ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 2, February 2017

A Comprehensive Mathematical Modelling: Hybrid Energy Generation Systems used for Non-Approachable Area like Hills and Desert

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ABSTRACT: Renewable energy sources now become a famous alternative electrical energy generation source where power generation in conventional ways is not practical. In the last few years the photovoltaic and wind power energy generation have been increased tremendously. In this paper we represents a hybrid energy system which combines both solar panel and wind turbine generator as an alternative for conventional energy generation sources of electrical energy like coal based plant and hydro electric power generation. A suitable control technique which is also cost effective has been developed to trace the operating point at which maximum power can be produced from the PV energy generation system and wind power generation system under continuously changing environmental conditions. The whole hybrid energy generation system is explained and presented along with comprehensive MATLAB simulation results that discover the reliability and feasibility of the system. A software simulation model is developed in MATLAB/Simulink. This paper presents the design and analysis of a hybrid Solar and Wind System for rural electrification in a remote area in Rajasthan. It is need to provide electricity for household use to each family in each locality including remote areas of each state. Energy is crucial input in the process of economic, social and industrial development. Electrical energy plays a important role in our daily routine life. But the traditional energy generation sources to produce electricity are decreasing day by day significantly. In this regards nonconventional or renewable energy resources such as bio-energy, Solar, Wind, Ocean, Tidal and Geothermal are taking this challenge. A large population of the world lives in remote rural areas and there is no access of electricity. The installation of energy generation systems and distribution of electricity costs are considerably higher for remote rural areas. Moreover, there is greater transmission line losses and poor supply reliability. The combining of technologies means hybrid energy generation technology provides interesting opportunities to overcome transmission line losses and reliability of supply and to mitigate fuel price increases, deliver operating cost reductions, and offer higher service quality than traditional single-source generation systems. A hybrid system is a transient system that exhibits both continuous and discrete dynamic behaviour a system that can both flow and jump.

KEYWORDS: Hybrid Energy Generation System, Solar Energy Generation System, Wind Energy Generation System, Energy Demand

I. INTRODUCTION

Because of the severe condition of industrial ammunition which includes oil, gas and others, the development of renewable energy sources is progressively improving. This is the cause why renewable energy sources have become more important in present days. Few other causes include advantages like ample availability in nature, eco-friendly and recyclable. Many sustainable energy sources like solar, wind, ocean, geothermal, hydro and tidal are there. Among these renewable sources solar and wind energy are the world's latest growing sustainable energy resources. With no emission of pollutants, energy generation is done from Wind and Photo Voltaic cells.

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Vol. 6, Issue 2, February 2017

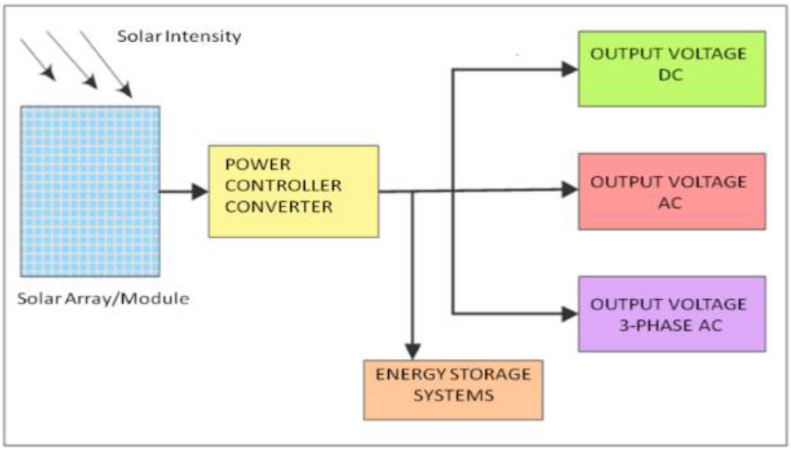

Fig. 1.1 a Typical Solar Powered System

As the Time passed, the demand for electricity is gradually increasing. But the available base load plants are not able to deliver electricity as per the consumer demand. So these energy sources can be used to fill the gap between supply side and consumer demand during heavy loads. Sustainable energy, small scale stand-alone power generating systems can also be used in remote areas where conventional power generation is not possible to establish. In the present thesis work, a wind-photovoltaic hybrid power generation system model is simulated in MATLAB and gives satisfactory result. A hybrid generation system is more advantageous as individual power generation system is not reliable alone. At the time any one of the system is getting shutdown at that time the other system can supply power with reliability. A block diagram of entire hybrid system is shown below.

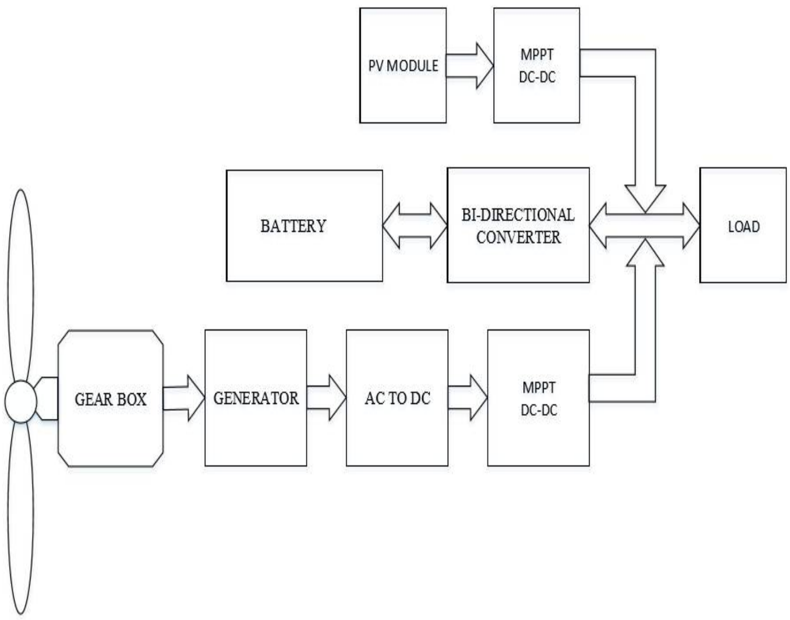

Fig 1.2 Block diagram of hybrid system

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ISSN (Online): 2278 – 8875

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Vol. 6, Issue 2, February 2017

II. SOLAR ENERGY CONVERSION SYSTEM

A photovoltaic energy system is mainly powered by solar energy. The configuration of PV system is manifested in figure 1.3.

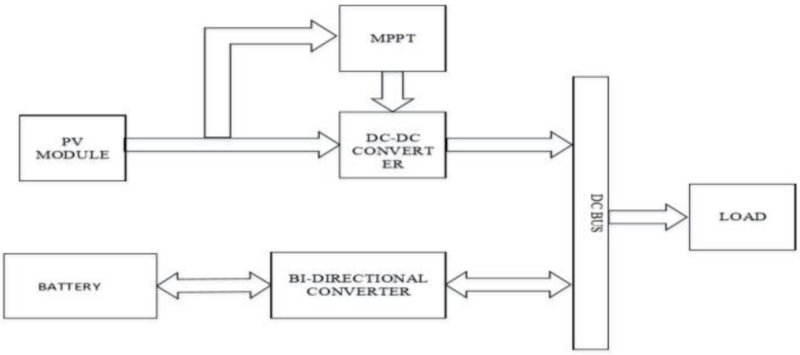

Fig 1.3 Overall Block Diagram of PV Energy System

It contains PV modules or arrays, which convert solar energy in the form of solar irradiation into electric energy. The dc-dc converter changes the level of the voltage to match it with the electrical appliances that are supplied by this system. This DC-DC converter may be either buck or boost or buck-boost contingent on the required and available voltage levels. The maximum power point tracking system coerces the maximum power from the PV modules. A bi-directional converter which is able to supply the current in both the directions is used to charge the battery when there is a power generation is more and load is light while the energy stored by the battery is discharged into the load when there is a power demand.

A. MODELLING OF PV CELL

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The below figures the equivalent circuit of PV cell. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as.

$$I = I_{PV} - I_O \left[exp\left(\frac{V+IR_S}{aV_T}\right) - 1\right] - \left(\frac{V+IR_S}{R_P}\right)$$

Where

I_{PV}–Photocurrent current,
I_O–diode's Reverse saturation current,
V–Voltage across the diode,
A– Ideal factor
V_T –Thermal voltage
R_S– Series resistance
R_P–Shunt resistance

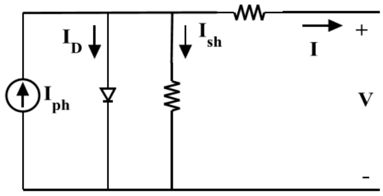

Fig 1.4 Equivalent circuit of Single diode modal of a solar cell

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Vol. 6, Issue 2, February 2017

PV cell photocurrent, which depends on the radiation and temperature, can be expressed as.

$I_{PV} = (I_{PV\_STC} + K_I \Delta T) G / G_{STC}$

Where

K_I – cell's short circuit current temperature coefficient

G – solar irradiation in W/m^2

G_{STC} – nominal solar irradiation in W/m^2

I_{PV_STC} – Light generated current under standard test condition

The reverse saturation current varies as a cubic function of temperature, which is represented as

$I_O = I_{O_{STC}} \left(\frac{T_{STC}}{T}\right)^3 exp\left[qE_g / aK\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right]$

Where

I_{0_STC} – Nominal saturation current

E_g – Energy band gap of semiconductor

T_{STC} –temperature at standard test condition

q – Charge of electrons

The reverse saturation current can be further improved as a function of temperature as follows

$I_O = (I_{SC\_STC} + K_1 \Delta T) / \exp\left[(V_{OC\_STC} + K_V \Delta T) / aV_T\right] - 1$

Where

I_{SC_STC} – short circuit current at standard test condition

V_{OC_STC} – short circuit voltage at standard test condition

K_V – temperature coefficient of open circuit voltage

Many authors proposed more developed models for better accuracy and for different purposes. In some of the models, the effect of the recombination of carriers is represented by an extra diode. Some authors also used three diode models which included influences of some other effects that are not considered in previous models. But due to simplicity we use single diode model for our work. Efficiency of a PV cell does not depend on the variation in the shunt resistance R_P of the cell but efficiency of a PV cell greatly depends on the variation in series resistance R_S. As R_P of the cell is inversely proportional to the shunt leakage current to ground so it can be assumed to be very large value for a very small leakage current to ground. As the total power generated by a single PV cell is very low, we used a combination of PV cells to fulfil our desired requirement. This grid of PV cells is knows as PV array. The equations of the PV array can be represented as

$$I = I_{PV} N_P - I_O N_P \left[exp\left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S}\right) - 1\right] - \left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{R_P\left(\frac{N_S}{N_P}\right)}\right)$$

N_S – Number of series cells

N_P – Number of parallel cells

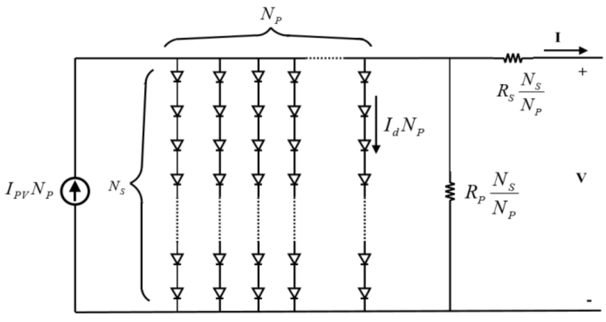

Fig 1.5 Representation of PV module

A small change in series resistance can affect more on the efficiency of a PV cells but variation in shunt resistance does not affect more. For very small leakage current to ground, shunt resistance assumed to be infinity and can be treated as open. After considering shunt resistance infinity, the mathematical equation of the model can be expressed as.

$$I = I_{PV} N_P - I_O N_P \left[exp\left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S}\right) - 1\right]$$

I-V and P-V characteristics of PV module are shown in figures 1.6 and 1.7 respectively.

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Vol. 6, Issue 2, February 2017

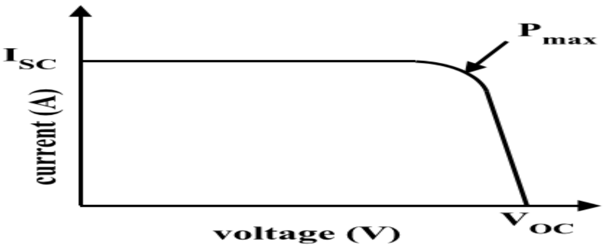

Fig. 1.6 I-V characteristics

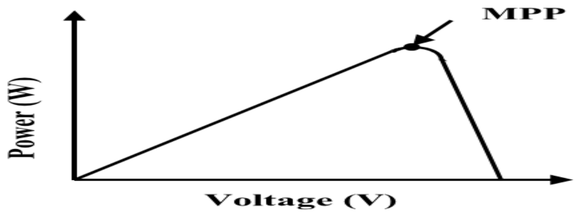

Fig. 1.7 P-V characteristics

The two key parameters which are used to relate the electrical performance are the open circuit voltage of the cell VOC and short circuit current of the cell Isc. The maximum power can be stated as

$P_{MAX} = V_{MAX} I_{MAX}$

The parameters used for the modelling of PV module are shown in table 1.1

TABLE 1.1 Parameters of the PV array at 23^0C, 1000w/m^2

S. NO.	Parameter	Value
1	I_{mp}	7.61 A
2	V_{mp}	26.3 V
3	I_{sc}	8.21 A
4	P_{max}	200.143 W
3	V_{oc}	32.9 V
6	K_v	-0.1230 V/K
7	Ki	0.0032 A/K
8	N_s	34
9	N_p	4

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B. MAXIMUM POWER POINT TRACKING (MPPT)

Maximum power point tracking (MPPT) system is an electronic control system that can be able to coerce the maximum power from a PV system. It does not involve a single mechanical component that results in the movement of the modules with respect to sun light or sun intensity, changing their direction and make them face straight towards the sun. MPPT control system is a completely electronic system which can deliver maximum allowable power by varying the operating point of the modules electrically.

*** Perturb and observe**

Each and every MPPT algorithm has its own advantages and disadvantages. Perturb and observe (P&O) method is widely used due its simplicity. In this algorithm we introduce a perturbation in the operating voltage of the panel. Perturbation in voltage can be done by altering the value of duty-cycle of dc-dc converter.

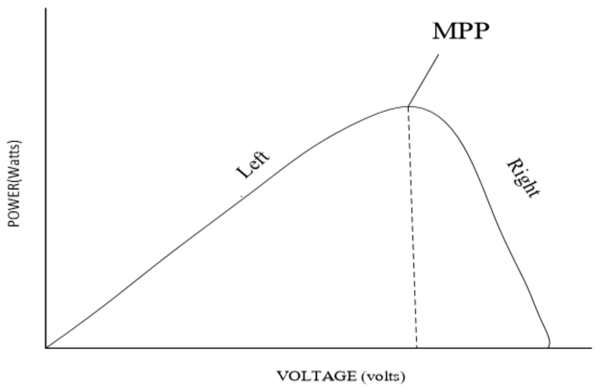

Fig. 1.8 P-V characteristics (basic idea of P&O algorithm)

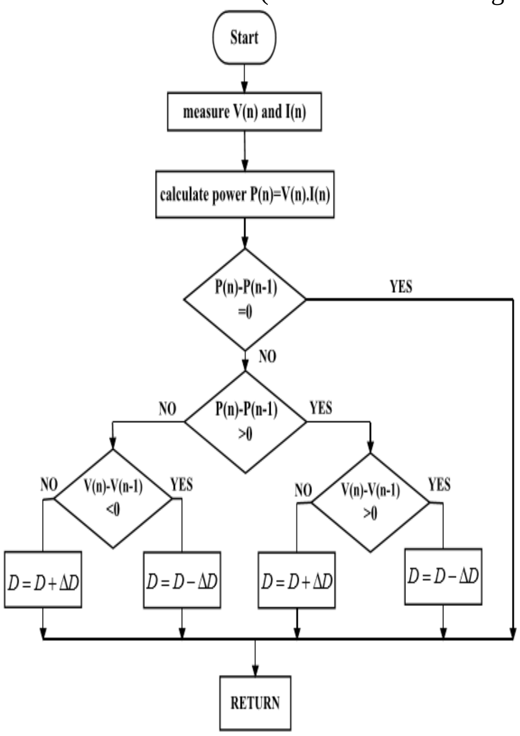

Fig 1.9 Flowchart of Perturb & Observe MPPT algorithm

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ISSN (Online): 2278 – 8875

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Website: www.ijareeie.com

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III. WIND ENERGY CONVERSION SYSTEM

The schematic diagram of the wind energy system is manifested in figure below.

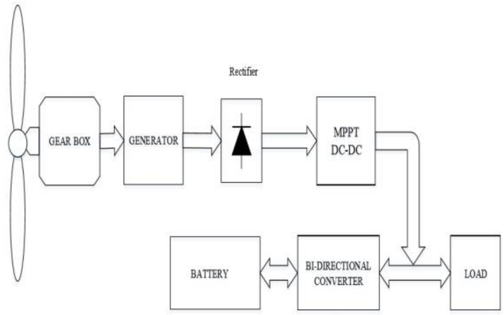

Fig 1.10 Overall Block Diagram of Wind Energy System

This system comprises of a wind turbine which transforms wind's kinetic energy into rotating motion, a gear box to match the turbine speed to generator speed, a generator which converts mechanical energy into electrical energy, a rectifier which converts ac voltage to dc, a controllable dc-dc converter to trace the maximum power point, a battery is charged and discharged through bi-directional converter.

A. MODELLING OF WIND TURBINES

A wind turbine converts kinetic energy of air i.e. wind power into mechanical power i.e. rotating motion of the turbine that can be used directly to run the machine or generator. Power captured by wind turbine blade is a concomitant of the blade shape, the pitch angle, speed of rotation, radius of the rotor. The equation for the power generated is shown below.

$$P_M = \frac{1}{2}\pi\rho C_P(\lambda, \beta)R^2V^3$$

Where

P_M – Power captured by wind turbine

ρ –Air density

β –Pitch angle (in degrees)

R –Blade radius (in meters)

V –Wind speed (in m/s)

The term λ is the tip-speed ratio, given by the equation

$$\lambda = \frac{\Omega R}{V}$$

Where

Ω - Rotor speed of rotation (in rad/sec)

C_P can be expressed as the function of the tip-speed ratio (λ)

$$C_P = \frac{1}{2}\left(\frac{116}{\lambda_1} - 0.4\beta - 3\right) exp^{\frac{-16.3}{\lambda_1}} \qquad \lambda_1 = \left(\frac{1}{\frac{1}{\lambda + 0.089} - \frac{0.033}{\beta^3 + 1}}\right)$$

Where

C_P – Wind turbine power coefficient

λ – Tip- speed ratio

λ_1 – Constant

B. PERMANENT MAGNET SYNCHRONOUS GENERATOR (PMSG)

A synchronous machine generates power in large amounts and has its field on the rotor and the armature on the stator. The rotor may be of salient pole type or cylindrical type. In the permanent magnet synchronous generator, the magnetic field is obtained by using a permanent magnet, but not an electromagnet. The field flux remains constant in this case

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and the supply required to excite the field winding is not necessary and slip rings are not required. All the other things remain the same as normal synchronous generator. The EMF generated by a synchronous generator is given as follows

$$E = 4.44.f.\Phi.t$$

Where,
F is the frequency
Φ is the flux
t is the number of turns

C. MPPT OF WIND POWER

Wind power verses wind speed characteristics of wind power system is shown in figure below

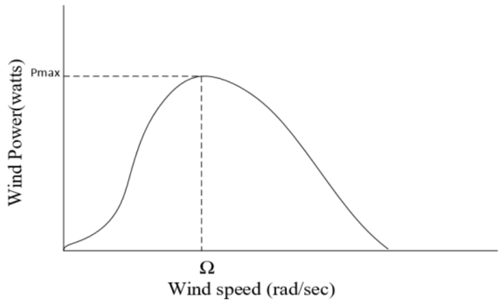

Fig 1.11 Powers vs. Speed Characteristics of Wind Turbine

$$\frac{dp}{d\Omega} = 0$$

From chain rule

$$\frac{dP}{d\Omega} = \frac{dP}{dD} \times \frac{dD}{dV_W} \times \frac{dV_W}{d\Omega_e} \times \frac{d\Omega_e}{d\Omega}$$

Where
P – Wind power
Ω – Rotor speed
Ωe – Generator- phase voltage angular speed.
V_W – Rectifier output voltage
D – Duty cycle of converter
For buck-boost converter

$$V_O = \frac{D}{1+D} V_W$$

Where
V_O – Output of buck-boost converter
V_W – Input of buck-boost converter
From equation (3.8) we can write

$$\frac{dD}{dV_W} = -\frac{D^2}{V_O} \neq 0$$

As we can see from the above equation that $\frac{dD}{dV_W}$ having negative and non –zero value the rotor speed of the wind turbine can be correlated with the generator-phase voltage angular speed as follows:

$$\Omega_e = p.\Omega$$

$$\frac{d\Omega_e}{d\Omega} = p > 0$$

Where
p – Number of pole pairs in the generator
From above equation we observe that $\frac{d\Omega_e}{d\Omega}$ is positive and non-zero value. The output voltage of the rectifier which is proportional to the output voltage of generator can be written as

$$V_{ph} = 4.44.f.\Phi.t$$

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And $f \propto \Omega_e$
So $\frac{dV_{ph}}{d\Omega_e} > 0\ As V_{ph} \propto V_W$

$$\frac{dV_{ph}}{d\Omega_e} \approx \frac{dV_W}{d\Omega_e} > 0$$

Where
V_{ph} – Generator output
f – Frequency of rotor
Φ – Flux
t – Number of turns

From above equation we see that $\frac{dD}{dV_W}, \frac{d\Omega_e}{d\Omega}, \frac{dV_W}{d\Omega_e}$ are non-zero value. So $\frac{dp}{d\Omega} = 0$ can be possible if and only if $\frac{dP}{dD}$ becomes zero. From the above equations we can concludes that the operating point at which the crest power can be coerced is traced by varying the duty- cycle of converter.

IV. HYBRID POWER SYSTEM: MODELLING AND SIMULATION

The following subsections present the implementation of the PV/wind turbine system model. Modelling and simulation are implemented using MATLAB/ Simulink and Sim-Power System software packages. The block diagram of the developed hybrid power system is shown in below Figure:

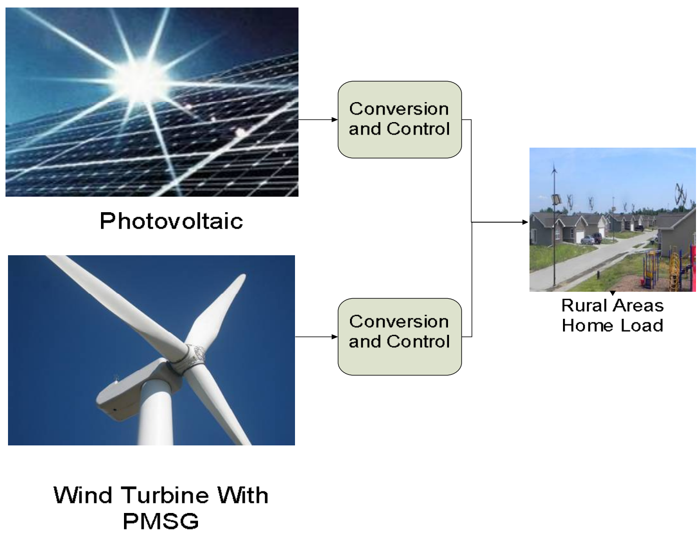

Figure 1.12 - Block diagram of the developed hybrid power system

A. PV MODEL SIMULATION

A model of PV panel with moderate complexity which includes the series resistance, the saturation current of the diode, and the temperature independence of the photocurrent source is considered based on the Shockley diode equation. The PV model is built and implemented using Simulink to verify the nonlinear I–V and P–V output characteristics. The block diagram of the proposed model is implemented and shown in Figure 1.13. Each function uses a notation with a meaningful lettering to make it readable and maintainable.

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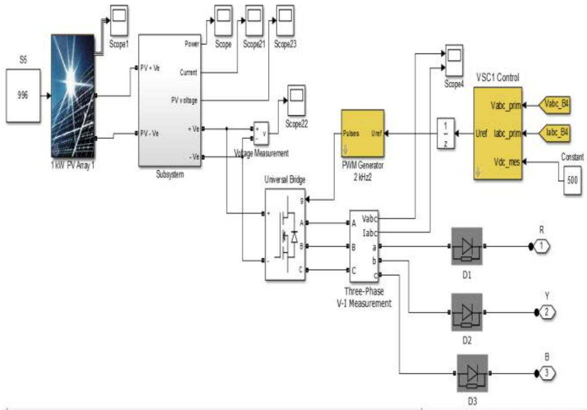

Figure 1.13 PV Model Simulation

B. THE WIND TURBINE MODEL

The built-in Simulation Power System block model of a Permanent Magnet Synchronous Generator is used as a power generator driven by the wind turbine (MATHWORKS 2012). As shown in Figure 1.14, the rotor shaft is driven by the wind turbine which produces the mechanical torque according to the generator and wind speed values

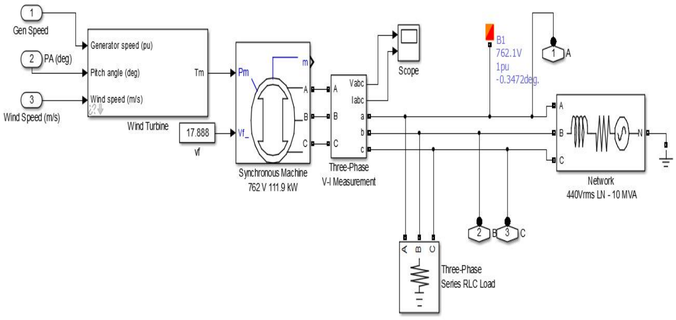

Figure 1.14 – Implementation of the Wind Turbine PMSG Model

C. HYBRIDWIND/PHOTOVOLTAICMODEL

The dynamic simulation model is described for a hybrid power system comprises PV panels, wind turbine, converters and RL load.

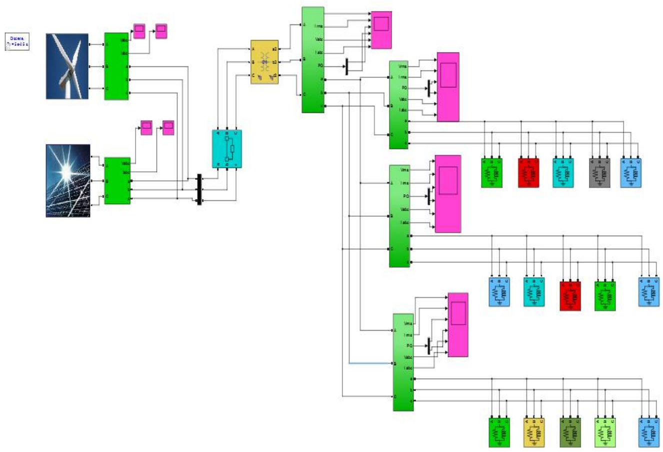

Figure 1.15 – Hybrid Wind/Photovoltaic Model

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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The availability of hybrid system model is important for its theoretical study, as it can be used to study its behaviour. In this chapter the dynamic simulation model is described for a PV, wind turbine. Modelling and simulation are implemented using MatLab/Simulink and Simulation Power System software packages.

- For PV panel: a generalized model has been developed. It was found that both simulated and measured results for the output power of PV module are in good agreement.
- For wind turbine: a PI controller has been implemented to control the blade pitch angle. Simulation result shows that the control system successfully maintains the generator output power to its nominal value for high wind speeds.

V. RESULTS

Fig 1.16, 1.17 represents the I-V and P-V characteristics of a PV module. From fig 1.16, We can see that short circuit current (I_{SC}) of PV module is approximately 8.2A and open circuit voltage (V_{OC}) is approximately 32.9 volts. From fig 1.17 we can observe that maximum power is approximately 200W and it occurs at a current of 7.61A and voltage at 26.3V approximately.

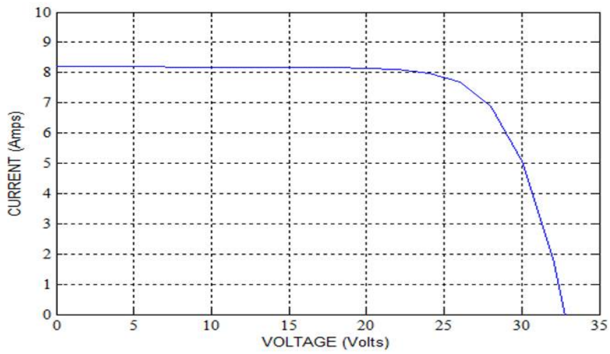

Fig 1.16 V-I curve of PV module

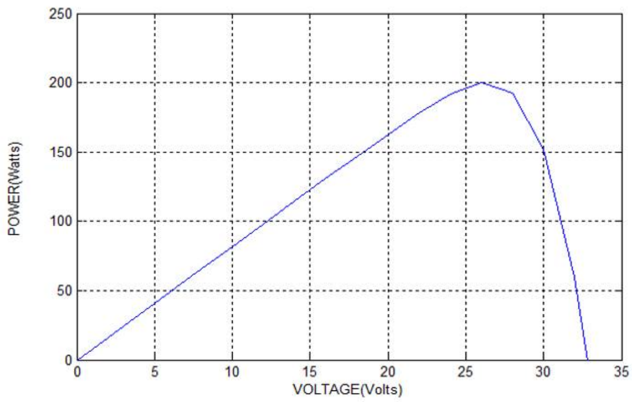

Fig 1.17 P-V curve of PV module

In figure 1.18, 1.19 we can see the effect of change in solar irradiation on PV characteristics. From figure 1.18 we observe that as we increase the solar irradiation short circuit current increases. Variation in Solar irradiation effects mostly on current, as we can observe from fig 1.18 as we increase solar irradiation from 700 w/m2 to 1000 w/m2 current increases from 5.7A to 8.2A approximately but effect of variation of solar irradiation on voltage is very less. Figure 1.19 shows the effect of variation of solar irradiation on P-V characteristics. As solar irradiation increases, power generated also increases. Increase in power is mainly due to increment in current. Figure 1.20 , 1.21 shown the solar system output voltage and current respectively.

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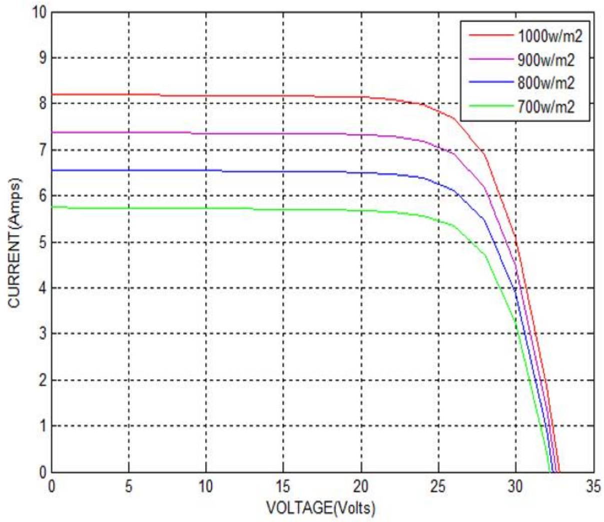

Fig 1.18 Effect of Variation of Irradiation on I-V Characteristics

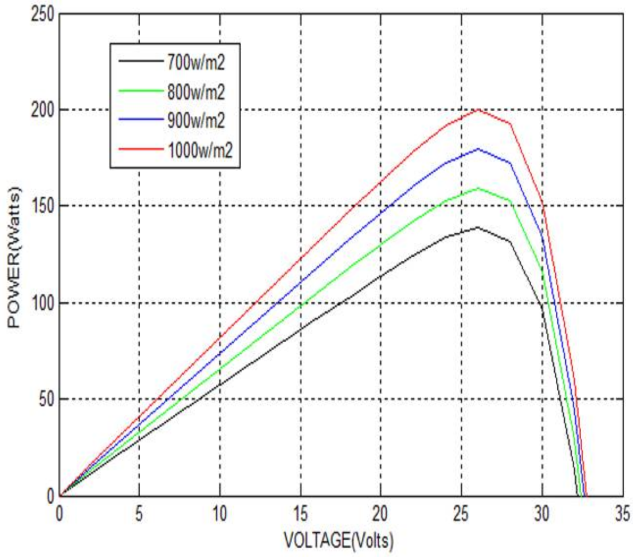

Fig 1.19 Effect of Variation of Irradiation on P-V Characteristics

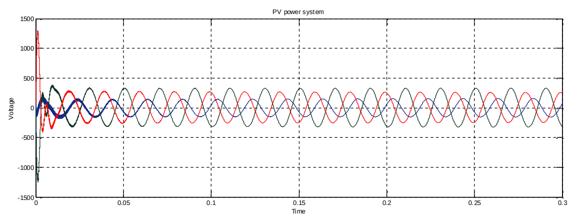

Fig 1.20 Solar System Output Voltage

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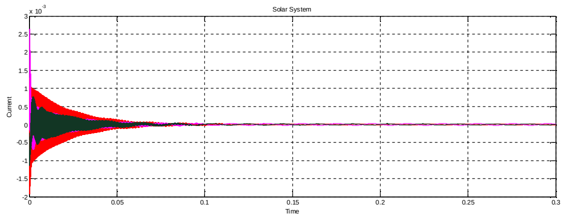

Fig 1.21 Solar System Output Current

Wind turbine power Characteristics is shown in figure 1.22 and PMSG output Voltage and Current is shown in the figure 1.23, 1.24 respectively. Output Voltage of wind generator at which maximum power is achieved is shown in the fig 1.25.

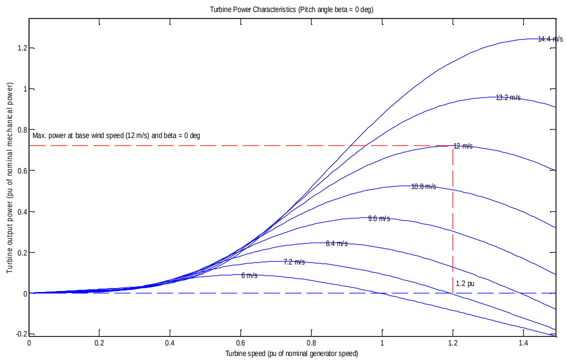

Fig 1.22 Turbine Power Characteristics (pitch angle beta=0°)

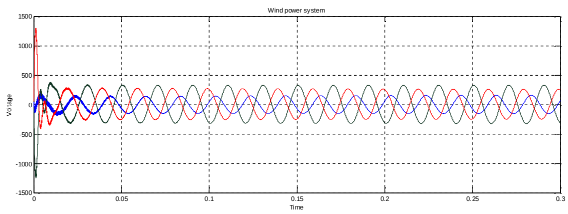

Fig 1.23 Three Phase Line Output Voltage of Wind System

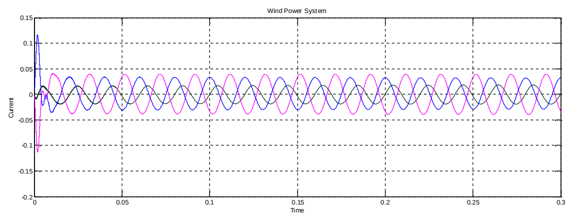

Fig 1.24 Three Phase Line Output Currnt of Wind System

The proposed PV model was simulated using MATLAB Simulink software Measurements were taken over 12 month's (One Year) period; using hourly average irradiance and wind speed. These real-time parameters are used as inputs of the developed hybrid PV/wind model. The performance of the system is shown in Figure 1.25 and Hybrid Power Output throughout the Year is shown in figure 1.26

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

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Vol. 6, Issue 1, January 2017

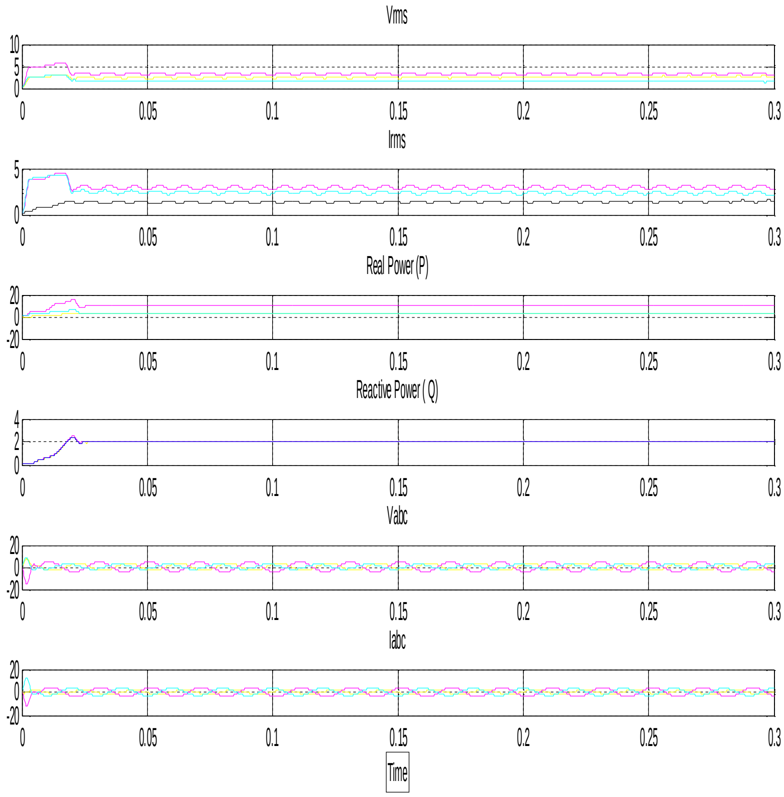

Fig 1.25 Measurements of Hybrid Power System

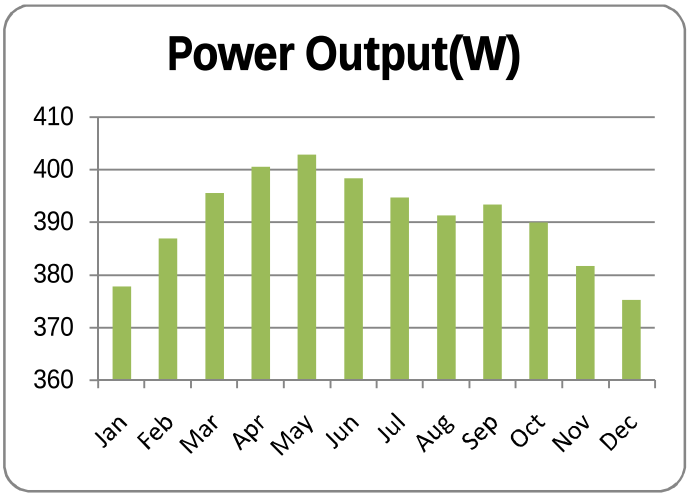

Fig 1.25 Hybrid Power Output Throughout the Year

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Vol. 6, Issue 1, January 2017

VI. CONCLUSION

To provide better power supply services for household the mini hybrid wind - solar power plant is use-full and in this thesis we have studied the off grid Electrification through hybrid power. Power is main issue for remote or isolated areas base station, because grid extension is not feasible. In these sites the above proposed renewable base hybrid system is most sustainable solution. These solutions of power supply to the households are cost effective and available throughout the year. The circumstance of each sites are studied in order to decide the feasible combination of alternative energy resources. Alternate power solutions are not commonly used in household system today but are actively evaluated for remote and isolated areas over worldwide. With the help of above pre-feasibility study the solar and wind hybrid energy system are most viable power solution for remote/hilly areas in Indian sites over conventional grid supply system.

- ✓ PV cell, module and array are simulated and effect of environmental conditions on their characteristics is studied
- ✓ Wind energy system has been studied and simulated
- ✓ Both the systems are integrated and the hybrid system is used for supply services for household

VII. FUTURE SCOPE

In this paper we analysis the various data about the wind, solar for generating the electricity from the hybrid system (Combination of both) at small level that help to the decision makers to visualize the idea for various factors in construct a Hybrid generation plant with a various minimum cost with highest generating capacity. The result shows by the experimental and theoretical data that has been able to predict the energy generation through hybrid system. For future scope different time period has been use for calculating the power and efficiency. This method motivates the engineers to install small scale solar wind hybrid system in Rajasthan region. The government of India takes a major decision towards the hybrid energy sources. The Jawaharlal Nehru solar mission (JNNSM) target to produce 20 Giga watts up to 2022 and should 100 % Renewable up to 2050.

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