A novel approach for modelling of small renewable energy hybrid micro grid with storage

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ABSTRACT: The objective of the paper is to design and implement a hybrid micro grid comprises of solar photovoltaic (SPV), wind energy conversion system (WECS) and battery storage. The model is designed for stand-alone as well as integrated operation with an existing grid. MATLAB /Simulink is used as the modelling environment. The proposed model consists of PV cell array, wind turbine model, battery for storage, buck boost converter topology and an inverter. The advancement in the renewable source of energy from last decade have taken a good pace, that's due to the increase in power supply demand and continued rise in prices of conventional sources of energies. Moreover, in recent year's generation of electricity using the different types of renewable sources are specifically evaluated in the economic performance of the overall equipment. This Paper illustrates wind and solar hybrid system for supplying electricity to the power grid.

KEYWORDS: *PV panel, hybrid system, renewable energy, wind turbine, power grid, boost converter.*

I. INTRODUCTION

Renewable source of energy has become more popular and important energy recourses all over the world in the past few years, that is because of the depletion of conventional energy and pollution impact on environment. Among all various renewable energy sources, wind and solar energy sources are most promising. The main advantages of using solar and wind energy systems are that they are non-polluting and non - deflectable. Since the oil crisis of the early 1970s, the utilization of solar and wind power has become increasingly noteworthy, popular and cost-effective. But the main disadvantage of solar and wind energy system is that it depends on seasonal variation and it is unpredictable in nature. As both wind and solar energy sources are not consistent and non-stable in nature. A hybrid system of wind and PV power sources provides a stable form of power generation. Hybrid energy systems are cost effective energy solutions with high reliability and power quality. Individual photovoltaic (PV) or wind energy system, do not generate utilizable energy for a large portion of time during the year. This is because of dependency on variable sunshine hours in PV system and on relatively high cut-in wind speeds. In this paper individual modeling of PV and wind energy system is done and studied in Matlab/Simulink software. A Hybrid model of PV and Wind system is also implemented and studied.

II. MATHEMATICAL MODELING OF SOLAR PV CELL

Solar (PV) systems capture the sunlight and directly convert it into electricity. Photovoltaic (PV) cell is the basic element of a PV system. A photovoltaic cell is a semiconductor diode whose p-n junction is open to the light [3]. When sunlight strikes the solar cell junction, free electrons and holes are generated and a current is delivered to the load when it is short circuited. A grouping of PV cells forms a solar panel. To obtain large output voltage solar panels are formed by connecting PV cells in series and to achieve large output current cells are connected in parallel. Fig.1 shows the equivalent circuit of a PV cell.

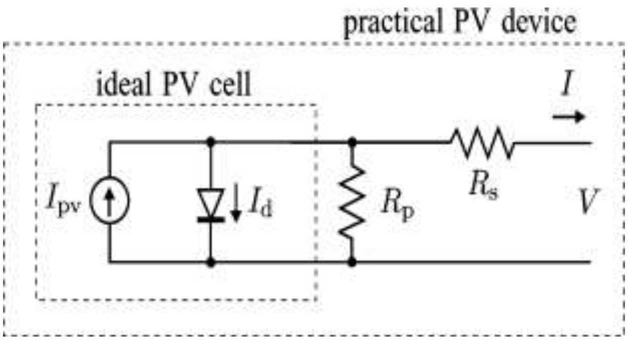

Fig. 1 Equivalent circuit of a PV cell

The basic equation that describes the I-V characteristics of the PV cell [3a] is given as:

$$I = Ipv,cell - Io,cell\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (1)$$

Table 1: Glossary of parameter in modeling of PV equation

S.No.	Parameter	Description
1	$I_{pv,\ cell}$	incident light current (which is directly proportional to the sun radiation),
2	Id	Shockley diode
3	$I_{o,\ cell}$	Reverse saturation current
4	Q	Electron charge
5	K	Boltzman Constant
6	T	Temperature of the p-n junction
7	A	Ideality constant

The equation (1) of PV cell does not show the I-V characteristics of a practical PV array. To observe PV array characteristics inclusion of some additional parameters to the equation (1) is necessary. Hence the equation is represented as:

$$I = Ipv - Io\left[\exp\left(\frac{V + Rs\ I}{Vt\ a}\right) - 1\right] - \frac{V + Rs\,I}{Rp} \quad (2)$$

In this equation V_t is the thermal voltage and R_s & R_p are the equivalent series and parallel resistances. Equation (2) describes the single diode model shown in Fig.1.

The incident light current of PV cell depends on solar irradiation and is greatly affected by the temperature can be expressed as:

$$Ipv = \left(Ipv,n + KI\Delta I\right)\frac{G}{Gn} \quad (3)$$

Where $I_{pv,\ n}$ = incident light current at nominal conditions (25^0 C and 1000W/m^2)

$\Delta T = T - T_n$ (difference between actual and nominal temp)

G and G_n is the actual and nominal irradiation respectively

The reverse saturation current Io also affects by temperature which is represented as:

$$Io = Io\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qEg}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (4)$$

Where E_g = band gap energy of the semiconductor

$I_{o,\ n}$ = nominal saturation current

Table 2 shows the electrical parameters that are considered for designing the PV array with ambient temperature (T_{amb}) of 25°C and solar insolation of 1000w/m^2.

Table 2: Values of electrical quantities used

S. No.	Parameters	Values
1.	Voltage at Maximum power	70.4 V
2.	Current at Maximum power	1.93 A
3.	Open circuit voltage	86.8 V
4.	Short circuit current	2.02 A
5.	Reference Temperature	55°C

III. MODELING OF SOLAR PV MODULE in SIMULINK

PV cell converts the solar radiation directly into electricity with both I-V and P-V output characteristics. Based on the mathematical equations shown in equation (1-4) Simulink modeling of PV module is done in following steps:

A. STEP I

A subsystem is shown in fig. 2. This model calculates the short circuit current (I_{SC}') with inputs of Solar Insolation/irradiance (S) = 1000w/m^2, Ambient temperature (T_{amb}) = 25°C, short circuit current (I_{SC}) = 2.02A, and reference temperature (T_{ref}) = 55°C

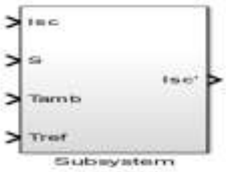

Fig. 2 Subsystem to calculate I_{SC}'

Fig. 3 shows the circuit of this subsystem.

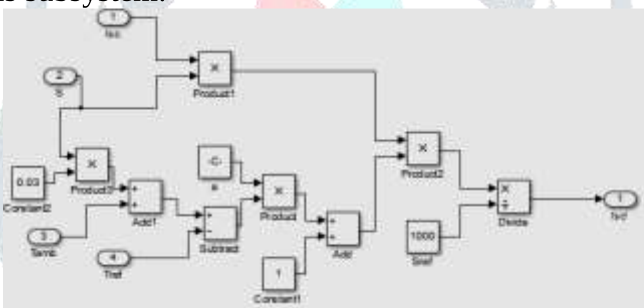

Fig. 3 circuit of subsystem to calculate I_{SC}'

B. STEP II

A subsystem is shown in fig. 4.This model calculates the open circuit voltage (V_{oc}') with inputs of S = 1000w/m^2, T_{amb}=25°C, V_{oc}' = 1.93A, T_{ref} = 55°C.

Fig. 4 Subsystem 1 to calculate V_{oc}'

Fig. 5 shows the circuit of this subsystem.

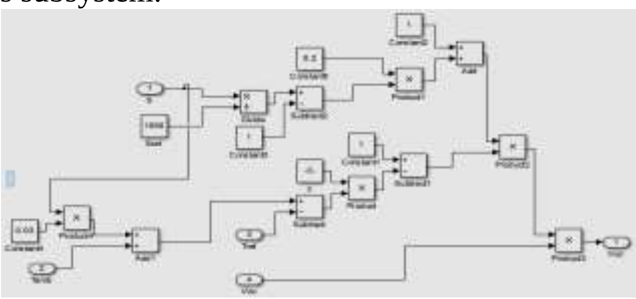

Fig. 5 Circuit of subsystem 1 to calculate V_{oc}'

C. STEP III

A subsystem to calculate the current at Maximum power (I_m') with inputs of S = 1000w/m^2, T_{amb}=25°C, I_m = 1.93A T_{ref} = 55°C is shown in fig.6.

Fig. 6 subsystem 2 to calculate I_m'

Fig. 7 shows the circuit of this subsystem 2

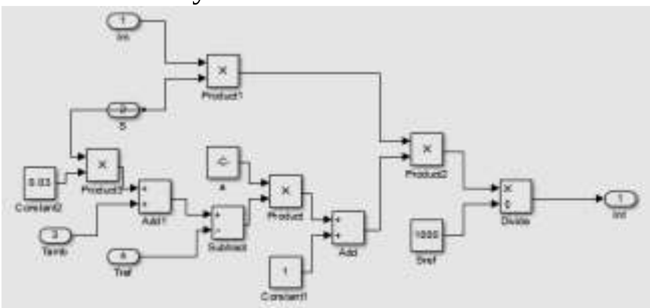

Fig.7 Circuit of subsystem 2 to calculate I_m'

D. STEP IV

A subsystem to calculate the Voltage at Maximum power (V_m') with inputs of S = 1000w/m^2, T_{amb}=25°C, V_m = 70.4V T_{ref} = 55°C is shown in fig.8.

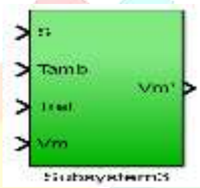

Fig. 8 subsystem 3 to calculate V_m'

Fig. 9 shows the circuit of this subsystem 3.

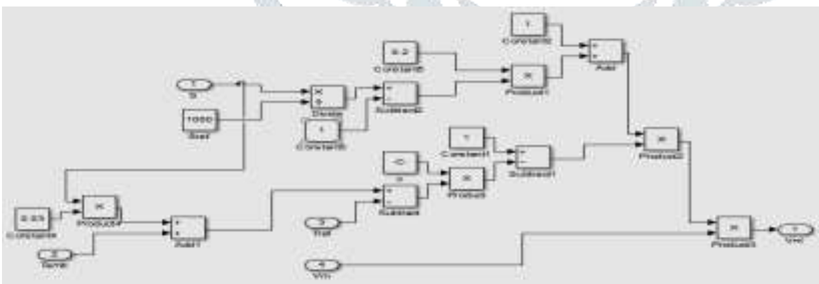

Fig. 9 Circuit of subsystem 3 to calculate V_m'

E. STEP V

A complete PV mathematical model equation subsystem is displayed in figure 10. Here all the subsystem are connected with each other to get the final I_{pv}.

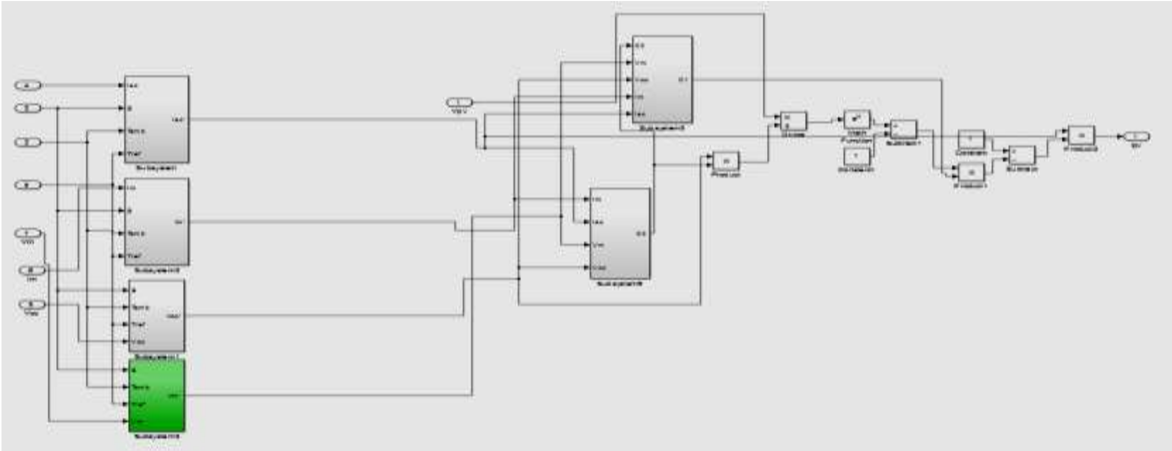

Fig.10 Interconnection of all subsystems

In figure 11 the complete simulation model of PV array is displayed.

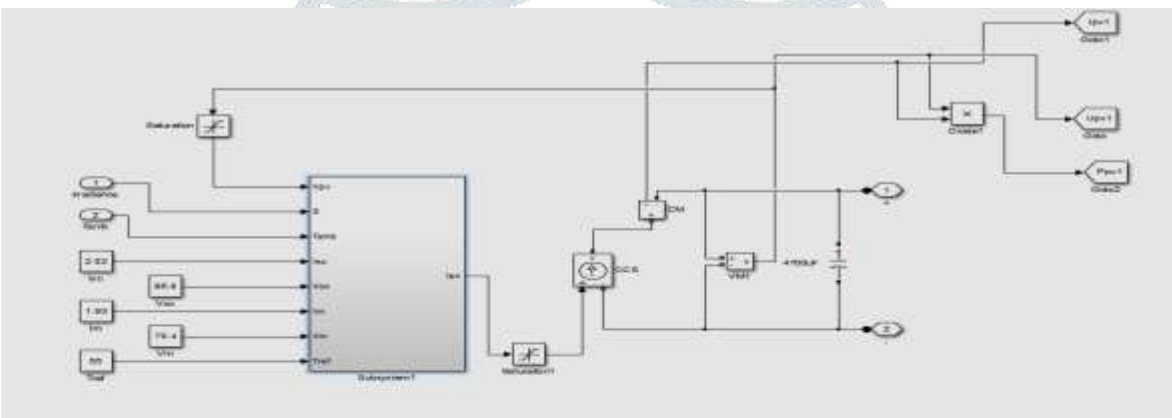

Fig. 11 Complete model of a PV array

Figure 12 shows the V-I and P-V curve of the PV cell. The V-I and P-V curve of the PV cell is totally dependent on the Solar irradiations. If there is change in the environmental condition then the solar irradiation level change which results different maximum power. So maximum power point tracking algorithm are used to maintain the maximum power constant if there is any change in the solar irradiation level

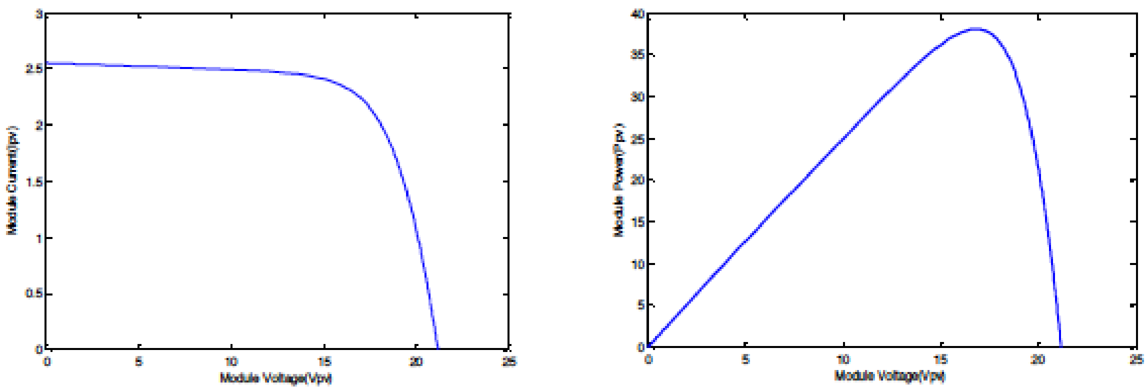

Fig. 12 V-I and P-V curve of PV cell

IV. MODELING OF WIND TURBINE

Wind energy is an environment friendly and endless source. Therefore, a wind energy generation system may be one of the promising sources of alternative energy for the future demand.Wind turbines convert the kinetic energy of wind into mechanical energy. The magnitude of this converted mechanical energy depends on the air density and the wind velocity. The wind power (P_m) that is developed by the turbine is given by the equation:

$$P_m = \frac{1}{2} C_P(\lambda, \beta) \rho A w^3 \qquad (5)$$

Where C_P = performance coefficient of turbine

ρ = air density (kg/m^3)

A = area of turbine blades (m^3)

w = wind velocity (m/sec)

λ = tip speed ratio of the rotor blade tip speed to wind speed

β = blade pitch angle (deg)

The coefficient C_P is the fraction of kinetic energy which is converted by wind turbine into mechanical energy. It is related to the tip speed ratio (λ).

Wind turbine output torque (T_m) can be calculated using equation:

$$T_m = \frac{1}{2} \rho A C_p \frac{w}{\lambda} \qquad (6)$$

Figure 13 illustrates the ideal power curve of the wind turbine.

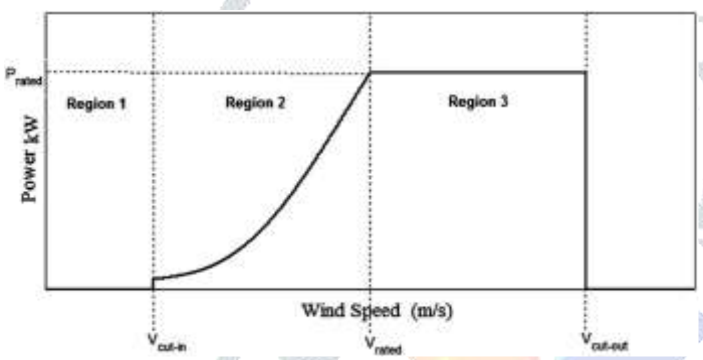

Fig. 13 ideal power curve of wind turbine

Using above equation no. (5-6) a Simulink model is implemented as shown in fig. 14.

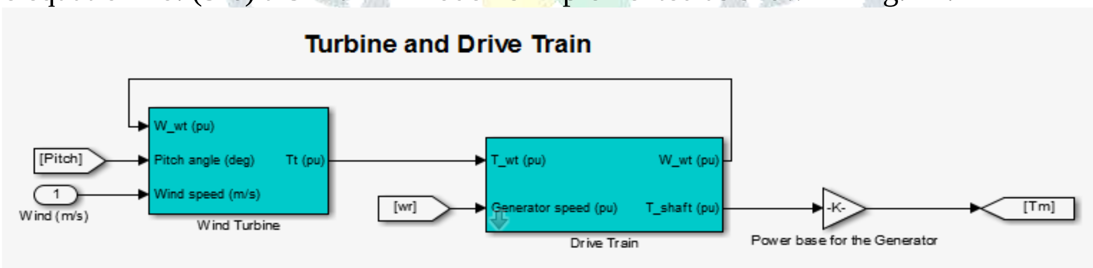

Fig. 14 Simulink model of wind turbine

This wind turbine is connected to a three phase synchronous generator which converts this mechanical power into electrical power which is shown in figure 15.

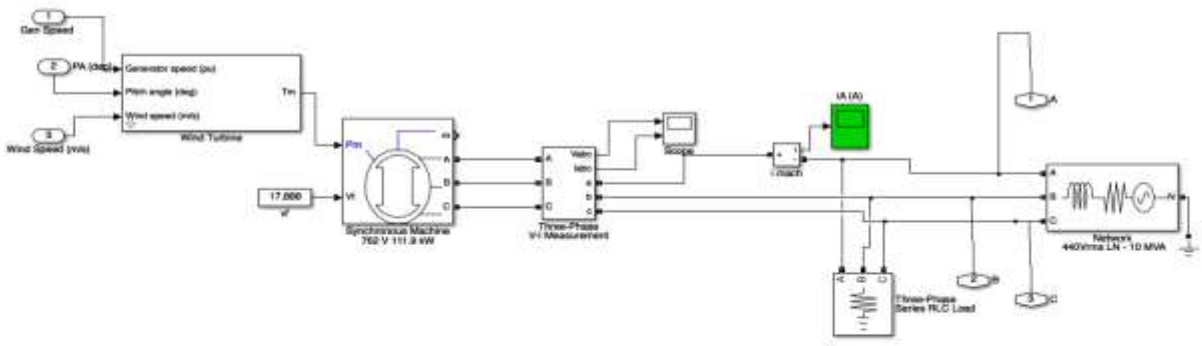

Fig. 15 Simulink model of wind turbine

IV. PROPOSED HYBRID PV/WIND SYSTEM

A grouping of Wind and PV energy system into a hybrid generation system may increase their efficiency by increasing their overall energy output, by reducing energy storage requirement. This makes system less costly and more reliable as compared to individual energy system.

A hybrid system of wind and PV connected to grid is simulated. It consists of a three phase converter with PWM generator and voltage source converter which convert DC to AC of grid frequency. A simulink model of hybrid system is shown in fig. 15

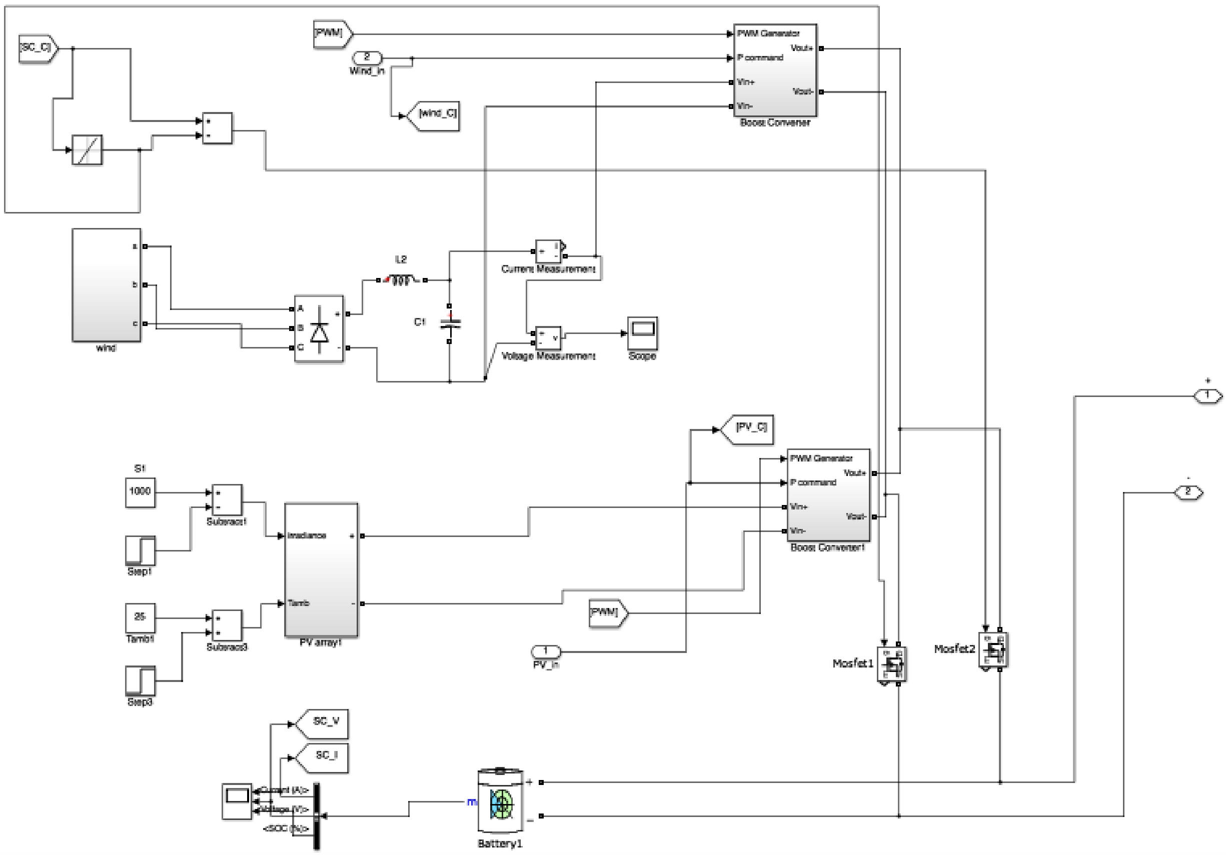

Fig. 15 Simulink model of wind/PV hybrid system with storage

Fig. 16 shows a complete simulink model of grid connected hybrid system.

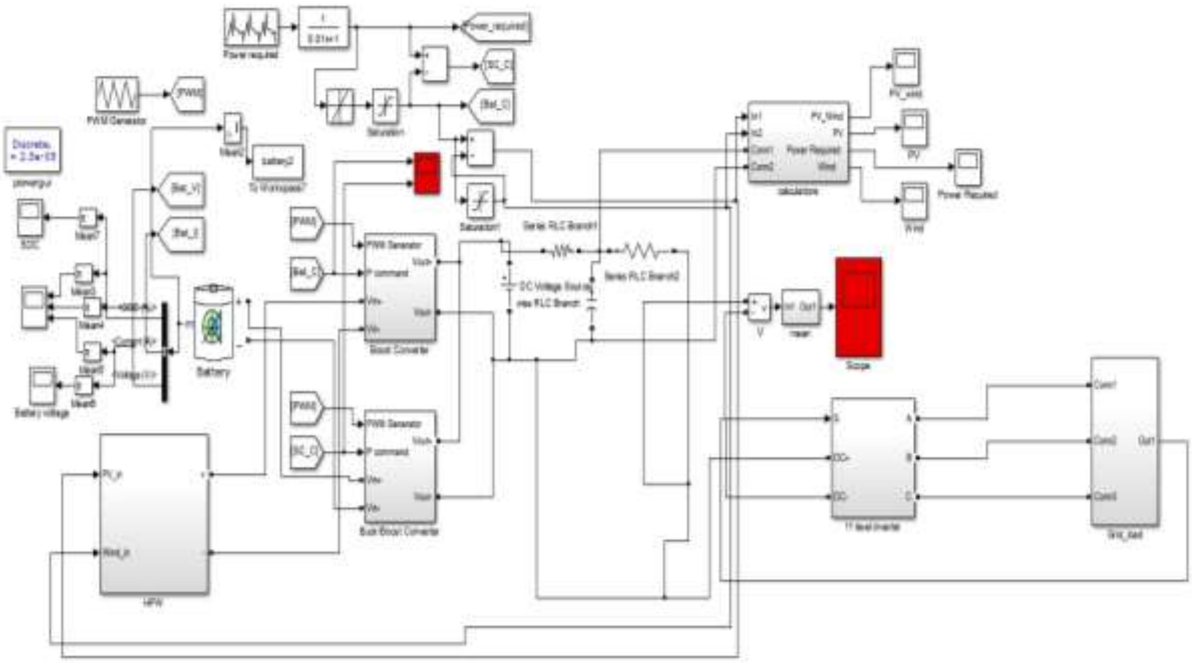

Fig. 16 Complete Simulink model of grid connected wind/PV hybrid system

V. RESULT AND DISCUSSION

Different waveforms shown below are the output waveforms of our simulation model. These are the simulation result. In figure 17, 18 and 19 the Inverter voltage, load voltage and frequency of the integrated system is shown respectively. From the figure 19 it can be seen that the Hybrid system is synchronized at 50Hz frequency with the grid successfully.

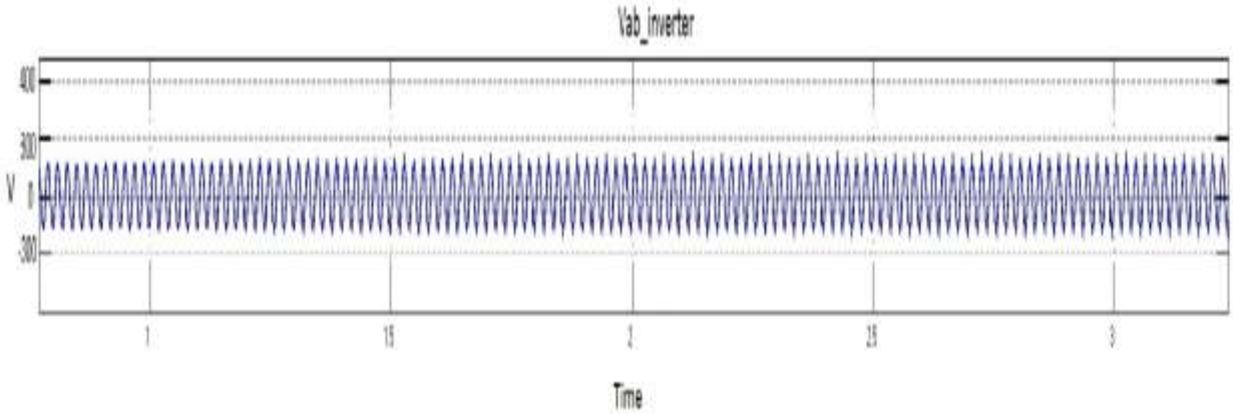

Fig. 17 Inverter Voltage

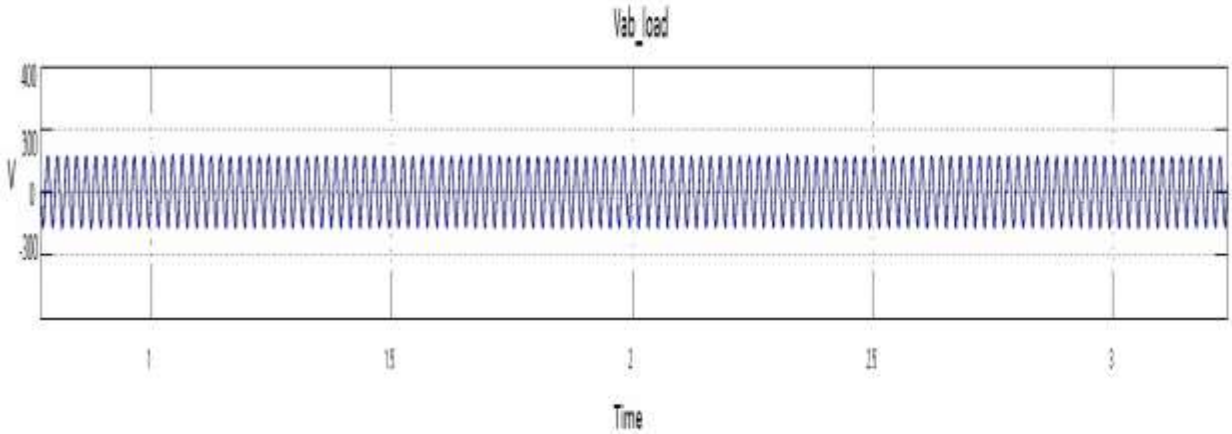

Fig. 18 Load Voltage

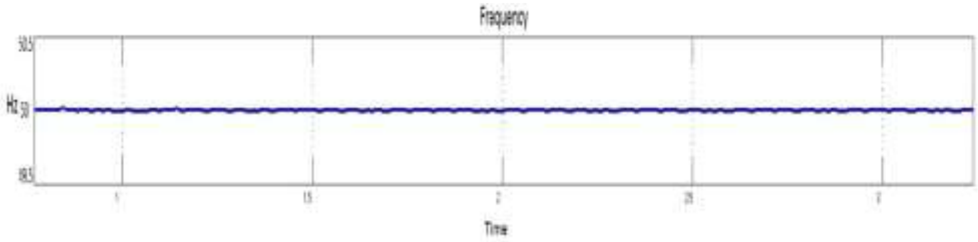

Fig. 19 Frequency of the System

POWER DEMAND FULFILMENT

We have considered a load demand curve to display the robustness of the system in catering to the load demand. Figure 20 displayed the monthly load demand. The maximum peak load demand around 140KW is in the months of summers and rest is about average demand around 60-70KW.

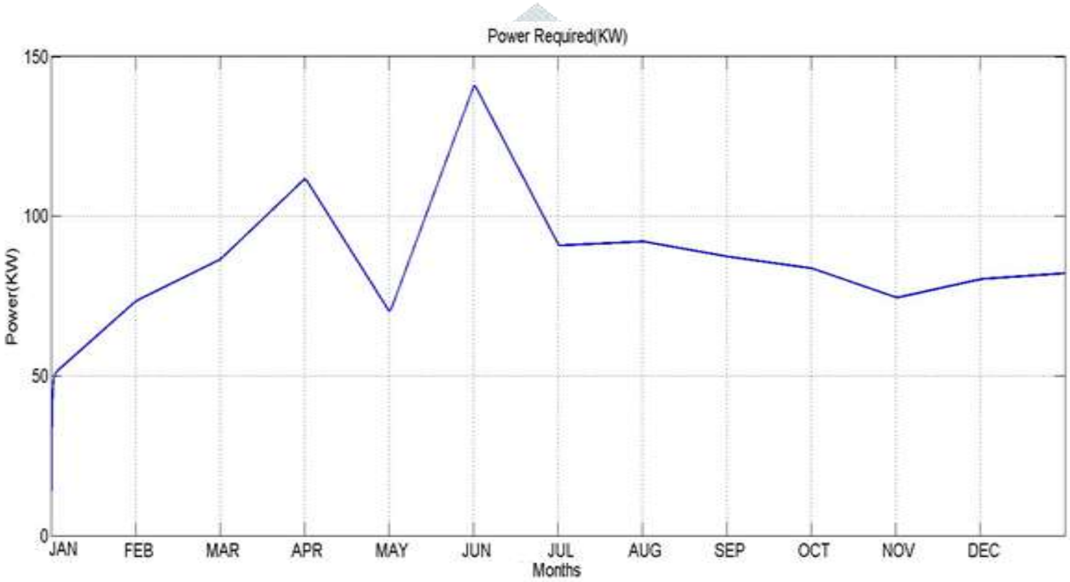

Fig. 20 Power Demand

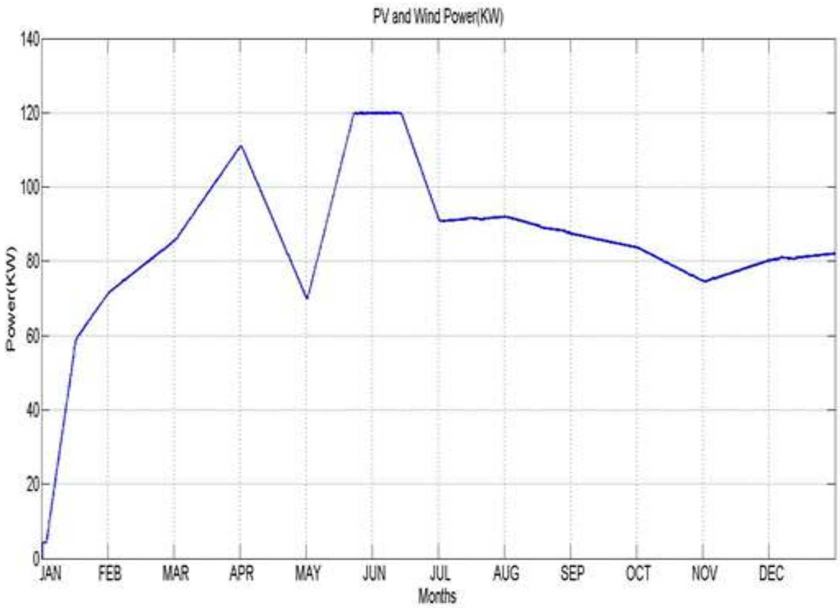

Fig 21 PV-Wind Combined Power generation

Figure 21 shows the power generated throughout the year using PV – Wind hybrid system and both generated power are shown altogether.

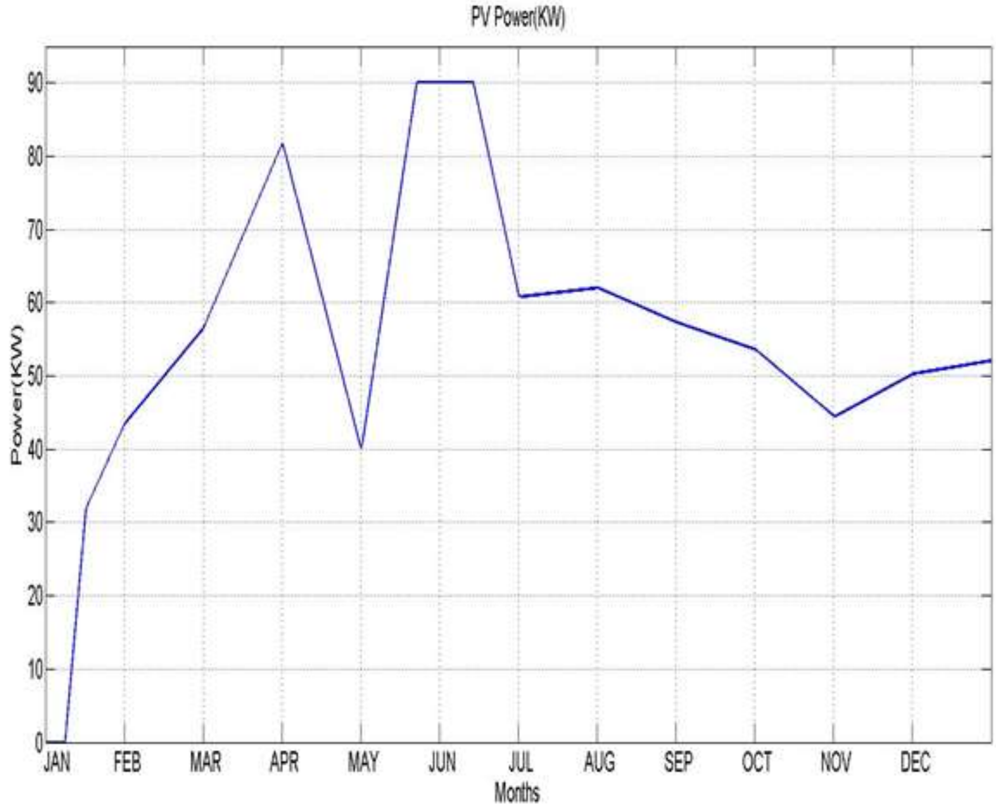

Fig. 22 PV Power Generation

Figure 22 and 23 displays the separated graphs of the power generation using PV and wind respectively. Here from both the figure it can be seen that the PV has played the major role in catering the Load demand in comparison to wind power. The maximum the wind have provided is 30KW.

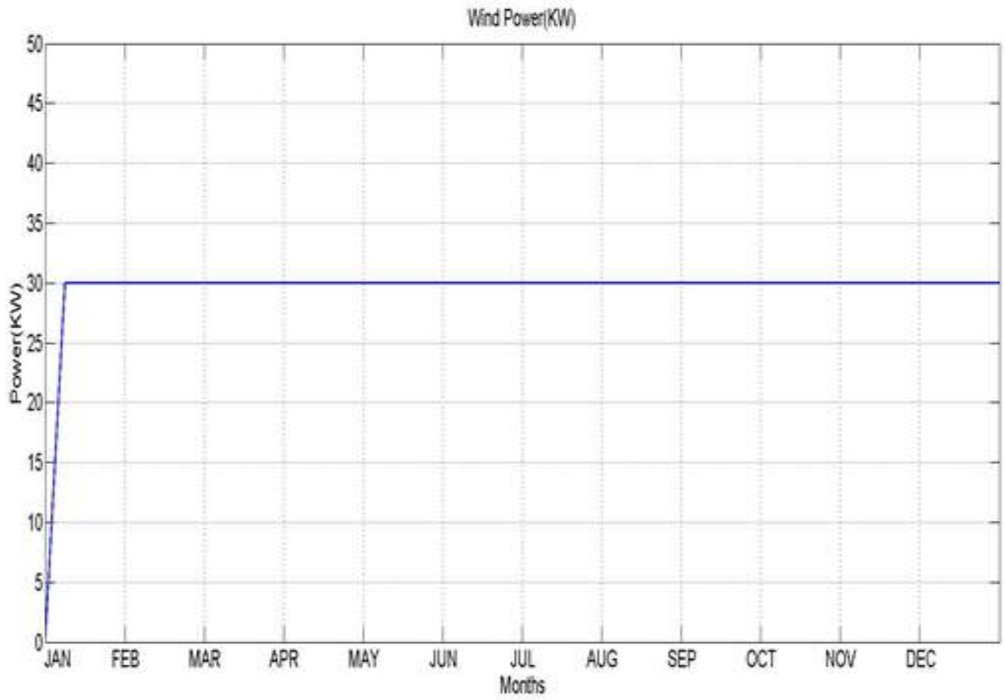

Fig. 23 Wind Power Generation

Figure 24 shows the battery state of charge, we can see during discharging, battery start supplying constant voltage and state of charge start decreasing and also during discharging current become positive, which shows battery is supplying the power to the load.

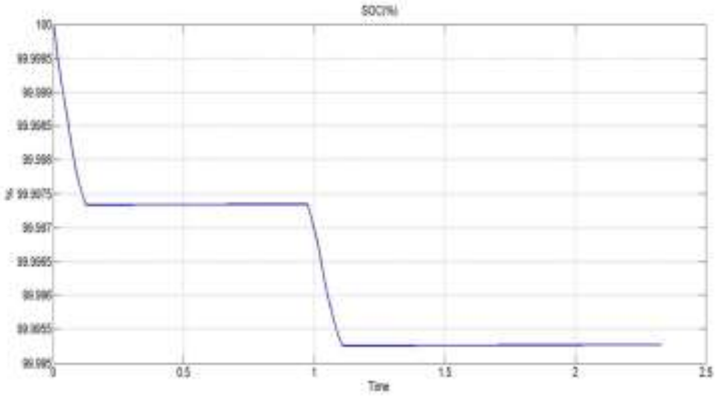

Fig. 24 Battery SoC

Tabular form description of power demand and power generated is shown in table 4.2

Table 2 Power Generated Vs Power Required

S. No.	Power Required (KW)	Power Generated PV-Wind(KW)
1	50	50
2	73.53	72.8
3	86.59	86
4	111.82	110.56
5	69.86	68.24
6	141.29	140.84
7	90.79	90.56
8	92.03	91.60
9	87.31	87.50
10	83.60	83.10
11	74.45	73.18
12	80.3	79.50

VI. CONCLUSION

Individual modelling and simulation study of Wind and PV system has been successfully carried out in MATLAB/Simulink. Then a hybrid model has been simulated by combining these energy resources with the help of converter and voltage regulator. A Hybrid System of wind and PV is simulated with the Load curve requirement through the year. The simulation result of implemented hybrid system shows the generated output voltages which can be supplied to the grid. This hybrid system is more reliable as compared to single energy system.

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