

Maximum Power Point Tracking of Grid Connected Solar Wind Hybrid System

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Abstract - *The use of renewable energy technology to meet the energy demands has been increasing for the past few years. However, the important drawbacks associated with renewable energy systems are their inability to guarantee reliability and their intermittent nature. At present, standalone solar photovoltaic and wind systems have been promoted on a larger scale. Standalone solar photovoltaic energy system cannot provide reliable power during night time or non-sunny days. The standalone wind system cannot satisfy constant load demands due to fluctuations in the magnitude of wind speeds from hour to hour throughout the year. Therefore, energy storage systems will be required for each of these systems in order to satisfy the power demands which are expensive and the size has to be reduced to a minimum possible for the renewable energy system to be cost effective. Hybrid power systems can be used to reduce energy storage requirements and for economical operation it is desirable to operate the system in its maximum power point value. The proposed method is to operate the wind solar hybrid system at its maximum power point by using sufficient power electronic devices and corresponding control method. The system is modeled in MATLAB SIMULINK and simulation results show that maximum power is tracked from a hybrid system at varying environmental conditions.*

Key Words: *doubly fed induction generators, permanent magnet synchronous generators, maximum power point tracking.*

1. INTRODUCTION

ENERGY has a vital role for the development of a nation and it has to be conserved in a most efficient manner. Energy is the ultimate factor responsible for both industrial and agricultural development. The new technologies which are developed to produce energy in

the most environmental friendly manner and conservation of energy resources in most economical way has equal importance. The use of renewable energy technology to meet the energy demands has been steadily increasing for the past few years. Import of petroleum products constitutes a major drain on our foreign exchange reserve. Renewable energy sources are considered to be the better option to meet these challenges. The important drawbacks associated with renewable energy systems are their inability to guarantee reliability and their intermittent nature. A major challenge of grid integrating an increasing number of renewable-energy-based distributed generators is faced while ensuring stability, voltage regulation, and power quality [1].

Because of some challenges such as conventional energy sources consumption, pollution, global climate change and security of energy supply, significant efforts have been made to develop renewable energy sources such as wind energy. Wind power growth with a 20% annual rate has experienced the fastest growth among all renewable energy sources since five years ago. It is predicted that by 2020 up to 12% of the world's electricity will have been supplied by wind power. In terms of wind power generation technology as a result of numerous technical benefits (higher energy yield, reducing power fluctuations and improving var supply) the modern MW-size wind turbines always use variable speed operation which is achieved by electrical converters[2]. These converters are typically associated with individual generators and they contribute significantly to the costs of wind turbines. Variable speed wind turbines have many advantages over fixed-speed generation such as increased energy capture, operation at maximum power point, improved efficiency, and power quality [3]. The variable speed wind turbine generators such as doubly fed induction generators (DFIGs) and permanent magnet synchronous generators (PMSGs) with primary converters are emerging as the preferred technologies [4]. However, the presence of a gearbox that couples the wind turbine to the generator causes problems. The gearbox suffers from faults and requires regular maintenance [5]. PMSG has received much attention in wind-energy application because of their property of self-excitation, which allows an operation at a high power factor and high efficiency [6]. The use of

permanent magnet in the rotor of the PMSG makes it unnecessary to supply magnetizing current through the stator for constant air-gap flux.

Solar energy is green energy, which is inexhaustible and environmentally friendly. It is becoming one of the most promising alternatives for conventional energy sources. Due to this, photovoltaic solar energy has been increasingly used to generate electric power from sunshine. A PV solar device, cell, or module converts solar energy directly to electrical energy [7]. If many cells are connected in series and parallel, a solar photovoltaic module is formed. Several PV solar devices are used to form a PV cell and several cells are used to form a PV module. Solar energy obtained from a solar PV cell is not constant all the time. The amount of extracted power from a PV system is a function of the PV array voltage and current set point [8]. Furthermore the power is affected by external conditions like solar irradiance and temperature. Under uniform solar irradiance level with no partial shading, the nonlinear current-voltage (I-V) characteristics of a PV solar module will have one optimal operating point corresponding to a unique maximum power point (MPP) on its power-voltage (P-V) curve [9]. In practice, since a solar module is composed of many solar cells which are connected with each other in series and/or in parallel, if some cells on the panel are shaded, sometimes caused by surrounding buildings, passing cloud in the sky or birds landing on solar panel, the P-V characteristics of solar panels becomes very complicated as multiple maximum power points exist on the P-V characteristic curves [10].

At present, standalone solar photovoltaic and wind systems have been promoted around the world on a comparatively larger scale. These independent systems cannot provide continuous source of energy, as they are seasonal. For example, standalone solar photovoltaic energy system cannot provide reliable power during non-sunny days. The standalone wind system cannot satisfy constant load demands due to significant fluctuations in the magnitude of wind speeds from hour to hour throughout the year. Therefore, energy storage systems will be required for each of these systems in order to satisfy the power demands. Usually storage system is expensive and the size has to be reduced to a minimum possible for the renewable energy system to be cost effective. Hybrid power systems can be used to reduce energy storage requirements.

2. DG SYSTEM OVERVIEW

Fig. 1 shows the single-line diagram of the study system. A wind farm is modelled as a fully controlled converter-inverter-based permanent-magnet synchronous generator and a photovoltaic solar farm is modelled as a voltage-source inverter with a dc-bus capacitor. Both are integrated into a distribution network at different points.

The load is considered to be of passive R-L type and it is also given at different point. Both units are designed to supply maximum power to the grid at varying environmental conditions.

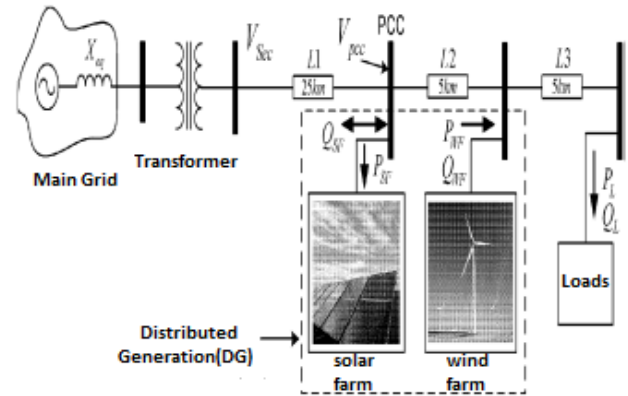


Fig-1: Single line diagram of the distributed generation study system

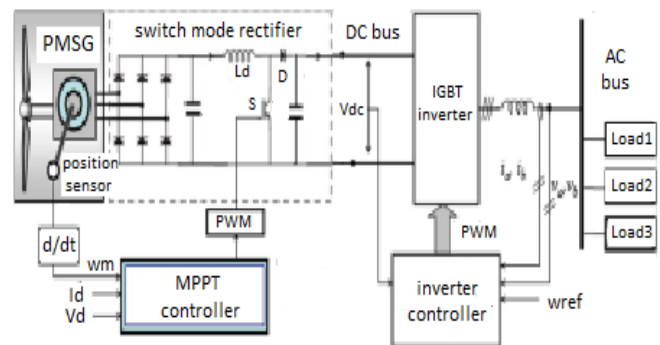


Fig -2: Control structure of a PMSG-based stand-alone variable-speed wind turbine

3. WIND ENERGY CONVERSION SYSTEM

3.1 System Configuration

The system configuration of wind energy conversion system consists of a variable speed wind turbine, Permanent magnet synchronous generator, a switch mode rectifier and PWM voltage source inverter. The output of a variable-speed PMSG is not suitable for use as it varies in amplitude and frequency due to fluctuating wind. A constant dc voltage is required for direct use, storage, or conversion to ac via an inverter. In this paper, a single-switch three-phase switch-mode rectifier is used to convert the ac output voltage of the generator to a constant dc voltage before conversion to ac voltage via an inverter. The single-switch three-phase switch-mode rectifier consists of a three-phase diode bridge rectifier and a dc to dc converter. The output of the switch-mode rectifier can be controlled by controlling the duty cycle of an active switch at any wind speed to extract maximum

power from the wind turbine and to supply the loads. An IGBT inverter is used to regulate the output voltage and frequency.

3.2 Wind Turbine Model

The amount of power captured by the wind turbine (power delivered by the rotor) is given by

$$P_t = 0.5A\rho C_p(\lambda, \beta)(V_w)^3 \tag{1}$$

where ρ is the air density (1.225kg/m³), V_w is the wind speed in meters per second, A is the blades' swept area(1.06m²), and C_p is the turbine-rotor-power coefficient, which is a function of the tip-speed ratio (λ) and pitch angle (β). ω is the rotational speed of turbine rotor in mechanical radians per second, and R is the radius of the turbine. The coefficient of performance of a wind turbine is influenced by the tip-speed to wind-speed ratio, which is given by

$$TSR = \lambda = \left(\frac{\omega R}{V_w}\right) \tag{2}$$

C_p is given by the following equation

$$C_p = 0.22 \left(\frac{116}{\Gamma} - 0.4\beta - 5\right) \exp\left(\frac{-12.5}{\Gamma}\right) \tag{3}$$

$$\Gamma = \frac{1}{\left(\frac{1}{\lambda + 0.08\beta}\right) - \left(\frac{0.035}{\beta^3 + 1}\right)} \tag{4}$$

The wind turbine can produce maximum power when the turbine operates at maximum λ (i.e., at C_{p_d}). Therefore, it is necessary to keep the rotor speed at an optimum value of the tip-speed ratio λ_c . If the wind speed varies, the rotor speed should be adjusted to follow the change.

3.3 Generator Side Converter Control

The optimum power from a wind turbine is calculated as

$$P_{opt} = 0.5A\rho C_{p-opt} \left(\frac{\omega_{m-opt} R}{\lambda_{opt}}\right)^3 \tag{5}$$

$$= K_{opt} \omega_{m-opt}^3 \tag{6}$$

Where

$$K_{opt} = 0.5A\rho C_{p-opt} \left(\frac{R}{\lambda_{opt}}\right)^3 \tag{7}$$

The proposed control objective is to control the duty cycle of the switch S in Fig. 2 to extract maximum power from the variable-speed wind turbine and transfer the power to the load.

In order to do this first generator speed ω_m is measured. Then reference torque is measured using the equation:

$$P_{ref} = K_{opt} \omega_m^3 \tag{8}$$

K_{opt} can be measured from the values corresponding to maximum power point at a particular wind speed and it is calculated as $1.7 \times 10^{-3} \text{ Nm}/(\text{rad/s})^2$.

The actual power in the dc side can be calculated using the equation:

$$P_g = V_d I_d \tag{9}$$

3.4 Grid Side Inverter Control

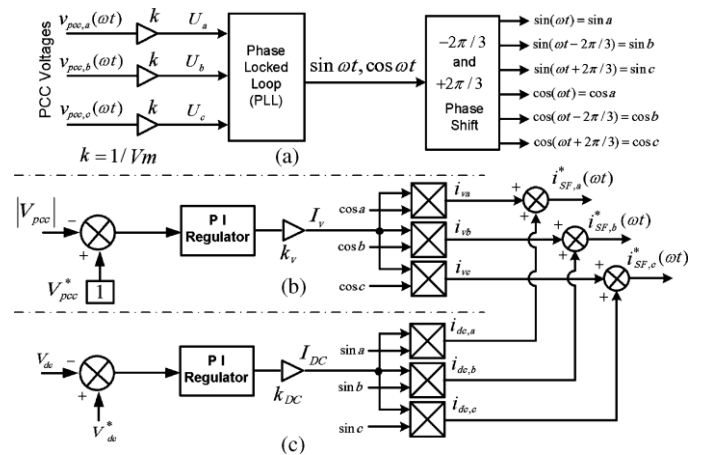


Fig-3: Inverter control scheme to regulate pcc voltage and dc power

Fig. 3 shows the block diagram of the control scheme used to achieve the proposed concept. The controller is composed of two proportional-integral (PI) based voltage-regulation loops. One loop regulates the PCC voltage, while the other maintains the dc-bus voltage across capacitor at a constant level. The PCC voltage is regulated by providing leading or lagging reactive power during bus voltage drop and rise, respectively. A phase-locked loop (PLL) based control approach is used to maintain synchronization with PCC voltage. A hysteresis current controller is utilized to perform switching of inverter switches.

4. PV SOLAR SYSTEM

4.1 PV Array Modeling

PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Fig. 4 and by an equation as in (10). The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level and temperature during the operation.

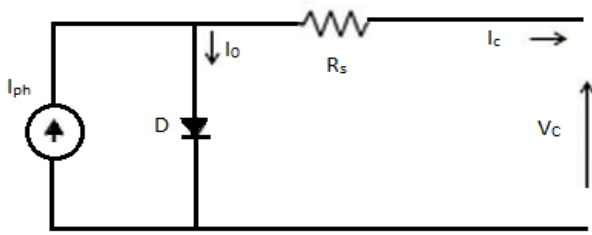


Fig-4: Simplified equivalent circuit of a photo voltaic cell

$$V_c = \frac{AkT_c}{e} \ln \frac{(I_{ph} + I_o - I_c)}{I_o} - R_s I_c \quad (10)$$

where the symbols are defined as follows:

e: electron charge (1.602×10^{-19} C).

k: Boltzmann constant (1.38×10^{-23} J/oK).

Ic: cell output current, A.

Iph: photocurrent, function of irradiation level and junction temperature (5 A).

Io: reverse saturation current of diode (0.0002 A).

Rs: series resistance of cell (0.001 Ω).

Tc: reference cell operating temperature (20 °C).

Vc: cell output voltage, V.

Both k and Tc should have the same temperature unit, either Kelvin or Celsius. Eq. (10) gives the voltage of a single solar cell which is then multiplied by the number of the cells connected in series to calculate the full array voltage. Since the array current is the sum of the currents flowing through the cells in parallel branches, the cell current Ic is obtained by dividing the array current by the number of the cells connected in parallel before being used in equation (10). If the temperature and solar irradiation levels change, the voltage and current outputs of the PV array will follow this change. Hence, the effects of the changes in temperature and solar irradiation levels should also be included in the final PV array model. For a known temperature and a known solar irradiation level, a model is obtained and then this model is modified to handle different cases of temperature and irradiation levels. When the ambient temperature and irradiation levels change, the cell operating temperature also changes, resulting in a new output voltage and a new photocurrent value. The solar cell operating temperature varies as a function of solar irradiation level and ambient temperature. The variable ambient temperature Ta affects the cell output voltage and cell photocurrent. These effects are represented in the model by the temperature coefficients C_{TV} and C_{TI} for cell output voltage and cell photocurrent, respectively, as:

$$C_{TV} = 1 + \beta_T (T_a - T_x) \quad (11)$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_c} (T_x - T_a) \quad (12)$$

where, $\beta_T = 0.004$ and $\gamma_T = 0.06$ for the cell used and $T_a=20^\circ\text{C}$ is the ambient temperature during the cell testing. This is used to obtain the modified model of the cell for another ambient temperature Tx. Even if the ambient temperature does not change significantly during the daytime, the solar irradiation level changes depending on the amount of sunlight and clouds. A change in solar irradiation level causes a change in the cell photocurrent and operating temperature, which in turn affects the cell output voltage. If the solar irradiation level increases from S_{x1} to S_{x2} , the cell operating temperature and the photocurrent will also increase from T_{x1} to T_{x2} and from I_{ph1} to I_{ph2} , respectively. Thus the change in the operating temperature and in the photocurrent due to variation in the solar irradiation level can be expressed via two constants, C_{SV} and C_{SI} , which are the correction factors for changes in cell output voltage Vc and photocurrent Iph, respectively:

$$C_{SV} = 1 + \beta_T \alpha_s (S_x - S_c) \quad (13)$$

$$C_{SI} = 1 + \frac{1}{S_c} (S_x - S_c) \quad (14)$$

where, S_c is the benchmark reference solar irradiation level during the cell testing to obtain the modified cell model. S_x is the new level of the solar irradiation.

Using correction factors, C_{TV} , C_{TV} , C_{TV} and C_{TV} , the new values of the cell output voltage V_c and Photocurrent I_{ph} are obtained for the new temperature Tx and solar irradiation S_x as follows:

$$V_{cx} = C_{TV} C_{SV} V_c \quad (15)$$

$$I_{phx} = C_{TI} C_{SI} I_{ph} \quad (16)$$

4.2 Maximum Power Point Tracking

The output power of solar cell depends mainly on three parameters which are temperature, solar irradiation and cell output voltage. The maximum power point can be tracked by varying the cell voltage or by varying the solar irradiation. In order to vary the solar irradiation the axis of solar panel is adjusted mechanically with respect to the position of the sun. Because of the development of power electronic devices electrical method of power tracking is preferred. In this the output voltage of solar cell is controlled by using power electronic converters to a particular reference value corresponding to the maximum power point.

When simulation starts a small initial value is assigned to the maximum power. Then PV array is simulated for different sampling time to get value of voltage, current and power. The power obtained at present time and previous time is

compared. The maximum power point is obtained when output at kth sample is less than that of (k-1)th sample. The voltage and power at that instant is taken and it is set as reference value. The reference value of voltage and power at various conditions of temperature and solar irradiation is calculated. These values are used to prepare look up table for voltage and power.

4.3 Inverter Control

The controller is similar to that of wind energy system which composed of two proportional-integral (PI) based voltage-regulation loops. One loop regulates the PCC voltage, while the other maintains the dc-bus voltage across SF inverter capacitor at a constant level. The dc reference value is provided from the look up table which is prepared for different temperature and solar irradiation as given in table 1. The PCC voltage is regulated by providing leading or lagging reactive power during bus voltage drop and rise, respectively. A phase-locked loop (PLL) based control approach is used to maintain synchronization with PCC voltage. A hysteresis current controller is utilized to perform switching of inverter switches.

Table -1:

Temperature (°C)	Solar Irradiation(W/m ²)	Voltage (V)	Power (W)
20	500	146.6	2423
	600	150.1	2982
	700	153.1	3552
	800	155.7	4132
	900	158.1	4721
30	1000	160.2	5318
	500	134.8	2217
	600	138	2728
	700	140.8	3250
	800	143.2	3781
40	900	145.4	4320
	1000	147.3	4860
	500	123	2013
	600	126	2477
	700	128.5	2951
	800	130.7	3433
	900	132.7	3923
	1000	134.5	4419

5. SIMULATION RESULTS

In order to verify the modeling of wind turbine, a ramp input is given to the rotor speed at a particular wind speed. The variation of power developed with the variation of rotor speed at different wind speed is shown in the Fig. 5. It shows that for different wind speed maximum power is obtained at different rotor speed and as the wind speed increases the maximum power obtained and speed at which maximum power obtained increases.

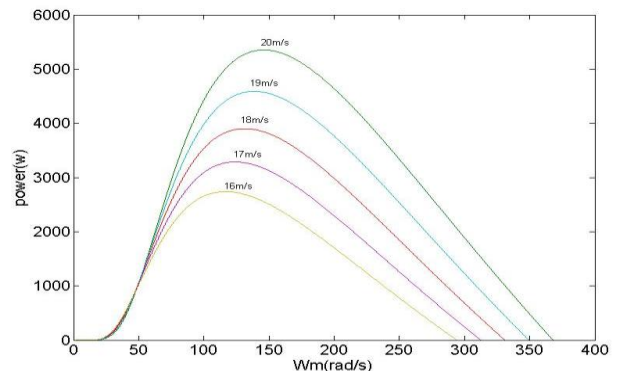


Fig-5: Variation of power due to change in rotor speed at different wind speed

When the turbine is connected to the system the input to the wind turbine is given in the form of step signal having initial value 20, final value 21 at a step time of 5 second in order to represent change in wind speed from 20m/s to 21m/s. The rotor speed is given initially a value of 100rad/sec till PMSG develop a speed more than that. After the developed speed of PMSG become more than 100rad/sec that value is given as the input rotor speed of wind turbine. The Output power and torque of wind turbine is given in Fig. 6 and Fig. 7 respectively. It shows the variation of those quantities when the wind speed changes. The reference and actual power output of system is given in Fig. 8 which shows that actual power developed in the dc side is almost tracking the reference power.

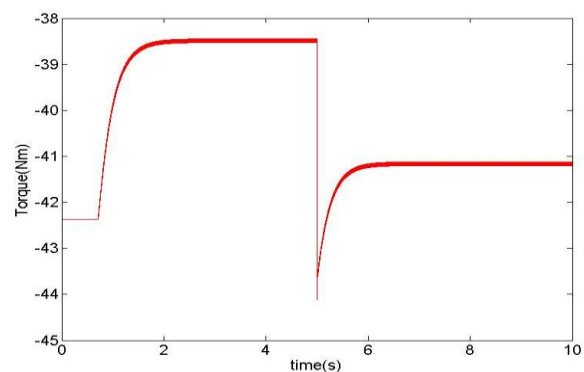


Fig-6: Variation of output torque due to change in wind speed

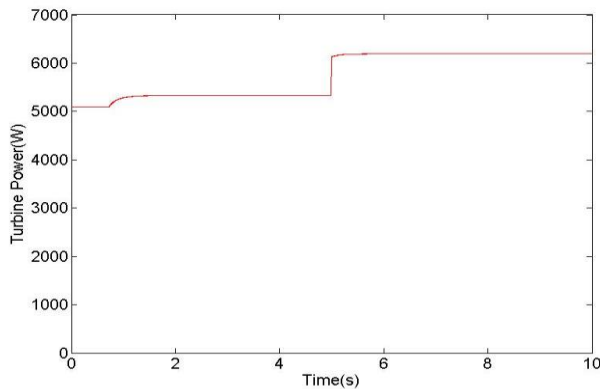


Fig-7: Variation of output power due to change in wind speed

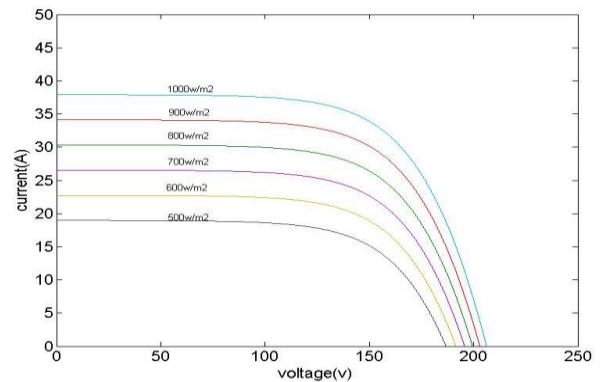


Fig-10: Variation of current due to change in voltage at different value of solar irradiation

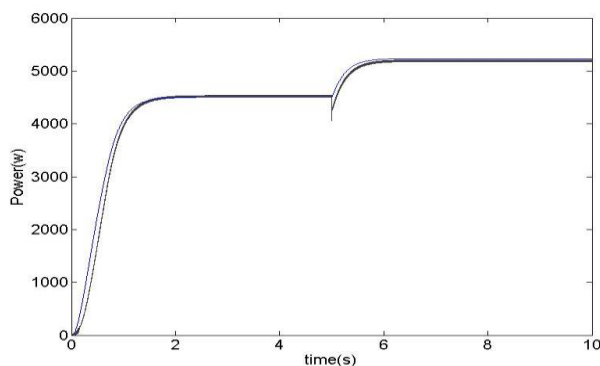


Fig-8: Tracking of reference power and actual power at different wind speed

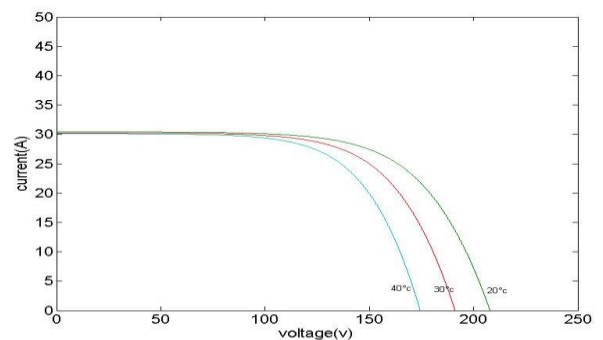


Fig-11: Variation of current due to change in voltage at different temperature

In order to verify the modeling of solar array, a ramp input is given as the current at a particular temperature and solar irradiation. The VI characteristic and PV characteristics at different temperature and solar irradiation is shown in the Fig. 9 to Fig. 12. From Fig. 9 and Fig. 10 it is clear that as the solar irradiation increases the maximum power and voltage corresponding to maximum power increases. Fig. 11 and Fig. 12 show that when temperature increases the maximum power and voltage corresponding to maximum power decreases.

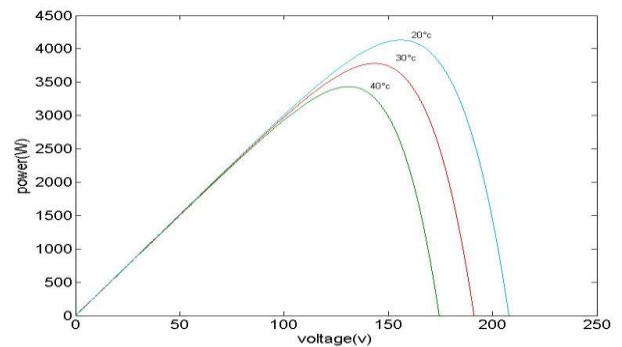


Fig-12: Variation of power due to change in voltage at different temperature.

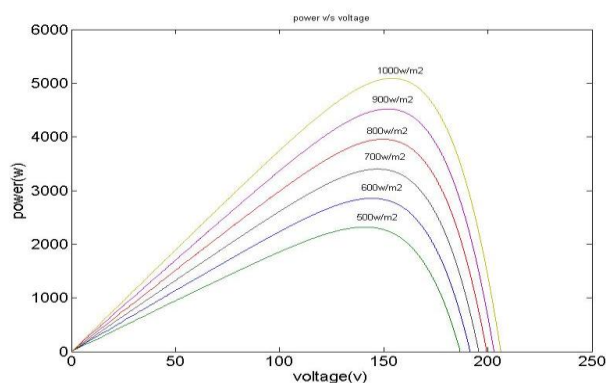


Fig-9: Variation of power due to change in voltage at different value of solar irradiation

3. CONCLUSIONS

In the present scenario standalone solar photovoltaic and wind systems have been promoted around the world on a comparatively larger scale. These independent systems cannot provide continuous source of energy, as they are seasonal. The solar and wind energies are complement in nature. In this paper a new method is used to operate the hybrid system at its maximum value. Wind energy system is operated in its maximum power point by controlling rotor speed at various wind speed. PV solar system is operated at maximum power point by controlling cell output voltage at various temperature and solar

irradiation. Both systems are connected to a grid in parallel to supply the power. By integrating the solar photovoltaic and wind systems, the reliability of the systems can be improved and the unit cost of power can be minimized. The simulation results demonstrates that the controllers work very well at varying conditions of wind speed for wind farm and varying temperature and irradiation for solar farm.

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BIOGRAPHIES



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