

## A Review Paper on Modeling And Simulation of Permanent Magnet Synchronous Generator Based on Wind Energy Conversion System

Venugopal J Kante<sup>1</sup>, Dr.Z.J.Khan<sup>2</sup>

<sup>1</sup>Student of M.Tech (Energy.Mannagement.System), Department of Electrical Engineering, Rajiv Gandhi College of Engineering Research & Technology, Chandrapur (M.S), India

<sup>2</sup>Professor & Head, Department of Electrical Engineering, Rajiv Gandhi College of Engineering Research & Technology, Chandrapur (M.S), India

### Abstract

This paper present's a comprehensive review on study of modeling and simulation of permanent magnet synchronous generator based on wind energy conversion system, in which the basic wind energy conversion equation, wind turbine mathematical equation, wind turbine controls, and drive train, different types of drive train, are discussed, the PMSG (permanent magnet synchronous generator is introduced as construction, mathematical equation of PMSG are established in the d-q model, and different types of wind generator concept in short is discussed, configuration of different power converter's is proposed with modeling and simulation of PMSG based on WECS at variable speed operation and maximum power capture, various control technique for the system are discussed for both machine-side and grid-side in detail, the different types of MPPT technique is presented in this paper.

**Index Terms**— wind energy conversion, wind turbine, drive train, permanent magnet synchronous generator, converter topology, MPPT Methodology

### I. INTRODUCTION

Wind power is an important renewable energy resource and the fastest growing technology amongst different renewable energy generation technologies [1].wind energy conversion system consist of wind turbine, pitch angle control, drive train , generator and power converter. There are various kinds of generators used in WECS such as induction generator (IG), double feed induction generator (DFIG) and permanent magnet synchronous generator (PMSG). The PMSG based on WECS can connect to the turbine without using gearbox. The gearbox causes in the cost maintenance and then it will decrease the weight of nacelle.[2] many developed generation systems are used to extract maximum wind energy. Optimum wind energy extraction is achieved by running wind turbine generator in a variable speed mode because of the higher energy gain and reduced losses and stresses [3]. Wind turbines are classified with a view to the rotational speed, the power regulation, and the generator system. When considering the construction of the direct drive system, the turbines are classified in to the geared and the direct-driven types [4, 5]. The direct-drive type is known with its advantages, as it has a lower cost, smaller size, and consequently it's

Weight is Reduced [6]. Geared system with different generator types are used in wind power generation, while the use of PM generator with direct-drive system has many competitive advantages, because of its great energy yield, noise reduction, and good reliability, and high efficiency [7, 8]. PM generator can readily deliver power without undergoing the process of voltage buildup and there is no danger of losses of excitation. But with the development of the power electronic and permanent magnets material, such as NdFeB (neodymium-iron-boron) a rapid development in PM generator is achieved. Recent technique such as FOC (Field oriented control) of PMSG (permanent magnet synchronous generator) allows control of active and reactive power in machine-side and can be applied to the grid-side [4]. Such wind turbine system satisfy maximum power tracking can be obtained for small-scale wind turbine through power electronic interfacing with the grid and using control of DC-voltage and the grid injection current[9].

The main component of permanent magnet synchronous generator based on WECS is illustrated in figure.1.study of each Component of the system is introduced in this paper in details. Several review studies were introduced concerning turbine control, drive train , generator, power electronic used with wind turbines and converter topologies for different generator types, unlike this study focus on modeling

and simulation of permanent magnet synchronous generator based on WECS.

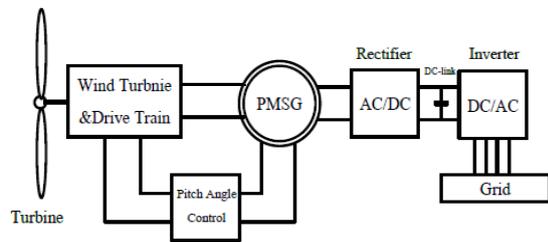


Figure.1 shows PMSG based on WECS

## II. Wind energy conversion

The kinetic energy of wind is given by

$$E_c = \frac{1}{2}mv^2 \quad (1)$$

$$m = \rho vS \quad (2)$$

Where

$m$  = air mass

$v$  = wind speed

$\rho$  = air density

$S$  = covered surface of the turbine

The wind power is given by

$$P_W = E_c = \frac{1}{2}mv^2 = \frac{1}{2}\rho Sv^3 \quad (3)$$

## III. Wind turbine System.

### 3.1 Turbine mathematical model

In the literature survey, several studies have been reported regarding wind turbines and wind power driven generators in ref [1 2 3 4 5 6 7 8 9] Wind turbine is applied to convert the wind energy to mechanical torque. The mechanical torque of turbine can be calculated from mechanical power at the turbine extracted from wind power. This fact of the wind speed after the turbine isn't zero. Then, the power coefficient of the turbine ( $C_p$ ) is used. The power coefficient is function of pitch angle ( $\beta$ ) and tip speed ( $\lambda$ ). Pitch angle is angle of turbine blade, whereas tip speed is the ratio of rotational speed and wind speed. The power coefficient maximum of ( $C_p$ ) is known as the limit of Betz

A generic equation is used to model  $c_p(\lambda, \beta)$ . This equation, based on the modelling turbine characteristics, which is also called as power coefficient equation

$$C_p(\lambda, \beta) = C_1 (C_2/\lambda_i - C_3\beta - C_4) e^{-C_5/\lambda_i} + C_6\lambda \quad (4)$$

With

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (5)$$

The coefficients  $c_1$  to  $c_6$  are:  $c_1=0.5176$ ,  $c_2=116$ ,  $c_3=0.4$ ,  $c_4=5$ ,  $c_5=21$  and  $c_6=0.0068$ . The  $c_p$ - $\lambda$  characteristics, for different values of the pitch angle  $\beta$ , are illustrated below in figure 2. The maximum value of  $C_p$  ( $C_{pmax} = 0.48$ ) is achieved for  $\beta = 0$  degree and for  $\lambda = 8.1$ . This particular value of  $\lambda$  is defined as the nominal value ( $\lambda_{nom}$ ).

The power coefficient is given by,

$$C_p = \frac{P_m}{P_W}; C_p < 1 \quad (6)$$

$$P_m = C_p(\lambda, \beta) \frac{\rho S}{2} V_{wind}^3 \quad (7)$$

Where,  $P_m$  is the mechanical output power of the turbine,  $C_p$  is the performance coefficient of the turbine,  $\rho$  is the air density,  $S$  is the turbine swept area,  $V_{wind}$  is the wind speed,  $k_p$  is the gain power,  $\lambda$  is the tip speed ratio,  $\beta$  is the blade pitch angle. The tip speed ratio is defined as

$$\lambda = \frac{\omega_t R}{V_{wind}} \quad (8)$$

Where  $\omega_t$  is the rotational speed ( $rad/sec$ ), of the wind turbine, and  $R$  is the rotor radius (m),

The mechanical torque is given by,

$$T_m = \frac{P_m}{\omega_t} \quad (9)$$

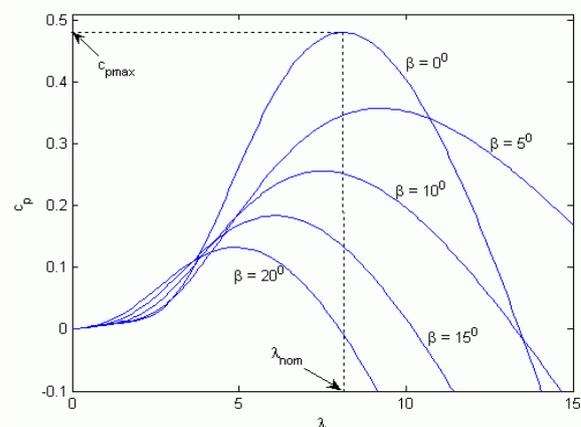


Figure 2 shows  $C_p(\lambda, \beta)$  characteristic for different values of the pitch angle.

### 3.2 Turbine Control.

Control of the wind turbines is important to keep the extracted power within its rated values. Three control techniques are available to adjust the turbine operating speed which is illustrated in figure

3. The fixed speed wind turbines are often controlled by passive stall and active stall control methods in ref [1][9], while variable speed turbines are controlled by pitch controlled method [2345678]. passive stall control is used to limit the power extraction where rotor blade geometry is utilized to limit the lift force when the wind speed becomes too high by creating turbulence behind a rotor blade. The advantage with passive stall control is the fixed connection of the rotor blades to the hub, and the disadvantages is the maximization of the power production only at a certain wind speed which is determined by the geometry of the rotor blade.

Active stall control and pitch control method use pitch mechanism to limit the output power. Active stall control method is also used for large fixed speed turbines [1]. At low wind speeds the blades are pitched as in pitch control achieving maximum efficiency, while at high wind speeds the blades are pitched slightly in to the direction opposite to that of a pitch-controlled turbine. With active stall control compensation of variation in air density is available. This pitching method makes emergency stopping and starting of wind turbine easier.

In pitch control method the pitch angle is varied in a wider range if compared with active stall control. During high wind speed situations, the angle of attack can be maintained to a lower value by varying the Pitch angle. This control method enables better exploitation of the system during high wind situations and decreasing the thrust force on the turbine and the emergency stopping can also be performed. The high Slope of the power curve at high wind speeds which will cause a large output power variation for a small Variation in wind speed must be considered. This control method is used for medium

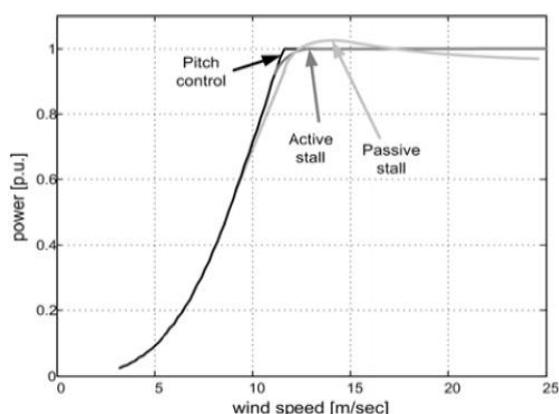


Figure .3 shows different wind turbine control strategies.

#### IV. Drive Train.

In power system studies drive trains are modeled as a series of rigid disk's connected via mass less shafts. For small-signal analysis of permanent magnet synchronous generator (PMSG) in conventional wind power plant's. The one mass or

lumped-mass model is used because the drive train behaves as single equivalent mass. Different models of drive train for wind turbine have been reviewed in this paper

In[1]author presents the gearbox is coupled between wind turbine and induction generator of 225 KW 50 Hz the gear box ratio is 1:23.4 is discussed. In [2] author describe about the two mass drive train. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the turbine, and obtained the mechanical output power generated by turbine, such as load torque, turbine moment of inertia, and load power is discussed. In[3] author presents for VSWT , the drive train modeling is not so influential due to the decoupling effect of the power electronic converter's between the generator and the grid system therefore in [3] study on simple one mass lumped model of WTGS is used is discussed. In [4][5][8] author presented a wind turbine is direct-drive with permanent magnet synchronous generator is discussed. In [6] author discuss about the one-mass model is used for dynamic model of PMSG-WT based on power system. In [7] author focuses on the interaction between wind farms and AC grid. The drive train can be treated as one-lumped mass model for the sake of time efficiency and acceptable precision is discussed. In[9] author present's a multi mass drive train is considered for small-signal stability studies of WECS with DFIG but in[9] it is sufficient to consider the two mass model (one for the turbine, the other for the generator) is discussed .

#### 4.1 Different types of Drive Train model.

##### 4.2 One mass drive train.

In a one-mass drive train model all inertia components are lumped together, i.e. modeled as a single rotating mass. The equation for the one-mass model is based on the second law of Newton, deriving the state equation for the rotor angular speed at the wind turbine given by

$$\frac{d\omega_t}{dt} = \frac{1}{J} (T_t - T_g) \quad (10)$$

Where  $J$  is the moment of inertia for blades, hub and generator,  $T_t$  is the mechanical torque,  $T_g$  is electrical torque.

##### 4.3 Two mass drive train.

The equation for the two-mass model are based on the torsional version of the second law of Newton, deriving the state equation for the rotor angular speed at the wind turbine and for the rotor angular speed at the generator is given by

$$\frac{d\omega_t}{dt} = \frac{1}{J_t} (T_t - T_{dt} - T_{at} - T_{ts}) \quad (11)$$

$$\frac{d\omega_g}{dt} = \frac{1}{J_g} (T_{ts} - T_{dg} - T_{ag} - T_g) \quad (12)$$

Where  $J_t$  the moment of inertia for blades and hub,  $T_{dt}$  is the resistant torque in the wind turbine bearing,  $T_{at}$  is the resistant torque in the hub and blade due to the viscosity of the air flow,  $T_{ts}$  is the torque of torsional stiffness,  $\omega_g$  is the rotor angular speed at the generator,  $J_g$  is the generator moment of inertia,  $T_{dg}$  is the resistant torque in the generator bearing,  $T_{ag}$  is the resistant torque due to the viscosity of the airflow in the generator.

#### 4.4 Three mass drive train.

The equations for the three-mass model are also based on the torsional version of the second law of Newton and it is given by

$$\frac{d\omega_t}{dt} = \frac{1}{J_b} (T_t - T_{db} - T_{bs}) \quad (13)$$

$$\frac{d\omega_h}{dt} = \frac{1}{J_h} (T_{bs} - T_{dh} - T_{ss}) \quad (14)$$

$$\frac{d\omega_g}{dt} = \frac{1}{J_g} (T_{ss} - T_{dg} - T_g) \quad (15)$$

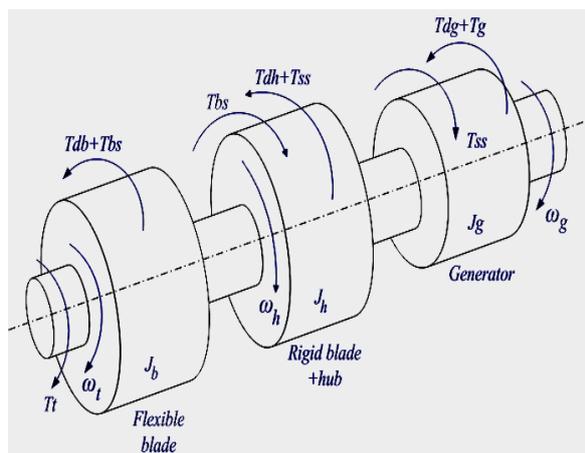


Figure .4 shows three mass drive train

Where  $J_b$  is the moment of inertia of the flexible blades section,  $T_{db}$  is the resistant torque of the flexible blades,  $T_{bs}$  is the torsional flexible blades stiffness torque,  $\omega_h$  is the rotor angular speed at the rigid blades and the hub of the wind turbine,  $J_h$  is the moment of inertia of the hub and the rigid blades section,  $T_{dh}$  is the resistant torque of the rigid blades and hub,  $T_{ss}$  is the torsional shaft stiffness torque,  $T_{dg}$  is the resistant torque of the generator.

## V. Generator.

The electrical generator system of the wind turbine includes all components for converting mechanical energy in to electrical power. A brief review of the generator has been illustrated here

In [1] author present existing constant speed system and variable speed drive for wind turbine is discussed. In which existing constant speed system consist of a induction generator which is mechanically coupled to the shaft of a turbine and electrical power generated is directly feed in to grid Where as the variable speed system uses only a six pole winding through out the operation. Therefore the speed variation in the case of the variable speed controller is smooth from minimum wind speed; as a result the power generated in this range is always better than the original system (which is constant speed system) is discussed. In [2][3][4][5][6][7][8] author discussed about the permanent magnet synchronous generator based on wind energy power generation. In [9] author presented the DFIG (Double feed induction generator) is used as a generator is discussed

### 5.1 Different types of wind generator.

- Classification of induction generator.
  - Squirrel cage induction generator (SGIG)
  - Wound rotor induction generator (WRIG)
- Classification of induction generator on the basis of their excitation.
  - Grid connected induction generator (GCIG)
  - Self-excited induction generator (SEIG)
- Classification of induction generator on the basis of prime mover used and their location's
  - Fixed speed concept using multistage gearbox
  - Limited variable speed concept using a multistage gearbox
  - Variable speed direct drive concept with a partial scale power converter.
- Variable speed direct drive concept with a full-scale power converter.
  - Electrical excited synchronous generator (EESG)
  - Permanent magnet synchronous generator (PMSG)
- Types of permanent magnet machines.
  - Axial-flux PM machine: - produces magnetic flux in axial direction.
  - Radial-flux PM machine: - produces magnetic flux in radial direction.
  - Transversal-flux PM machine: - produces magnetic flux in perpendicular to the direction of rotor rotation.

- Variable speed single stage geared concept with a full scale power converter
- PM synchronous generator (PMSG)
- Variable speed multiple stage geared concept with a full-scale power converter.
- PM synchronous generator (PMSG)
- Squirrel cage induction generator (SGIG)
- Double feed induction generator (DFIG)

### 5.2 Permanent Magnet Synchronous Generator.

Many designs for permanent magnet where proposed such as, modular design, outer rotor design, the coreless type, PMSG has large number of poles to operate at low speed as it works in a gearless drive train system. To increase the efficiency and reduce the weight of the active parts, direct-drive generators are usually designed with a large diameter and a small pole pitch. The rotor excitation is provided by PM which decreases the reactive power compensation arrangement used in electrically excited generators and removes the slip rings, minimizing size and lowering cost of the system. Regarding electrical losses than PM excitation which increases with number of poles, although PM also has low losses because of the circulation of eddy current and, consequently, control of output voltage independent of load current is the main advantage of the wound rotor excitation system which is very important in constant speed hydro and turbo generator. This advantage is not important in variable speed wind driven systems since they are connected to grid via power electronic interface.

Modular design of PMSG allows simplicity in manufacturing process by using high quality magnet (NdFeB) which ensures larger life time. The generator coil can be protected against environment conditions to satisfy working in offshore farms. The damper windings are not existed in PMSG and the stator direct flux is constant since the excitation is provided by the magnets unlike that in the electrically excited generator. It is common in large-scale stability analysis to neglect the stator flux transients of synchronous generators.

### 5.3 Mathematical Equation of PMSG.

Considering the equivalent circuit of PMSG based on WECS in figure.5 below the model of PMSG is established in the  $d-q$  synchronous reference frame, the three-phase sinusoidal mathematical equations are expressed in the rotor reference frame ( $d-q$  frame). All quantities in the rotor reference frame are referred to the stator. And it is give as

$$\frac{d}{dt} i_d = \frac{1}{L_d} v_d - \frac{R}{L_d} i_d + \frac{L_q}{L_d} P \omega_r i_q \quad (16)$$

$$\frac{d}{dt} i_q = \frac{1}{L_q} v_q - \frac{R}{L_q} i_q - \frac{L_d}{L_q} P \omega_r i_d - \frac{\lambda P \omega_r}{L_q} \quad (17)$$

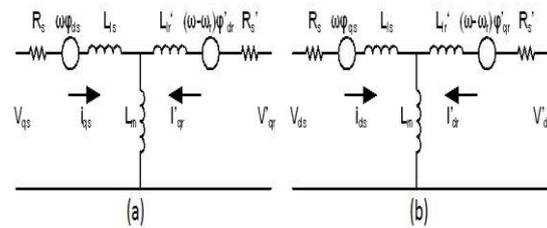


Figure.5 shows equivalent circuit of PMSG in  $d-q$  reference frame

The electromagnetic torque equation is given by

$$T_e = 1.5P [\lambda i_q + (L_d - L_q) i_d i_q] \quad (18)$$

Where

$L_q$  &  $L_d$  are q and d axis inductance, R is resistance of the stator windings,  $i_q$  &  $i_d$  are q and d axis current,  $v_q$  &  $v_d$  are q and d axis voltage,  $\omega_r$  is angular velocity of the rotor,  $\lambda$  is amplitude of flux induced by permanent magnets of rotor in the stator phase, P is the number of pole pairs.

The mechanical equation is given by

$$\frac{d}{dt} \omega_r = \frac{1}{J} (T_e - T_f - F \omega_r - T_m) \quad (19)$$

$$\frac{d\theta}{dt} = \omega_r \quad (20)$$

Where J is combined inertia of rotor and load, F is combined viscous friction of rotor and load,  $\theta$  is rotor angular position,  $T_m$  is shaft mechanical torque,  $T_f$  is shaft static friction torque.

## VI. Converter Topology.

With development of the power electronics' converters and switching devices in market, and especially those having higher reliability and lower cost makes many of the converter topology incorporated to wind power system to improve control and to increase the reliability of the system.

The topologies of converter's which suit PMSG based on wind energy conversion system are the partially scaled converter type and full scaled converter type, the partially scaled converter topology with PMSG is proposed in ref [4], where a 20% power converter is placed in series with the stator winding to actively damp the generator. In the following subsection's more interest is focused on the full scale converter type. Since it is the main type and most used one in modeling and simulation of PMSG based wind energy conversion system, full scale

converters are divided in to two main categories and they are described as follows in ref [5, 6]

### 6.1 Unidirectional converter.

In order to make cost efficient solution when no reactive control is needed, the machine-side converters consist of a diode rectifier which allows the flow of power in one direction from machine to the grid

### 6.2 Thyristor grid-side inverter.

In the configuration given in figure.6 optimal energy is captured by regulating speed through controlling of the DC-link voltage. Using this configuration makes a considerable decrease in the cost of the inverter, but on the other hand its reactive power needs to be compensated, and its harmonics distortion needs to be minimized.

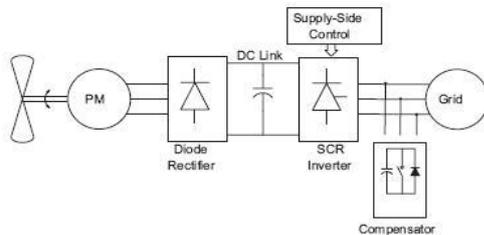


Figure.6 shows Diode Rectifier with Thyristor Inverter

Using an active compensation filter that was proposed in ref [[7], where a VSC (voltage source inverter) is used as shown in fig for the compensator. The error signal between the reference and actual compensator current is used to drive the PWM (pulse width modulated) control.

### 6.3 Fully controlled inverter with DC- Chopper.

This type of inverter is proposed in ref [5] with control strategies that can be applied to the converter. Using an extra DC/DC converter, the control of machine side DC-voltage is performed through variation of the duty cycle and maintains appropriate inverter side DC- voltage. Such DC/DC converter allows for selective harmonics elimination giving reduced losses. Another use of DC/DC converter based on interleaved boost converter in ref [3], which is composed of several identical boost converters connected in parallel as shown in figure.7. The converters are controlled by the interleaved switching signals with the same frequency and phase shift.

The input current is shared among the DC/DC converter, so that high reliability and efficiency in power electronic system can be obtained. In addition it is possible to improve the system characteristics such as maintenance, repair, fault tolerance, and low heat dissipation. High

performance rectifier with wide speed range was proposed in ref [2] using a boost chopper illustrated in figure.8. Where SW1 and SW2 are the two power devices in series. This arrangement is used for high voltage level which makes high dielectric strength and the structure can reduce current ripples by eliminating the harmonics.

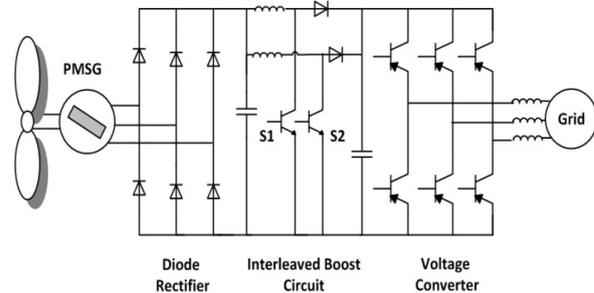


Figure.7 shows Diode rectifier with controlled inverter and interleaved boost converter.

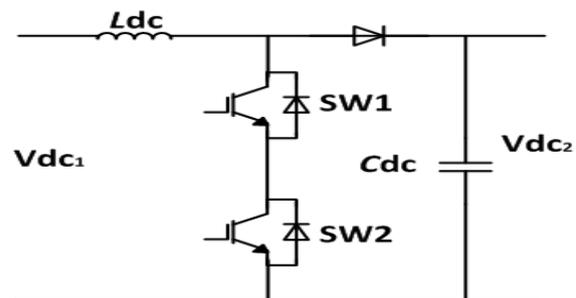


Figure.8 shows basic boost converter

### 6.4 Bidirectional Back to Back PWM converters.

Using these types of converters, the machine-side converter can completely regulate the generator input/output in terms of speed, power factor, and electromagnetic torque.

### 6.5 Voltage Source Converter.

The most frequently used converter configuration with modeling and simulation of PMSG based wind energy conversion is this type, and it is also called as (back to back) voltage source converter. It consist of fully controlled converters with intermediate DC-link as shown in figure.9

Low voltage, high current level, and reliability demands require parallel operation of such converter to be used as proposed in ref [4], where isolated DC-link dual back to back PWM parallel converter is used as illustrated in figure.10,Such configuration solves the zero-sequence circulating current problem using the CPS (carrier phase shift) technique.

Three level flying capacitor converters with CPS silent PWM technique was also proposed in ref [3] in high power application as illustrated in figure.11

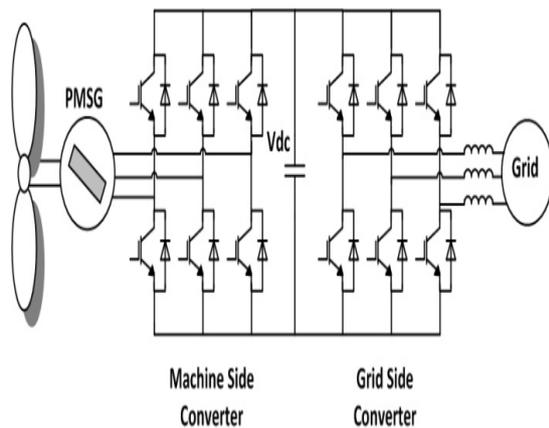


Figure.9 shows Back to Back voltage source converter.

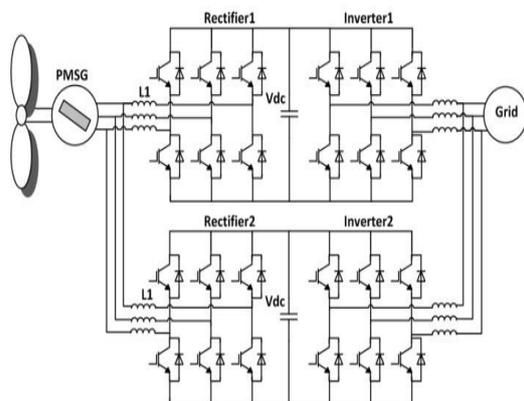


Figure.10 shows Parallel Back to Back voltage source converter.

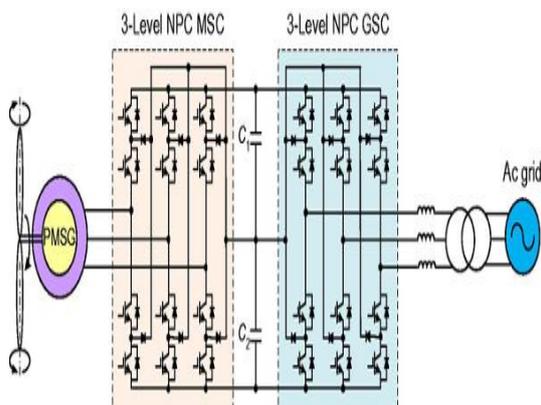
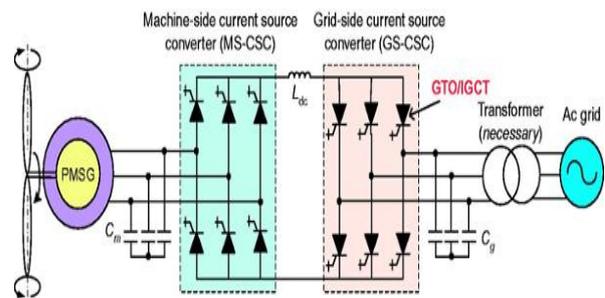


Figure.11 shows Flying capacitor three level Back to Back converter

### 6.6 Current Source Converter.

The PWM CSC (current source converter) has simple construction as shown in figure.12. Which provides excellent grid integration performance. Such as sinusoidal current and fully controlled power factor in ref [3, 5]. The operation of the current source converters requires a constant current source, which could be maintained by either the machine-side or grid-side converter.



Source: Dai et al. (2009)

Figure.12 shows Basic current source converter

## VII. System control.

A basic diagram of the control system of PMSC based on wind energy conversion system is shown in figure.13. The active and reactive power delivered to the grid can be controlled to improve the system performance. In addition the system control can enhance the (FRT Fault Ride Through) capability of the wind farm during fault condition to satisfy the low voltage ride through requirements given in subsection .the chopper might be eliminated according to the control strategy and system design.

The two Back to Back converter are controlled independently through the decoupled d-q vector control approach for modern PMSG wind turbine design in ref [2, 4].The controller of the machine-side converter normally has a fast inner current loop, controlling the stator  $i_{sd}$  or  $i_{sq}$  current components, where the  $d$ -axis current component is normally used to control flux and the  $q$ -axis current component utilized to control the torque, combined with an outer slower loop for torque and/or stator reactive power control

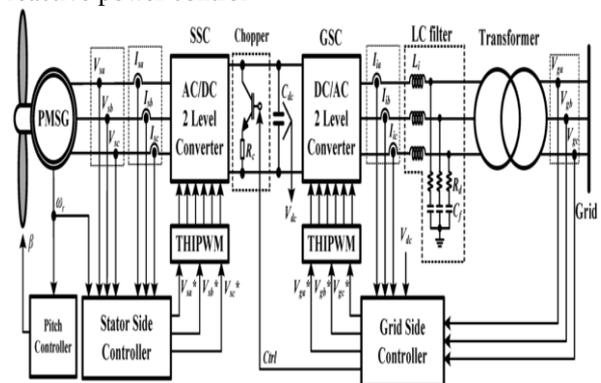


Figure.13 shows PMSG control system

### 7.1 Torque Control.

In torque control method the control is done as illustrated in figure.14.through the direct and the quadrature current components  $I_d$  and  $I_q$  which generate the reference voltage  $V_{dref}$  and  $V_{qref}$ . the PWM for desired generator voltages are generated after inversion the direct and quadrature reference voltage to three phase system [5],

If the stator current is controlled to have the  $q$ -component only the generator will provide the maximum torque. This control method is also called  $I_d = 0$  control and applied to improve the efficiency of the machine. With this control, the machine torque is coordinated with the magnitude of the  $q$ -axis current, while the  $d$ -axis current is always kept to zero.

According to the rotor-flux-oriented strategy, the stator current vector should always be kept aligned with the back EMF of the PMSG. In other words, the torque angle  $\delta$  is controlled.

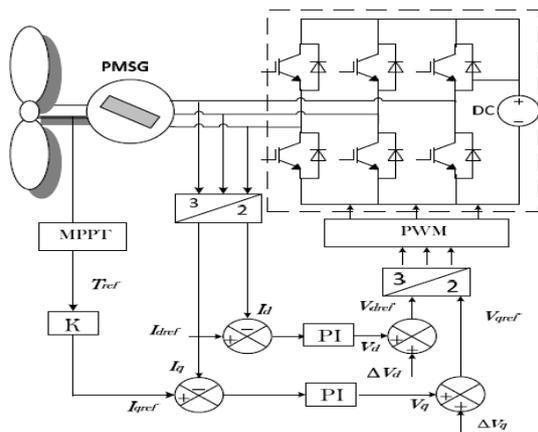


Figure.14 shows basic machine-side control scheme.

### 7.2 Unity Power Factor Control.

The unity power factor control of the rectifier can be implemented by making the direct stator current component compensate the reactive power demand of the generator. This would lead to a reduced converter rating and consequently a smaller size and hence reduce the cost of the power circuit. This is one of the significant considerations for megawatt level wind turbine design. In this control, the stator voltage varies depending on speed which leads to over voltages at over speeds [1]. Since the reactive power supplied to grid is independent on generator reactive power it is not common to control the machine-side reactive power.

### 7.3 Constant stator voltage control.

To keep the stator voltage within its rated value the constant stator voltage control is used, where the  $d$ -axis is aligned to stator voltage vector which is called stator voltage oriented reference frame. The active power then depends on the stator current  $d$ -axis component. While the reactive power depends on the  $q$ -axis quadrature component only.

$$P = \frac{3}{2} V_{sd} i_{sd} \quad (21)$$

$$Q = \frac{3}{2} V_{sd} i_{sq} \quad (22)$$

In this control there is no over voltage, but the reactive power demand of the generator will increase the converter ratings.

## VIII. Grid-side converter.

The grid-side converter is normally controlled in such a way that to maintain the DC-link capacitor voltage in set value and to maintain the converter operation with a desired power factor.

### 8.1 Current controlled inverter with hysteresis controllers.

This control method is convenient for small power applications and the inverter is controlled by a hysteresis control of the current [9]. As shown in figure.15 An LC filter is integrated to reduce current harmonics caused by switching. The currents when working at unity power factor is given by

$$I_{ref} = \sqrt{2} \frac{P_{r\_grid}}{3V_{r\_grid}} \quad (23)$$

And then the reference currents are multiplied by a three phase sinusoidal generator to obtain the instantaneous reference current to synchronize current with the grid voltage.

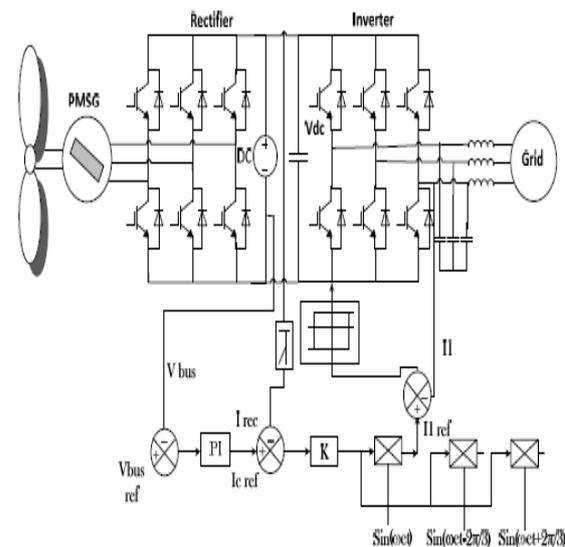


Figure.15 shows current controlled inverter with hysteresis controllers' scheme.

### 8.2 PWM-Controlled Inverter with PI Current Controllers.

The inverter current references are generated using the desired active and reactive values and then the reference voltage components are generated by PI controllers, where

$$P = V_{sd} i_{sd} + V_{sq} i_{sq} \quad (24)$$

$$Q = V_{sq} i_{sq} + V_{sd} i_{sd} \quad (25)$$

As illustrated in figure.16. The active power is generated using DC bus voltage and the reactive is set as the requirements of the grid, and omitted if a unity power factor is a demand. [6]

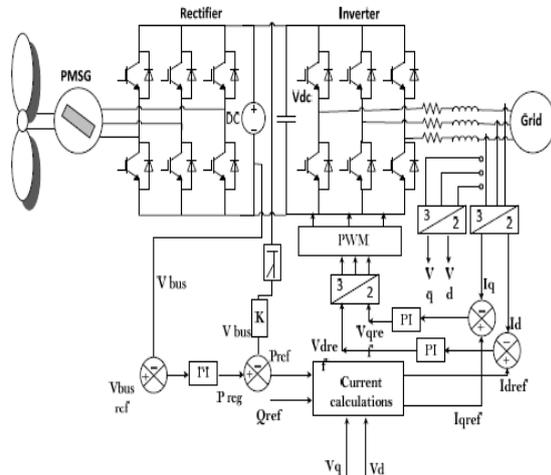


Figure.16 shows PWM-Inverter with active and reactive power control scheme.

### IX. Maximum Power Point Tracking Methodology.

The function of MPPT (maximum power point tracking) is to automatically adjust the generator speed to converge to the optimum one where the generated power is maximized. This may be obtained using PI control with the use of the electrical power at the grid-side instead of the mechanical power of wind turbine. With this option, the losses of both generators and converters will also be taken into consideration and, the overall energy conversion can then be optimized.

For a given wind speed, the optimal rotational speed of the wind turbine rotor can be simply estimated as follows;

$$\omega_{opt} = \frac{V_{wind} \lambda_{opt}}{R} \quad (26)$$

Then the maximum mechanical output power of the turbine is given as follows;

$$P_{Turbine} = \left(\frac{1}{2} \rho_{air}\right) \times C_{P\ max} \times \left(\frac{\omega_{opt} R}{\lambda_{opt}}\right)^3 \quad (27)$$

Then, the maximum power  $P_{Turbine\_max}$  can be achieved by regulating the turbine speed in different wind speed under rated power of the wind power system. Therefore, an optimum value of tip speed ratio  $\lambda_{opt}$  can be maintained and maximum wind power can be captured. The MPPT curve and the corresponding torque are defined as function of  $\omega_{opt}$ , the speed referred to the generator side of the gear box;

$$MPPT = K_p \omega_{opt}^3 \quad (28)$$

From the optimum power the optimum torque can be calculated;

$$MPPT = K_t \omega_{opt}^2 \quad (29)$$

There are different methods to perform MPPT control for wind turbines.

#### 9.1 Tip Speed Ratio Control.

Using TSR (tip speed ratio) control, the wind speed needs to be measured using anemometer. This is difficult to perform, since the accurate wind speed is not available and the cost with increasing complexity is the result

#### 9.2 Power Signal Feedback Control.

With this control the turbine maximum speed curves must be known. With comparing the current speed and the stored speed curves the controller and tracks the maximum power point.

#### 9.3 Hill Climbing Searching Control.

This control is used in small turbines and is very similar to MPPT scheme used in photovoltaic system. When the wind turbine speed increases, the output power should normally increase as well otherwise the speed should be decreased.

#### 9.4 Sensor less Control.

In the machine-side converter, control of the speed is required to extract maximum power during speed variation. Presence of sensors for rotor speed and position signals has effects on cost, system size and reliability. Therefore, sensor less concept is utilized to estimate rotor position and speed signals. [3, 4]. In ref [5] a novel method to obtain the information is by monitoring the terminal waveform (output control signal) and rate of change. Recently, position and speed estimation is proposed in ref [6] by using an adaptive network based on fuzzy interference system for wide range of speed operation. Such estimator indicates immunity against parameter variation [4]

### X. CONCLUSION.

This paper present a comprehensive review on study of modeling and simulation of permanent magnet synchronous generator based on WECS. Detail of the MPPT concept is provided for variable speed operation. The PMSG is introduced as construction and model with some information about generators already available in market. Different types of wind turbine generator is also discussed, the mathematical equation of PMSG which is established in d-q reference frame is also provided in this paper, and concept about the drive train, different types of

drive train, configurations of the possible power converters have been presented and discussed as well the semiconductor power switches used in converters. Wind turbine controls have been considered as pitch control and stall control. Various control methods and techniques for generator side and grid side converters are presented in details for the purpose of satisfaction of technical requirements. Such requirements are control of active and reactive power, high quality of power delivered to the grid, capability of voltage ride-through during voltage dip, better stability performance as well as possibility to simplify the wind turbine system by using sensor less control

#### ACKNOWLEDGMENT.

Author thanks to Prof. Dr. Z. J. Khan (H.O.D Electrical Engineering Department) Rajiv Gandhi College of Engineering Research & Technology, Chandrapur (M.S) India, for supporting to conduct such research work.

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