Comparison of Wind Turbine Driven PMSG Fed Wind Energy Conversion Systems Using Reactive Power Controlled Two Level Inverter

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Abstract— Wind energy conversion systems are now seeking great importance today. Replacing Fixed speed wind turbine system with variable speed turbine system improves the performance. To extract and deliver maximum power from wind energy systems, power electronic devices are using. To reduce the harmonics due to the switching action , reactive power control algorithm is used in this work. To maintain the dc link voltage, a rectifier is used. The whole system is simulated for wind energy conversion systems using reactive power controlled Two level inverter with controlled and uncontrolled rectifiers.

Keywords— Wind energy conversion system, Permanent Magnet Synchronous Generator, Pitch angle control, diode rectifier, DC link Voltage, Sine PWM, Two level inverter, Reactive Power control, Total Harmonic Distortion.

INTRODUCTION

Throughout the world, in last three to four decades the generation of electricity using renewable sources has created great interest. Solar and Wind are the main sources that we can use. The advantages of this sources are they are pollution free, environmental friendly and sustainable. Using this sources we can meet the energy deficiency present over the world. There are countries , where there is no continuous power is not present . So in such places, the utilization of such natural sources are very useful.

Wind is such a natural source to replace the conventional sources. There are many areas over the world , where there is a large availability of wind. In those places wind energy conversion system (WECS) can be taken as a energy production system to support the grid. For a WECS it is very critical to select the generators and to design the wind turbine and converter control algorithms. The wind turbine system design should be done for maximum power tracking. There are mainly two types of wind turbine systems. One is fixed speed wind turbine (FSIG) system and other is variable speed wind turbine systems (VSIG) [1,2].

The turbine converts the kinetic energy present in wind to mechanical energy and the mechanical energy is to be converted to electrical energy by means of a generator. The fixed speed wind turbine uses SCIG and WRIG. They always produces a electrical power with a fixed frequency corresponding to its synchronous speed. The rotor always runs at a constant speed for all wind speed. The fixed speed wind turbine can never achieve or operate at peak efficiency across a range of wind speeds. Also the FSIG needs to draw a small amount of current for its excitation , from grid. That will introduce reactive power consumption. Due to above drawbacks VSIG are preferring in most cases. VSIG are mainly permanent magnet synchronous generator (PMSG), Doubly fed induction generator(DFIG). Among PMSG and DFIG , PMSG is preferred due to its small size ,presence of permanent magnet rotor, and absence of excitation [3].

The electrical power produced from PMSG is having variable frequency, since the wind speed is varying. So in order to convert this variable frequency power to a constant frequency power the system uses power electronic interfaces. The power electronic interface is a AC/DC/AC converter. The AC-DC conversion can be done by using a diode rectifier or a controlled rectifier. If the rectifier is controlled one, it is easy to maintain constant DC link voltage. The DC-AC conversion is offered by inverters, mainly two level inverters. There may be switching actions and due to that harmonics content may present there. The harmonic content leads to reactive power consumption. So in order to overcome the reactive power consumption control algorithms uses. Here in this work a reactive power control algorithm is proposed [4,5].

PROPOSED SYSTEM

The proposed WECS is shown in fig 1. The wind turbine converts kinetic energy to mechanical energy and the PMSG converts the mechanical energy to electrical energy. Pitch angle provided in the system is for tracking maximum power. The two mass driven train act as a mean to overcome the vibrations present in shaft of a wind turbine. The entire system is studied by using a diode rectifier and a controlled rectifier. The diode rectifier present will convert the AC power into DC power. The electrical power generated will be a

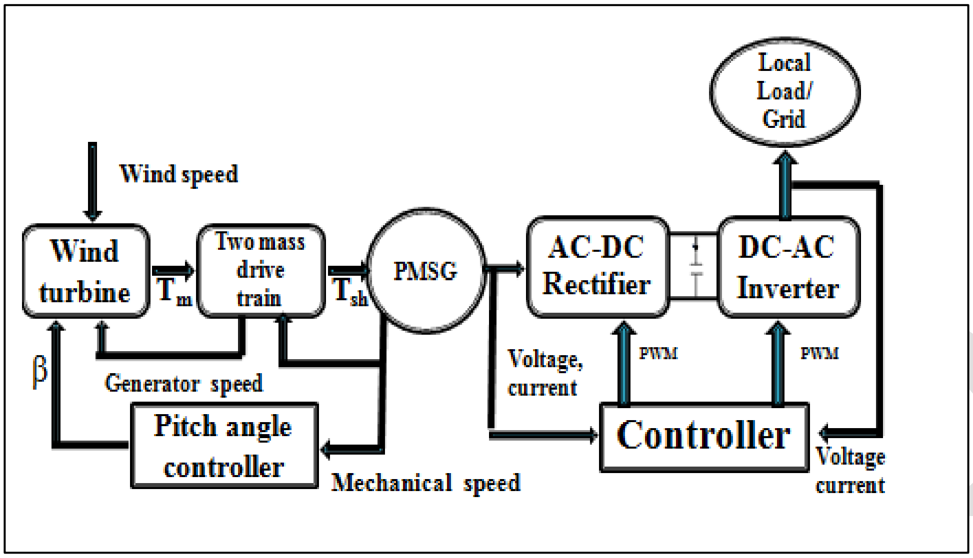

Fig. 1 proposed wind energy conversion system

variable frequency one. That is o be converted in to constant grid frequency supply by using the power electronic interface. The controllable inverter helps in converting the DC power to an AC power with grid frequency and magnitude.

WIND TURBINE DRIVEN PMSG MODELING

The modeling of wind turbine is the most important part for a WECS. The turbine modeling should be done to capture maximum kinetic energy from the wind with less cost. The mathematical expressions for the modeling of wind turbine systems are given below.

The expression of the mechanical torque developed by a wind turbine *Tm* is given by the following [4, 6]:

$$T_m = \frac{1}{2}\rho\pi R_t{}^2 C_p(\lambda,\beta)\frac{v^3}{\Omega_r} \qquad (1)$$

Such that:

$$\lambda = \frac{R_t\Omega_r}{v} \qquad (2)$$

In order to simulate the wind generation system, expression of *Cp (λ , β)* has been considered , such that; [4]

$$C_P = [0.5 - 0.00167(\beta-2)]\sin\left(\frac{\pi(\lambda+0.1)}{12-0.3(\beta-2)}\right) - 0.00184\,(\beta-2)(\lambda-3) \qquad (3)$$

The conversion of wind energy into mechanical energy over the rotor of a wind turbine is influenced by various forces acting on the blades and on the tower of the wind turbine. So this may change the pitch angle. According to bets concept maximum power can be captured when coefficient of performance value is maximum. Which is maximum when pitch angle is zero. So inoder to keep the pitch angle zero for all wind speed a pitch angle controller is also provided. There may be vibrations in the mechanical torque produced from the turbine due to sudden variation of wind speed. So that should be avoided by using a two mass drive train. The modeling equation for the drive train are given below.

The equation of the torque for drive train is given by

$$H_g\frac{d\omega_g}{dt} = T_e + \frac{T_m}{n} \qquad (4)$$

Since the wind turbine shaft and generator are coupled together via a gearbox, the wind turbine shaft system should not be considered stiff.

$$H_m.\frac{d\omega_m}{dt} = T_\omega - T_m \quad (5)$$

The mechanical torque *Tm* can be modeled with the following equation.

$$T_m = K\frac{\theta}{n} + D\frac{\omega_g - \omega_m}{n} \quad (6)$$

$$\frac{d\theta}{dt} = \omega_g - \omega_m \quad (7)$$

where n is the gear ratio, θ is the angle between the turbine rotor and the generator rotor, ω m , ω g , H m and H g are the turbine and generator rotor speed and inertia constant, respectively .K and D are the drive train stiffness and damping constants, Tω is the torque provided by the wind and T e is the electromagnetic torque.

The modeling of PMSG system is also important for a WECS. The mathematical modeling equations based on d-q reference frame are given below [7,8].

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} r_s & 0 \\ 0 & r_s \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{d}{dt}\begin{bmatrix} \varphi_d \\ \varphi_q \end{bmatrix} + \omega_r\begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}\begin{bmatrix} \varphi_d \\ \varphi_q \end{bmatrix} \quad (8)$$

For a sinusoidal distribution of the back e.m.f, the flux and current phases are linked by the following expressions:

$$\varphi_d = L_d i_d + \varphi_r \quad (9)$$

$$\varphi_q = L_q i_q$$

where φ_r is the rotor flux.

Substituting equation (5) on equation (4), we obtain the following system via *Laplace* transformation

$$\{ \; v_d = (r_s + L_d\rho)i_d - e_d \quad (10)$$

$$v_q = (e_s + L_q\rho)i_q + e_q$$

Such that the direct and the quadrature back e.m.f components are expressed as:

$$\begin{cases} e_d = \omega_r L_q i_q \\ e_q = \omega_r L_d i_d + \omega_r \varphi_r \end{cases} \quad (11)$$

The stator active and reactive powers of the PMSG Machine are given by the equations (8):

$$\begin{cases} P_s = \frac{3}{2}(v_d i_d + v_q i_q) \\ Q_s = \frac{3}{2}(v_q i_d - v_d i_q) \end{cases} \quad (12)$$

Under generator operation, the mechanical equation is expressed as follows:

$$T_m - T_{em} = J\frac{d\Omega_r}{dt} + K_f\Omega_r \quad (13)$$

The electromagnetic torque can be expressed ,in (d, q frame)as follows:

$$T_{em} = \frac{3}{2}n_p\left(\varphi_r - \left(L_q - L_d\right)i_d\right)i_q \quad (14)$$

REACTIVE POWER CONTROL ALGORITHM

Presence of power electronic devices and non linear components draw reactive power from the grid. This will reduce the active power produced and will affect the power quality of the system. In order t reduce the reactive power consumption d-q axis control can be done. The reactive power controlled inverter control algorithm presented here is used to increase the efficiency of wind energy conversion system by reducing the reactive power present in the system. The control algorithm also helps in interfacing the variable power produced from the PMSG driven wind energy conversion system to a grid supply. The control method used here is to produce a reference signal for pulse production which is meant to reduce the reactive power consumption and THD. There is an abc-dq transformation for the easier control of dc link voltage and reactive power control. [9-14] .

WECS using uncontrolled rectifier and reactive power controlled Two level inverter

The WECS using uncontrolled rectifier and controlled two level inverter is shown in Fig. 2. Here the uncontrolled rectifier will introduces a large amount of harmonic content in the switching system and since there is no control DC link voltage cant be maintained to constant. The wind turbine system is a variable speed one. So the variation in speed will also be there in the dc link voltage and obviously in the inverter output also. Since we are using a reactive power control in the inverter side, the control will reduce the reactive power control and THD component not the voltage amplitude.

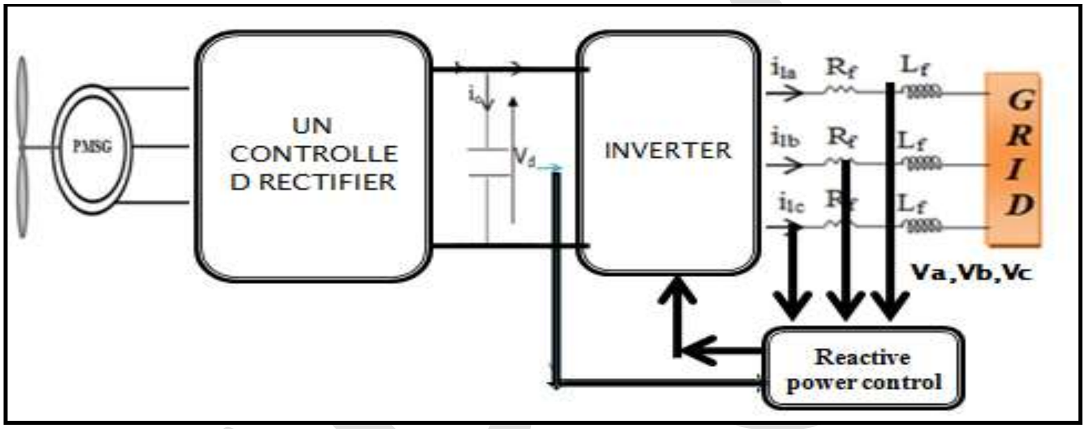

Fig. 2 WECS using uncontrolled rectifier and two level inverter

WECS using controlled rectifier and reactive power controlled Two level inverter

The WECS using controlled rectifier and controlled two level inverter is shown in Fig. 3, which is having controlled rectifier to control the dc link voltage. The control of dc link voltage is done by controlling the speed and torque of the PMSG. The current controller and voltage controller provided in the rectifier controller will helps to maintain the torque and speed of PMSG. So there will not be any vibrations in the output of PMSG and will get a constant DC link voltage. By using reactive power controlled two level inverter a constant 415V, 50Hz supply with less THD can be obtained.

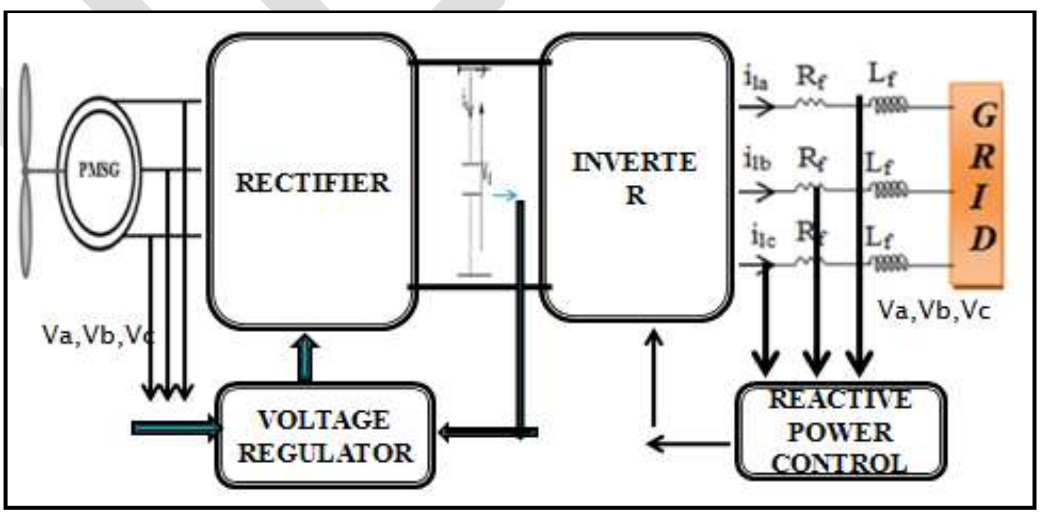

Fig. 3 WECS using controlled rectifier and two level inverter

RESULTS OBTAINED

The simulation study of the WECS using the controlled and uncontrolled rectifiers are done by choosing the following parameters. A four pole PMSG machine is used for the study. The parameters are given in table 1.

Table XII Parameters for both the wind turbine and PMSG

Parameters of machine		Parameters of turbine	
PARAMETER	VALUE	PARAMETER	VALUE
P_r, rated power	2.00 KW	Air density	1.08 kg/m^3
L_d L_q	0.01 H	A, area swept by blades	31.98 m^2
R_r , rotor resistance R_s, stator resistance	0.425 ohm	V, base wind speed	12 m/s
Pole pairs	4	C_{pmax}	0.48
Voltage constant	300 V_{pp}/rpm	Lambda	8.1
Torque constant Inertia constant Viscous	2.48 Nm/A 0.01197 kgm^2 0.001189 N.m.s	Pitch angle , β	0

The wind turbine and PMSG modeled using above equations are shown in fig 4 and fig 5.

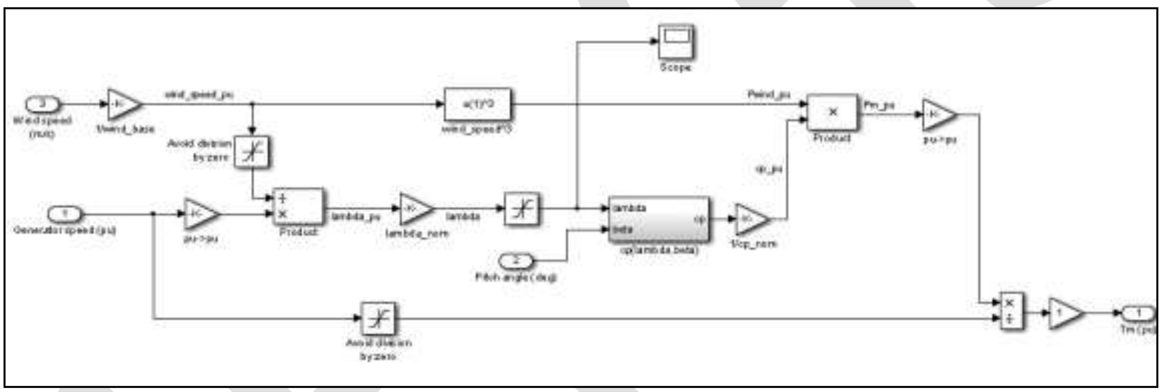

Fig. 4 Model For Wind Turbine System

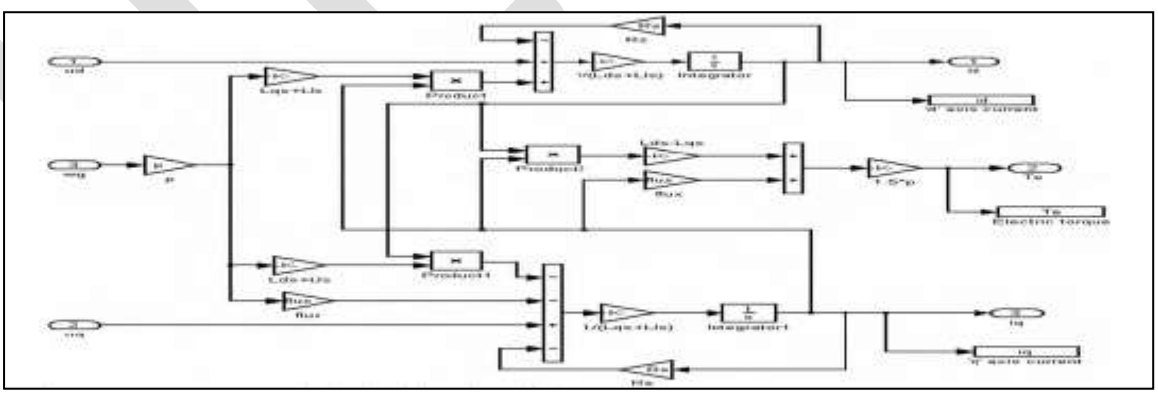

Fig. 5 Model For PMSG System

The simulation waveforms for wind velocity, torque produced from wind turbine system (T_m) and torque given to PMSG after two mass drive train (T_{sh}) are shown in below Fig. 6 . It is clear that the sudden torque variations in the input side of a PMSG affects its performance.

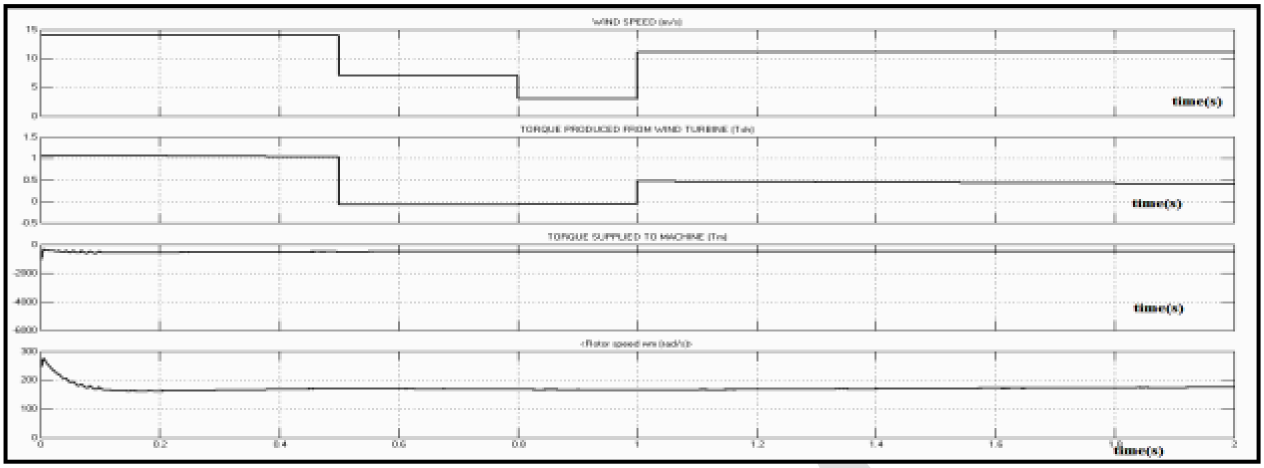

Fig. 6 Wind speed, Shaft torque, machine torque and rotor speed

The WECS using uncontrolled rectifier MATLAB model is shown in fig. 7.

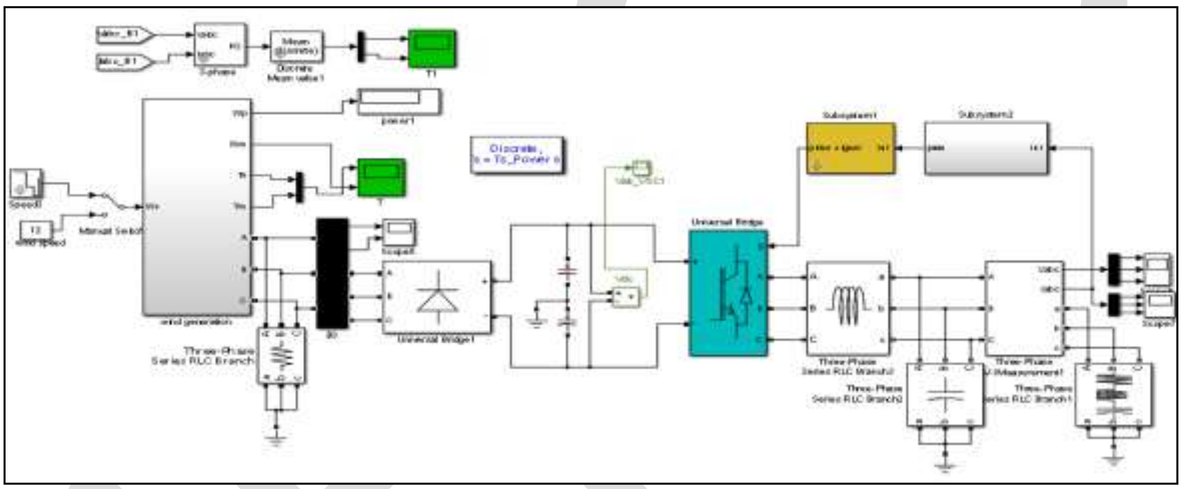

Fig. 7 Simulink model of WECS using uncontrolled rectifier and five level inverter

The generated voltage and current wave forms from PMSG of a WECS using uncontrolled rectifier is shown in Fig. 8. The DC link voltages using an uncontrolled rectifier with variations are shown in Fig. 9.

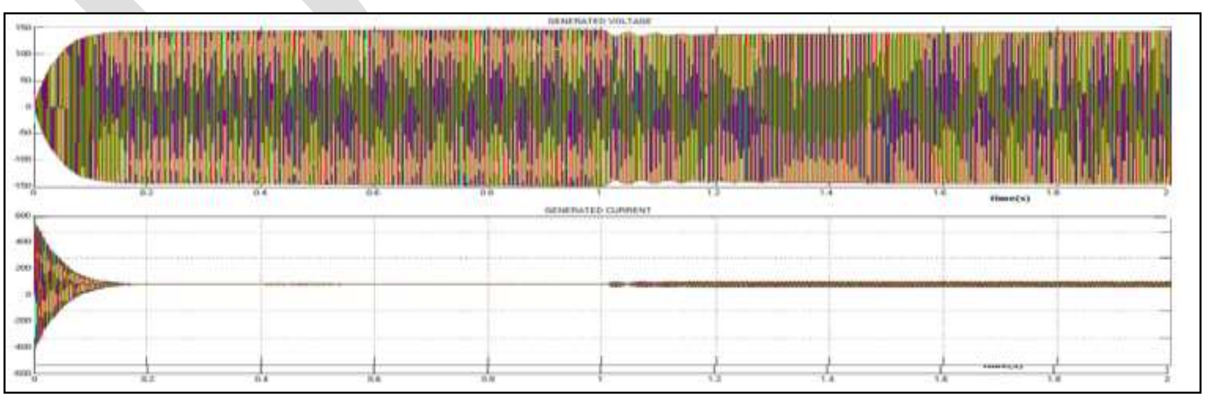

Fig. 8 Generated voltage and current from PMSG

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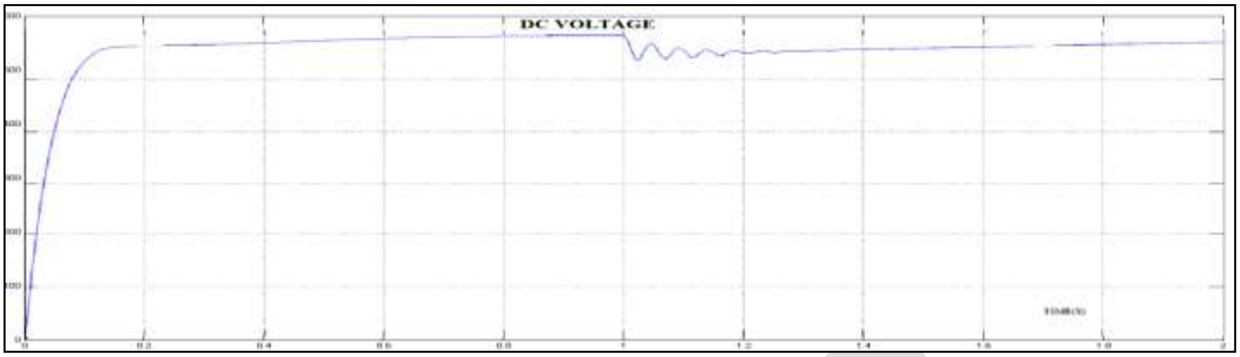

Fig. 9 Dc link voltage

The output voltage and current obtained from the Two level inverter using reactive power control is shown in Fig.10.

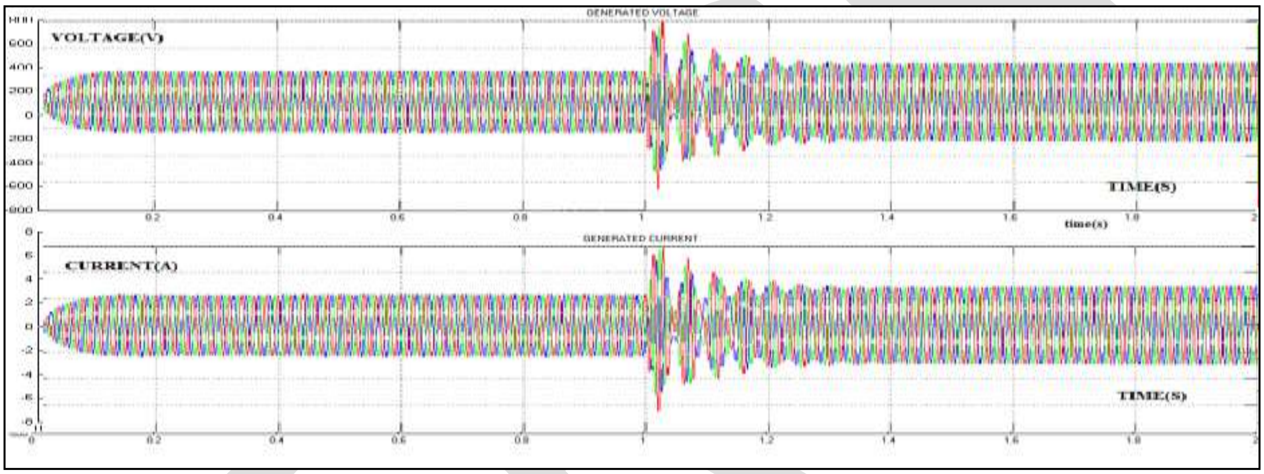

Fig. 10 Three phase output voltage and current from inverter

The WECS using controlled rectifier MATLAB model is shown in fig. 11. Here the vector control provided on the rectifier side will maintain a constant dc link voltage.

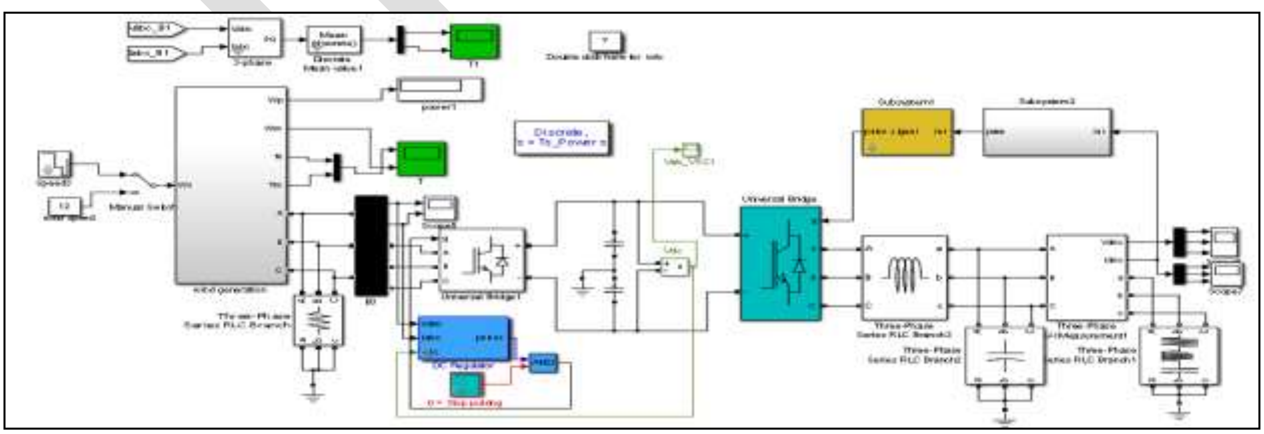

Fig. 11 Simulink model of WECS using uncontrolled rectifier and Two level inverter

The generated voltage and current wave forms from PMSG of a WECS using controlled rectifier is shown in Fig. 12. The DC link voltages using an controlled rectifier without variations are shown in Fig. 13. Where there is a small dip only in dc link voltage at 1 s due sudden high variation.

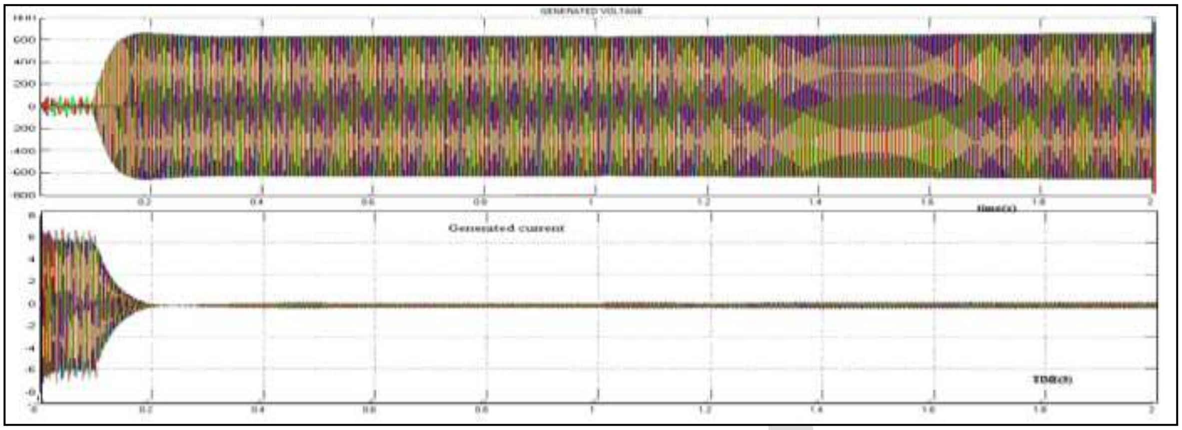

Fig. 12 Generated voltage and current from PMSG

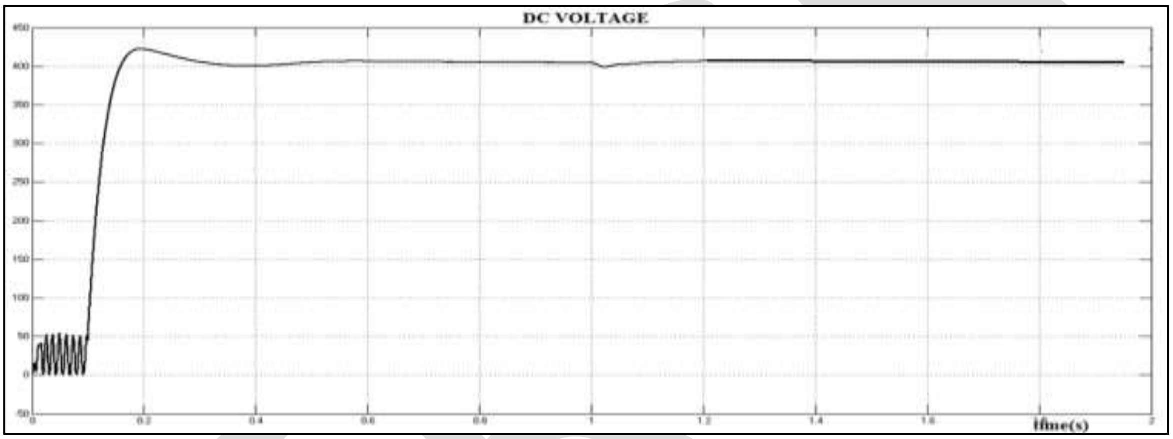

Fig. 13 Dc link voltage

The output voltage and current obtained from the Two level inverter using reactive power control is shown in Fig.14

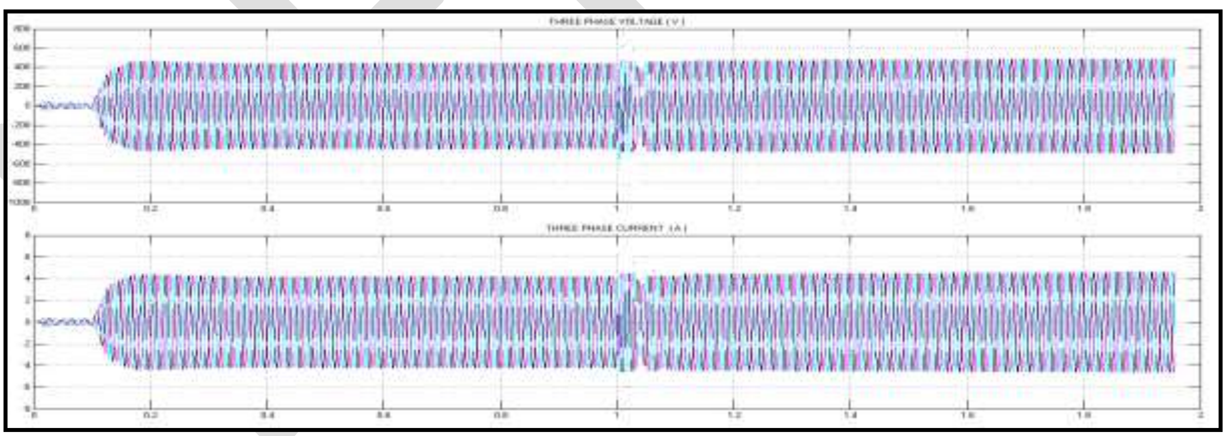

Fig. 14 Three phase output voltage and current from inverter

The THD analysis of both the system with controlled and uncontrolled rectifier system with Two level inverter is given below. It is clear from the analysis that using a controlled rectifier and a reactive power controlled inverter the reactive power consumption and THD can be reduced

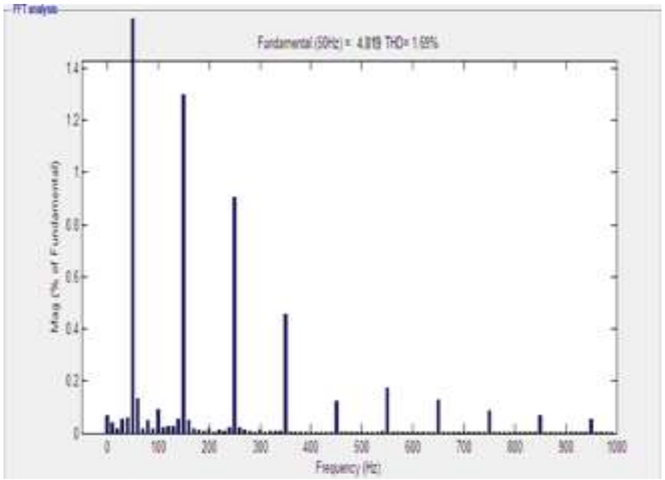

Fig. 15 THD of WECS with uncontrolled rectifier

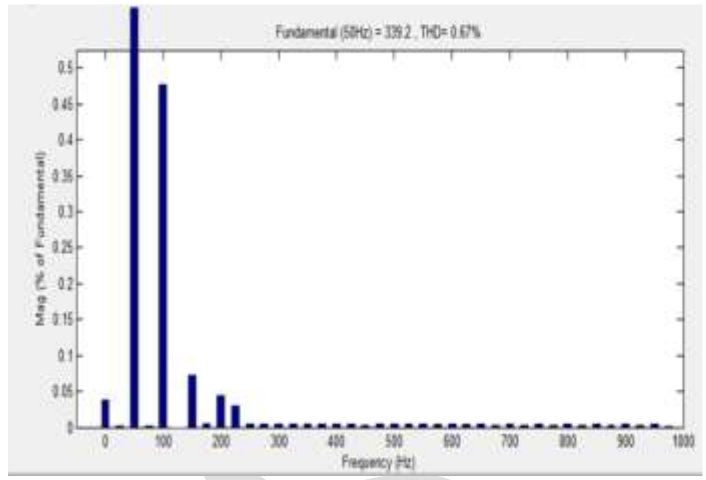

Fig. 16 THD of WECS with uncontrolled rectifier

CONCLUSION

In this paper a wind energy conversion system with two level inverter using controlled and uncontrolled rectifier systems has been introduced. Model has been implemented using MATLAB/Simulink software. The control provided on the rectifier side and reactive power control on inverter side improves the system performance. The THD level and reactive power consuming for a local load were studied for both the systems. By using a two level inverter and a controlled rectifier in a WEC system it is noted that the THD value and the reactive power consumptions are reduced than a system with two level inverter and uncontrolled rectifier. The THD values are lower than the IEEE standards also. This system provides a smooth grid interacting supply.

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