

STATE OF THE ART and NEW TECHNOLOGIES OF DIRECT DRIVE WIND TURBINES

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ABSTRACT

Direct drive wind turbines are becoming more attractive for off-and onshore. As maintenance and downtime cost by gearbox problems are reduced and efficiency is improved. Future design concepts and prototype are presented and state of the art gearless turbines are described.

1 ADVANTAGES OF DIRECT DRIVE WIND TURBINE

Gearbox problems are responsible for many turbine failures. According to data collected by Germanische Lloyd (GL), 26% of turbine down time are due to the gearbox, another 13% to the shaft and couplings and 17% to the generator. Lifetime of the gearboxes sometimes does not reach 5 years and its replacement creates cost of up to 200.000,00 € for a 1.5 MW turbine in Germany which is more than 10% of the turbine investment cost. Figure 1 shows a defect gearbox.



Fig. 1: Gearbox failure

On the right side of figure 2 a conventional turbine concept is shown. The torque produced by the rotor is reduced by a gearbox at a very high gear ratio up to 1:100. At the same time, the speed at the output shaft is increased by the same ratio adjusted to the high speed generator that feeds electric power to the grid. On the left side, a Direct Drive System is shown using a High Torque Generator that is directly coupled to the hub with the rotor blades. In both cases, converters enable variable speed of the rotor in order to increase aerodynamic efficiency.

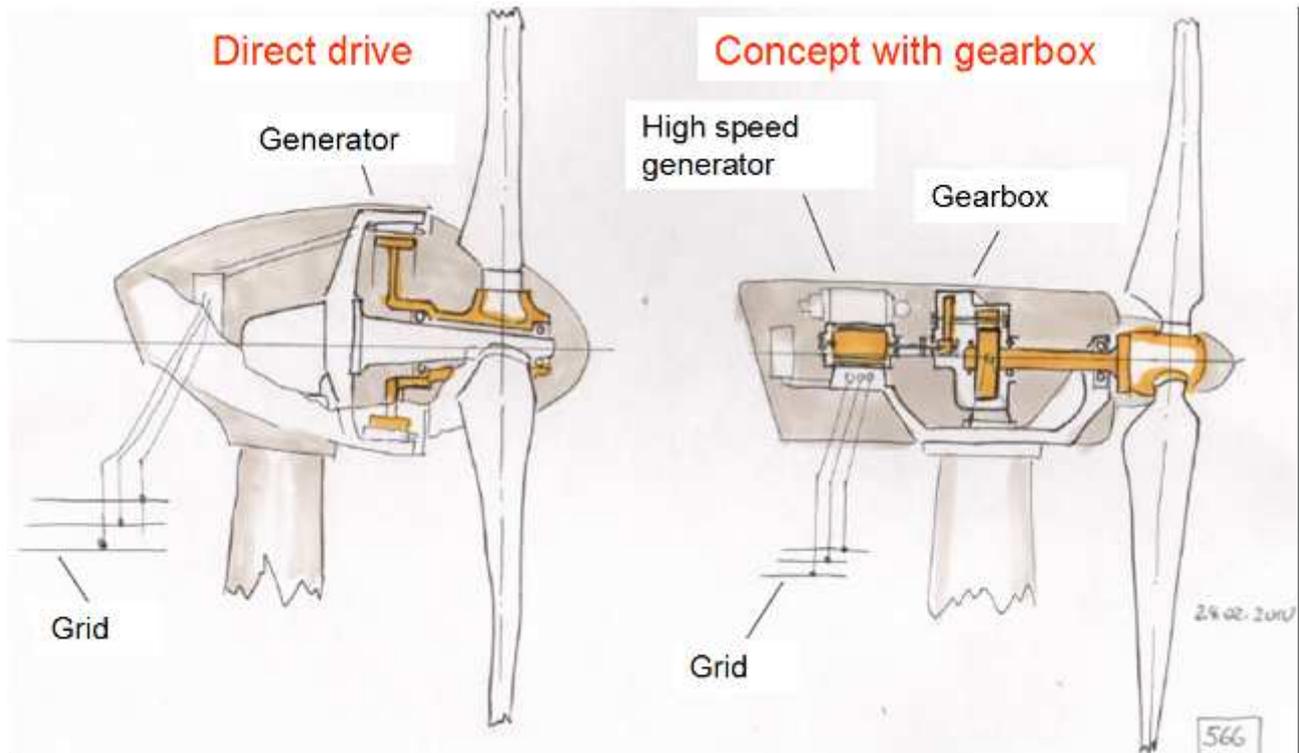


Fig. 2: Comparison wind turbine with and without gearbox(by author)

Gearless Turbines have important advantages compared to turbines with the conventional drive train:

- Maintenance requirements are reduced close to zero
- The downtime due to gearbox failure or breakdown does not exist
- Life time for bearings is increased and lubrication requirements are reduced due to low speed operation
- Therefore the availability of Direct Drive is very high
- Energy yield increases about 10%
- The overall efficiency is about 10% higher, as there are no losses in the gearbox

Figure 3 presents efficiency for different drive train concepts over a range of wind speed from 20% to 100%.

The PMDD concept with permanent magnet excitation of a direct drive generator shows important advantages in efficiency at lower wind speeds, upper line in orange color. The lower line in black color represents the efficiency of the drive train of a conventional Danish turbine concept with a gearbox and a high speed double fed induction generator followed by a high speed synchronous

generator with permanent magnet excitation and gearbox. The blue line represents the concept with low ratio gearbox 1:10 and a medium speed synchronous generator with permanent magnet excitation.

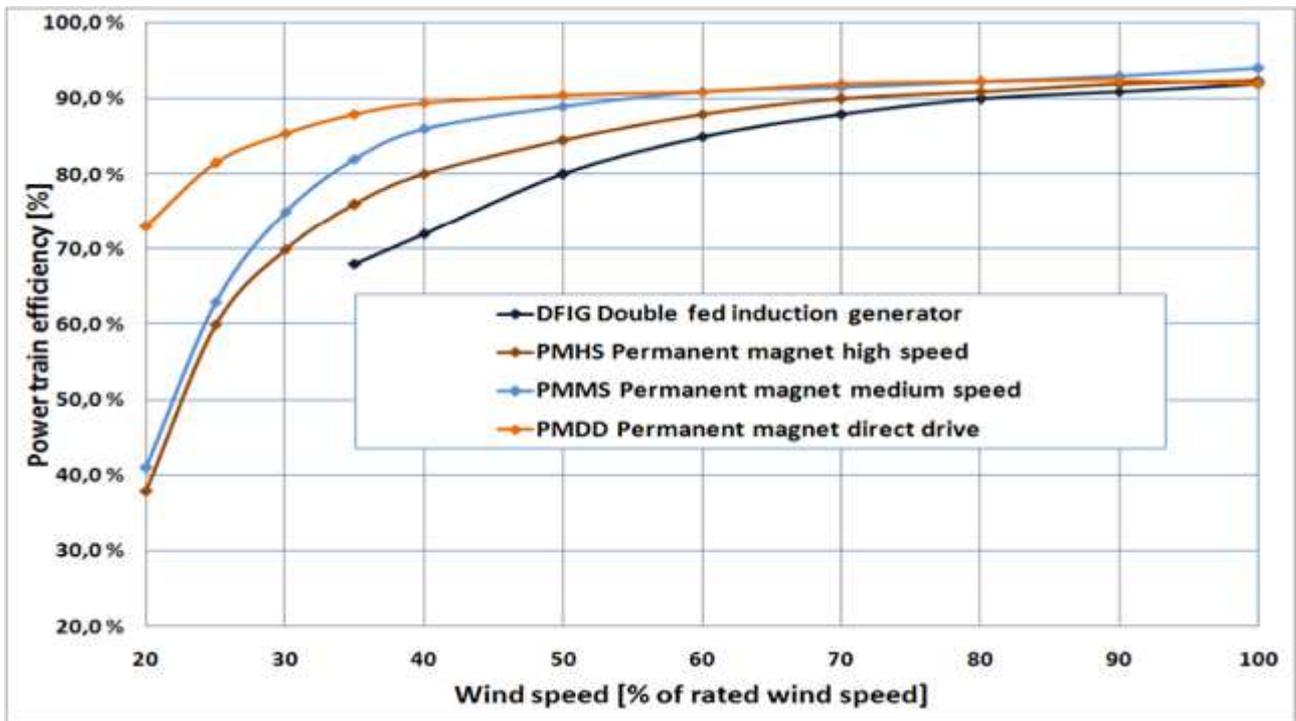


Fig. 3: Efficiency comparison for different drive train concepts (by author)

2 BEARING CONCEPTS

The rotor of electric machines is usually located inside the stator as demonstrated on the left side of figure 4. The innovative generator concept by Vensys is using outer rotor and permanent magnet excitation on the inner side of the rotor as shown on the right side of figure 4. In case the rotor uses permanent magnets, the outside diameter DA_2 of such machines is smaller compared to DA_1 of inner rotor concepts for the same air gap diameter D .

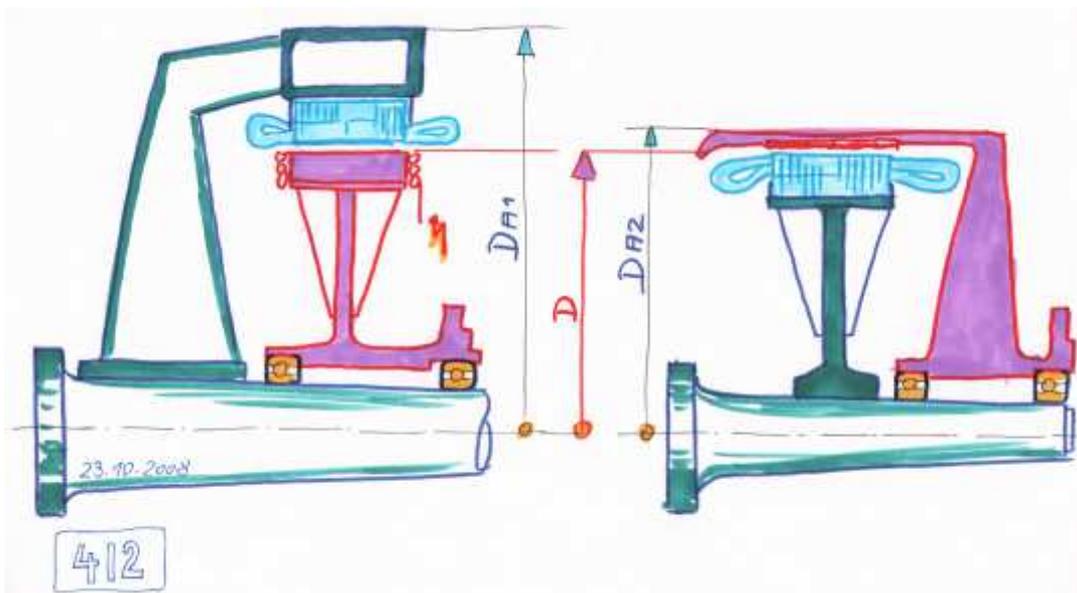


Fig. 4: Comparison outer and inner rotor (by author)

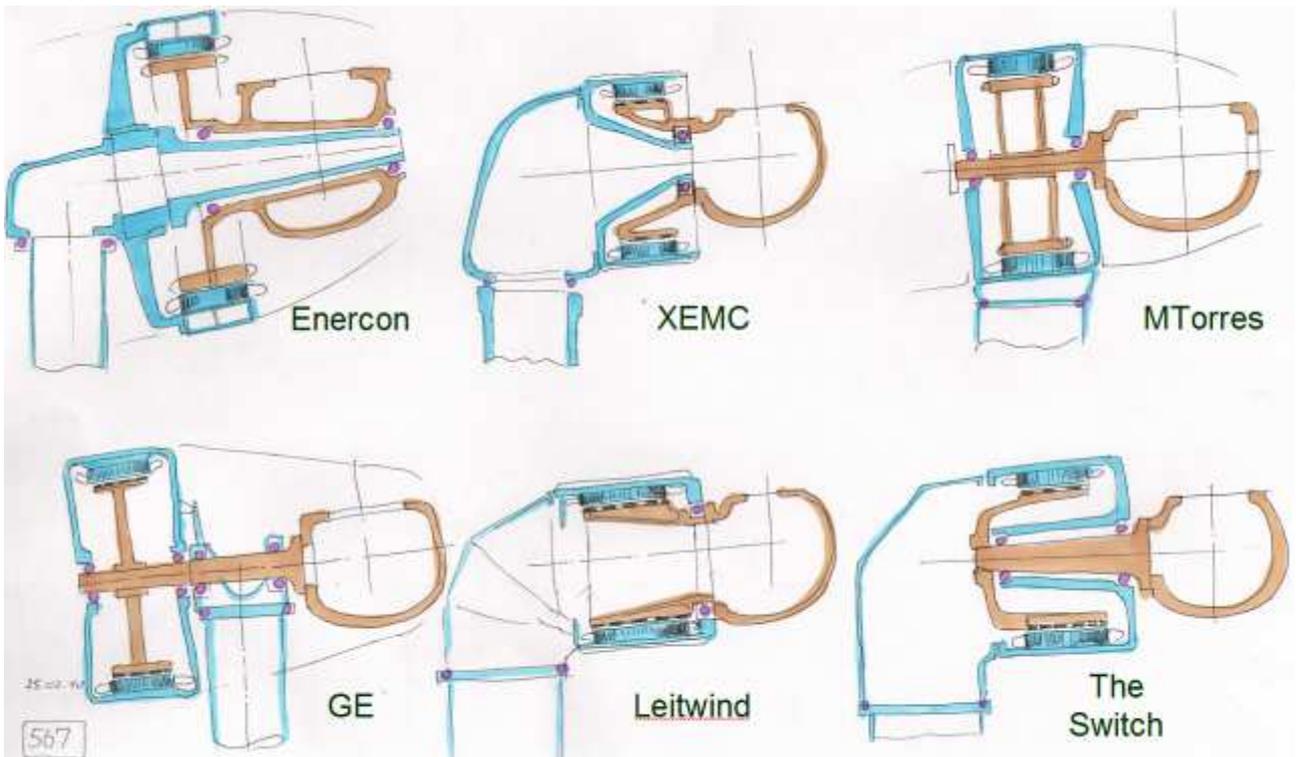


Fig. 5: Bearing concept with inner rotor (by author)

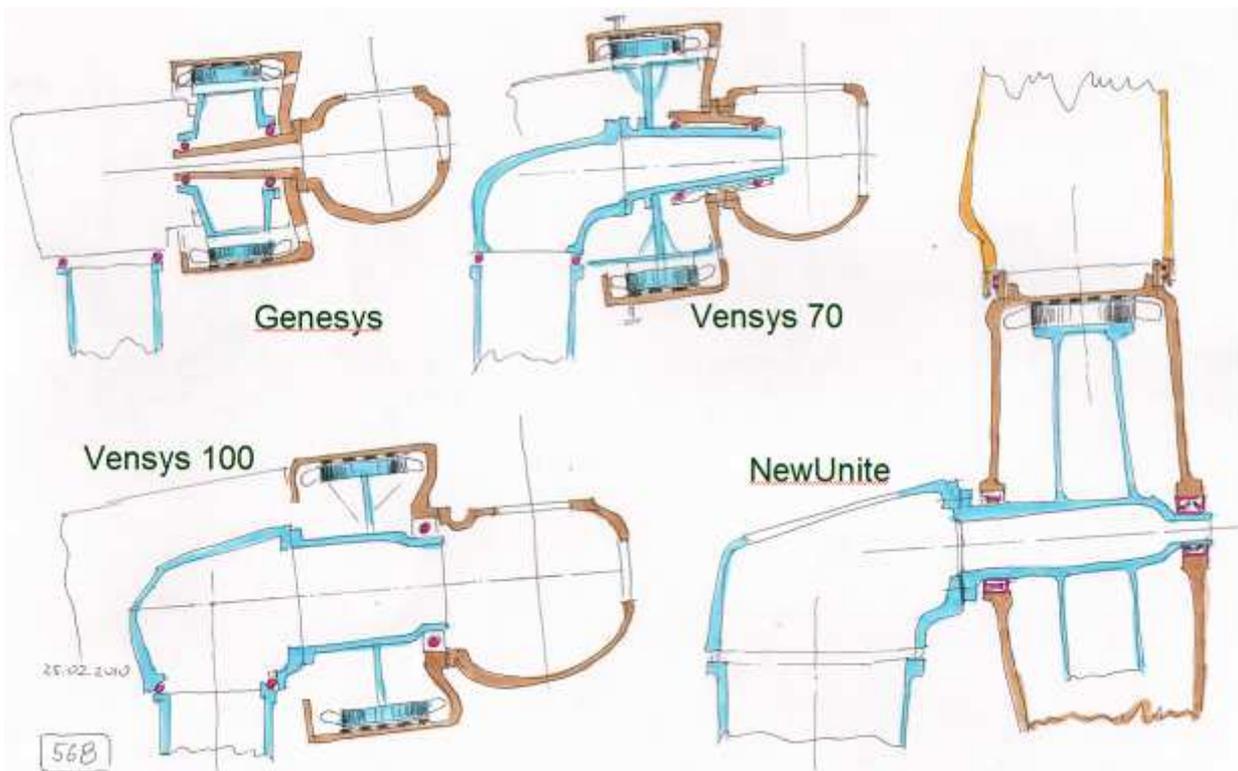


Fig. 6: Bearing concept with outer rotor (by author)

An innovative and robust bearing concept with only a large diameter slewing bearing is used in Vensys100, Leitwind and XEMC as shown in figure 5 for inner rotor and 6 for outer rotor turbines. A further innovation is shown in figure 6 on the right side, where the generator is integrated in the rotor hub.

3 GENERATOR DESIGN CONCEPT - STATE OF THE ART

There are world wide several most important manufacturers for direct drive wind turbine, they are Enercon, Vensys as original designer and his license holder Goldwind, Zephyros as original designer and his license holder XEMC

Manufacturer	Power [MW]	Rotor Arrangement	Number of blades
Enercon	3	Internal	3
Genesys	0,6	External	3
Vensys	1,5	External	3
Vensys	2,5	External	3
Harakosan	2	Internal	3

Tab. 1: state of the art wind turbines

3.1 Enercon

Enercon's E 82 (figure 7 and 8) is the most important Direct Drive Product worldwide with 82m rotor and 2MW rated power following a simple concept to have only a few slowly rotating parts. The generator has an inner wound rotor with external excitation and an outer stator of about 5m diameter. Two bearings on a rigid shaft carry the hub and the generator rotor. The cooling system is using fresh air from outside. Enercon has sold different turbines using this concept with more than 24.000 MW worldwide. Their market share in Germany is own 60%. In 2011 Enercon launched a 3MW Turbine E-101 using combined cooling by air and liquid.

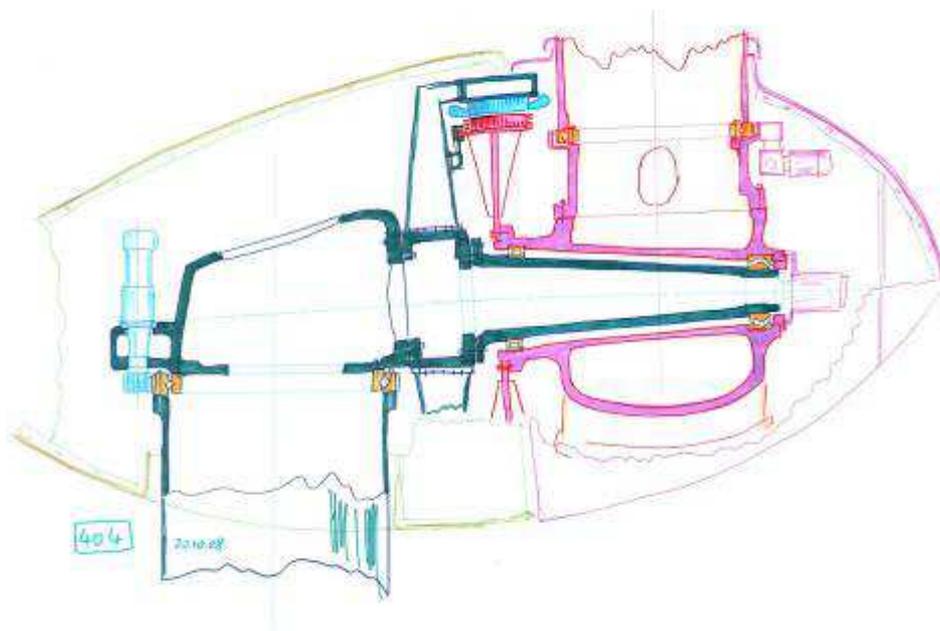


Fig. 7: Design concept of Enercon E82 (by author)

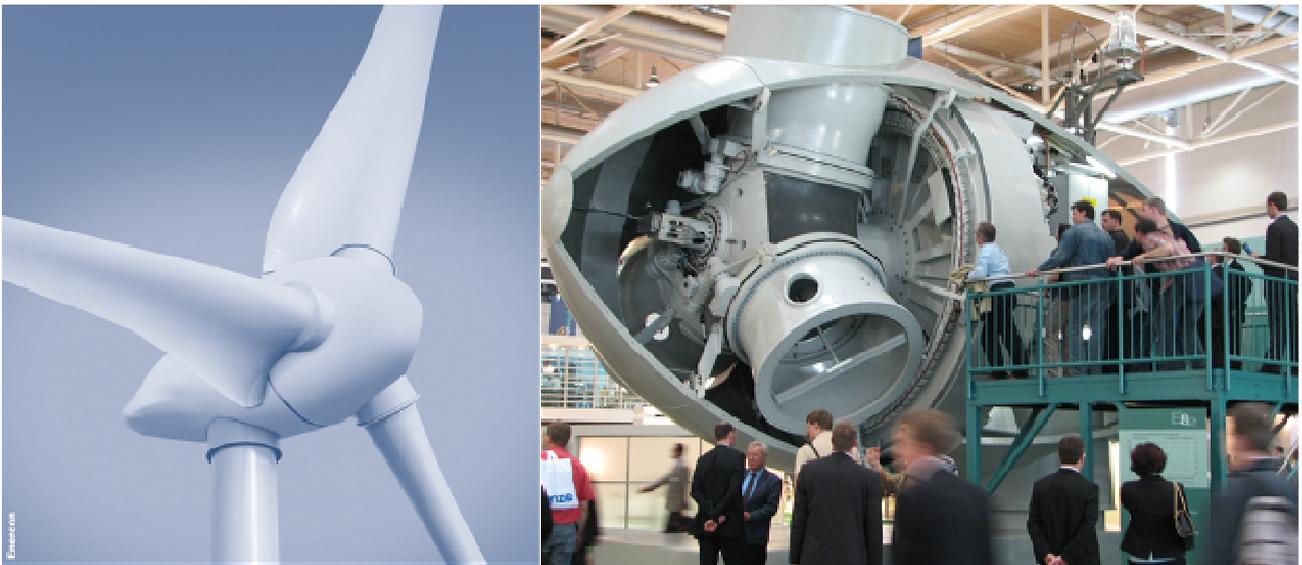


Fig. 8: Enercon (Origin: www.enercon.de)

3.2 Vensys and Goldwind

Vensys has a similar design (figure 9 and 10), but compared to Enercon, the generator has a different layout with an excitation system by permanent magnets on the outer rotor. This leads to a smaller outer diameter and higher efficiency. The iron core is air cooled by the outside air flow through a channel on the stator. Goldwind in China, Eozen in Spain, CKD in the Czech Republic and Impsa in Brazil are using this concept by license. The rotor is 70,77 and 82m, the rated power is 1,5 MW.

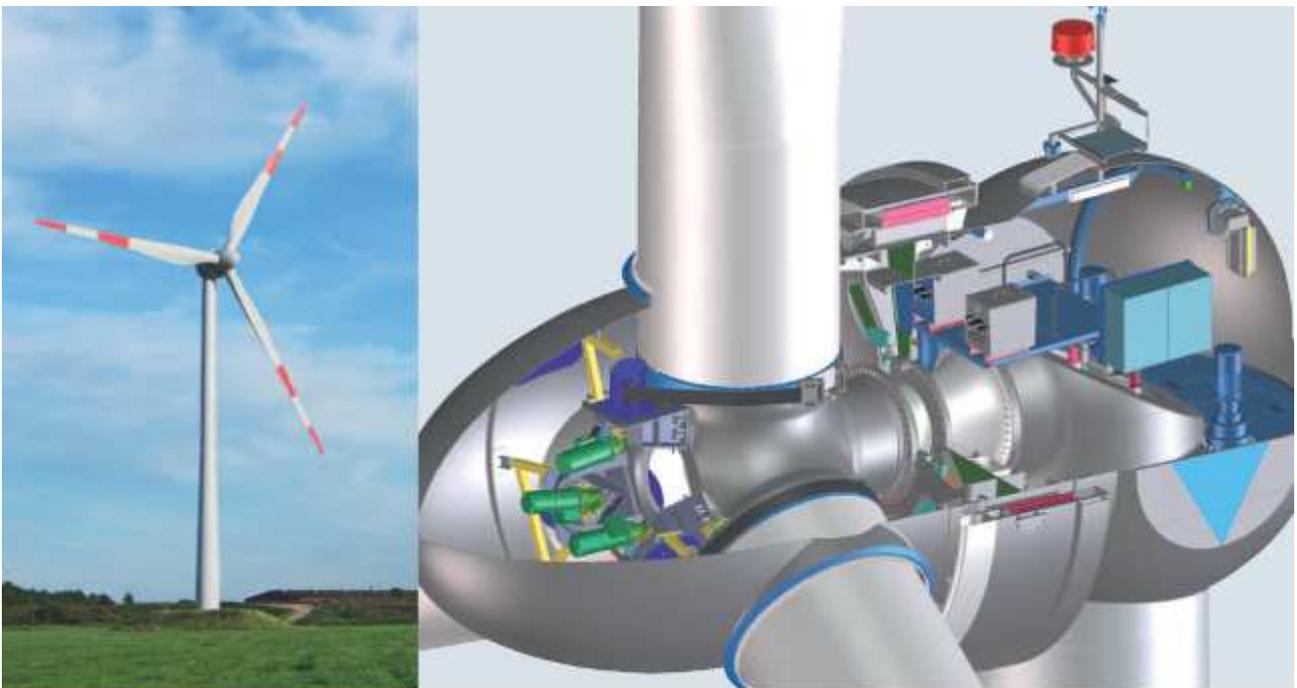


Fig. 9: Vensys V70 (Origin: Vensys brochure)

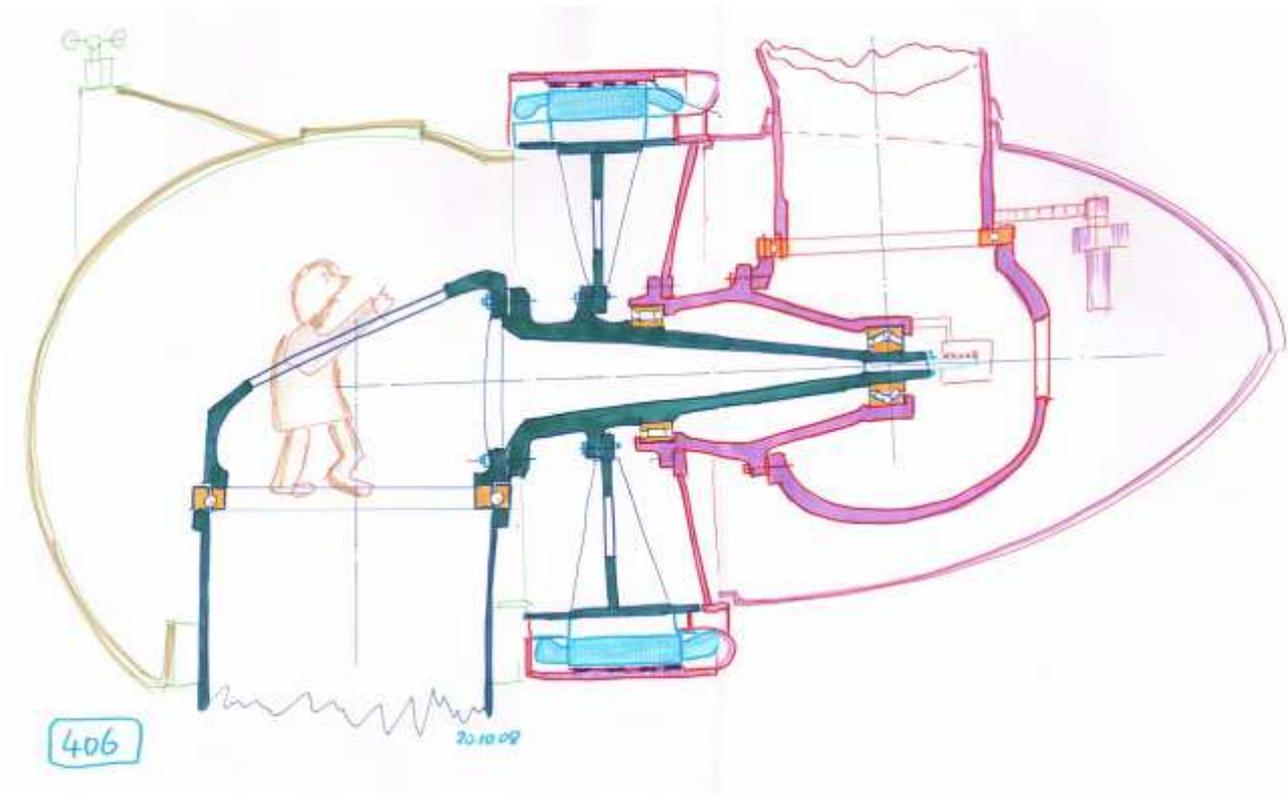


Fig. 10. Design concept 1.5 MW of Vensys/Goldwind V70 (by author)

The Vensys/Goldwind wind turbine V90 (figure 11 and 12) has 2.5 MW rated power, that is 66% more than his forerunner. And thanks to the active cooling system the weight of this turbine is only 10% more than his forerunner.



Fig. 11: Vensys V90 (Origin: Vensys brochure)

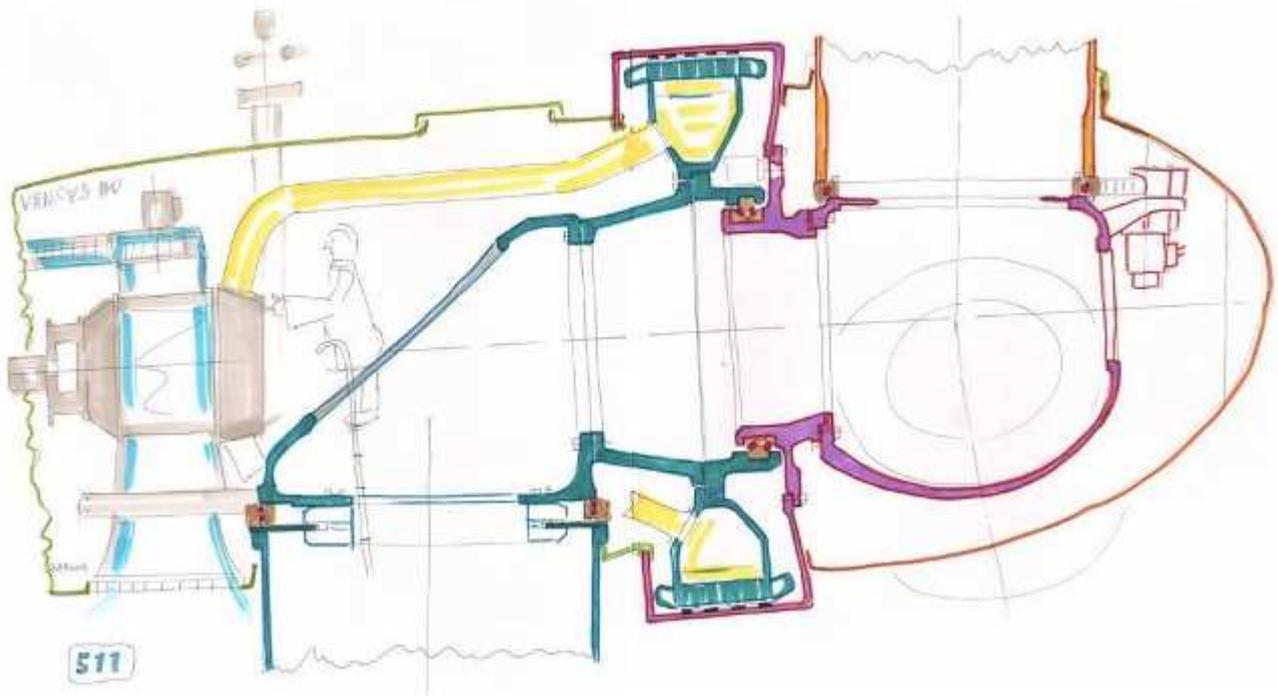


Fig. 12. Design concept 2.5 MW of Vensys/Goldwind V90 (by author)

3.3 Zephyros and XEMC.

The Harakosan Turbine Z72 (see figure 13 and 14) is based on the design of the Zephyros project from the Netherlands. The generator is a multipole permanent magnet generator that is directly mounted to the hub. The magnets take care of the rotor excitation, so there is no external field excitation needed. This implies that the generator losses are reduced by 25% compared to a wound rotor. The stator, equipped with cooling fins, is located on the outside and is cooled by the outside air. The stator windings have a 7 kV insulation and are connected to an ABB ACS 1000 medium voltage converter. The generator, designed and delivered first by ABB Finland and XEMC China has a weight of 49 tons and the dimensions are 3,9 m x 2,0 m. A specially designed cylindrical roller bearing of large diameter carries rotor and hub.



Fig. 13: Harakosan Z72 (Origin.: Harakosan brochure)

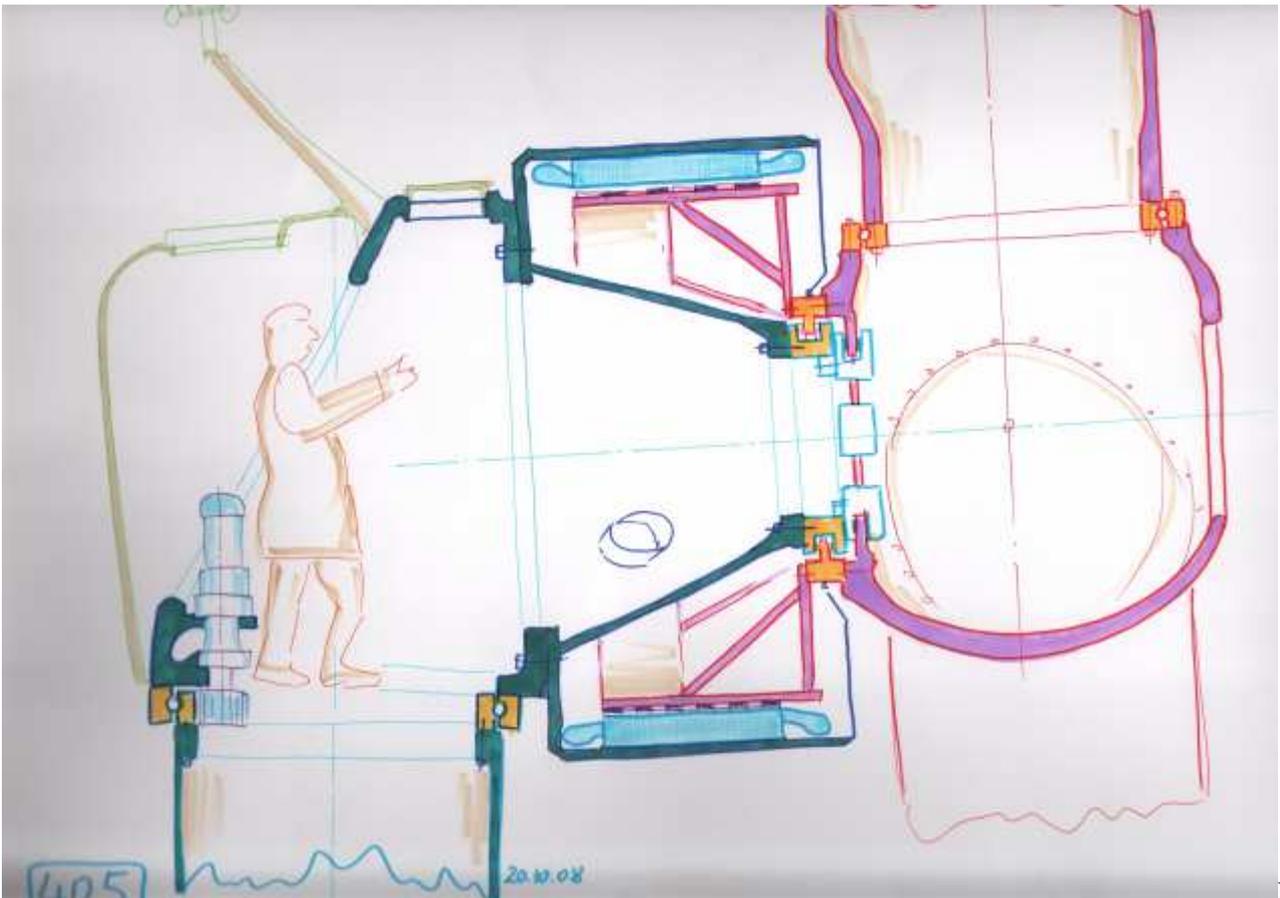


Fig. 14: Design concept of Harakosan Z72 (by author)

4 GENERATOR DESIGN CONCEPT - FUTURE CONCEPTS

In the following pages, several future concepts , which are in development or prototype phase, are shown and described.

Manufacturer	Power [MW]	Rotor Arrangement	Number of blades
Siemens	3	External	3
Alstom	6	Internal	3
XEMC Darwind	5	Internal	3
Envision	3,6	Internal	2
Sway	10	External	3
Innowind	3,2	External	3
(The Switch)	3	External	-

4.1 XEMC Darwind 5MW

The specialty is a generator design with inner PM rotor and stator iron core with cooling fins at the outer surface for passive cooling. This avoids using a powerful, potentially unreliable cooling system. An additional inner cooling circuit is provided (see figure 15 and 16). The stator iron core is only mounted on the left side and the bearing of the hub and the generator rotor is mounted on the right side of the coned inner shaft. The XEMC-Darwind turbine is based on the single main bearing concept. The bearing has a large diameter that enables it to bear the enormous force of the rotor: there is no central shaft. The bearing component is integrated into the generator and is possible because the turbine uses direct-drive technology. This innovative design not only creates a compact and lightweight permanent magnet direct-drive generator; it also results in significant savings in logistics, foundation and support structure costs. This concept is similar to the Harakosan Turbine Z72.

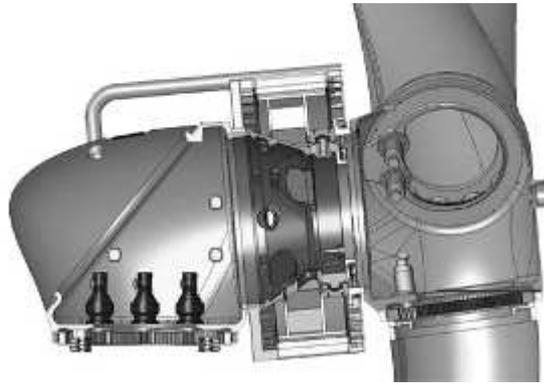


Fig. 15: XEMC Darwind (Origin: www.xemc-darwind.com)

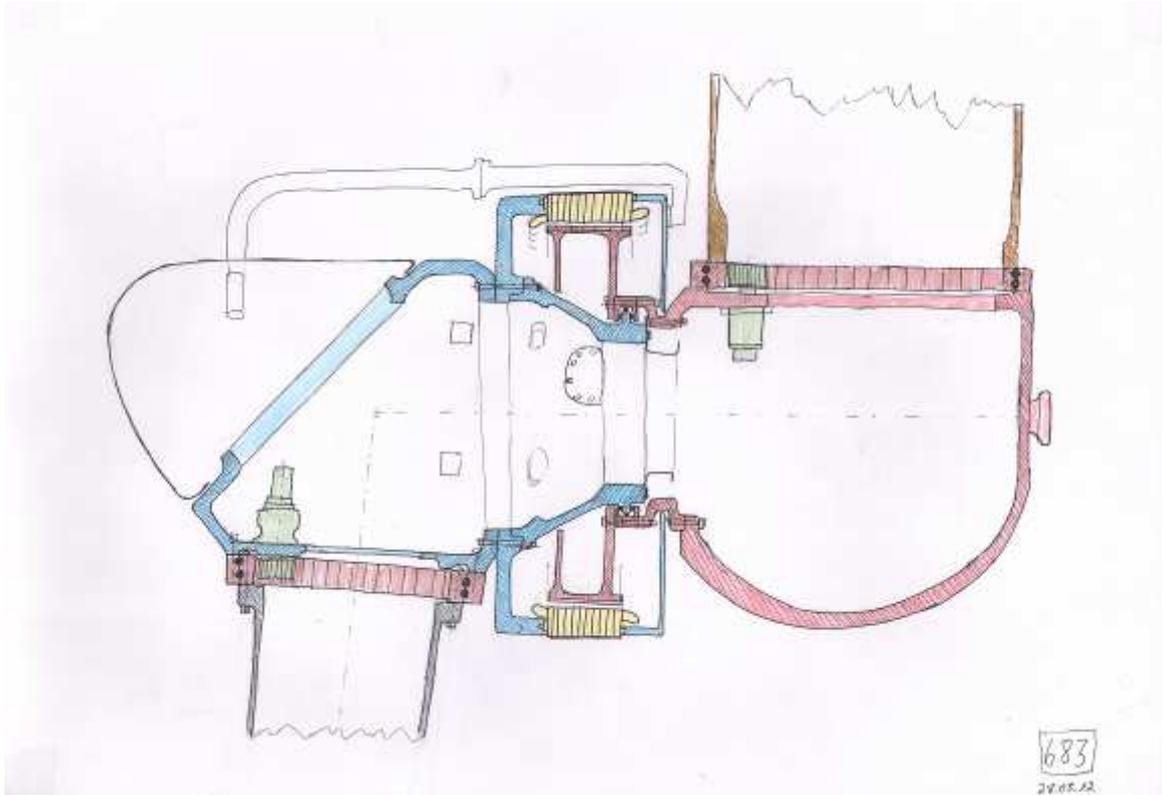


Fig. 16: Design concept of Zyphyros/XEMC (by author)

4.2 Envision

The Chinese-owned Envision Energy has launched the E-128 3,6 MW (see figure 17 and 18) as a new concept. The prototype is announced to be erected in summer 2012 in Denmark where the R&D Team (Danish Global Innovation Centre) is based. Two bearings and a stationary main pin on the right side carries the rotor which is a well-known bearing concept similar to Enercon. The wind turbine uses a flexible torque shaft to connect the hub on the right side of the tower with the generator on the left side. The torque shaft is out of carbon fiber and is inspired by Spanish pure torque concepts. The idea is to separate the deformation of the rotor bearing system by wind loads from the bearing system of the generator. Each 62meter blade consist of a 20 meter inner section with a fixed blade angle and a pitchable 42 outer blade, manufactured by LM. The pitch bearings and electric pitch mechanism are located in between inner and outer blade part.



Fig. 17: Envision (Origin: Envision brochure)

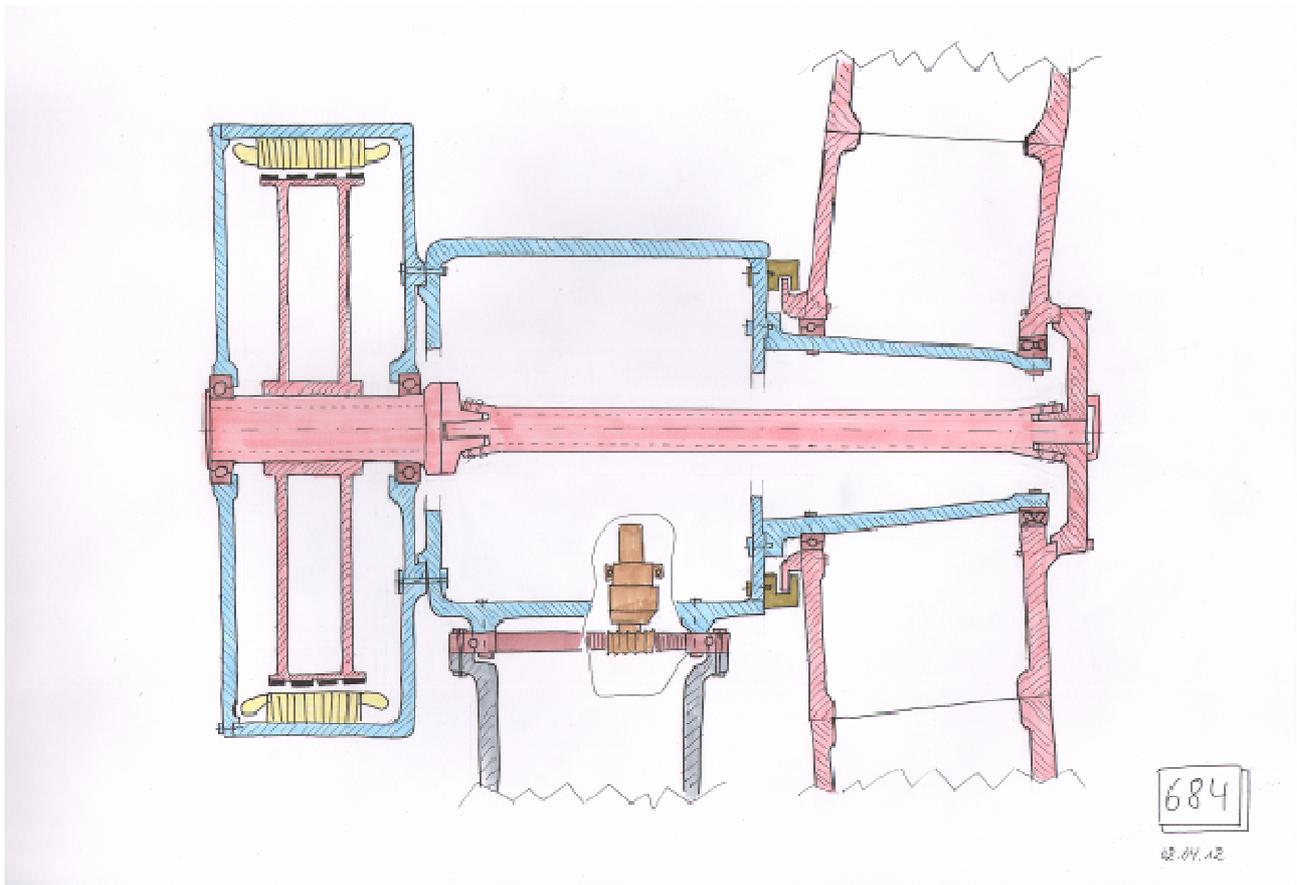


Fig. 18: Design concept of Envision E-128 (by author)

4.3 Sway AS

The 10 MW turbine is designed for both fixed seabed and floating installations and is scheduled to be commercially available before 2015. (see figure 20 and 21)The generator rotor resembles a bicycle rim with tension members connected to the bearings on a rigid shaft (blue colored). The generator stator is rigidly connected to the shaft by tension members, as well. The rotor blades forms a fork which are rotational mounted on a fixed shaft with additional tension member to transfer the torque to the generator rotor. Compared to the in-hub wind turbine by INNOWIND (see fig 28) SWAY has an open hub with large diameters suited for excellent passive cooling.

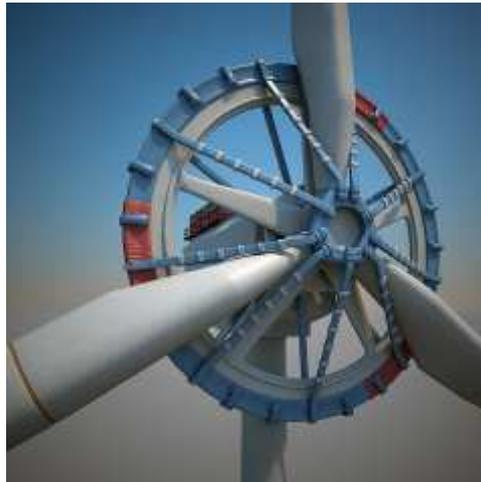


Fig. 19: Sway AS (Origin.: www.turbosquid.com/3d-models/3d-model-sway-wind-turbine/563463)

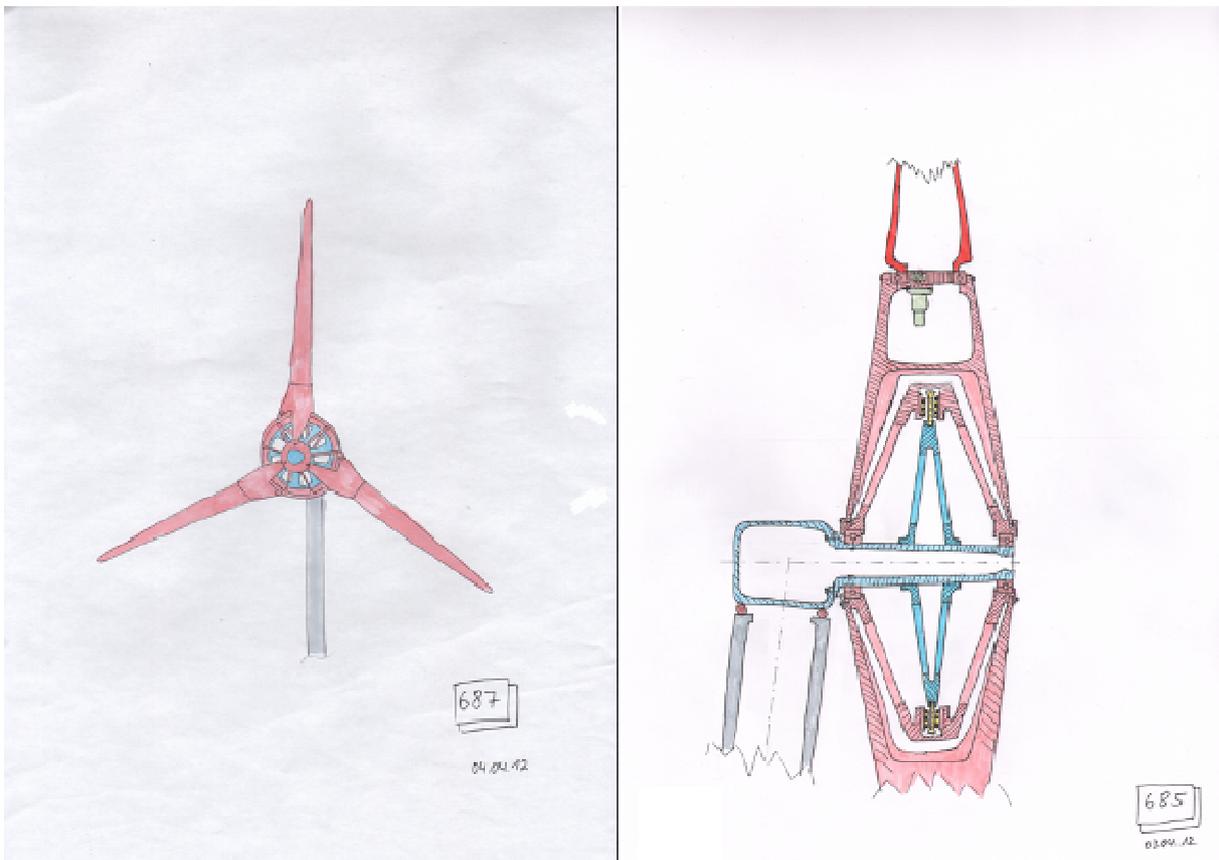


Fig. 20: Sway perspective and cross-sectional view (by author)

4.4 The Switch

The Switch is fully committed to wind power generation as manufacturer of generators and converters (see figure 22 and 23) . The purpose-built permanent magnet generators (PMG), all wind power applications are covered . Each PMG is designed with special magnet shapes and arrangements to match specific wind conditions for smooth operation and maximum efficiency. The Switch PMGs provide excellent availability and productivity. By eliminating cogging, the overall mechanical stress is reduced . This improves reliability and extends the turbine's lifetime. The Switch low-speed, direct-drive PMGs operate without any gearbox to create superior all-round drive train efficiency. Torque variations are effectively filtered to eliminate undesirable vibration. Direct-drive PMG versions are available with either inner or outer rotors from 1,6 to 6 MW rated power.



Fig. 21: The Switch PMG3200-12 (Origin: www.theswitch.com)

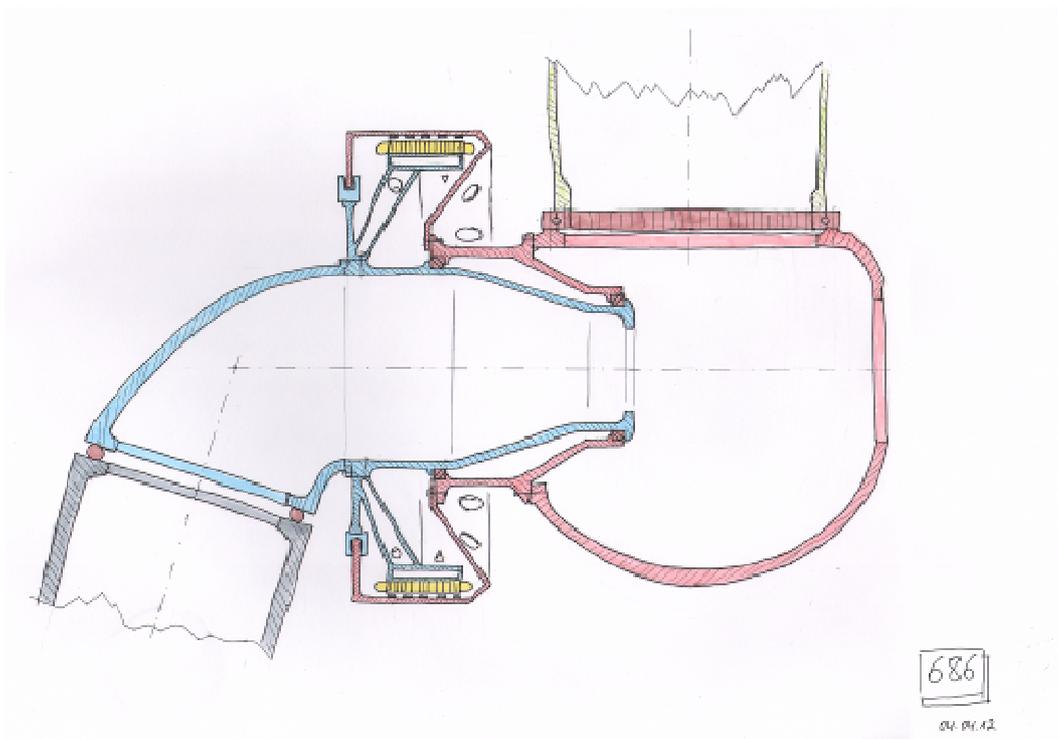


Fig. 22: The Switch PMG3200-12 Generator integrated (by author)

4.5 Siemens

The SWT-3.0-101 rotor is a three-bladed cantilevered construction, mounted upwind of the tower. The power output is controlled by pitch regulation. The rotor speed is variable and is designed to maximize the aerodynamic efficiency. (see figure 24 and 25)

The B49 blades are made of fiberglass-reinforced epoxy in Siemens' proprietary IntegralBlade® manufacturing process. In this process the blades are cast in one piece to eliminate weaker areas at glue joints. The blades are mounted on pitch bearings and can be feathered 80 degrees for shutdown purposes. Each blade has its own independent pitching mechanism capable of feathering the blade under any operating condition. The blade pitch arrangement allows for optimization of the power output throughout the operating range, and the blades are feathered during standstill to minimize wind loads. The rotor hub is cast in nodular cast iron and is fitted to the generator rotor with a flange connection. The hub is sufficiently large to provide a comfortable working environment for service technicians during maintenance of blade roots and pitch bearings from inside the structure. A cast, hollow and fixed main shaft ensures a comfortable internal access from the canopy to the hub. The rotating parts of the wind turbine are supported by a single, double-tapered roller bearing. The bearing is grease lubricated. The generator is a fully enclosed synchronous generator with permanent magnet excitation. The generator rotor construction and stator winding are designed for high efficiency at partial loads. The generator is positioned between the tower and the hub producing a comfortably lean arrangement of the internals in the nacelle. The mechanical brake is fitted to the non-drive end of the generator rotor and has three hydraulic calipers. A cast bed frame connects the shaft to the tower. The yaw bearing is an externally geared ring with a friction bearing. A series of electric planetary gear motors drives the yawing. The weather screen and housing around the machinery in the nacelle is made of fiberglass-reinforced laminated panels with multiple fire-protecting properties. The design implies fully integrated lightning and EMC protection. The SWT-3.0-101 wind turbine is mounted on a tapered tubular steel tower. The tower has internal ascent and direct access to the yaw system and nacelle. It is equip-ped with platforms and internal electric lighting. [Origin.: www.energy.siemens.com/hq/en/power-generation/renewables/wind-power/]

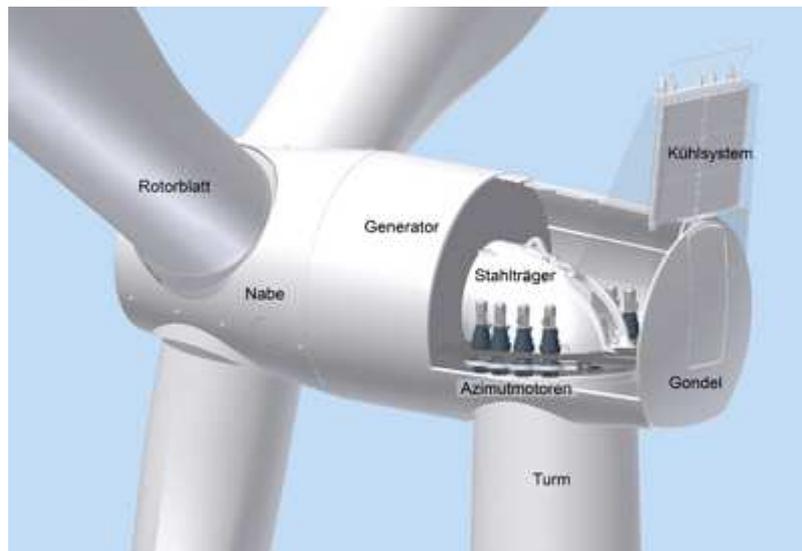


Fig. 23: Siemens SWT-3.0-101 (Origin: www.energy.siemens.com/hq/en/power-generation/renewables/wind-power/)

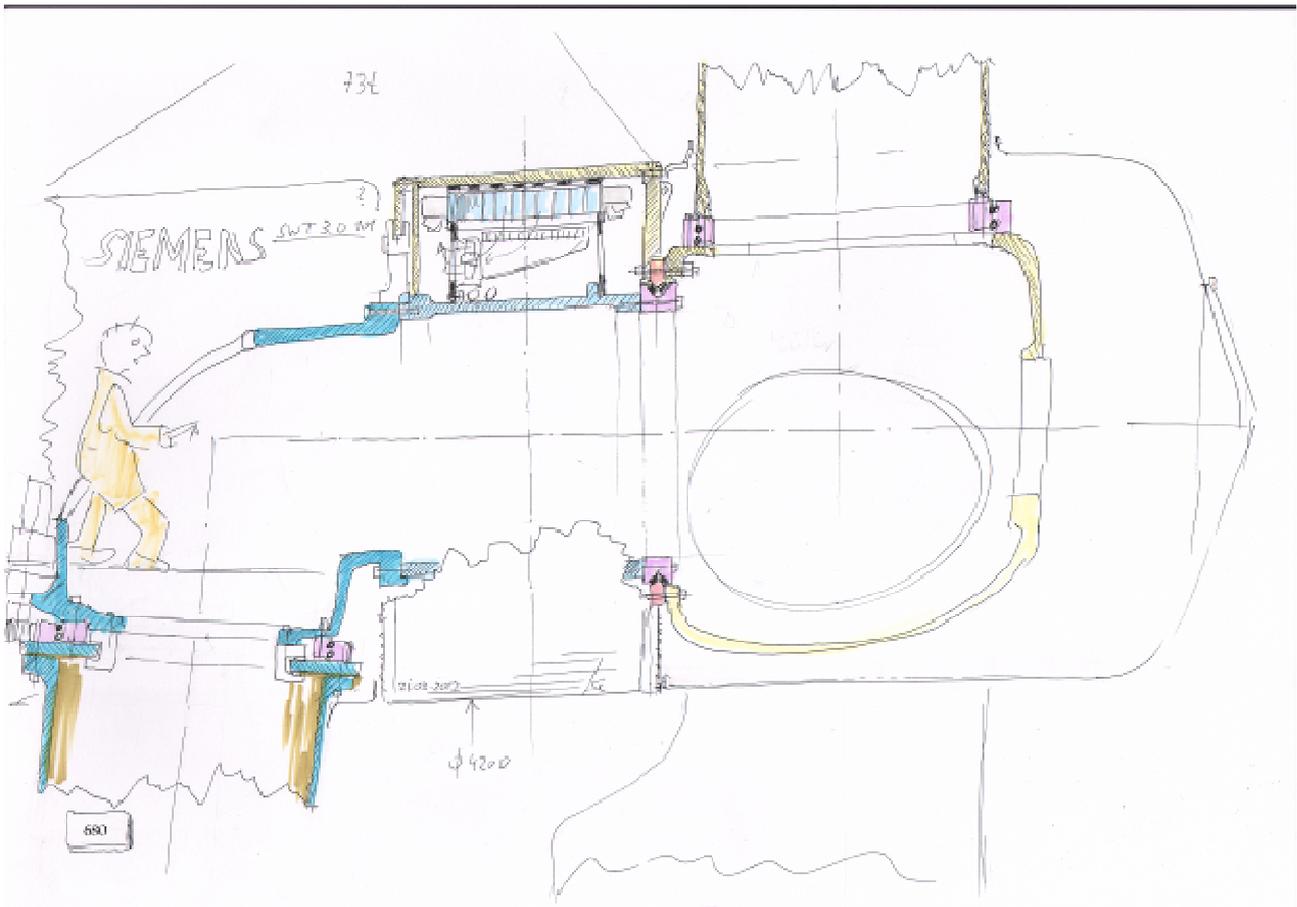


Fig. 24: Design Concept of Siemens SWT-3.0-101 (by author)

4.6 Alstom Haliade

The 6 MW Haliade 150 wind turbine has been developed in response to a call for tenders launched by the French government. It is the largest turbine prototype so far with a 150m rotor diameter. (see figure 26 and 27) The ALSTOM PURE TORQUE™ design protects the generator and improves performance by diverting unwanted stresses from the wind safely to the turbine's tower through the main frame.

The design separates the turbine rotor and generator to ensure that only torque is transferred to the generator. This allows the minimum sufficient air gap to be maintained between the generator rotor and stator. The “Advanced High Density” direct drive PMG, supplied by power conversion specialist Convertteam, is a more compact and lightweight design compared to earlier generation direct drive systems. [Origin: www.alstom.de]



Fig. 25: Alstom (Origin: www.alstom.com)

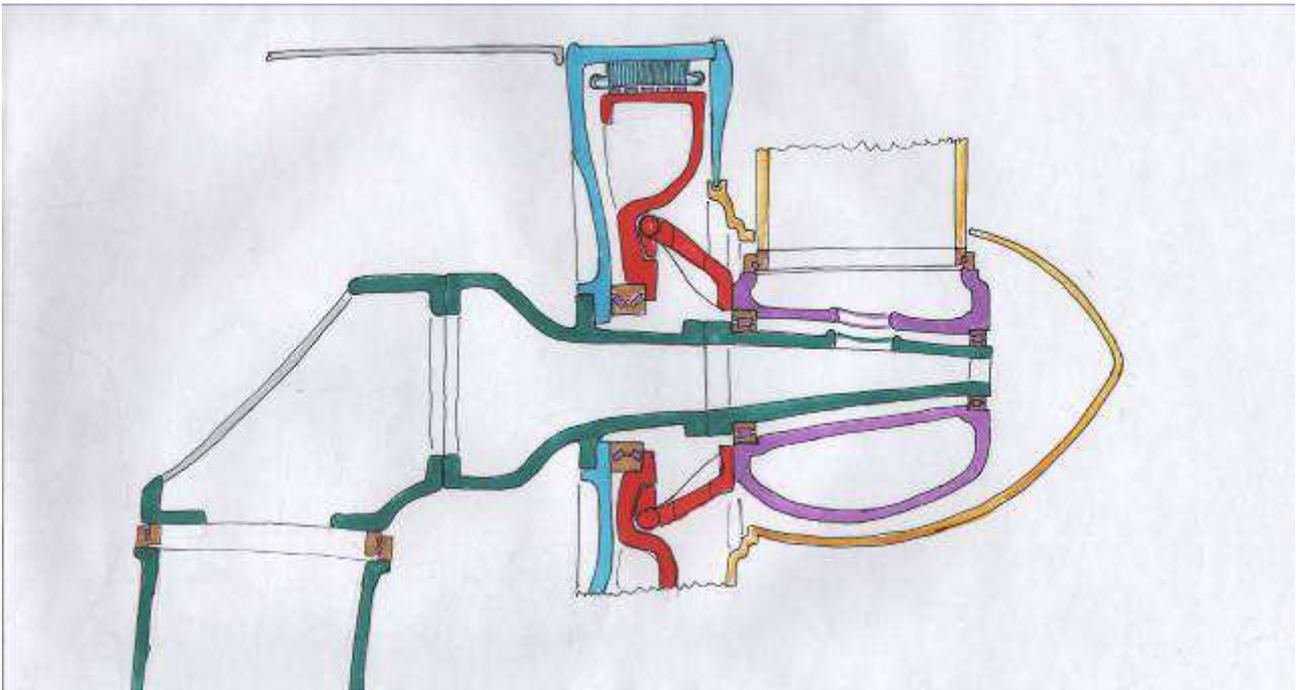


Fig. 26: Design Concept of 6 MW Haliade 150 (by author)

4.7 Innwind

INNOWIND has been working on new solutions for direct drive wind turbine for 20 years. In figure 27 a new generator concept is presented. We call it In - Hub- Generator as the generator is integrated in the hub. The generator in hub concept leads to a more robust design with less parts and connecting flanges than the concepts according to Enercon, Vensys/Goldwind and Haracoston. The generator is a multipole synchronous machine with excitation by permanent magnets on the outer rotor with blades directly mounted. Deformation in the air gap is reduced due to the location of the main rotor bearings on both sides of the generator.

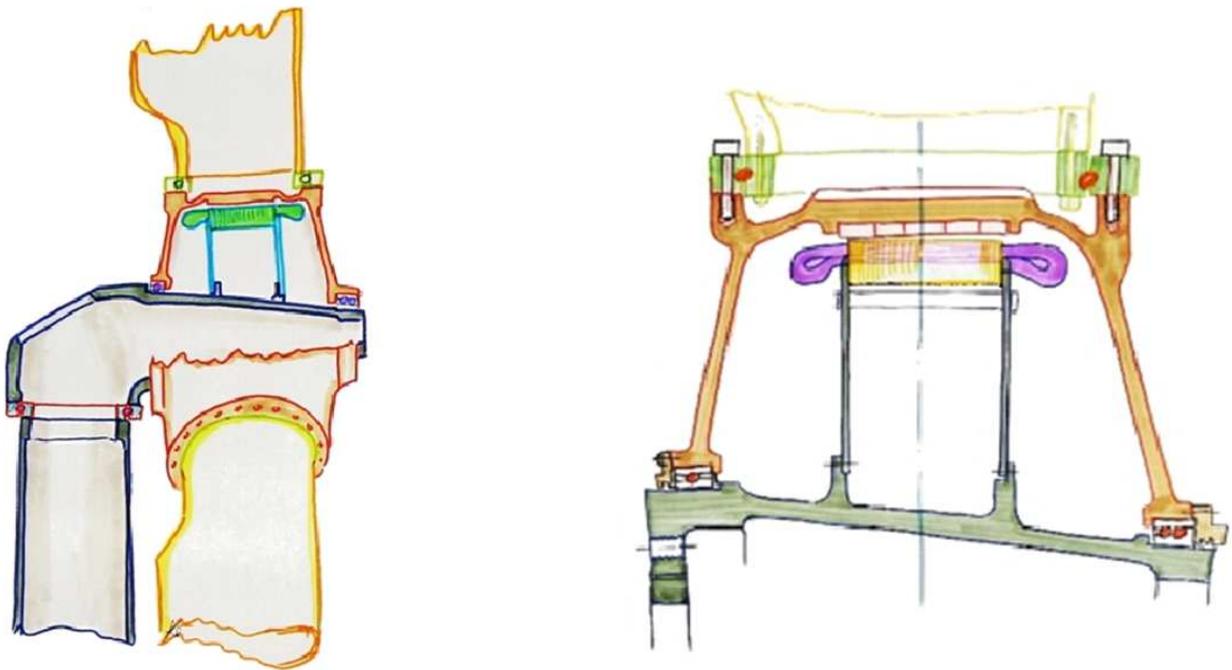


Fig. 27: In-Hub-Generator concept for direct drive wind turbine (by author)

5 Conclusion

Direct drive wind turbine concepts with gearless drive trains has been developed and improved in the last 20 years. Compared to turbines with gearboxes reliability and efficiency is increased and cost for maintenance and down time is reduced. Their design is more robust with half of the parts and components. The newest turbine design in the range von 2 to 3 MW is proving that the tower head mass is at the same level as gearbox turbines. Offshore turbines are under development for 5 to 10 MW and the trend for onshore turbines is also in the direction of direct drive.