How to Handle Electricity from µW to MW in Windmill Applications

Within the complex entity known as "The Windmill", handling electricity in an extreme wide range of power levels is the omnipresent challenge. Data needs to be gathered, transferred and processed at the lowest power levels. Mechanics and hydraulics need to be controlled to operate the mill. The quality of fulfilment depends on several electric subsystems. These in turn need to be supplied with power magnitudes below the mills output. Channelling the harvested energy to the grid is the most obvious task focusing on megawatts and beyond. Infineon provides solutions within each of the 12 decades covering the power range from µW to MW. **Martin Schulz, Infineon Technologies, Warstein, Germany**

Looking at a windmill it is often only seen that it is a megawatt application but underestimated, that it can only operate because of the interaction of a multitude of electronic components as depicted in Figure 1.

The detailed observation of a startup procedure reveals that electronic of every power level is involved even before the rotor starts turning.

Microwatts to milliwatts

The regime from µW to mW relates to different types of sensors. Besides the electrical parameters to be measured, the data necessary to operate a windmill include angle measurement, temperature, moisture and pressure.

A basic parameter is the temperature inside the mill's nacelle that is measured and, depending on the installation site, regulated to the desired level. While in a windmill in colder regions the nacelle needs to be heated to operating temperature, other installation sites may require no thermal treatment, simple ventilation or even cooling utilizing air conditioning systems. Besides the nacelle's temperature, the thermal conditions of the generator, gearboxes, liquid cooling systems and power electronic subsystems need to be monitored. Wind speed and direction are detected using anemometer and vane①.

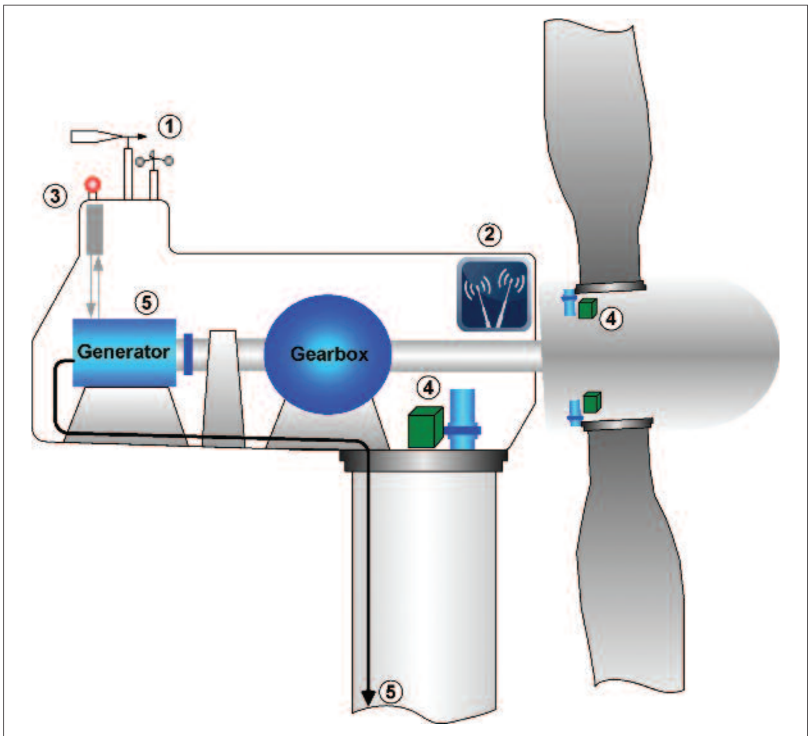

Figure 1: Schematic view of a windmill's components

Milliwatts to watts

The scale from mW to a few Watt is related to data transmission②. Most windmills are connected to networks that allow remote access to capture and monitor data on the operating conditions. Communication via D-Net, GSM or UMTS typically needs less than 10W to operate properly.

Watts to several hundred watts

Power systems from a few watts to several hundred watts include the air beacon, pumps for hydraulics and the liquid cooling systems, air condition compressors and some smaller ventilation assemblies③. Auxiliary drives need to be supplied to cover their own consumption, usually with switch-mode power supplies in a range below 100W. This power range is served using ASICS, moulded power components or discrete power electronic devices.

Kilowatt range

These decades are about controlling the mechanics of the windmill④. Two parameters dominate the tasks to be fulfilled before the mill's generator starts turning - wind speed and wind direction. First the nacelle has to be aligned with the wind's direction and additionally the blades orientation has to be fitted properly to create the starting torque. As blade control contributes to the safety of the mill and even enables emergency stop functionality,

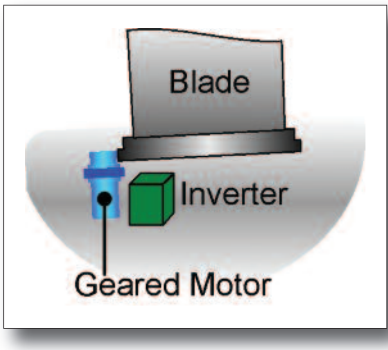

Figure 2: **Pitch-Control system for a single blade**

pitch-control drives feature an independent power supply so they can safely operate in case of grid failure or disconnection. During operation of the mill, ventilation will be needed to dissipate the generator's losses to the ambient using fans in the range of several kilowatts as well.

Up to megawatts

Depending on the windmill or wind park arrangement, energy generation and transmission starts at several hundred kilowatts while the largest windmill today has a maximum output of 6MW. In case of wind farms or arrays of a multitude of mills, 10^6 watts can easily grow to exceed 10^8 watts with the largest farm in Europe today delivering 500MW.

With a focus on power electronics, the most interesting sections refer to Pitch Control, Yaw Control and Energy Generation.

Pitch control

A drive train for a single blade is shown in Figure 2. It consists of a geared motor driving a toothed wheel to rotate the blade along its longitudinal axes. Electrically the system is connected to the grid and consists of a setup similar to UPS systems as shown in Figure 3.

In comparison to an industrial UPS, pitch-control is a far more demanding application in mechanical, electrical and thermal aspects. Additional mechanical stress comes as a consequence of the mounting location. Rotating with the mill's hub, the drive experiences centrifugal forces and a higher amount of vibrations compared to stationary designs.

To rotate the blade, the drive has to provide the initial breakaway torque. In a standstill condition this is not a critical task. If however the pitch-control has to realign the blade during operation, the forces that the wind applies to the blade have to be added. Keeping in mind that a single blade in a multi-megawatt mill has a weight of several tons, the inertia that has to be overcome is immense. Thus, electrically, the mode of operation is characterized by short bursts of maximum power leading to high demands in power cycling capability.

In normal operation the rotating speed of a blade reaches 3°/s while in case of an emergency stop up to 12°/s are demanded defining the accounting overload condition. Dimensioning of a proper drive additionally has to take into account, that the battery voltage usually is below the DC-link voltage driven by the grid. To achieve the same output power as in grid connected conditions even higher currents have to be considered in case the grid becomes disconnected. Thermally, the drive suffers from ambient temperatures in a range from -30°C to +70°C.

To serve all these needs, Infineon has cooperated with leading drive manufacturers and done extensive research especially regarding vibrations. Tests included multi-axis vibration of entire inverter designs to help developers identify weak spots in the inverter's construction and improve the design's overall stamina regarding mechanical stress. Amplitude, frequency spectrum and acceleration levels in the tests by far exceeded the values demanded by industrial standards. New power modules like the SmartPACK or the EconoPACK™4 were developed in accordance with the knowledge gained from such tests. One prominent result is the implementation of new interconnection technologies. Ultrasonic welding techniques to connect the electric terminals as shown in Figure 4 lead to increased capabilities in handling mechanical and thermo-mechanical stress [1]. Further improvement regarding interconnection is achieved by using PressFIT-connections. Infineon has first introduced this highly reliable and solder free connectors in low-power modules like the Easy- and Smart series [2] and migrated the approach to EconoPACK™3 as well as medium power devices like the EconoPACK™4 as depicted in Figure 5.

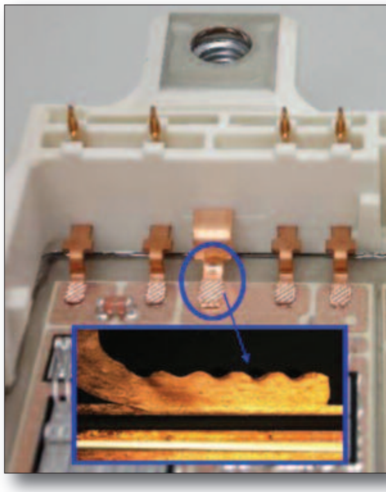

Figure 4: **EconoPACK™4 with highly reliable ultrasonic welding for the terminals**

Yaw control

Rotating the nacelle, or Yaw-Control, is very similar to pitch control. However, the power levels are shifted by one decade. Adding up the weight from hub, blades, generator and housing, nacelles in the actual largest windmills exceed a mass of 600 metric tons. Usually hundreds of kilowatts are used to turn the nacelle, necessary simply to overcome the nacelles enormous inertia and the rotor's angular

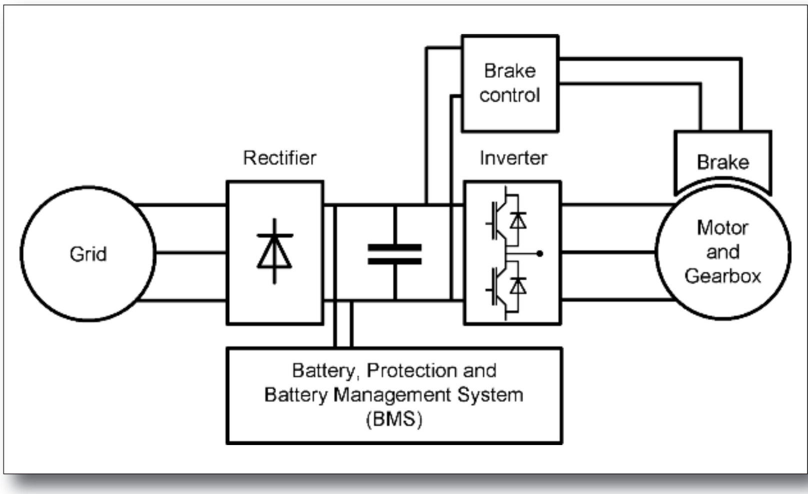

Figure 3: **Electric setup of the pitch-control drive**

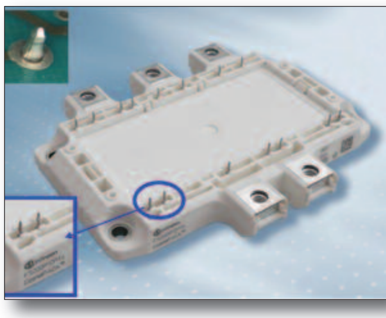

Figure 5: **EconoPACK4, detailed view to PressFIT control terminals**

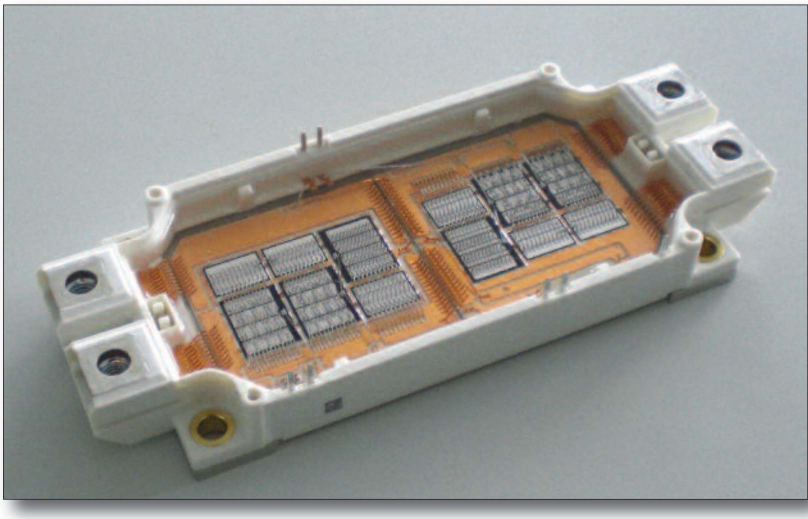

Figure 6: The new 600A/1200V EconoDUAL™3 featuring thermally optimized ceramic substrates and copper-wire bonding for high power density designs

momentum. As space in the nacelle is highly limited, inverter sizes are supposed to be as small as possible for this application too. The ongoing trend of reducing inverter sizes leads to increased power density demands towards power electronic devices. To serve this trend, Infineon has recently introduced the FF600R12ME4, a 600A/1200V half-bridge module in the well established EconoDUAL™3 package. Designed for high power densities, the package features thermally optimized ceramic substrates and achieves higher current carrying capabilities by implementing copper-wire bonding. Both these features can be seen in Figure 6.

If several drives are implemented, they can be used to reduce the backlash of the mechanical components by applying torque in opposite directions, usually this functionality is supported by mechanical brakes so continuous operation at a rotational speed of zero does not occur. Aligning the nacelle to the wind direction happens less often than acting the pitch control. Additionally, moving the nacelle does not need to be a high speed procedure. All these facts make the azimuth control a less critical application regarding power and thermal cycling.

Energy generation

The task of harvesting energy has, over the recent years, evolved in several topologies for power electronics to transfer energy from the generator to the mains. Full inverters on synchronous generators coexist with double fed induction machines. While in full inverters usually high-power modules like the PrimePACK are used, inverters powering the rotor of a double fed induction generator often feature medium power devices.

The EconoPACK+ was introduced in 2000 in conjunction with IGBT3. The 1700V derivate became a de-facto standard for this application very soon. Here too, effort is done to toughen up the existing design. The redesigned EconoPACK+ now also features PressFIT-Control-Terminals along with ultrasonic welding for the power terminals. Additionally the new power terminals now are injection moulded to increase their mechanical robustness. Figure 7 shows the actual D-Series type. Despite the changes in detail, the connections of the module remain compatible to its progenitors in mechanical and electrical aspects.

To cope with the needs of grid connected inverters in the range of several megawatts, the PrimePACK was developed especially for applications with increased lifetime demands. The PrimePACK was the first high-power module making use of ultrasonic welding for power terminals. It also offered the modularity to mount modules in half-bridge topology from 600A to 1400A in a common footprint. The modules as seen on the photograph in Figure 8 are designed with prolonged creepage distances mandatory for 3.3kV-designs. The modules equipped with 1700V IGBT are therefore predestined to operate in harsh environments.

Especially in offshore wind parks the combination of atmospheric conditions, temperature, humidity and load profile forms a challenging environment for power electronic designers.

Being aware of these challenges,

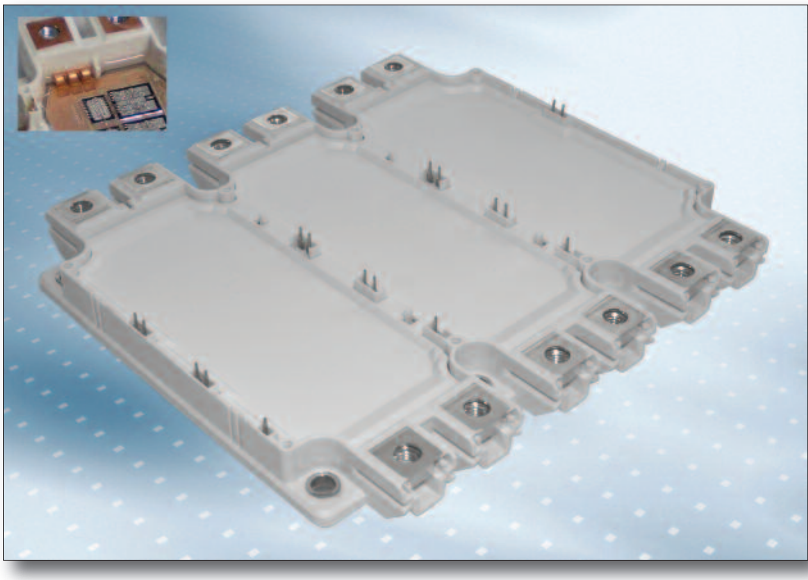

Figure 7: The new EconoPACK™+ D-Series, featuring PressFIT and ultrasonic welding for the injection moulded power terminals

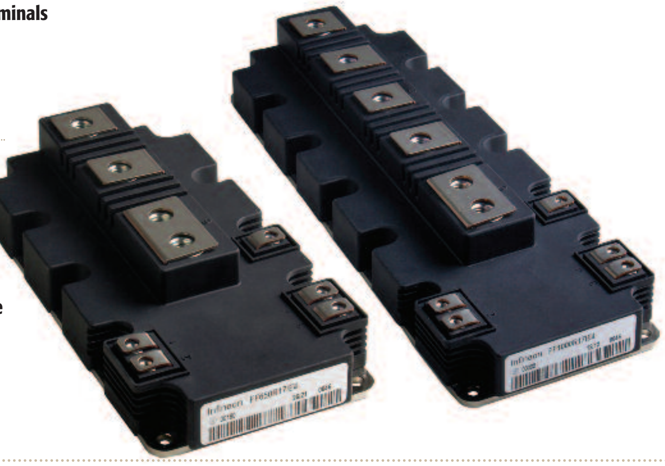

Figure 8: PrimePACK2 and 3, offering enlarged creepage and clearance distances to operate in harsh environment and demanding applications

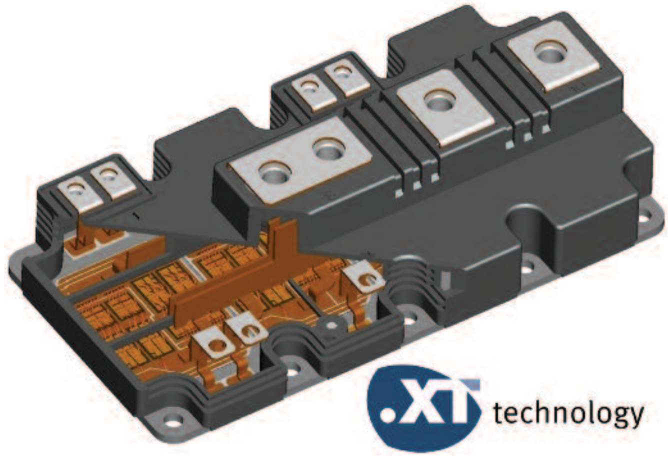

Figure 9: PrimePACK2 with .XT-Technology featuring copper wire bonding, diffusion soldering of the Silicon dies and the high reliability soldering joint for DCB-substrates

Infineon has developed a new set of interconnection technologies called .XT, concentrating on the improvement of every interconnection included in a power electronic module [4].

Next generation of power modules

Three major failure mechanisms toady limit the lifetime of power electronic devices depending on the load profile:

- Power Cycling leads to bond-wire failure,
- at long cycles the solder joint between silicon chips and DCB-substrate becomes the limiting factor,
- Thermal Cycling today leads to delaminating of the solder joint between ceramics and base plates.

Furthermore, the ongoing trend of increasing power densities, accompanied by increased junction temperatures, will be enforced by the implementation of wide band gap materials like Silicon Carbide (SiC) in the future. This in turn makes the development of new interconnection technologies an inevitable necessity as today's soldering processes cannot cope with the temperature levels to be expected.

The .XT-Technology therefore includes three essential changes to be used in the next generations of power modules. First the soldering of ceramics is migrated to the so called high reliability solder connection to achieve higher thermal cycling capabilities. The second step targets the chip soldering joint substituting soft soldering by diffusion soldering. Finally, the chip's surface changes to allow copper wire bonding. The combination of these changes leads to lifetime improvement of a factor 10 compared to today's designs. Parts of the .XT technologies were already implemented in further module families. The copper wire bonding used in the FF600R12ME4 shown in Figure 6 is a spin-off of the .XT-development. The first module to be fully equipped with all details of the .XT-Technology will be the 900A/1200V PrimePACK FF900R12IP4LD as it is sketched in Figure 9.

Though the lead type today is a 1200V module, the technology is expected to be exported to 1700V modules later as well. It is also targeted to use .XT for a variety of different module types in the future.

The reoccurring request of having a pre-constructed high-power subsystem has lead to Stack-Assemblies. Consisting of the power semiconductor itself, heat transfer management and driver

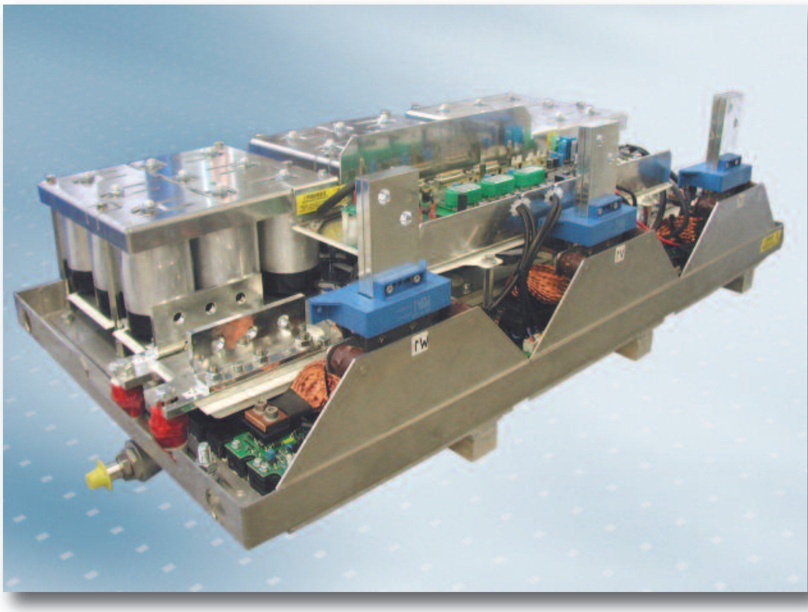

Figure 10: **Pre-assembled ModSTACK HD**

electronic, building blocks like the ModSTACK HD were designed to assist the customer in solving individual problems. Due to not having a control electronic or processor attached, these are not complete inverters. Stacks are thorough designed subsystems allowing the customer to attach the desired control unit. As driver electronic, protection mechanisms, thermal management and DC-Bus construction are complete, using Stacks as a power section speeds up development and reduces time-to-market. Figure 10 shows a ready to use ModSTACK HD capable to operate up to a DC-link voltage of 1100V and providing 2MW of output power.

Due to the modular design, these Stacks can easily be combined to form the topology needed for the particular windmill design. Furthermore paralleling is possible in case the 2MW are not enough. Customizing is an option, depending on customer's demand.

Conclusions

Having an in depth knowledge and detailed understanding on the application "Windmill" is a key factor to develop electronic components that fulfil the high expectations in lifetime, reliability and efficiency. Starting from sensors in a µW range and offering solutions and support to develop power electronics within 12 decades of power, Infineon is a competent partner to serve the demanding market of renewable energies.

Literature

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More Wind Power for China

Infineon Technologies and Xinjiang Chinese Goldwind Science and Technology recently signed a license agreement for core components needed in manufacturing of wind turbines.

According to the agreement, Goldwind gains the license to produce Infineon IGBT stacks used in converters of megawatt-grade wind turbines. Furthermore, Infineon will supply IGBT stacks to Goldwind. "Introduction of the technology and the subsequent in-house production will effectively secure supply of the core converter component, deliver larger cost effectiveness and strengthen the in-house converter development. This will enhance competitiveness of our products," commented Wu Gang, board chairman of Goldwind. "From this partnership, we can learn from sophisticated process technologies and quality control experience from Infineon, which is expected to contribute to improvement of our production management and control."

Infineon plans to set up an application engineering centre in Beijing. As wind turbines evolve toward higher capacity and grid friendliness, the full-power converter has become one of the most critical elements of PMDD (Permanent Magnet Direct Drive) wind turbines, for example those manufactured by Goldwind.

Infineon has been supplying IGBT stacks as a subsystem to build and develop converters to be manufactured by Goldwind since 2007. From their first installed base at Beijing Guanting Reservoir in July 2009, Goldwind converters featuring Infineon IGBT stacks have achieved an availability of over 99% and survived several tests under extreme conditions. Having applied the IGBT stacks in its 1.5MW wind turbines, Goldwind plans to utilize it in its 2.5MW and further to 3.0MW units now under volume production after the local ramp-up.

Goldwind is China's premier wind turbine manufacturer, with strong independent R&D capabilities and the longest operating history in the domestic wind energy sector. Goldwind turbines are in operation throughout China and are also sold in major international markets including Europe and the Americas. As of June 30, 2010, the company's cumulative sales amounted to more than 8,000 turbines, potentially replacing 7 million tons of standard coal and reducing carbon dioxide emissions by 17 million tons per year.

www.goldwind.cn, www.infineon.com/power