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# Performance, Analysis and Simulation of Wind Energy Conversion System Connected with Grid

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***Abstract:** This paper deals with permanent magnet synchronous generator (PMSG) based wind energy conversion system (WECS) integrated with grid with two back to back connected converters with a common DC link. The machine side converter is used to extract maximum power from the wind. In this paper a study of WECS is done by using a constant speed wind turbine and 2 mass drive train in Matlab. Moreover, by maintaining the dc link voltage at its reference value, the output ac voltage of the inverter can be kept constant irrespective of variations in the wind speed and load. An effective control technique for the inverter, based on the pulse width modulation (PWM) has been developed to make the line voltages at the point of common coupling.*

***Keywords:** Permanent magnet synchronous generator (PMSG), Wind energy conversion system (WECS) ,DC link capacitor ,variable speed wind turbine, Pulse width modulation (PWM), Insulated gate bipolar transistor (IGBT) Voltage and frequency control.*

## I. INTRODUCTION

Now days the consumption of fossil fuel is increasing day by day. The main reason behind the use of fossil fuel is to generate more and more energy. Due to consumption of more fossil fuel all living and non living beings including the environment is badly affected continuously.

In order to overcome these causes the renewable source of electricity generation is very advantageous because there is no harmful emission and the infinite availability of prime mover that is converted into electricity.

For the installation of wind energy MNRE scheme (The Ministry of New & Renewable energy) has introduced to aware more and more people about this technology, government also gives incentives in order to promote wind energy. Wind is air in motion; this is actually derived from solar energy. About 2% of total solar flux that reaches the earth's surface is transformed into wind energy due to uneven heating of atmosphere.

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This kinetic energy of wind is used to gain the rotational motion of wind turbine which is coupled with an electrical generator to supply over a region acting as stand alone or supplying power to a grid. An actual WECS (Wind energy conversion system) be considered as follow [1] which can be used in two different ways

(A) Isolated stand alone system
(B) Grid connected system

Figure 1 shows Isolated Standalone system which is used to provide energy to small scale industries or towns located in remote areas. Whereas Grid connected system leads to increased energy efficiency, increases support and reliability of system.

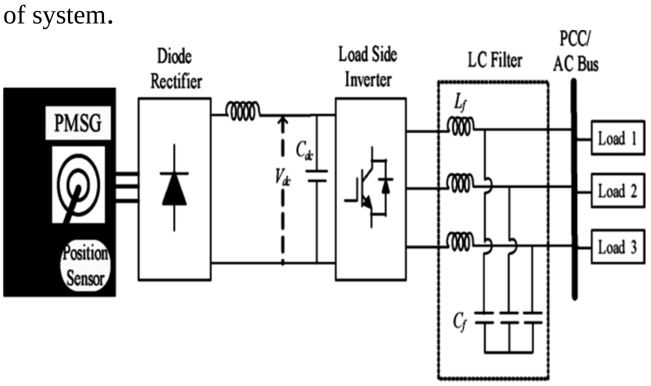


**Fig. 1. Standalone wind energy system.**

In wind energy application variable speed wind turbines are much better performance due to its maximum power point tracking algorithm (MPPT) .Now a days Doubly fed Induction generator are widely used in a variable speed wind turbine but te main drawback is the requirement of gear box to match turbine and rotor speed. The gearbox many times suffers and requires regular maintenance making the system unreliable [2] . The reliability of variable speed wind turbine can be improved significantly using a direct drive based permanent magnet synchronous generator (PMSG). To extract maximum power from the fluctuating wind, variable-speed operation of the wind-turbine generator is necessary. This requires a sophisticated control strategy for the generator. Optimum power/torque tracking is a popular control strategy, as it helps to achieve optimum wind-energy utilization [4-8]. Some of these control strategies use wind velocity to obtain the desired shaft speed to vary the generator speed. However, anemometer-based control strategy increases cost and reduces the reliability of the overall system. These control strategies are not suitable or too expensive for a small-scale wind turbine.

For output maximization of a PMSG based wind turbine a control strategy has been developed.


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The generator side switch mode rectifier is controlled to achieve maximum power from the wind .This method requires one switching device (IGBT) insulated gate bipolar transistor, which is used to control generator torque to extract maximum power.

## II WIND TURBINE CHARACTERISTICS

### *1 modeling of wind turbine*

Fig (3) shows the control structure of grid connected variable speed wind turbine which consists of wind turbine, PMSG ,single switch-three phase-switch mode rectifier and a vector controlled PWM voltage source inverter .The output of a variable speed wind turbine is not suitable for use as it varies in amplitude and frequency due to fluctuating wind .A constant DC voltage is required for direct use, or conversion to ac via inverter .The single switch three phase switch mode rectifier consist of a three phase diode bridge rectifier. The output of switch mode rectifier can be controlled by controlling the duty cycle of an active switch .At any wind speed to extract maximum power from the wind turbine and to supply loads .A vector controlled IGBT inverter is used to regulate the output voltage and frequency during load or wind variation. A horizontal axis wind turbine is used to drive the PMSG. A surface mounted non salient pole type PMSG is used. The kinetic energy presents in the wind is converted into the mechanical torque using a wind turbine. Mechanical energy is converted into electrical energy using a PMSG. To facilitate variable speed operation for achieving MPPT, the PMSG cannot be interfaced with the grid directly. Phase voltages are then applied to 10 KW load with suitable breakers.

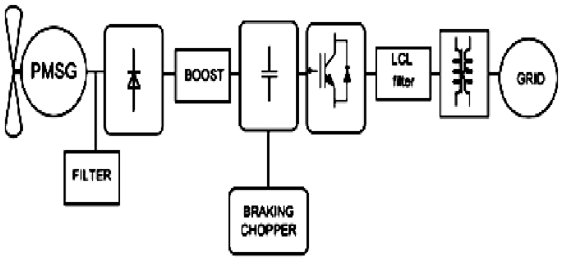


**Fig 2: Block diagram of wind turbine connected with grid**

This block implements a variable pitch wind turbine model. The performance coefficient $C_p$ of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta). $C_p$ reaches its maximum value at zero beta . According to the Aerodynamics, the aerodynamic power of the wind turbine can be expressed as

$$P_r = 1/2 \rho \pi R^2 Cp\,(\lambda)\, v3 \quad \ldots (1)$$

When the rotor speed is adjusted to maintain its optimal value, the maximum power can be gained as

$$P_{rmax} = k_{opt}\omega^3 \quad \ldots (2)$$

Where $k_{opt}$ is decided by

$$Kopt = \rho\pi R5Cpmax2\lambda 3opt \quad \ldots (3)$$

$$Tm\ opt = Kopt\ (\omega m\_opt)^2.$$

The mechanical rotor power generated by the turbine as a function of the rotor speed for different wind speed is shown in Fig. 3.

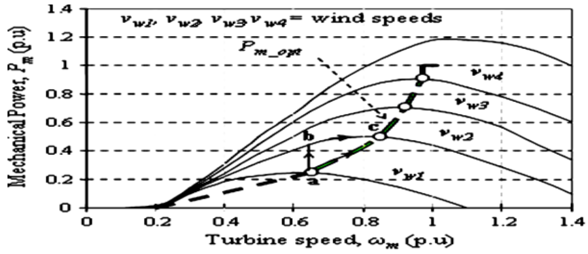


**Fig 3: Variation of mechanical power with turbine speed**

The optimum power is also shown in this figure. The optimum power curve (*P*opt) shows how maximum energy can be captured from the fluctuating wind. The function of the controller is to keep the turbine operating on this curve, as the wind velocity varies. It is observed from this figure 3 that there is always a matching rotor speed which produces optimum power for any wind speed. If the controller can properly follow the optimum curve, the wind turbine will produce maximum power at any speed within the allowable range. The optimum torque can be calculated from the optimum power given by equation (3). For the generator speed below the rated maximum speed, the generator follows equation (3)[6] . If $V_{dc}$ is maintained constant at its reference value and keeping the modulation index of load side inverter at 1.5, the amplitude of output ac voltage can be controlled and maintained at the rated voltage . The relation between dc voltage and output ac voltage of three-phase pulse width modulation (PWM) inverter is given by [7]

$$V_{LL1} = \frac{\sqrt{3}}{2\sqrt{2}}\, k\, V_{dc}$$

Where

$V_{LL1}$ is Fundamental phase-phase root-mean-square (rms) Voltage on the ac side

K = Fundamental phase-phase root-mean-square (rms) Voltage on the ac side

$V_{dc}$ is the dc link voltage

### *2. Two mass Drive Train*

Here WECS is represented with the two-mass drive train model. The differential equations governing its mechanical dynamics are presented as follows [11]

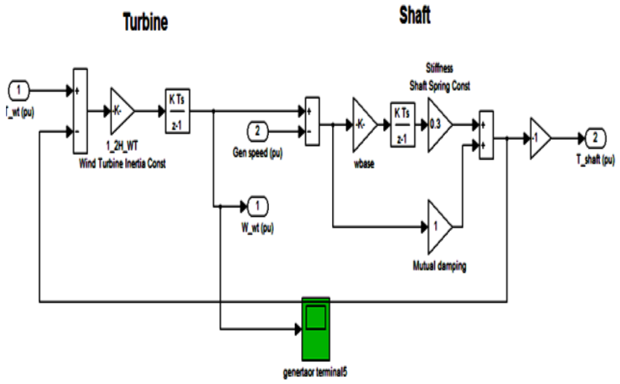


**Fig 4 Two mass drive train**


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$2H_t\, dw_t /dt = T_m - T_{sh}$
$1/w_{elb} * d\theta_{tw}/dt = w_t - w_r$
$2H_g dw_r/dt = T_{sh} - T_g$
Where $H_t$ is the inertia constant of the turbine, $H_g$ is the inertia
Constant of the PMSG, $\theta tw$ is the shaft twist angle, $w_t$ is the Angular speed of the wind turbine in p.u., wr is the rotor speed
of the PMSG in p.u., $w_{elb}$ is the electrical base speed, and the
Shaft torque $T_{sh}$ is
$T_{sh} = K_{sh}\, \theta_{tw} + D_t\, d\theta_{tw}/dt$
Where $K_{sh}$ is the shaft stiffness and $D_t$ is the damping coefficient.

## III. PERMANENT MAGNET SYNCHRONOUS MACHINE

The permanent magnet synchronous machine operates as a generator .The electrical and mechanical parts of this machine is represented by second order state space model. The sinusoidal model assumes that the flux established by the permanent magnet is sinusoidal which implies that electromotive forces are sinusoidal. These equations are represented in rotor reference frame .All quantities in the rotor reference frame referred to the stator.

$$\frac{d}{dt} i_d = \frac{1}{Ld} v_d - \frac{R}{Ld} i_d + \frac{Lq}{Ld}\, p\omega_r \mathrm{iq}$$
$$\frac{d}{dt} i_q = \frac{1}{Lq} v_q - \frac{R}{Lq} i_q + \frac{Ld}{Lq}\, p\omega_r \mathrm{id} - \frac{\lambda p \omega_r}{Lq}$$
$$T_e = 1.5\mathrm{P}\, [\lambda\, i_q + (Ld - Lq) i_d\, i_q\ ]$$

The Lq and Ld inductances represent the relation between the phase inductance and the rotor position due to the saliency of the rotor. For example, the inductance measured between phase a and b (phase c is left open) is given by

$$L_{ab} = L_d + L_q + (L_q - L_d)\cos(2\theta_e + \frac{\pi}{3})$$

$\theta_e$ Represents the electrical angle
$L_q$, $L_d$ q and d axis inductances
$L_q$, $L_d$ q and d axis inductances
R Resistance of the stator windings
$I_q$, $I_d$ q and d axis currents
$V_q$, $V_d$ q and d axis voltages
Wr Angular velocity of the rotor
λ Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
P Number of pole pairs
Te Electromagnetic torque

## IV. CONTROL OF PROPOSED WIND ENERGY SYSTEM

In this proposed wind energy system the output ac voltage is controlled through amplitude and frequency. Power from PMSG based wind turbine is fed to ac-dc-ac converters to maintain the output voltage at desired amplitude and frequency. The reactive power and an active power exchange with the grid are function of phase and amplitude of terminal voltage at AC terminals of a GSC. The objective of controlling a GSC is to keep constant DC link voltage under change in generated active power while keeping sinusoidal currents of PMSG as shown in figure 4.

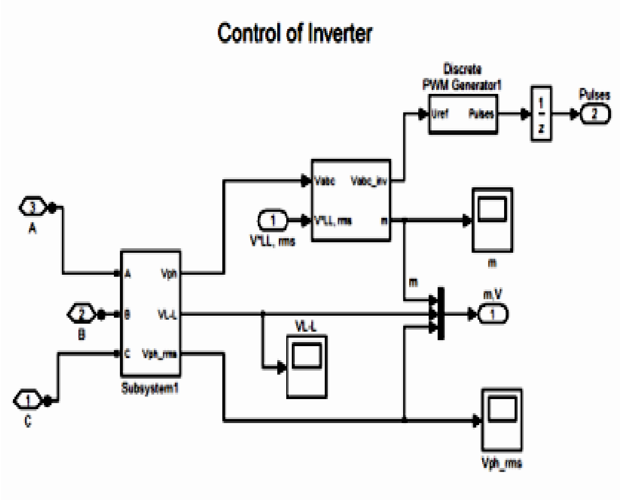


**Fig 5 Inverter control system**

Figure 6 shows the equivalent circuit of voltage source converter PWM VSI used here is a three phase VSI with six switches. In this figure three phase converters has six semiconductors displayed in three legs a, b and c. Only one switch on the same leg can be conducting at the same time each switch (S1, S2, S3, S4, S5 & S6) in the inverter branch is composed of semiconductor devices connected with antiparallel diode. The semiconductor device is a controllable device and diode is for protection.

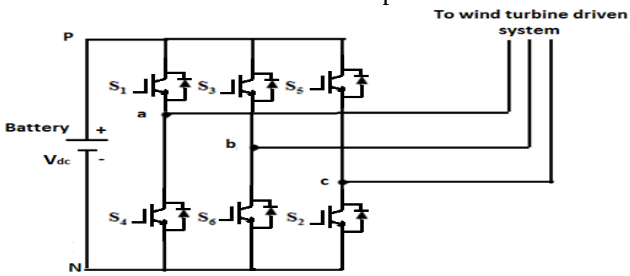


**Fig 6 Six switch composition of converter**

Due to unbalanced load connected to an inverter the currents will not same in all the phases and hence LC filters will cause unequal voltage drops. Hence it is necessary to compensate voltage imbalance .To achieve this goal the rms value of phase voltages and the reference phase voltage is given to a PI controller. The output of PI controller is multiplied with a unit sine wave generator to get the reference phase voltages. By using these reference voltages PWM pulses are generated to switch the load side inverter. The schematic of this control arrangement is shown in below figure 7. [9]

Phase voltage is firstly arranged to the rms value and compare it with reference value and this reference value is calculated by $V_{LLrms}$ and giving this rms value to PI controller .One voltage has been generated for inverter this voltage is given to the reference voltage of PWM .The above fig is of fixed reference value 222 or by peak detection method the output of which is shown by dotted but in this paper we are using a simple arrangement for reference value 400.


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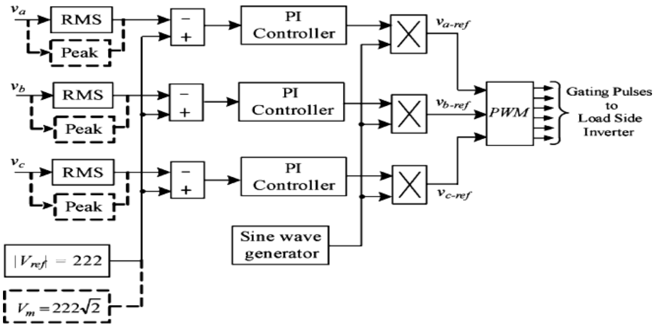


**Fig 7 Control System of inverter**

## V. FILTER DESIGN

In order to achieve almost sinusoidal voltage the resonance frequency of the filter has to be well below the lowest harmonic frequency of the inverter voltage resulting from pulse width modulation. The resonance frequency determines damping and stability. Resonance frequency is determined by the product of L and C [12]

$$W_r = \frac{1}{\sqrt{LC}}$$

The choice of the individual values of L and C is a remaining degree of freedom. From the view of cost and weights, the capacitor is much cheaper device. Looking at the inverter current a big choke has the advantage that it limits the current which the inverter has to deliver for charging the filter capacitors. The current adds to the motor current and is an extra load to the inverter. A choke that is too small therefore either reduces the output power of the inverter or causes extra costs because of oversized power semiconductors. [10]

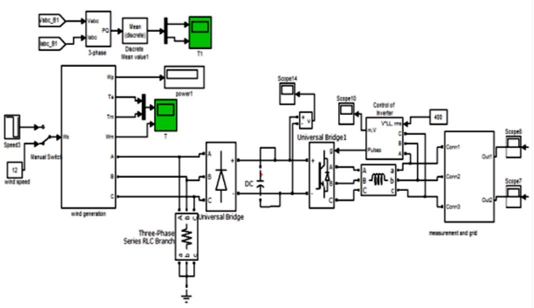

**Fig 8 Proposed wind energy conversion system in Matlab/Simulink**

## VI. RESULT

All the modeling is done in Matlab simulink with simulation type continuous powergui.In this section the measurements results for the grid connection of permanent magnet synchronous generator using the power electronic converter described above. Figure 9.6 shows phase voltages and phase currents. The output of WECS using PWM technique is shown below in which the phase voltages line currents , rms value of phase currents active power and rotor speed is shown in figure 9.1,modulation index is maintained at 1.5 as shown in figure 9.2.simulation results of developed WECS connected to a utility grid under different conditions . I.e. under constant wind speed , step change in wind speed.

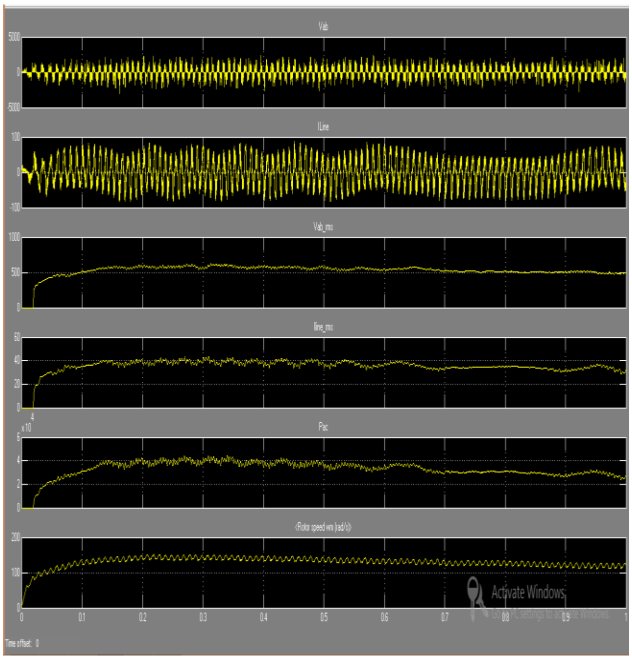

**Fig 9.1 Figure 9(a) shows that phase voltages (b) shows line currents (c) rms value of phase voltage (d) rms value of phase currents (e) active power (f) rotor speed for wind speed 7m/s**

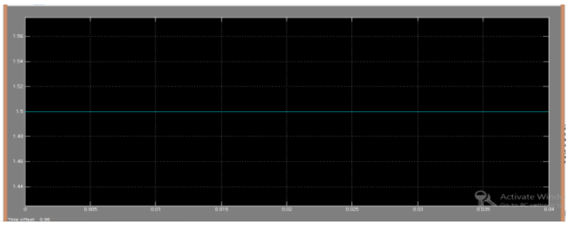

**Fig 9.2 shows the modulation index**

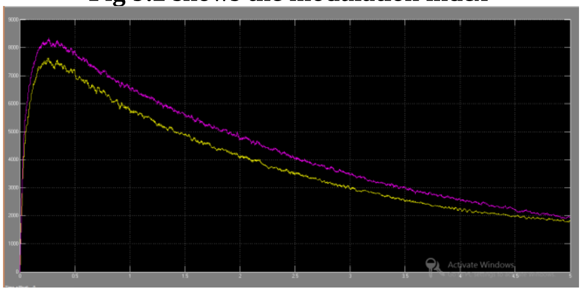

**Fig 9.3 Instantaneous active and reactive power waveforms**

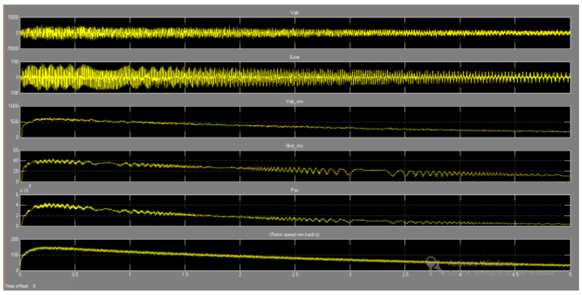

**Fig 9.4 Figure 9(a) shows that phase voltages (b) shows line currents (c) rms value of phase voltage (d) rms value of phase currents (e) active power (f) rotor speed for wind speed 12 m/sec**


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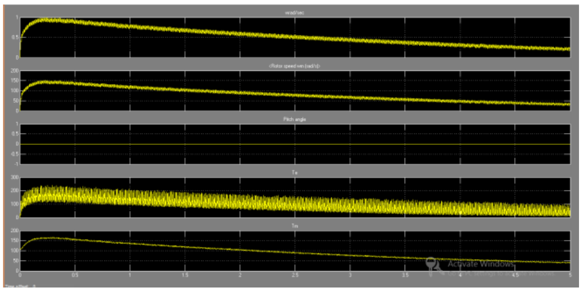

Fig 9.5 (a) wind speed (b) rotor speed (c) pitch angle (d) Electrical Torque (e) Torque

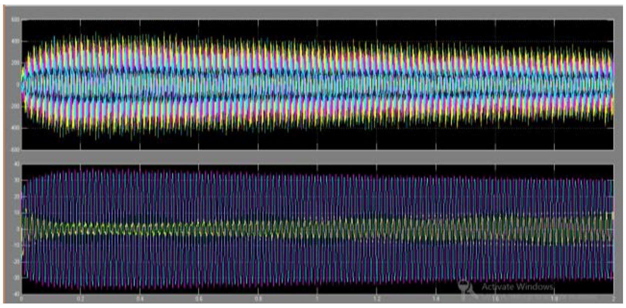

Fig 9.6 Waveform of Voltage and currents across the grid in constant wind speed 12m/s

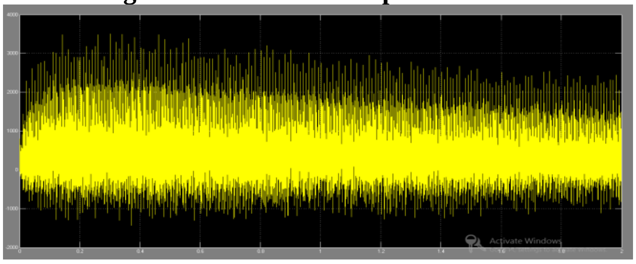

Fig 9.7 Waveforms of DC link voltage

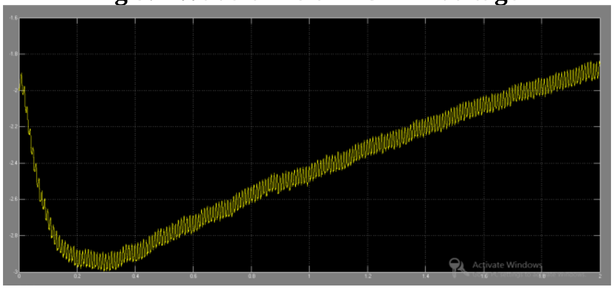

Fig 9.8 shaft torque

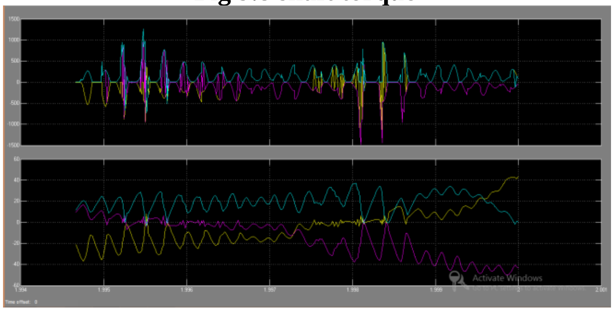

Fig 9.9 voltage and current before entering machine side converter

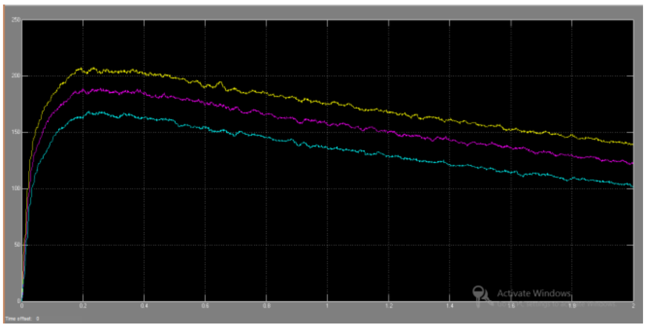

Fig 9.10 Waveform of Rms value of phase voltages

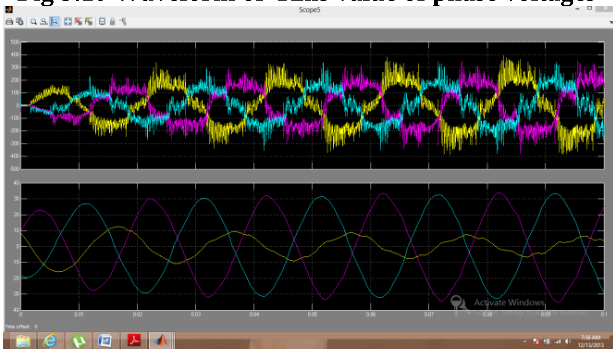

Fig 9.11Waveform of Phase Voltage and currents for small time 7m/sec

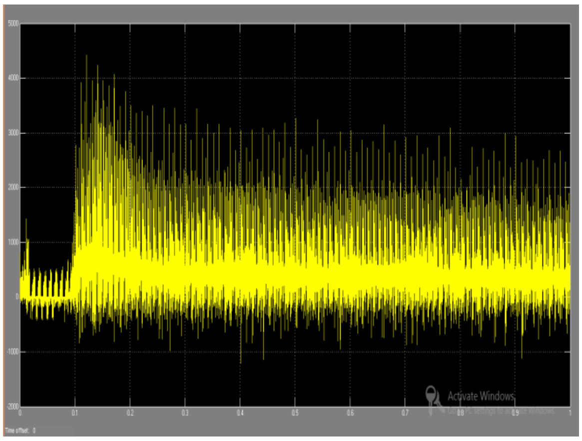

Fig 9.12 shows DC link voltage during fault

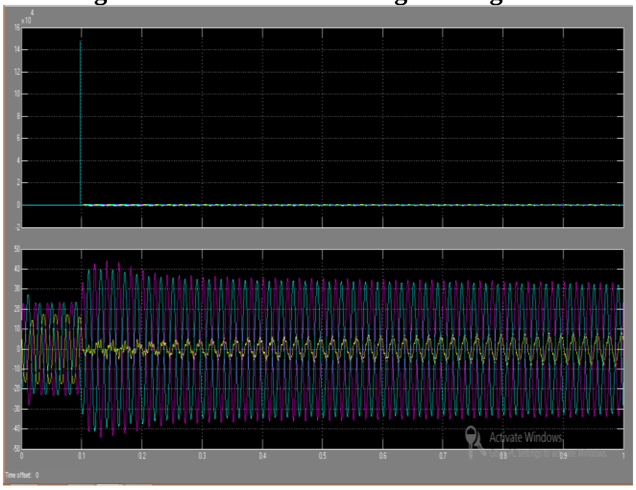

Fig 9.13 shows voltage and current waveform after fault

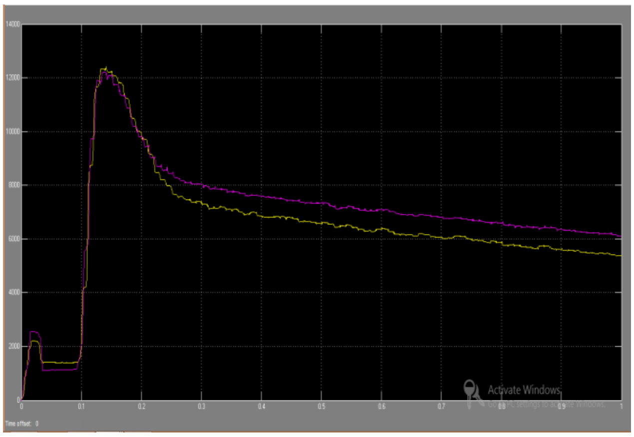

**Fig 9.14 shows active and reactive power after fault**

**Table I Parameters of turbine generator system**

| | |
|---|---|
| **Wind Turbine** | |
| Density of air | 1.225 Kg/$m^3$ |
| Area swept by blades , A | 1.06$m^2$ |
| Base wind speed | 12 m/s |
| **PMSG** | |
| No of poles | 10 |
| Rated speed | 153 rad/s |
| Rated current | 12 amp |
| Armature resistance | 0.425Ω |
| Magnetic flux linkage | 0.433 wb |
| Stator inductance | 4 mH |
| Rated torque | 40 Nm |
| Rated power | 6 kW |

## VII. DISCUSSION

In this paper we can see that output voltage and currents are near about desired value .Active power for constant speed gives constant value. When a three phase fault occurs with transition time 1/60 5/60 . We can see that DC link voltage has changed starting values are near about 500 for small duration of time and after that its value varies near 3000 and above. We can compare its value by the DC voltages before fault. In future we can work for MPPT which is more accurate and also give some effort for improving power quality by using FACTS devices.

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