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Some Investigations on Recent Advances in Wind Energy Conversion Systems

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Abstract. Wind energy one of the world's fastest growing energy technologies. It is estimated that 16% of the world's electricity will be harnessed from wind power by 2020. Efficient and stable utilization of wind energy has been an important problem. The present work is a comprehensive report on various topologies and generators used in WECS aimed at drawing comparison between the various options available based on application.

Keywords: WTG (Wind Turbine Generator), Comparison, PSFC (Partial Scale Frequency Converter), FSFC(Full Scale Frequency Converter).

1. Introduction

The wind power sector is poised for a tremendous growth in terms of total installed capacity. The total installed capacity has registered a growth BY 20 times from 2001 to 2010 [1]. The generation capacity increased from 26000 MW in 2001 to 507000 MW in 2010 WECS can operate in conjunction with grid or in isolation, based on this they can be classified as grid connected or autonomous/standalone systems. There are two operating modes of wind turbine generating systems, the fixed speed operating mode and the variable speed operating mode [2].

FSWT(Fixed speed wind turbine) including SCIG (Squirrel-Cage Induction Generator), led the market until 2003 when DFIG (Doubly Fed Induction Generator), which is the main concept of VSWT with PSFC, overtook and has been the leading WTG concept with 85% of the market share reported in 2008 [3]. For VSWT with FSFC, WRSG (Wound Rotor Synchronous Generator) has been the main concept; however PMSG (Permanent Magnet Synchronous Generator) has been drawing more attention and increasing its market share in the past recent years due to the benefits of PMSG and drawbacks of WRSG [7]. Since there is much literature available on these WTG concepts in the market .

In order to extract maximum power the turbine rotor speed should be changed in proportion with the wind speed. This requires variable speed operation. Most modern WTGs are designed for variable speed operation[2]. Compared with fixed speed the variable speed operation offers distinct advantages like increased efficiency, reduced mechanical stresses and audible noise at low wind speed. The earlier versions used the Squirrel cage induction generator and the multistage gearbox directly connected to the grid or load as in the case of standalone operation. Since 1990s most manufacturers have switched to variable speed options to enable a more flexible match considering power quality, efficiency, energy yield and audible noise. Variable speed wind turbines are further classified as geared drive system and direct drive systems Wind generators. The geared drive system comprises of a multistage gear box and DFIG (Doubly Fed Induction Generator) and a partial scale converter. The gearbox suffers from faults and requires regular maintenance. The direct drive systems on the other hand connect the low-speed high- torque generators to the wind turbine directly and a full-scale converter is used for grid connection. As a high reliability maintenance free solution, direct drive is a promising in wind power generation especially for off-share application. The common generators used in this category are PMSG (Permanent Magnet Synchronous Generator) and EESG (Electrically Excited Synchronous Generator). With significant growth of wind turbine installed capacity and rapid development of wind energy technologies, various wind turbine concepts have been developed. The development of modern wind energy conversion technology has been going on since 1970s, and the rapid development has been surged from 1990s. During these years, various wind energy conversion concepts have been proposed and developed; meanwhile, a series of wind driven systems for different purpose have been built.

1.1. Geared Drive DFIG

DFIG uses a multistage gearbox to connect the low speed wind turbine to the high speed wound rotor induction generator (WRIG) to achieve variable speed generating with partial-scale converter to rotor winding., the rotor is connected through a power converter while the stator connects the grid directly. The rating of the power converters is greatly and hence is a economical proposition , this concept is attractive and popular in the market. Many manufacturers, such as Vestas, Gamesa, GE and Repower, have provided the wind turbine system with this concept. Flexible control active and reactive power, reactive power compensation can be achieved. The capacity of required power converters is small. DFIG still controls a significant share of the worlds wind market.

Disadvantages:

- The need for gear box and high-speed transmission, increasing cost and reducing the transmission efficiency, but also an increase in system maintenance.
- In most cases, there is need for water cooling system increases system maintenance.
- Cut-in wind speed is larger than that of PMSG.
- Less compact than PMSG.

1.2. The Direct-Drive EESG

The electrically excited synchronous generator is the regular alternator equipped with field winding which is excited by a DC source. Hence it requires additional converter for exciting the rotor of EESG, In 1992 wind pioneer Enercon of Germany introduced a 500 kW variable speed, direct drive system (no gearbox) EESG as a distinct alternative wind technology solution. The company dominates the direct drive segment to this day with an evolutionary range of successor models currently with a 30 kW – 7.5 MW ranges of power ratings and an operational track record exceeding 15,500 wind turbines.

Even though widely accepted as a mature wind technology, direct drive's global market share has never exceeded roughly 10%–15%, but the number of new entrants is growing rapidly. Mtorres of Spain also chose in-house developed and manufactured generators with electrical field excitation. The advantage, however, is that the excitation can be varied and hence the output voltage of the wind-driven EESG can be controlled in terms of amplitude and frequency due to fluctuating wind this problem is overcome. Moreover, Permanent magnets are not required reducing the cost of the system drastically. The disadvantage of the direct-drive EESG system can be summarized as follows [8]:

- In order to arrange space for excitation windings and pole shoes, the pole pitch has to be large enough for the specific large diameter design, so a larger number of parts and windings make it a heavy weight and expensive solution.
- It is necessary to excite the rotor windings with DC source, using slip rings and brushes, or
- Brushless exciter with a rotating rectifier
- Field losses are inevitable.

1.3. The Direct-Drive PMSG Generating System

The application of permanent magnet generators (PMG's) to wind turbines is a relatively new, but growing, trend in the energy industry. According to specialist providers, they offer advantages in key areas such as efficiency and design flexibility and PMGs are now being used by leading manufacturers in the industry. Among other powerful newcomers in the direct drive segment are GE Energy and Siemens Wind

Power. These two, and almost all other new international entrants, apply PMGs in their designs. Permanent-magnet machines are characterized as having large air gaps, which reduce flux linkage even in machines with multi-magnetic poles. As a result, low-rotational-speed generators can be manufactured with relatively small sizes with respect to its power rating. Moreover, the gearbox can be omitted due to low rotational Speed in the PMSG wind generation system, thus resulting in low cost. To increase the efficiency, to reduce the weight of the active parts, and to keep the end winding losses small, direct-drive generators are usually designed with a large diameter and small pole pitch. Compared with the traditional electrically excited synchronous generator, the requirement of a larger pole number can be met with permanent magnets which allow small pole pitch [4]-[5]. In addition, permanents magnet synchronous generators (PMSGs) have the high torque density and the absence of excitation losses. Furthermore, the performance of PM's is improving and the cost of PM is decreasing in recent years, the direct-drive permanent magnet wind generators have recently received increasing attention, especially for offshore wind energy[6]-[10]. Thanks to the application of high energy PM materials such as neodymium-iron-boron, the volume and cost of this type of machine can be dramatically reduced. The distinct advantages offered by PMSGs are simple rotor design without field winding. The absence of field windings also results in higher efficiency since heat dissipation is avoided. PMSG is gaining a lot of attention for WECS due to compact size, high reliability higher power to weight ratio, reduced losses and robustness. The disadvantages associated with PMSG are

- High cost of permanent magnets makes it an expensive option.
- Manufacturing, assembling and maintenance are difficult.
- Demagnetization of PM material in harsh Environment. Also, operating temperatures inside the generator rotor must be limited to a maximum of 80°C in order to retain magnetic properties

1.4. The Hybrid Drive PMSG

A mix between fast-speed geared and direct drive wind systems is often referred to as a 'Hybrid' solution. This third, medium speed segment occupies only a minority market position. Areva Multibrid of Germany/France and WinWinD of Finland today manufacture these commercial hybrid-type turbines under aerodyn license, while Gamesa of Spain is currently testing a different 4.5 MW medium-speed prototype. Like some of its main competitors (GE and Vestas), Gamesa made a switch away from a doubly-fed generator to a permanent magnet (PM)-type synchronous generator. Being a full converter technology it also offers greater project developer application flexibility at combined 50 Hz and 60 Hz wind markets.

2. Common Topologies in Use

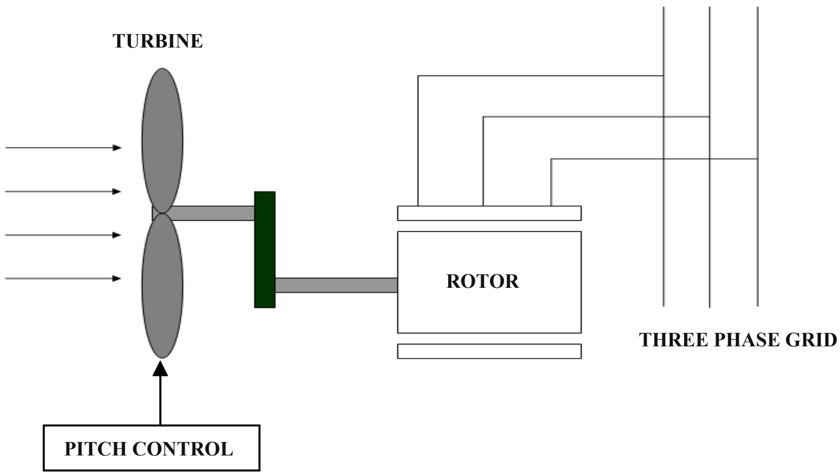

Fig.1 (Pitch Controlled Induction Generator)

(Fig. 1) presents the structure of the wind turbine and the induction generator. The stator winding of the wind generator is connected directly to the grid and the rotor is driven by the wind turbine. The wind energy is converted by the wind turbine into electrical power with the help of the induction generator and is transmitted to the grid through the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. The reactive power absorbed by the induction generator is provided by the grid or by some devices like capacitor banks.

2.1. Common Topologies in Use in a PMSG based WECS

The energy extracted from wind is transferred from the generator to the dc-link by the generator-side rectifier and then to the utility by the grid-side inverter. In this system, the dc-link capacitor provides decoupling between the generator-side and the grid-side converters, and thereby offers separate control flexibilities for the two converters.

Variable speed wind energy conversion system (WECS) is used to generate electrical energy. A diode-bridge rectifier (Fig.2) is used as an AC-DC converter and then chopper based generator speed control is implemented in order to achieve maximum power at all available wind speeds. It requires a DC to DC boost converter increasing the cost .

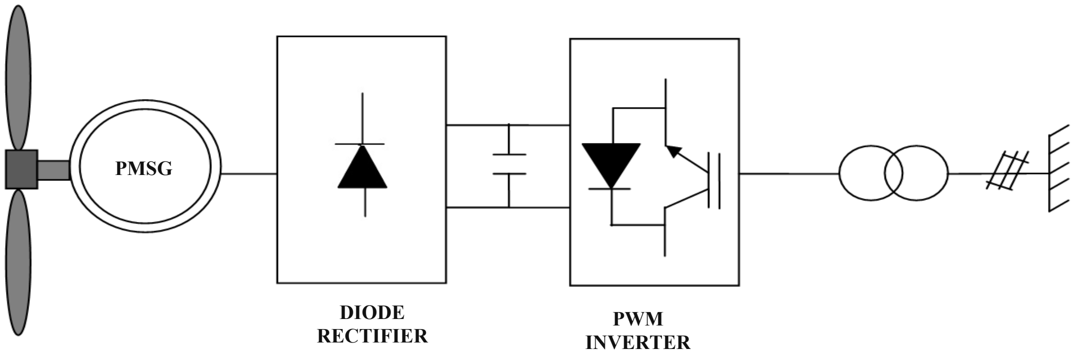

Fig.2 (Diode rectifier based PMSG)

Another prevalent topology employs an active rectifier (PWM converter)(fig 3) that converts AC voltages at the generator terminals into DC voltage. Grid side inverter transforms the DC link voltage into AC voltage with constant frequency. Therefore the generator and the grid are decoupled. Generator side converter enables speed controlling the electromechanical torque of the generator. Stator current can be controlled instantaneously so the dynamic responses are fast compared to the topology employing diode rectifier. Active converter control is implemented both on the grid side and the generator side. The solution of using full power rating PWM rectifier(fig,3) is obviously more expensive and complex but most modern manufacturers like Enercon incorporate fully controlled converters in their design[10][11].

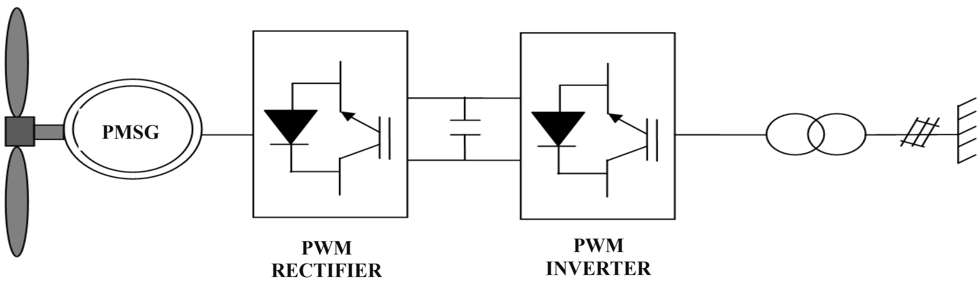

Fig.3 (PMSG Using PWM Rectifier)

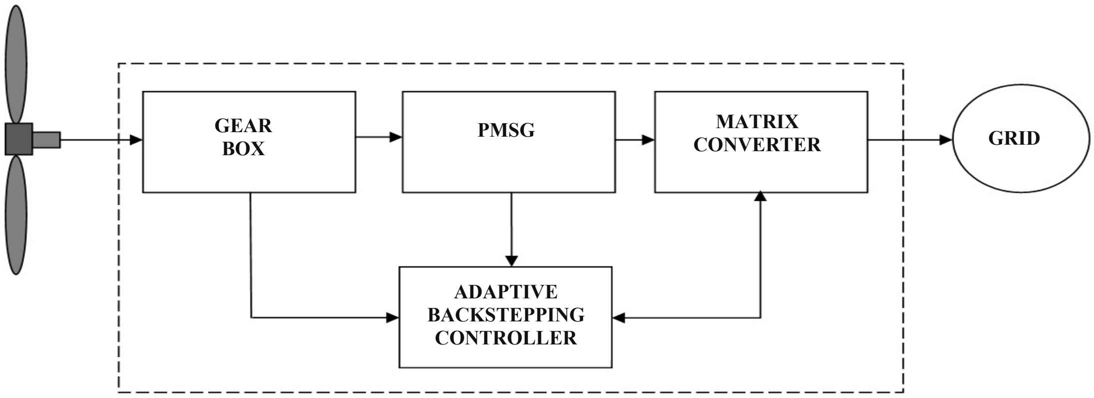

Fig.4 (Matrix Converter)

The matrix converter (fig.4) realizes a direct AC/AC conversion, and it is a good candidate for this application. This converter can control the magnitude, frequency and phase angle of the output voltage as well as the input power factor [13].

3. Comparison between the Various Converter Options for PMSG based WECS

Table 1

CONVERTER	MERITS	DEMERITS
Diode Rectifier and PWM Inverter	• Economical alternative • Ease of control and simple circuit configuration • Extensive available literature	• Voltage control across the inverter cannot be realized. • The DC link capacitor is bulky and has a short life time.
Back to back PWM converters with DC link	• Voltage control across the DC link is possible. • More flexible control is possible. • Decoupling between the generator and the grid.	• Expensive option • Requires sophisticated control, large physical dimensions, high weight, and excessive volume. • Low reliability of the DC link capacitor. • The poor line power factor and harmonic distortion in line and machine currents.
Matrix Converter	• Elimination of DC link capacitor increases system reliability. • More compact and light weight compared to other options.	• Low voltage gain • Requires Bidirectional Switches. • Low ride through capabilities.

4. Conclusion

By comparing and contrasting the various generator options it is found that the direct drive PMSGs rule the market in WECS. Given their proven advantage over geared drive segment future research would concentrate on reducing the size of the WTG, reducing the cost of converters and improving the output voltage waveform hence power quality in order to comply with stricter and more stringent grid codes. Moreover given the design specifications required by offshore wind farm it can be said that PMSG emerges as a best possible solution. Other technological innovations which focus on the design from electrical point of view in future offshore turbine includes multi-pole permanent magnet generator and high voltage output converters eliminating the need for turbine transformers.

5. References

[1] World Wind Energy Council, ‘Global wind 2008 report’.

[2] World Wind EnergyAssociation, ‘World wind energy report’.

[3] N.A. Schinas, N. A. Vovos, ‘An Autonomous System Supplied Only by a Pitch-Controlled Variable-Speed Wind Turbine’, *IEEE Trans.Energy Convers,*Vol,. 22, No. 2, 2007

[4] Mukhtiar Singh and Ambrish Chandra, ‘Control of PMSG based Variable Speed Wind Turbine Battery Hybrid system in an Isolated Network,*’IEEE Trans. Energy Convers*., vol. 16, no. 2, pp. 134-139.

[5] R. Mittal, Sandhu and D. K Jain, ‘Isolated Variable Speed Driven PMSG for WECS’ *Intl. Jounal of Eng.andTech.*, vol-1, No.3,2009.

[6] M.E .Haque, K.M. Muttaqi and M.Nagnevitsky,’ Control of Variable Speed Wind Turbine with a PMSG’, *‘Power and Energy Soc.meeting’,2008.*

[7] T. Senjyu,Y. Kikunaga, A.Yona, H. sekiene and Ahmed Yusuf Saber ‘Coordinate Control of Wind Turbine and Battery in Wind Power Generator System’. *‘Power and Energy Soc.meeting’, 2008.*

[8] Cheng K.W.E., Lin J. K., Bao Y.J., Xue X.D. ‘Review of Wind Generating system’ , ‘*8th international conference Control and Management (APSCOM 2009)’.*

[9] Li and Z. Chen, “Overview of Different Wind Generator Systems and Their Comparisons,” *Renewable PowerGeneration*, Vol. 2, No. 2, 2008, pp. 123-138.

[10] F. Valenciaga and P. F. Puleston, ‘High-Order Sliding Control for a Wind Energy Conversion System Based on a Permanent MagnetSynchronous Generator’, *IEEE Trans.Energy Convers,* Vol 23, No.3.

[11] Vinod Kumar, R. R. Joshi, and R. C. Bansal,Optimal Control of Matrix-Converter-Based WECS for Performance Enhancement andEfficiency Optimization ‘*IEEE Trans.Energy Convers., Vol. 24, NO. 1, 2009’.*

[12] V.Sheeja, P.Jayaprakash, Bhim Singh and R.Uma,“Stand-alone windpower generating system employing permanent magnet synchronous generator”, *Proc. of IEEE conference*, ICSET- 2008. pp. 616 – 621.

[13] ‘ Recent Trends in Offshore Wind Energy’, Wind Energy THE FACTS.