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Power Electronics Converters for a Wind Energy Conversion System: Review

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***Abstract*— This paper is a review on different generator topologies with power electronics converters. As demand of electricity is increasing the researchers are moving from asynchronous to synchronous generator whereas some researchers introduces the concept of asynchronous generator with wound rotor. Due to rapid growth in power electronics for offering high power, the application of power electronics converters are playing a key role in wind energy conversion system. This paper deals with the four types of generators such as squirrel cage induction generator (SCIG), doubly fed induction generator (DFIG), permanent magnet synchronous generator (PMSG) and wound rotor synchronous generator (WRSG) with their power electronics converters on the basis of their topologies, cost, circuit complexity and efficiency. This paper is a review on the different types of generator topologies with their combination with power electronics converters for wind energy conversion system (WECS).**

***Index Terms* — Converter, DFIG, Generator, PMSG, SCIG, WECS, Wind turbine, WRSG**

I. INTRODUCTION

Energy resources are divided into two categories: The non-renewable energy sources and the renewable energy sources. In this category all conventional energy sources such as coal, petroleum, natural gases etc. come and the second category consists of renewable energy sources such as solar energy, wind energy etc. Due to the increasing demand on electrical energy, a considerable amount of effort is being made to generate electricity from new sources of energy Due to shortcoming of non renewable energy sources and environment friendly nature of renewable energy sources; researcher paid their attention towards renewable energy sources. In renewable energy sources wind energy is most promising and world's fastest growing energy source field. Today India is facing shortage of electricity that's why the wind power generation has taken a high level of attention and acceptability in comparison with other types of renewable energy technologies being used in India. New developed technologies in wind power conversion system have contributed for the significant advances in wind energy penetration and to get maximum power from available wind in nature. The annual growth in wind energy system installation is highest for India.

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The total potential for renewable power generation in India as on 31.03.11 is estimated at 89760 MW shown in Fig. 1. In MW (55%), whereas SHP (small-hydro power) has potential of 15,385 MW (17%), Biomass power has potential of 17,538 MW (20%) and 5000 MW (6%) from biogases-based cogeneration in sugar mills. State-wise review shows that Gujarat has the highest share of wind power generation with 14% share (12,489 MW), followed by Karnataka with 12% share (11,071 MW) and Maharashtra with 11% share (9596 MW) [1].

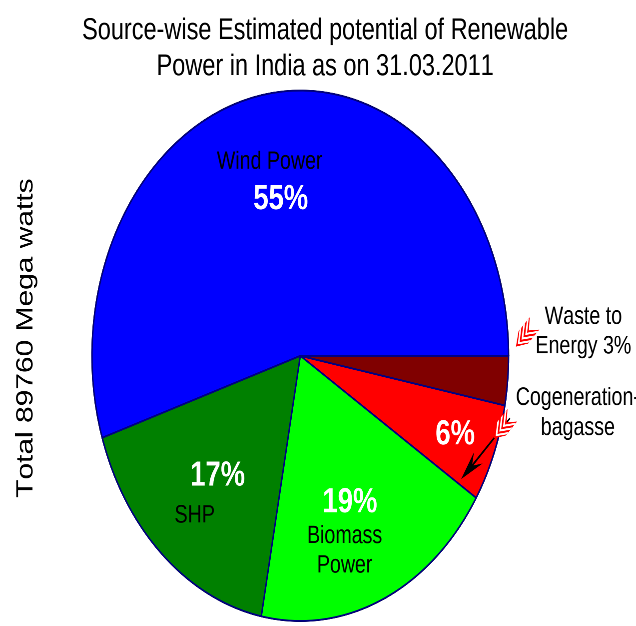

Fig.1 Renewable power generation in India

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A block diagram of wind energy conversion system is shown in Fig. 2.

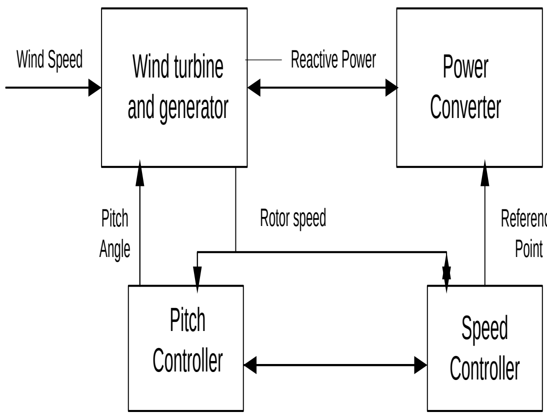

Fig.2 Block diagram of WECS

II. Wind turbine

Wind turbine converts wind energy into electricity for distribution. The performance and efficiency of any wind energy conversion system (WECS) depends upon the characteristics of wind turbines. This section consists of a brief discussion about types of wind turbines and their characteristics. The power in the wind is proportional to the cube of the wind speed and it may be expressed as

$$P_w = 0.5\rho A v_w^3$$

Where ρ is air density (kg/m^3), A is the area (m^3) swept by blades and v_w is wind speed (m/s).

A wind turbine can only extract a fraction of the power from the wind. This fraction is described by the power coefficient of the turbine and expressed by C_p. The maximum limit of C_p can be 0.59 (Betz limit). C_p is a function of pitch angle β and tip speed ratio λ. Hence mechanical power of the wind turbine is given by [2] [3]

$$P_m = 0.5\rho C_p(\lambda, \beta) Avw3$$

The tip speed ratio is defined as the ratio between the blade tip speed and the wind speed v_w and is given by

$$\lambda = \omega R / v_w$$

Where ω is turbine rotational speed.

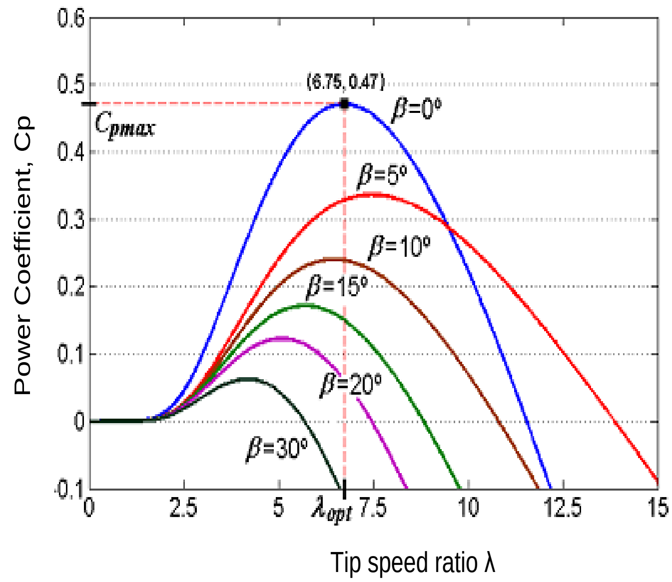

Fig.3 Cp- λ characteristics for different values of β

Fig. 4 shows the variable speed pitch controlled wind turbine characteristics. When the wind speed is below the cut-in wind speed then there will be no generation. When the speed is above cut-in speed but below the rated speed the power optimization method or MPPT method is used to extract maximum power. In this region the speed is maintained at a constant value corresponding to optimum tip speed ratio λ. Above rated speed but below cut-out wind speed pitch controller is used to control the wind power at the wind turbine blade. At very high wind speed it means above cut out speed there will be again no generation of power.

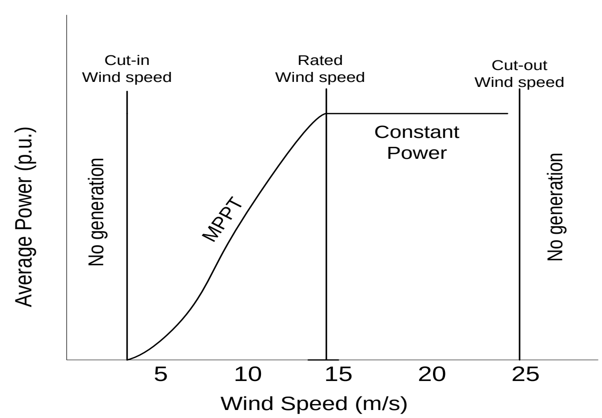

Fig.4 Variable speed pitch controlled wind turbine

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III. GENERATOR TOPOLOGIES WITH CONVERTERS

This section is basically a review of different types of generator topologies which are useful for WECS.

Different generators are as follows:

1. Induction generator
2. Synchronous generator

Different power converter topologies are as follows:

1. Soft starter
2. Diode Rectifier
3. Back-To-Back Converters
4. Multilevel Converters
5. Matrix Converters
6. Resonant Converters
7. B-4 Converter

1. Induction Generator:

The most often used generator for WECS is Induction generator. Induction generator is categorized into two types that are:

One with squirrel cage and second one with wound rotor.

a. Squirrel Cage Induction Generator (SCIG)

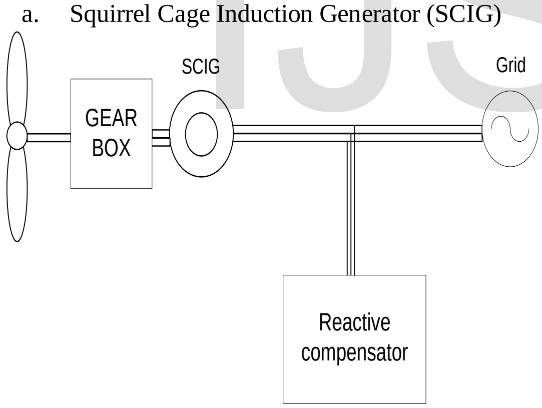

Fig.5 Fixed speed concept using multistage gearbox

A SCIG based WECS for fixed speed concept is shown in fig. 5. This type of WECS is used in conventional concept i.e. an upwind, stall regulated and three bladed wind turbine concept of WECS development. In this configuration rotor of SCIG is directly connected to the turbine through the multistage gearbox. Stator is connected to the grid through the coupling transformer.

This type of configuration has following advantage and disadvantages:

Advantages:

1. It is cheap and easy to construct.
2. Since it is being used at fixed wind speed so it provides stable control frequency.

Disadvantages:

i. Gearbox maintenance and its cost is a problematic issue.
ii. A soft-starter is required for smooth grid connection.
iii. SCIG always draw reactive power from the grid so reactive power compensation is required.
iv. Problem with obtaining excitation current from the stator terminal.
v. Overheating and torque pulsation may occur in connection with weak grid.

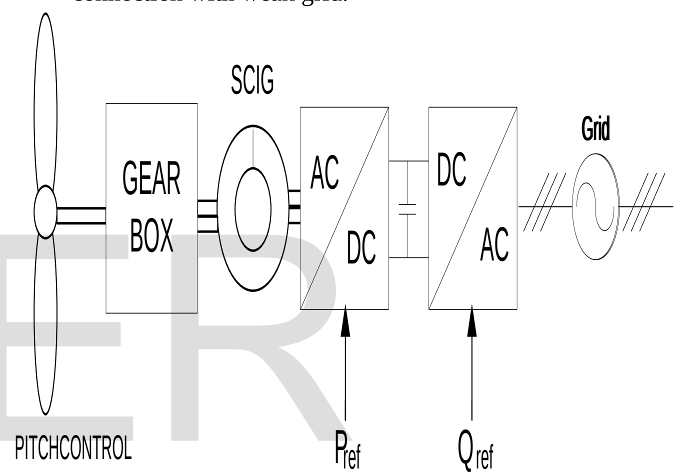

Fig.6 Variable speed wind concept with SCIG

SCIG based variable speed concept WECS uses a full scale back to back power converter in place of capacitor bank and soft starter as shown in fig. 6 [4].

The SCIG is a very popular machine due to its mechanical simplicity and construction. Methods of control include uncontrolled rectifier with inverter [14] full power frequency converter, fixed capacitor bank, thyristor and static VAR controller, matrix converter [5] [22].

Advantages:

1. It captures better energy than fixed speed concept.
2. There is no need of capacitor bank.
3. Variable speed concept reduces the mechanical stress on turbine.
4. Electrically isolated from grid.

Disadvantages:

1. Problem with gear box maintenance remains same.
2. Problem with obtaining excitation current from the stator terminal remains same.
3. Converter rating is high so it increase the converter cost.
4. Increases the control complexity because of more no of switches.

b. Doubly fed induction generator (DFIG)

A significant advantage of DFIG is its ability to produce more output than its rated power without being overheated. It has an ability to transfer maximum power over a wide speed range in both sub-synchronous and super-synchronous modes. Converter is connected to rotor so the power rating of converter is reduced and whole power flows through the stator. DFIG based WECS with back to back converter is shown in fig. 8 [6]-[13].

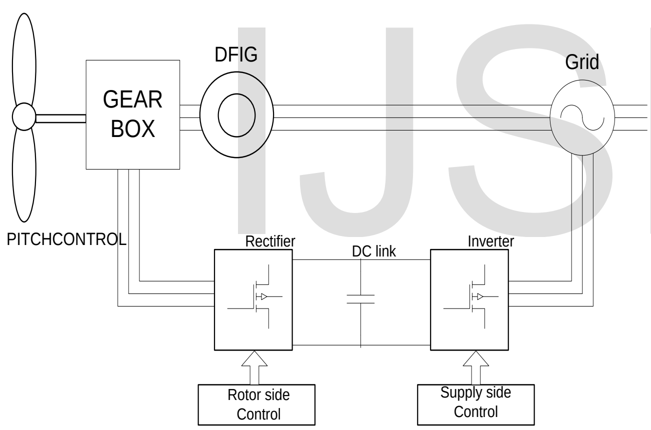

Fig.7 DGIG based WECS with back to back converter

Other types of converter options are diode bridge rectifier with dc link capacitor followed by thyristor inverter, matrix converter.

Advantages:

1. Converter rating is (25-30) % of total power so it reduces converter cost.
2. Suitable for high power application

Disadvantages:

i. Stator winding is directly connected to grid so very sensitive to grid fault condition.
ii. Gear box maintenance is problematic and cost oriented issue.

2. Synchronous Generator

Synchronous generator is categorized into two set of categories. First on is permanent magnet synchronous generator and second one is wound rotor synchronous generator.

a. Permanent Magnet Synchronous Generator (PMSG)

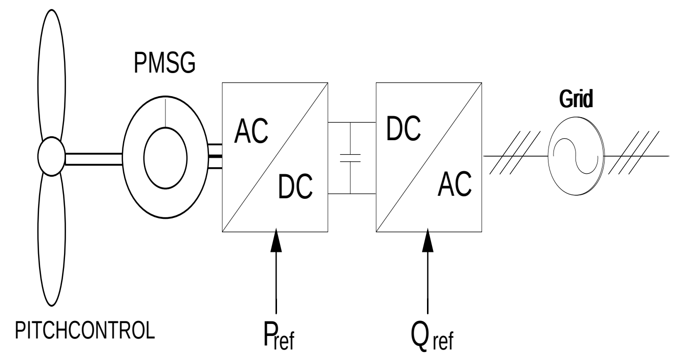

Fig.8 PMSG based WECS

In permanent magnet based WECS the output voltage and current is proportional to electromagnetic torque and rotor speed.

A diode rectifier with a dc link capacitor followed by inverter circuit is most widely used converter with PMSG based WECS as shown in fig. 9. It is economical and easy to control. It has a simple configuration in construction. On the other hand, it has some limitations. The dc link capacitor is bulky and having short life span. There is much more ripples in inverter output voltage.

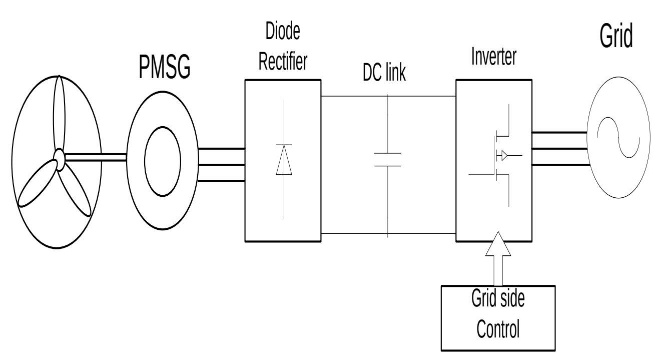

Fig.9 PMSG based WECS with diode rectifier/VSI

In palce of dc link capacitor a dc/dc boost stage is also being used as shown in fig. 10 [25]. It provides control of generator side dc voltage through the variation in switching ratio. One additonal switching stage is used so it decreases its efficiency and increses cost.

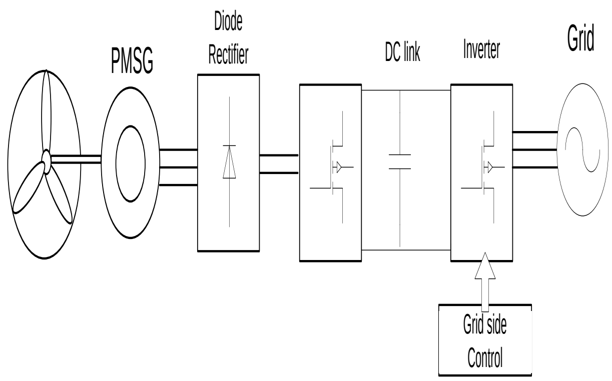

Fig.10 PMSG based WECS with diode rectifier/boost stage/VSI

Some author discuss about the PMSG wind energy conversion system using current source inverter with inductor [17] [18].

But now most popular topology is back to back frequency converter for PMSG based WECS shown in fig. 11 [16] [20] [21][24]. Advantges of this technogoy is that it provides active and reactive power control and increases power factor because of PWM modulation techniques. It is expensive. It requires shopisticated control so it increases complexity of the circuit.

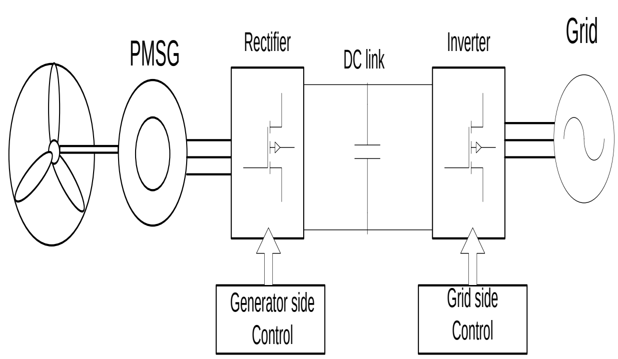

Fig.11 PMSG based WECS with back to back converter

Other topologies are use of multilevel converters, matrix converter and B4 converter for PMSG based WECS [26]. B-4 converter is used to improve the efficiency and decrease the cost. Matrix converter has its advantage of having a good option for designing of high power generation with small level of harmonics with low voltage rating of power devices. But it has low voltage gain and it increases complexity of circuit by requirement of nine bi-directional switches. Matrix converter gives a choice to get rid of dc link stage.

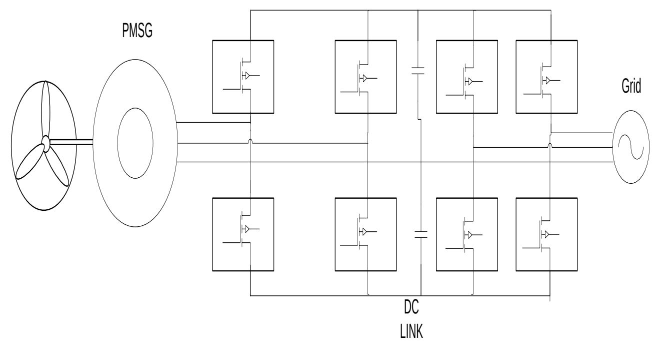

Fig.12 PMSG based WECS with B4 converter

To increase the operating range of wind speed author discuss about a system composed of a wind turbine, a permanent-magnet generator, a diode bridge rectifier, and a dc power system [28]. To increase the fault tolerance PMSG based WECS having a energy storage system is presented.

Advantages:

1. Light weight and small size in construction
2. Low losses and high efficiency.
3. No need of external excitation current.
4. No need of gear box.

Disadvantages:

1. Useful for small wind turbine because for high wind turbine size of permanent magnet matters.
2. Demagnetization of permanent magnet is a big issue.

b. Wound Rotor Synchronous Generator (WRSG)

Wound rotor synchronous machine is built with a rotor having a separate winding for field system and is excited by a DC source. It is well suited for full power control with power electronics converters. The load characteristics and power factor may be controlled by controlling the magnetizing current i.e. dc excitation provided to rotor winding. WRSG with uncontrolled rectifier followed by controlled VSI is shown in fig. 14 [27].

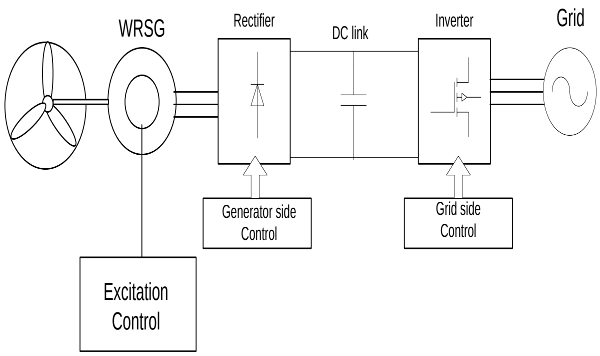

Fig. 13 WRSG based WECS using diode rectifier/controlled VSI

To improve the performance a back to back converter is used with WRSG as shown in fig. 15 [29].

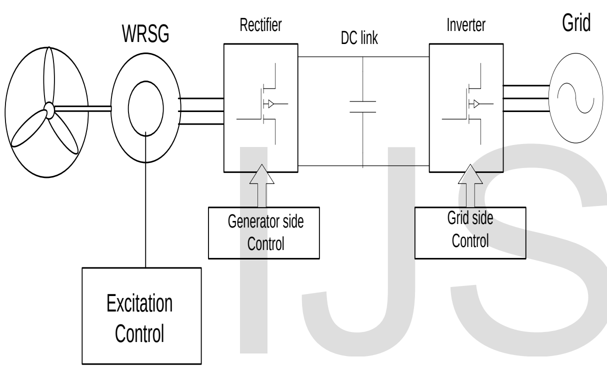

Fig. 14 WRSG based WECS with back to back converter

Power rating of semiconductor devices is limited. So designing of high power generation of wind energy conversion system is a challenging issue. To solve this problem authors discuss about split phase alternator with cascaded multilevel inverter [30].

Advantages:

1. Suitable for high power generation.
2. Independent control of real and reactive active power.
3. Improved power factor since it is self excited generator.
4. No need of gear box.

Disadvantages:

i. It requires additional converter to excite the winding of rotor.
ii. Higher maintenance cost in comparison with induction generator.

IV. SIMULATED RESULTS

Simulations of the proposed SVO method carried out using Matlab/Simulink. In this model the dynamic performance of WRSG wind turbine under the variation of wind speed using pitch angle control is shown. The nominal dc link voltage is set at 480 V and the dc capacitance is 90000μF. The rotor side converter is used to control the WRSG stator active and reactive power based on the proposed SVO method. During simulation, the sampling time is 50 micro-second and the line resistance and inductance of rotor side is 2pu and 0.02pu.

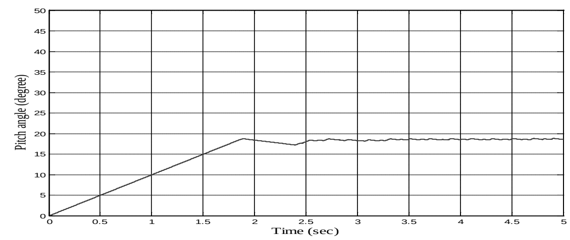

Fig.15 Pitch angle variation for wind turbine

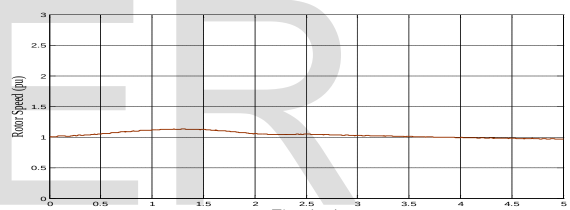

Fig.16 Angular rotor speed of the generator

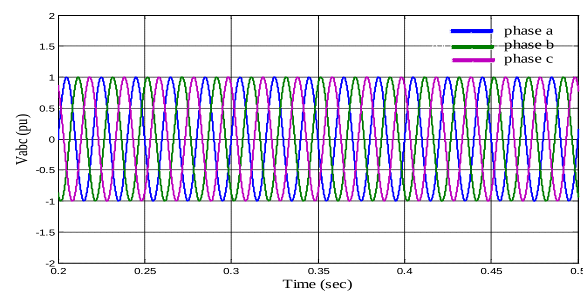

Fig.17 Three phase voltage fed to grid

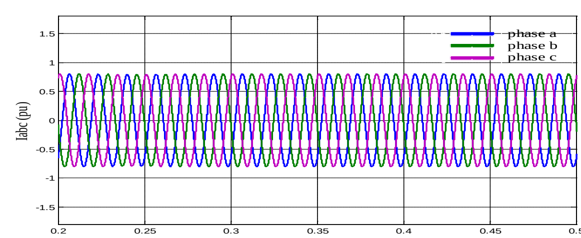

Fig.18 Three phase current fed to grid

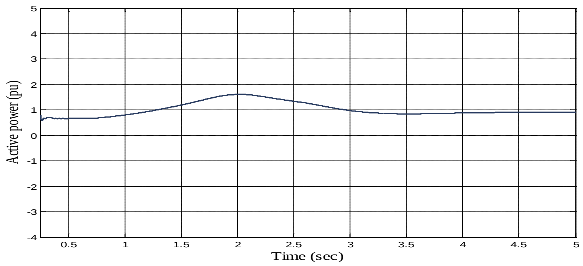

Fig.19 Active power delivered to the grid

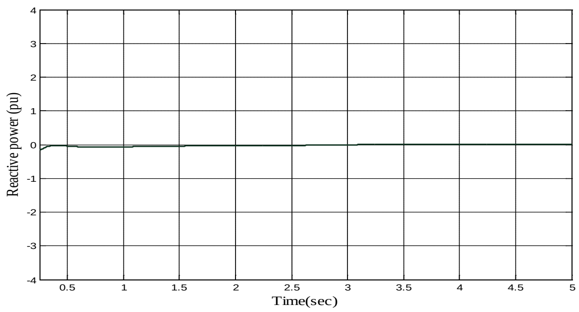

Fig.20 Reactive power delivered to the grid

V. SUMMARY

This paper is a review on the different types of generator topologies with their combination with power electronics converters for wind energy conversion system (WECS). It provides strength and weakness of different topologies. mostly used wind generators are Induction generator, DFIG, PMSG and WRSG. Back to back converter is most popular frequency converter for WECS. Wind energy technology is a renewable, available, and environmentally clean resource that has reached a degree of technological maturity to be an acceptable utility generation technology. Wind energy technology is now cost competitive with more conventional utility power sources. The regulatory trend of the 1990s is likely to level the playing field for environmentally sustainable options like wind energy by reflecting the true costs of resource depletion, pollution and the economic consequences of energy imports.

VI. REFERENCES

[1] "Energy Statistics 2012" 19th issue *by Central Statistics Office, Ministry of Statistics and Programme Implementation*, Government of India, New Delhi

[2] I.Syed Meer Kulam Ali P.Aravindan Dr.M.Y.Sanavullah," Mppt Based Permanent Magnet Synchronous Generator For Wind Energy Conversion System", *International Journal of Communications and Engineering* volume 04– no.4, issue: 02 March2012.

[3] Engr. G. Ofualagba and Dr. E.," Wind Energy Conversion System- Wind Turbine Modeling", *IEEE Power and Energy Society General Meeting -Conversion and Delivery of Electrical Energy in the 21st Century, pp. 20-24 July 2008*

[4] Ruben Pefia, Roberto Cardenas, Ramon Blasco, Greg Asher, Jon Clare, " A cage induction generator using back to back PWM converters for variable speed grid connected wind energy system", *The 27th Annual Conference of the IEEE Industrial Electronics Society*, IECON'01,2001

[5] Vinod Kumar, R. R. Joshi, and R. C. Bansal, "Optimal Control of Matrix Converter-Based WECS for Performance Enhancement and Efficiency Optimization", *IEEE Transactions on Energy Conversion*, vol. 24, No. 1, March 2009

[6] Rajib Datta, V. T. Ranganathan, "A Method of Tracking the Peak Power Points for a Variable Speed Wind Energy Conversion System", IEEE Transactions On Energy Conversion, vol. 18, No. 1, March 2003

[7] Zhang, Xiangyu, Li, He-ming M., Wang, Yi ,"Control of DFIG-based wind farms for power network frequency support",IEEE International conference on Power System Technology (POWERCON), pp. 1-6, 2010

[8] Mehdi T. Abolhassani, , Prasad Enjeti, Hamid Toliyat," Integrated Doubly Fed Electric Alternator/Active Filter (IDEA), a Viable Power Quality Solution,for Wind Energy Conversion Systems", *IEEE Transactions on Energy Conversion*, vol. 23, No. 2, June 2008

[9] Wei Qiao, Wei Zhou, José M. Aller, Ronald G. Harley, "Wind Speed Estimation Based Sensorless OutputMaximization Control for a Wind Turbine Driving a DFIG", *IEEE Transactions on Power Electronics*, vol. 23, No. 3, May 2008

[10] R. Pena, J.C.Clare, G. M. Asher," Doubly fed induction generator using back-to-back PWM converters and its application to variable- speed wind-energy generation", IEE Proc.-Electr. Power Appl, vo1 143, No. 3, May 1996

[11] Shuhui Li, Sitanshu Sinha," A Simulation Analysis of Double-Fed Induction Generator for Wind Energy Conversion Using PSpice", IEEE Power Engineering Society General Meeting, 2006.

[12] He Yikang, Hu Jiabing, Zhao Rende," Modeling and Control of Wind-Turbine Used DFIG under Network Fault Conditions", Proceedings of the Eighth International Conference on Electrical Machines and Systems ICEMS, vol. 2, pp. 986-991, 2005.

[13] Lie Xu & Phillip Cartwright,"Direct Active and Reactive Power Control of DFIG for Wind Energy Generation", *IEEE Transaction on Energy Conversion, vol. 21 issue 3, 2006*

[14] R.M. Hilloowala, A.M. Sharaf," Modelling, Simulation and Analysis Of Variable Speed Constant Frequency Wind Energy Conversion Scheme Using Self Excited Induction Generator", IEEE Proceedings., Twenty-Third Southeastern Symposium on System Theory, 1991.

[15] E.Spooner and A.C.Williamson, "Directly Connected PMSG for Wind Turbine Application "*IEEE. Elec. Power Appl.* vol 43,no1, Jan1996

[16] Monica Chinchilla, Santiago Arnaltes and Juan Carlos Burgos, "Control of Permanent-Magnet Generators Applied to Variable Speed Wind Energy Systems Connected to Grid", *IEEE Transactions on Energy Conversion, vol. 21, No. 1, March 2006*

[17] Jingya Dai, Dewei (David) Xu, and Bin Wu," A Novel Control Scheme for Current-Source-Converter-Based PMSG Wind Energy Conversion Systems", *IEEE Transactions on Power Electronics*, vol. 24, No. 4, April 2009.

[18] Yongqiang Lang, Bin Wu, Zargari, Navid Reza," A Novel Reactive Power Control Scheme for CSC Based PMSG Wind Energy System", IEEE Industry Applications Society Annual Meeting, IAS '08,2008

[19] B. Venkatesa Perumal and Jayanta K. Chatterjee, "Voltage and Frequency Control of a Stand Alone Brushless Wind

Electric Generation Using Generalized Impedance Controller", *IEEE Transactions on Energy Conversion*, vol. 23, No. 2, June 2008

[20] Hong-Woo Kima, Sung-Soo Kim, Hee-Sang Ko," Modeling and control of PMSG-based variable-speed wind turbine", *Electric Power Systems Research80 (2010)* pp.46–52,2010

[21] M. I. Marei and H. S. K. El-Goharey," Modeling and Dynamic Analysis of Gearless Variable-Speed Permanent Magnet Synchronous Generator Based Wind Energy Conversion System", *International Conference on Renewable Energies and Power Quality (ICREPQ'12)*, Santiago de Compostela (Spain), 28th to 30th March, 2012

[22] S. Masoud Barakati, Mehrdad Kazerani, J. Dwight Aplevich, "Maximum Power Tracking Control for a Wind Turbine System Including a Matrix Converter", *IEEE Transactions on Energy Conversion*, vol. 24, No. 3, September 2009

[23] Eftichios Koutroulis and Kostas Kalaitzakis," Design of a Maximum Power Tracking System for Wind-Energy-Conversion Applications", *IEEE Transactions on Industrial Electronics*, vol. 53, No. 2, April 2006

[24] I. Schiemenz, M. Stiebler," Control of a Permanent Magnet Synchronous Generator Used in a Variable Speed Wind Energy System",IEEE International conference on Electric Machines and Drives Conference, IEMDC 2001.

[25] Kenji Amei, Yukichi Takayasu, Takahisa Ohji, Masaaki Sakui," A Maximum Power Control of Wind Generator System Using a Permanent
Magnet Synchronous Generator and a Boost Chopper Circuit", IEEE Proceedings of the Power Conversion Conference, 2002. PCC-Osaka, vol. 3, pp. 1447-1452, 2002.

[26] A. B. Raju, K. Chatterjee, B. G. Fernandes," A Simple Maximum Power Point Tracker for Grid connected Variable Speed Wind Energy Conversion System with Reduced Switch Count Power Converters", IEEE 34th Annual Power Electronics Specialist Conference,PESC '03, vol.2 , pp. 748-753, 2003

[27] Seul-Ki Kim, Eung-Sang Kim, Jae-Young Yoon and Ho-Yong Kim," PSCAD/EMTDC Based Dynamic Modeling and Analysis of a Variable Speed Wind Turbine", IEEE Power Engineering Society General Meeting,vol. 2, pp.1735-1741, 2004

[28] Andrew M. Knight, Member, IEEE, and Glenn E. Peters," Simple Wind Energy Controller for an Expanded Operating Range", *IEEE Transactions on Energy Conversion*, vol. 20, No. 2, June 2005

[29] Shailendra Sharma & Bhim Singh,"Variable Speed Stand-alone Wind Energy Conversion System using Synchronous Generator", *IEEE International Conference on Power and Energy System*,ICPES 2011

[30] Paulson Samuel, Rajesh Gupta & Dinesh Chandra,"Grid Interface of Wind Power With Large Split-Winding Alternator Using Cascaded Multilevel Inverter", *IEEE Transactions on Energy Conversion*, vol. 26, No. 1, March 2011.