<u>New Direct Drive Turbine Design</u>
<u>using Advanced Cooling with Evaporating CO2</u>

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Summary

The presentation deals with a new turbine design based on an active cooling system using carbon dioxide which absorbs the generator heat losses by evaporation. This cooling method opens new design possibilities as no air is led to the winding system and allows for a fully sealed generator which is ideal for the coming offshore application. At the same time, the generator is designed for replacing the hub and bearing the blades directly without an additional hub part. Therefore the number of parts to be lifted on site can be reduced from three to two which is also an important issue with regard to offshore turbine erection. Finally, tower head masses of direct drive turbines are compared. The result shows, these modern direct drive turbines are no longer heavier than modern gear turbines, some of them are even lighter and the new turbine design developed by our Research Group confirms this tendency.

1 Introduction

The direct drive technology will be the future technology. No turbine technology is as reliable and long living as direct drive turbines. This thesis is confirmed by the current market situation in Germany showing that Enercon holds more than 50 % of the market share, although higher investment cost for their turbines have to be paid. Unfortunately Enercon is the only big direct drive player worldwide until now and based on its earlier turbine designs like E-30, E-40 and E-66 the image of heavy weight direct drive turbines on the one side and the lighter gear turbines on the other side has became manifest in the wind turbine branch.
Further until now, most direct drive turbines are using an air cooling system either using ambient air or an internal air circulation system. This cooling method needs a high temperature difference between cooling medium and generator winding system to generate the needed heat flow. So the winding system is warmed up to 120°C and more and not very homogenous as the generator geometry mostly causes an inhomogeneous temperature allocation with some hot spots.

2 Who we are

The Wind Energy Research Group at the University of Applied Sciences was found by Prof. Dr.-Ing Klinger in the earlier nineties of the last century. At that time, the group was consisting only of students and graduates and was involved in several industrial projects with local industries. One day a consultancy project quickened its particular interest. This project dealt with the damage analysis of a small wind energy turbine. Animated by the revealed design faults they started to work on a layout for an own optimized design. Of course, this design was a direct drive one with permanent magnet excitation on an external rotor, features which you will find at each turbine designed by the group. A few years later, the group could win an investor for this design and the first major project called Genesys 600 (600 kW) could be launched in 1995. Only after two years, the prototype was erected in Saarland not far from the University place. After this initial wind project and some experiences with the Genesys prototype, the spin-off Vensys was hived in 2000. From that time, the research group worked as R+D team for Vensys until the end of 2005. At this time and as a result of this cooperation, two new developments have been archieved; the final design of Vensys 62 with 1.2 MW and the base design for Vensys 90 2.5 MW which currently is entering the market. In the middle of 2006, a new contractor from China could be found who was interested to go ahead for a completely new 2 MW turbine concept. In the meantime, this project is nearly finished and so a follow-up project with an European contractor was already been started at the beginning of this year and is running now. In the meantime, the Group consists of professors, grad-


Genesys 600 kW, 1997


Vensys 62 (1.2 MW), 2003

uated engineers, technicians, secretary and graduated bachelors of engineering who are doing their master study in parallel. Altogether there are twelve people.

3 New evaporation cooling principle

Fig. 1 gives a short overview about the new cooling system and how it works. It shows a cooling circuit including a heat exchanger (condenser), a circulation pump and a symbolized generator winding system (only hydraulically) which is connected to the cooling circuit by the collector and distribution line.

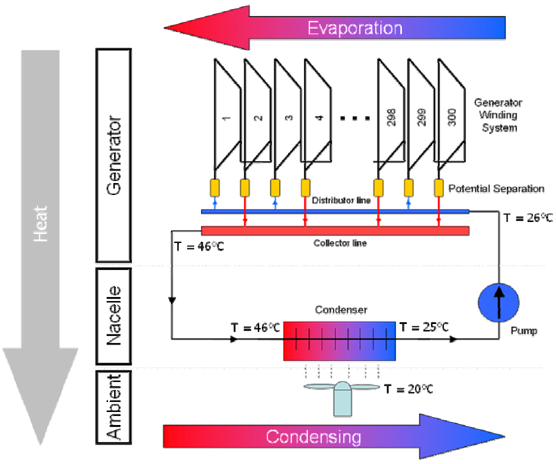

Fig. 1 Principle of CO2 cooling system

As shown in ***Fig. 2***, potential separators are used because the electrically active part, the generator winding system has to be electrically insulated from the remaining parts of the cooling system to avoid short cuts into the winding and to protect the cooling system components against the high voltage. The CO_2 itself is electrically nonconductive so that there is no electrical connection through the medium like it would be with a cooling using water.

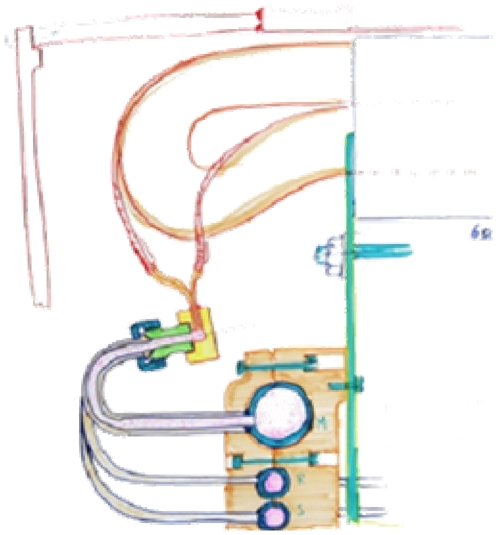

Fig. 2 Interface cooling to winding system

To realize such a cooling circuit, the coils have to be built by a hollow conductor (***Fig. 3***). Several coils are hydraulically connected in series and represent a long and narrow cooling channel of about 35 meters length.

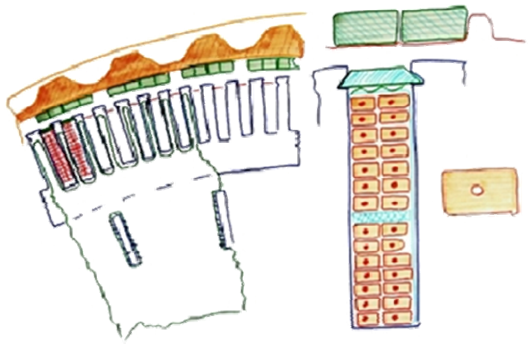

Fig. 3 The hollow conductor winding system

The cooling functions as follows; the pump feeds the distribution line with liquid carbon dioxide where it is distributed to the coils of the generator winding system. As long as the generator is working, the liquid carbon dioxide begins to boil shortly after entering the channel and evaporates completely until reaching the channels end. So the temperature between in and outlet is nearly at the same level as only lateral heat is used to store the energy coming from the generator losses in copper, iron core and so on. After leaving the coil system through particular potential separators, the carbon dioxide steam is led to the condenser where it is liquefied again and super cooled a little before the circle starts anew. On this way the heat is transported from the generator through the nacelle to the ambient air without any direct contact between any corrosive air and the winding system. This is increasing the generator's life time significantly.
Further, due to the short distance between heat source and sink, this cooling works without bigger temperature differences between generator parts and the cooling medium, which means that in contrast to air cooling concepts a very low temperature level, for instance 10 Kelvin above ambient, can be achieved which reduces the copper losses.

4 In-hub generator design

Using the cooling concept described above, allows for a fully sealed and closed generator like shown in ***Fig. 4***. In addition to the innovative cooling system due to the cooling, the new design is merging the hub and the generator as the blades are directly mounted on the generator outside. The combined bearing system for rotor and generator allows for an optimal load lead-through the supporting structure.
The bearings are located at each side of the rotor, balancing the loads of generator and blades.

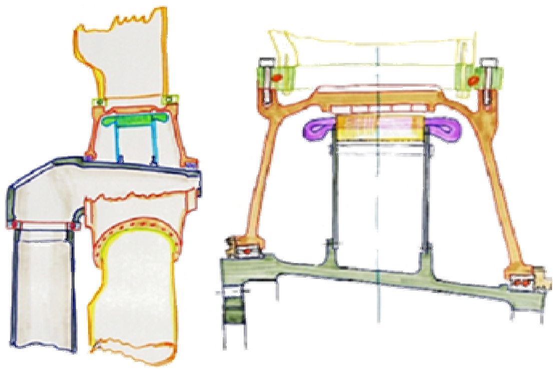

Fig. 4 In-hub generator and bearing concept

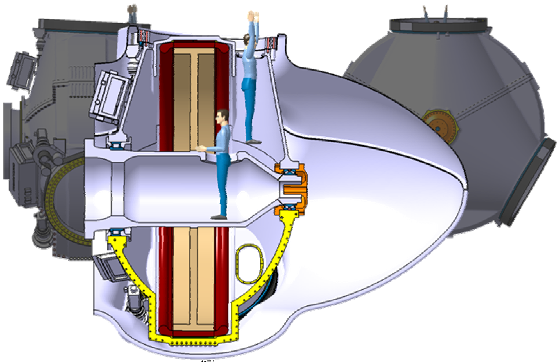

Fig. 5 In-hub generator design

In ***Fig. 5*** a large ring generator is shown with a still standing shaft carrying the bearings. The rotating generator hub is divided in three identical parts and each part carries permanent magnets for excitation. Together they build the generator's rotor. The winding system is fixed on the stator shaft with a special support structure and there is an opening in the shaft which allows entering the generator and the blades for blade maintenance. The total mass of the generator hub with less than 5 meter diameter and about 3.5 meter length is about 50 tons.
Based on the generator design presented above, a new turbine design called WERG-85 was worked out and is shown in ***Fig. 6*** and ***Fig. 7***. Hereby the nacelle contains the required remaining aggregates like converter system, circulation pump, head exchanger and a conventional yaw system. It is very conspicuous that besides tower and blades, the turbine only consists of two parts; the generator hub on the one hand and the nacelle on the other hand. As consequence the number of parts to be lifted compared with other direct drive turbines could be reduced from three to two.

Fig. 6 The WERG-85 turbine

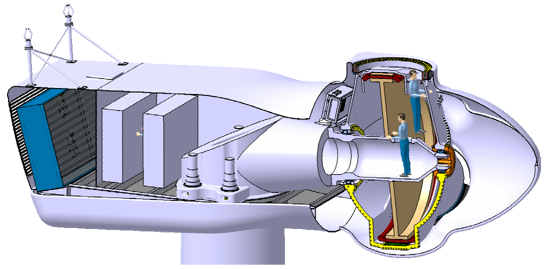

Fig. 7 WERG-85 internal arrangement

5 Additional design features of WERG-85

For reducing the maintenance effort, a standard pitch system has been replaced by a synchronous belt drive solution which avoids any backlash, lubrication and wear. Synchronous belt pitch systems are used in Vensys turbines right from the beginning and have been proven for many years.
In addition, the required pitch control boxes are mounted on the outside of the generator hub where maintenance people have a direct access from the nacelle (***Fig. 8***).

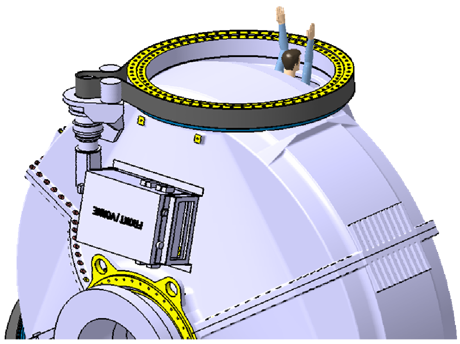

Fig. 8 The WERG-85 pitch solution

6 Advantages of cooling and turbine design WERG-85

Advantages of the turbine design:

- Direct drive for high reliability and availability.
- Permanent magnet excitation saving excitation energy.
- Only small air gap deflections due to the bearing concept
- The synchronous belt pitch system is nearly maintenance free
- Highest accessibility of pitch control boxes
- The non rotating shaft allows the access to the generator.
- The number of parts to be lifted has been reduced.
- In total the tower head mass is about 110t and below the average value for turbines with similar rated power.

Advantages of the cooling system:

- The fully sealed generator avoids aggressive ambient air at the winding system.

- There are no hot spots as the heat is directly collected where it is generated.
- The winding system is operating only a few centigrade above ambient temperature and as a result the copper resistance is reduced.
- Last but not least the low temperature level causes an increased lifetime of the winding insulation.

7 Tower head mass comparison [1,2]

Increased tower head mass of wind turbines is responsible for higher costs for erection, tower and foundation. Generally direct drive turbines have the image to be heavier than gear type turbines which was true for Enercons first turbines produced in series like E-30, E-40 and later on E-66 which were really heavier than the gear turbines of the same time (***Fig. 9***). Although there were further direct drive turbines lighter in weight than Enercon's, this thesis could not be stopped. However, in the mean time there are several direct drive turbines on the market and are shown in ***Fig. 9*** too. It is obvious that modern direct drive designs, also Enercons E-70 and E-82, are much lighter than the first direct drive generation ten years ago.

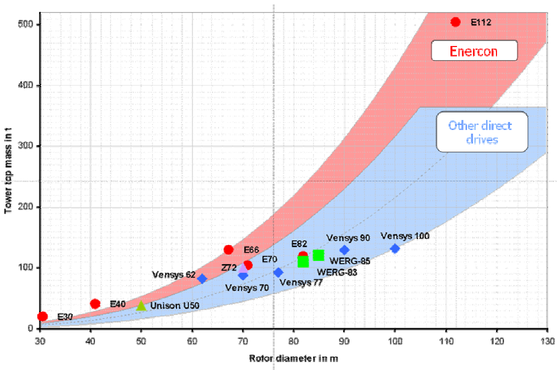

Fig. 9 Comparison direct drive masses [3,4,5]

A further comparison also with gear turbines is shown in ***Fig. 10*** which confirms that modern direct drive turbines are no longer heavier than gear type turbines, some of them are even lighter. The WERG-85 design needs a relatively heavy generator due to a requested rotational speed with regard to the available blades. However, the WERG-85 confirms the tendency.

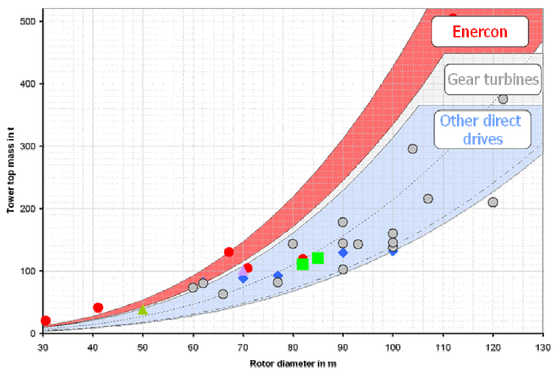

Fig. 10 Comparison direct drive vs. gear

Today following players are dealing with direct drives on the market:

- Enercon, Germany
- Vensys, Germany
  - *Goldwind*
  - *CKD*
  - *Eozen*
  - *Impsa*
  - *India*
- Zephyros, Netherlands
  - Harakosan
  - XEMC, China
- Leitwind, Italy
- Impsa, Argentina
- MTorres, Spain
- Unison, Korea
- Mitsubishi, Japan
- Scanwind, Norway
- Siemens, Germany (!)

8 Conclusions

The new turbine design WERG-85 with carbon dioxide evaporation cooling concept sets new standards for direct drive concepts. Especially with regard to easy maintenance, low erection cost and a high reliability, the new design provides advantages as for example the tower head mass is slightly lower than the average for gear turbines. The new cooling avoids problems which are common in the concepts based on air cooling used until now and opens new design features like a closed generator.

Siemens, as a global player in the area of conventional turbines with gearboxes, is now testing several direct drive systems, what seems to confirm the trend to direct drive turbines.

9 References

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