Modelling & Performance Analysis of Wind Energy with Matrix Converter

Deepanshi Rathore, Sudhanshu Tripathi

Abstract— **There are two great problems before us: The apprehension of exhaustion of traditional energy resources & environmental control. Only answer seems is the use of renewable energy resources. Energy from wind is continuously getting place in the mind of research students. Now a days, wind turbines are being used. This wind turbine is fitted with a doubly fed induction generator & AC-DC-AC converter. This converter is fitted between the rotor of the generator and electrical grid. It control the speed of shaft of wind turbine & ultimately controls the power. In these converter there become a dc link for storage of energy. But it has certain drawback related to weight, size, cost & life time etc.**

So we feel necessity to use another converter for better response. Such a converter is Matrix Converter (MC) .it performs the AC-AC conversion directly without any dc link. So it increases output power. The matrix converter controls the maximum power point tracking MPPT by adjusting the PMSG terminal frequency hence the shaft speed. Space Vector Modulation is used to generate the PWM signals of the matrix converter switches. The MPPT algorithm is included in the speed control system of the PMSG. The system dynamic performance is investigated using Matlab/Simulink.

Index Terms— **Matrix Converter, Maximum Power Point Technique, PMSG, Wind Turbine.**

I. INTRODUCTION

Ground realities has compelled us to utilize renewable energy resources for power production. These realities are that fossil fuel reserves stock in the ground are continuously decaying. At a one side, we are required to produce energy at cheaper cost. On the other side we have also to think about environmental pollution being produced because of the process of production and utilization of energy. In these requirement context the wind resource has no match. Wind resource is also available in abundance as well as at cheaper cost in comparison to the other available resources. The most important fact associated with the use of wind power is that it is eco-friendly in nature.

A great technical reality before us regarding the utilization of resource is that there always occur variation in wind velocity. Our wind turbines comes at the first stage harnessing power of wind. Now in the second stage of harnessing power from wind comes our generators. These generators are loaded with the responsibility of converting available mechanical power from wind into electrical energy. For this purpose there are many option. Some of these options are: induction machines, doubly fed induction machines, PMSM etc. From the system selection point of view we have a universal criteria of consideration of features along with drawbacks of the system to be intended to be utilized. Some of very notable features of PMSG are – small size, simplicity of construction, low cost of maintenance, availability of high efficiency and no requirement of any extra dc source for excitation of magnetic field for synchronizing purpose to obtain unity power factor. It has better voltage and power capabilities. Also, it does not require brushes and slip rings which increase the maintenance work and cost too.

Because of the random variation on the wind velocities, the electrical power generated from the PMSG will vary also and unable to connect to the grid. Therefore, MPPT has been emerged and becoming an essential part in the variable speed wind turbine. The three phase ac line voltage is applied to matrix converter after appropriate filtering. The matrix converter converts the fixed voltage to voltage with variable amplitude and frequency.

The output can be supplied to any load that requires variable voltage with variable frequencies such as to drive an induction motor and the permanent magnet synchronous motor. This topology can be used in the fields of industrial AC motor drives, in a marine application, in a military application especially for military vehicles, in an aerospace application. The control pulses for the converter are developed in Matlab. The proposed modulation techniques for matrix converter are Pulse Width Modulation.

II. MODELING OF WIND TURBINE

The mechanical power of the turbine is given by:

$$P_m = \tfrac{1}{2}\,\rho A u^3 c_p \qquad (1)$$

where *Pm* is the power extracted from the airflow, ρ is the air density, *A* is the area covered by the rotor, *u* is the wind speed upstream of the rotor, and c_p is the performance coefficient or power coefficient.

The power coefficient is a function of the pitch angle of rotor blades θ and of the tip speed ratio λ, which is the ratio between blade tip speed and wind speed upstream of the rotor.

The computation of the power coefficient requires the use of blade element theory and the knowledge of blade geometry. We consider the blade geometry using the numerical approximation developed in [7], assuming that the power coefficient is given by:

$$C_p = 0.73\lambda_i\, e^{-18.4/\lambda_{ii}} \qquad (2)$$

where λ_i and λ_{ii} are respectively given by:

$$\lambda_i = 151/\lambda_{ii} - 0.58\theta - 0.002\,\theta^{2.14} - 13.2 \qquad (3)$$

$$\lambda_{ii} = 1/\left[\,1/(\lambda - 0.02\theta) - 0.003/(\theta^3+1)\right] \quad (4)$$

The maximum power coefficient is given for a null pitch angle and is equal to:

$$C_{pmax} = 0.4412 \quad (5)$$

where the optimum tip speed ratio is equal to:

$$\lambda opt = 7.057 \quad (6)$$

The power coefficient is illustrated in Figure 2.1 as a function of the tip speed ratio.

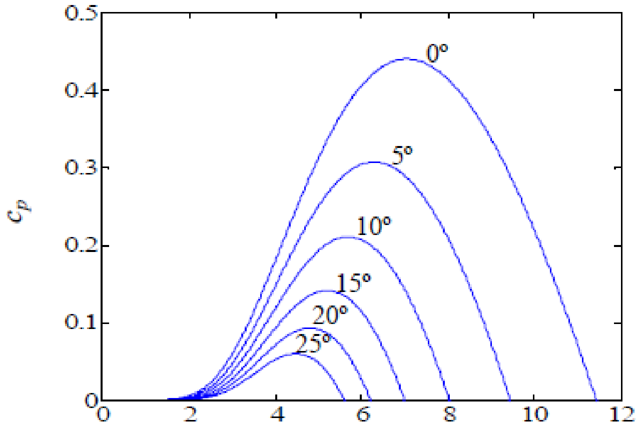

Fig. 2.1. Power coefficient curves versus tip speed ratio

The mechanical power extracted from the wind is modelled by (1) to (4). The equations for modelling rotor motion are given by:

$$\frac{d\omega m}{dt} = 1/J_m\,(T_m - T_{dm} - T_{am} - T_{elas}) \quad (7)$$

$$\frac{d\omega e}{dt} = 1/J_e\,(T_{elas} - T_{de} - T_{ae} - T_e) \quad (8)$$

Where ω_m is the rotor speed of turbine, J_m is turbine moment of inertia, T_m is the mechanical torque, T_{dm} is the resistant torque in the turbine bearing, T_{am} is the resistant torque in the hub and blades due to the viscosity of the airflow, T_{elas} is the torque of the torsional stiffness, ω_e is the rotor speed of the electric machine, Je is the electric machine moment of inertia, T_{de} is the resistant torque in electric machine bearing, T_{ae} is the resistant torque due to the viscosity of the airflow in the electric machine, and Te is the electric torque. The equations for modelling a permanent magnetic synchronous machine, PMSM, can be found in diverse literature; using the motor machine convention, the following set of equations is considered:

$$\frac{did}{dt} = 1/L_d\,(u_d - p\omega_e L_q i_q - R_d i_d) \quad (9)$$

$$\frac{diq}{dt} = 1/L_q\,(u_q - p\omega_e\,(L_q i_q + M i_f) - R_q i_q) \quad (10)$$

where i_f is the equivalent rotor current, M is the mutual inductance, p is the number of pairs of poles; and where in $d\ q$ axes id and iq are the stator currents, Ld and Lq are the stator inductances, Rd and Rq are the stator resistances, ud and uq are the stator voltages. A unity power factor is imposed to the electric machine, implying a null Qe . The electric power Pe is given by:

$$P_e = [\,u_d\ u_q\ u_f]\ [i_d\ i_q\ i_f\,]^T \quad (11)$$

The output power injected in the electric network characterized by P and Q in α β axes is given by:

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

where in α β axes, i_α and i_β are the phase currents, u_α and u_β are the phase voltages. The apparent output power is given by:

$$S = (\,P^2 + Q^2 + H^2)^{1/2}$$

where H is the harmonic power.

III. PMSM

The mathematical model for the vector control of the PMSM can be derived from its dynamic d-q model which can be obtained from well-known model of the induction machine with the equation of damper winding and field current dynamics removed. The synchronously rotating rotor reference frame is chosen so the stator winding quantities are transformed to the synchronously rotating reference frame that is revolving at rotor speed.

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

1) Saturation is neglected.
2) The induced EMF is sinusoidal.
3) Core losses are negligible.
4) There are no field current dynamics.

It is also be assumed that rotor flux is constant at a given operating point and concentrated along the d axis while there is zero flux along the q axis, an assumption similarly made in the derivation of indirect vector controlled induction motor drives [5]. The rotor reference frame is chosen because the position of the rotor magnets determine independently of the stator voltages and currents, the instantaneous induced emf and subsequently the stator currents and torque of the machine. When rotor references frame are considered, it means the equivalent q and d axis stator windings are transformed to the reference frames that are revolving at rotor speed. The consequences is that there is zero speed differential between the rotor and stator magnetic fields and the stator q and d axis windings have a fixed phase relationship with the rotor magnet axis which is the d axis in the modelling. The stator equations of the induction machine in the rotor reference frames using flux linkages are taken to derive the model of the PMSM as shown in Fig.3.1:

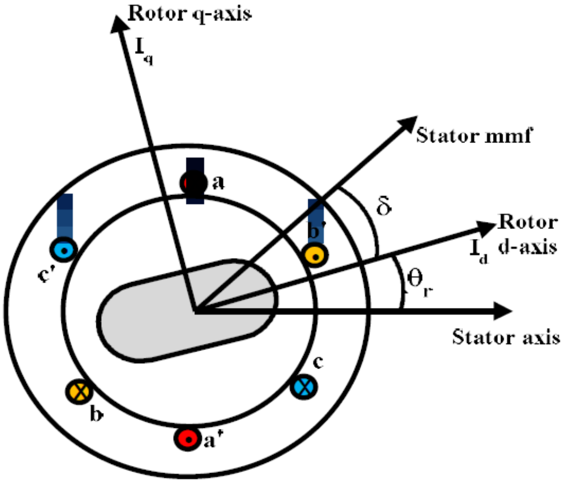

Fig.3.1: PM machine synchronously rotating d-q reference frame.

So an PM machine is described by the following set of general equations:

Voltage equations are given by:

$$V_d = R_s i_d – \omega_r \lambda_q + \frac{d\lambda d}{dt} \qquad (1)$$

$$V_q = R_s i_q – \omega_r \lambda_d + \frac{d\lambda d}{dt} \qquad (2)$$

Flux linkages are given by

$$\lambda_q = L_q i_q \qquad (3)$$

$$\lambda_d = L_d i_d + \lambda_f \qquad (4)$$

Substituting (3) & (4) into (1) & (2), we get

$$V_q = R_s i_q + \omega_r (L_d i_d + \lambda_f) + \frac{d}{dt}(L_q i_q) \qquad (5)$$

$$V_d = R_s i_d - \omega_r L_q i_q + \frac{d}{dt}(L_d i_d + \lambda_f) \qquad (6)$$

Arranging equations (5) and (6) in matrix form

$$\begin{pmatrix} V_q \\ V_d \end{pmatrix} = \begin{pmatrix} R_s + \frac{dL_q}{dt} & \omega_r L_d \\ -\omega_r L_q & R_s + \frac{dL_d}{dt} \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} \omega_r \lambda_f \\ \frac{d\lambda_f}{dt} \end{pmatrix}$$

The developed torque motor is being given by

$$T_e = 3/2\,(P/2)\,(\lambda_d i_q – \lambda_q i_d) \qquad (8)$$

$$T_e = 3/4\,P[\lambda_f i_q + (L_d - L_q)\,i_q i_d] \qquad (9)$$

The mechanical torque equation is

$$T_e = T_L + B\omega_m + J\frac{d\omega m}{dt} \qquad (10)$$

Solving for rotor mechanical speed from (10), we get

$$\omega_m = \int 1(\,T_e – T_L - B\omega_m / J\,)\,dt \qquad (11)$$

and rotor electrical speed is $\omega_r = \omega_m(P/2)$. (12).

IV. MATRIX CONVERTER

Matrix converter is a direct AC-AC converter topology that is able to directly convert energy from an AC source to an AC load without the need of a bulky and limited lifetime energy storage element. Due to the significant advantages offered by matrix converter, such as adjustable power factor, capability of regeneration and high quality sinusoidal input/output waveforms, matrix converter has been one of the AC – AC topologies that receive extensive research attention for being an alternative to replace traditional AC-DC-AC converters in the variable voltage and variable frequency AC drive applications. The main advantage of a matrix converter is to obtained variable frequency output from fixed frequency input supply. The matrix converter consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. With nine bi-directional switches the matrix converter can theoretically assume 512 different switching states combinations. But not all of them can be usefully employed [5]. Regardless to the control method used, the choice of the matrix converter switching states combinations to be used must comply with two basic rules. The input terminals of the converter are connected to a three phase voltage-fed system, usually the grid, while the output terminal are connected to a three phase current- fed system, like an induction motor might be. Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short-circuited and the output currents should not be interrupted. From a practical point of view these rules imply that one and only one bi -directional switch per output phase must be switched on at any instant.

One of the key benefits of the Matrix Converter technology is the possibility of greater power density due to the absence of a DC link. This is translated into a realistic advantage if the filter size is also optimized, by having a sufficiently high switching frequency of semiconductor devices. This means, though, a compromise between filter size and semiconductor losses must be found. Factors such as the absence of electrolytic capacitors, the advantage for increasing power density, reducing size, reducing weight and obtaining good input power quality are fundamental to power supply applications

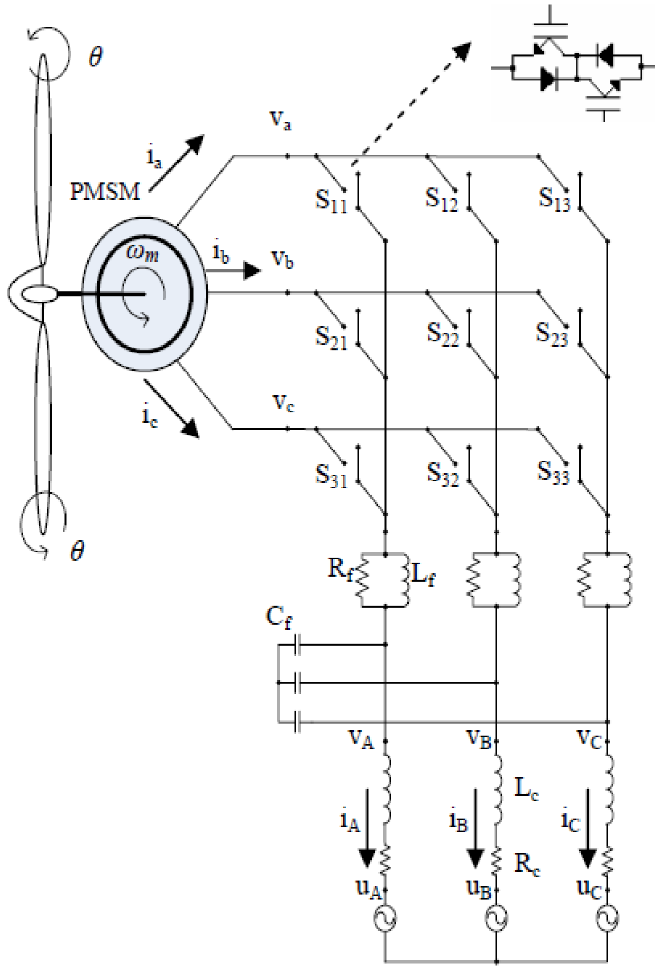

Fig 4.1: Structure of Matrix Converter with Wind Energy

4.1 Static Frequency Changer (AC/AC Converter)

A static frequency changer is a converter which can convert ac power at a given frequency to ac power at a different frequency. In this conversion, voltage magnitude and phase angle can be controlled as well. The block diagram of a three-phase to three-phase static frequency changer is shown below.

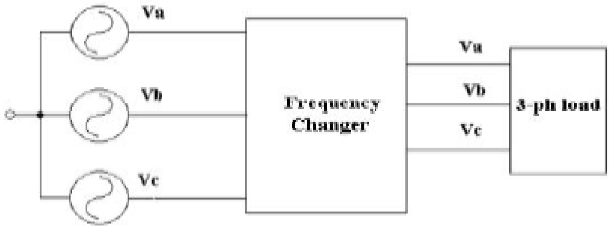

Fig. 4.2: Block diagram of frequency changer.

The input power supply with fixed frequency is applied to the frequency changer block. The frequency changer changes the frequency of the input power supply depending on the required output frequency. The variable frequency output voltage is obtained from the frequency changer. Therefore, electrical energy can be transferred between the input and output of the converter without a dc-link. A single-stage static frequency changer can be realized by thyristor. In that case, it is called a naturally-commutated cyclo-converter, featuring restricted frequency conversion. It is also possible to realize a single-stage static frequency changer by controllable switches. In this case, it is called a forced commutated cyclo-converter or a Matrix Converter (MC).

V. SIMULATION & RESULT

A 10 MW wind farm consisting of five wind turbines each of 2 MW connected with a 25 kV distribution system. This grid-tie wind turbine model based on PMSG and three-phase-to-three-phase matrix interface converter has been carried out in Matlab/Simulink environment. The complete Simulink model is shown in figure 5.1.

The Type 4 wind turbine presented in this model consists of a synchronous generator connected to a diode rectifier, a DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM converter. The Type 4 technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. In this model the wind speed is maintained constant at 15 m/s. The control system of the DC-DC converter is used to maintain the speed at 1 pu. The reactive power produced by the wind turbine is regulated at 0 Mvar.

This system consists of a three-phase matrix converter (MC) constructed from 9 back-to-back IGBT switches. The MC is supplied by an ideal 60Hz three-phase source and drives a static resistive load at 60Hz. The switching algorithm is based on an indirect space-vector modulation. Indirect space-vector modulation allows direct control of input current and output voltage and hence allows the power factor of the source to be controlled. The switching algorithm utilizes a symmetric switching sequence. LC filters are also included in this model so that the output waveforms can be seen clearly.

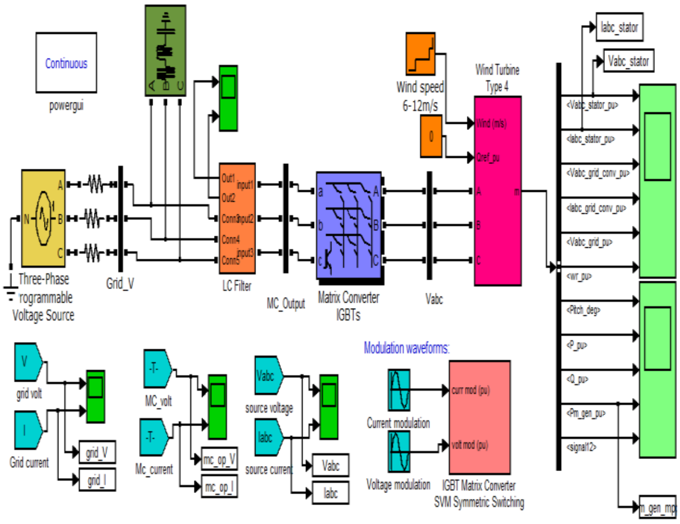

Figure 5.1: Complete Simulink Model of Wind turbine with Matrix Converter

5.1 PMSM Side Voltage and Current Waveforms

The obtained PMSM voltage and current waveforms have been shown in Figure 5.1 & 5.2 respectively, when the WTG system model has been used with the LC filter. It is observed that PMSM was running as a generator. When the WTG system model has been used with the LC filter. The voltage and current wave forms were determined for 0.5 second.

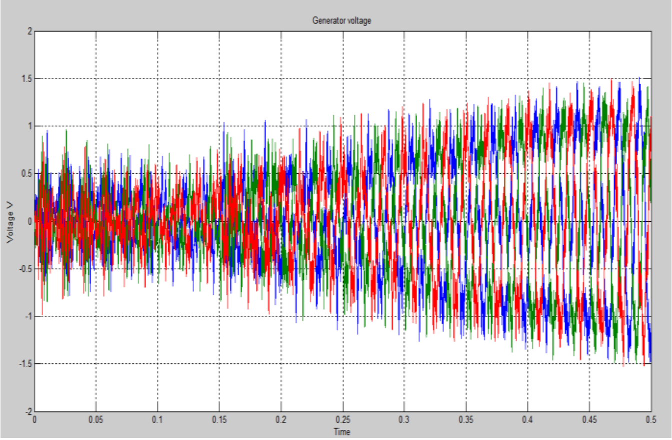

Figure 5.2: Voltage waveform of wind turbine

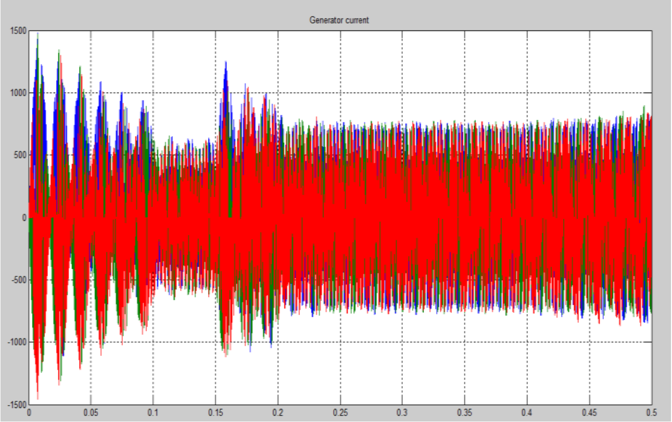

Figure 5.3: Voltage waveform of wind turbine

5.2 Load End-Side Current and Voltage Waveform

The obtained Load end side voltage and current waveforms have been shown in Figure 5.4.

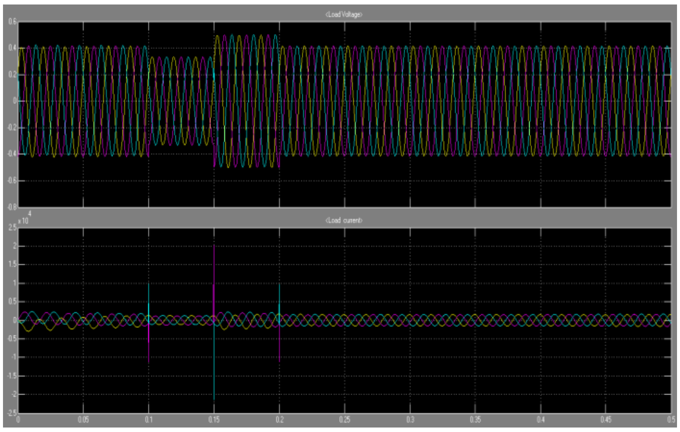

Figure 5.4: Load end-side voltage (phase to phase) and line current waveform with LC filter

WTG system model has been used with the LC filter. Figure 5.4 shows the load side phase voltage and current wave forms determined for 0.5 second.

Figure 5.5 & 5.6 shows the output waveform of matrix converter respectively

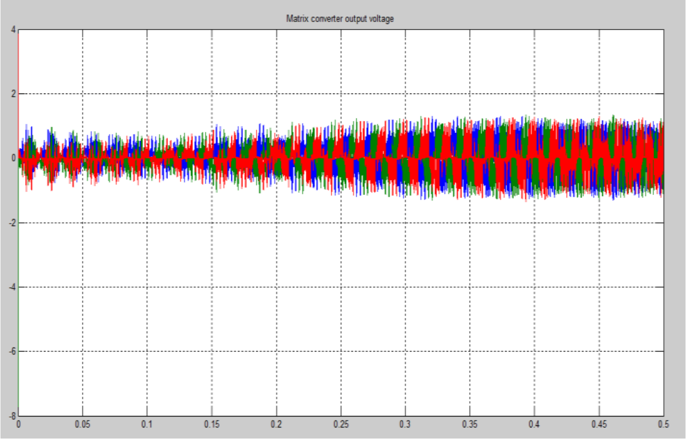

Figure 5.5: Output Voltage waveform of Matrix Converter

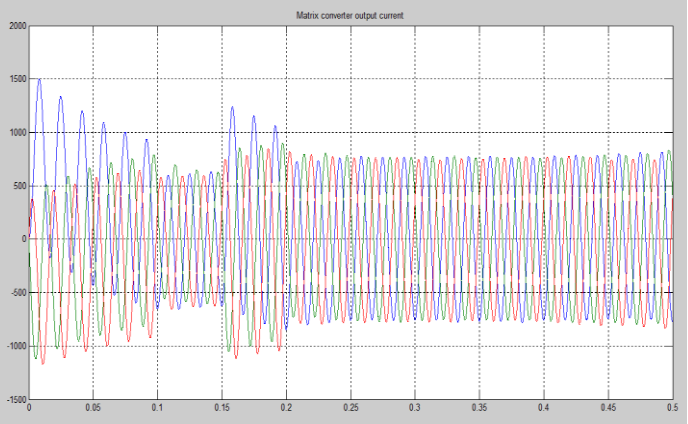

Figure 5.6: Output Voltage waveform of Matrix Converter

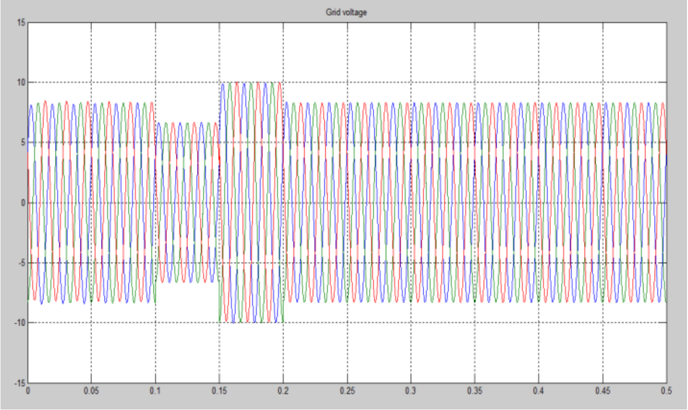

Figure 5.7: Voltage waveform of Grid connected to wind energy system

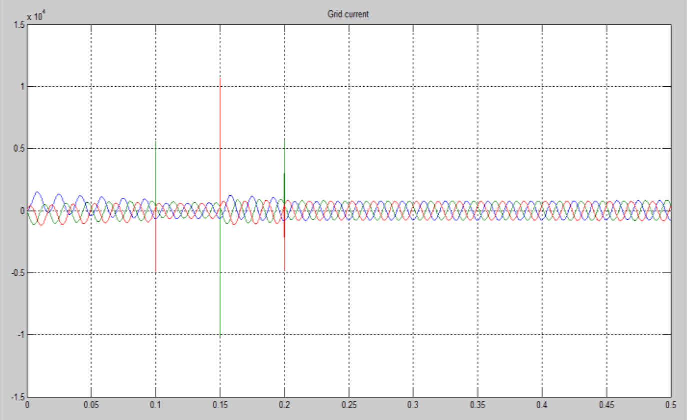

Figure 5.8: Current waveform of Grid connected to wind energy system

The final output waveform are getting in the figure 5.7 & 5.8 respectively as well as the performance of wind turbine is shown in figure 5.9 & 5.10 respectively.

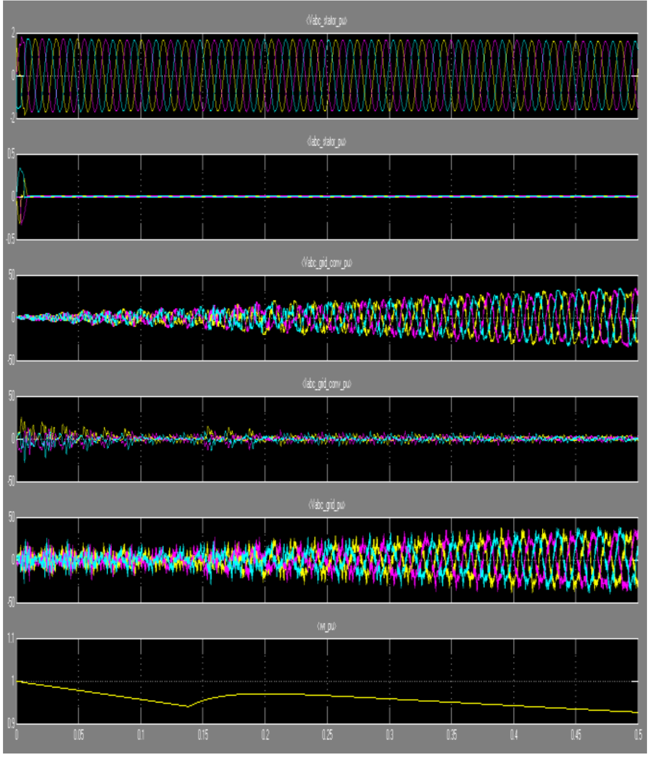

Figure 5.9: Waveform of (i) Stator voltage of PMSM (ii) Stator current of PMSM (iii) Voltage of grid connected wind energy (iv) Current waveform of grid (v) Voltage waveform of grid (vi) Rotor Speed.

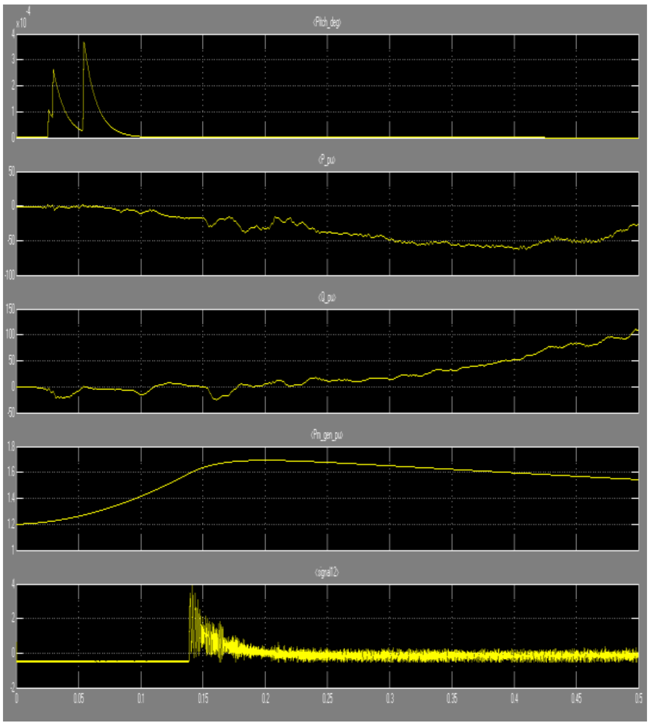

Figure 5.10: Waveform of (i) Pitch angle (ii) Active power of wind turbine (iii) Reactive power of wind turbine (iv) Mechanical power of generator (v) Field Voltage of PMSM.

VI. CONCLUSION

The increased wind power penetration in power systems networks leads to new technical challenges, implying research of more realistic physical models for wind energy systems. In this paper it is demonstrated that the suitable MPPT method for the wind energy conversion system including an MC ensures the maximum possible quality power generation at variable wind profile. The matrix converter controls the terminal voltage and frequency of the permanent magnet synchronous generator in such a way that the wind turbine is operating at its maximum power point for all wind velocities. The popularity of permanent magnet synchronous generator are due to its competitive advantages over other types of generators and hence are more widely being used in large power grids in order to add power to the grid.

The simulation results show that the performance of the grid connected wind energy conversion system is better at variable wind profile using matrix converter.

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