SIMULATION OF MPPT TECHNIQUE USING BOOST CONVERTER FOR WIND ENERGY CONVERSION SYSTEM

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ABSTRACT

The present work focuses on maximum power point tracking (MPPT) for permanent magnet synchronous generator (PMSG) based wind energy conversion systems using boost converter. Comparative results are presented for the system without MPPT and with the proposed method. Both these cases are implemented using MATLAB/Simulink®. The proposed scheme uses dc link voltage and current as inputs. The scheme has the benefits of increased system reliability and eliminates the need for shaft speed sensing. At the grid-side, an IGBT based PWM inverter is used. Simulation results are shown for a three phase resistive load under fixed and variable wind speed conditions.

Keywords: Boost Converter, Permanent Magnet Synchronous Generator (PMSG), Wind Energy Conversion System (WECS).

I. INTRODUCTION

Among the various renewable energy sources, wind has emerged as a strong contender, second only to solar energy. Wind as an energy source has great potential, particularly, in remote locations like deserts, hilly regions, and offshore areas. Since wind is a variable energy source, the use of variable speed generation scheme is an obvious choice. For small scale installations, use of PMSG is more beneficial because of its compact size, high power density, no need for gearbox [1].

To obtain maximum power from wind at any point of time, a MPPT algorithm has to be incorporated in the system. The three chief categories of tracking methods are: Tip speed ratio (TSR) control, Power signal feedback (PSF) and Hill climb search (HCS).

In TSR control, the TSR is kept constant irrespective of the wind speed by varying the generator rotor speed. The TSR is dependent on wind speed measurement which is difficult to be obtained with high accuracy and turbine shaft speed [2].

In PSF control, the data points for maximum output power and the corresponding wind turbine speed are recorded in a lookup table. The error between the optimum power and the actual turbine output power is fed to the controller for MPPT action. This method requires the knowledge of the system parameters to a high degree of accuracy [3-5].

In HCS based method, a system parameter is chosen and perturbed in small steps. This may be the rotor speed or the dc link voltage or the duty cycle of the converter, etc. Corresponding changes are noted in the output power. Depending on the sign of the derivative of power with respect to the perturbed parameter, further action is taken to shift the operating point to a point where the slope is zero. At this operation point the power extracted is maximum [6]. This method does not require wind speed measurements and is independent of system data.

The main objective of this paper is to develop a HCS based MPPT technique using duty cycle as the perturbed parameters and analyze its application to different source conditions.

II. MATHEMATICAL MODELING

Fig. 1 shows the block diagram of the proposed system to which MPPT method is applied. As discussed above, due to the relative advantages of PMSG, it has been utilized in the system. An uncontrolled three phase bridge rectifier has been used due to its simplicity and higher reliability. A DC/DC boost converter is used at the output terminals of the rectifier. MPPT control signal is given to the boost converter and it accordingly boosts up the voltage across the load resistor. A PWM bridge inverter is used at the load side.

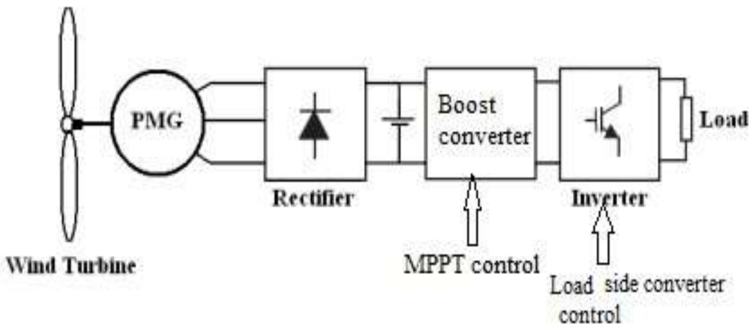

Fig. 1 Block diagram of the WECS under study

III. WIND TURBINE CHARACTERISTICS

The power contained in wind P_{wind} can be given as;

$$P_{wind} = \frac{1}{2}\rho A V^3 \quad (1)$$

Where, ρ is the air density, A is the area swept by the turbine blades, V is the wind speed.

Power extracted by the wind turbine P_m is;

$$P_m = \frac{1}{2}\rho A V^3 C_p(\lambda, \beta) \quad (2)$$

Where, C_p is the turbine power coefficient. It is a transcendental function of blade pitch angle *(β)* and tip speed ratio *(λ)*.

$$C_p = 0.5\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-\frac{21}{\lambda_i}} + 0.0068\lambda \quad (3)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda} - 0.035 \quad (4)$$

$$\lambda = \frac{\omega R}{V} \quad (5)$$

Where, ω is the rotor speed, R is the turbine radius.

β is fixed by the shape of turbine blades. Thus C_p can be expressed as a function of λ only. A typical $C_p(\lambda)$ curve is shown in Fig. 2.

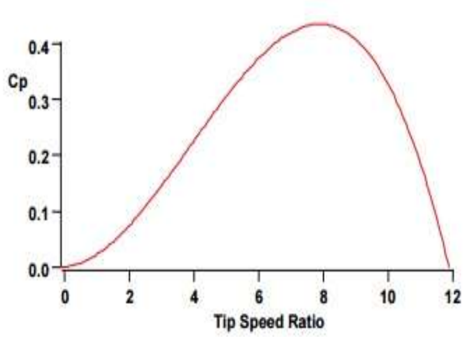

Fig. 2 Turbine Power Coefficient as a Function of TSR [4]

Power output of the generator P_G;

$$P_G = \eta P_m \tag{6}$$

Where, η is the generator efficiency.

Using the relations (2) - (6) it can be inferred that at any particular wind speed, the generator outputs maximum power at a specific rotor speed. By controlling the duty ratio of the intermediate boost converter the load resistance referred to the generator terminals is varied along with the changes in wind, such that maximum power is extracted continuously.

The parameters of the wind turbine, generator and boost converter are given in Tables 1-3.

Table 1. Parameters for Wind Turbine Used in Model [7]

Parameter	Value
Nominal mechanical output power	8500 W
Base wind speed	12 m/s
Maximum power at base wind speed	7650 W

Table 2. Parameters for PMSG used in model [7]

Parameter	Value
Number of poles	10
Rated angular speed	153 rad/s
Magnetic flux linkage	0.2781 V.s
Stator inductance	8.35 mH
Stator resistance	0.425Ω

IV. BOOST CONVERTER

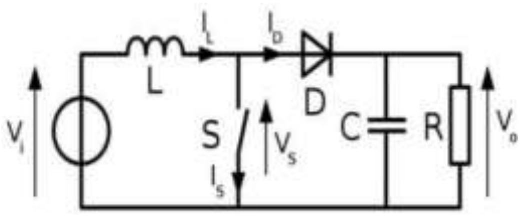

Fig. 3 Schematic of Boost Converter [8]

$$V_o = \frac{1}{1-D} V_I \tag{7}$$

The values for the various components of the boost converter are calculated using the following equations; [8]

$$L = \frac{V_I * (V_O - V_I)}{\Delta I_L * f_s * V_O} \tag{8}$$

$$\Delta I_L = (0.2\ to\ 0.4) * I_O * \frac{V_O}{V_I} \tag{9}$$

$$C_{min} = \frac{I_O * D}{f_s * \Delta V_O} \tag{10}$$

Where, V_I is the input voltage, V_O is the output voltage, I_O is the output current, D is the duty ratio, L is the inductance, C_{min} is the minimum value of capacitance required, ΔI_L is the ripple current, f_s is the switching frequency.

Table 3. Parameters for Components of Boost Converter Used in Model

Parameter	**Value**
Inductance	0.595 mH
Output capacitance	642.8 μF
Switching Frequency	40 Hz

V. MPPT ALGORITHM

Most of the HCS based methods use the relation between generator output power and rotor speed. These characteristics have to be stored and shaft speed measurements have to be done. The optimal output power is calculated and compared to the actual generator output power. The resulting error is used to control a power interface. Such methods require the prior information about generator characteristics, which may not be available accurately. Sensors are required for wind speed measurements which add to the cost of the entire system. As a solution to the above limitations, the proposed method is based on duty cycle of the boost converter. A detailed mathematical analysis of the used method has been presented below.

From equations (2) and (5), it can be concluded that maximum turbine output power P_{max} is proportional to the cube of wind speed V and hence to the cube of optimum rotor speed ω_{opt} which keeps the TSR at its optimal value λ_{opt} for a given wind speed. Mathematically we can write,

$$P_{max} \propto V^3 \propto \omega_{opt}^3 \tag{11}$$

For a PMSG with a constant flux, the phase back electromotive force (emf) E is a linear function of generator rotor speed [9], which equals the turbine speed;

$$E = K_e \varphi \omega \tag{12}$$

The phase terminal voltage V_{ac} for a non-salient PMSG is written as;

$$V_{ac} = E - I_{ac}(R_s + j\omega_e L_s) = K_e \varphi \omega_{opt} - I_{ac}(R_s + j\omega_e L_s) \tag{13}$$

$$\omega_e = p\omega_{opt} \tag{14}$$

Due to the diode bridge rectifier, the ac-side voltage amplitude $V_{ac\text{-}amp}$ and the dc side voltage V_{dc} can be expressed as [10];

$$V_{dc} = \frac{3\sqrt{3}}{\Pi} V_{ac-amp} \tag{15}$$

Based on equations (3.43), (3.44), (3.45) we can write the following relationship;

$$V_{dc} \propto \omega \tag{16}$$

At the point of maxima, the optimal value of the rectified dc voltage $V_{dc\text{-}opt}$ at a given wind speed is proportional to the optimal rotor speed ω_{opt} .

$$V_{dc-opt} \propto \omega_{opt} \tag{17}$$

Equations (11) and (17) give;

$$P_{max} \propto V_{dc-opt}^{3} \tag{18}$$

The maximum dc-side electric power at a given wind speed can be expressed as;

$$P_{dc} = \eta P_{max} = V_{dc-opt} I_{dc-opt} \tag{19}$$

$I_{dc\text{-}opt}$ is the value of dc side current at optimum point.
From (18) and (19),

$$I_{dc-opt} \propto V_{dc-opt}^{2} \tag{20}$$

Or, we can write, $I_{dc-opt} = kV_{dc-opt}^{2}$ (21)

The relationship of equation (20) can be depicted in the form of a set of curves as shown in Fig. 4. It shows the curves of I_{dc} versus V_{dc}^2 at different wind speeds, which are labeled as v_{w1}, v_{w2}, and v_{w3} respectively. The points of intersection such as (V_{dc1}^2, I_{dc1}), (V_{dc2}^2, I_{dc2}) and (V_{dc3}^2, I_{dc3}) are the operating points when applying equation (21) to track MPP. The power versus V_{dc} curve of these wind speeds, *vw*1, *vw*2 and *vw*3 are shown in Fig. 5. P_1, P_2 and P_3 are the output powers when applying MPPT.

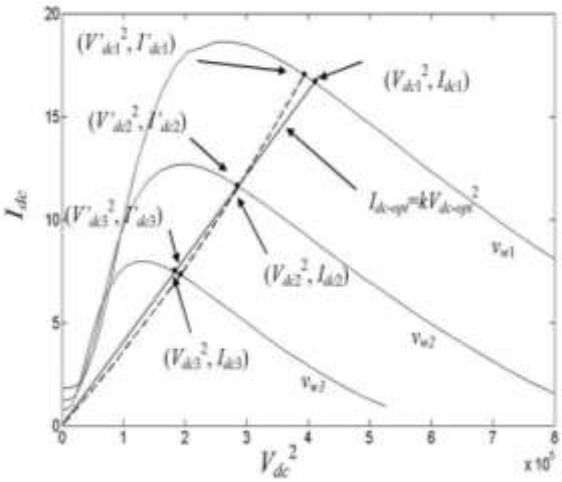

Fig. 4 Wind Energy Electrical Characteristics – I_{dc} Vs V_{dc}^2 Curves for Different wind Speeds [11]

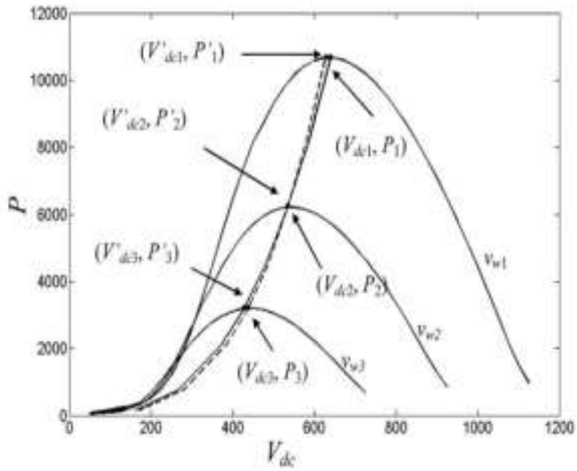

Fig. 5 Wind Energy Electrical Characteristics – P Vs V_{dc} Curves for Different Wind Speeds [11]

Considering Fig. 5, we can observe three zones of operation:

$$\frac{dP}{dV_{dc}}_{V_{dc}=V_{dc-opt}} = 0 \tag{22}$$

$$\frac{dP}{dV_{dc}}_{V_{dc}=V_{dc-opt}} < 0 \tag{23}$$

$$\frac{dP}{dV_{dc}}_{V_{dc}=V_{dc-opt}} > 0 \tag{24}$$

Also,

$$\frac{dP}{dV} = \frac{dVI}{dV} = I + V\frac{dI}{dV} \tag{25}$$

Whenever $\frac{dP}{dV} \neq 0$ appropriate control action will be taken by the controller.

$$\text{If } \frac{dP}{dV} = 0 \text{ then } -\frac{I}{V} = \frac{dI}{dV} \tag{26}$$

For the algorithm used, the values of dc side voltages and currents are sampled at regular intervals. According to the logic described above, the duty ratio of the dc-dc converter is computed accordingly. Following this change, the rectified output voltage V_{dc} of the converter changes simultaneously. The ratio I/V and ΔI/ΔV are calculated for the previous as well as current cycles and compared. The direction of search will depend on this comparison. If the change is positive and increasing, the perturbation will continue in the same direction in the subsequent cycle. This will cause the rotational speed to increase. If the change is decreasing, the direction of the search will be reversed. When the quantity $\Delta P/\Delta V$ equals zero, it means that the the MPP has been tracked and the operating point will settle around this point [12].

VI. RESULTS AND DISCUSSION

The Simulink model of the system is shown in Fig. 6. Such a configuration can be used to supply different AC loads or connected to the grid, etc. A three phase resistive load of rating 2000 W, 415 V, 50 Hz is used for simulation. The system is simulated under fixed and variable wind speed. Output parameters are shown in blue and input parameters are shown in purple in the plots.

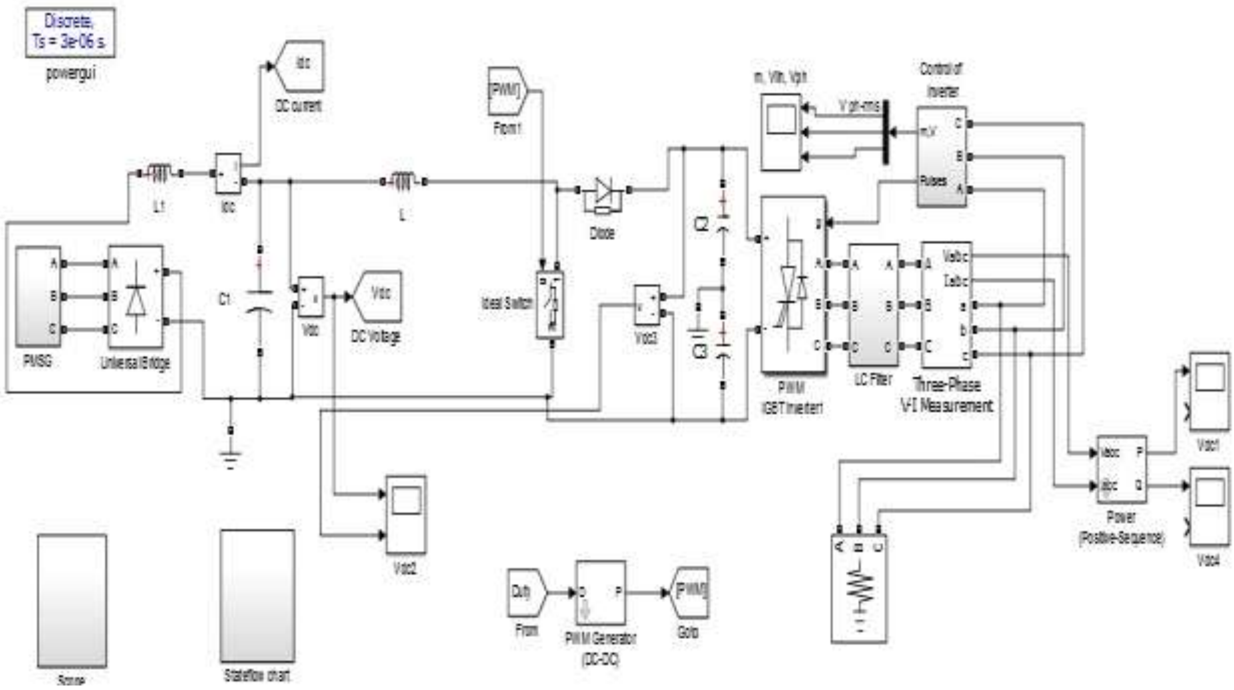

Fig. 6 Simulink Model of the System

VII. FIXED WIND SPEED

Wind speed is set at 12 m/s.

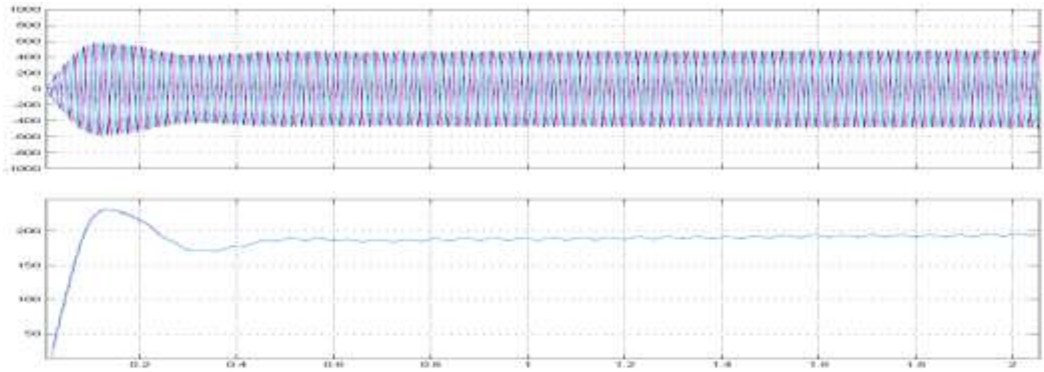

Fig. 7 Plot of line voltage (above) and phase voltage (below) at the inverter output terminals

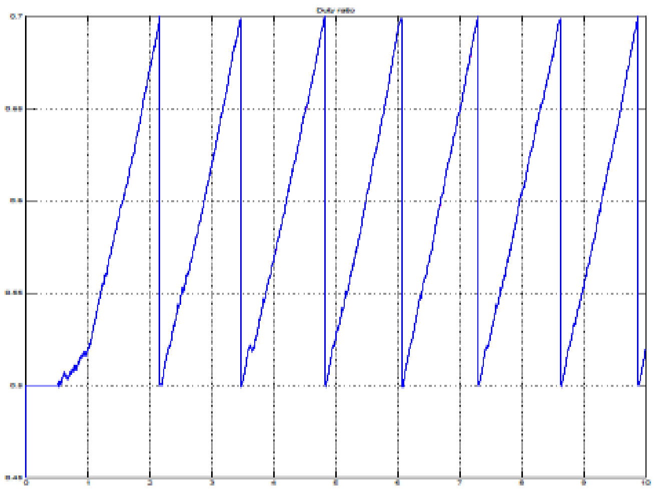

Fig. 8 Plot of duty ratio

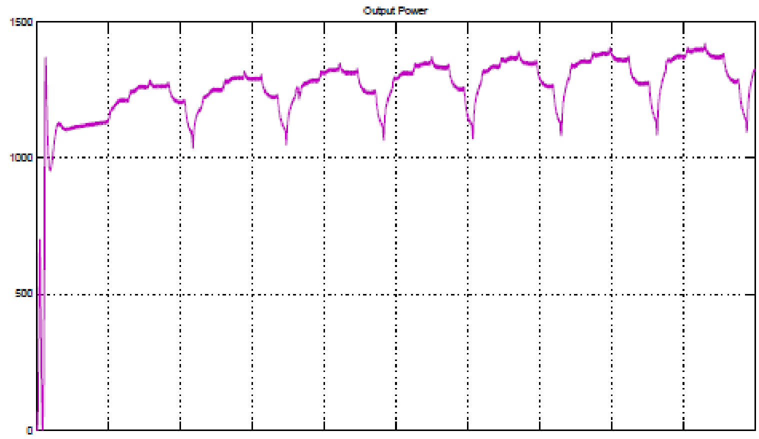

Fig. 9 Plot of output active power

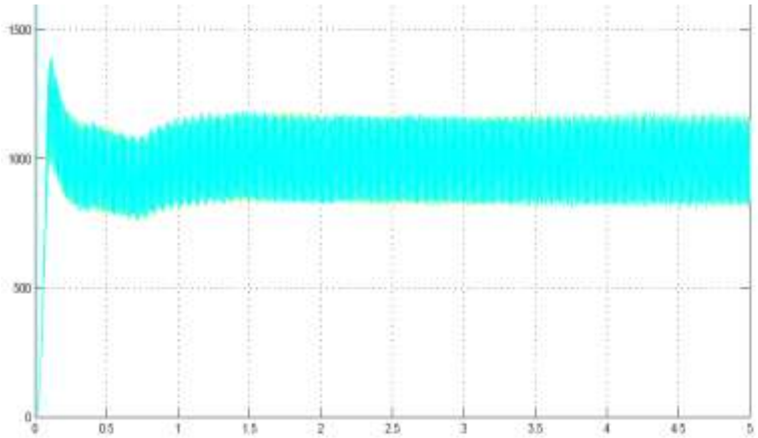

Fig. 10 Plot of output active power without MPPT

Fig. 7 shows the plots for output line and phase voltages at the inverter output terminals. Line voltage becomes stable around 420 V (rms). Fig. 8 shows the plot of duty ratio. Fig. 9 and 10 show the plots for output power with and without MPPT control. Without MPPT, the power delivered to load has a mean value of 1000 W. With MPPT, the output power is close to 1500 W. The results show the effectiveness of the proposed algorithm.

VIII. STEP CHANGE IN WIND SPEED

The wind speed variation for this case is shown in Fig. 11. Fig. 12 shows the plot of output voltage. With the increase in wind speed, there is an increase in the voltage. Corresponding plots for output power with and without MPPT control are plotted in Fig. 13 and 14. Comparison for the conditions with and without power tracking control has been done. In Fig. 13, the output power is close to 1000 W when wind speed is 8 m/s and increases to nearly1300 W when speed is stepped up to 12 m/s. In Fig. 14, at a speed of 8 m/s, the output power is around 800 W and when speed is increased to 12 m/s, the power increases to around 1000 W. This shows that greater power is extracted with MPPT control.

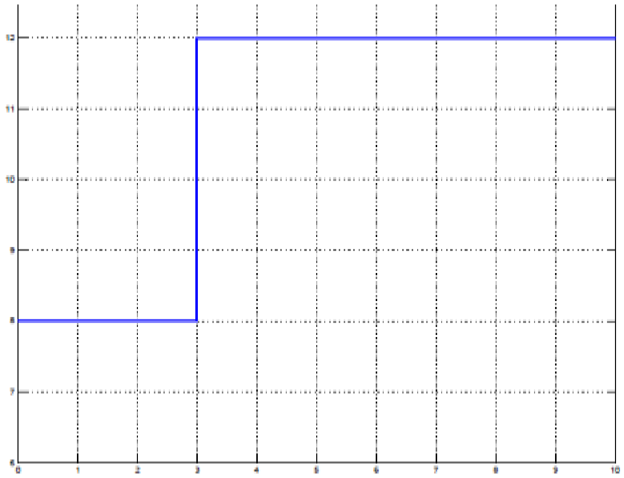

Fig. 11 Plot of Wind Speed

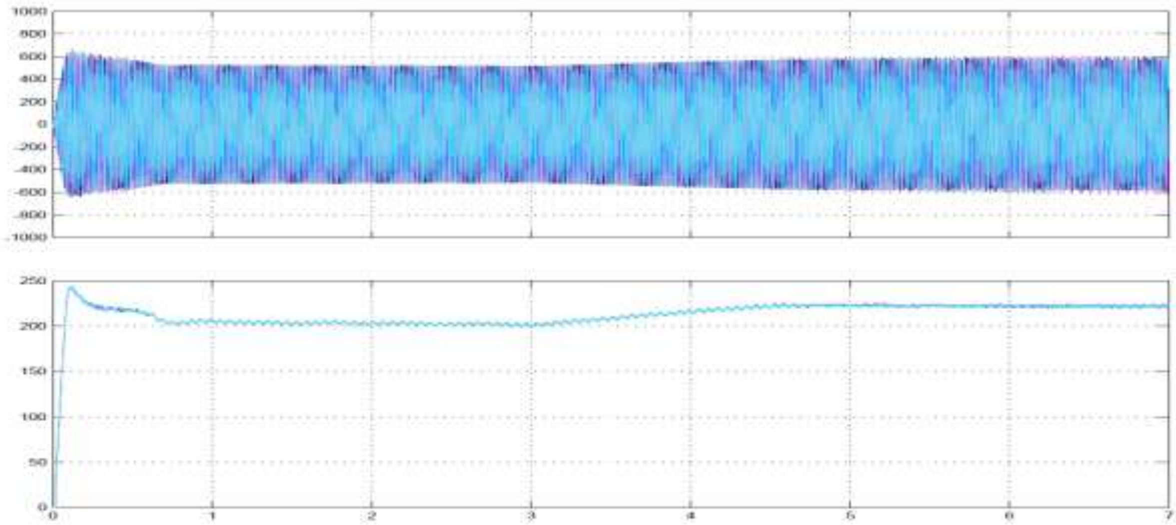

Fig. 12 Plot of Output Line (above) and Phase (below) Voltage

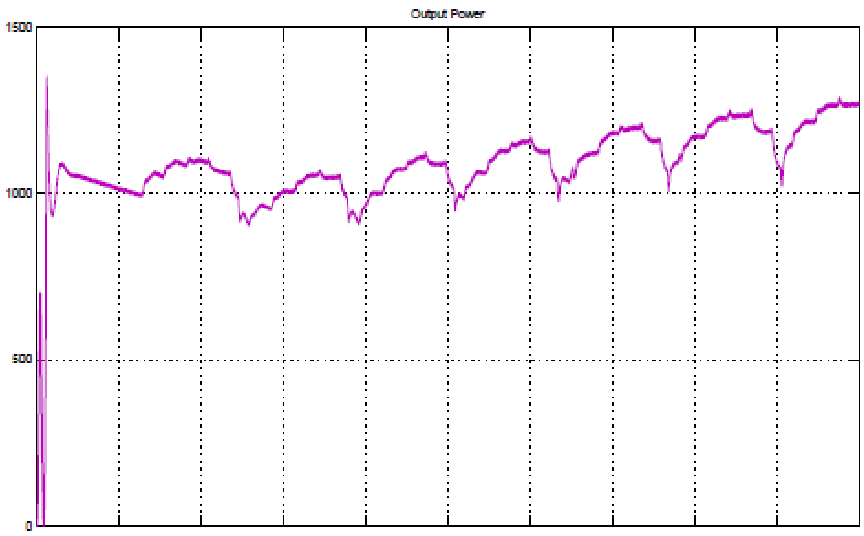

Fig. 13 Plot of Output Active Power with MPPT Control

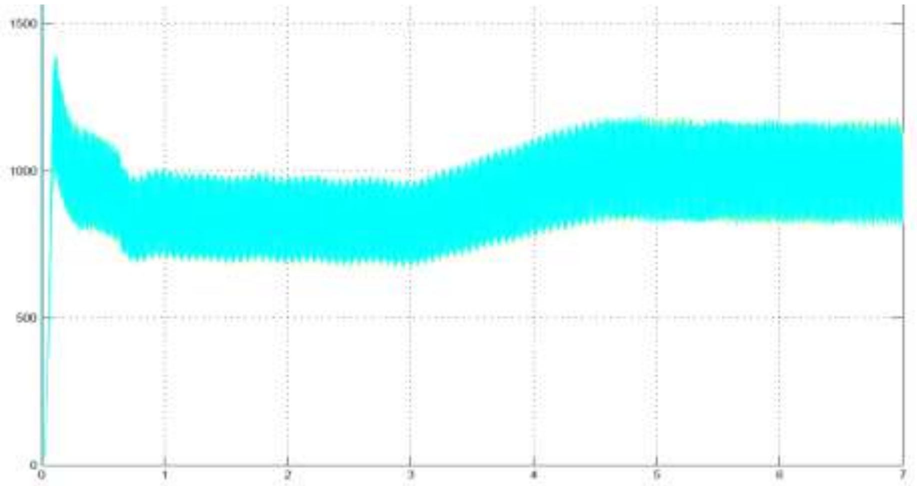

Fig. 14 Plot of Output Active Power without MPPT Control

IX. CONCLUSION

A modified HCS based MPPT technique has been proposed in this paper. This technique uses dc link voltage and current as inputs. By computing the ratio of current and voltage and comparing the changes in sign, the duty ratio of the boost converter is adjusted. There is no requirement for wind speed measurements or system characteristics. Hence this method is simple in terms of implementation. The system has been simulated under fixed and variable wind speed conditions with a resistive load. Comparison has been done for the performance of the system with the proposed MPPT and without MPPT method.

The application of the discussed method can be studied for integrated renewable energy systems. Protection features can be developed to consider the circumstance of over-load or over-current.

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