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Electric Development Engineer at The Switch

# Making the switch

**Permanent-magnet generator (PMG) technology offers a viable alternative for future offshore turbines. Key benefits include increased reliability and higher annual energy production, particularly at partial loads. As future offshore turbines grow in size, a medium-speed drive-train concept with a two-stage gearbox is an attractive alternative for direct-driven PMGs, because it eliminates the large consumption of magnets used in a large direct-drive PMG, while still reaching high efficiency.**

The wind power industry is rapidly shifting towards offshore production. While the global installed offshore capacity was less than 100MW just a decade ago, this number had grown to almost 3,000MW by January 2011. The European Wind Energy Association (EWEA) estimates that Europe alone plans to increase the produced amount of offshore wind power to more than 150GW by 2030[1]. During the last decade, the average offshore turbine capacity has increased from 2MW up to 3.2MW and this trend is expected to grow. A common turbine size in newly developed offshore projects is currently in the 5MW range, and pilot projects of up to 10MW are under way. As the maintenance of offshore turbines is typically extremely expensive due to difficult access to the site, turbine reliability has become a critical feature. What comes to drive-train components, a direct-driven PMG offers a viable solution with its simple mechanical construction and good energy-production capacity throughout the whole operating range. As unit sizes are constantly growing, turbine efficiency has become an increasingly important selection criterion.

## Offshore wind energy

The main factor favouring offshore wind energy production is the good availability of large areas that have significantly better wind conditions than land-based production. The average wind speed at sea can be up to 20 per cent higher than on land. Due to the cubical effect of wind speed on produced power, offshore turbines are capable of producing substantially higher amounts of energy than land-based turbines with an equivalent sweeping area[2]. The high

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potential of offshore wind production is boosted by smoother wind and higher wind speeds, which lead to smaller fatigue loads for turbine components and allow shorter and cheaper tower constructions.

Currently, one of the biggest issues relating to offshore development is the high cost. Some estimates suggest that the related expenses per constructedMW can be twice as much as for land-based turbines[3]. This is, however, partly compensated by the higher amount of offshore energy produced, resulting from better wind conditions. Cost reduction perMW can be achieved by increasing unit size, as an entire wind park project typically includes plenty of costs that are only loosely tied to the unit size, such as turbine foundations costs, installation expenses, as well as the costs related to the establishment of grid interface as well as operation and maintenance[3]. While logistics-related restrictions, mainly road transportation in land-based production, usually limit the direct-drive turbine maximum size to below 3 or 4MW, bigger turbine components, even complete nacelles, can be transported to an offshore site by using vessels. The need to reduce costs by increasing unit size and by deploying smoother logistics for bigger units has guided offshore development towards bigger sizes. Companies such as AMSC, Clipper Wind and Sway AS currently have pilot projects of up to 10MW. In addition to increasing unit sizes in offshore, costs can also be driven down by increasing turbine reliability and by reducing the need for maintenance. One estimate indicates that difficult access to a site can bring offshore turbine O&M costs up to 16 €/MWh[4]. As a result, the availability of an offshore turbine must be close to 100 per cent, as every extra service break significantly reduces the profitability of an offshore project.

## Gearless turbine design with brushless excitation

A straightforward approach to increasing the reliability of a power generating drive-train is to reduce the number of moving components. Even though still extensively used in offshore production, the traditional double-fed induction generator (DFIG) concept with a 3-stage gearbox has two major drawbacks, which are particularly problematic in the offshore environment. Firstly, a gearbox is usually considered a key failure point of the drive-train. Secondly, the DFIG's slip-ring unit, which provides magnetisation energy to the rotor, needs regular maintenance. An additional disadvantage of the DFIG concept – both onshore and offshore – is related to its lower efficiency at partial loads due to the need for external energy for rotor windings, which, combined to additional losses from gearbox, leads into lower energy production.

The need for higher energy yields and reliability has resulted in an increased demand for gearless technologies, which in practice means a turbine concept with a synchronous direct-drive generator. The DFIG concept cannot be used in such low speeds, as the generator's efficiency and power level would dramatically collapse. A synchronous generator with electrical excitation, a concept deployed for example by Enercon, still requires either slip rings or a brushless magnetisation device to feed electricity into the rotor field winding. The concept also entails an electrical failure risk in the rotor winding. From a mechanical perspective, the simplest construction for a direct-drive generator would be to replace the rotor field winding with permanent magnet excitation, a design in which the rotor is a simple hollow steel cylinder with magnets fixed on the surface. In a direct-drive PMG, the absence of slip rings and a gearbox eliminates all kinds of mechanical contacts between moving parts, which are vulnerable to wearing and thus prone to fail. In the direct-drive PMG concept, the only wearing parts are typically one or two bearings.

As the production of the magnetic field with permanent magnets eliminates the need for slip rings as opposed to using field winding, the PMG concept's mechanical design is flexible, which allows a high degree of turbine integration. Some turbine designs use a PMG with an outer rotor, where the outer part is rotating with magnets on its inner surface. Such design enables an effective cooling of the magnets as they are separated from the outside air flow only by a rotor yoke comprised of a relatively thin layer of steel. The higher wind speed the turbine is exposed to, the more effective the cooling becomes. The need for cooling the magnets may not appear obvious given that the rotor side losses of the PMG are close to zero due to lack of field winding. Eddy current losses, even though fairly small, always

The Switch's generator

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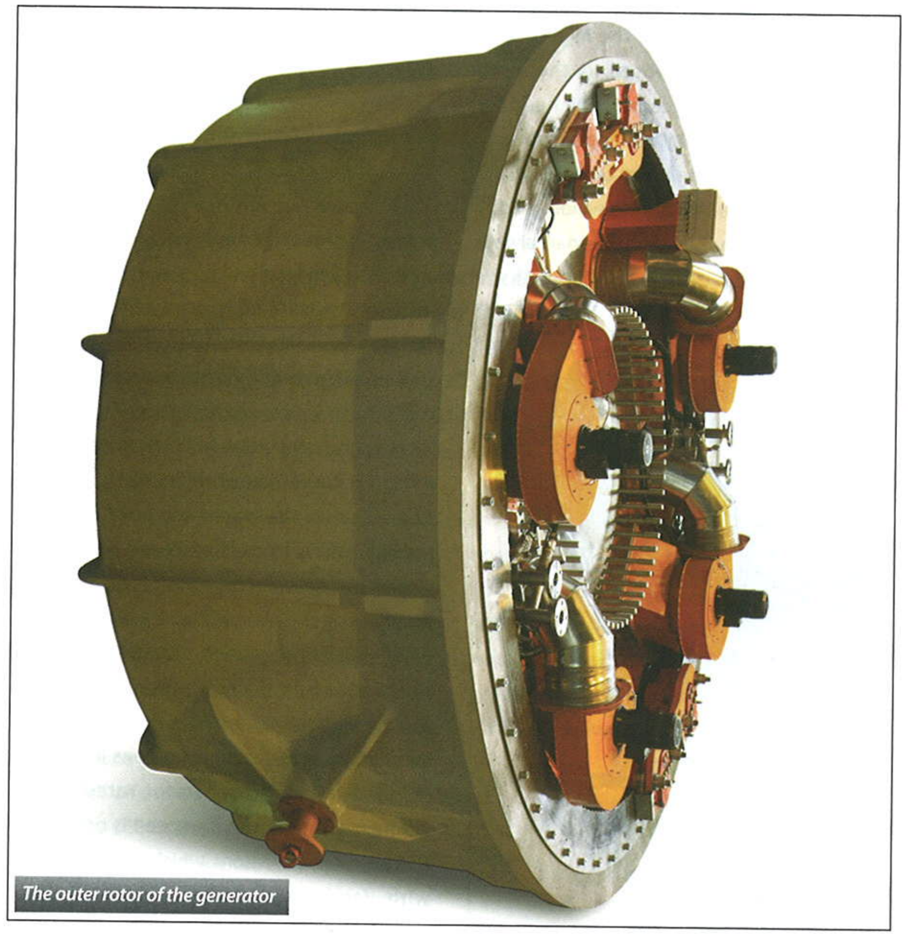
cause some extra heating in the rotor core and magnets. But more importantly, the heat loss originating from the stator side and crossing the air gap in fact also tends to heat up the magnets. The lower the magnet temperature can be kept, the cheaper the selected magnet grade can be, as magnets with a higher temperature class are always more expensive. This plays a particularly important role in large offshore direct-drive generators where the share of magnet costs of the total generator manufacturing cost is considerable. Cooler magnets also increase direct-drive PMG efficiency thanks to a slightly lower stator current, resulting from higher, temperature dependent magnetic flux.

In addition to a simple mechanical construction, which results in increased reliability, a direct-drive PMG can maintain good efficiency throughout the whole operating range, resulting in good energy production especially at partial loads, where the turbine mostly operates. At the rated point, though, Ohmic losses on the stator side with a direct-drive machine (regardless of the type of magnetisation) are very high. Typically up to four or five per cent of the input mechanical power is converted into losses in the stator winding. This is due to weak electromagnetic induction caused by a low rotation speed, which consequently means that an increased number of coil-turns are needed in the stator winding to produce the rated voltage. This inevitably leads to high stator resistance and high stator Ohmic losses. Despite the lower-rated point efficiency, the high partial load efficiency can be achieved since no magnetisation power is needed, and more importantly because stator Ohmic losses, which can comprise more than 80 per cent of the total losses, decrease proportionally to torque squared. Compared with land-based installations, good wind conditions in offshore result in a higher generator rated speed. Furthermore, the blade tip speed is not limited due to acoustical reasons, which is often the case with land-based turbines located near populated areas. Higher rotation speeds in offshore directly result in higher efficiency due to stronger induction as well as to a more compact turbine design due to the lower torque. The weight of the turbine can further be reduced by maximising the PMG's power density. In practice, this means using a design that operates close to the thermal and electromagnetic boundaries at the rated point. Optimising the PMG for rated conditions would lead to severe over-sizing of the whole turbine, as the occurrences when the turbine must deliver full power at maximum ambient temperature are extremely limited. Instead, the turbine should be de-rated in the above-mentioned, yet fairly rare conditions, because such a design leads to a compact turbine without significantly sacrificing annual energy production. Instead of focusing on rated point characteristics, turbine designers should increasingly pay attention to partial loads.

### Medium-speed PMG for higher powers

Although direct-drive PMGs have proven to be highly suited for offshore turbines, the concept has limitations when used in a high-power range. As the rotation speed of the turbine decreases while going towards higher powers, torque increases more than linearly with the power, leading to large-size generators at higher powers. Since the generator torque production capacity increases proportionally to rotor radius squared, while only linearly with its length, it makes sense from a practical perspective to maximise the generator diameter in order to minimise the consumption of active materials such as winding copper, stator and rotor core material and magnets.



The outer rotor of the generator

The large generator diameter unfortunately leads to large manufacturing tolerances, especially in the case of the air gap, which is the most important part both electromagnetically and mechanically. Moreover, it is critical that an adequate air gap can be maintained in all operating conditions. The majority of existing direct-drive concepts allows the transmission of wind loads from blades to the generator rotor, which can lead to possible air gap deformations. When the turbine is exposed to extreme power loads or fault situations, such as generator short-circuit, choosing a large air gap becomes of critical importance in the design. While an increased air gap length can be compensated with an electrically excited synchronous machine by increasing the rotor field current or by increasing the number of turns in field winding, this results in an undesired effect for the PMG, whereby more magnet material must be added to compensate for higher magnetic resistance due to a longer air gap. The consumption of magnet material is therefore largely dictated by extreme operating conditions, which in practice, leads to unnecessarily large amounts of magnet material needed in normal production, and consequently an expensive design. However, turbine concepts exist in which wind forces are not transmitted into the generator air gap, but those can translate into more complex and expensive turbine designs.

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The increased consumption of magnet material in the case of a high-power direct-drive PMG can be avoided by using a so-called medium-speed turbine concept. Even though this design still requires a gearbox to increase generator speed, there is no need for a high-speed gear stage, which is often the most vulnerable part of a gearbox. Depending on the design, a gearbox can have either one or two stages. With the one-stage gearbox, the generator speed will be in the range of 100 to 200 RPM, while with the two-stage gearbox, the generator would run at between 200 and 500 RPM. The lack of a high-speed stage will not reduce the gearbox weight significantly, as it only carries a small torque. But increasing the generator speed up to 30-fold results in a significantly smaller generator when in comparison with the direct-drive. In the medium-speed range, especially in the case of the two-stage gearbox concept, the generator speed is high enough to obtain efficiencies that exceed 97 per cent, approaching values that are normally typical only for high-speed generators. A gearbox between the turbine hub and the generator usually eliminates the most harmful forces that could lead to generator air gap deformations. As a result, the generator air gap can be designed smaller, which leads to a lower consumption of magnets. A multi-megawatt medium-speed PMG may require only 10 per cent of the amount of magnets needed for direct-drive generators that have an equal power rating. Given the Chinese government's recent restrictions for their rare earth export quota, this can become a significant benefit for medium-speed PMGs in large offshore turbines.

### References


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## Natural Power's ZephIR aligns with remote power specialists Ampair

Natural Power's product innovation business ZephIR, which provides the industry leading CW lidar system ZephIR 300, has recently announced a strategic alignment with remote power specialists Ampair to provide customers with a managed wind data and power service. Despite the very low power requirements of a modern lidar system such as ZephIR, a reliable and easily transported power supply is still important for the remote and harsh locations in which the system is often deployed. The strategic alignment provides ZephIR customers with an integrated and robust renewables power solution taking into consideration likely ZephIR deployment scenarios.

Industry veterans, Ampair, bring customers a network of international representatives who provide local support in selecting and maintaining either off-the-shelf or bespoke renewable power pods. A trailer version, the TrailerPod™, which allows for deployment at sites with 4x4 access and a helicopter version, HeliPods™, which can be air-lifted, or moved by truck or boat to very remote sites, are available now and have been designed specifically for the ZephIR 300 system following many months of design, preparation and testing between the two companies.

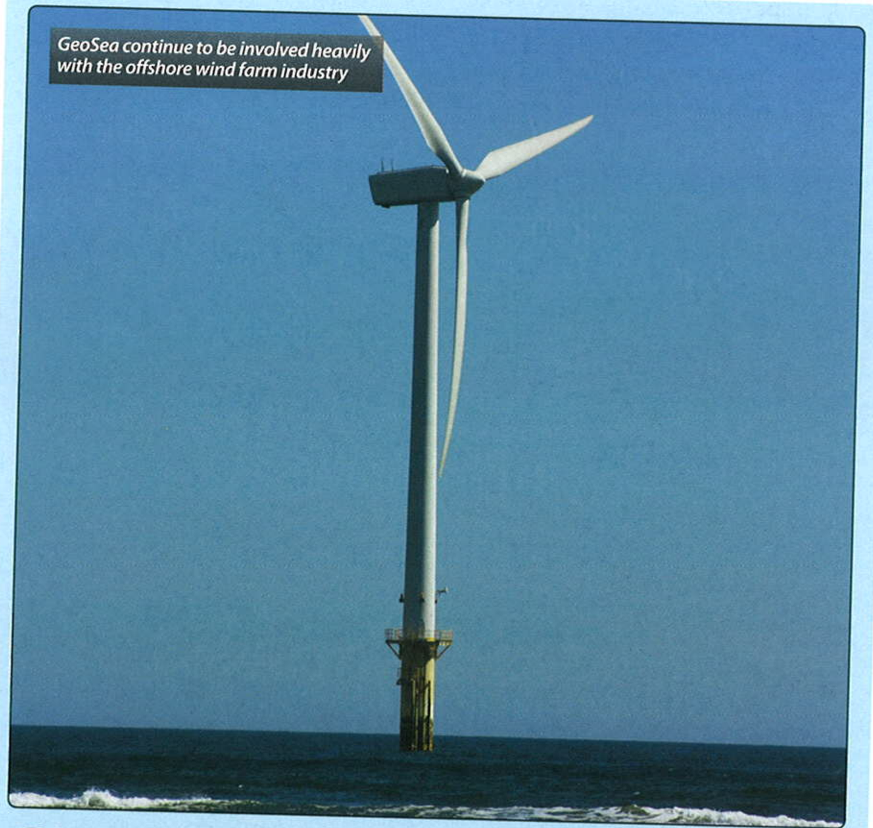
www.yourwindlidar.com

## Solergy introduce new BICPV product

Solergy Inc., developers of the Cogeneration Concentrated Photovoltaic (Cogen CPV™) solar energy system, have introduced their new BICPV product for building rooftops, greenhouses and agriculture.

The announcement follows the signing of a Memorandum of Understanding (MOU) between Solergy and Azienda Agricola Ciccolella, a producer of high quality olive oil and cut roses in the Puglia region of Italy. Solergy will integrate a 105kW Cogen BICPV system in Ciccolella's greenhouses used to cultivate roses. In parallel, the two companies will collaborate to develop the Cogen solar market for greenhouses and orchards throughout the Puglia region, representing hundreds of megawatts.

www.solergyinc.com



GeoSea continue to be involved heavily with the offshore wind farm industry

## GeoSea continue to influence the wind farm industry

GeoSea is a fast growing company specialising in complex offshore marine construction projects. The company is part of the Belgian DEME group, a world leader in the field of dredging, marine engineering and environmental operations. GeoSea is active around the globe. At Costa Azul, Mexico, GeoSea has drilled oversized monopiles, with a diameter of 3 m, in hard rock for the construction of an LNG-terminal. The company is active on the present Thorntonbank project where it constructs a 300MW wind farm off the Belgian coast.

GeoSea has participated in the installation of 15 European wind farms at sea, including the Alpha Ventus project, the EnBW Baltic 2 wind farm, 32 km north of the island of Rügen, and the Trianel West Borkum II wind farm in German waters.

GeoSea is currently positioning monopiles of up to 650 tonnes at the Walney wind farm, and at the Ormonde farm in the Irish Sea it has placed jacket piles at a depth of 30 metres with absolute accuracy. GeoSea's jack-up platforms include Goliath, Vagant, Buzzard, Zeebouwer, Halewijn, Tijl II, and Kobe

They are assigned to projects around the globe, including on the North Sea, the Middle East and Australia. Furthermore, a new jack-up vessel "Neptune" is currently under construction for GeoSea, which will outdo the previous platforms in every respect. GeoSea business also covers more traditional activities such as soil investigation, drilling of large diameter monopiles, and high-tech directional drilling.

www.geosea.be

## Sitec strikes deal with France

Sitec Infrastructure Services, the UK based service provider to the telecoms and renewable energy infrastructure markets, has struck a deal with wind turbine manufacturer, Evance to become an approved installer and distributor.

It's a deal that follows hard on the heels of tie ins with wind turbine maker's QuietRevolution and Evoco as well as affiliations with solar PV system providers, and gives Sitec an impressive portfolio of partners across the renewable energy sector.

www.sitec-is.co.uk