

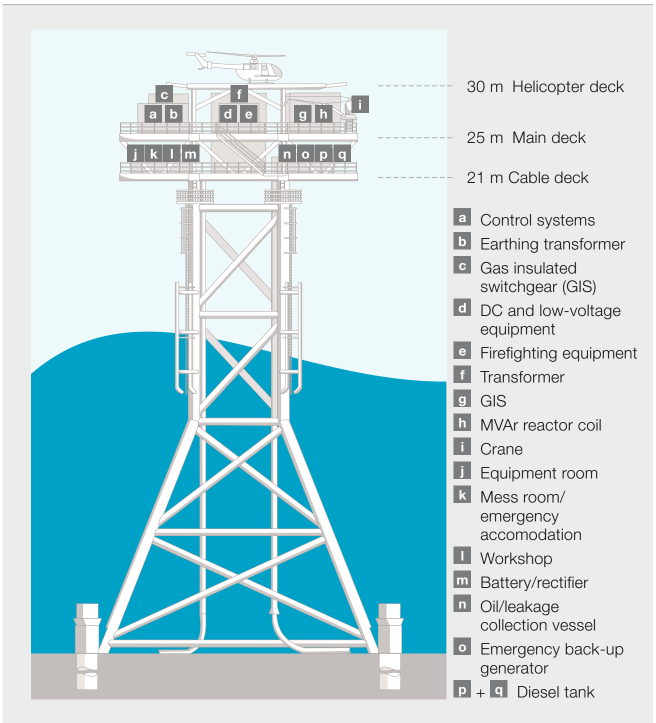
Factbox 2 Technical data Multibrid M5000

- Rotor diameter: 116 m
- Height of hub: 90 m
- Rated output: 5 MW
- Speed: 5.9–14.8 rpm
- Cut-in wind speed: 3.5 m/s (= force 3)
- Rated wind speed: 12.5 m/s (= force 6)
- Cut-out wind speed: 25 m/s (= force 10)
- Blade tip speed: 90 m/s (= 324 km/h)
- Weight of nacelle without rotor and hub: 200 t
- Weight of nacelle with rotor and hub: 309 t
- Weight of steel in tripod, tower, nacelle: 1,000 t

The wind turbines stand almost as tall as Cologne's cathedral.



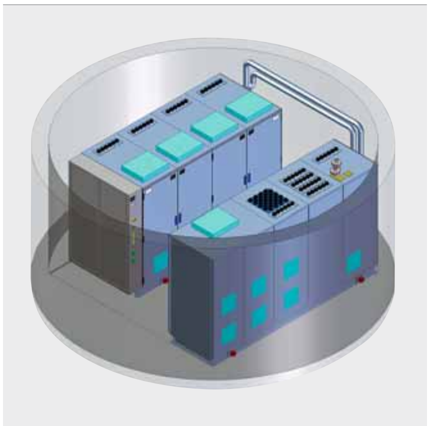
The converters are located on a dedicated platform.



Converters

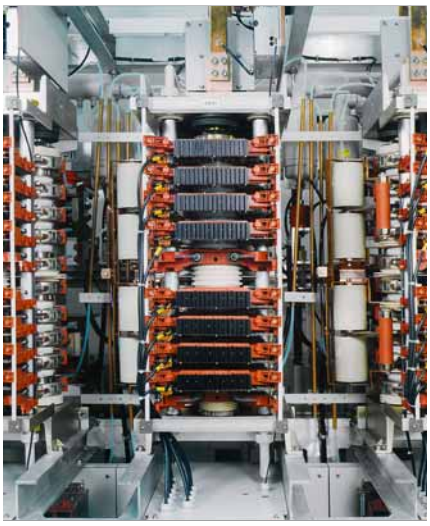
This arrangement allows wind turbines to be utilized at their optimal point of operation, and transmit the energy to the grid with high efficiency. With larger turbine unit sizes, medium-voltage converter systems are most suitable for handling the corresponding high power. The flexibility of industrial full-scale converter-based systems allows easy adaptation to different operation modes and grid requirements. Three important issues are of concern in using a power electronic system. These are reliability, efficiency, and cost.

1 The PCS6000 converter fits inside the tower.



2 The PCS6000 medium-voltage, full-power converter with control cabinet

3 A three-level double-phase IGCT module as used in the PCS6000



System description

Today, turbines with a power greater than 2 MW are mainly variable-speed turbines. For offshore applications, where low maintenance requirements are essential, a turbine whose generator is excited by a permanent magnet is widely considered the preferred solution. This solution calls for a full-scale converter. The conversion efficiency of this system is very competitive, especially in partial load operation.

In order to benefit from the broad experience gained from this kind of application, the converter is based on a standard industrial design. This will increase the reliability of the new turbine generation owing to the reduced failure rate achieved by the simple system structure.

The PCS6000 wind converter is based on modular power electronics building blocks (PEBB) using high-power semiconductors. This approach enables the development of remarkably compact converters

For 5 MW wind turbines, ABB made a four-quadrant PCS6000-based converter. It uses standard IGCT (integrated gate-commutated thyristor) – PEBB technology. The complete converter is based on a PEBB platform, a control platform and a platform for mechanics. This brings high advantages in terms of costs, quality and reliability. The PCS6000 combines two NPC (neutral point connected) phases. It achieves an advantageous power density – an important factor for converters located inside the wind turbine. 1 shows the PCS6000 5 MW converter placed inside a tower of the offshore installation 2.

The PCS6000 Wind converter needs only one platform inside the tower with all necessary auxiliary components such as the water cooling system, grid filter and generator dv/dt filter. The very compact design allows access from all sides for service and maintenance. The converter system is controlled by the ABB AC 800PEC Programmable Logic Controller.[1)] All measurement and control connections from the control system to the medium-voltage compartment are isolated via fiber optic links. Only one pair of fiber optic links is necessary for the communication between the PCS6000 wind-converter control and the auxiliary cabinet for the cooling and filter functions. This ensures an operation of the system that is immune to disturbances caused by EMC. The IP54 (ingression protection) design of the cabinets assures durability in the face of condensation inside the tower. Care and attention is applied to the design of all components with regard to withstanding possible vibrations. To secure the safety of maintenance and service personnel, the converter has an earthing switch and fail-safe door interlocks.

The PEBB-concept has significantly improved serviceability 3. Components can be exchanged in a convenient and swift way, without disconnecting bus bars or cooling pipes. The double stack can be opened very easily by discharging a spring, then spreading the heat sinks with a tool, permitting the IGCT to be removed from the stack 4. The PCS6000 wind converter does not even require fuses: The intelligent protection system prevents mechanical damage caused by a semiconductor failure. Broken semiconductors cannot cause fault arcs.

Footnote

1) See also "Design patterns" in *ABB Review* 2/2008, pages 62–65.

4 IGCT for a 9MVA PEBB

This is an additional important benefit for the offshore installation, where the weather can restrict access to the wind turbine for periods of days.

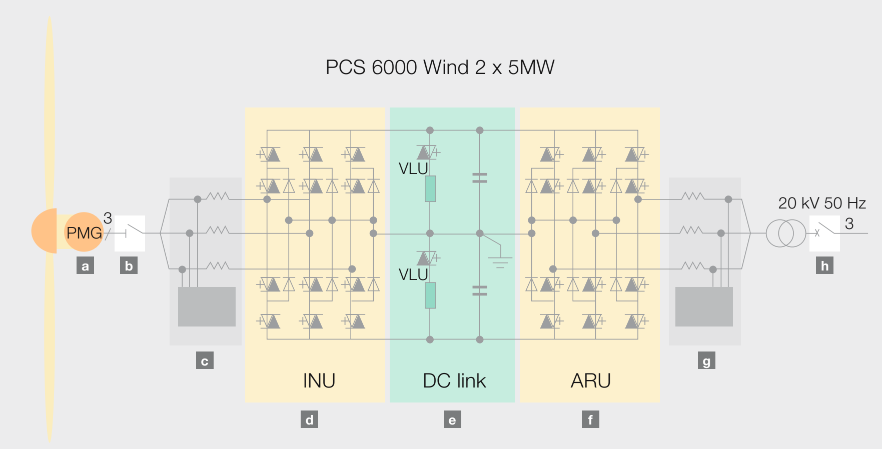
Inside the wind-power converter

The main building blocks of the converter are the two inverter modules connected by the DC link. The basic circuit diagram also shows auxiliary circuits such as the grid-filter circuit and the edge filter on the generator side. Three-level inverters are commonly used in medium-voltage industrial converters. The transformer can be designed to easily withstand the dv/dt of the switching IGCTs. A grid filter is necessary, however. Its main function is the limitation of harmonic currents to a level that enables IEEE 519-1992 to be fulfilled on even very weak grids. Using an extended filter, the German "VDEW Guideline" can also be met. The grid filter is an LC filter in combination with a special damping circuit for the lowest-order harmonic. On the generator side, a small dv/dt filter limits the rate of voltage rise at the generator terminals.

5 shows the basic circuit diagram of the four-quadrant three-level wind power converter. The power from the inverter unit (INU) is rectified to the DC link and from the DC link with the active rectifier unit (ARU) to the grid. The DC link is protected by a voltage limiter unit (VLU) for smooth uninterrupted operation of the turbine during a fault ride-through situation on the grid. This avoids torque oscillations for the turbine during a grid disturbance.

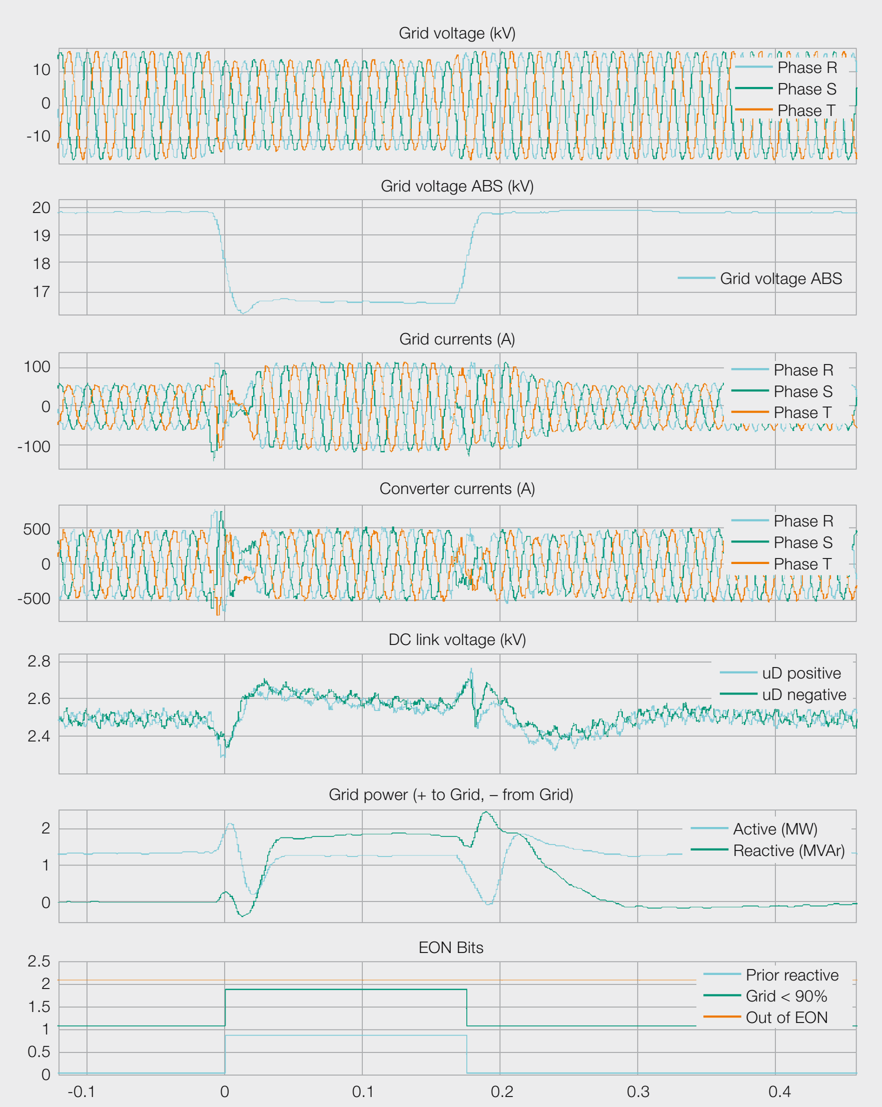
In normal operation, two semiconductor switches in each phase are always in the blocking state. This allows operation at twice the DC-link voltage of a two-level converter using the same elements. Compared to the series connection of elements, the three-level configuration has substantial advantages: The neutral-point diodes guarantee the voltage-sharing between the two blocking IGCTs without the need for special voltage sharing networks. Additionally, the neutral-point potential may also be switched to the output terminals. This results in smaller voltage steps at the output and a lower current ripple. Compared to a two-level converter with the same average

5 Basic circuit diagram of the four-quadrant, three-level wind-power converter



a Permanent magnet synchronous generator
b Loadbreaker
c dV/dt filter
d 5 MW generator converter
e DC link brake chopper
f 5MW grid converter
g Grid filter
h Circuit breaker transformer

6 Recording of an E.ON flicker with ABB DIAS transient recorder tool



Converters

switching frequency of the individual IGCTs, the ripple is four times lower. This very low current ripple significantly reduces the torque ripple on the generator side and therefore the load at the planetary gearbox.

Benefits of the PCS6000 4Q-topology

The ABB wind power converter for full-scale power conversion is based on the four-quadrant concept, ie, a bi-directional power flow is possible in principle. The application itself doesn't require a bi-directional power flow, ie, the generator related converter part could be realized as a unidirectional converter. Before the turbine is erected offshore, detailed tests of the gearbox and the generator are performed. The PCS6000 converter starts the generator as a motor, powering the gearbox via the driving collar while at the same time providing reactive current for the generator windings for a heat-run test. During these in-factory tests, all important protection and cooling systems are tested and adjusted. The bi-directional power flow allows the positioning of the turbine rotor to an exact position where the rotor can be locked with the hydraulic brake for investigations of the rotor blades or the pitch system. The upper control system determines the desired position for the rotor. It communicates with the converter controller using the PROFIBUS protocol. The PCS 6000 converter can move the rotor to the desired position smoothly and with high accuracy – even during very strong winds.

Encoders are known to cause failures. The PCS6000 wind converter operates without encoder to reduce maintenance and ensure high availability. A special feature is the soft-start routine for the main transformer. The DC link of the PCS6000 converter is pre-charged with a small pre-charge unit to take the voltage up to the nominal DC link level. Then, the grid side converter (ARU) slowly ramps the voltage up and synchronizes the transformer to the grid without causing current inrush. This feature helps connect large transformers to weak grids and prevents voltage dips caused by direct switched transformers in a wind farm. Another main benefit of the full scale power converter is the capability to provide reactive power to the grid. Additional reactive power compensation equipment is not needed, as is the case for traditional wind turbines with double feed induction generators. The PCS6000 wind converter is able to inject and absorb reactive power to control the voltage at the connection point to the grid.

Grid codes

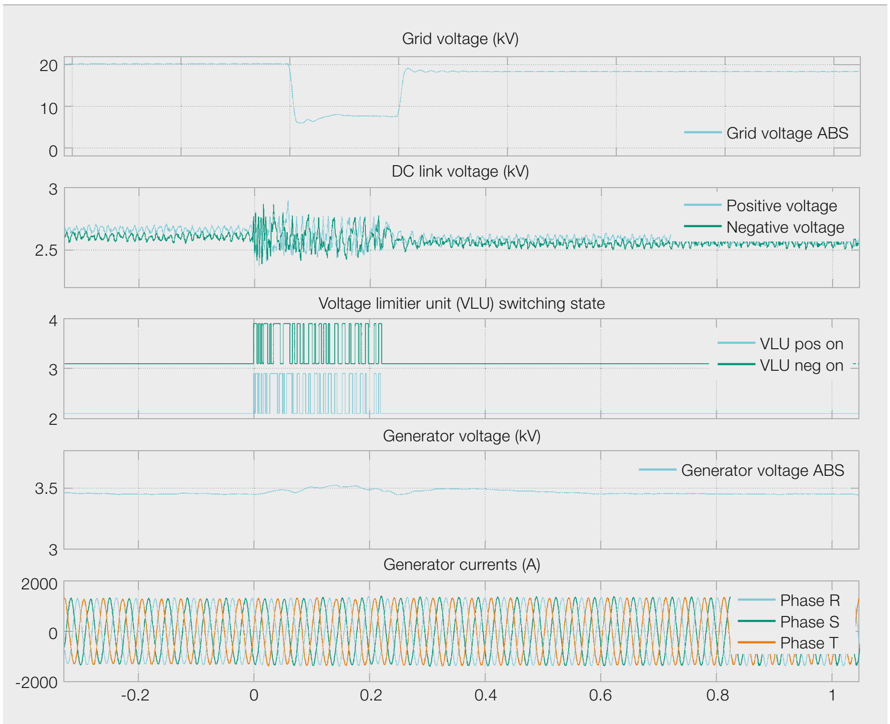
The PCS6000 wind converter ensures continuous operation even during times of grid faults. The fast dynamic voltage control during balanced and unbalanced grid faults is a function of the PCS6000 wind converter necessary to achieve the grid codes. 6 shows a real measured voltage dip during turbine operation with the prototype of the Multibrid M5000 wind turbine in Bremerhaven, Germany.

During extreme grid faults, the full-scale power converter has to provide 100 percent reactive current to support the grid. Therefore, the grid-side converter (ARU) cannot feed the active power from the generator into the grid. This would cause overvoltage in the DC link of the converter system and de-load of the generator because of normal protection functions. The PCS6000 wind converter system is equipped with a voltage limiter unit (brake chopper) that can dissipate the active power during the grid fault in such a way, that the turbine continues to run unaffected 7. The generator will not see any oscillations in the current (the current being an indicator for the actual load torque).

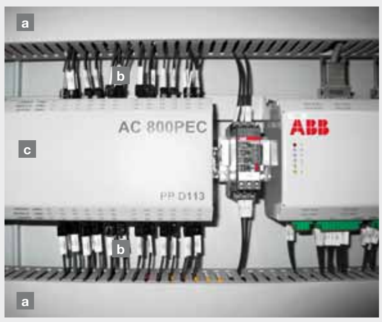
PCS6000 control system

The PCS6000 power converter controller receives run/stop signals from the turbine controller (master/slave sys-

7 Brake chopper operation during extreme grid faults



8 AC 800PEC power converter controller with fiber-optic links



a Cable duct
b Fiber optic cables to/from optical modules
c AC 800PEC controller module
d Fast analog and digital input/output module

tem) using a digital link via PROFIBUS. Torque commands to the permanent-magnet synchronous generator (PMSG) are based on speed measurements with an update rate of at least 10 ms. A serial link connects the standard industrial programmable logic controller (PLC) master controller to the converter controller AC800 PEC 8.

9 Remote access to the PCS6000 converter system via Internet

The active rectifier (ARU) must be able to operate the machine at maximum torque per ampere over the power curve until the voltage at the machine terminals reaches the limit of the active rectifier. From this point it must limit terminal voltage while the machine continues up the power curve. The inverter (INU) provides real power to the grid while regulating the DC voltage. In order to meet these objectives, a field-oriented control strategy is proposed without the use of rotor-position sensors. The sensorless algorithm is based on a phase-locked loop (PLL), which synchronizes the internal/back EMF (electromagnetic force) of the generator in proper phase and frequency to the permanent magnet flux. The feedback quantities for control are the generator currents and the control outputs (to the modulator) are three phase references for the stator terminal voltage. The power supply for the control system and all important I/O boards are protected by an uninterruptible DC power supply in case of auxiliary power supply loss. The PCS6000 converter control is prepared for long blackouts. The AC800 PEC control system detects condensation after a long power loss and starts an anti condensation routine before the turbine will be restarted.

Maintenance and service

The most important qualities of a power converter are that it should be reliable and easily maintained and serviced, even when located in a difficult area offshore. The PCS6000 wind converter possesses approved software tools to enable remote service support for the converter. ABB's Diagnostic Information Analysis System (DIAS) is a smart tool for supervising the process. In case of a problem, ABB service personnel are able to provide quality remote support to local service teams. The power converter control system AC800 PEC records all important signals and the status of the converter along with a timestamp during a fault. ABB personnel are able to analyze this with the built-in transient recorder, which remotely records events and provides direct guidance to the personnel on site. Additionally, a simple human-machine interface (HMI) is available from remote locations to give a quick overview of the PCS6000 wind converter. The system can automatically send e-mails with attached failure reports to ABB or the customer's service teams. 9 shows an overview of the world-wide remote monitoring and diagnostic tools.

> Turbines of up to 5 MW are already in series production, and turbines with higher power levels are either under development or at the prototype stage.

The next generation of turbines

Turbines of up to 5 MW are already in series production, and turbines with higher power levels are either under development or at the prototype stage. Most turbines of the next generation are expected to be deployed in large wind-farms, situated either offshore or in areas with low population density. Turbines in the range of 7 to 10 MW are expected in the future. For such wind farms, the requirements on the control of the turbines are different from the traditional arrangements. Furthermore, today's wind power plants are usually operated to feed as much energy as possible to the grid, even if there is just a gusty wind. The future turbines on large wind farms face new control requirements. The offshore farm is seen as a large power generation plant. In case of a grid-frequency drop for example, the turbines have to maintain the power level to support the grid. A further requirement might be to limit the generated power to a level below the actual maximum level. Another important demand is that the turbine must stay in operation when reclosing operations are performed, as may happen when short-circuit problems occur in the grid.

ABB has successfully applied reliable and efficient medium-voltage converter technology to wind-power applications.

The combination of powerful hardware and flexible control topology, supported by enhanced simulation facilities, is best suited to serve the wind power industry and to integrate even the largest wind turbines into grids with demanding connection requirements. If future turbines demand higher power, ABB has already the medium power converters for up to 14 MVA.

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