Energy Management Approach for Grid Connected Renewable Energy Sources

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Abstract— The generation of electricity using fossil fuel, coal and diesel which causes global worming effects so it has required significant energy reduction in all areas but at the same time increasing number of electric appliances has increased energy consumption, so to overcome this problem we need to design and implement efficient energy management system with grid tied renewable resources. This system describes microcontroller based energy management system with the help of renewable resources such as solar panel and wind turbine with the help of MATLAB/Simulink software. Microcontroller is used to schedule and control the energy generation from solar panel, wind turbine and grid. The energy consumption of appliances and generation of renewable energies are used for analyzing the total energy estimation and control the energy to minimize the energy cost. The intermittent nature of wind and solar energy make them unreliable. Hence Maximum Power Point Tracking algorithm is used to get maximum power from solar and wind when it is available .The simulation result of these hybrid energy management system presented in graph which shows the effectiveness of proposed system model compare to stand alone system.

Key words: Solar and Wind Renewable Energy, Storage, Simulation Tool, Algorithm

NOMENCLATURE

PV = photovoltaic
WT = wind turbine
MPPT = Maximum Power Point Tracking
AC = Alternating Current
DC = Direct Current
LDR = Light Dependent Register
OC = Open Circuit
SC = Short Circuit
PMSG = permanent Magnet Synchronous Generator
PWM = Pulse Width Modulation
WECS =Wind Energy Conversion System
KE = kinetic Energy
P&O= perturb and Observe
Rp = Shunt resistance of a PV Module
Rs = Series resistance of a PV module

I. INTRODUCTION

Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly. India ranks sixth in the world in total energy consumption and needs to accelerate the development of the sector to meet its growth aspirations. The development of renewable energy has been an increasingly critical topic in the 21st century with the growing problem of global warming and other environmental issues. With greater research, alternative renewable sources such as wind, water, geothermal and solar energy have become more important for electric power generation.

A renewable energy management system includes two or more energy sources, usually solar and wind energy. Hybrid renewable energy system with grid connection has more advantage than stand-alone system. Battery is used with bidirectional converter to store the energy when load requirement is less than the generated energy and it also serve the energy to the load when generated energy is less than the required energy.**[1]** The maximum point power tracking of the wind generator and PV array is performed by using MPPT algorithms. MPPT is an algorithm that is used for extracting maximum available power from PV module and wind energy system under varying operating conditions. In solar photovoltaic system, MPPT is achieved with the DC to DC converter which operates PV module at its maximum power point by using the simple Perturb and Observe (P&O) Algorithm. In case of Wind energy system, the tracking of windmill power around the maximum power operating point is achieved by the proposed P&O algorithm.**[2]** The combine use of these sources which becoming widely used to overcome energy generation problems and reduce global warming effects. By using grid connected hybrid system a reliable and environment friendly power can be provided. To fulfill this achievement various combinations of renewable sources can be used and scheduled properly to get efficient power. Grid is used in case when generation is very low from wind and solar.

This paper is organized as follows proposed system description and mathematical modeling in section II and section III presents the simulation results and section IV concludes the paper.

II. PROPOSED SYSTEM DESCRIPTION AND MODELING

The proposed hybrid system is shown in Fig 1, system is modeled and simulated by using MATLAB/SIMULINK.

Solar cells produce energy by performing two basic tasks: (a) absorption of light energy to create free charge carriers within a material and (b) the separation of the negative and positive charge carriers in order to produce electric current that flows in one direction across terminals that have a voltage difference. MPPT algorithm is used for maximum power point tracking. Boost converter is used to step up and regulate voltage. Wind turbine is used to convert wind energy into mechanical and Permanent magnet synchronous generator (PMSG) is used to convert mechanical energy into electrical energy which is followed by an ac/dc converter is used in the proposed work to convert variable speed wind to a constant dc bus voltage. The power from Wind is fed to DC bus. Details mathematical modeling of each power source is discussed in subsequent sub sections. Then rectifier is used for DC output. These DC source from solar and wind is supplied to DC appliances. Battery is connected with bidirectional converter (buck-boost). A three phase bidirectional dc/ac converter is connected between dc and ac buses which can transfer power in either direction. Grid is used in case when generation is very low from wind and solar.

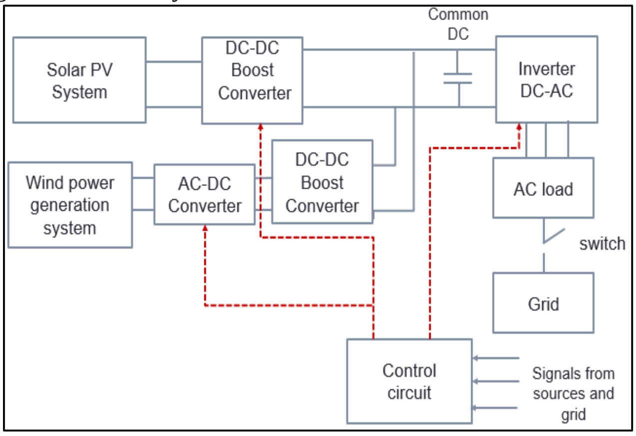

Fig. 1: Proposed System Block Diagram

A. Equivalent Circuit of Solar Panel:

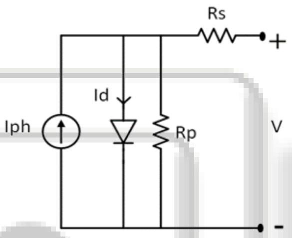

Fig. 2: Equivalent Circuit of PV Cell [2]

The current source Ipv represents the cell photo current, Rp and Rs are used to represent the shunt and series resistance of the cell respectively. Usually the value of Rp is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. [2]

The current equation of solar panel is given as,

$$I = I_{ph} - I_{d}$$

$$\mathbf{I_{PV} = \left[N_p I_{ph} - N_p I_0 \left(\exp\left[\frac{q * (V_{pv} + I_{PV} R_s)}{N_s A k T}\right] - 1\right)\right]}$$

Where,

I_{ph} Light generated current in a PV module
I_{ph} Output current of a PV module (A)
N_p Number of cells connected in parallel
I_o PV module saturation current (A)
q Electron charge = 1.6×10^{-19} C
V_{pv} Output voltage of a PV module (V)
I_{pv} Output current of a PV module (A)
Rs Series resistance of a PV module
R_p Shunt resistance of a PV module
Ns Number of cells connected in series
A=B Ideality factor = 1.6
K Boltzmann constant = 1.3805 × 10-23 J/K
T Module operating temperature in Kelvin

B. MPPT for Solar (Maximum Power Point Tracking):

MPPT is technique to achieve maximum energy from solar. There are two ways to achieve maximum power:

1) Mechanically:

Solar panel will move according to sun direction using LDR (light dependent resister) sensor, Motor and Relays to achieve maximum power from the solar panel. Below flow chart will describes the status of solar tracker at each time. Here, V_e, V_m, V_w are the corresponding output voltages of LDR kept to sense the sun position when it is in east, middle (noon) and west position respectively. **[3]**

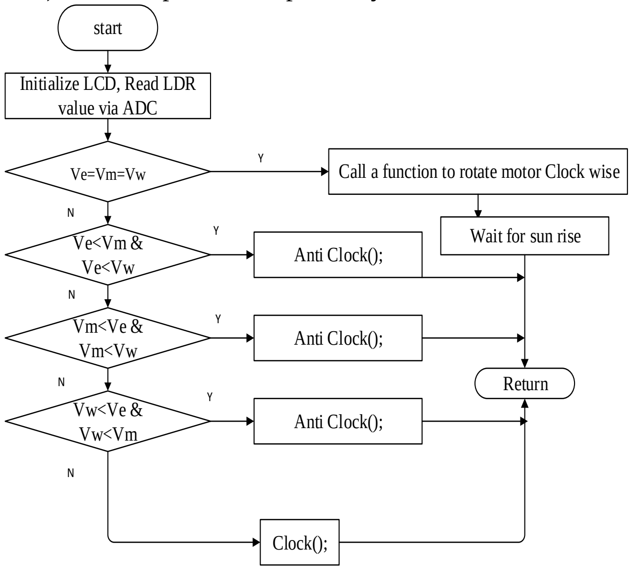

Fig. 3: Flow Chart of Solar Tracker [3]

2) Electrically:

There are different methods to find the MPP have been published and developed. According many aspects these techniques differ such as required sensors, complexity, range of effectiveness, according to speed, cost, if there is change in irradiation and temperature than also the effectiveness of tracking, requirement of hardware and its implementation. 19 different MPPT algorithms are there among these techniques, the Incremental conductance algorithms and the P&O algorithms are generally used.

Few of the most popular techniques are:

- Fractional open Circuit Voltage
- Neural Networks
- Fuzzy Logic
- Incremental Conductance Method
- Perturb and Observe (Hill Climbing Method)

3) Comparisons of Different MPPT Methods

MPPT methods	Coverage speed	Sensed parameter
Perturb & Observe	Varies	Voltage
Incremental Conduction	Varies	Voltage, Current
Fraction open Circuit Voltage	Fast	Varies
Neural network	Fast	Varies
Fuzzy logic	Medium	Voltage

Table 1: Comparisons of MPPT Methods

4) Proposed Algorithm Perturb and Observe Method:

The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power P is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If P is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed. [9-10-11]

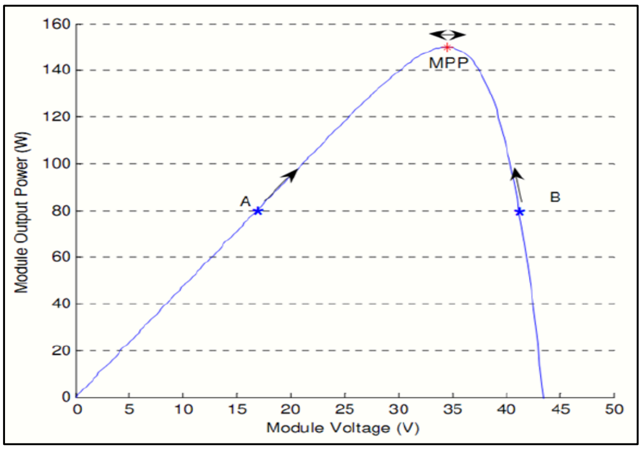

Fig. 4: MPPT Charecteristics using P&O

Solar panel characteristics showing MPP and operating points A and B shows the plot of module output power versus module voltage for a solar pan el at a given irradiation. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel. Consider A and B as two operating points. As shown in the figure above, the point A is on the left hand side of the MPP. Therefore, we can move towards the MPP by providing g a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation, the value of P becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP. The flowchart for the P&O algorithm is shown in below Figure 5.

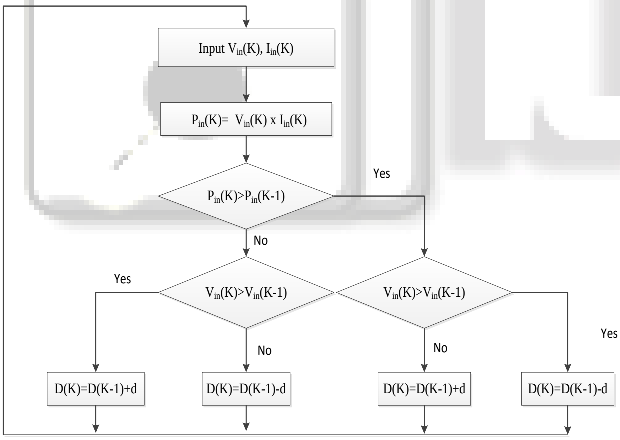

Fig. 5: Flow Chart of MPPT using P&O

C. *Wind Energy:*

Generally a wind turbine consists of a set of rotor blades rotating around a hub, a gearbox-generator set placed inside the nacelle. The basic components of a wind turbine system are shown in figure below.

The shaft of the wind turbine is mechanically coupled to the rotor shaft of the generator, so that the mechanical power developed by the wind turbine (by kinetic energy to mechanical energy conversion) is transmitted to the rotor shaft. This rotor structure has a rotor winding (either field or armature). In both the cases, we get a moving conductor in a stationary magnetic field or a stationary conductor in moving magnetic field. In either case, electric voltage is generated by the generator principle.

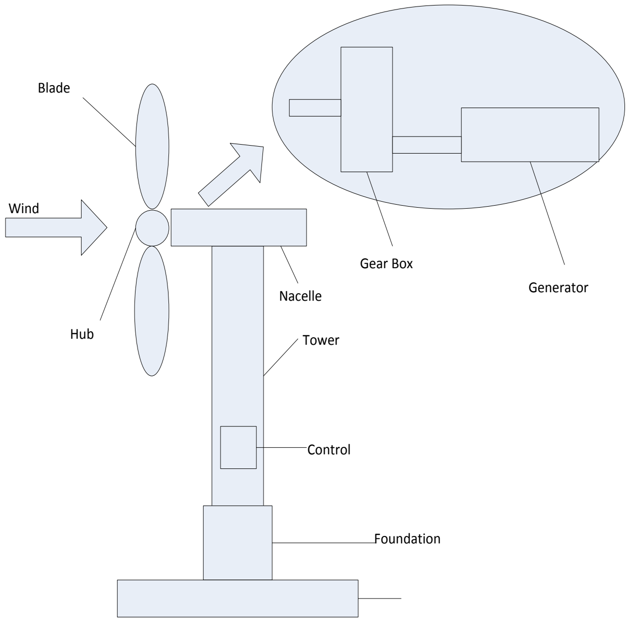

Fig. 6: Wind Energy Generation

1) *Power extracted from Wind:*

The kinetic energy (KE) in wind is given by:

$$\mathbf{KE = \frac{1}{2} m V_w^2}$$

Where

m is the mass of air in Kg,

V_w is the speed of wind in m/s.

The power in wind is calculated as the flux of kinetic energy per unit area in a given time, and can be written as

$$\mathbf{P = \frac{d(KE)}{dt} = \frac{1}{2}\frac{dm}{dt} V_w^2 = \frac{1}{2}\dot{m} V_w^2} \text{ ………. (2.2)}$$

Where

$\dot{m}$ is the mass flow rate of air per second, in kg/s, and it can be expresses in terms of is the mass flow rate of air per second in kg/s and it can be expresses in terms of the density of air (ρ kg/m)

$$\mathbf{\dot{m} = \rho \dot{Q} = \rho A V_w} \text{ ………………………….. (2.3)}$$

Where

A is the area swept by the blades of the wind turbine in m^2.

Substituting equation 2.2 in 2.3, we get

$$\mathbf{P = \frac{1}{2} \rho A V_w^3} \text{ ………………………………… (2.4)}$$

Then the ratio of wind power extracted by the wind turbine to the total wind power is the dimensionless power coefficient C_p, which will also effects the power extracted from wind. So the equation can be written as

$$\mathbf{P = \frac{1}{2} \rho A V_w^3 C_p} \text{ ………………………….. (2.5)}$$

Where,

C_p Power coefficient is a function of the pitch angle θ of rotor blades and of the tip speed ratio λ . **[12, 16]**

λ Tip speed ration is the ratio between blade tip speeds

V_w is wind speed value upstream of the rotor, given by:

$$\mathbf{\lambda = \frac{\omega_w R}{V_w}} \text{ ………………………………… (2.6)}$$

Where,

ω_w is blade tip speed in rad/s ,

R is rotor radius in m

V_w is wind speed upstream of the rotor in m/s.

The turbine power coefficient C_p, describes the power extraction efficiency of the wind turbine. It is a nonlinear function of both tip speed ratio, λ and the blade pitch angle β. While its maximum theoretical value is approximately 59, it is practically between 4 and 45. There are many different versions of fitted equations for C_p made in the literatures. A generic equation has been used to model $C_p(\lambda,\theta)$ and based on the modeling turbine characteristics as shown in the following equations the power coefficient $C_p(\lambda,\theta)$ is presented below in form of function of tip speed ratio and the blade pitch angle. [17]

$$C_p(\lambda,\theta) = c_1\left(\frac{c_2}{\lambda} - c_3\beta - c_4\right)e^{-c_5/\lambda} + c_6\lambda \quad \text{.......(2.7)}$$

Where

$$\frac{1}{\lambda} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

2) PMSG (permanent Magnet Synchronous Generator):

Variable speed of wind turbine is popular for capturing maximum power from the wind. Now, a day's doubly Feed Induction Generator (DFIG) as a variable speed of wind turbine. Speed wind turbine. This required a gear box for matching the wind turbine speed and the wind generator rotor speed. The gear box requires regular maintenance and many times suffer from faults making the system unreliable. To solve this problem permanent magnet synchronous generator (PMSG) is used because it is a self-excited machine and it has high power factor and good efficiency. [18]

3) MPPT Algorithm for Wind:

The wind generator consists of a wind turbine coupled with a permanent magnet synchronous generator (PMSG). The three phase diode rectifier is used for converting AC voltage to DC voltage and then fed to the buck converter in that the voltage input-output ratio is controlled by a PWM (Pulse width modulation) signal from the MPPT controller. The MPPT controller read the voltage and current values of the wind generator output to determine the PWM signal. The schematic of the Wind Energy Conversion System (WECS) is shown in Fig.7 and the flowchart for P&O algorithm is illustrated in Fig.

The P&O algorithm operates by varying the duty cycle of the buck converter, thus varying the output voltage of the wind generator and observe the resulting power to increase or decrease the duty cycle in the next cycle. If the increase of duty cycle produces an increase of the power, then the direction of the perturbation signal (duty Cycle) is the same as the previous cycle. In Contradiction, if the perturbation duty cycle produces a decrease of the power, then the direction of perturbation signal is reversed. [12-13-14]

In this topology, the AC outputs' voltages from individual solar PV, wind and battery bank stream, through individual DC/AC and AC/DC-DC/AC units, are feeding the loads directly. The renewable energy sources can act as current sources provided that the battery bank exists as a voltage source to control the common AC bus voltage by charging or discharging. Hence, the individual units can be employed for MPPT systems to have the maximum power from the solar PV and wind systems provided that the battery bank exists as a voltage source to control the common AC bus voltage by charging or discharging. The battery bank is charged when there is an extra power and discharged and can supply power in case of shortage of power from the renewable energy sources. The integration of hybrid solar and wind power in a stand-alone system can reduce the size of energy storage needed to supply continuous power. [19]

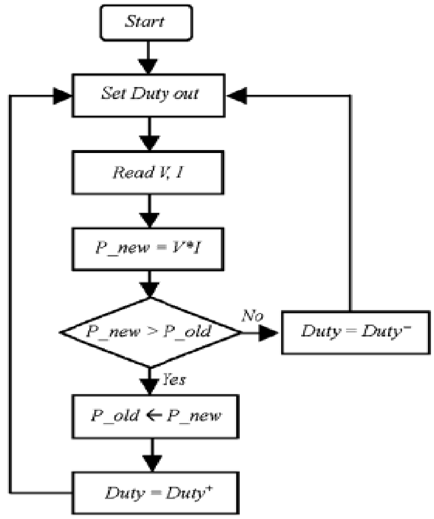

Fig. 7: Flow Chart of MPPT for Wind

D. Boost Converter

Operation of Boost Converter: There are two operating modes for the DC-DC converter, and the mode of operation depends up on the short circuiting and opening of the high frequency switch. When the switch is closed, the inductor will charge. This is mode-1 operation and is known as charging mode. Similarly in the second mode the switch is open and the inductor start discharging which is known as the discharging mode.

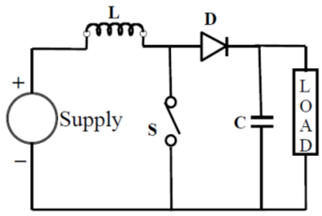

Fig. 8: Equivalent circuit of Boost converter

In Mode 1 operation the switch is closed the inductor gets charged through the battery and stores the energy. In this mode inductor current rises (exponentially) but for simplicity we assume that the charging and the discharging of the inductor are linear. The diode blocks the current flowing and so the load current remains constant which is being supplied due to the discharging of the capacitor.

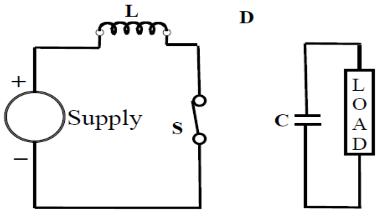

Fig. 8.1: Mode 1

In mode 2 the switch is open and so the diode becomes short circuited. The energy stored in the inductor gets discharged through opposite polarities which charge the capacitor. The load current remains constant throughout the operation.

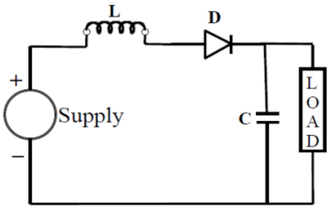

Fig. 8.2: Mode 1

E. SPWM Inverter

The most common and popular technique for generating True sine Wave is Pulse Width Modulation (PWM). Sinusoidal Pulse Width Modulation is the best technique for this. This PWM technique involves generation of a digital waveform, for which the duty cycle can be modulated in such a way so that the average voltage waveform corresponds to a pure sine wave. The simplest way of producing the SPWM signal is through comparing a low power sine wave reference with a high frequency triangular wave. This SPWM signal can be used to control switches. This technique produces a much more similar AC waveform than that of others. **[23]**

F. Selection Parameters for Solar-Wind Hybrid System

For load of 6 tube lights, 6 fans and 20 computers for 5 labs of EC department making out 13KW Power requirement.
20 Computers= 20X100W=2000WX6=12000W
6 tube lights=6X40=240WX6=1200W
6 fanes= 6X60W=360W=1800W

Simulation is done for 10KW Solar System and 6KW wind system.

For solar system reference temperature of 25^0c and 1000w/m^2 irradiation and for wind system 12 m/s to 6 m/s variable wind speed considered for simulation.

G. Matlab/Simulink Implementation of Solar-Wind Hybrid System

1) Model of 10KW Photovoltaic Sub-System

We have used 49W single solar panel as a reference. For making 10KW PV panel we have simulated using parallel combination of 20 same PV cells and 360 cell in series.

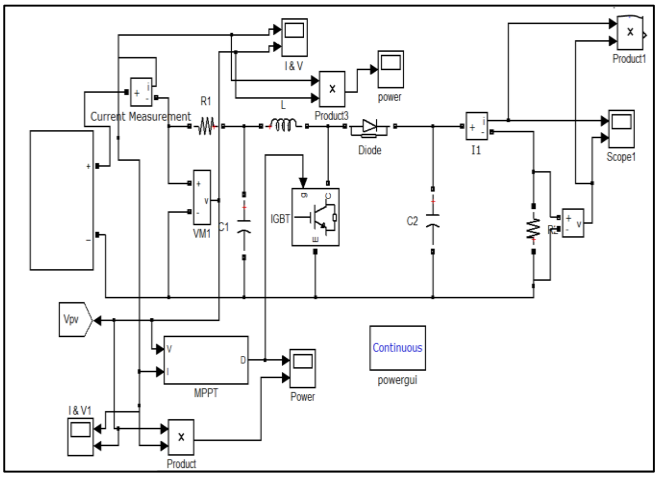

Fig. 9: 10kw PV Mathematical Model

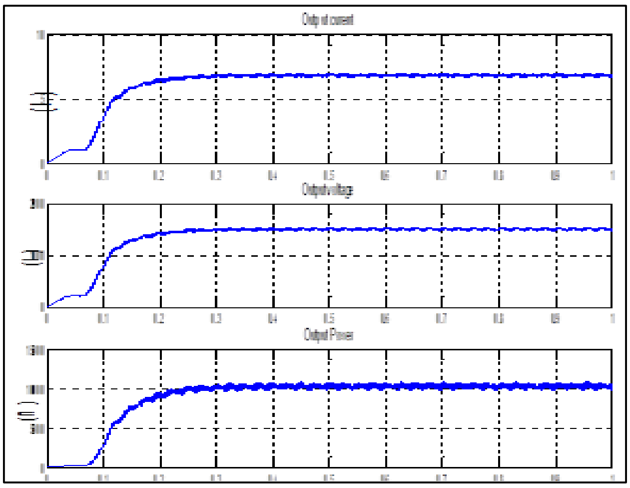

Fig. 10: Output power of 10kw PV system

2) Model of 6KW Wind Sub-System

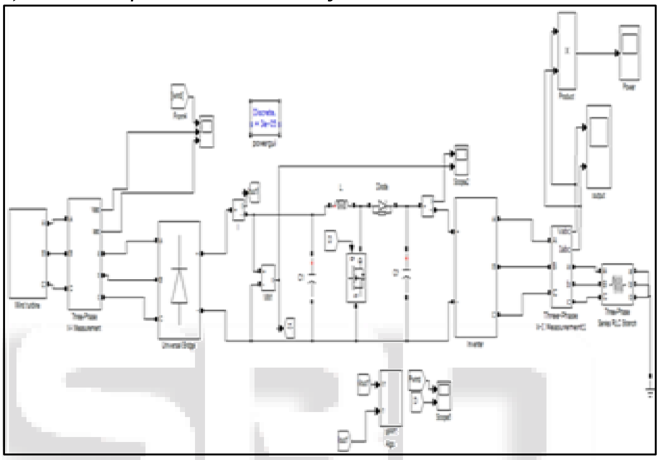

Fig. 11: 6kw wind system model

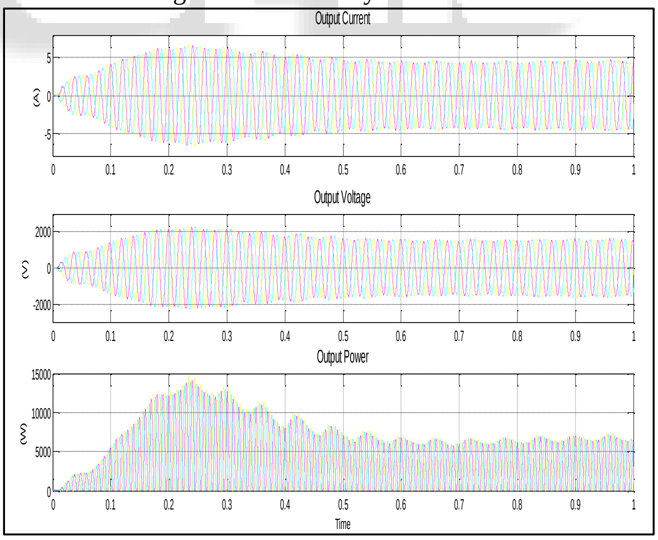

Fig. 12: Output power of 6kw wind system

3) Simulation Results of Hybrid System

Due to the uncertainty of the wind and solar energy 3 cases have taken in consideration.

- Case 1: For 0-3 seconds PV-wind both are available and providing require supply to load.
- Case 2: For 3-3.5 seconds only wind energy is available and which provides the supply to load.
- Case 3: After 3.5 seconds PV and Wind both are not available and load will drive through grid supply.

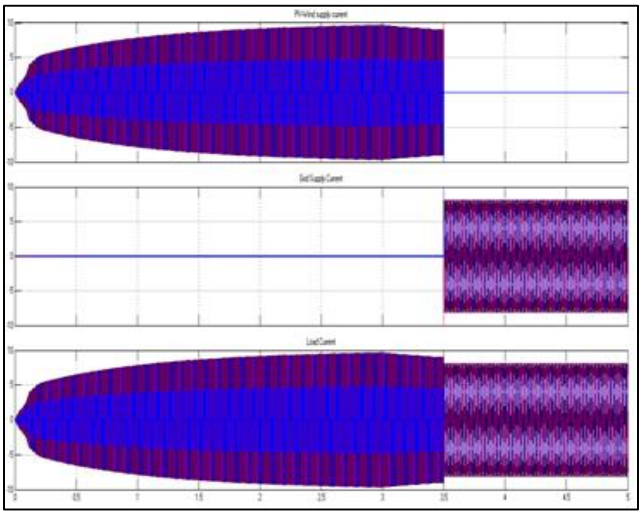

Fig. 13: Output of PV-Wind hybrid system

4) Simulated Parameter Results

Input	Rating	Output
PV system	10 KW	**PV Output:** Voltage =175 V Current = 54 A Power = 9450 W **PV Output with Boost converter** Voltage = 1470 V Current = 6.5 A Power = 9555 W
Wind System	6 KW	**Wind Turbine Output** Voltage =580V Current = 10 A Power = 5800 W **Wind Turbine output with Boost converter** Voltage =1480 V Current = 4 A Power = 5920W
Hybrid System PV- 10KW Wind-6KW	16KW	Voltage = 1500 V Current = 9A Power = 13500 W

Table 2: Output Parameters

III. CONCLUSION

A complete model simulating the proposed hybrid generation system including the wind and solar system is done using Matlab/Simulink. The MPPT control system has been developed for both the wind and solar energy sources. The simulation results showed satisfactory performance of the hybrid system. The future work will be to design the proposed hybrid system and implement in hardware.

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