Generator and Power Converter Topology For Wind Energy Conversion System

Shivangee Shukla*[1] and Pooja Maurya[2]

ABSTRACT

This paper presents an overview of wind generators and power converter used in wind energy conversion systems. Renewable energies, and in particular wind energy, are taking a more and more relevant part in the generation of electric power. The incorporation of a variable speed function into a wind turbine has a variety of benefits, including: improved power yield during low wind speed conditions, reduced mechanical loading on drive train components, reduced audible noise, reduction in tower passing effects. A power electronic converter enables efficient conversion of the variable frequency output of a wind generator, driven by a variable speed wind turbine, to a fixed frequency appropriate for the grid or a load. Multilevel converters show interesting advantages in this field, such as high efficiency, low harmonic distortion and lower switching losses which is particularly useful for renewable energies, where converters usually work at these low power levels. The equal voltage cascaded multilevel converter configuration has the advantage of its modularity over the configuration of any other multilevel converter. Finally, it presents a convert topology from the simplest converters for starting up the turbine to advanced power converter topologies, where the whole power is flowing through the converter.

***Keywords**: wind energy conversion system, renewable energy, wind turbine, power converters, and generators.*

1. INTRODUCTION

The major components of a typical wind energy conversion system include a wind turbine, generator, interconnection apparatus and control systems. Wind turbines can be classified into the vertical axis type and the horizontal axis type. Most modern wind turbines use a horizontal axis configuration with two or three blades, operating either down-wind or up-wind. Wind power generation is an important alternative to mitigate this problem mainly due its smaller environmental impact and its renewable characteristic that contribute for a sustainable development .Three factors have made wind power generation cost-competitive, these are: (i) the state incentives,(ii) the wind industry that have improved the aerodynamic efficiency of wind turbine, (iii) the evolution of power semiconductors and new control methodology for the variable-speed wind turbine, that allows the optimization of wind turbine performance. A wind turbine can be designed for a constant speed or variable speed operation. Variable speed wind turbines can produce 8% to 15% more energy output as compared to their constant speed counterparts, however, they necessitate power electronic converters to provide a fixed frequency and fixed voltage power to their loads.

1*. Shivangee Shukla, Department of Electrical Engg, SRMSCET, Bareilly, U.P, India, Email: shivi.sshukla@gmail.com; Phone: 9415190086

2. Pooja Maurya, Department of Electrical Engg, SRMSCET, Bareilly, U.P, India, Email: maurya.anj.pooja@gmail.com

2. GENERATORS AND TOPOLOGIES

There are mainly following three classes of Generators:

2.1 D.C. generators

D.C. generators are relatively unusual in wind turbine applications because they are expensive and require regular maintenance. Nowadays for most of D.C. applications, for example , it is more common to employ an a.c. generator to generate a.c., which is then converted to D.C. with simple solid-state rectifiers.

2.2 Synchronous Generators

A synchronous generator usually consist of a stator holding a set of three-phase windings, which supplies the external load, and a rotor that provides a source of magnetic field. The rotor may be supplied either from permanent magnetic or from a direct current flowing in a wound field. Synchronous generators when fitted to a wind turbine must be controlled carefully to prevent the rotor speed accelerating through synchronous speed especially during turbulent winds. Moreover it requires flexible coupling in the drive train, or to mount the gearbox assembly on springs or dampers to absorb turbulence. Synchronous generators are more costly than induction generators, particularly in smaller size ranges.

2.2.1 Wound Field Synchronous Generator (WFSG)

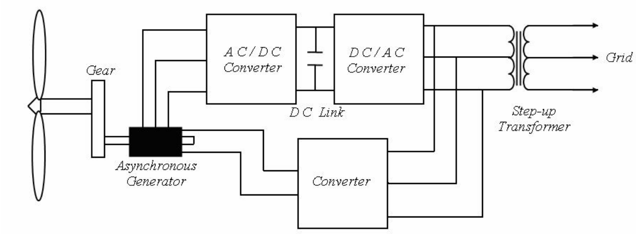

Fig. 1. Variable Speed Field Winding Synchronous generator

The WPS with wound field synchronous generator is show in Figure 1. The stator winding is connected to network through a four-quadrant power converter comprised of two back-to-back PWM-VSI. The stator side converter regulates the electromagnetic torque, while the supply side converter regulates the real and reactive power delivered by the WPS to the utility. The Wound Field Synchronous Generator has some advantages that are:

- The efficiency of this machine is usually high, because it employs the whole stator current for the electromagnetic torque production.
- The main benefit of the employment of wound field synchronous generator with salient pole is that it allows the direct control of the power factor of the machine, consequently the stator current may be minimized any operation circumstances.
- The pole pitch of this generator can be smaller than that of induction machine . The existence of a winding circuit in the rotor may be a drawback as compared with permanent magnet synchronous generator. In addition, to regulate the active and reactive power generated, the converter must be sized typically 1.2 times of the WPS rated power.

2.2.2 Permanent-Magnet Synchronous Generator (PMSG)

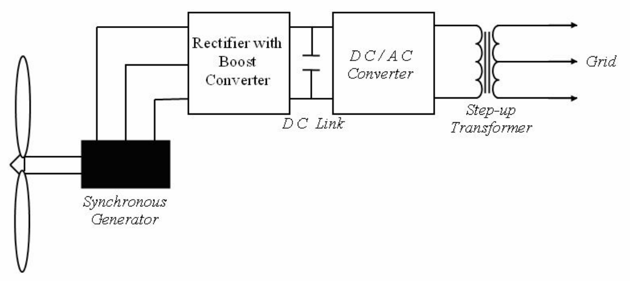

Fig. 2. Permanent-Magnet Synchronous Generator with a Boost Chopper

Figure 2 shows a WPS where a permanent magnet Synchronous generator connected to a three-phase rectifier followed by boost converter. In this case, the boost converter controls the electromagnet torque. The supply side converter regulates de DC link voltage as well as control the input power factor. One drawback of this configuration is the use of diode rectifier that increases the current amplitude and distortion of the PMSG. As a r esult this configuration has been considered for small size WPS (smaller than 50 kW).

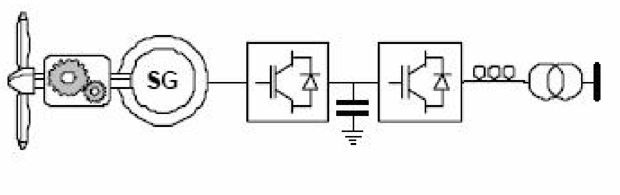

Fig.3. Permanent-Magnet Synchronous Generator with PWM converter

Other scheme using PMSG is sho w in Figure 3, in the system, the PWM rectifier is placed between the generator and the DC link, and PWM inverter is connected to the network. The advantage of this system regarding the system showed in Figure 2, is the use of field orientation c ontrol (FOC) that it allow the generator to operate near its optimal working point in order to minimize the losse s in the generator and power electronic circuit . The main drawbacks, in the use of PMSG, are the cost of p ermanent magnet that increase the price of machine, demagnetization of the permanent magnet material and it is not possible to control the power factor of th e machine.

The advantages of PM machines over electrically excite machines can be given below:

- Higher efficiency and energy y ield.
- No additional power supply for the magnet field excitation.
- Improvement in the thermal cha racteristics of the PM machine due to the absence of the field losses.
- Higher reliability due to the absence of mechanical components such as slip rings.
- Lighter and therefore higher p ower to weight ratio.

However, PM machines have some disadvantages, which can be given below:

- High cost of PM material.
- Difficulties to handle in manu facture.
- Demagnetization of PM at high temperature.

In recent years, the use of PM s is more attractive than before, because the performance of PMs is improving and the cost of PM is decreasing. The trends make PM machines with a full-scale power converter more attractive for direct drive wind turbines. Considering the performance of PM is improving and the cost of PM i s decreasing in recent years, in addition to that the cost of power electronics is decreasing, variable speed direct-drive PM machines with a full-scale pow er converter become more attractive for offshore w ind powers.

2.3Induction Generators

Induction generator offers man y advantages over a conventional synchronous ge nerator as a source of isolated power supply. Reduced unit cost, ruggedness, brush less (in squirrel cage, construction), reduced size, absence of separate DC source and ease of maintenance, self-protection a gainst severe overloads and short circuits, are the ma in advantages Further induction generators are loose ly coupled devices, i.e. they are heavily damped and th erefore have the ability to absorb slight change in rot or speed and drive train transient to some extent can t herefore be absorbed. Reactive power consumption and poor voltage regulation under varying speed are the major drawback of the induction generators, but the development of static power co nverters has facilitated the control of induction gener ator, regarding output and frequency.

The AC generator type that has most often been used in wind turbines is the i nduction generator. There are two kinds of induction generator used in wind turbines that are: squirrel ca ge and wound rotor.

2.3.1 Doubly Fed Induction Generator (DFIG)

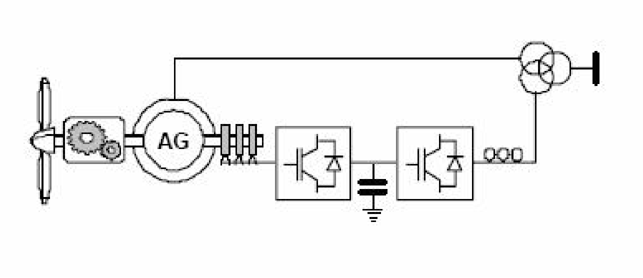

Fig.4. Doubly Fed Wound Rotor Induction Generator

The wind power system shown in Figure 4 consists of a doubly fed induction generator (DFIG), where the stator winding is directly connected to the network and the rotor winding is connected to the network through a four quadrant power converter comprised of two back-to-back PWM-VSI.

Compared to synchronous generator, this DFIG offers the following advantages:

- Reduced inverter cost, because inverter rating typically 25% of the total system power. This is because the converters only need to control the slip power of the rotor.
- Reduced cost of the inverter filter and EMI filters, because filters rated for 0.25 p.u. total system power, and inverter harmonics represent a smaller fraction of total system harmonics.
- Robustness and stable response of this machine facing against external disturbance.

The main disadvantages of DFIG wind turbines in comparison to FSIGs are their increased capital cost and the need for periodic slip ring maintenance.

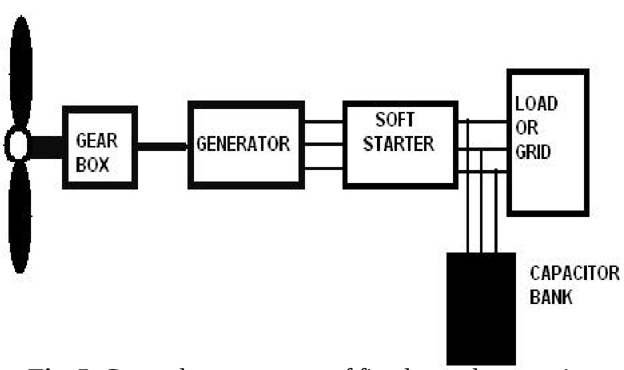

Fig .5. General arrangement of fixed-speed generation system

2.3.2 Squirrel Cage Induction Generator (SCIG)

A WPS with squirrel cage induction generator is show in Figure 6. The stator winding is connected to network through a four-quadrant power converter comprised of two PWM VSI connects back-to-back trough a DC link.

The supply side converter regulates the real and reactive power delivered from the system to the utility and regulates the DC link.

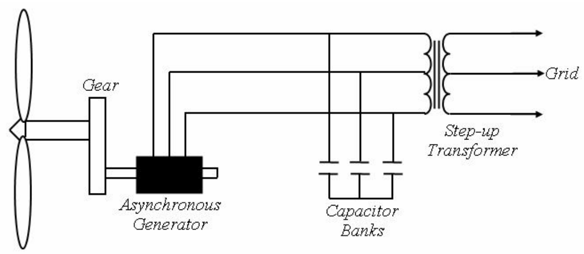

Fig .5. Variable Speed Squirrel Cage Induction Generator

The uses of squirrel cage induction generator have some advantages

- The squirrel cage induction machine is extremely rugged; brush less, reliable, economical a universally popular.
- Rectifier can generate programmable excitation for the generator.
- Fast transient response is possible.
- The inverter can be operated as a VAR/harmonic compensator when spare capacity is available.

Among the drawbacks are: (i) complex system control (FOC) whose performance is dependent on the good knowledge of the generator parameter that varies with temperature and frequency. (ii) the stator side converter must be oversized 30 -50% with respect to rated power, in order to supply the magnetizing requirement of the machine.

3. POWER CONVERTERS

Many different power converters can be used in wind turbine applications. In the case of using an induction generator, the power converter has to convert from a fixed voltage and frequency to a variable voltage and frequency. Other generator types can demand other complex protection. However, the most use by reduce the disturbances to the grid.

3.1 Soft starter

The soft starter is a power converter, which has been introduced to fixed speed wind turbines to reduce the transient current during connection or disconnection of the generator to the grid. When the generator speed exceeds the synchronous speed, the soft-starter is connected. Using firing angle control of the thyristors in the soft starter the generator is smoothly connected to the grid over a predefined number of grid period.

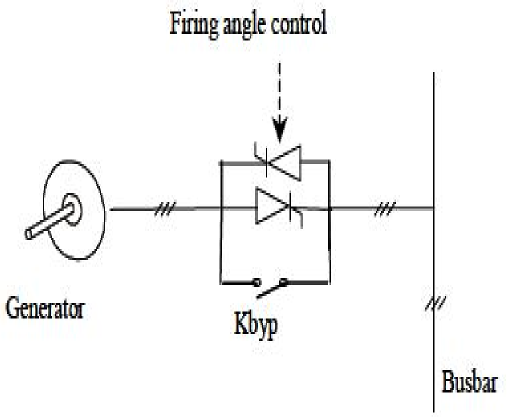

Fig. 7. Connection diagram of soft starter with generators.

The commutating devices are two thyristors for each phase. These are connected in anti-parallel. The relationship between the firing angle (α) and the resulting amplification of the soft starter is non-linear and depends additionally on the power factor of the connected element. In the case of a resistive load, may vary between 0 (full on) and 90 (full off) degrees, in the case of a purely inductive load between 90 (full on) and 180 (full off) degrees. For any power factor between 0 and 90 degrees, α will be somewhere between the limits draw in figure 8.

When the generator is completely connected to the grid a contactor (kbyp) by pass the soft-starter in order to reduce the losses during normal operation.

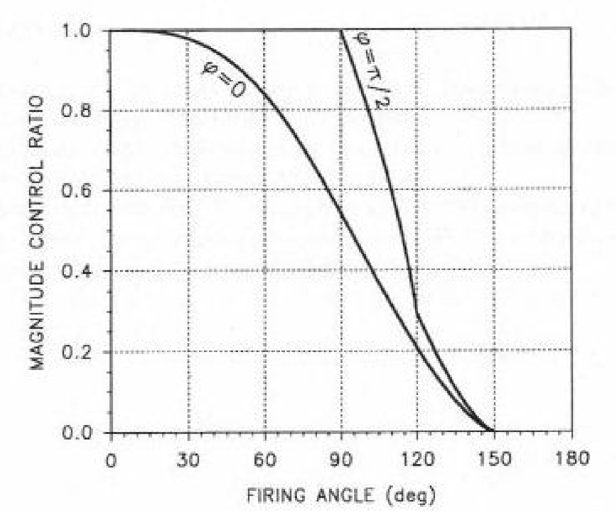

Fig. 8. Control characteristic for a fully controlled soft starter

- The soft-starter is very cheap
- It is a standard converter in many wind turbines.
- Soft sarter is similar to a primary resistance or primary reactance starter in that it is in series with the supply to the motor.

3.2 Capacitor bank

For the power factor compensation of the reactive power in the generator, AC capacitor banks are used, as shown in Figure 9. The generators are normally compensated into whole power range. The switching of capacitors is done as a function of the average value of measured reactive power during certain period.

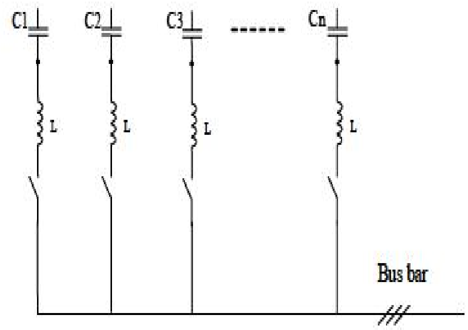

Fig.9. Capacitor bank configuration for power factor compensation in a wind turbine

The capacitor banks are usually mounted in the bottom of the tower. In order to reduce the current at connection/disconnection of ca pacitors a coil (L) can be connected in series. The ca pacitors may be heavy loaded and damaged in the case of over-voltages to the grid and thereby they may increase the maintenance cost.

3.3 Diode rectifier

The diode rectifier is the most common used topology in power electronic a pplications. For a three-phase system it consists of si x diodes. It is shown in Figure 10

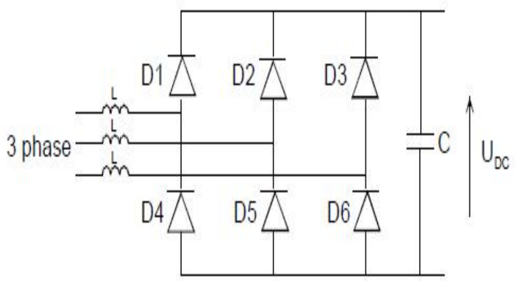

Fig. 10. Diode rectifier for three-phase ac/dc conversion

The diode rectifier can only b e used in on quadrant, it is simple and it is not pos sible to control it. It could be used in some applications w ith a dc-bus.

3.4 The back-to-back PWM-VSI

The back-to-back PWM-VSI is a bi-directional power converter consisting of two conventional PWM-VSI. The topology is shown in Figure 11.

The back-to-back four-quadrant PWM-VSI is widely used in WPS. The PWM mo dulation reduces the current harmonic component in the input and output of the system. As a result, it reduces the torque pulsation on the generator and improves the output Power quality, respectively.

Normally, a field orientation control (FOC) is preferred for control the stat or/rotor side converter while the supply side converte r use vector controller.

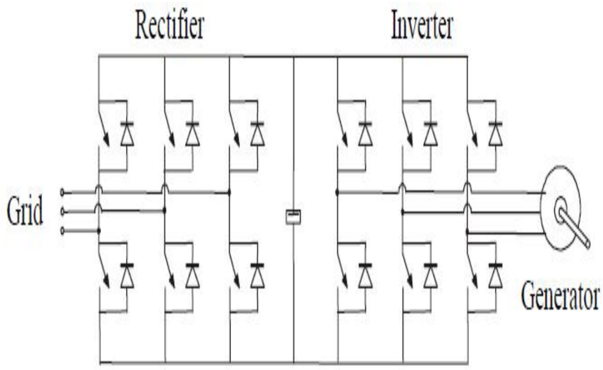

Fig. 11. The back-to-back PWM-VSI converter topology

3.4.1 Advantages of the back-to-back PWM-VSI

The PWM-VSI is the most freque ntly used three phase frequency converter. Furthermore, many manufacturers produce components especially designed for use in this type of converter (e.g., a transistor-pack comprising six bridge coupled transistors and anti-paralleled diodes). Due to this, the component costs can be low compared to converters. A technical advant age of the PWM-VSI is the capacitor decoupling be tween the grid inverter and the generator inverter.

4. WIND POWER ELECTRICITY PRODUCTION

In 1997 German installed capac ity surpassed the U.S. and led until once again overtaken by the U.S. in 2008. China has been rapidl y expanding its wind installations the late 2000s and passed the U.S. In 2010 to become the world leader.

Europe accounted for 48% of th e world total wind power generation capacity in 2009. In 2010, Spain became Europe’s leading produc er of wind energy; achieving 42,976 GWh. Germany held the top spot in Europe in terms of installe d capacity, with a total of 27,215 MW as of 31 December 2010. The world’s five leading countries in term s of installed wind power capacity are:

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Table-I

Rank	Nation	2009	2010	2011
1.	Chain	25,777 .0MW	44,733 MW	62,733 MW
2.	US	35,1 9.0 MW	40,180 MW	46,919 MW
3.	Germany	25,777 MW	27,215 MW	29,060 MW
4.	Spain	19,149 .0 MW	20,676 MW	21,674 MW
5.	India	10,925 .0 MW	13,065 MW	16,084 MW

In 2010, more than half of all new wind power was added outside of the tradi tional markets in Europe and North America. This was largely from new construction in China, which a ccounted for nearly half the new wind installations (16 .5 GW).

5. INSTALLED WIND POWER CAPACITY

Table-II

Country	Wind power production	% world total
US	95.2	27.6
China	55.5	15.9
Spain	43.7	12.7
Germany	36.5	10.6
India	20.6	6.0
UK	10.2	3.0
France	9.7	2.8
Italy	8.4	2.5
Rest of world	65.6	19
World total	344.8TWH	100%

6. CONCLUSION

According to this paper to dis cuss the capacity of the power generation from WECs , i.e. factors affecting wind power, their classificati on, choice of generator & power converter, problems related with grid connections. In the small and medium WTS both the SCIG and PMSG have been used w hile for large size WTS both DFIG and SG are preferred. The back-to-back four-quadrant PWM-VSI converter is preferred because the PWM modu lation reduces the current harmonic component in the input and output of the system. As a result, it reduces the torque pulsation on the generator and allows improving the output power quality.

As a result, it reduces the to rque pulsation on the latest trend of wind power gen eration from off shore sites. Today wind power accoun ts for about0.4% of world's electricity demand. Wo rldwide wind energy industry could install an estimated 1200, 000 MW by 2020,which needs global exp loitation of available wind potential and to generate power from off shore sites. Global wind power insta llations increased by 41,236 in 2011, bringing total installed capacity up to 238,351 MW, a 20.6% increase o n the 197,637 MW installed at the end of 2010. For the last two years more than half of all new wind power was added outside of the traditional mar kets of Europe and North America, mainly driven by the continuing boom in China which accounted for nearly half of all of the installations at 18,000 MW. Ch ina now has 62,733 MW of wind power installed.

As of 2011, 83 countries around the world are using wind power on a commerci al basis.

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