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Design and Simulation of Solar-Wind Hybrid Power Generation System

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***Abstract*—** Hybrid system name implies the combination of two or more sustainable / non sustainable energy sources. Presently hybrid systems including wind power as one of the basic along with photovoltaic power are more appealing. The primary reason of such hybrid power system is to taken irregularity and unpredictability of wind energy and to make the power supply more reliable. Hybrid wind power with Photovoltaic module can bypass the limitation of wind power irregularity, since Photovoltaic module can acts as an energy barrier and adjust the output power effectively. Wind power and solar energy can mix to form hybrid power system specifically for the power supply. In addition advantage of this kind of hybrid system is that they are the couple renewable energies, which is suitable to the ecological conditions. Two contingences are studied and identified according to power generation from each energy sources, and load requirement. Hill Climb Search algorithm is used as Maximum Power Point Tracking (MPPT) control technique for the wind power system in order to enhance the power generated. The proportional integral control scheme of inverter is intended to keep the load voltage and frequency of the AC supply at stable level indifferent of advance in natural conditions and load. A Simulink model of Hybrid system with DC/DC converter and voltage standardized inverter and energy storage system for stand-alone application developed MATLAB/SIMLINK environment.

***Keywords*—**component; Renewable energy, Solar, PMSG, DC/DC converter, PI Controller

I. *Introduction*

The sustainable energy sources are solar, wind, and geothermal, tidal, Hydro e.t.c, are endless in environment. The sustainable energy sources have been bringing about encouraging by building tolerable and eco-friendly power generation. Because of draw backs in conventional resources like oils, coal, it has forced to develop the hybrid power generation. Hence new approach to balance the load demand is including sustainable energy sources into structure. Hybrid system allows the integration of sustainable energy sources and allocation of dependency on oils, coal. While assist the balance between supply and demand. The considerable behavior of composite power generation system involves, system performance, functional efficiency [1]. The composite power generation system enables to defeat the drawbacks in Wind and a Photovoltaic resource since their functioning characteristics relies over the unfavorable changes in environment conditions. It is likely to approve that composite stand-alone electricity production systems are habitually more reliable and less costly than systems that hang on a mono source of energy [2]. On other hand one ecological condition can make one type of sustainable energy source (SES) more beneficial than other. For example, Photovoltaic (PV) system is excellent for locations having more solar radiance levels and wind power system is ideal for sites having sophisticated wind flow conditions [3].

For sustainable energy sources outstandingly the variable speed and wind energy transformation systems. Permanent Magnet Synchronous Generator (PMSG) is bringing reputation. PMSG have a loss free rotating device and power looses are restricted to the stator winding and stator core. Considering the PMSG to eliminating gear box which adds the weight, losses, cost and maintenance [4].gearless construction of wind conversion system acts as an economical and reliable wind power conversion system. In a PV system, a solar cell alone can generate power of 1 and 2 watt [5]. The solar cell modeled can be explained by the two diode model [6]. The solar cells are connected in series and parallel to form a PV panel or module to form an array in order to produces appropriate expansive of power.

Thus a PV system consisting of PV array, DC converter and wind power system containing of wind turbine, PMSG, rectifier and dc converter is combined into SOLAR-WIND hybrid power system (SWHPS). The efficiency and reliability of the SWHPS mainly depends upon the control strategy of DC converter. The Solar-Wind power generation cannot be functioning at Maximum power point without proper control technique in the MPPT boost converter. If the MPP is not tracked by the controller the power losses will occur in the system and in spite of wind and solar power accessible. The output voltage of the PV-Wind power generation is quite low as compared with desired operating value of 220V using DC converter with MPPT controller.

The control technique of the MPPT controlled Boost converter for the wind power generation and PV based generation selected on the basis of ease of execution and strength of Hill Climb Search algorithm respectively.

This paper deals with the simulation and control of solar-wind hybrid systems including energy storage battery connected to AC load. Study of modeling and simulation on the entire PV/WIND/Battery hybrid system is carried out under MATLAB/SIMULINK environment.

II. MODELING AND CONTROL OF HYBRID SYSTEM

A. Photovoltaic Power System:

Fig.1 shows a simplified scheme of a Photovoltaic system with DC-DC converter. This section is discussed about PV module design which is a matrix of elementary cells that are the heart of PV system. The design of PV systems starts from the model of the elementary PV cell that is derived from the PN Junction [7].

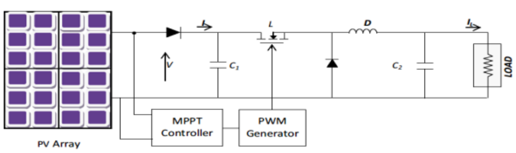

Figure 1. A PV system with converter

*1) **Ideal photovoltaic cell***:

The PV cell combines the behavior of either voltage or current sources according to the operating point. This behavior can be obtained by connecting a sunlight-sensitive current source with a PN-junction of a semi conductor material being sensitive to sunlight and temperature. The dot-line square in Fig.2 shows the model of the ideal PV cell.
The DC current generated by the PV cell is expressed as follows.

$$I = I_{pv,cell} - I_{s,cell}\left(e^{\frac{V}{aVt}} - 1\right) \qquad (1)$$

The first term in equation (1), that is $I_{pv,\ cell}$ is proportional to the irradiance intensity whereas the second term, the diode current expresses the non-linear relationship between the PV cell current and voltage. A practical PV cell, shows in Fig.2, includes series and parallel resistances [8]. The series resistance represents the contact resistance of the elements constituting the PV cell while the parallel resistance models the leakage current of the P-N junction.

This model is known as the single diode equivalent circuit of the PV cell. The larger number of diodes the equivalent circuit contains, the more accurate is the modeling of the PV cell behavior, however, at the expense of more computation complexity. The single diode model shown in Fig.2 is adopted for this study, due tom its simplicity.

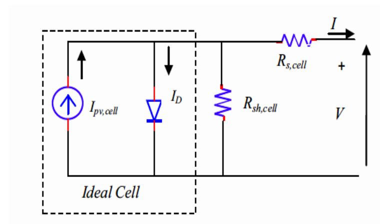

Figure 2. Equivalent circuit of an ideal and practical PV cell

2) ***PV module modeling***:

Technically photovoltaic devices are available as sets of series and /or parallel connected PV cells combined into one item, the PV module, to produce higher voltage, current and power as shown in Fig.3,

The equation of the I-V characteristic of the PV module is obtained from Eq. (1) by including the equivalent module series resistance, shunt resistance and the number of cells connected in series and in parallel

$$I = N_p(I_{pv} - I_s\left(e^{\frac{q(V + I.R_s)}{aNsKT}} - 1\right) - \frac{(V + I.R_s)}{R_{sh}} \qquad (2)$$

Where $V_{T=}$ the PV cell thermal voltage in Eq. (1) is substituted by that of module thermal voltage can be given by (V_T=N_sKT/q) and N_S and N_p are respectively the number of cells connected in series and parallel forming the PV Module.

The constant a expressing the degree of ideality of the diode may be arbitrary constant chosen from the interval (1, 1.5) [9]. The light generation of the PV cell can be depends on the irradiance and is also influenced by temperature.

$$I_{ph} = \left(\frac{G}{G_{STC}}\right)\left(I_{PVn} + K_i(T - T_{STC})\right) \qquad (3)$$

$Ipv_{n\ is}$ the nominal light-generated current provided at $G_{STC,}$ T_{STC}, which refer to the values at nominal or Standard Test Conditions (1 KW/m^2,25^{0}C).The nominal light-generated current is not available in the datasheet of the PV panel but estimated as [10].

$$I_{PVn} = \left(\frac{R_s + R_{sh}}{R_s}\right) \qquad (4)$$

The second term in Eq. (2) is the diode current that is function of the voltage and current coefficients given by the equation below.

$$I_s = \frac{I_{SCn} + K_1 \Delta T}{e^{\frac{V_{OCn} + K_V \Delta T}{aV_t}} - 1} \quad (5)$$

Where I_{scn} is the nominal short-circuit current or the maximum current available at the terminals of the practical device at nominal conditions.

3) I-V and P-V characteristics;

A PV module can be modeled as a current source that is dependent on the solar irradiance and temperature. The complex relationship between the temperature and sunbeam results in a non-linear current–voltage characteristics. A typical I–V and P–V curve for the variations of irradiance and temperature is shown in Fig. 4 (a) and (b), respectively. As can be observed, the MPP is not a fixed point; it various continuously as the temperature or the sunbeam do. Due to this dynamics, the controller needs to track the MPP by updating the duty cycle of the converter at every control sample. A quicker response from the controller (to match the MPP) will result in better extraction of the PV energy and vice versa [10].

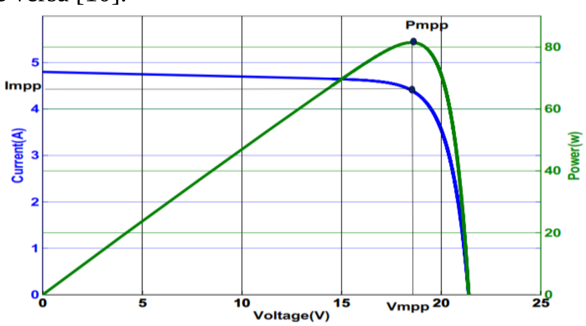

Figure 3. Solar cell characteristics of current-voltage and power - voltage characteristics

B***) Wind turbine:***

Wind turbines work by convert the kinetic energy in the wind first into rotational kinetic energy in the turbine and again to electrical energy. The accessible energy conversion mainly depends on the wind speed and the swept area of the turbine. When outline a wind farm it is important to know the expected power and energy output of each wind turbine adequate to calculate its economic viability.

Calculate on the aerodynamic characteristics, the wind power captured by the wind turbine can be expressed.

$$P = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 V^3 \quad (6)$$

Where $C_p(\lambda, \beta)$ is the wind power coefficient which is an operation of λ and β, ρ is the air density, R is the radius of wind turbine blade, and V is the velocity of air (or) speed of wind. is the blade pitch angle, and λ is the speed ratio;

$$\lambda = \frac{kR}{V} \quad (7)$$

Where k is the wind turbine rotational speed. There exits an optimal tip speed ratio λopt that can maximize Cp and P. Then, the maximum wind power P_{max} captured by wind turbine can be described as.

$$P_{max} = \frac{1}{2} \rho \pi R^5 \frac{C_{p,max}}{\lambda^3{}_{opt}} k^3 \quad (8)$$

The output mechanical power versus rotational speed characteristic of wind turbine for dissimilar wind speeds is shown in Fig. 1, in which the dotted line shows the maximum power points for different wind turbine rotational speed w and different wind speed V. Each P–k curve is characterized by a unique turbine speed corresponding to the maximum power point for that wind velocity. The peak power points in the P–k curves correspond to dP / dk = 0 [11].

The mechanical power generated by turbine speed under dissimilar wind speeds and the target optimum power is shown in Fig.4. The objective of any MPPT controller is to keep the performance of the turbine on this curve [12].

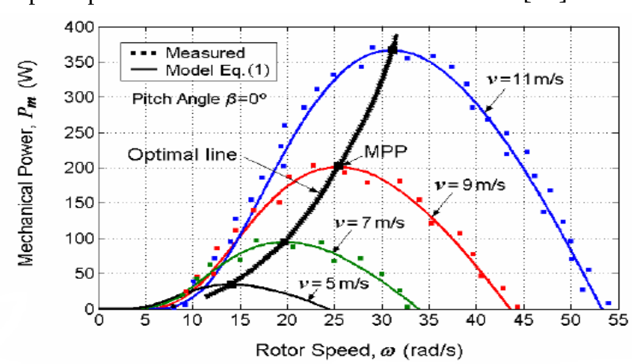

Figure 4. Mechanical power generated by turbine speed under different wind speeds

C) *Storage Power System;*

Wind turbines and Photovoltaic array alone are fairly unable to track the power demand, leading to the introduction of suitable energy storage systems. In modern years most of the target on the development of electric storage technology has been on batter storage. There is a different variety of battery types serving various purposes. Different types of battery models reported in the research, especially: empirical, electrochemical and electric circuit-based. Empirical and electrochemical parallelisms are not well suited to perform cell dynamics for the purpose of state-of-charge (SOC) estimations of battery banks. More ever, electric circuit-based models can be applicable to show the electrical characteristics of batteries. The simplest electric circuit consists of an ideal voltage source in series with an inward resistance.

In this work, a universal battery model advisable for dynamic simulation presented in is considered [13]. This model presumes that the battery is composed of a controlled-voltage source and a series resistance, as shown in Fig.6. This universal battery model considers the SOC as the only state variable [14].

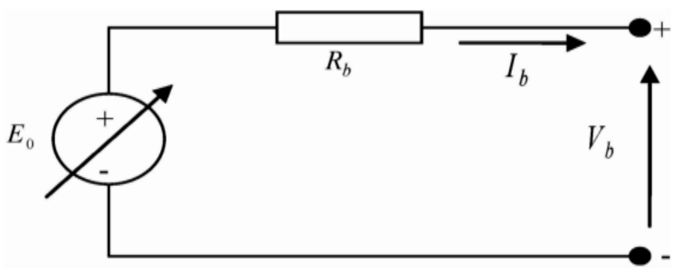

Figure 5. A generic battery model.

The controlled voltage source is given by the following expression.

$$E = E_o - \frac{V_p Q_b}{Q_b - \int i_b dt} + A \exp\left(-B_t \int i_b dt\right) \quad (9)$$

Where E_o is the constant voltage of battery (V), Vp is the polarization voltage (V), Q_b is the battery capacity (AH), i_b is the battery current (A), A is exponential zone amplitude (V), B {is exponential zone time constant inverse (AK') [15].

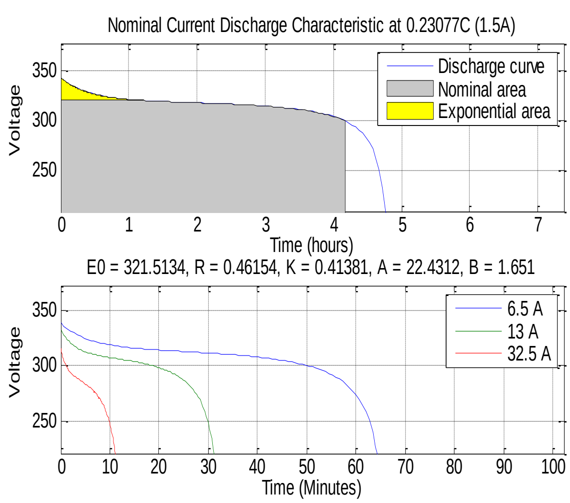

Figure 6. Typical characteristics of Ni-Cd battery

III. System Control

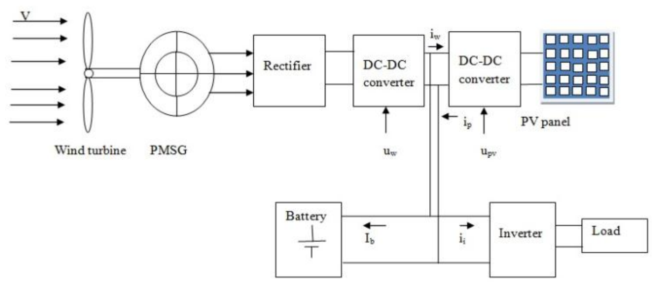

Figure 7. Block diagram of PV-Wind hybrid system

The block diagram of PV-wind hybrid power system is shown in Fig. 7. The hybrid generations consist of Photovoltaic based generation, Wind Power Generation, Battery; Voltage regulated inverter and AC load. A comprehensive mathematical analysis of the Hybrid generation will be discussed in this section.

A. Perturb and Observe MPPT Algorithm for PV array:

Perturb and Observe algorithm, shown in Fig .8, is used in this paper for maximum power tracking of PV array. This method involves perturbation of the voltage, V, and observing the change in power output, P. If the perturbation in one direction increases the power output of the PV array, then the same direction of perturbation is continued. Otherwise, the direction of perturbation is reversed. Thus, it is a continuous process of searching for the voltage on power Vs voltage (P-V) curve, which increases the power output of the PV array. This method is well described in the literature [12], hence, not explained here in detail.

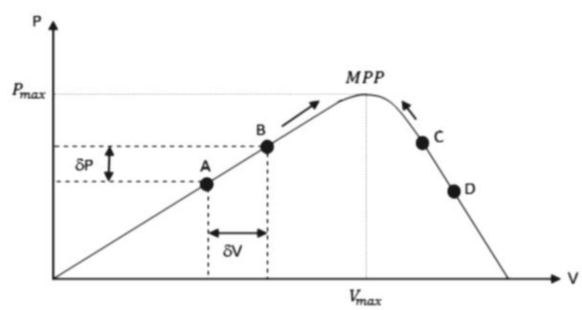

Figure 8. Description of P&O algorithm for MPPT

B. Hill Climb Search MPPT algorithm for wind turbine

The HCS algorithm for MPPT control logic implementation for wind power generation system is shown in Fig. 9.

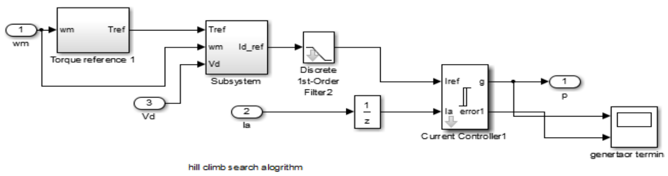

Figure 9. Sub-system implementation of MPPT control for Wind Power

The inputs to the controller are voltage, current and speed of PMSG. Using the speed and voltage samples the reference current is calculated. It is compared with the current measured and the error is utilized to compute the duty cycle of the power electronic switch in converter which controls the operation of wind power generation at MPP.

C. PWM inverter design:

The inverter plays a key role in the hybrid power generation. The load voltage, frequency is controlled and maintained constant using inverter in stand-alone operation.

The proposed PWM regulated inverter maintains the output voltage and frequency constant irrespective of change in wind Speed, solar irradiation levels and load condition. The rectified and boosted DC voltage from the PV, wind is applied as input to the inverter. The schematic diagram of PWM regulated inverter is shown in Fig. 10

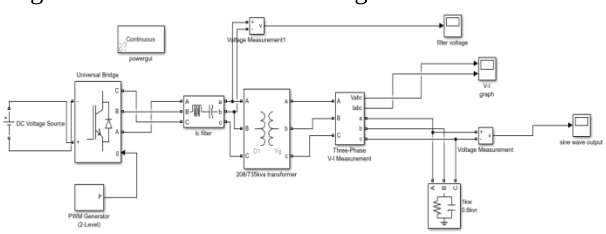

Figure 10. PWM inverter

Case 1: PI voltage regulated inverter:

The important aspect of voltage regulated inverter is to maintain output voltage and frequency constant. In order to achieve the task a discrete Phase Lock Loop (PLL) with Synchronous Reference Frame (SRF) is implemented to generate control signal of the inverter. The block diagram of the control scheme is shown in Fig. 12. Where V_{Lab}, V_{Lbc}, V_{Lca}, are the live voltage of the load.

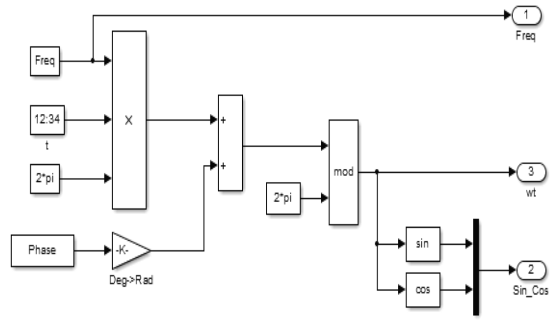

Figure 11. Block diagram of PI voltage regulated inverter

Case 2: DC-DC converter;

A DC-DC converter is a stable device that converts fixed dc input voltage to a variable dc output voltage. A converter conceivable possibility of as dc analogous of an ac transformer since they behave in an exactly mannerism as choppers necessitate one stage transmutation these are more efficient. In this paper the dc-dc converter is used for increases the battery storage power. The same results are obtained non-existence of source-2. The results in the absence of both PV and wind power, battery is charged from the grid. Battery is charged from the grid.

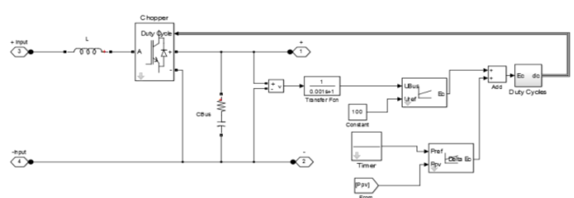

Figure 12. DC-DC converter

IV. Simulation Results and Discussion

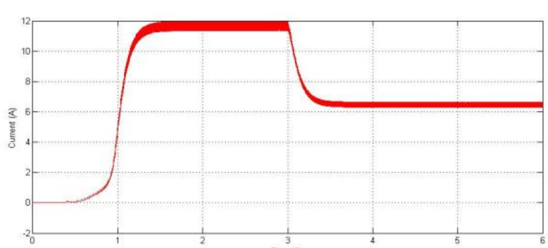

Figure 13. Output of Current Wind

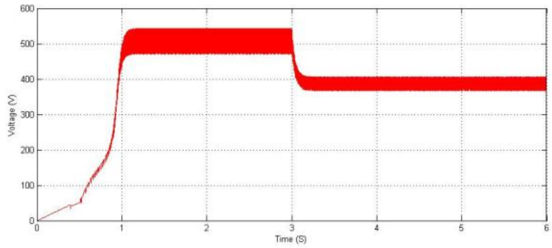

Figure 14. Output of Voltage Wind

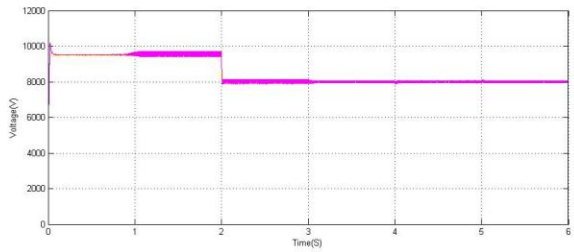

Figure 15. Output Voltage for PV changing irradiation level

Case 1 PI voltage regulated

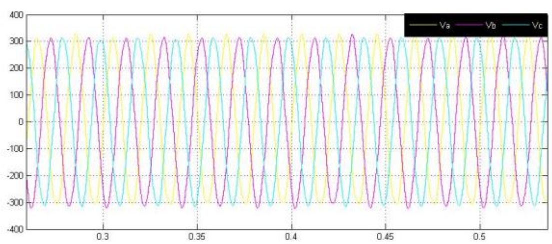

Figure 16.Inverter output voltage

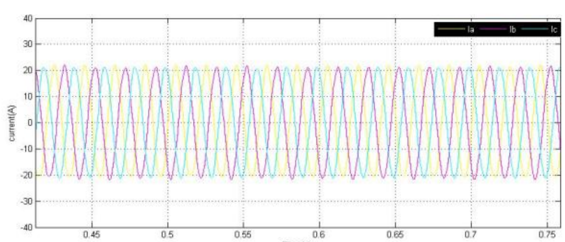

Figure 17. Inverter output current

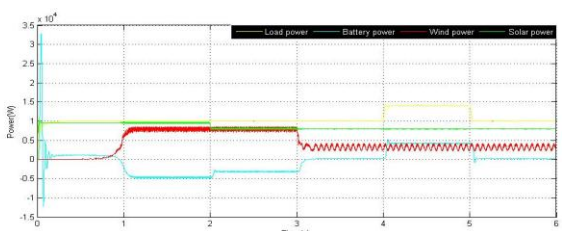

Figure 18. Power Generation of a Hybrid System under Different Wind Speeds and Solar illuminations.

Case 2.DC-DC converter

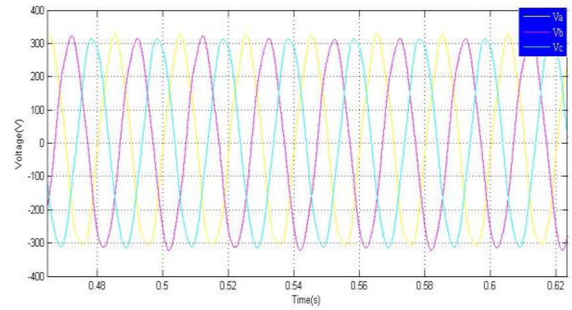

Figure 19. Output Voltage for inverter

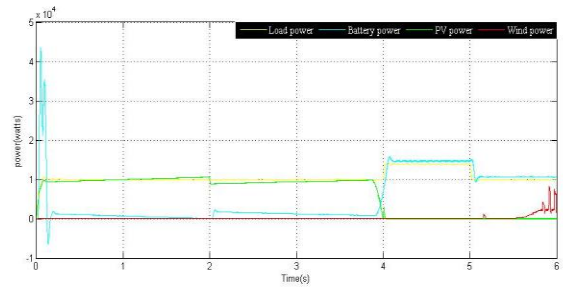

Figure 20. Power Generation of Hybrid System under different Wind Speeds and solar illumination.

The PV power generation limb mannerism is examined. Fig.15 shows the voltage with MPPT controller under various irradiance conditions. It proves that the PV power generation limb can readily execute the MPPT and obtain the amplified output power at a given irradiance; fig 13,and fig 14 shows the output current and voltage for the PMSG wind system with HCS algorithm MPPT controller.

It can be clearly that MPPT plays a main key role in the hybrid power generation system .In order to reduce or increases the efficiency and performances of the hybrid system.

In the first case with PI voltage control inverter the voltage is unstable and battery power is less with disturbance frequencies compared to the dc –dc converter the battery power is high shows fig 18, and fig 20.The power flow in the second case provide the power efficiency and the advantage of dc - dc converter compared to PI regulated inverter.

V. CONCLUSION

Nature has given ample opportunities to mankind to make best use of its resources and still maintain its beauty. In this alliance, the suggested hybrid PV-wind system provides an elegant integration of the wind turbine and solar PV to extract optimum energy from the two sources. It produces a compress converter system, while decreases the cost

The suggested scheme of solar-wind hybrid system greatly improves the presentation of the WECS in terms of enhanced generation efficiency. The solar PV augmentation of applicable capacity with minimum battery storage facility make available solution for power generation difficulty during low wind speed situations.

The DC-DC converter is more power capable and reliable compared to the PI regulated inverter, in this context dc-dc converter improves the power generation system of which sources of solar and wind power generation systems.

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