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Wind Energy Conversion Based On Matrix Converter

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ABSTRACT

In recent years renewable sources such as solar, wave and wind are used for the generation of electricity. Wind is one of the major renewable sources. The amount of energy from a Wind Energy Conversion System (WECS**)** depends not only on the wind at the site, but also on the control strategy used for the WECS. In assistance to get the appropriate wind energy from the conversion system, wind turbine generator will be run in variable speed mode. The variable speed capability is achieved through the use of an advanced power electronic converter. Fixed speed wind turbines and induction generators are often used in wind farms. But the limitations of such generators are low efficiency and poor power quality which necessitates the variable speed wind turbine generators such as Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG). A high-performance configuration can be obtained by using a PMSG and a converter in combination AC-DC-AC connect between stator & rotor points for providing the required variable speed operation.

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1. INTRODUCTION

The basic components of wind energy conversion system are shown in the Figure1. It consists of wind turbine coupled to a permanent magnet synchronous generator a power electronic converter connected to the grid [1]. The wind turbine produces output torque required to drive the permanent magnet synchronous generator depending upon the wind velocity. The output voltage generated from the permanent magnet synchronous generator is fed to the grid through a matrix converter. The control of the power fed to the grid is done by controlling the duty ratio of the matrix converter [2].

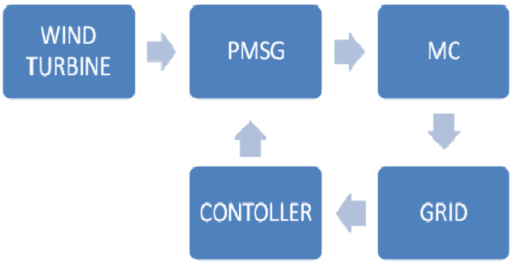


Figure 1. Wind energy conversion system

Wheeler *et.al* [2] have demonstrated a four output leg matrix converter and a variable speed diesel generator integrated together to produce a three phase plus neutral utility power supply. Harmonics reduction was also carried out [2]. Modeling of a converter connected six phase PMSG is done by using dynamic equations of the machine and then realization using definable S function in MATLAB/ simu link. The interface is done with measurement blocks in MATLAB itself [3]. The overall circuit for which variable speed wind turbine along connected with permanent magnet synchronous generator will be used to connect an AC grid along with Voltage Source Converter at HVDC by using converters was designed and simulations results were explained [4].

A method to analyze the steady state performance of a standalone PMSG driven by a diesel engine is presented [5]. The fundamental principle of matrix converter, the modulation technologies and the control strategies are discussed by. The use of protection circuits, filters are presented [6]. The main objective of the project is to develop a control strategy to regulate power flow through the grid by adjusting the duty ratio of the matrix converter and hence to develop a mathematical model for the same [7]. The magnitude of fundamental frequency component is controlled by adjusting the modulation ratio [8]. Neft *et.al* [9] developed several indirect modulation techniques in which MC is considered as a two stage power conversion unit (a rectifier stage to provide a virtual dc link and an inverter stage to produce three output voltages).

The first section provides the basic introduction of the project which deals with the information inference from the various references and also the literature review. The modeling of wind generators and their associated theory. The section deals with the of matrix converter for power regulation. The section deals with the technique used to regulate the flow of power to the grid through the matrix converter in variable speed [10]. Laszlo Huber et al (1995) developed a design for implementation of the three phases to three phases MC with power factor correction at input [11]. It consists of the simulation results and gives the conclusion.

2. DYNAMIC OF WIND TURBINE

Figure 1 Wind energy conversion devices can be broadly classified into two types according to their axis alignment

i. **Horizontal axis wind turbines.**
ii. **Vertical axis wind turbines.**

The wind turbines convert the energy contained in the wind into mechanical energy which is then converted into electrical energy by means of generators. The wind turbine extracts power from wind and then converts it into mechanical power. The amount of aerodynamic torque is related to the wind speed as follows [1].

$$T_w = 0.5\rho\pi R^3 V_w^2 C_P(\theta,\lambda)/\lambda \tag{1}$$

where ρ is the air density, R is the turbine radius, V_w is the wind speed and C_P is the power coefficient, 0 is the pitch angle of rotor, A is turbine rotor area.

The tip speed ratio is λ= Rw_m/V_w , where ω_m the turbine rotor speed and aerodynamic power [10] is,

$$P_w = \frac{1}{2}\rho C_P(\lambda) A V_w^3 \tag{2}$$

Power coefficient, C_p is given by,

$$C_P = 0.22(\beta^{116} - 0.4\theta - 5)exp^{\frac{-125}{\beta}} \tag{3}$$

Where θ is the pitch angle and β is related to λ as

$$\beta = \frac{1}{\frac{1}{\lambda + .08\theta} - \frac{0.035}{\theta^3 + 1}} \tag{4}$$

The relationship between C_p and γ for the given values of pitch angle is shown in Figure 2.

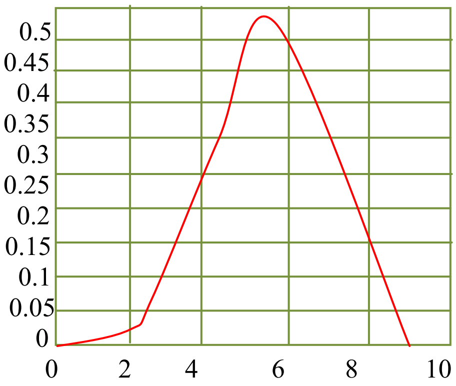


Figure 2. Power coefficient $C_p(\theta, \gamma)$ curves

The rate of change in mechanical angular speed related to equivalent inertia of generator and turbine, J_{eq} is as follows

$$\begin{cases} \frac{d\omega}{dt} = (T_e - T_{w-g} - B_m\omega_g)/J_{eq} \\ \frac{d\propto_g}{dt} = \omega_g \end{cases} \tag{5}$$

Where T_e is the electromagnetic torque, T_{w-g} is the aerodynamic torque transferred to the generator and B_m is the rotating damping. The torque input to generator related to gear ratio, n_g as

$$T_{w-g} = T_w/n_g \tag{6}$$

According to the relation between Cp and λ given by Figure 2 as the turbine speed changes for a given wind velocity there will be a certain turbine speed that gives a maximum power output.

3. MATHEMATICAL MODELING OF MC

The Matrix Converter used here a direct three phase to three phase variable frequency & variable voltage converter. The three-phase Matrix Converter makes an nine bidirectional switches, which are each composed of back to back connected insulated gate bipolar transistors (IGBT), resulting in a total of 18 devices.

Each of these switches can either block or conduct the current in both directions depending on the gate control signals, thus allowing any input phase to be connected to any output phase at any time [6]. Figure 3 depicts the general topology of the Matrix Converter. Each of the nine switches depicted is comprised of back-to-back IGBTs configured as shown if Figure 3 also allows an unidirectional current with bidirectional voltage blocking & controlled bidirectional power flow.

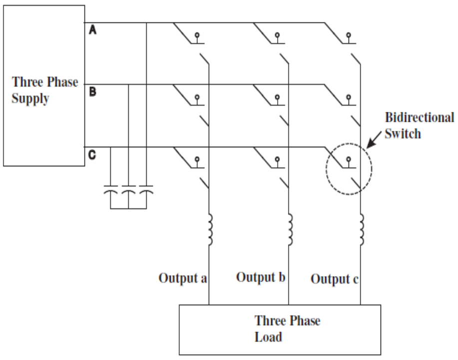


Figure 3. Simplified representation of Matrix converter

The mathematical modeling of MC comprises of three sections. They are principle and switching algorithm, power circuit and load model [1]. The mathematical modeling of MC is shown in Figure 4.

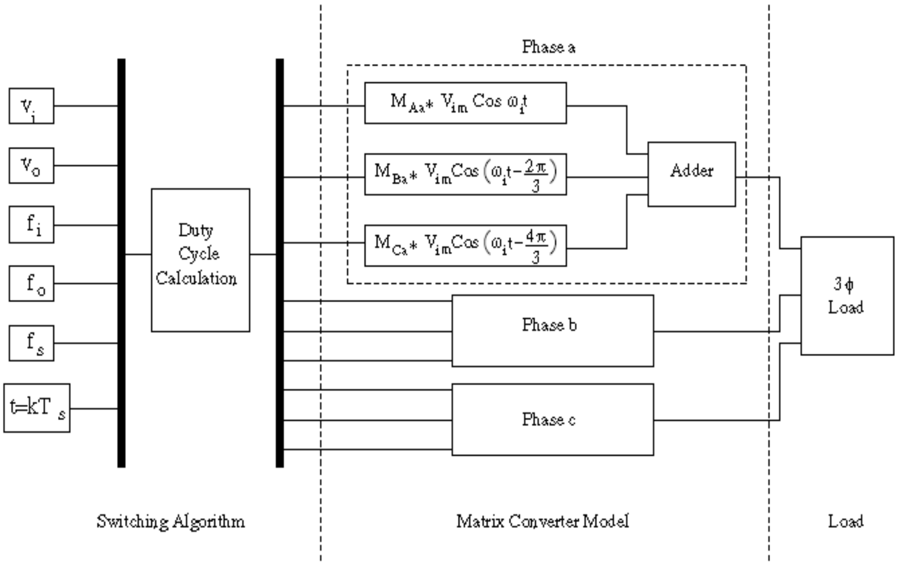


Figure 4. Mathematical modeling of matrix converter

3.1 Switching and Control Algorithm

The three phase input voltages of the converter [7] are,

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} V_{im}\cos(\omega_i t) \\ V_{im}\cos(\omega_i t - \dfrac{2\pi}{3}) \\ V_{im}\cos(\omega_i t - \dfrac{4\pi}{3}) \end{bmatrix} \tag{7}$$

The output voltage vectors of the MC are,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V_{om}\cos(\omega_o t) \\ V_{om}\cos(\omega_o t - \frac{2\pi}{3}) \\ V_{om}\cos(\omega_o t - \frac{4\pi}{3}) \end{bmatrix} \tag{8}$$

where ω_i and ω_o are the frequencies of input and output voltage of MC respectively. The relationship between input and output voltages is given as follows,

$$V_o(t) = \mathrm{M}(t)\,.\,V_i(t) \tag{9}$$

$M(t)$ is the transfer matrix given by

$$M(t) = \begin{pmatrix} M_{Aa} & M_{Ba} & M_{Ca} \\ M_{Ab} & M_{Bb} & M_{Cb} \\ M_{Ac} & M_{Bc} & M_{Cc} \end{pmatrix} \tag{10}$$

Such that, $M_{Aa} = \frac{t_{aA}}{T_s}$ duty cycle of switch S_{Aa}. T_s is the sampling period. The input current is given by,

$$I_{in} = M^T I_o \tag{11}$$

Duty cycles must satisfy the following conditions in order to avoid short circuit on the input side [6].

$$\begin{gathered} M_{Aa} + M_{Ba} + M_{Ca} = 1 \\ M_{Ab} + M_{Bb} + M_{Cb} = 1 \\ M_{Ac} + M_{Bc} + M_{Cc} = 1 \end{gathered} \tag{12}$$

Duty cycles for the transfer ratio of 0.5 are,

$$\begin{gathered} M_{Aa} = \tfrac{1}{3}(1 + 2q cos(\omega_n t + \theta)) \\ M_{Ba} = \tfrac{1}{3}(1 + 2q cos\left(\omega_n t + \theta - \tfrac{2\pi}{3}\right)) \\ M_{Ca} = \tfrac{1}{3}(1 + 2q cos\left(\omega_n t + \theta - \tfrac{4\pi}{3}\right)) \end{gathered} \tag{13}$$

$$\begin{gathered} M_{Ab} = \tfrac{1}{3}(1 + 2q cos\left(\omega_m t + \theta - \tfrac{4\pi}{3}\right)) \\ M_{Bb} = \tfrac{1}{3}\big(1 + 2q cos(\omega_m t + \theta)\big) \\ M_{Cb} = \tfrac{1}{3}(1 + 2q cos\left(\omega_m t + \theta - \tfrac{2\pi}{3}\right)) \end{gathered} \tag{14}$$

$$\begin{gathered} M_{Ac} = \tfrac{1}{3}(1 + 2q cos\left(\omega_m t + \theta - \tfrac{4\pi}{3}\right)) \\ M_{Bc} = \tfrac{1}{3}(1 + 2q cos\left(\omega_m t + \theta - \tfrac{2\pi}{3}\right)) \\ M_{Cc} = \tfrac{1}{3}\big(1 + 2q cos(\omega_m t + \theta)\big) \end{gathered} \tag{15}$$

$\omega_m = \omega_o - \omega_s$ the modulation frequency θ is the relative phase of the output and q is the voltage transfer ratio. The switching times for voltage transfer ratio of 0.866 are

$$T_{\beta\gamma} = \frac{T_5}{3}\left[1 + \frac{2V_{o\gamma}V_{i\beta}}{V_{im}^2} + \frac{2q}{3q_m}\sin\left(\omega_i t + \psi_\beta\right)\sin(3\omega_i t)\right] \tag{16}$$

$\psi_\beta = 0, 2\pi/3, 4\pi/3$ corresponds to the input phases A, B, C respectively, q_m is the maximum voltage ratio (0.866), q is the required voltage ratio, V_{im} is the input voltage vector magnitude, T_s is the sampling period and $V_{o\gamma}$ is given by

$$V_{o\gamma} = qV_{in}\cos\left(\omega_o t + \psi_\gamma\right) - \frac{q}{6}V_{in}\cos(3\omega_o t) + \frac{1}{4q_m}V_{in}(3\omega_i t) \tag{17}$$

Where ψ_γ : $0,2\pi/3,4\pi/3$ corresponds to the output phases a, b, c respectively.

4. CONTROL SCHEME TO REGULATE POWER FLOW

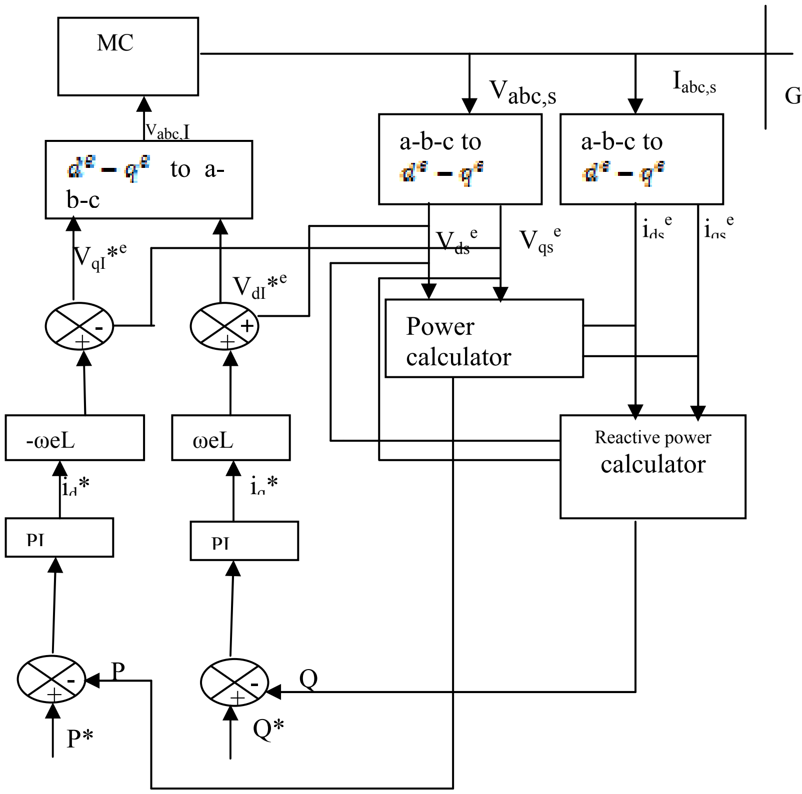
The control voltages are phase delayed, or advanced, by an angle δ with reference to the ac supply voltage V_i, the converter ac terminal voltage will be delayed, or advanced, accordingly, making the converter function as a rectifier or an inverter. The magnitude of fundamental frequency component is controlled by adjusting the modulation ratio [8]. The vector control scheme to regulate power flow is detailed in Figure 5.

The utility system voltage $V_{abc,s}$ is transformed synchronously rotating reference frame by Parks transformation. Parks Transformation computes the direct axis v_d, quadratic axis v_q in a two rotating reference frame according to the following equations

$$v_{ds}^e = \frac{2}{3}\begin{bmatrix} v_a \sin(\omega t) + v_b \sin\left(\omega t - \frac{2\pi}{3}\right) \\ + v_c \sin\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \tag{18}$$

$$v_{ds}^e = \frac{2}{3}\begin{bmatrix} v_a \cos(\omega t) + v_b \cos\left(\omega t - \frac{2\pi}{3}\right) \\ + v_c \cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \tag{19}$$

Where ω = rotation speed of the rotating frame



P* is obtained from the maximum power point tracker.

Figure 5. Control scheme to regulate power flow.

The actual active power (P) and reactive power (Q) are computed by,

$$P = v^{e}_{ds}\, i^{e}_{ds} + v^{e}_{qs}\, i^{e}_{qs} \tag{20}$$

$$Q = v^{e}_{qs}\, i^{e}_{ds} + v^{e}_{ds} i^{e}_{qs} \tag{21}$$

These powers are compared with the reference values P* and Q* to generate the reference values of the terminal voltages v^{e*}_{dl} and v^{e*}_{ql} in accordance with following equations,

$$v^{e}_{ds} = Ri^{e}_{d} + Lpi^{e}_{d} - Lwi^{e}_{q} + v^{e}_{dl} \tag{22}$$

$$v^{e}_{qs} = Ri^{e}_{q} + Lpi^{e}_{q} - Lwi^{e}_{d} + v^{e}_{ql} \tag{23}$$

These are then sequentially processed to the generate signals for the matrix converter applications [10], forcing the matrix converter ac terminals to take values with required phase shift from the supply for the necessary power flow.

4.1. Maximum Power Point Tracking

For extracting maximum power from the WES, the firing angle of the inverter is adjusted in closed loop. The maximum power available of WES is given by,

$$P_{max} = f(V) = -3.0 + 1.08V_w - 0.125V_w^2 + 0.842V_w^3 \tag{24}$$

Where V_w is the wind velocity, the value is 6 m/sec.
The reference power is,

$$P_{ref} = \eta_g p_{max} \tag{25}$$

Where η_g conversion efficiencies of the generator, the value is 0.8.

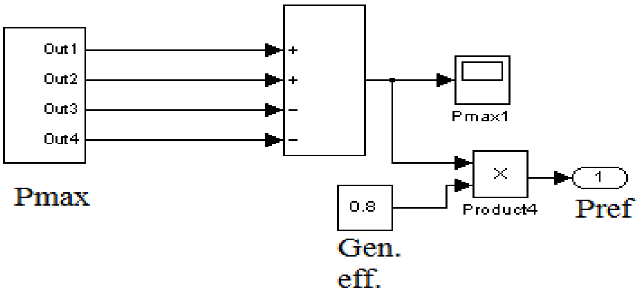


Figure 6. MPPT Tracker.

5. SIMULATION MODEL & RESULTS

The setup was simulated for a change in wind velocity and the results with respect to voltage, current, power and duty ratio are presented [1].

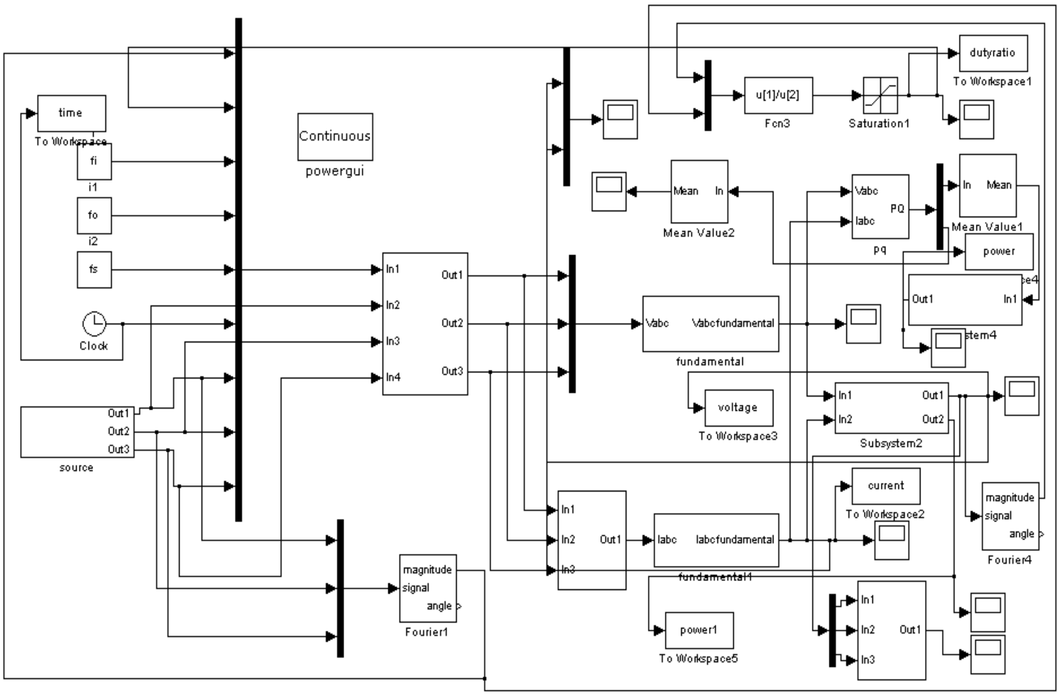


Figure 7. Simulink model.

The variation of grid voltage when the wind velocity is changed from 15m/s to 10m/s at 1sec shown in Figure 8. The grid voltage is higher for higher wind velocity and vice –versa. The grid voltage reduces at time t=1sec because the wind velocity reduces to 10m/s.

The grid current also changes owing to the change in the wind velocity to facilitate the power transmission. The results are shown in Figure 9.

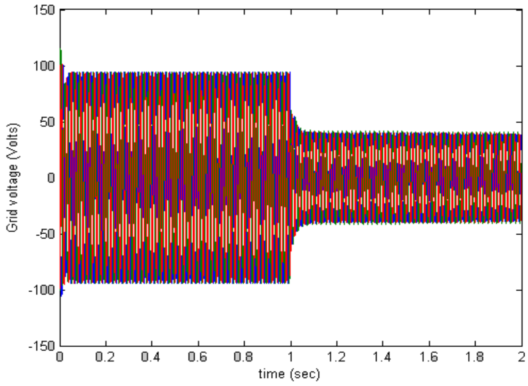


Figure 8. Variation of grid voltage.

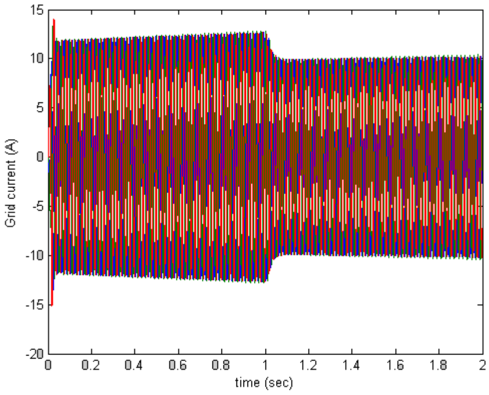


Figure 9. Variation of grid current.

The variation of duty ratio is also simulated as shown in Figure 10. The duty ratio decreases from 0.55 to 0.25 at 1sec due to the change in the wind velocity.

The maximum and reference power for the wind velocities corresponding to 15m/s and 10m/s is shown in Figure 11. These reference power corresponds to the value of 4000Wand 1100W at their wind speeds 15m/s and 10m/s respectively.

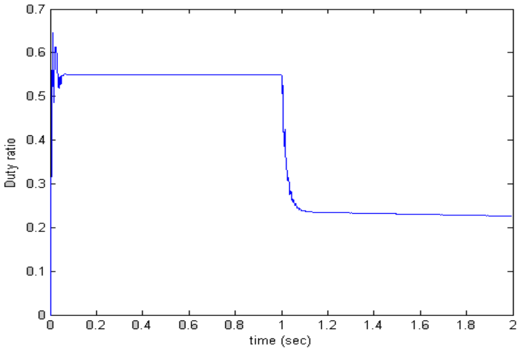


Figure 10. Variation of duty ratio.

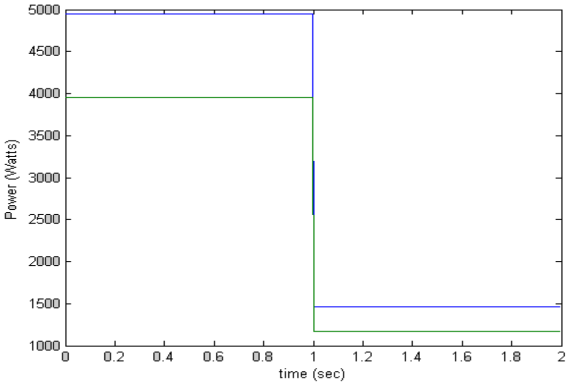


Figure 11. Maximum and reference power tracked

The above simulation results clearly portray that by varying the duty cycle ratio, we can track the maximum power point at every instant of peak voltages with respect to time. The merits of the proposed model are:

- System efficiency is improved
- Implementation of power factor control is less expensive
- Active & Reactive power is completely controlled

The grid power is approximately equal to the reference power therefore as shown in Figure 12, henceforth we can conclude that the power regulator block is working satisfactorily.

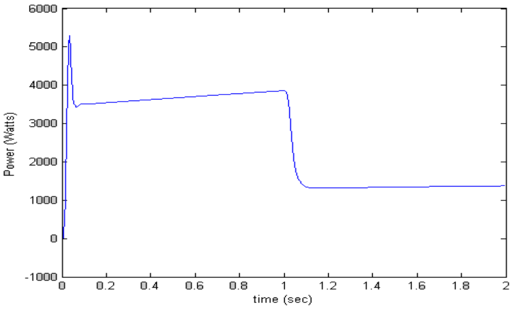


Figure 12. Actual power controlled in the grid.

7. CONCLUSION

In this study, the mathematical model for the matrix converter has been developed to produce constant frequency for changing wind speeds and a controller for maximum utilization of wind energy is designed. The control scheme is proposed to regulate the power flow by generating the reference voltage. The proposed system appears to produce efficient results and has good coherence with statistical experimental data.

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