VENPOWER
PERMANENT MAGNET GENERATOR SYSTEMS

**Who is VENPOWER?**

VENPOWER GmbH began life as *PM-Generators GmbH*, which was founded by three shareholders in August 2009. From the beginning, our mission has been to design and manufacture excellent generator systems for wind turbines rated upwards of 3 MW. We are developing systems to be technologically and commercially optimized for both inland and offshore deployment, particularly as components in large wind parks – and our systems will be manufactured in Germany. Our estimates show that current and future market prices are well within reach, and all applicable national and international standards can be met and exceeded.

The basis for the foundation of PM-Generators was the invention of a revolutionary type of generator by the majority shareholder and managing director Peter Hein. Starting in 1995, Peter Hein played a key role in the development of large permanent magnet drives in the largest German electronics and electrical engineering company – with activities ranging from machine computation and dimensioning, design, development of manufacturing technologies, quality assurance, to complete technological and commercial project execution. Aside from large ship propulsion drives, the 3 MW generator for SCANWIND was also delivered during this period (2006) – at the time the largest permanent magnet generator on the planet.

Together with Hans-Henning Jacobs, a founder of the company REPOWER, the vast potential of the new generator concept was soon clear. A specialized full-scale frequency converter would enable the machine design to be optimized for price and technological characteristics, such that we can now with certainty say that:

**<u>Only with our system</u> is it technologically <u>and</u> commercially feasible now, and in the near future, to build and operate wind parks using wind turbines rated > 3 MW.**

Two patents have already been registered regarding our new generator technology and one additional patent regarding the specialized frequency converter. Our engineering team has been growing rapidly. The company ENASYS Gmbh, in collaboration with Professor Steffen Bernet's Power Electronics Chair at the Technical University of Dresden, developed system software for the frequency converter and have been working with us to demonstrate the excellent characteristics of our system. A complete system test rig was built for this purpose at ENASYS in Berlin, which is being adapted into a larger scale rig currently under construction in Rathenow. There, the frequency converters will be tested at rated power, and the generators with a mechanical power of 0.5 MW. The assembly and commissioning of the equipment there is currently underway. In all, around 20 MSc and Dipl-Ing engineers are presently working on development and two PhD dissertations are being written.

The new type of generator is of the type Flux-Switching Permanent Magnet (FSPM) drive. The application of an FSPM generator in a large direct-drive wind turbine is a global nuance – for which we created and registered the name ***Permavent***®. FSPM-type drives have been used in a series of small linear motors for tool machines since around 2004.

Since November 1, we have been striving to fulfill the above-stated mission under our new company name **VENPOWER** GmbH.

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***What is the state of the art, and which risks do developers and operators face using currently available designs for turbines rated above 3 MW?***

**Wind turbine concepts with gearboxes are not technologically or commerically suited for use at rated power above 3 MW, especially not for use in large wind farms, which are intended to be operated for 25 years like a power plant.**

The market is calling for wind turbines with increasing power ratings; currently, this means ratings upwards of 5 MW. For engineers, a scaling proportional to the power of the known methods and narrowly-margined current designs will not be sufficient. Rather, the physics of the turbine system in relation to the torque must be considered, which is significant greater than proportional to power.

When the materials of the first gear stage of 2.5 MW turbines are continually driven beyond their specified strength, they will inevitably fail and/or require expensive overhauling. Thus, it would be foolish to build turbines with 3x the torque requirements using exactly the same techniques. Gears are loaded linearly. The option of increasing the surface area of the first gear stage to reduce the pressure is a physical impossibility. As a result, gearbox lifetime is reduced – this is especially problematic for offshore deployment.

For these reasons, many developers are turning to **direct-drive** solutions – currently synchronous machines, excited either electrically or with permanent magnets.

**For turbines for wind farms rated above 3 MW, direct-drive systems with synchronous generators, while technologically feasible, are not commercially suited for offshore deployment,**
even if the grid feed-in tariffs continually rise.

Much like for the gearboxes, the weight of these generators increases in proportion to the torque, and thus greater than proportional to the power rating. As a direct result, the mass and diameter of these machines becomes incredibly large. Aside from the resulting greater than proportional material costs, this results in immense cost for construction and maintenance. To reduce weight, permanent magnet (PM) solutions are being proposed and developed. The exponentially increasing costs of raw materials, particularly for rare earth elements, could pose a risk to this trend.

While it is possible for small electrical machines to design a very small air gap between rotor and stator, this is not feasible for classical concepts in large drives. This leads in turn to the need to increase the excitation. For electrical excitation, this translates to higher cost and lower efficiency, and for permanent magnet excitation to more magnetic material.

The rotor of a PM synchronous machine is a gigantic magnet with tremendous attraction forces. The manufacturing and assembly of this component is very challenging and takes lots of space and capital investment. Stators for large synchronous generators are manufactured (quite literally, in this case) by hand the world over. Only the assembly of the coils is partially automated. This imposes an upper limit on the quantities that can be realistically fabricated in Europe to a small two-figure number. Attaining a sustainable market price is thus effectively impossible due to the high unit costs. The prospects are only worsened by the fact that the costs for steel sheet metal, copper, and magnets are with high probability going to rise.

**For use in wind farms, current frequency converters are not technologically capable of fulfilling the grid connection requirements of the near future.**

In order to operate wind farms using turbines with high rated power, the turbines must be capable of feeding in to a grid that is growing more complex and integrated every day. Currently, the most popular turbine converter systems have difficulty rising to this challenge, and require expensive grid-side filters. They are not able to automatically adapt to varying grid conditions. Large wind farms, however, need converters that, much like the large generators in coal-fired and hydroelectric power plants, can inject a stable, sinusoidal, harmonic-free, quickly and accurately controlled current into the grid. Furthermore, they must be able to inject reactive power when desired.

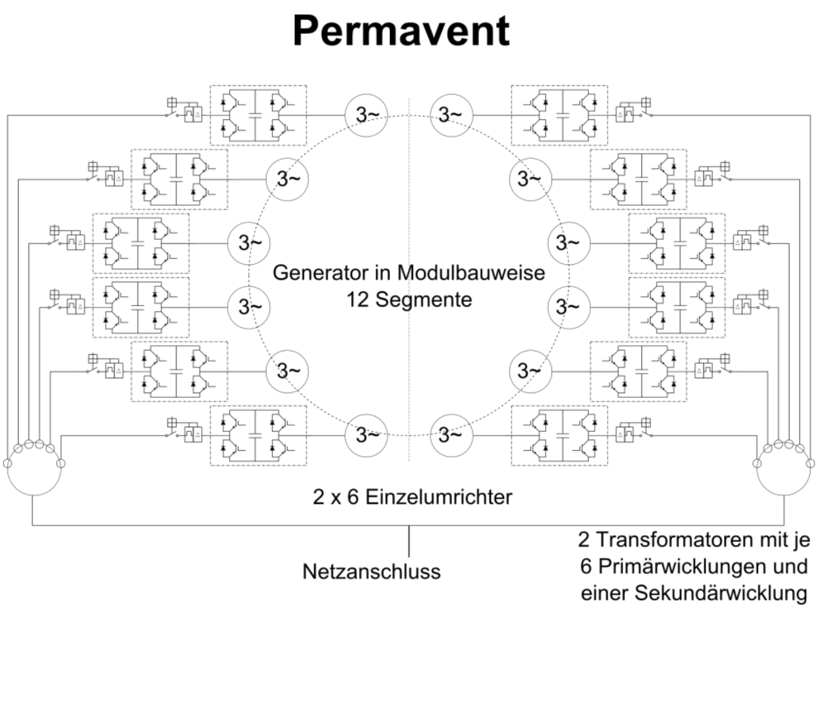
***What will the turbine concept of the future look like, and how is this embodied by the Permavent®-System?***

**For the turbine operator, in addition to the investment,**
**the characteristics of high availability, high efficiency, good operating parameters,**
**and low maintenance costs are the determining factors**
**for the choice of a turbine technology.**

At the heart of the Permavent® system lie the concepts of **modularity** and **redundancy**. The basic building blocks of the system are 420 kW power electronics converter modules, which are in turn constructed using Primepack-IGBT units. For the 5 MW system, the generator is built with 12 of these modules on the stator. A segment of this type weighs approximately 2 tons. Aside from the coil windings, which constitute a complete, independent 3-phase AC system, the magnets are also integrated into the stator segment assembly where they are protected from corrosion and damage over the entire lifespan of the turbine. An innovative cooling system, inspired by the heat-pipe principal though much more effective at thermal transport, is integrated into each converter module. Even at rated power, no system component reaches temperatures above 70°C. This has a large effect on the efficiency, and also on the lifespan, and opens up new possibilities for insulation materials which are resistant to condensation and salt-spray which offer the module complete protection

The rotor of the generator is constructed purely of steel. During rotation, this part ensures that the magnetic resistance and direction of the magnetic flux through the windings changes. Since this function is fulfilled by the first few centimeters of the rotor surface, this component is an excellent candidate for weight and stiffness optimization. For example with the 5 MW system, a rotor weight of 22 tons is sufficient.

The stator modules are radially assembled onto a rigid steel construction frame, which allows the air-gap to be optimized for a specific turbine, and thus also optimizes the requirements for expensive magnet material. The result is that compared to rotating-field machines up to 30% less NEODYM is necessary. The low operating temperatures of the magnets also takes advantage of this fact. As is the case for the rotor, the construction frame is optimized for weight and stiffness. Merely ca 31 tons at 5 MW are needed for this structure, which is also divisible into small, transportable units.



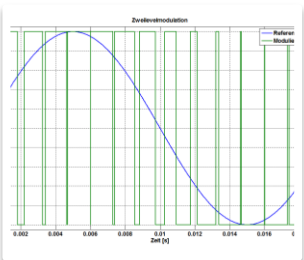
Each active stator segment is equipped with a galvanically isolated converter module. The 3-phase AC system of the stator can be directly connected to the converter without circuit breakers or fuses, due to the fact that the electrical connection is short-circuit tolerant, and the fact that fault currents in the stator windings do not exceed rated current. Over adapted power switches and 2 specialized grid transformers, a symmetrical, 3-phase, sinusoidal current is injected into the grid, which is not in any way dependent on the harmonic content of the grid voltage. The power factor is remotely adjustable. Only our Permavent® generator, using a specialized multi-level modulation, can provide this level of power quality with minimal effort. Even with 4 modules, the requirements specified by current grid-codes are met and exceeded.

Today's converters require LCL filters for damping voltage harmonics which arise from the grid-side converter. The harmonics are a result of modulating (switching alternately between the d.c.-link voltage $V_{dc}$ and 0) the constant DC voltage of the d.c.-link capacitors into a signal with a large sinusoidal first harmonic at the grid frequency of 50 Hz (or 60 Hz) and smaller undesired harmonics at the switching frequency and multiples thereof. Typically, the switching frequency is from 1 to 4 kHz.

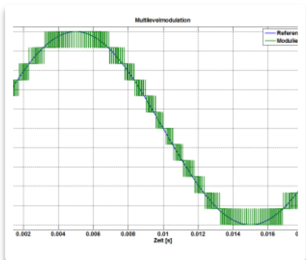
The filter is dimensioned such that the resonant frequency significantly lower than the switching frequency so that the undesired harmonics are attenuated and the grid-codes are met. The filter size is primarily dictated by the switching frequency, since the current ripple (the amplitude of the unwanted harmonics) is reduced with higher switching frequencies. The higher the switching frequency, the lower the current ripple, and the smaller the filter can be. However, the other side of the coin is that switching losses go up in the power semiconductors for higher switching frequencies.

Since an LCL filter has a resonant frequency with very high gain, it is possible that harmonics in the grid voltage (caused by other entities on the grid) can stimulate the filter at its resonant frequeny. This can lead to additional heating of the filter, and in extreme cases to its destruction and failure.

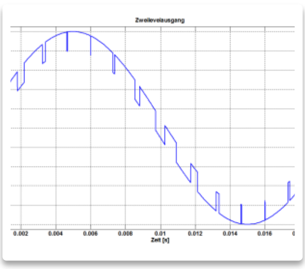
With the new VENPOWER multilevel converter modulation scheme, the use of an LCL filter is unnecessary due to the extremely low harmonic content generated by the converter, while at the same time the switching frequency is kept low. This is made possible by switching 12 frequency converters in parallel, which operate in perfect synchronization with one another to implement our multilevel modulation scheme.



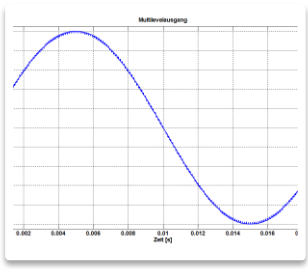
Modulation Standardwechselrichter



Modulation VENPOWER Multilevel



Netzspannung Standardwechselrichter



Netzspannung VENPOWER Multilevel

The output voltage is, compared with that of a standard converter, so low in harmonics that an LCL filter is not necessary. At the same time, the dynamic controller has no difficulty safely navigating a fault-ride through scenario.

The consistent galvanic isolation all the way down to both grid-connection transformers, and the low fault currents in the generator make a total failure of the system effectively impossible. No other concept on the market today provides this level of availability. Integrated arc fault protection systems round off the reliability and protection concept. Should one of the converter modules malfunction, the faulty module need not be immediately swapped out, since the remaining healthy modules can continue operating – perhaps even up to rated system power. Exchanging a module can be accomplished by 2 technicians and a small crane.

All turbine components are designed for the expected system lifespan of 25 years. The minimal component count in our system also contributes to an extremely good MTBF value. Furthermore, the system uses a redundant control architecture, consisting of local controller units for each converter module, each equipped with extensive protection circuitry, and a redundant central controller in a "hot-spare" configuration. The central controllers are equipped with a universal interface which allows a connection to all types of modern tower controllers. This control architecture provides for excellent system monitoring, similar to that of a large power plant.

Because of the modular nature of the Permavent® system components, large generators can be manufactured using the manufacturing processes used for small machines. These processes are much more efficient since they readily lend themselves to automation, which also improves the quality of the end product. Large quantities can be produced with significantly lower capital investment. Manufacturing in Europe also becomes feasible. Grid feed-in tariffs are political boundary conditions that in the present day, are the subject of continual discussion, criticism, and modification. Thus, these tariffs should not be used in the calculations of investment, maintenance, and repair costs.

Here at VENPOWER, our experience base lies in generator design and construction, of course using FEM, in addition to competency with converter development and manufacturing. Together with our partners ENASYS, the Neuenhauser Group, and the support of the scientists of the Technical University of Dresden, we can assume responsibility for the complete Permavent®-System, and we can adapt it to any wind turbine system and application. We have access to a complete development environment.

We have equipped the Permavent®-System with clearly defined interfaces, for mechanical integration as well as to electrical-electronic systems, which allows for easy integration of the few components into any wind turbine or wind park system. The technological risk is limited to three assemblies: generator module, converter module, and grid transformer. Power ratings of 3 MW and upwards can be reached by assembling the required number of modules onto a simple steel framework, connecting each of these modules to a converter module with three cables, and connecting three more cables from the converter module to the corresponding transformer (via a power circuit breaker). The cooler primary and warm return connections must be connected to the central cooler. A few Ethernet cables must be connected for intra-converter communications, a few sensors connected, and the auxiliary power supply of 24V or 230Vac should be connected.

Adjustment of the power rating is done by simply adapting the number of qualified generator and converter modules with its firmware, and adaptation of the torque with the strength and stiffness of the stator and rotor construction. And just here is where we see an incredible opportunity for acceptance compared to all other current concepts, not just from the wind turbine manufacturers, but also from the turbine and farm operators.