Review on Wind Energy Conversion System Topologies for different Wind Turbines-Generators

***Krishna S. Patel*[1], *Vijay H. Makwana*[2]**

[1]Ph.D. Research Scholar, Electrical Department, Gujarat Technological University, India.

[2] Electrical Engineering, G H Patel College of Engineering & Technology, Gujarat Technological University, India.

Abstract

Governmental and organizational support on wind energy sources has led to a fast growth of wind power generation in the previous few years for an enhancement of wind energy conversion technology. The constant rise of the wind power diffusion level brings a result that wind power generation progressively becomes an important part of power generation in the grid, which takes in the study on wind turbines with different generators to a growth the maximum power capture, minimize the cost. Doubly Fed Induction Generators (DFIG) used for geared operation in wind energy conversion system for variable speeds while Squirrel Cage Induction generators (SCIG) used for both fixed speed and variable speed geared operation for the onshore application. But Permanent Magnet Synchronous generators (PMSG) operate gearless and used for the offshore application. This paper outlines the different types of wind turbine generators used in Wind Energy Conversion Systems (WECS).

Keywords:*Wind Power Generation, Wind Turbines, DFIG, SCIG, PMSG, Variable Speed*.

INTRODUCTION

Renewable energy sources have been appealing excessive consideration because of limited reserves, cost increases and adverse environmental impact of fossil fuels. Among all renewable sources, wind energy is one of the highest rising renewable energy sources [1].

Wind energy has been used for pumping water, milling grains, and sailing the seas for hundreds of years. Windmills used to generate electricity with the growth of 12 kW DC windmill generator in the nineteenth century [2]. Since the 1980s, wind energy has become satisfactorily grown up to produce electricity efficiently and reliably. A range of wind power technologies has been developed over the past two eras, which have enhanced the conversion efficiency and reduced the costs of wind energy production. Today, most of the wind turbines are onshore or land-based. The size of wind turbines has improved from a few kilowatts to several megawatts to produce additional energy and to decrease their impact on land use and site. A lot of wind turbines will be moving towards offshore installation in the near future where the winds are stronger and hence the need of wind turbines of a higher rating.

Last Year, India has a registered fourth biggest market worldwide, both in terms of cumulative capacity and annually added extras. As of December 2016, new wind power 3612 MW was added to make the sum of 28700 MW. Total wind power capacity increased till the March 2017 up to 31177 MW [3]. The total installed capacity of renewable energy cross over the 50 GW in the December 2016. Wind power accounts 14% of total installed power capacity along with all renewable energy sources of India [4]. In 2016, total wind power installations accounted 6.6% of the global market in India. Total domestic installed capacity accounted 9.1% share for wind power capacity. India has set a fixed aim to produce 60 GW of electricity by 2022 from wind power in February 2015 [5].

Figure 1represents India's cumulative installed wind power capacity during 2005 and 2016 [3] [6], and Table Idisplays the state-wise total wind power cumulative installed capacity in India [7].

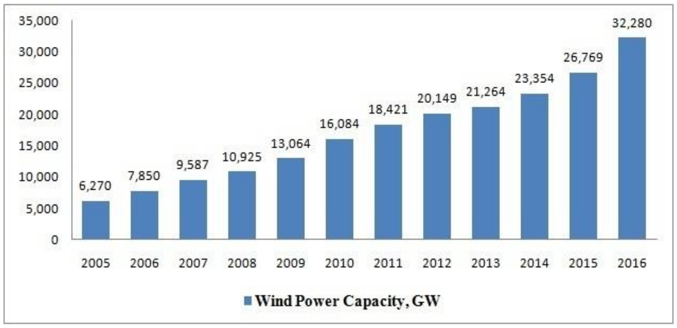

Fig. 1: *India's Total Cumulative Installed Wind Power Capacity During 2005-2016 [3] [6].*

The paper is divided into the following Sections. Section II presents the wind turbine and its conversion equations with simulation results. In Section III the three commonly uses different types of wind turbine generators; Doubly Fed Induction Generators (DFIG), Squirrel Cage Induction generators (SCIG) and Permanent Magnet Synchronous generators (PMSG) discussed. Section IV will underline the wind turbine generator trends and comparison. Section V concludes the most appropriate choice amongst all renewable energy sources and wind turbine generators according to the demand.

Table 1:*State-wise Cumulative Wind Power Installed Capacity in India as of October 2017 [7].*

State wise total installed capacity in MW	
Tamil Nadu	7694.30
Maharashtra	4666.10
Gujarat	4441.50
Rajasthan	4216.60
Karnataka	3154.20
Madhya Pradesh	2288.60
Andhra Pradesh	2092.50
Telangana	98.7
Kerala	43.5
Other	4.3
Total	28,700.40

WIND TURBINE CONFIGURATION AND TOPOLOGIES

The wind turbine is one of the most significant elements in wind energy conversion systems. There were two types of wind turbine used, fixed speed and the variable speed wind turbine [8]. At the end of 1990, the fixed speed wind turbine was more in use with the power rating less than 1 kW and mostly it was SCIG (Squirrel cage Induction Generator) type. Nowadays, a variable speed wind turbine is used to achieve maximum aerodynamic efficiency over a wide range of wind speeds. Today's horizontal axis wind turbines lead wind marketplace, mainly in huge commercial wind farm [9].

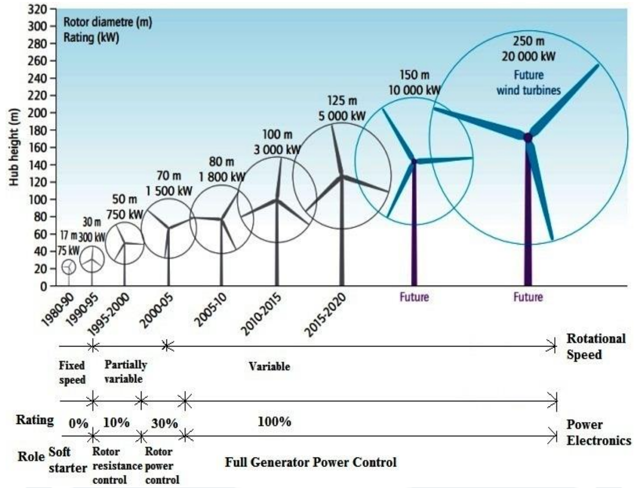

Fig. 2: *Wind Turbine Development Between 1980 and 2020 [10].*

The emerging sizes of wind turbines are illustrated in Fig. 2, the individual size and the power rating of wind turbines have been increased significantly. This figure also shows the functional role and development of power electronics with its rating coverage. In 2017, an average rating of wind turbines 14 GW for offshore and 52 GW of onshore installed worldwide and now 5 MW with a diameter of 125 m wind turbines are available on the market [10]. Today's most of the wind turbine manufacturer issue products in the range of 3-5MW power. This trend is mainly inspired to decrease the price of energy produced per kilowatt hour.

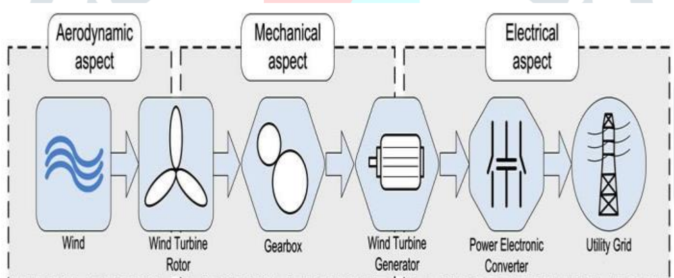

Fig. 3: Wind Energy Conversion System Layout

A wind turbine is composed of numerous parts to attain kinetic energy to electrical energy conversion as seen in above Fig 3. The output power of the wind turbine is given by the following equations [8]:

$$P_m = C_P(\lambda,\beta).P_W \quad (1)$$

$$P_W = \frac{1}{2}.\pi.R^2.V^3.\rho_{AIR} \quad (2)$$

Where P_W and P_m represent the wind power and the mechanical power of the wind respectively, C_P is the performance coefficient of the turbine, V represents the wind speed, R is the rotor radius of the blade and ρ_{AIR} is the air density.

The performance coefficient $C_P(\lambda,\beta)$ is in function of λ which is the Tip speed ratio (TSR) and β is the pitch angle of the blade in degrees. Cp is at its maximum value 0.48 when β=0 and the tip speed ratio (TSR) λ=8.1 as shown in below Fig.4.

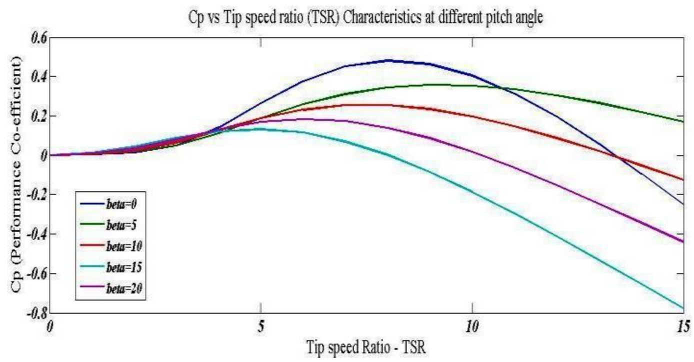

Fig. 4:*PerformancecoefficientC$_P$ as a function of tip speed ratio (TSR) λ with different pitch angle*

The equation of $C_P(\lambda,\beta)$ based on the modeling turbine characteristics is [11],

$$C_P(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\left(\frac{-C_5}{\lambda_i}\right)} + C_6\lambda \quad (3)$$

With,
$$\lambda_i = \frac{1}{\left(\left(\frac{1}{\lambda} + 0.08\beta\right) - \left(\frac{0.035}{\beta^3} + 1\right)\right)} \quad (4)$$

Where the coefficients C_1 to C_6 are: C_1 = 0.5176, C_2 = 116, C_3= 0.56, C_4= 5, C_5 = 21and C_6= 0.0068. For blade pitch angle β = 0 degrees, the P_m mechanical power as a role of generator speed for different wind speeds is shown in the below Fig.5 with base rotational speed = 1.2 pu, K_P maximum power of base wind speed = 0.73 pu, and base wind speeds = 12 m/s default parameters.

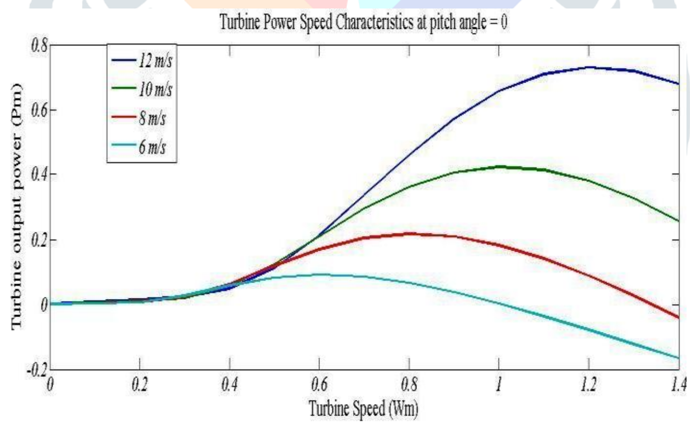

Fig.5: *Power versus Speed characteristics*.

GENERATORS TYPES

Different types of wind turbine-generator configurations that fall under the induction generator and the synchronous generator categories with different geared and direct wind turbine topologies are shown in the Fig.6 [13].

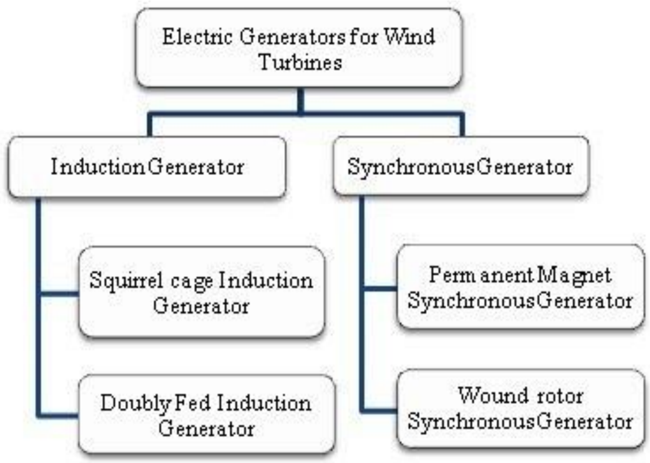

Fig.6: *Different Electric Generators used for the Large Wind Turbines [15]*

In this paper, three most frequently used wind turbine generators discussed.

A. SCIG (Squirrel cage Induction Generator)

SCIG is generally considered as fixed-speed. It is especially robust and small maintenance is needed; only bearing lubrication because the rotor is composed of metallic bars that are very effective in resistive vibratory motion and dirt [16]. Rotor speed variations of SCIG are very small. It can vary by changing rotor slip only. However, SCIG is still used for variable-speed wind energy generation with a full-scale power electronic converter [17]. The SCIG could operate for minimum ranges of wind speeds through a gearbox as shown in Fig.7. To extraction of more power from the wind is complex because of the generator overloading issue. Hence the pitch angle regulation is required to achieve an optimal power extraction [18, 19].

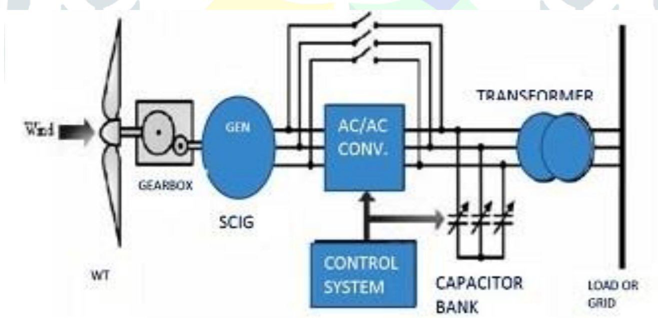

Fig. 7: *Schematic of a SCIG.*

1) Merits of SCIG:
- Simple & robust construction [16].
- Metallic rotor bars are well resistant to vibrations and dirt.
- Completely separated from the grid for the variable speed operation.

2) Demerits of SCIG:
- Cannot be operated gear less.
- Higher mechanical stress & lower efficiency

B. DFIG (Doubly Fed Induction Generator)

DFIGs are most commonly used generators in the wind industry for the onshore application. In DFIG the stator terminals are directly connected to the grid and the rotor terminal connected across a reduced capacity power converter with the rotor side converter and grid side converter [21]. A gearbox is used to couple the rotor of the generator with the wind turbine. These converters usually are voltage source type back-to-back converter and VFC-variable frequency converter type. They are built up of two IGBT converters and decouples the electrical grid frequency and the mechanical rotor frequency, which in-turn enables variable speed operation [22, 23].
A schematic of a DFIG is shown in Fig.8. The rotor voltage is applied from the back to back voltage source converters. The Rotor Side Converter (RSC) controlling the harmonics and controls reactive power and active power, while the Grid Side Converter (GSC) controls the power factor and keep the DC link voltage constant [25].

1) Merits of DFIG:
- Rugged, brush less and High efficient,
- Its converter rating is 25%-30% of the nominal power rating of generator only,
- Converter compensates the reactive power and make sure smooth grid integration [24],
- It can run about 30% of synchronous speed; hence it has a wide range of speeds [25].

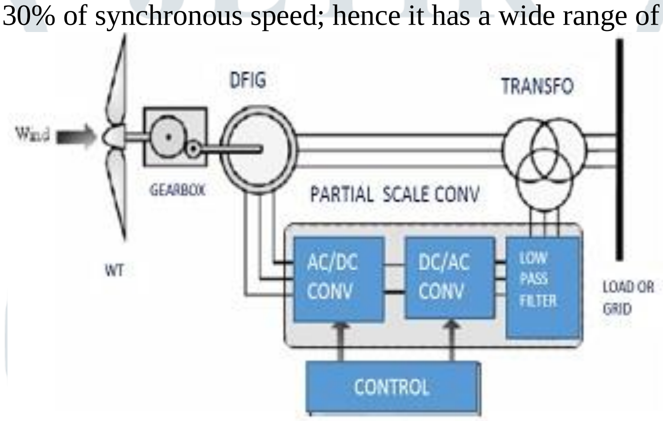

Fig.8: *Schematic of a DFIG*

2) Demerits of DFIG:
- Medium reliability,
- Reduced long life due to bearings and gear faults,
- Difficulties associated with the grid fault ride-through, suffer a lot from large peak currents during grid fault [26].

C.PMSG (Permanent Magnet Synchronous Generator)

PMSG does not need a gearbox as it is direct driven type generator. In DFIG and SCIG to couple the slow rotating turbine rotor blade to a generator, medium-speed single-stage gearboxes (1:10) or high-speed multiple stage gearboxes (1:100) are required [28,29,30].
Onshore based wind turbines have a serious problem of decreased reliability and long life so this becomes a vital issue to look into for offshore installations [31]. For mainly offshore installations, wind turbine manufacturing companies have started manufacturing PMSG [28]. A schematic of a PMSG is presented in Fig.9. This type of generator is mainly efficient with power losses of about 65% of DFIG.

1) Merits of PMSG:
- Improved reliability,
- Referable to the removal of Gearbox and bearings, longevity of PMSG increased compared to DFIG and SCIG which are the primary causes of faults in the generators [30]
- High efficiency,
- Less maintenance cost due to the elimination of gearbox.

2) Demerits of PMSG:
- High cost,
- Less maturity as it is the latest technology,
- The external diameter of the direct drive PMSG is nearly two times the size of gears drive SCIG,
- Enlarged weight and volume that can make serious proportions, particularly for wind turbines greater than 3MW [31].

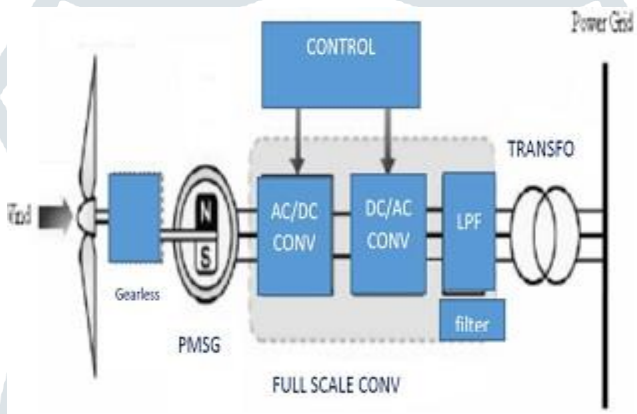

Fig.9: *Schematic of a PMSG*

POWER CONVERTER TOPOLOGIES:

Power Converters are widely used in wind energy conversion systems(WECS). According to the system power ratings and type of wind turbines, a variety of power converter configurations are available for the optimal control of wind energy systems [21].

Different power converter topologies are as follows:
1. AC voltage controllers (Soft starter),
2. DC/DC boost converters,
3. Two level voltage source converters,
4. Three-level neutral point clamped (NPC) converters,

In Fixed-speed, induction generator- based WECS, in which a soft starter is employed to reduce inrush current caused by electromagnetic transients that take place at the moment the generator is connected to the grid. The soft starter is essentially an AC voltage controller using SCR devices, whose output voltage is adjusted such that it increases slowly with time during the system start-up [21,24].
In variable-speed WECS using squirrel cage induction generators (SCIGs), doubly fed induction generators (DFIGs) or synchronous generators (SGs), where a back-to back converter configuration with two identical PWM converters is used. The converters can be either voltage source converters (VSCs) or current source converters (CSCs). Also a variable-speed wind energy system only for synchronous generators, where a low-cost diode rectifier with a DC/DC boost converter can be used instead of the PWM rectifier [25,36].

WIND TURBINE GENERATORS TREND AND COMPARISON

A market interest in SCIG has decreased and it was lost in 2003 when DFIG overtake the market [32]. With the introduction of the DFIG, uses of wound rotor induction generator (WRIG) have reduced after 1997 due to high power consumption. Since 2000 DFIG was the important concept with 84% share of the market [32, 33]. With a large amount of power capacity required, the robust and reliable generator like PMSG become more interesting for offshore wind turbines in the market. The higher cost of materials used in PMSG compared to DFIG so higher efficiency achieved due to the use of high conducting core material. However, PMSG has the most competent option in the market among all current generators due to their high reliability and low maintenance cost [36].

Iron magnets have been mostly used in Permanent Magnet Synchronous generator, which is made of Alnico material that is more costly than the steel parts of DFIG. Also, PMSG has higher reliability because they have less moving parts. The biggest difficulty for PMSG is the difference in cost compared to DFIG [35]. PMSG is the mainly utilized for above 3MW large capacity power generation of offshore and onshore wind turbine application. The maintenance cost of generators is too high for high rated power levels, which requires costly equipment and extra time for offshore wind turbines compared to onshore wind turbines [34, 35]. The higher preliminary cost of PMSG compared to DFIG is frequently acceptable substitution for the increased efficiency and reliability of PMSG under these two scenarios.

Table II shows the comparison of three most regularly used wind turbine generators for wind energy conversion systems with various suitable parameters [18, 36]. The necessities for capturing more wind power and having larger capacity wind turbines with less yearly mean wind speeds in the regions, PMSG concepts more remarkable with the grid connection requirements [30, 34]. The direct drive PMSG system has a usual efficiency nearly 1.6% larger than the SCIG fixed speed system for the rated power 3 MW and it can create additional energy as a minimum 10–15% higher than the fixed single speed model due to the variable speed process [37].

Most of the manufactures geared drive wind turbine concepts in recent market penetration. The wind market is predominated by DFIG with a various step gearbox and still, the most commonly used generators is the induction generators such as DFIG, SCIG, and WRIG (Wound Rotor). Manufacturers like, Vestas, Suzlon, Gamesa, GE wind and Nordex manufacture multi stage geared DFIG wind turbine. Companies like Repower and Enercon manufacture direct drive wind turbines such as PMSG [34, 38]. Table III shows the comparisons of all Renewable energy Sources in India as of December 2017 [39-43].

Table - II Summary of Wind Turbine Generators [18, 36]

Comparisons of Different Wind Turbine Generators				
Wind turbine type	**Fixed speed**	**Variable speed**		
Generator	**SCIG**	**DFIG**	**SCIG**	**PMSG**
Converter capacity	**Not applicable**	**Reduced**	**Full**	**Full**
Power converter topologies	No	2 levels VSC	2 and 3 levels VSC, PWM CSC	2 and 3 levels VSC, PWM CSC, Boost + diode rectifier
Gearbox	Stall	Yes	Yes	Optional
Speed range	<1%	± 30%	Full	Full
Aerodynamic power control	Active stall, pitch	Pitch	Pitch	Pitch
Soft starter	Yes	No	No	No
Active power control and MPPT	Not applicable	Yes	Yes	Yes
External reactive power compensation	Needed	No	No	No
Grid compatibility	Worst	Best	Better	Better

Table – III Comparisons of all Renewable energy Sources in India as of the end of 2017 [39-43].

<table>
<tr><td colspan="5">Comparisons of all Renewable energy Sources in India – 2017</td></tr>
<tr><th>Source</th><th>Total Installed Capacity (MW)</th><th>Tariff/ Cost (Rs/kWh)</th><th>Installed grid interactive Renewable power capacity</th><th>2022 Target (MW)</th></tr>
<tr><td>Wind power</td><td>32715.37</td><td>Rs. 2.83</td><td>56.80%</td><td>60000.00</td></tr>
<tr><td>Solar power - Ground Mounted</td><td>14751.07</td><td>Rs. 11.58</td><td rowspan="2">18.60%</td><td rowspan="2">100000.00</td></tr>
<tr><td>Solar power - Rooftop</td><td>823.64</td><td>Rs. 3.86</td></tr>
<tr><td>Biomass power</td><td rowspan="2">8181.70</td><td rowspan="2">Rs. 6.43</td><td rowspan="2">15.90%</td><td rowspan="3">10000.00</td></tr>
<tr><td>(Biomass & Gasification and Biogases Cogeneration)</td></tr>
<tr><td>Waste-to-Power</td><td>114.08</td><td>Rs. 3.22</td><td>0.20%</td></tr>
<tr><td>Small Hydro power</td><td>4399.35</td><td>Rs. 3.86</td><td>8.50%</td><td>5000.00</td></tr>
<tr><td>TOTAL</td><td>60985.21</td><td></td><td></td><td>175000.00</td></tr>
</table>

CONCLUSION

This paper has reviewed the wind turbine configurations with their modeling equations and various characteristics. Also, different technologies for wind generators used in wind energy conversion systems discussed with their comparisons.

Looking at the data we have come to the conclusion that wind energy is far greater amongst all other renewable energy sources for several causes. The wind turbine has the maximum return on investment because it will produce additional green energy, more electricity and lead to greater autonomy from established conventional energy sources.

It is very clear that several stages geared drive DFIG with a biased scale IGBT based power converters are the recent market leaders with greater than 80%market share but DFIG suffers a lot from high peak currents at the time of grid related faults. While variable speed wind turbine SCIG full scale power converter completely disconnected from the grid may be more attractive and more efficient option with grid related fault but it is still geared operated. The main merit of the DFIG is that a 30% of the produced power is gone throughout the power converter as compared with other variable speed wind turbine like SCIG, PMSG which needed a full-scale power converter to operate.Therefore, the overall cost is reduced. PMSG has drawn more attention to increased large capacity wind turbines installation and their share of the market has been improved in current years because of PMSG has higher output power ratings and higher reliability.

REFERENCES

[1] Renewable Energy Policy Network for the 21st Century (REN21), Renewables Global Status Report 2009. Carlin PW, Laxson AS, Muljadi EB (2001).

[2] The history and state of the art of variable-speed wind turbine technology. National Renewable Energy Laboratory, NREL/TP-500-28607, Golden.

[3] Global Wind Energy Reports (2016) Global wind statistics 2016.Global Wind Energy Council (GWEC) India.

[4] "Physical Progress (Achievements)". Ministry of New and Renewable Energy, Govt. Of India. 31 July 2017. Retrieved 19 September 2016.

[5] "Executive Summary Power Sector February 2017" (pdf). Report. Central Electricity Authority, Ministry of Power, Govt. Of India. 28 February 2017. Retrieved 24 April 2017.

[6] India wind energy outlook 2016, Global Wind Energy Council (GWEC) India.

[7] "Power Sector Oct-2016"(pdf). Report. Government of India, Ministry of Power, Central Electricity Authority New Delhi, State wise installed capacity, 19 October 2016.

[8] E. Camm et al., ''Characteristics of wind turbine generators for wind power plants,'' in Proc. IEEE Power Energy Soc. (PES) Gen. Meet., Calgary, AB, Canada, Jul. 2009, pp. 1–5.

[9] Bin Wu, Yongqiang Lang, Navid Zargari, Samir Kouro,"Power conversion and control of wind energy systems", July 2011 Wiley-IEEE Press.

[10] Frede Blaabjerg; Ke Ma, "Wind Energy Systems", 2017 IEEE Journals & Magazines, 16 May 2017, pp: 2116 – 2131.

[11] Siegfried Heier, "Grid Integration of Wind Energy Conversion Systems," John Wiley & Sons Ltd, 1998, ISBN 0-471-97143-X.

[12] Haitham Abu-Rub, Mariusz Malinowski, Kamal Al-Haddad, "Power Electronics for Renewable Energy Systems, Transportation, and Industrial Applications", Wiley-IEEE Press, June 2014.

[13] H. Li, Z. Chen, "Overview of different wind generator systems and their comparisons", IET Renew. Power genre., 2008, Vol. 2, No. 2, pp. 123–138.

[14] S. Yasmeena, G. Tulasiram Das, "A Review of Technical Issues for Grid-Connected Renewable Energy Sources" International Journal of Energy and Power Engineering, Sep.2015, Vol. 4, No. 5-1, 2015, pp. 22-32.

[15] Z. Daneshi-Far, G. A. Capolino, H. Henao, "Review of Failures and Condition Monitoring in Wind Turbine Generators", XIX International Conference on Electrical Machines - ICEM 2010, Rome., pp. 1-6

[16] Akhmatov V, "Induction generators for wind power". Multi-Science, 2007, Brentwood.

[17] Sanjiba Kumar Bisoyi, R.K.Jarial, R.A.Gupta, "A Review Of The State Of The Art Of Generators And Power Electronics Converter Topologies For Wind Energy Conversion System", International Journal of Emerging Technology and Advanced Engineering Vol. 3, Special Issue 3: ICERTSD 2013, Feb 2013, pp. 283-291.

[18] Anissia Beainy, Chantal Maatouk, Nazih Moubayed, "Comparison of Different Types of Generator for Wind Energy Conversion System Topologies", IEEE Conference on Renewable Energies for Developing Countries (REDEC), 13-15 July 2016, pp:1 - 6.

[19] Li H, Chen Z , "Overview of different wind generator systems and their comparisons", Renew Power Genre, 2008, Vol- 2 (2), pp : 123–138.

[20] Varun Kumar, A.S. Pandey and S.K. Sinha, "Grid Integration and Power Quality Issues of Wind and Solar Energy System: A Review", 2016 IEEE International Conference on Emerging Trends in Electrical, Electronics and Sustainable Energy Systems (ICETEESES–16), pp: 71 –80.

[21] L. H. Hansen, L. Helle, F. Blaabjerg, E. Ritchie, S. Munk-Nielsen, H. Bindner, P. Srensen, and B. Bak-Jensen, "Conceptual survey of generators and power electronics for wind turbines," Risø Nat. Lab., Roskilde, Denmark, Tech. Rep. Riso-R1205 (EN), Dec. 2001

[22] F. Blaabjerg, Z. Chen, and S. Kjaer, ''Power electronics as an efficient interface in dispersed power generation systems,'' IEEE Trans. Power Electron., vol. 19, no. 5, Sep. 2004, pp. 1184–1194.

[23] F. Iov, R. Teodorescu, F. Blaabjerg, B. Andersen, J. Birk, and J. Miranda, "Grid code compliance of the grid side converter in wind turbine systems," in Proc. IEEE PESC, Jun. 18–22, 2006, pp. 1–7.

[24] L. Solero, "Power Electronic converters devoted to stand-alone wind energy generating systems", EPE Journal, Vol. 12, Nº 2, May 2002, pp. 43-48.

[25] Gonzalo Abad, Grzegorz Iwanski, and Jesus Lopez, "Doubly fed Induction Machine, Modeling, and control of wind energy generation", Wiley-IEEE Press, Sept. 2011.

[26]Preeti Chakrawarti1, Preeti Jain, "Complete Analysis of Doubly Fed Induction Generator Wind Turbine-Maximum Power Tracking Characteristics", International Journal of Electrical and ElectronicsResearch, March, 2015, Vol. 3, Issue 1, pp. 12-20.

[27]N. S. Patil, Y. N. Bhosle, "A Review on Wind Turbine Generator Topologies", International Conference on Power, Energy and Control (ICPEC), Feb. 2013, pp. 625-629.

[28]H. Polinder; F. F. A. van der Pijl; G. -J. de Vilder; P. J. Tavner ,"Comparison of direct drive and geared generator concepts for wind turbine" IEEE Trans Energy Conversion, 2006, Volume: 21, Issue: 3, pp. 725–733.

[29]Bang, D.-j., Under, H.P., Shrestha, G., Ferreira, J., "Promising direct drive generator system for large wind turbines", Wind Power to the Grid Seminar (EPE-WECS 2008), 2008.

[30] Dubois, M., "Optimized permanent magnet generator topologies for direct drive wind turbine", . PhD thesis, Delft University of Technology, Delft, The Netherlands, 2004.

[31]Semken RS, et al "Direct-drive permanent magnet generators for high-power wind turbines: benefits and limiting factors", Renew Power Generation IET 6(1) 2012.

[32] "Indian Wind Energy - Projects, Companies, Research, Data, Statistics - Energy Alternatives India"(pdf). Report. Indian Wind Energy Corporation, In Retrieved 2010-11-27.

[33]"All India Installed Capacity (In MW) Of Power Stations"(pdf). Report. Ministry of Power, Govt. Of India, 31 March 2017.

[34]Gupta A, Jain DK, Dahiya S, "Some investigations on recent advances in wind energy conversion systems". IPCSIT Press, 2012, Singapore.

[35]Chen Y, Pillay P, Khan A, "PM wind generator topologies". IEEE Transactions IND, 2005, Vol-41 (6), pp: 1619–1626

[36]Dubois MR, Polinder H, Ferreira JA, "Comparison of generator topologies for direct-drive wind turbines". IEEE Nordic Workshop on Power and Industrial Electronics (NORPIE), Jan. 2013, Denmark.

[37]N. Goudarzi, W. D. Zhu, "A review on the development of wind turbine generators across the world", International Journal of Dynamics and Control, June 2013, Vol. 1, Issue 2, pp 192–202.

[38]"India Energy Subsidy"(pdf). Report. Institute of sustainable development, The India Economic Times, January 2018.

[39]"Government Issues guidelines for tariff-based wind power projects". (Pdf). Report. The India Economic Times, 12 December 2017.

[40]"Installed Capacity Vs Generation (Grid Interactive Renewable Energy)" (Pdf). Report. Ministry of New Renewable Energy, 16 September 2017.

[41]"Reassessing Wind Potential Estimates for India: Economic and Policy Implications" by Amol Phadke, Ranjit Bharvirkar and Jagmeet Khangura; Lawrence Berkeley National Lab (2012).

[42]"Here are India's INDC objectives and how much it will cost" , The Indian Express. 2015-10-02. Retrieved 2017-12-27.

[43]"Executive Summary Power Sector September 2016" (pdf). Report. Central Electricity Authority, Ministry of Power, Govt. Of India. 30 September2016.