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Modeling and Analysis of Hybrid Renewable Energy system using MPPT

Vasantha Kumari. P, B.S. Shalavadi, Department of Electrical & Electronics Engineering, SDM College of Engineering & Technology, Dharwad

Abstract— This paper presents a standalone hybrid solar pv-wind energy system for maximum power point tracking (MPPT) algorithm. The performance of the hybrid system is evaluated using perturb and observe (P & O) method for tracking the maximum power from the PV array. The developed model is studied for different irradiation, temperature and wind speed, and the corresponding output power is obtained. The modeling and simulation of hybrid system is done using MATLAB/Simulink software.

Index Terms— Boost converter, Inverter, Maximum power point tracking (MPPT) Technique, Photovoltaic (PV) system, Permanet Magnet Synchoronous Generator (PMSG), Perturb and Observe method, Rectifier and Wind system.

1 Introduction

IN the world, the population growth has been increasing day by day and there by the demand for the electricity is also increasing, but the fossil fuels, coal, uranium oil, gas and etc are limited. So in order to overcome this we use a alternative source of energy that is renewable energy sources which plays a vital role in electricity generation. Different renewable energy sources are solar pv, wind, Biomass and fuel cells can be used as a alternate solution for the generation of the electricity and thus complete our daily energy demand. The solar photovoltaic (PV) array directly converts the solar energy into the electrical energy, but efficiency of the PV system is low and cost is high. The efficiency of solar panel depends upon the irradiation and temperature, during the cloudy weather condition the irradiations of the PV panel will be varying. The efficiency of the photovoltaic system may be increased by using maximum power point technique [1]. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable. However by combining these two intermittent sources and by incorporating maximum power point tracking (MPPT) algorithms, the system power transfer efficiency and reliability can be improved significantly. Whenever a source is unavailable or insufficient in meeting the load demands, the other energy source can compensate for the difference [2]. When a solar cell is operating without a MPPT technique the power drawn from the pv cell is determined by the load. And when the MPPT is implemented the amount of power drew from the PV cell by regulating the duty cycle of the DC-DC converter [3]. The Perturb and Observe (P & O) MPPT is a popular method for PV-MPPT owing to its low cost and simple implementation [4]. Incremental conductance method employs the higher speed for maximum power point tracking (MPPT). But it suffers from distortions around the maximum power point. Hence we go for P & O algorithm where it is simple and effective method [5]. Th solar energy will contribute to lower efficiency due to the photovoltaic panels of non linear I-V & P-V output characteristics. So in order to improve the efficiency of the photovoltaic panels we use MPPT technique that controls a DC-DC converter. In general there is a unique point on the I-V & P-V curve, called the maximum power point(MPP) at which entire pv system (array, inverter etc), operates with maximum efficiency and produces its maximum output power[6].

2 Hybrid System Description

2.1 Methodology

The block diagram of the hybrid system is shown in figure1.

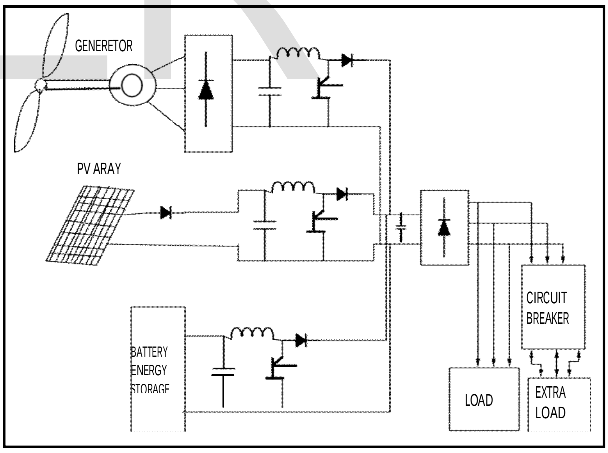

Fig. 1. Configuration of a proposed hybrid energy system

The hybrid system consists of a photovoltaic module, wind system, battery, circuit breaker and load as shown in above figure1. Where the solar PV array absorbs the radiation from the sun and then converts the light energy into the electricity and the wind converts the mechanical power into the electricity depending upon the wind speed and pitch angle. And the output from the wind is of AC and from solar it is DC and depending upon the requirement we use the converter for conversion process and then it is fed to the load. And a circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit. Its basic function is to interrupt current flow after a fault is detected.

The main aim of this project is to track the maximum power from the sun by using suitable MPPT technique that is P & O method there by the efficiency of the system is improved. And depending on the wind speed the wind power is obtained since these two sources are intermittent in nature. Therefore the combination of the both can achieve a reliable power supply and there by stability of the system can be improved. For reliable operation voltage must be maintained constant. Battery is used to store the energy generated from both the systems therefore power can be supplied to the load from both the systems either separately or simultaneously which enhances the reliability.The model is build using MATLAB/SIMULINK.

2.2 Solar Energy System

Solar cell is a semiconducting diode which converts sun light into the electrical energy. Photovoltaic cells can be made of silicon (Si), Gallium arsenide (GaAS), Cadmium telluride (CdTe) and a PV module in which a single PV cell cannot supply the needed output power. So as to increase the output power, PV cells must be connected in series, parallel or in combination of both. If PV panels are connected in series then it produces high voltage and power and if connected in parallel results in high current and power respectively. The solar system converts sunlight into electricity without effecting the environment. The equivalent circuit of the solar cell is shown in figure2. The circuit consists of current source, single diode, shunt resistor to limit the leakage current and series resistor. The figure3 shows the I-V & P-V characteristics of the PV array at different solar intensities.

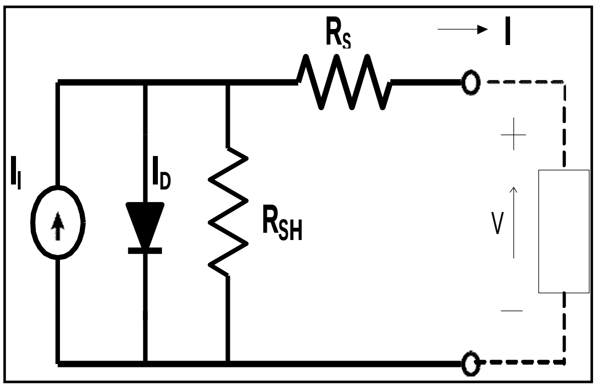

Fig. 2. Equivalent circuit of a PV model

The current equation of the solar cell is given by,

$$I = I_{ph} - I_D - I_{sh}$$

$$I = I_{ph} - I_o\,[\exp(qV_D/nKT)] - (V_D/R_s)$$

Where I_{ph} is the photo current, I_o is the saturation current, q is the electron charge, V_D is the Diode voltage, n is the number of cells connected in series and parallel, K is the Boltzmann constant($1.38*10^{-23}$ J/K), T is the cell temperature of the p-n junction and R_s is the starting resistance.

The power output of solar cell is P = V*I

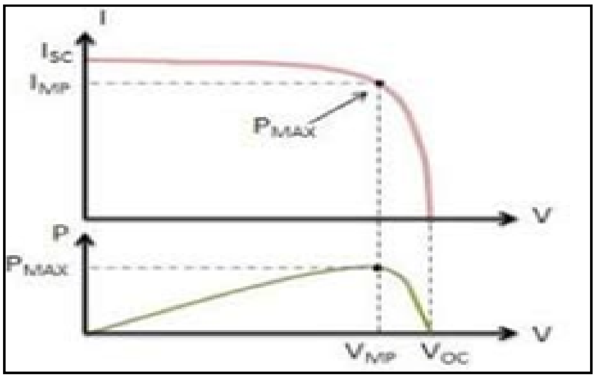

Fig. 3. Output characteristics of a pv array

2.3 Wind Energy System

Wind turbine converts kinetic energy of wind power into mechanical power. Generator is used to convert mechanical power into the electrical power. Output of the generator system is rectified and given to the boost converter. Boost converter is used to increase the output voltage. Wind turbine is designed to convert the wind energy into the electrical energy. And wind turbine consists of three main parts rotor, generator and structure. The mechanical power captured from wind by a wind turbine can be formulated as,

$$Pm = 0.5\rho\ ACpV^3$$

Where 0.59 is the theoretical maximum value of the power coefficient, ρ is the air density, Cp is th power coefficient, A is the area swept by the rotor in m^2, V^3 is the wind speed in (m/s).

3 Components of Hybrid System

3.1 Boost Converter

A Boost converter (step -up converter) is a DC to DC power converter that steps up voltage from its (supply) to its output (load). It is a class of switched mode power supply (SMPS) containing at least two semiconductors and at least one energy storage element such as a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters are made of capacitors (sometimes in combination with inductors) are normally added to such a converters output and input.The switch is typically a MOSFET, IGBT or BJT. The power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called as a step-up converter. Since it "steps up" the source voltage. Since power (P = VI) must be conserved, the output current is lower than the source current. For high efficiency the SMPS must turn on and off quickly and have low losses. But here in the simulation model where the pv array and the P & O MPPT are connected to the boost converter to boost the voltage respectively. The figure4 shows the Boost converter circuit.

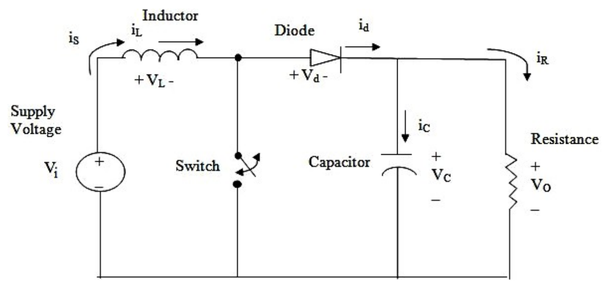

Fig. 4. Boost converter circuit

When the switch is in on condition, the current increases linearly in the boost inductor and the diode is off state. when the switch is off state, the energy stored in the inductor is discharged through the diode to the source load. And the duty cycle generated by the MPPT controller is fed to the DC-DC boost converters and the MOSFET switches producing stepped up voltage. The output (V_{out}) generated by the boost converter is always greater than the input voltage (V_{in}) and is validated by the formula,

$$V_{out} \ / \ V_{in} = 1 / (1 - D)$$

Where D is the duty cycle between 0 and 1

3.2 Inverter

An inverter is an electronic device which transforms the direct current (DC) into an alternating current (AC) at a given voltage and frequency. Generally Diodes, IGBT or Thyristors are used to design the inverter model. And these inverters are used in standalone photovoltaic systems for powering electrical devices. The most popular inverters are used to supply AC power are of three types: Square wave inverters (suitable for purely resistive loads), Modified sinusoidal wave inverter (suitable for resistive and capacitive loads, with inductive loads can produce noise). And pure sinusoidal wave inverters (suitable for all types of loads because they faithfully reproduce a sinusoidal wave equal to that of our domestic power grid). But here in the model the inverter is used to convert the direct current (DC) of the solar panel into the alternating current significantly.

3.3 Permanent Magnet Synchronous Generator (PMSG)

A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The term synchronous refers here to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field is generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature. Synchronous generators are the majority source of commercial electricity energy. They are commonly used to convert the mechanical power output into an electrical power. Some designs of wind turbines also use this generator type. And a synchronous machine generates a power in large amounts and has its field on the rotor and the armature on the stator. The rotor may be of sailent pole type or cyclindrical type in the PMSG, the magnetic field is obtained by using a permanent magnet, but not an electromagnet. The field flux remains constant in this case and the supply required to excite the field winding is not necessary and slip rings are not required. All other things remain the same as normal synchronous generator. One of the advantages of PMSG has less mechanical loss and require less space when compared to the electrical generators because of its design.

The EMF generated by a synchronous generator is given as,

$$E = 4.44 f \varphi T K_p K_d$$

Where f is the frequency, φ is the flux, T is the number of turns, K_p is the pitch factor, K_d is the distribution factor.

3.4 Rectifier

Rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction to direct current (DC), which flows in only one direction. In grid connected non-conventional energy sources like wind, biogas and solar energy conversion system, the three phase generator is directly connected to the rectifier. The MPPT controller measures the rectifier voltage and current to find the maximum power.

4 Maximum Power Point TRACKING (MPPT)

Maximum power point tracking (MPPT) is a technique which can extract maximum available power from the PV module. The MPPT mechanism makes use of an algorithm and an electronic circuit. MPPT algorithms are crucial in photovoltaic applications because the MPP of a solar panel fluctuates with the solar irradiation and temperature where this has a nonlinear PV & IV characteristics and a typical solar panel converts only 30% to 40% of the incident solar radiations into electrical energy. So with the use of a MPPT Perturb and Observe algorithm we obtain the maximum power from the solar PV array.
In general, the MPPT is an electronic system, the principle of which is too fed the appropriate duty cycle, D to the power conversion system for the output of the PV array in the form of the current and voltage and or the inputs of solar irradiance and temperature. This duty cycle is converted to signal by a gate driver circuit for adjusting the power conversion system operation. The optimal duty cycle depends on the location of the operational point on the P-V curve. MPPT controller generates duty cycle in order to create switching signals for the DC-DC converter. The switching signal is delivered to the gate of MOSFET permitting the boost converter to operate the solar pv system at optimum voltage and current so that the maxi-

mum power extraction is possible and the power from the solar module is calculated by measuring the voltage and current.

There are several methods of MPPT techniques such as Perturb and Observe (P & O) method, Incremental Conductance(IC) method, Artificial Neural Network (ANN), Fuzzy Logic (FL), Open circuit voltage method, short circuit current method and Particle Swarm Optimization (PSO) method.

5 Perturb and OBSERVE (P & O) Method

The P & O MPPT is a popular method for PV – MPPT due to its low cost and simple implementation and this method will sense the voltage (voltage sensor) from the PV array voltage and then measures the PV panel voltage and current. The cost of implementation of voltage sensor is less and hence easy to implement. The voltage of the PV panel is perturbed by small magnitude (ΔV) and the changing of power (ΔP) is observed. Adjustments are made in the same direction until there is no more increment in power. If the ΔP is less than zero, the working point will move far from the MPP, and the direction of perturbation must be inverted to return toward the MPP. P& O method is also called as "Hill climbing method" because it climbs the power curve to reach MPP. The flowchart of the P & O method is shown in figure5.

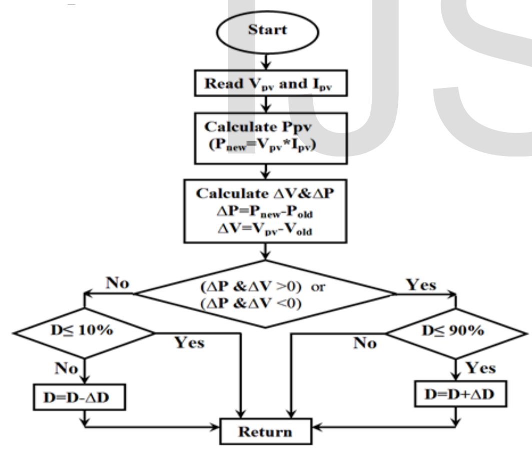

Fig. 5. The flowchart of the P & O method.

The P& O algorithm operates periodically by perturbing that is incrementing or decrementing the array terminal voltage or current and the corresponding pv output power is obtained with that of the previous perturbation cycle. Again a voltage perturbation is introduced and the power is measured again. The technique will compute the change in power measured respectively. When the maximum power point is reached P & O technique will oscillate around that point, the MPP. The perturbation value to the duty cycle is constant through out the operation of the algorithm. The value of perturbation ΔD chosen manually and varies from 0.1to 0.5. After each perturbation the algorithm will send the new updated duty cycle to the DC – DC converter. A common problem in this technique is that the pv module terminalvoltage is perturbed every MPPT cycle. Therefore when the MPP is reached, the output power oscillates around the maximum resulting in power loss in the PV system and it fails to operate under rapidly changing environmental conditions (slow response). So to overcome this we go for different MPPT techniques like particle swarm optimization (PSO) method, Fuzzy logic (FL) and Artifical neural network (ANN).

6 Simulation Model Of Hybrid System

6.1 Simulink Model of Solar System

The figure6. Shows the Simulink model of solar system. This model consists of pv array, boost converter, inverter, control block, utility grid, irradiation, temperature, load and P & O MPPT technique. The irradiation from the sun is converted in to the electrical energy by photovoltaic effect. And the voltage and the current from the panel are measured and corresponding power is obtained. And this PV array is connected to the boost conveter to step up the voltage from supply end to the load and a p & o mppt is also connected to the boost conveter because after each perturbation the algorithm will send the new updated duty cycle to the DC – DC converter. This p & o technique will sense the voltage from the PV array significantly. The voltage of the PV panel is perturbed by small magnitude (ΔV) and the changing of power (ΔP) is observed. Adjustments are made in the same direction until there is no more increment in power. When the maximum power point is reached P & O technique will oscillate around that point, the MPP. The perturbation value to the duty cycle is constant through out the operation of the algorithm.

Specifications used for modeling of solar system are shown below:

- Solar panel Rating : 100KW
- Parallel strings : 66
- Series strings : 5
- Irradiation : 1000 W/m^2
- Temperature : 25 degrees
- Voltage at maximum power point Vmp(V) : 54.7
- Current at maximum power point Imp(A): 5.58
- Maximum Power(W) : 305.226
- Open circuit voltage V_{oc}(V) = 64.2
- Short circuit current I_{sc}(A) = 5.96
- Module : Sunpower spr-305E-WHT-D
- 54.7*5.58*66*5 = 100KW

6.2 Simulink Model of Wind System

The figure7. Shows the Simulink model of wind system. This model consists of Permanent magnet synchronous generator with rectifier to convert ac to dc. The input to the wind system is varying wind speed. Mechanical energy from the turbine is converted into the electrical energy through the generator. AC output voltage from the generator is converted to DC output voltage through rectifier.

Specifications used for modeling of wind system are shown

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below:

- Nominal Mechanical output power(W): 8.5e3
- Base power of the electrical generator(VA) : 8.5e3/0.9
- Base wind speed(m/s) : 12
- Maximum power at base wind speed(p.u of nominal mechanical power) : 0.8
- Base rotational speed (p.u of bas generator speed) : 1
- Pitch angle beta to display wind turbine characteristics(degrees) : 0
- Number of phases : 3
- Back EMF waveform : sinusoidal
- Rotor type : sailent-pole
- Mechanical input : Torque Tm

And a figure8. Shows a Simulink model of a Hybrid energy system using P & O technique.

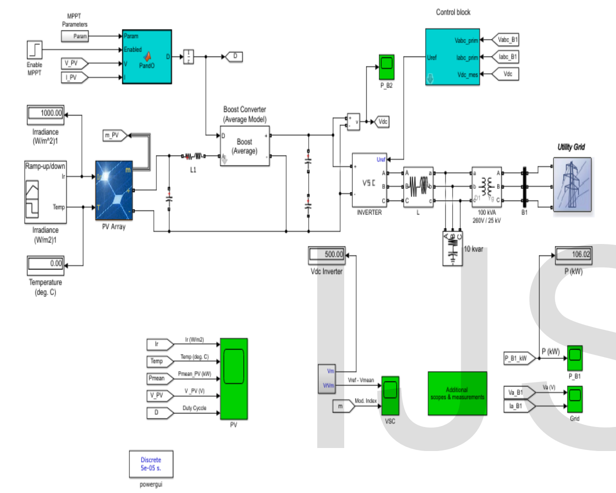

Fig. 6. Simulink model of a solar system

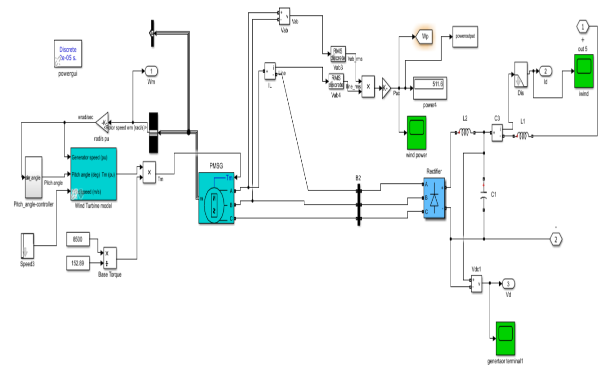

Fig. 7. Simulink model of a wind system

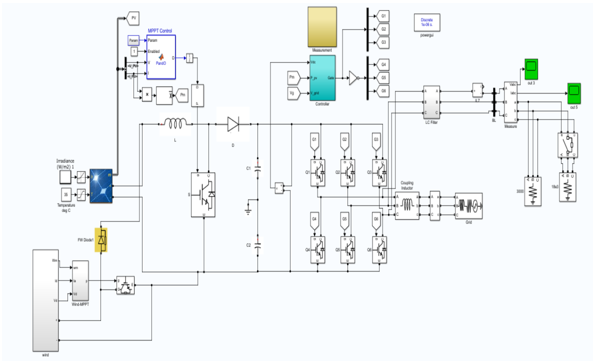

Fig. 8. Simulink model of a Hybrid energy system using P&O technique.

7. Simulation Results and Discussion

The simulation analysis of hybrid solar and wind system is carried out with the help of MATLAB/Simulink software. The analysis is carried out with the different irradiance levels, temperature and with different wind speeds and corresponding output power is obtained.

7.1 Simulation Results of Solar System

The output power of the solar PV system at different Irradiation and temperature is shown in table1 and fig9 & 10 shows the PV & IV vharacteristics of solar for radiation and temperature, the output power & voltage are increasing with the increase in irradiation and temperature as the input.

TABLE 1
CHANGE IN POWER W.R T THE IRRADIATION AND TEMPERATURE

Irradiance (W/m²)	Temperature (Degrees)	Voltage (V)	Power (KW)
1000	25	392	100
250	25	340	30

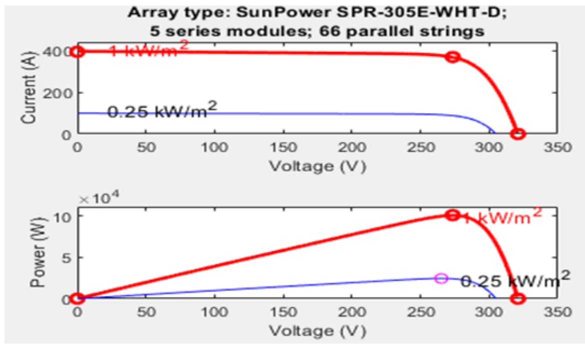

Fig. 9. Output of solar PV & IV Curves

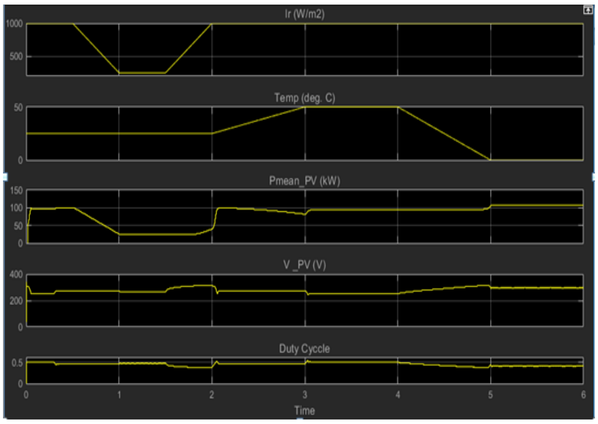

Fig. 10. Output from Simulink model of a solar system

7.2 Simulation Results of Wind System

The output power of the wind system at wind speed is shown in table2 and fig11 shows the output power from wind where the output power is increasing with the increase in the wind speed.

TABLE 2
CHANGE IN POWER W.R T WIND SPEED

Wind Seed (m/s)	Power (KW)
4	1075
6	2482
8	3413
12	6270

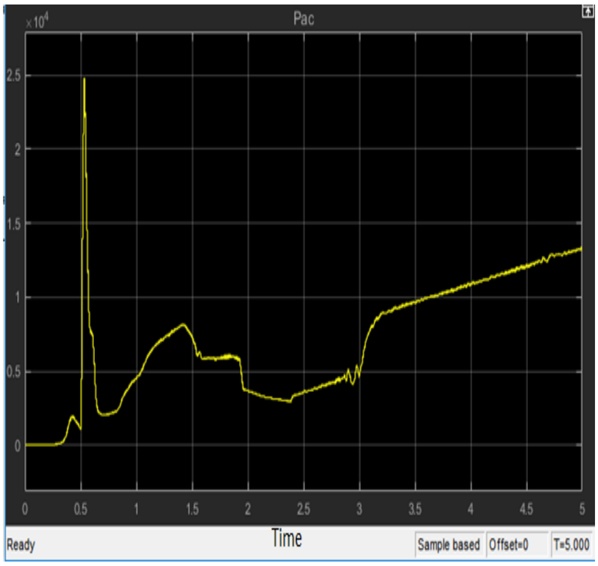

Fig. 11. Output from Simulink model of a wind system

7.3 Simulation Results of Hybrid Energy System Using P & O technique

The output power of the Hybrid energy system with different irradiation, temperature and wind speed is shown in table3 and fig12 shows the outpower power from solar and wind are increasing with respect to the increase in the irradiation, temperature and wind speed respectively.

TABLE 3
CHANGE IN OUTPUT POWER W.R T THE IRRADIATION, TEMPERATURE AND WIND SPEED

Irradiation (w/m^2)	Temperature (Degrees)	Wind Speed (m/s)	Output Power (KW)
1000	35	12	9
800	30	10	8
600	25	8	6
400	20	6	4

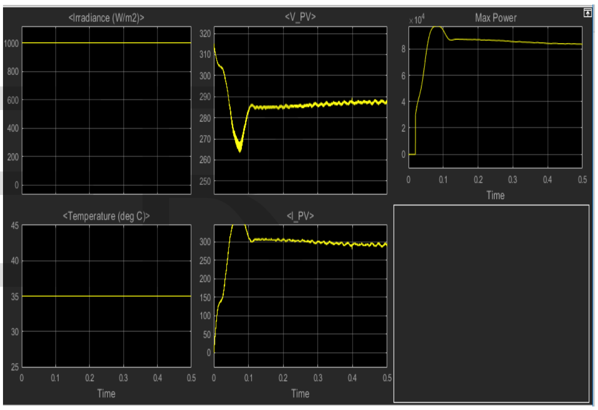

Fig. 12. Output from Simulink model of a Hybrid energy system using P & O technique

8. CONCLUSION

This work describes a hybrid energy system with variable irradiation, temperature and wind speed. Due to the variations in the wind speed and solar irradiance AC voltages varies. The available power from the solar system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the pv module was integrated with the wind turbine system. The performance of the developed system is evaluated in MATLAB/SIMULINK. From the simulation model of the table and graphs we can notice that by adopting Perturb and Observe MPPT method, with respect to the increase in the irradiation, temperature and wind speed the output power is also increasing and there by we get a maximum power by employing a MPPT technique. Thus a Hybrid solar and wind system performance are analyzed. And this system is accepted to meet up electricity demand.

FUTURE SCOPE

The Perturb & Observe technique has been failed to operate under rapid change in the environmental conditions that is it it has a slow response. So to overcome this we can go with the technique of Particle Swarm Optimization (PSO) MPPT method.

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