OPTIMAL LOAD DISPATCHING THROUGH WIND ENERGY AND SOLAR ENERGY SYSTEMS

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Abstract. Conventional resources of energy such as coal and fossil fuels are now being replaced with renewable sources. Solar PV and wind energy conversion systems are being widely employed for harvesting electric energy. Modern power electronic converters have made it possible to draw maximum power from these solar and wind energy conversion systems. This paper presents a hybrid energy system that integrates wind energy from Permanent Magnet Synchronous Generator (PMSG) and a photovoltaic (PV) solar system. Maximum Power Point Tracking (MPPT) algorithm is implemented that extracts maximum power from PV array under constantly changing environmental conditions. The outputs of wind turbine and PV array are integrated suitably in order to retain continuous power supply as per load requirement. Operation of wind generator is mainly determined by estimation of speed which is carried out by a sensor-less rotor speed estimator. This estimator replaces all mechanical sensors and they are no longer needed. The turbine speed is thus governed based on the estimated rotor speed by controlling the voltage and current at the input of Boost converter. The proposed system is designed and simulated on Matlab / Simulink platform and results are discussed.

Keywords: Permanent Magnet Synchronous Generator (PMSG) and a photovoltaic (PV) solar system. Maximum Power Point Tracking (MPPT) algorithm

1. Introduction

With the reserves of fossil fuels reaching the verge of depletion and continuous rise in the demand and cost of electric energy the need for harvesting energy through alternate renewable energy sources has gained significance. These renewable sources are found to be eco-friendly thus producing clean power. Of all the renewable energy sources that are available harvesting energy by means of wind and sun is opted due to their availability and technological advancements [1]. However usage of these alternate sources has been limited due to few reasons that include non-availability of sun during nights and low wind speed. Hybrid wind- solar energy systems have come into existence that use both sources effectively thus providing continuous power supply by proper load management. Power transfer capability, efficiency and reliability at the load side are significantly improved in hybrid energy systems. In the event of unavailability of any source, the other source will meet the load demand thus complementing each other.

Several hybrid wind and PV power systems are discussed in [2] using the conventional PI controllers for lower ratings. The proposed system consists of Wind turbine and solar PV module as inputs. Wind energy derived from PMSG, connected to converter, followed by grid side converter. To extract maximum power output from solar module Perturb and Observe (P&O) MPPT technique is used. Low rated hybrid systems comprising of PV and wind energy conversion systems [2] employing conventional PI controllers have been discussed [2]. The proposed system comprises

of wind turbine and solar PV module. To extract maximum power output from solar module Perturb and Observe (P&O) MPPT technique is used.
Solar energy is highly sustainable as it is freely available. Production of solar power does not result in emission of green house gases and hence does not have any adverse effects on the environment. Several methods using Maximum Power Point Tracking (MPPT) technique have been proposed for acquiring power to the maximum possible extent from PV systems. PV systems are available in standalone or grid connected system [3]. Operating point of the PV system is decided by the loading conditions. Output power of PV system changes with respect to the changes occurring in temperature and irradiance.
Of all the renewable energy sources available, wind energy system is one of the leading producers of electric energy. Wind energy systems employ either doubly fed induction generator or permanent magnet synchronous generator. Turbine and generator and connected through a gear box in a doubly fed induction generator. But in a permanent magnet synchronous generator turbine is directly connected to the generator [4]. Operation of wind generators is regulated by controlling the output voltage and current of AC-DC converter. Thus maximum power can be derived from solar PV and wind energy conversion system.

2. PROPOSED SYSTEM

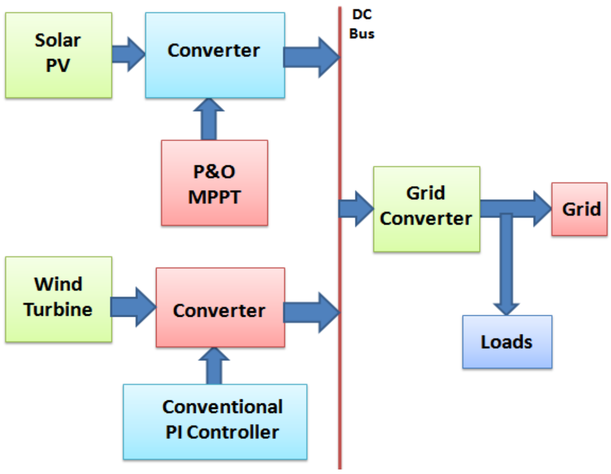

Fig. 1.Block diagram of Proposed System

Block diagram of Hybrid energy system comprising of wind system and solar PV array is shown in Fig.1. Permanent Magnet Synchronous Generator (PMSG) coupled wind turbine is connected to a three phase Diode Bridge rectifier. The output of rectifier is connected to the Grid side converter via a DC- DC converter. This DC- DC converter maintains a constant DC voltage at its output. Conventional PI controller is employed by which gate pulses of the converter are generated accordingly. This in turn is carried out by controlling the duty ratio by means of PWM control thereby achieving maximum power output.

Maximum power output may be attained by connecting a PV array to DC- DC converter. A three- phase inverter transforms DC power output into AC power which is then fed to the load. In the proposed system load is fed by 150KW by hybrid system comprising of Solar PV system and wind energy conversion system up to 0.5 seconds. After t= 0.5 sec, and additional load of 50KW is fed by the grid.

3 WIND ENERGY CONVERSION SYSTEM

3.1 Modeling of Wind Turbine

Wind turbines convert kinetic energy of the wind into mechanical power. Mechanical power of the wind is given by [5, 16]

$$P_m = \frac{1}{2}\rho C_p A_r V_w^3 \tag{1}$$

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Where C_P is power coefficient and if a function of tip is speed ratio λ and blade pitch angle θ (deg), A_r is wind turbine rotor swept area (m^2), V_w is wind speed (m/s) and ρ is air density (Kg/m^3)

$$C_p(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{\frac{18.4}{\lambda_i}} \tag{2}$$

where $$\lambda_i = \frac{1}{\dfrac{1}{\lambda - 0.02\beta} - \dfrac{0.003}{\beta^3 + 1}}$$

(3)

and TSR $$(\lambda) = \frac{\omega_r R_r}{V_w}$$

(4)

Pitch angle of rotor is assumed to be constant. Value of performance coefficient (Cp) is assumed to be 0.59 as per Betz's Law. However practical values of performance coefficient (Cp) fall in the range of 0.2-0.4

3.2 Permanent Magnet Synchronous Generator (PMSG)

Advantages of PMSG include minimal losses, robustness and high reliability. PMSG is also available in compact size and provides high power density. Construction of PMSG is highly sophisticated and does not require DC excitation system. Modern PMSG offers total controllability for grid interface such that maximum power can be extracted [6]. Gearless construction of PMSG enhances the turbine efficiency by 10 percent when employed in a wind farm. Dynamic model of PMSG in synchronous reference frame is given by eq(5)-eq(7). It is assumed that the speed of reference frame is ωe with respect to the generator [7].

$$V_{gd} = R_{sg} i_{gd} + L_{sg}\frac{di_{gd}}{dt} - \omega_e L_{sg} i_{gq} \tag{5}$$

$$V_{gq} = R_{sq} i_{gq} + L_{sg} \frac{di_{gq}}{dt} + \omega_e (L_{sg} i_{gd} + \lambda_m) \quad (6)$$

Electromagnetic torque is given as

$$T_e = \frac{3}{2} \frac{p}{2} \lambda_m i_{gq} \quad (7)$$

where,
Vgd and Vgq represent voltages of direct and quadrature axes with respect to synchronous reference frame.
Igd and igq represent currents in Amperes with respect to synchronous reference frame.
RSg, LSg represent stator resistance in ohms and inductance in H respectively,
λm represent flux linkages in wb,
p is the number of poles and
ωe represent the speed of reference frame in rad/s

4.SOLAR PV SYSTEM

Solar panels convert solar power into electrical energy. This conversion is either carried out by converting the energy directly or by heating the water through induced energy. These solar cells or PV cells are composed of semi conductor structures. When the semi conductor material absorbs a sun beam electrons are released from the atoms. This process results in a flow of current. Thus photovoltaic involves the process of absorption of sun beam and production of electricity. Thus solar power is converted into electric power [8] . Fig.2 shows the equivalent circuit of a solar PV module. Output of solar PV cell is varied with respect to radiation and temperature. Present values of temperature and radiation are considered to get the value of maximum power point. The details of ISC and VOC on the PV panels are provided by the manufacturer. These values are used for developing the mathematical model. Due to lower ratings a single solar cell will not be sufficient for a specific application. A number of solar panels are connected in series for obtaining the required voltage and current rating for the desired load [9].

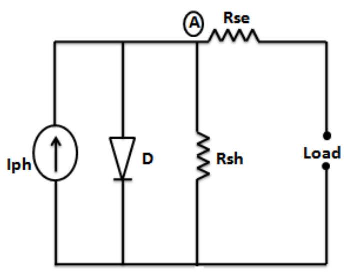


Fig.2 Equivalent Circuit Diagram of Solar PV Module

The equivalent circuit of a solar PV module is shown in Fig.2. The parallel combination of a current source and a diode depicts an ideal PV cell.
By applying Kirchhoff’s current law,

$$I_{ph} = I_d + I_{RP} + I \quad (8)$$

$$I = I_{ph} - (I_{RP} + I_d) \quad (9)$$

Current from the PV module is given as

$$I = I_{ph} - (I_{RP} + I_d) \quad (10)$$

Where I_{ph} is isolation current , I is cell current, I_o is reverse saturation current, V is cell voltage, R_s is series resistance, R_p is parallel resistance, V_T is thermal voltage

4.1 DC-DC Boost Converter

In a Solar PV system, it is required to attain an output voltage that is higher than the applied voltage. A suitable power electronic converter that meets this requirement is a DC-DC boost converter. In the proposed system a DC- DC boost converter is employed and controlled such that output voltage is improved by meeting the load requirement accordingly [10]. Circuit of a DC- DC boost converter is shown in Fig.3. [17]

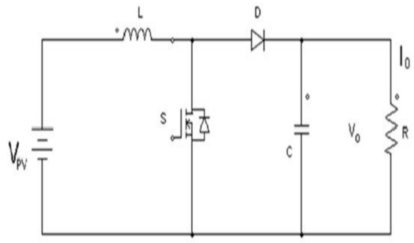


Fig.3 DC – DC Boost Converter

Boost converter comprises of an inductor, diode and switch connected as shown in Fig.3. The input for boost converter is the voltage obtained at the output terminals of Solar PV system. A constant voltage is maintained across the load by means of a capacitor that is connected as shown in Fig.3. When the switch is turned on the inductor gets charged [11]. When the switch is turned off the voltage across the load will be equal to summation of input voltage and voltage across the inductor. Thus an output voltage which is greater than the applied input voltage is obtained at the output terminals.

4.2 P&O MPPT Technique

Various methods are proposed for a solar PV system but Perturb and Observe method is most widely employed. In this method output voltage and output current of PVsystem are measured at any consecutive intervals and power is calculated [12, 13]. Also it is necessary to compute rate of change of power with respect to rate of change of voltage (dP/dV). The duty cycle is incremented or decremented based on the magnitude of the slope dP/dV. The voltage and power are adjusted to maximum power point. Slope dP/dV=0 indicates that maximum power point is obtained for the present environmental conditions. The computation process is continuous which involves continuous measurement of voltages and currents, calculation of power and slope dP/dV. The other way of determining MPP is by matching the impedances of solar PV and the load. This can be achieved by adjusting the duty cycle accordingly [14, 15].

Algorithmic steps:

Step 1: Consecutive readings of voltage and current obtained from solar PV module should be
considered.
Step 2: Powers P(n) and P(n-1) are calculated for n and (n-1) instants.
Step 3: If increase in power is detected, then duty cycle has to be decreased.
Step 4: If decrease in power is detected, then duty cycle has to be increased.
Step 5: Go to step 1.

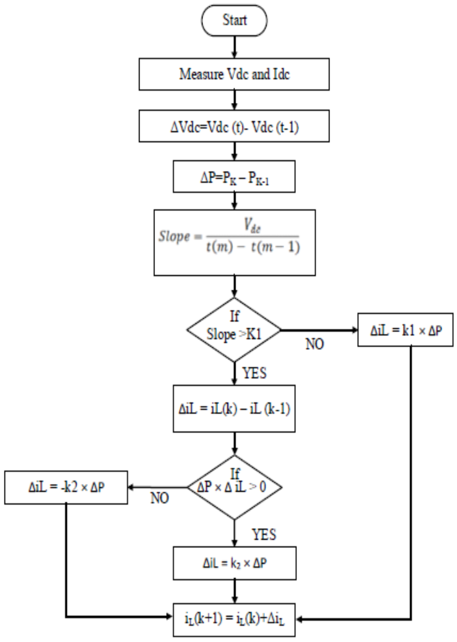
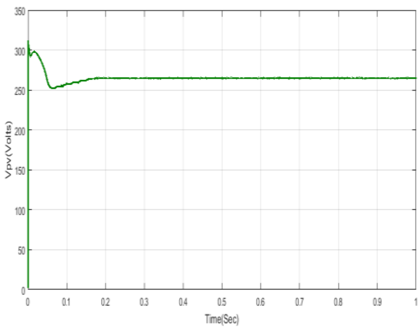


Fig. 4 Perturb and Observe algorithm

5. SIMULATION RESULT

Hybrid model of wind energy system and solar PV system is simulated using Matlab/Simulink. The simulation results of output voltage and output current of solar PV system are shown in Fig.5 & Fig.6. Fig.7 shows the DC link voltage of DC – DC Converter and Fig.8 shows Output Power of Solar PV System. From Fig.8 it is observed that the solar PV system can generate 100 KW power to the load.



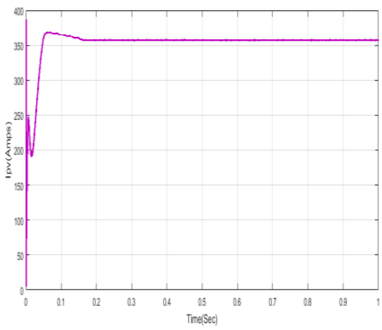


Fig.5 Output Voltage of Solar PV System **Fig.6** Output Current Solar PV System

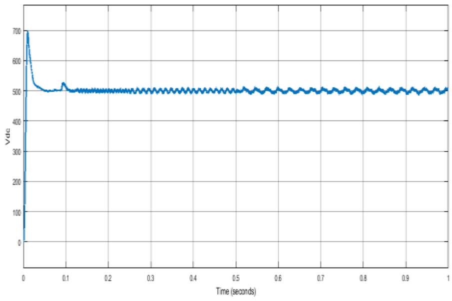


Fig.7 DC Link Voltage across DC –DC Converter

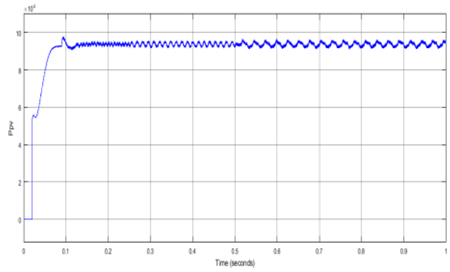


Fig.8 Output Power of Solar PV System

Fig.9 shows that the output power generated by the wind system is 50 KW. Fig.10 shows the total power injected to the Load by both Solar PV and Wind System. From Fig.11 it is observed that the total Power Injected to the load by both wind and solar PV system is 150KW. Fig.12 shows the power supplied by the grid system. From Fig.11 it is observed that up to t = 0.5 sec, power supplied by the grid is zero. After t = 0.5 sec grid supplies an additional power of 50 KW to the load. Fig.8 shows the total power at the load point. It is observed from Fig.12 that up to t = 0.5 sec the power requirement of load is met by both Solar PV and Wind system. After t = 0.5 sec the grid supplies the additional required power to the load.

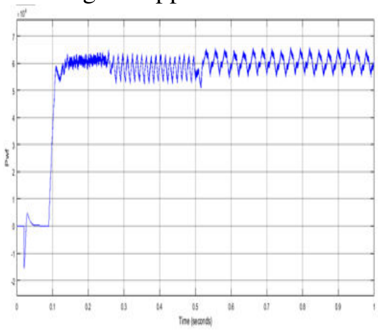


Fig.9 O/P Power Generated by Wind system

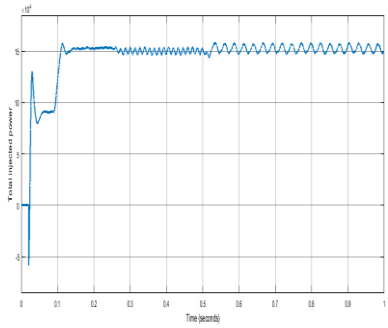


Fig.10 Power Generated by both Wind and Solar

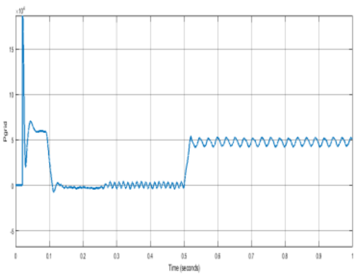


Fig.11 Power supplied by Grid System

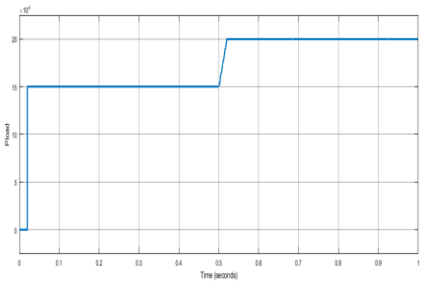


Fig.12 Required Power at Load Point

6 .CONCLUSION

By integrating and optimizing the solar photovoltaic and wind systems, the reliability of the systems can be improved and the unit cost of power can be minimized. This paper discusses the distribution of required power to the load using solar PV system and wind system. In this research work for optimal distribution of load using PV system, Perturb and Observe method is used for maximum power tracking from the sun rays and in wind system, the conventional PI controller is used for controlling the gate pulses to the inverter circuit. From the results it is concluded that from the above research work the required power is distributed to the load using solar PV and wind system. The results are verified using MATLAB/SIMULINK software.

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