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Modelling and Simulation of Solar PV-Wind Hybrid Power System with Battery Storage

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Abstract: The main aim of renewable energy generation is to improve the power quality and deliver maximum power into the grid with less total harmonic distortion, high efficiency, small size, and low cost. The proposed hybrid system consists of solar and wind energy, which are the boundless resources to generate efficient electrical energy. The solar and wind energy sources are intermittent in nature, because electrical energy generated by these sources are unreliable and interrupt service to load. The Hybrid system with battery storage has more scope especially in rural and remote areas, these areas do not benefit from grid supply because of increased demand and global warming. The proposed system has solar PV and Doubly Fed Induction Generator (DFIG) wind turbine, output of system will be store in battery to serve the load continuously. The incremental conductance technique of Maximum Power Point Tracking (MPPT) is used to maximize the output of Solar PV and boost converter is used to raise the DC voltage of solar PV and fed to the three phase neutral point clamped inverter. The DFIG has two control techniques, namely, Rotor side control and Grid side control. Rotor side converter and Grid side Converter have the capability of generating or absorbing reactive power and to maintain constant rotor speed, and controls the DC-link voltage. The controller for DFIG can be implemented by using vector control method. Simulation results confirm the dynamic behavior of the proposed system using Matlab/Simulink.
Keywords: MPPT, DFIG, Neutral point clamped inverter, Boost converter, Pitch angle controller.

I. INTRODUCTION

Present scenario the generation of electricity generation is limited by using conventional resources, day by day the electrical energy conception is increasing and the usage of non-renewable energy sources severe environmental effects like ozone layer depletion, radiation health issues etc. Because researchers try to generate electrical energy without effecting environment and human beings. One of such eco-friendly energy sources is photo voltaic system and wind energy system. The solar and wind resources are inexhaustible and intermittent in nature. Because of boundless resources researchers keep attention to generating more electrical energy. In general Photo Voltaic (PV) system can establish any where on the earth, because the PV system majorly operated in distributed application either by connecting isolated mode or grid connected mode. In case of isolated mode the power generated by PV system is independent and serve the load independently. But in case of grid connected mode the PV system is interconnect with the grid and serve the load through the grid supply. The wind system also operated in isolated and grid connected mode but to install the wind system elected air flow place is required.

The hybrid system [1] is a combination of two or more energy sources, which are inter connected each other through grid or isolated grid system. Now a days isolated hybrid system is more scope especially in rural and remote places because these areas are do not benefit from grid due to the increasing demand. The drawback of solar and wind hybrid system is resources are intermittent this makes system unreliable. But combining hybrid system with battery storage the reliability of system can be enhanced.

Often solar and wind energies are complementary in nature i.e if there is a plenty of wind less solar intensity and plenty solar intensity less wind flow. So the inter connection these energy are can be increased system efficiency. The major advantages of the solar and DFIG [1], which have made popular is that, the power electronics equipment only has handle a fraction (20-30%) of the total system. This means that the cost and losses system can reduced. The little quantity of sun light can generate more electricity, the initial cost of wind plant is less. This is major reason the researchers make attention on wind and solar hybrid system. In solar energy conversion system, PV cells are made up of semiconductor materials like silicon, when sun light strikes the solar cell the electrons knocked loose from the atoms in semiconductor material and starts moving. If electrical conductor are attached to positive and negative sides, forming an electrical circuit then voltage will developed across it. The generation electrical energy is depends on number solar cells, solar irradiance temperature and modelling of PV system. The generation of electrical energy is maximized by MPPT with boost converter. Different MPPT techniques like Perturb and Observe (P&O), incremental conductance, fuzzy logic and some other techniques are used to maximize the power [2] [3]. In wind energy conversion system, wind turbine is connected to gear box, which increase the generator shaft speed. The mechanical energy developed by wind turbine is converted into electrical energy

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through Doubly Fed Induction Generator (DFIG) [4]. The power generated by solar panels and DFIG is useful to serve the load through autonomous grid, which is inter connects the solar and wind conversion systems. During less solar and wind situation the storage battery is useful to serve the load continuously.

II. SYSTEM DESCRIPTION

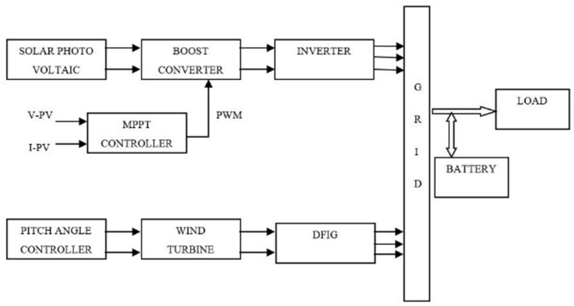

Fig.1 Proposed system block diagram [1].

The block diagram shown in Fig.1 presents the basic architecture of solar PV and wind hybrid power system. Solar and Wind resources are converted into electric energy by using suitable techniques. When solar energy fall on solar panel, which contains silicon converting to electric energy. The generating electric energy maximized by boost converter with help of incremental conductance MPPT technique.

The maximized DC supply will convert to AC supply to serve the load by using three level neutral point clamped inverter. The wind energy conversion system contains wind turbine, which is used to convert the kinetic energy into mechanical energy again mechanical energy converting into electric energy by using Doubly Fed Induction Generator (DFIG). Both generating energies are uninterrupted to load because battery is used to serve the load continuously.

The operating principle of doubly fed induction generator is like a conventional induction generator. The only difference is that the magnetic field created in rotor of DFIG is not static but the speed proportional to the frequency of AC currents fed into rotor windings. This means that the rotating magnetic field passing through stator winding not only rotates due to rotation of the generator rotor but also due to AC currents fed into generator rotor winding. This means that the speed of DFIG determined by both rotation speed of rotor and AC currents fed into the rotor. Therefore the AC currents fed into rotor wind determines rotor speed, stator frequency and alternating voltage induced across the stator winding.Vector control techniques [5] can be applied to control rotor currents.

If the stator rotating magnetic field and magnetic field produced due to AC currents fed into rotor are rotates same direction then the frequency of voltages induced across stator winding is depends on following equation.

$$f_{stator} = \frac{n_{rotor} * N_{poles}}{120} + f_{rotor} \quad (1)$$

If the stator rotating magnetic field and magnetic field produced due to AC currents fed into rotor are rotates opposite direction then the frequency of voltages induced across stator winding is depends on following equation.

$$f_{stator} = \frac{n_{rotor} * N_{poles}}{120} - f_{rotor} \quad (2)$$

III. PV SYSTEM DESCRIPTION

In PV system sun light energy is converted into electricity based on the concept of photo voltaic effect. The photo current depends on temperature, solar irradiance, number of solar cells and modelling of PV system. An ideal solar cell represented by current source parallel with diode. However no solar is ideal in the world. The practical solar cell consist of current source, diode there by series resistance, which as very small value and shunt resistance whose value is very high. The solar cell current equation as follows [1].

$$I = I_{pv} - I_o \left\{ exp^{\left[\frac{q(V+IR_S)}{AkT_C}\right]} - 1 \right\} - \frac{(V+IR_{Sh})}{R_{Sh}} \qquad (3)$$

where I_{pv} - photovoltaic current, *V*- thermal voltage,I_o- Reverse saturation current or leakage current of diode, *K*- boltman's constant and *A*-ideality factor of diode.

The power produced by a single PV cell is not enough for general use. So by connecting many single PV cell in series (for high voltage requirement) and in parallel (for high current requirement) can get us the desired power generally a series connection is chosen this set of arrangement is known as a module. Many number of PV modules placed each other at one place is known as PV array [14] or panel. The solar panel current equation as follows [6].

$$I = I_{pv}N_p - I_0 N_p \left[e^{\left[\frac{V+IR_s\left[\frac{N_s}{N_p}\right]}{aV_T N_s}\right]} - 1 \right] - \left[\frac{V+IR_s\left[\frac{N_s}{N_p}\right]}{aV_T N_s} \right] \quad (4)$$

where N_s- series cells N_p-parallel cells.

The above equations (1) and (2) represents the photo voltaic current of solar cell and panel respectively. These values are depends on light intensity, solar irradiation, and cell temperature.

A. Evaluation Of Mppt Technique

The photovoltaic system has a non-linear current-voltage and power-voltage characteristics that continuously varies with irradiation and temperature. In order to track the continuously varying maximum power point of the solar array the MPPT (maximum power point tracking) control technique plays an important role in the PV systems. The task of a maximum power point tracking (MPPT) network in a photovoltaic (PV) system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions.

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic DC to DC system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. By using MPPT the solar system can track the maximum power at V_{MPP} *or* I_{MPP}. Before maximum power point the power is increased with voltage or current and after maximum power point the power is decreased with increasing voltage or current. MPPT is works on this principle shown in Fig.2.

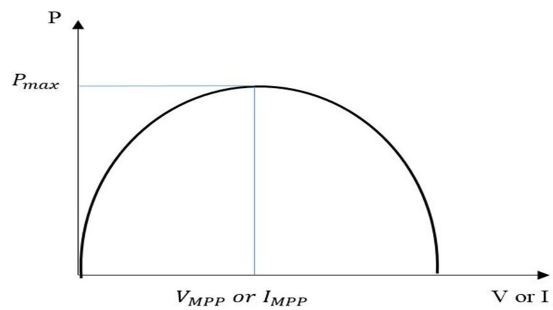

Fig.2 MPPT model output [7].

The present system consist of incremental conductance MPPT technique, which is little bit high efficiency compared to some other techniques like Perturb and Observe (P&O), fractional short circuit current and fractional open circuit voltage etc. The flow chart of incremental conductance technique as follows.

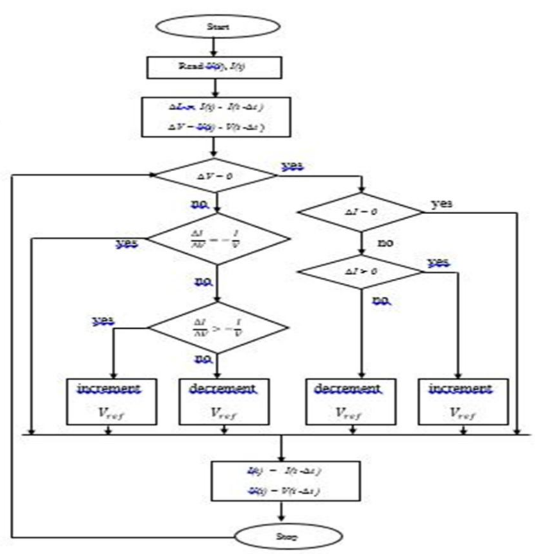

Fig.3 Incremental conductance flow chart [3].

B. Boost Converter

A boost converter is a step up converter, which is DC to DC power converter that step up the voltage from input to output. It is class of switched mode power supply containing at least one semiconductor element like diode or transistor and one energy storage element like capacitor or inductor. The boost converter consist of IGBT, the combination of MPPT controller and PWM [8] givespulses to the IGBT to maintain the rise the output voltage. The output of boost converter is given to three phase neutral point clamped inverter. The inductor must always have high current rating than the maximum current because the current increases with decrease inductance. The design equation of inductor is following below.

$$L = \frac{V_{in}(V_{out}-V_{in})}{I_l F_s V_{out}} \quad (5)$$

WhereV_{in} - typical voltage, V_{out} - desired output voltage,and I_l- inductor ripple current, which is 20% to 30% of the output current.

C. Three Level Npc Inverter

The three level Neutral Point Clamped (NPC) PWM inverter is general used in medium voltage range applications. The basic operation of NPC inverter is shown in table.1. The inverter consist of two capacitors and four transistors S_{a1}, S_{a2}, $S_{a3}$and S_{a4} shown in Fig.4.

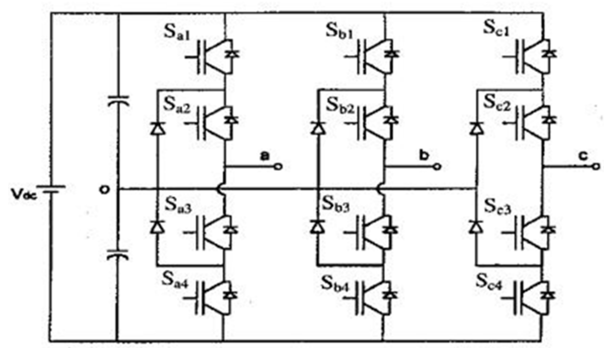

Fig.4 Three level clamped inverter [8].

S_{a1}	S_{a2}	S_{a3}	S_{a4}	output
1	1	0	0	+0.5V
0	1	1	0	0
0	0	1	1	-0.5V

Table.1 Switching sequence of NPC inverter [1].

IV. WIND ENERGY CONVERSION SYSTEM

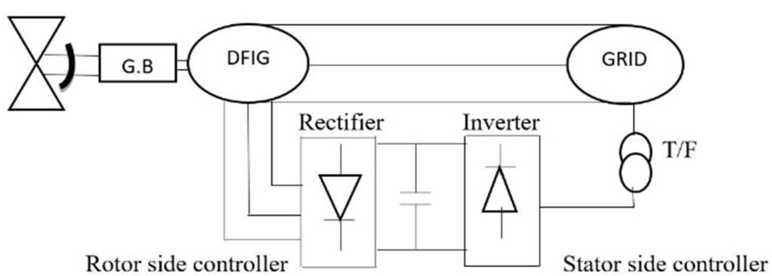

Fig.5 Wind energy system [9].

The wind energy conversion system design with the wind turbine, Doubly Fed Induction Generator (DFIG) and rotor side and stator side converters. The DFIG is asynchronous generator by using two controllers the system can maintain the speed as constant.The wind turbine convert the kinetic energy into mechanical energy and transmitted to shaft of the generator. The pitch angle controller controls the turbine speed to restrict the rated power at high wind speed and low wind speed.

A. Vector Active And Reactive Control Of Dfig

Active Power Control of a DFIG [11], the active power control of a DFIG is a series of regulating processes between wind turbine and induction generator. When wind velocity is high enough, the turbine controller regulates the pitch angle of the turbine blade to ensure the adequate torque for the given wind power. Another significant advantage of the DFIG is the real and reactive power control. Note that real power is directly related to the torque and speed of the generator [17].

The stator active power and reactive power are expressed as,

$$P_s = \frac{3}{2}Re(V_s i_s^*) = \frac{3}{2}(V_{ds}i_{ds} + V_{qs}i_{qs}) \qquad (6)$$

$$Q_s = \frac{3}{2}Im(V_s i_s^*) = \frac{3}{2}(V_{qs}i_{ds} - V_{ds}i_{qs} \qquad (7)$$

As the stator voltage oriented frame is used for the controllers synchronization, Vqs vanishes and the stator active and reactive power equation simplified to

$P_s = \frac{3}{2}V_{ds}i_{ds}$ (8) $Q_s = \frac{3}{2}V_{ds}i_{ds}$ (9)

According to the stator flux equatiomns in the synchgronous frame[10], in this condition, the strator currents can be written as,

$$i_{ds} = \left(-\frac{L_m}{L_s}\right)(i_{dr}) \qquad (10)$$

$$i_{qs} = (-\frac{L_m}{L_s})(i_{qr} + \frac{V_{ds}}{\omega_s}L_m \qquad (11)$$

So, the stator and reactive power are controlled through i_{dr} and i_{qr} respectively.

B. Rotor Side Controller

The rotor side converter provides varying excitation frequency based on wind speed conditions. It is used to maintain constant stator voltage and frequency to the variable wind speed. To maintain constant stator frequency the variable wind speed compared with the 1p.u and the resultant output given to PI controller. The PI controller to regulates the rated speed of the rotor and given to PWM converter [12].

C. Grid Side Controller

The grid side controller is known as stator side controller, which controls the flow of real and reactive power to the grid through grid interfacing inductance. The objective of grid side converter is to keep the dc link voltage constant regardless of magnitude and direction of the rotor power. The converter operates in a grid voltage oriented reference frame which is a synchronously rotating reference frame, with direct axis oriented along the grid voltage vector position [13].

V. SIMULATION STUDY

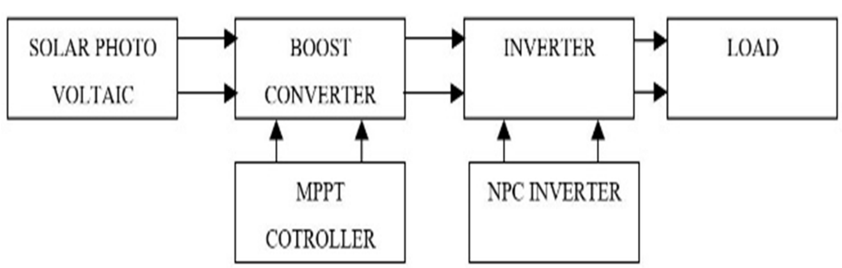

Fig.8 Simulation model of solar energy conversion system [15].

The solar PV system consisting of 4 number of series cells, 89 number of parallel cells, standard light intensity of a solar irradiation $1000W/m^2$, and temperature 25^0C.In solar energy conversion system by using the concept of single diode model solar cell with series resistance 0.008ohms, shunt resistance 1000ohms.

The solar irradiation has given in the form of step signal i.e$500\ W/m^2$ up to 0.5sec after it was raised to $1000\ W/m^2$.The generated voltage 295V is not sufficient since boost converter used for rise of voltage. The output voltage after boosting is 600V irrespective of variation of solar panel voltage. The voltage source converter generates the gate pulse signal to three level neutral point clamped inverter at 0.18sec, because the generated voltage of solar PV system has boosted at 0.18sec.

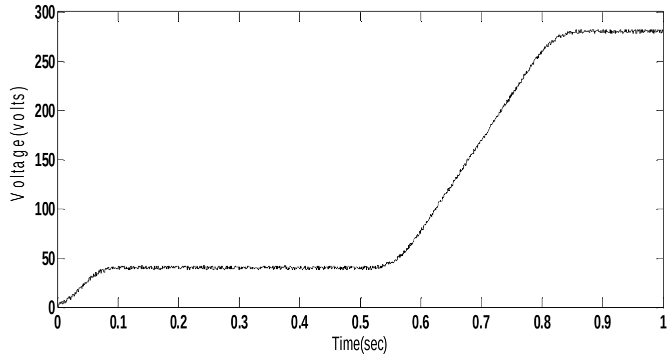

Fig.9 Solar panel output.

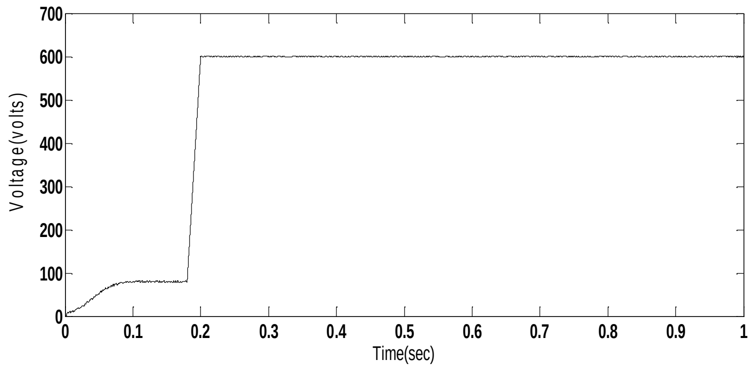

Fig.10 Boost converter output.

In year 2016 the monthly solar irradiance at GOKUL CAMPUS is varied from 262.52W/m^2 to 151.68W/m^2. This values are taken from HOMAR software shown in Fig.11 and output is shown in Fig.12.

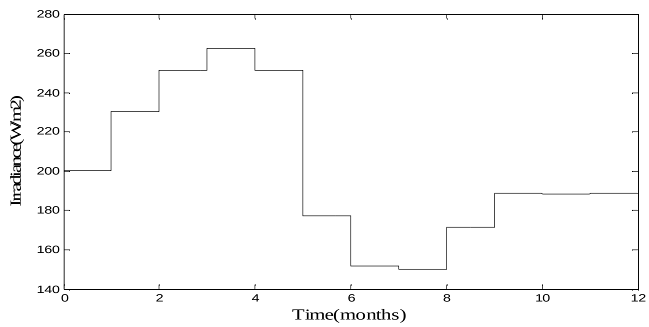

Fig.11 Monthly solar irradiance at GOKUL CAMPUS

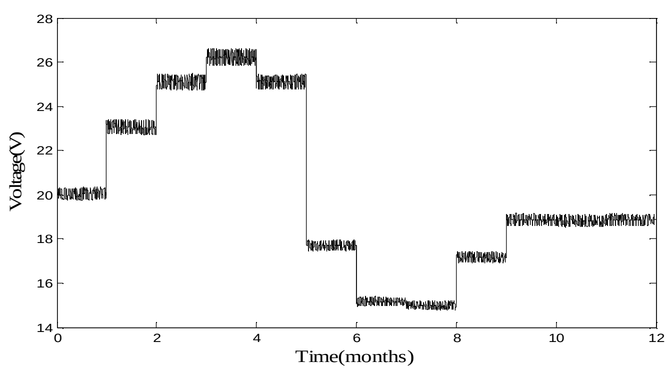

Fig.12 Variable monthly solar panel output.

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The wind energy conversion system consist of doubly fed induction generator (DFIG) has rating of 250kw, frequency 50Hz. The doubly fed induction generator operating as three phase wound rotor induction machine. It consists of two controllers, which are rotor side controller and stator side controller. The rotor output has given feedback to stator through rotor and stator side controllers to maintain the constant speed, because DFIG always supplies power to grid with 50Hz frequency irrespective of variation of speed.

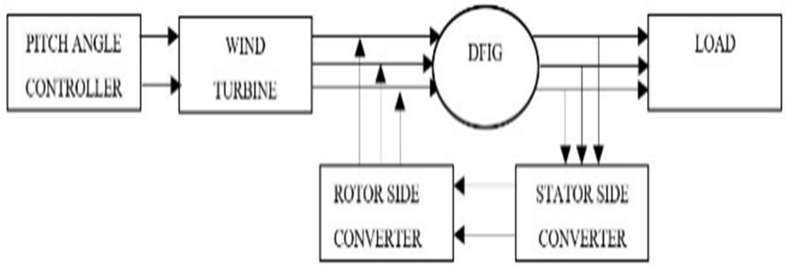

Fig.13 Simulation model of wind energy conversion system [16].

The wind speed has given in form of step input i.e up to 0.5sec wind speed is 4m/s after 0.5sec it raised to 14m/s. The two controllers operates to maintain DFIG has constant rotor speed (synchronous speed) 1p.u i.e 1500rpm irrespective of wind speed variation.

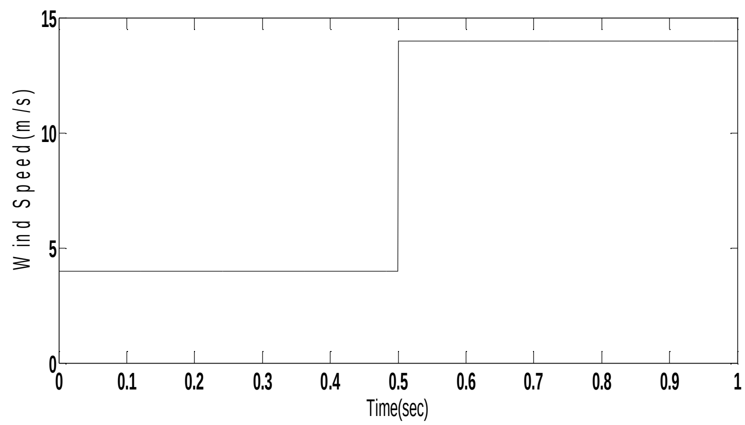

Fig.14 Wind speed in m/s.

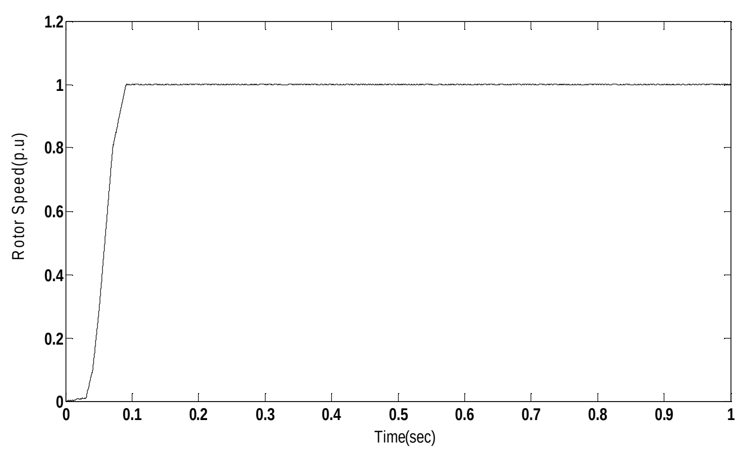

Fig.15Rotor speed in p.u

The following Fig. 4.19 is a monthly variable wind input to the doubly fed induction generator at GOKUL CAMPUS in the year 2016. It is due to presents of both converters the doubly fed induction generator rotating with constant speed and output is shown in Fig. 4.20 and Fig. 4.21. The values are varied from *5.4 m/s* to *3.86 m/s*. These values are taken from HOMAR software.

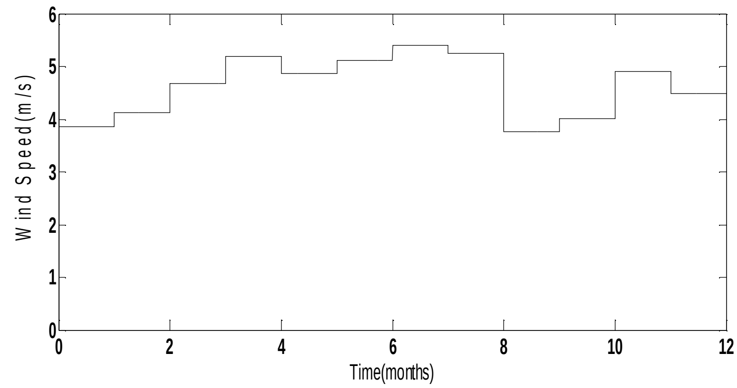

Fig.16 Monthly variable wind speed at GOKUL campus.

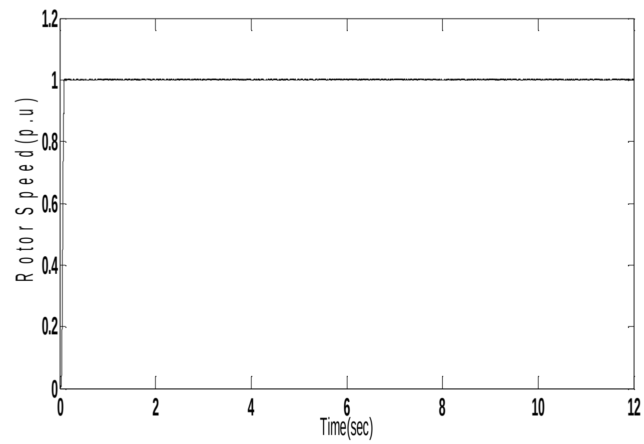

Fig.17 Wind turbine speed in per unit values.

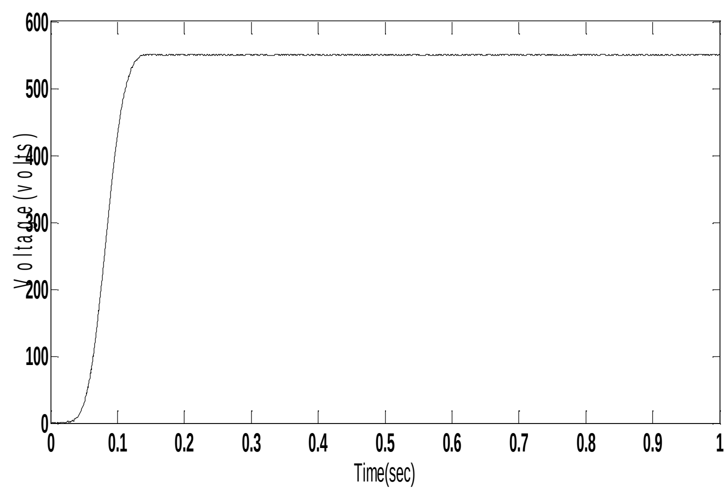

Fig.18 DC link voltage.

The electrical energy generated by these resources are unreliable and interrupt service to load. The solar PV and wind hybrid power system with battery storage has more scope, because by using 415V battery storage to overcome above defect.The solar and wind energy sources are intermittent in nature, because electrical energy generated by these sources are unreliable and interrupt service to load. The Hybrid system with battery storage has more advantages because this work presents 420V battery to store generated electrical energy.

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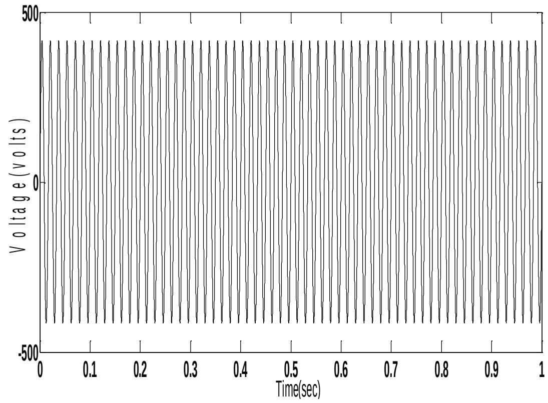

Fig.19 Step down Ac voltage of grid.

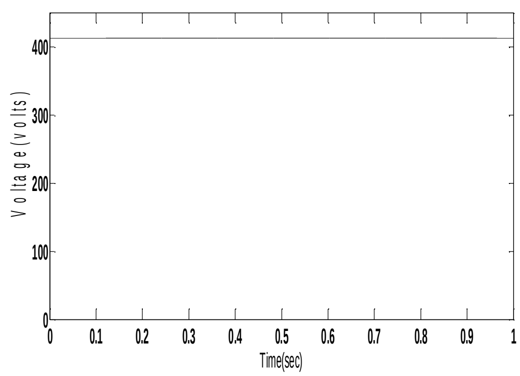

Fig.20 Battery storage voltage.

VI. CONCLUSION

In this work incremental conductance MPPT technique is developed and the output of the MPPT is given to PWM converter to generate the pulses which are required for Boost converter. The boost converter circuit is designed to raise the solar panel voltage, to convert this DC voltage to AC voltage by using three level NPC converter. One more energy source DFIG based wind turbine is used, now a days DFIG are extremely used in wind farms because it supplies power at constant voltage and frequency. To maintain constant voltage and frequency need two controllers, rotor side controller and grid side controller. These are back to back converters and implemented by using vector control principle.This work provides architecture with modelling and simulation of a hybrid energy sources with battery storage. The Characteristics and simulation results of solar PV and wind hybrid system with battery storage is verified in MATLAB-SIMULINK.

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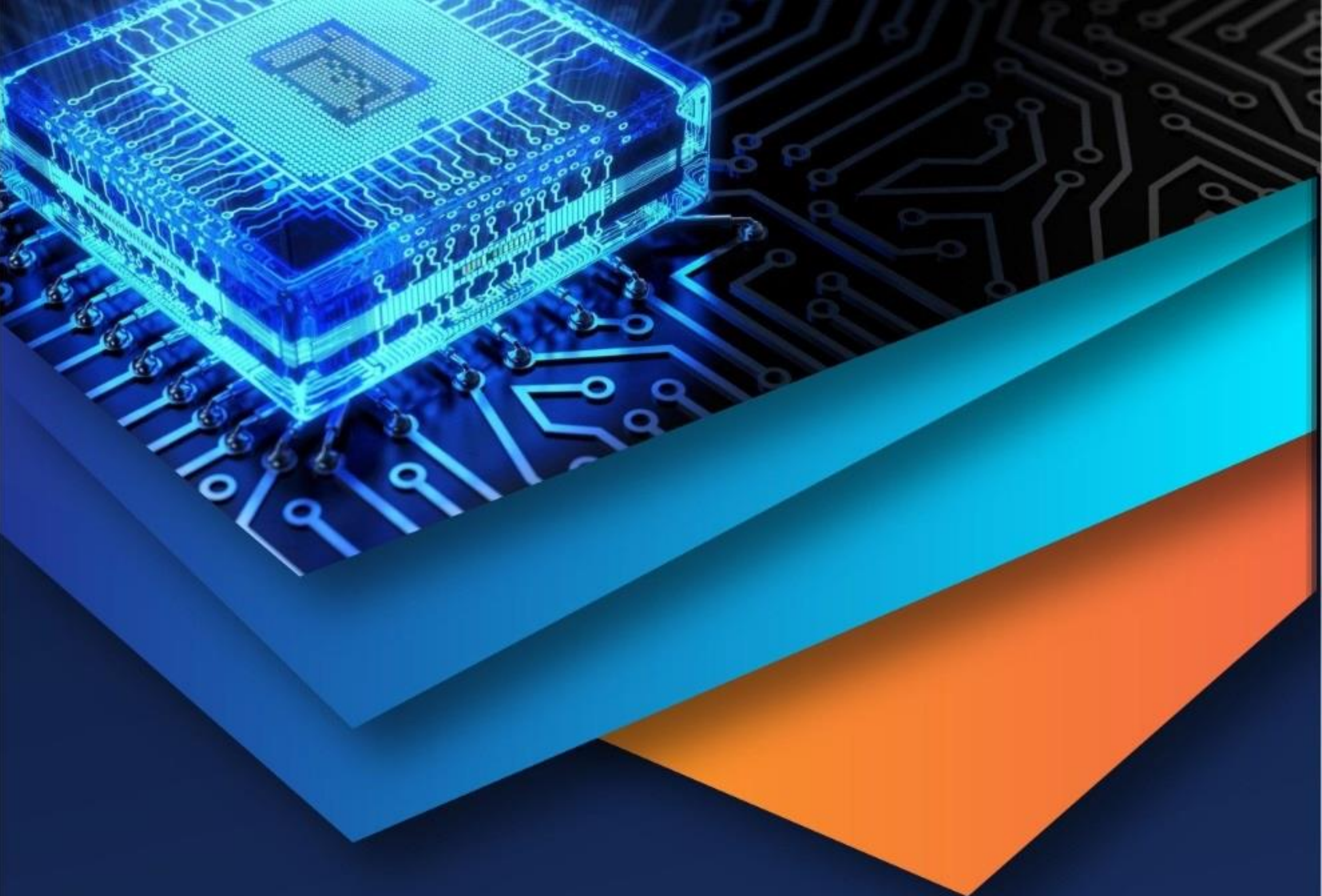

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