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MPPT for DFIG Fed Stand Alone Wind Energy Conversion System

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ABSTRACT

This paper deals with a control scheme to extract maximum power from the wind energy conversion system (WECS) using Maximum Power Point Tracking Algorithm (MPPT) from a Doubly Fed Induction Generator (DFIG). In order to ensure the continuous supply of power, battery backup is established. The control scheme for standalone system includes the charge controller circuit for battery bank and pitch control to ensure wind turbine within rated limits. A Boost converter is incorporated to control the charging and discharging rate of the battery.

Index Terms: Boost converter, Doubly Fed Induction Generator (DFIG), Maximum Power Point Tracking algorithm (MPPT), Pitch control, Wind energy conversion system (WECS).

1. INTRODUCTION

Recent development in renewable energy and power electronics resulting in significant energy security and economic growth and it would contribute to the reduction of environmental pollution. Among the renewable energy sources Wind energy is clean and readily available. The total amount of energy in wind over the earth surface is estimated to be 1.6x10^7 MW but a certain amount of energy is trapped from the wind. According to Albert Betz only 59.3% of energy is effectively trapped from the available wind. Inefficiencies in the design and the frictional losses will reduce the power available from the wind. While converting the wind power into electrical power it also incur losses in the drive train, generator and in the inverter. Further, when the wind speed exceeds the rated value, control systems limit the energy conversion in order to protect the generator, so the wind turbine converts only about 30% to 35% of the available energy into electrical energy. It is necessary to improve the power generated from the wind by reducing the losses in the system and providing the suitable control techniques. The small-sized wind turbine system coupled with battery bank as the energy storage element is common and essential for providing stable and reliable electricity for the rural and to the remote areas [1]–[4]. The advantage of using asynchronous machine in wind conversion system is that, the variable speed operation which allows the maximum extraction of power from WECS and thereby reducing the torque fluctuations [5]. The induction generators are widely used in wind turbines due to their ability to produce power at varying speeds and they are more rugged and the requirements of brushes or commutators are eliminated. However, the amplitude and the frequency of SCIG voltage vary with wind speed but in case of DFIG the constant amplitude and frequency of voltage is obtained. In order to ensure the regulated voltage, WECS are integrated with power converters [6]. The power output of WECS depends on wind flow which is erratic in nature. Due to the variability of wind speed the generated power is fluctuating and it can store the excess of energy generated from the wind when the generated power is greater than the required load power and then it supplied to the load when

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there is demand in load power [7-9]. In order to ensure the continuous supply of power to load, WECS needs to have an energy storage system [10].

Various MPPT algorithms are available. Several MPPT algorithms for small wind turbine are carried out in [11] and [12]. As the wind speed exceeds its rated value, the wind turbine power and the speed needs to be regulated to ensure the electrical and mechanical safety [13]. This can be achieved by changing the pitch angle and for this purpose pitch angle control is employed [14]. This paper deals with the extraction of maximum power from the wind by implementing Maximum power point tracking and the control is provided by pitch control technique.

2. MODELING OF WIND CONVERSION SYSTEM

Generation of electrical energy mainly depends on the availability of wind. With the variation in wind speed, production of electrical energy can be varied. The overall wind conversion system consists of the Doubly Fed Induction generator and the converter circuit along with the MPPT block which consists of algorithm for maximum power point tracking.

2.1. Proposed Conversion System

The proposed system for wind conversion system is shown in Fig1. The circuit topology for proposed standalone wind energy system consists of wind turbine, doubly fed induction generator (DFIG), which is driven by the wind turbine, three phase rectifier based on PWM and DC-DC boost converter. It is connected to the load through LC filter. The following system is proposed to supply the standalone load where it is difficult to provide the stable and reliable electricity to remote areas. Turbine and the drive train consists of shaft which is coupled to the generator whose purpose is to generate the mechanical torque. This mechanical torque is given as input to the wound rotor induction generator. The output power generated from the DFIG is supplied to the load through the rectifier unit and the converter unit. MPPT block consist of the maximum power point tracking algorithm which is used to extract the maximum power from the wind.

The energy generated from the wind is governed by the equation:

$$Pw = \frac{1}{2} \rho A V^3$$

Where, P_w is the Output power of the wind, ρ is the Air density (1.225 kg/m^3), A is the cross sectional area, Cp is the power coefficient of the wind and V is the wind speed (m/s). The relation between Cp and λ curve is shown in Fig 2. From the figure it can be noticed that the optimum value of power coefficient Cp is about 0.5 for λ equal 10 and for pitch angle $\beta = 0^0$.

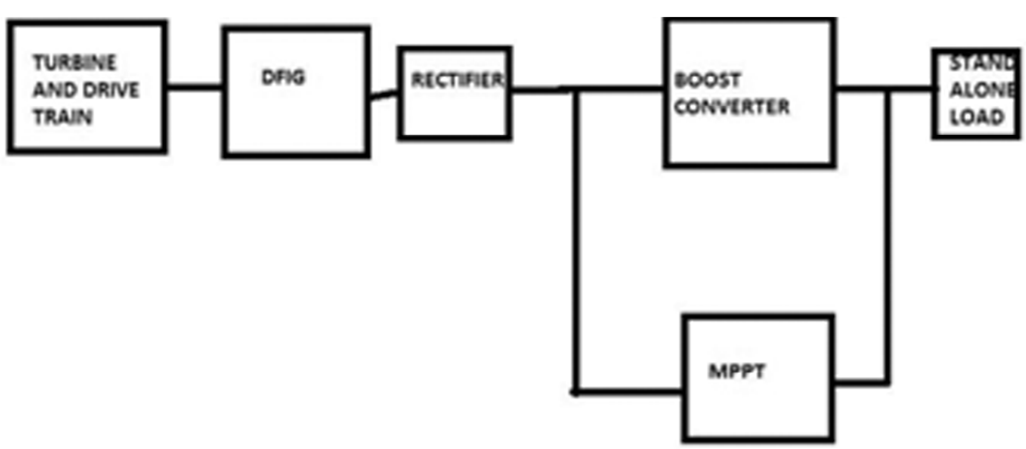

Figure 1: Proposed Wind Energy Conversion System

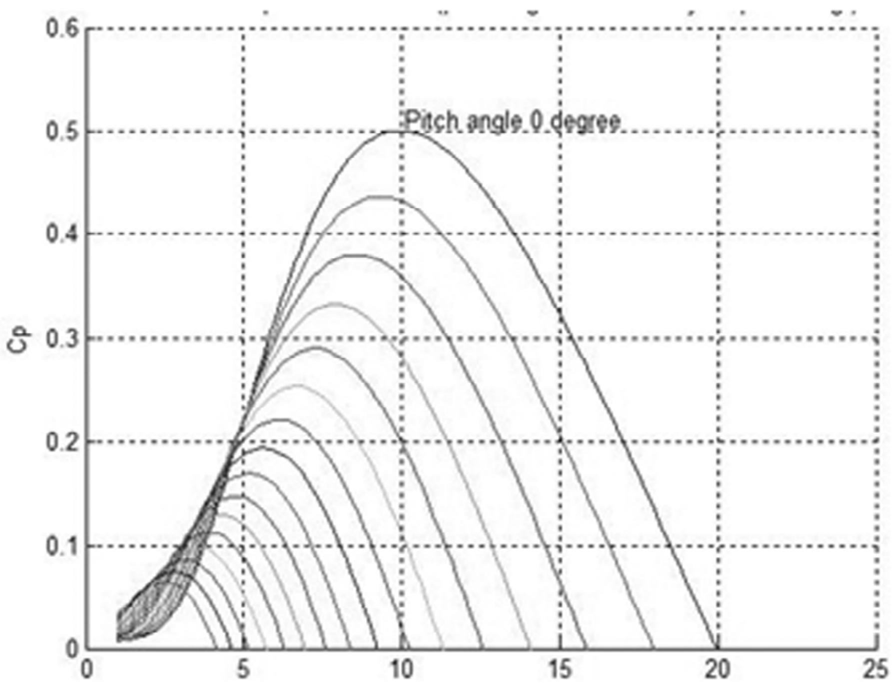

Figure 2: Wind Turbine CP Characteristcs

2.2. Doubly Fed Induction Generator

The wind turbine modeled using doubly fed induction generator (DFIG) consists of a wound rotor induction generator and an AC/DC/AC IGBT based PWM converter. The DFIG technology allows to extract the maximum power from the wind for low speeds by optimizing the turbine speed and minimizing the mechanical stress of the wind turbine. It is advantageous to use DFIG which offers the speed control with reduced cost and power losses are quite low because the power electronics components use only 25% of the overall output power. The stator winding of the asynchronous machine is directly connected to the grid and its rotor is connected via slip rings. The rotor consists of machine side converter and the grid side converter, which are connected back to back and a DC link capacitor is connected between the two converters. The stator winding is directly connected to the 50 Hz grid while the rotor is fed at the variable frequency through the AC/DC/AC converter. The overall block diagram of DFIG is shown in Fig 3.

3. IMPLEMENTATION OF MATLAB/SIMULINK

In this chapter various components of wind conversion system like DFIG, boost converter, pitch control and MPPT and their control is implemented in MATLAB/SIMULINK environment.

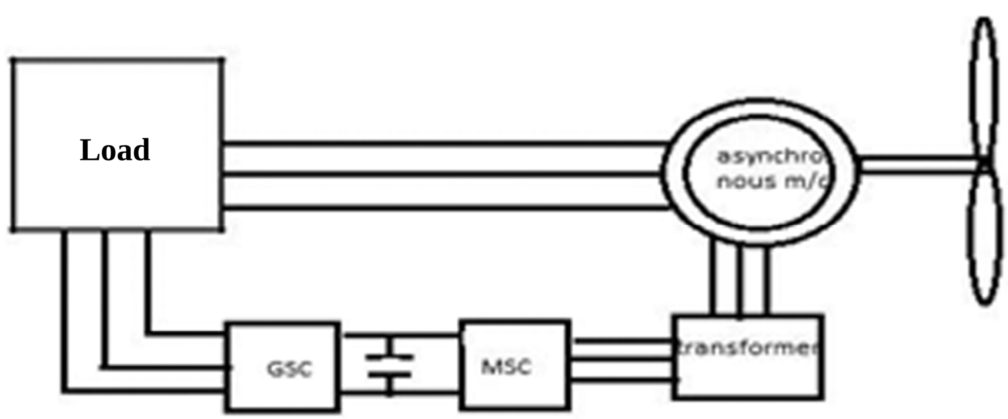

Figure 3: Block Diagram of Doubly Fed Induction Generator

3.1. Pitch angle control

Pitch angle control is the mechanical method of controlling the blade angle of the wind turbine. During low wind speed the pitch angle controller remains constant. When wind speed is not higher than the rated speed, the blade incidence stay near the angle 0°, which is similar to the generator with constant pitch, and generates the output power according to the changes in wind speed. If the wind speed is greater than the rated speed, the pitch control changes blade incidence so that the output power of generator is within the allowed range. If the wind turbine is allowed to operate over the entire range of wind speed without implementation of any control mechanism, the angular speed of the shaft exceeds its rated value and leads to damage the blades. So it is essential to control the speed of the turbine when wind speed exceeds the rated wind speed. The implementation of pitch angle control is shown in Fig 4. The PI controller generates an output based on change in speed. The output from PI controller which is then passed to a limiter to generate the pitch command for WT. The minimum value of limiter is set to 0^0 and the maximum value for this simulation is 50^0. The pitch control generates the command to control the speed which in turn controls the turbine speed. For this simulation the wind speed is kept below the rated speed if the wind speed exceeds the rated value means then the pitch angle control is employed to prevent the wind turbine from damage.

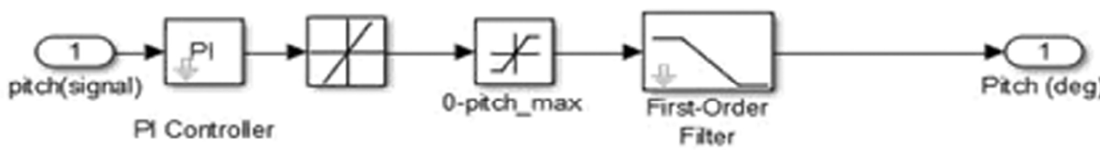

Figure 4: Modeling of Pitch Control Module

3.2. Maximum power point tracking

In the MPPT operation mode, the speed of the turbine is adjusted in such a way that the wind turbine can capture the maximum power based on the given wind speed. At the rated wind speed, the controller attempts to maintain the generator speed and the output power at its rated value by means of machine side converter control. The most commonly used MPPT algorithm is P&O. This algorithm uses a simple feedback arrangement and measures the voltage and current boost converter. These two signals

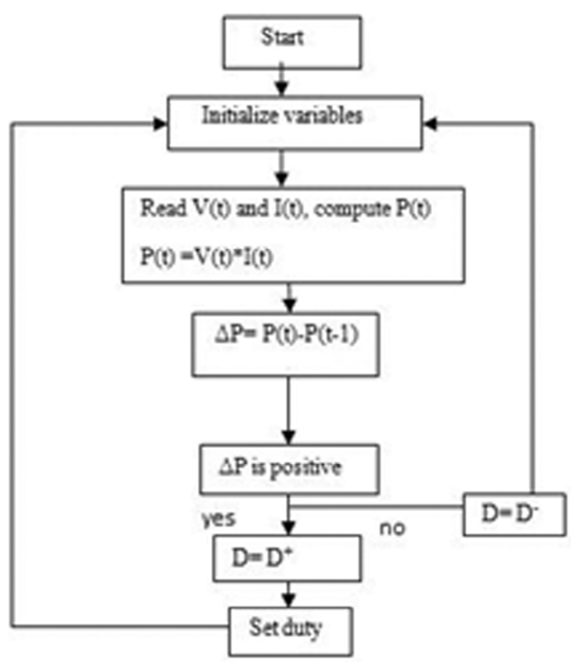

Figure 5: Modeling of Wind Conversion Module

are the inputs to MPPT controller, which generates the duty signal and the speed signal for maximum power extraction. The speed command is given to speed control which is connected with pitch controller and activates the pitch command to reduce the pitch angle. The output of the converter is periodically perturbed and the corresponding output power is compared with the previous output. If the change in power is positive then the operating point changes slightly. The major purpose of using MPPT is to generate the required duty cycle. The flow charts for the proposed perturb and observe algorithm is shown in Fig 5.

4. RESULTS AND DISCUSSION

In order to study the effects of entire WECS, the proposed System is modeled in MATLAB/SIMULINK environment by using different toolboxes. It includes wind turbine, drive train, rotor side converter and grid side converter. The simulation of wind conversion system using DFIG is shown in Fig 6. The numerical illustrations considered for the wind conversion system with the parameter values are given in the following tables. For modeling the wind conversion system a 4 hp machine is used. The active power is maintained at 0 MVar. Furthermore, the turbine speed is 1.2pu of generator's synchronous speed. The switch in the converter circuit is operated with the help of MPPT technique. It observes the output voltage and current value from the converter and it generates the duty cycle for the converter switch.

Table 1
WT System Specifications

Parameters	*Value*
Rated power	5000W
Cut-in- wind speed	4m/s
Rated wind speed	8m/s
Inertia co-efficient	7kgm^2
Optimum power co-efficient	0.46

Table 2
Doubly Fed Induction Machine Parameters

Parameters	*Values*
Rated power (P rated)	5000 W
Rated voltage (Vrated)	575 V
No.of poles	6
Base angular frequency (w rated)	314.16 rad/s
Angular moment of inertia (JWG)	1.9914 p. u.
Mechanical damping (D)	0.02 p. u.
Stator resistance (rs)	0.023 p. u.
Rotor resistance (rr)	0.016 p. u.
Stator leakage inductance (Lls)	0.18 p. u.
Rotor leakage inductance (Llr)	0.16p. u.
Mutual inductance (Lm)	0.9 p. u.

Table 3

Parameters	*Values*
Capacitance of boost converter	1000μF
Inductance of boost converter	420mH

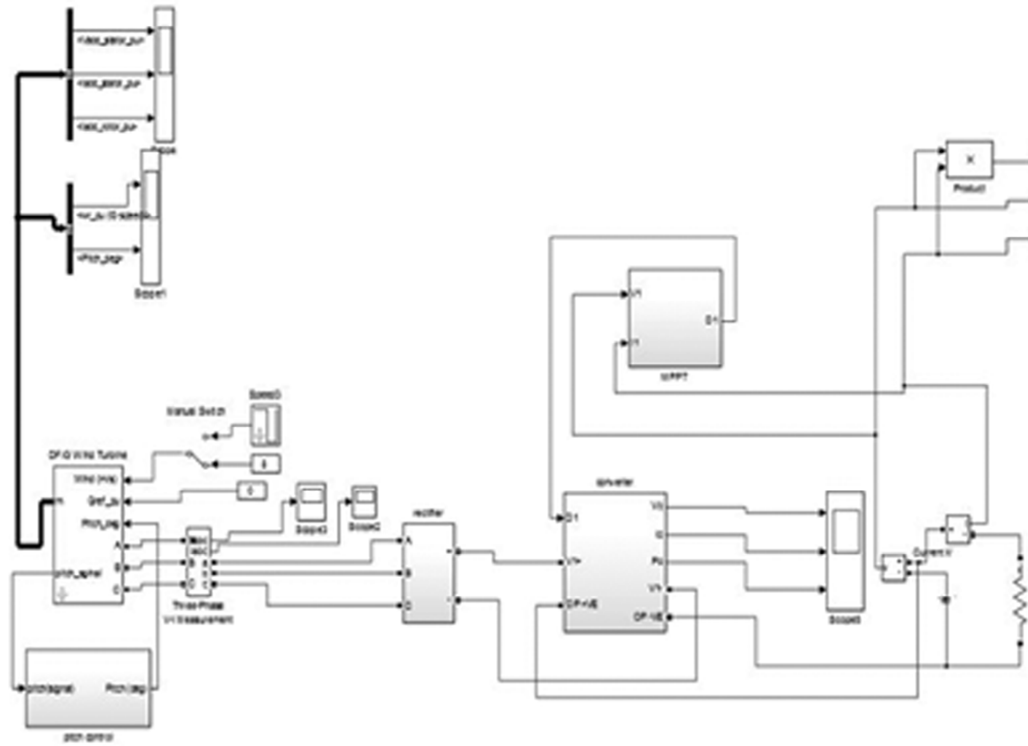

Figure 6: Modeling of Wind Conversion Module

The above system consists of wind turbine, doubly fed induction generator (DFIG), which is driven by the wind turbine, three phase rectifier based on PWM and DC-DC boost converter. It is connected to the load through LC filter. The wind turbine operates at the speed of 12 m/s. The output of the wind is AC which is converted into uncontrolled DC. This uncontrolled output is given as input to the boost converter and the controlled output is given directly to the load and the surplus energy is stored in the battery. The values of boost converter used here is calculated by using the necessary equations. The duty cycle for the power MOSFET is generated by the Maximum power point tracking which tracks the voltage and current from the boost converter and it generates the duty cycle accordingly. The stator current and the voltage obtained from the wind conversion system is shown in Fig 7.

4.1. Simulation Result of Boost converter

The simutaion of boost converter with MPPT control is shown in Fig 8. The input for boost converter is obtained from the bridge rectifier and the parameters of boost converters are shown in Table III. The purpose of the boost converter is to convert the uncontrolled DC into the controlled one. The simulated output voltage of the boost converter is shown in Fig 9. This waveform is plotted between the output voltage of the boost converter and time.

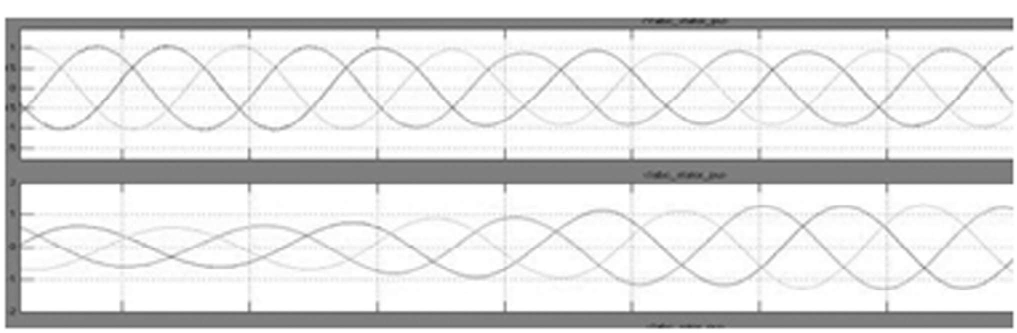

Figure 7: Stator Current and Voltages

The output power, voltage and current obtained across the load for various cases shown below. In the first case the operation is performed without the MPPT algorithm and in the second case the same system is operated with the implementation of MPPT algorithm. Fig 10 shows the output power, voltage and current waveforms that are obtained when the MPPT algorithm is not implemented. From the waveform it is seen that the power obtained is about 1 kW.

The waveform for output power, voltage and current are shown in Fig 11. This waveforms are obtained after implementing the MPPT technique. It can be seen that the output power is improved to 4 kW whereas it is only 1 kW in the above case.

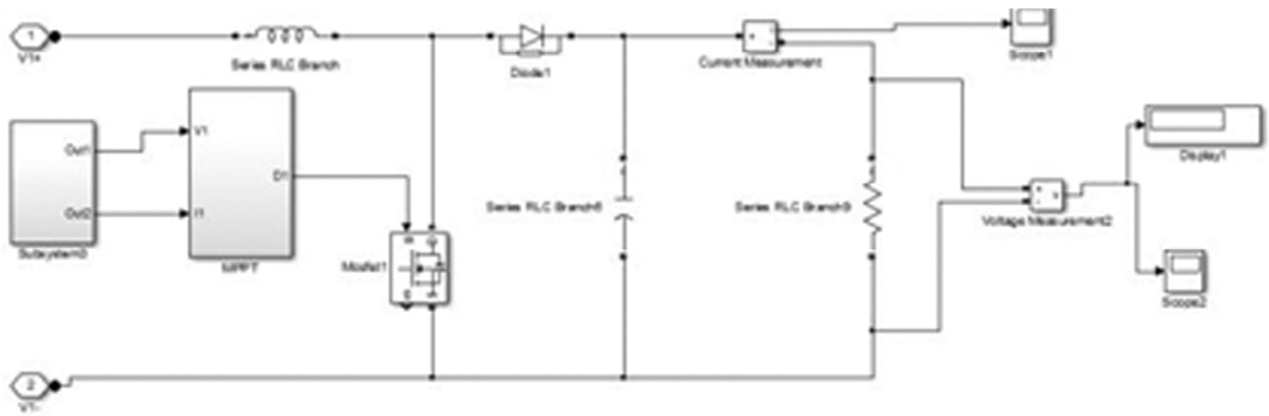

Figure 8: Implementation of Boost Converter Circuit

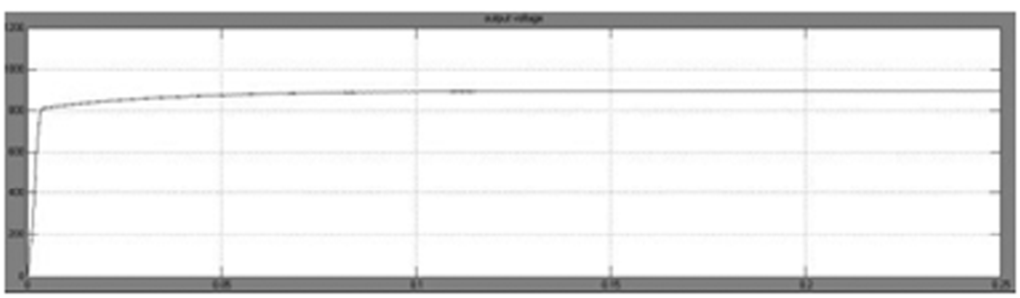

Figure 9: Boost Converter Output

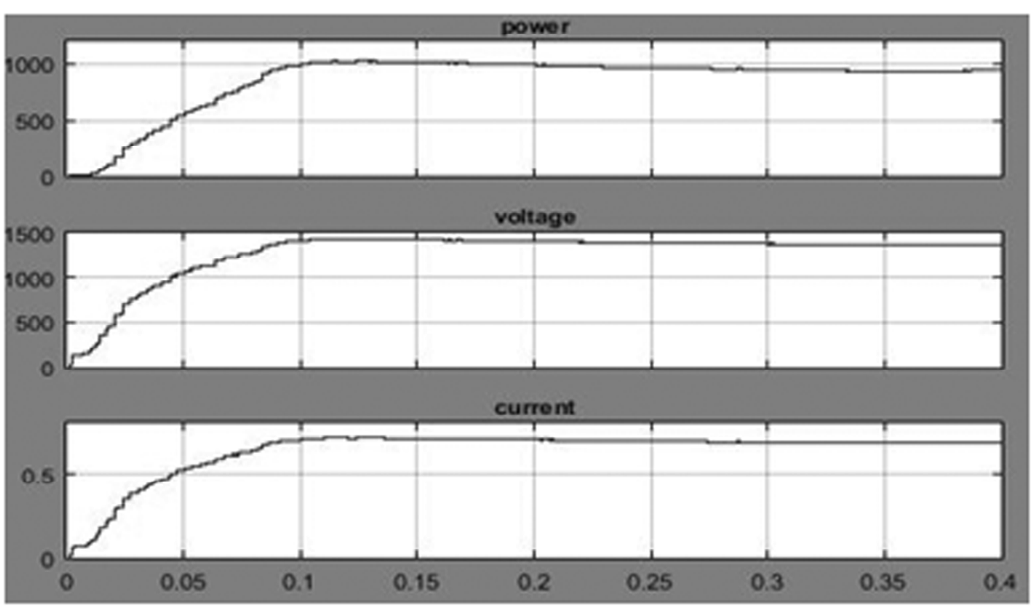

Figure 10: Waveforms Obtained Across The Load Before Using Mppt

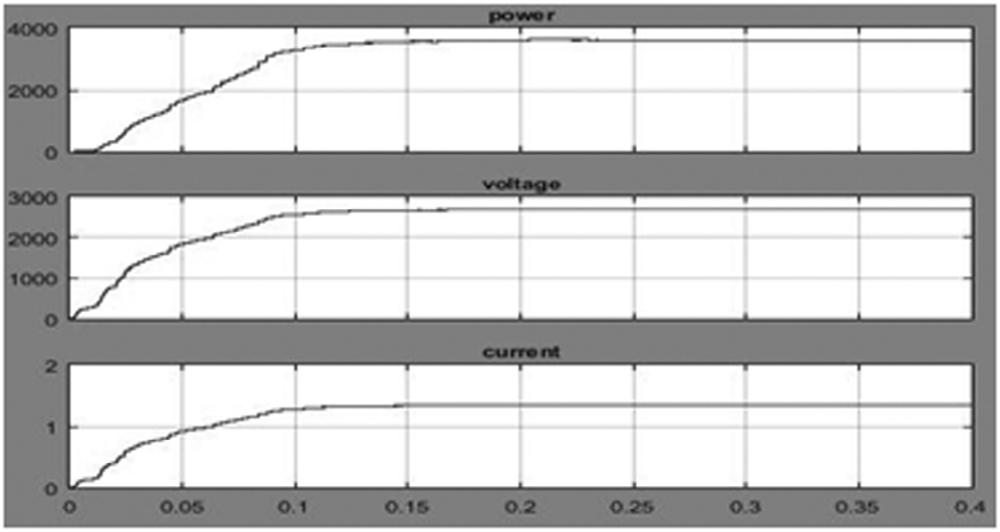

Figure 11: Output Power Obtained Across The Load After Using Mppt

From the Fig 10-11, it is observed that the energy obtained from the wind is improved by using the Maximum power point tracking. From the Fig we can see that the power is initially started from zero and reaches the steady-state after a certain period of time.

5. CONCLUSION

Thus a control strategy using Perturb and Observe technique for the stand-alone load has been presented in this paper, and simulation is implemented using MATLAB/SIMULINK. From the simulation results, it can be seen that the maximum power extracted from the wind is improved and the control is done by using the pitch control technique. The boost converter is controlled by the MPPT algorithm. Further, the surplus energy is stored in the battery and during the power shortage this stored energy is supply to the load. Considering the simulated results, it has been proved that the implementation of this proposed control strategy has improved the overall performance and efficiency of the existing Wind Energy Conversion System (WECS).

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