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Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)
Division Energy Economy & Grid Operation
Königstor 59
34119 Kassel / Germany
E-Mail: mbox@iwes.fraunhofer.de
www.iwes.fraunhofer.de

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Editorial staff:
Sebastian Pfaffel, Volker Berkhout, Stefan Faulstich, Paul Kühn, Katrin Linke, Philipp Lyding, Renate Rothkegel

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SPECIAL REPORT

Direct Drives and drive-train development trends

Written by Dr.-Ing. Jan Wenske – jan.wenske@iwes.fraunhofer.de

Wind energy business is currently in a phase of diversification concerning drive train concepts. Not only the number of manufacturers has increased, but the number of wind turbine drive-train concepts has increased as well.

Apart from Enercon most of the manufacturers used pretty much the same drive train concept in many of their turbines: a distributed drive-train featuring a gearbox with mostly three stages and a fast running induction or doubly-fed induction generator (IG, DFIG).

This situation was changing. Among the top 10 manufacturers 2010 Enercon and Goldwind have been following direct drive concepts for several years and others like Vestas, GE, Siemens, United Power, Gamesa have already produced or announced producing turbines deviating from the classical drive train concept shortly described above. These days appear all kinds of generator types (IG, DFIG, electrical excited synchronous as well as permanent magnet synchronous generators, EESG, PMSG) in nearly all combinations with drive train transmission ratios, from direct drive up to the high step-up solutions. The highest attention is currently paid to modern gearless designs (Direct Drives, DD; refer to figure 1) featuring single bearing and PMSG.

Constraints and driver for future trends

Components Supply Chain

In the beginning and the middle of the past decade there was a shortage in several key components. Accordingly in 2008, compared to 2006, there was already an oversupply in gearboxes, whereas the shortage in cast iron and forged items was nearly non-existent anymore. Bearings were the last key component with a significant shortage in 2008.

The trend to expand production capacities in wind turbine key components continued to date leading to a tremendous overcapacity, local content requirements and the market entry of new turbine manufacturer especially from Asia since the last 3 years intensify this trend. Regarding generators for direct drive should be noted, that so far no real cost-effective volume production is available.

Manufacturer	Country	rotor diameter [m]	rated power [MW]	generator type
Enercon	D	126	6 (7.5)	EESG
		112	4.5	
		101	2/2.3/3	
		82	2/2.3	
		70-71	1.8/2/2.3	
Vensys/Goldwind	CHN/D	70	1.5	PMSG
		100	2.5	
		-	6*	
Siemens	DK	120	6	PMSG
		113	2.3	
		101	3	
Leitwind	I	101	3	PMSG
		70	2	
		80	1.8	
GE	USA	113	4.1	PMSG
Lagerwey	NL	90	2.5	PMSG
EWT	NL	90	2	PMSG
MTorres	SP	-	2.5	EESG
		-	1.65	
Nordex	D	150	6*	PMSG
Alstom	F	150	6*	PMSG
XEMC Darwind	CHN	115	5	PMSG
AVANTIS/Hyundai	KOR	-	2.5	PMSG

** turbine type introduced or announced, but still no prototype*

Figure 1: Direct Drive turbines with more than 1.5 MW of rated power

list of abbreviations

IG	induction generator
DFIG	doubly-fed induction generator
EESG	electrical excited synchronous generator
PMSG	permanent magnet synchronous generators
DD	direct drive
PM	permanent magnet
HTS	high-temperature superconductor

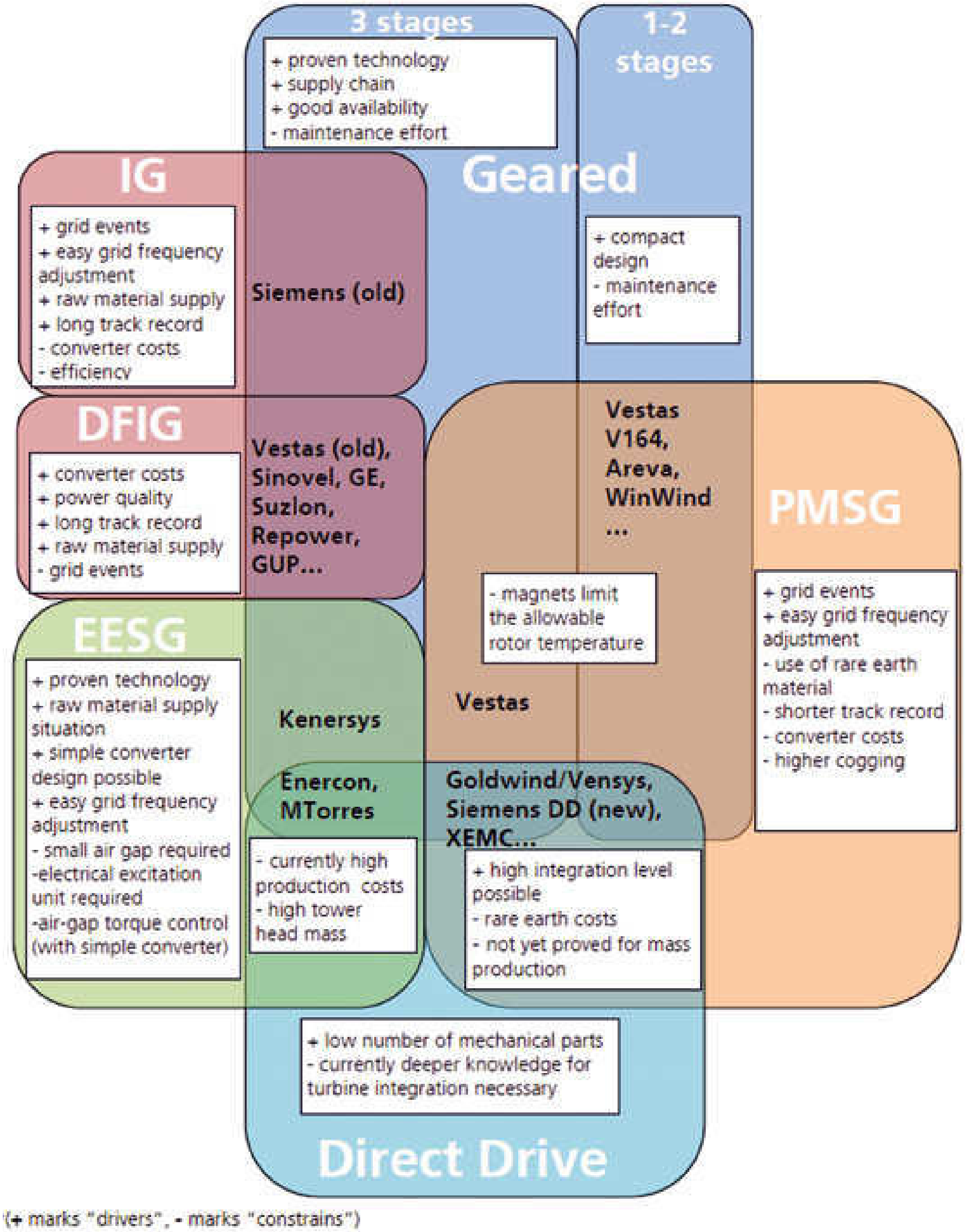

Figure 2: Drive train concepts with a pros and cons overview

Availability of raw materials and costs. Raw material price development has been proven to be highly volatile in the past. Since different raw materials are used in different concepts in various extents the development of the prices of certain raw materials is important for success of certain concepts. The amount of other raw materials varies significantly depending on the drive train design.

All generators need copper, however DD EESG turbines need the largest amount of copper. Consequently the prices of Enercon's and MTorres' turbines do, to a certain extent, depend on the copper price. The copper price has increased by 28% in the past year. However the copper price in the beginning of 2010 was relatively low and despite massive ups and downs copper prices have not increased significantly compared to the level from five years ago.

Neodymium and Dysprosium are key raw materials of the high performance magnets (NdFeB magnets) used in PMSGs and were subject to intense discussions recently, regarding pricing and environmental effects. In 2011 the price for 1 kg of raw neodymium (/Dysprosium) started with 36 euros (/243 euros), reached a top level of 195 euros (/1,700 euros) in July and fell back to 110 euros (/975 euros) end of this year. The slightly falling price trend continues, albeit at a historically very high level. At the moment 95% of the neodymium is produced in China.

Reliability. Reliability of wind turbines is an important issue, especially for offshore applications.

The to date newest ReliaWind study identified gearboxes to account for only 5% of the failures and downtime and stated a roughly three times higher value for downtime and failure rate caused by the main converters. But on the other hand gearbox failures often involve the systemic risk of prolonged downtime especially in offshore applications and gearing concepts require a periodic and relatively frequent maintenance in comparison to gearless drive trains.

Efficiency. Generalized, high speed (98.5%/97.5%) and medium speed (97%/96.5%) PMSGs/EESGs have a higher efficiency than low speed (95.5%) PMSGs and (92%) EESGs, due to design constraints, like material usage, mechanical dimensions, air gap dimensions plus cooling effort which at the end represent overall costs and turbine weight. However the main advantage of the direct drive concept at this point whether using PMSG or EESG is minimizing losses within the mechanical part of the drive train. On the other hand gearing turbines in actual designs, especially in those concepts using DFIG with less installed power for the converter parts (appr. 50–70% savings compared to a full converter design e.g. for PMSG application) show slightly higher efficiency values for the whole conversion of mechanical into electrical energy (Generator + Converter + Grid connection) in their optimal operating points. Consequently a clear statement concerning the overall efficiency of the different wind turbine drive train concepts cannot be made easily. At last, it should be the annual yield for a given wind distribution at the site instead of the efficiency at the nominal operating point that used as a benchmark. Furthermore, for a comparative study of different concepts all system inherent ancillary units should be taken into account.

Weight and dimensions. Onshore transportation has its constraints. For example motorway bridges in Germany have a height of four meters. Therefore the weight and size of turbines built onshore is an important factor. The weight and size issue connected with various turbine concepts has been discussed a lot in the past. However, it can be stated, that the modern DD turbine developments (e.g, by Siemens) are very close to the latest benchmark geared turbines (e.g. Vestas V90-3.0) in respect to their specific nacelle weight.

Grid Compatibility. One aspect gaining importance with the increasing utilization of wind energy is the "quality" of the power fed into the grid and the wind turbines reaction to grid events.

Turbines using full converters have better capabilities in handling grid events than DFIG turbines intrinsically. However, the power delivered by the geared DFIG solution is of good quality, even more sophisticated control effort and hardware protection systems are necessary to comply with most of the to date grid codes. The biggest limitations with DFIG technology reveal by the lack of a complete decoupling between the mechanical and electrical system performance.

Conclusion (drive train trends 2015)

The conclusion, due to the great differences between on- and offshore business, can't be uniform, but some trends become quite evident.

Onshore. The onshore wind energy business can be regarded as a relatively mature business. Components applied in medium sized onshore wind turbines, i.e. 1 MW – 2.5 MW are de facto standardized; the turbine production has turned into mass production with moving production lines already used by several manufacturers. The cost-sensitivity of onshore turbines will grow continuously. For the near future IWES expect, the average size of onshore turbines will be limited to approx. 3 MW.

The dominating concept for onshore wind turbines in the past decade, despite the above mentioned drawbacks, was the gearing DFIG design. But PMSG solutions have some advantages not to be neglected. The main advantages are the inherent slightly greater efficiency of the generator and their better grid compatibility. Obviously, DD turbines have a greater efficiency within the mechanical drive train than gearing concepts. The advantages of gearing PMSG over DD PMSG turbines are the lower demand on permanent magnet material as well as their 2–3% higher generator efficiency. At the moment the investment costs for PMSG systems, especially for DD concepts, are higher than for DFIG systems. Even though PMSG machines will become cheaper in the future due to increasing production numbers and a higher automation level, these effects will probably not outweigh the cost advantage of DFIG systems.

This leads to the assumption that different turbine concepts might be interesting for different markets due to different countries rely on different incentive mechanisms to foster the use of wind energy.

Offshore. The requirements for offshore application differ from the requirements for onshore turbines due to the different cost structure. Costs for service and maintenance are significantly higher than onshore. Failures can lead to extensive downtimes and thereafter cause high production losses. Consequently high reliability and sophisticated service concepts are inevitable.

Due to this fact DD PMG turbines seem to have at least a psychological advantage, but still holding only a short track record. Gearbox failures seem to be still an issue and unreliable electrical systems could become a massive problem for offshore applications. Most of the recently developed and announced offshore wind turbines, for example from Siemens, XEMC Darwind, Nordex, Alstom, are DD PMSG turbines. Some players like Sinovel, Repower and Bard favor geared concepts with DFIGs.

Other big players like Vestas and Gamesa have developed or are currently developing geared offshore turbines with a medium speed PMSG. Nonetheless a current trend toward DD PMSG for offshore turbines becomes apparent. At least in medium term the market share of gearless turbines will exceed that of those with gearing drive-train concepts.

Finally trial for a technical foresight (>2020) on offshore drive train applications

- For weight limiting of the DD generators despite of turbines power output up to 10 MW, the currently force densities within PM-Generators of approximately 60–70 kN/m² will increased to 90–100 kN/m². This will be solved by better cooling and rotor designs with magnetic flux concentration. In contrast the energy density and remanence field strengths of the used permanent magnetic material will increase only modestly (< 10%). Driven by serial production cost reduction, tooth-coil-winding stator designs will be featured additionally to the classical distributed stator winding.

- Due to the continue of rather high prices for high performance PM-material new 4–6 MW turbines with electrically excited DD generators will enter the offshore market. The design lowers the risk for unexpected production costs and avoids potential bottlenecks for PM-material. The systemic efficiency disadvantage relative to PM generators will be almost leveled by intelligent mechanical designs with a small, stabilized air gap in the range of 3–4 mm. The advantage of the adjustable excitation will be actively used to maximize efficiency at partial load.

- For some turbines featuring medium-speed generators also EESG and DFIG designs beside the PMSG will be used. Additionally first innovative hybrid designs for generators, with electrical and magnetic excitation as well as featuring reluctance effects, will appear within prototypes. These will combine the advantages of high power density and the low-loss control of the excitation field together.

- Transverse flux and HTS – generator designs have no relevance in the market for wind turbines until 2050.

- The drive train designs will evolve towards the highest integration and simplicity. The current trend towards ever larger single bearings will be replaced by a main support design with smaller bearings and a well defined load sharing. The figure 3 exemplary shows the concept of an innovative DD hub generator design with dual bearing support and with the main goal of minimizing manufacturing and maintenance costs as well as the overall nacelle weight. (refer to figure 3 DD offshore hub generator design of the FGWE/ Saarland and IWES)

Figure 3: Ultra high integrated hub-generator DD design

Fraunhofer Institute for
Wind Energy and Energy System Technology IWES

Fraunhofer IWES | Kassel

Königstor 59

34119 Kassel / Germany

Phone: +49 561 7294-0

Fax: +49 561 7294-100

Fraunhofer IWES | Bremerhaven

Am Seedeich 45

27572 Bremerhaven / Germany

Phone: +49 471 902629-0

Fax: +49 471 902629-19

info@iwes.fraunhofer.de

www.iwes.fraunhofer.de