A Novel Control Strategy for A Grid Connected PV System with Improved Power Quality using Bi-Directional DC-AC Converter

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Abstract- In recent days the power generation from Solar and wind has got the considerable importance because of its advantages. Both wind and solar generations completely relay on environmental conditions and are intermittent in nature so an energy storage system is used here to overcome this problem. The Hybrid generation is interconnected to the Grid using a Bi-Directional Dc-Ac converter. The Bi-directional converter acts as both inverter and rectifier depending on the conditions of controller. The irradiation given to the Soar panel is varying with respect to time. The output of the Solar panel is controlled using a Dc-Dc Boost converter with Incremental Conductance Maximum Power Point Tracking algorithm to obtain the maximum power. Wind Energy conversion system (WECS) is using a Permanent Magnet Synchronous Generator. The bi-directional dc-ac converter is using an “Opposed current half bridge type inverter” topology with PR controller and PWM. The Modeling and simulation of the Solar (photovoltaic) –wind hybrid system with battery energy storage is carried out using MATLAB/SIMULINK and the working of the system is analysed for different load patterns.

Keywords- wind power, solar power, battery, bi-directional dc-ac converter.

I. INTRODUCTION

The growth of power demand is one of the top most problems in the recent years. The power is normally generated by using non renewable energy sources like steam, oil, petroleum gases, nuclear, etc., But increasing the power production to meet the demand using these resources is not possible as the available raw material are not enough and investment cost become great issues. In order to overcome these issues, accumulating green energy will provide a better result. These energy systems are eco-friendly, but these have certain demerits in power generation and hence connecting them as hybrid systems will facilitate continuous power generation.

Wind and solar are the much used renewables as these are environmentally friendly, safe and cost-effective. However, there are some difficulties associated with combined utilization of solar and wind, e.g. intermittency of wind and instability of the grid[1]. For this purpose, advanced network of multiple renewable energy systems with storage units have been proposed [2],[3]. The intermittency of wind and solar generations can be compensated by using energy storage devices [4].

The energy storage using battery has the advantages like fast frequency regulation, load following, a damping services when DGs are integrated to grid. In the recent days Lithium-ion battery technology show many advantages compared to other like high power and energy density, high working cell voltage, self-discharge rate is low, and charge– discharge efficiency is high.

The bidirectional dc–ac converter in this paper is working as an interconnection between the Hybrid system, battery pack and the AC grid. This is responsible to meet the requirements of bidirectional power flow capability and to ensure desired power factor and regulate the DC-side power regulation.

Hybrid system and battery storage system are operating in parallel at DC link. PV system operates with INC MPPT method and controls boost converter to get the desired output voltage. The bidirectional dc–ac converter used here is of Opposed current half bridge architecture [5]. This is also called as Dual-Buck half-bridge inverter as it has two buck converter sandalsohas features of the conventional half-bridge inverter [6-9]. The converter has the advantages like there is no shoot-through issue as only one power switch is connected in eachphaseleg. This can also support reactive power flow and seamless energy transfer. The control scheme consists of the Proportional Resonant (PR) controller with Pulse Width Modulation (PWM). The system description is given in Section II. The hybrid system implementation and the details of the control architecture are given in Section III. The simulation results for the considered load patterns are presented and explained in Section IV. Conclusions and references are given in Section V.

II. SYSTEM DESCRIPTION

It consists of mainly five parts a) PV array; b) Wind Generating System c) Battery, d) Bi-directional DC-AC converter ande) Controller. The layout of the system is shown below in Fig.1

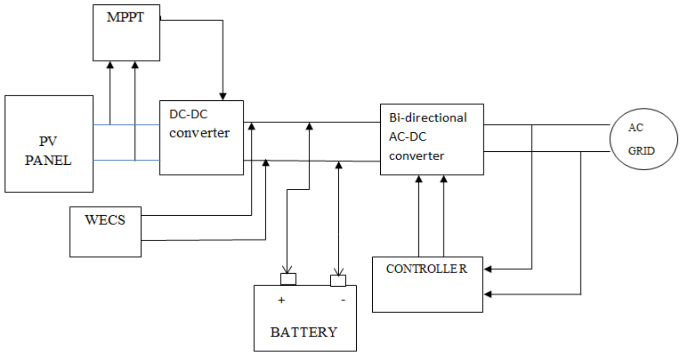

Fig.1: Schematic diagram of the system

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III. MODELING THE COMPONENTS OF HYBRID POWER SYSTEM

A. *Modeling of Photovoltaic system*

The equivalent PV cell consists of a diode, a series resistance, a shunt resistance and a current source.

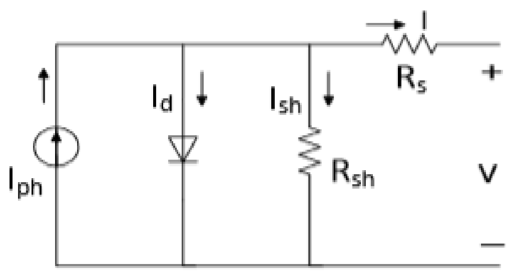

Fig.2: Equivalent circuit of PV cell

From the equivalent circuit the load current can be given as following equations:

The diode current Id is given as:

$$I_d = I_{rs}\left(e^{\frac{qV+qR_sI}{NKT}} - 1\right) \quad (1)$$

Current through shunt resistance is given as:

$$I_{sh} = \left(\frac{V+IR_s}{R_{sh}}\right) \quad (2)$$

The current I is given as:

$$I = I_{ph} - I_d - I_{sh} \quad (3)$$

BY substituting the values I is given as

$$I = I_{ph} - I_{rs}\left(e^{\left(\frac{qV+qR_sI}{NKT}\right)} - 1\right) - \left(\frac{V+IR_s}{R_{sh}}\right) \quad (4)$$

Where $I_{ph}$is photocurrent, I_d is the diode current, I_{sh} is current through shunt resistance, I is the output current, $R_{sh}$is the shunt resistance, $R_s$is series resistance and V is the cell voltage.

In this paper the PV panel is controlled by a DC-DC boost converter and this is controlled by using INC MPPT (as in fig 5) which will maintain duty ratio accordingly. The solar irradiation given to the PV panel is varied with time as shown in Fig.6.

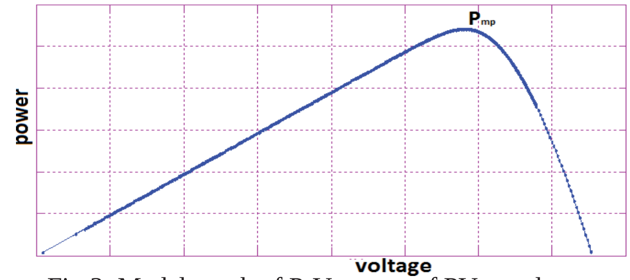

Fig.3: Model graph of P-V curves of PV panel.

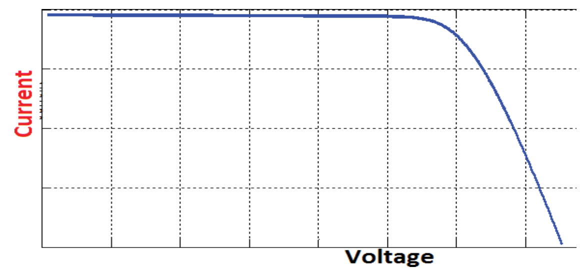

Fig.4: Model graph of I-V curves of PV panel.

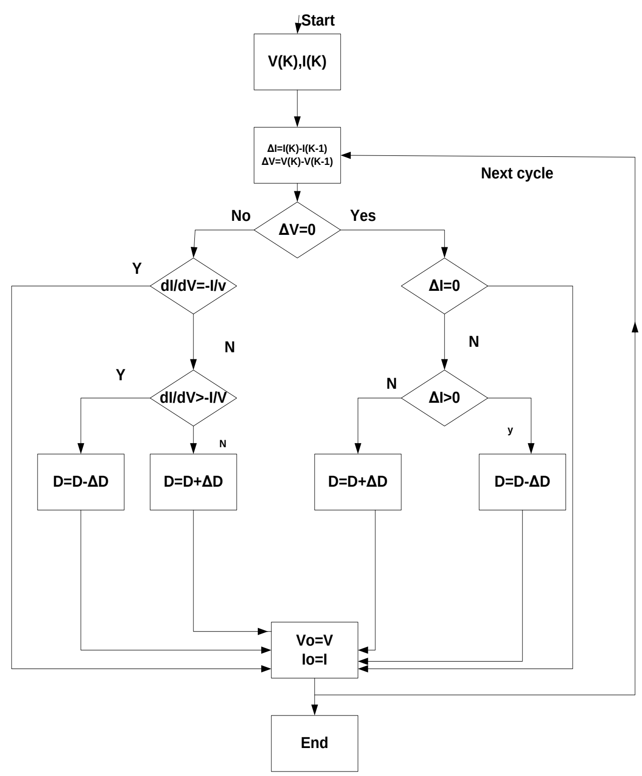

Fig.5: Algorithm for INC MPPT method.

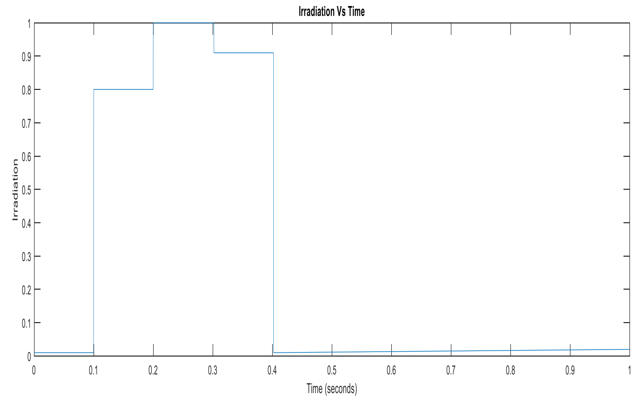

Fig.6: Variation of Solar Irradiance (W/m2) with Time (Sec)

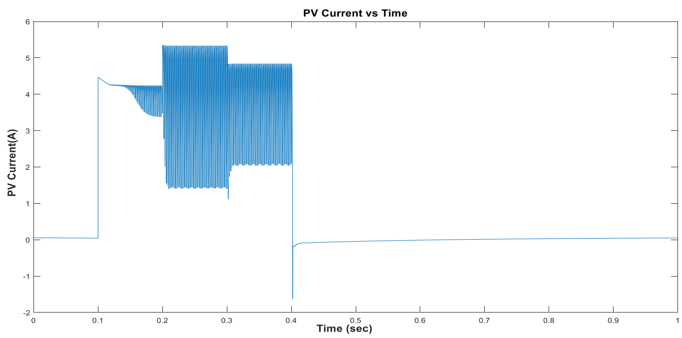

Fig.7: PV panel current(A) vs Time(Sec)

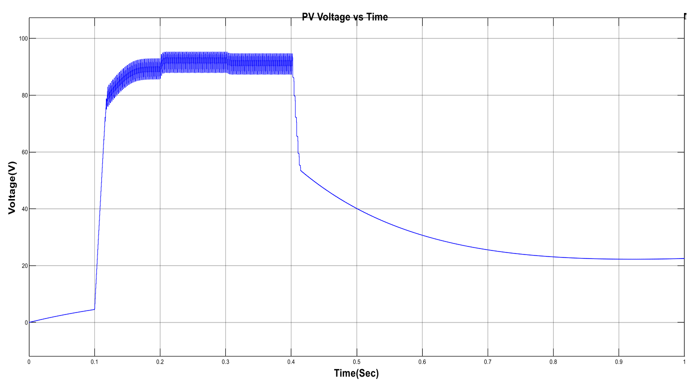

Fig.8: PV output Voltage (V) vsTime(Sec)

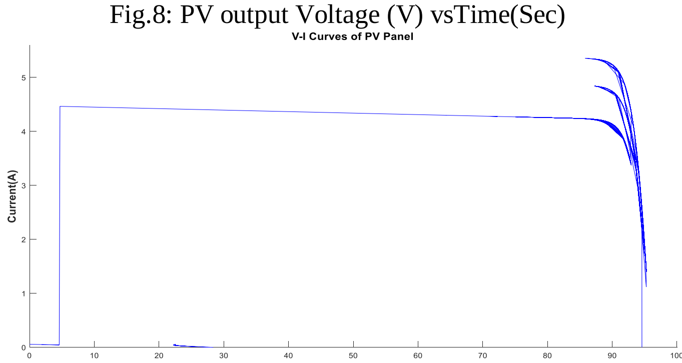

Fig.9: PV panel voltage Vs current

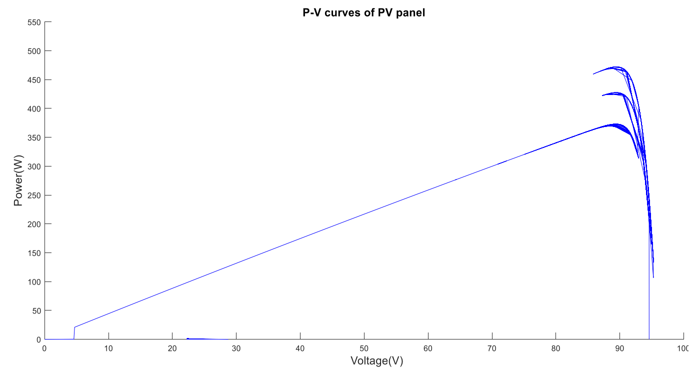

Fig.10: PV Panel Voltage Vs Power

B. *Wind turbine power system:*

In this paper vertical bladed wind turbine with Permanent Magnet synchronous Generator is used. Based on the aerodynamic characteristics, the power captured by the wind turbine can be given as

$$P = \frac{1}{2} C_p \rho A V^3 \quad (5)$$

Where C_p (⋋, β) is the wind turbine power coefficient, ρ is the air density, A is the area swept by of wind turbine blade, V is the wind speed. β is the blade pitch angle, R is the radius of turbine blade and ⋋ is the tip speed ratio given as:

$$\lambda = \omega * R / V \quad (6)$$

C. Bidirectional DC-AC converter

The fig.11 shows the model of dual buck converter based bidirectional converter. It has A1 & A2 which are power switches, D1& D2 are diodes, C1 & C2 capacitors, and L1&L2 are inductors. In the entire time for the appropriate functioning of structure the voltage through the both capacitor must be larger than the maximum AC voltage. Since it is two way tuning, it can act as AC-DC or DC-AC converter i.e, as a rectifier or inverter.

Operation

The operating modes of the bi-directional converter depend on the conduction states of the A1, A2, D1& D2.

a) AC-DC Conversion: During the positive half cycle of grid current (in fig.12a) leg A1 and D1 are operated. The current i_{ac} increases when A1 is ON as the voltage across inductor L1 is positiveasinFig.12(b).C1getsdischarged,and the energy ofboth C1 and C2 is transferred to the DC side. Current i_{ac}decreases when A1 is OFF and D1 is ON as the voltage $V_{L1}$is negative as in Fig12(c). Capacitor C2 is charged, and the energy of both C1 and C2 is transferredtotheDCsource.Inthe

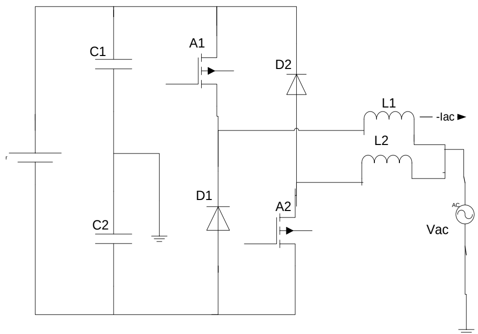

Fig.11: Bidirectional DC-AC converter with DBHBI type topology.

Fig.12(d). Capacitor C2 gets discharged. The energy of C1 & C2 is transferred to the DC source. The current i_{ac}decreases when D2 is ONas the voltage V_{L2} across inductor L2 is negative as shown in Fig. 12(e). The capacitor C1 gets charged. The energy of both C1 and C2 is transferred to the DC sources. So, in the entire positive half cycle C1 will be all the time discharging and but C2 is charged. In the negative half cycle, C1 is every time charged and C2 is discharged. Hence the charge equilibrium is preserved in the complete cycle.

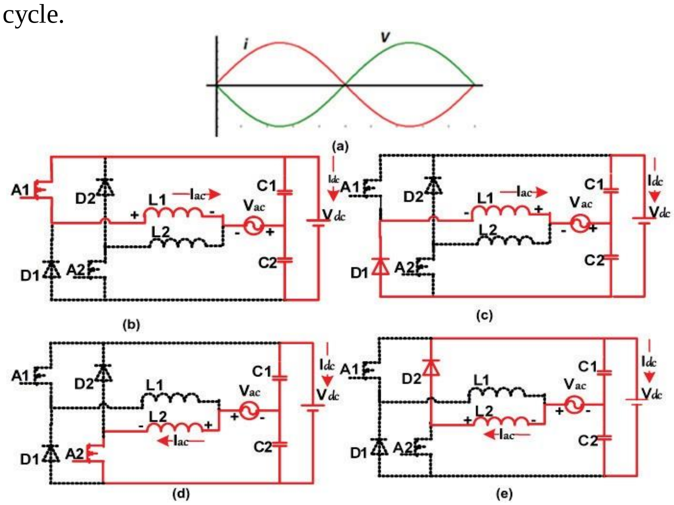

Fig.12. Operating under rectifier mode with pure active power transferring. (a) Conceptual Voltage and Current waveforms. (b) A1 isON.(c)D1isON.(d)A2isON.(e)D2isON.

b) DC-AC Conversion: The inverter modes of operation with pure active power transfer occur as shown in Figs 13(b), 13(c), 13(d) and 13(e). This mode analysis is also similar to that of rectifier mode. The current and voltage are in phase as shown in Fig 13(a). In this the energy from DC hybrid source istransferredtoACgrid. It can be concluded that C2 is always getting charged in the positive half cycle and C1 is always charged in the negative half cycle. Thus the charge balance is maintained in this way through the entirecycle.

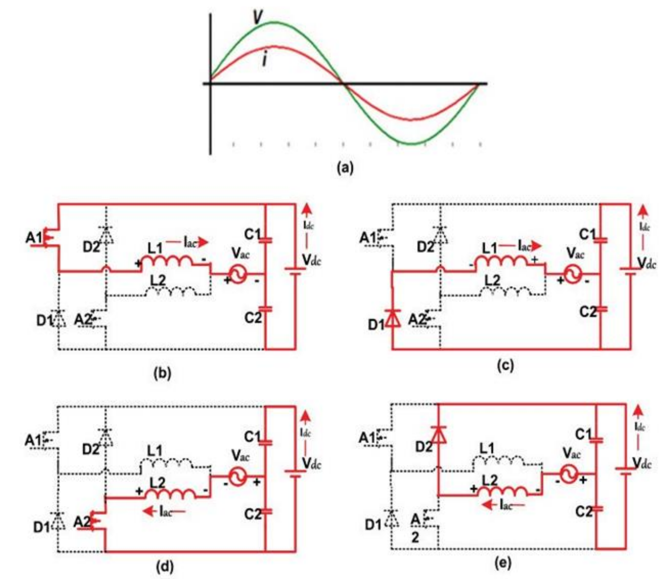

Fig.13. Operating under inverter mode with pure active powertransferring.(a)ConceptualVoltageandCurrentwaveforms .(b)A1is ON.(c)D1isON.(d)A2isON.(e) D2isON.

D. Proportional- Resonant controller with PWM:

TF of P-R regulator is

$$G_{PR}(S) = K_P + K_R \frac{2\omega_c(S)}{s^2+2\omega_c(S)+\omega_o{}^2} \qquad (7)$$

K_P- proportional gain of regulator
K_R–Resonant gain of regulator
ω_o-resonant occurrence of regulator is regularity of grid
ω_c- BW at Ac frequency of ω_o

By considering that D_{rA1}=$D_{iA2}$and D_{rA2}=D_{iA1}. By changing the current from $+i_{ac}$*to* $–i_{ac}$.the control signal to *DA1* which allows conduction in +ve current is used for *DA2* to conduct with -ve current. The –ve control signal given to *DA2* allows *DA1* to conduct with +ve current. So a single controller is enough to modulate current in both Rectifier & Inverter modes.The current referencei_{ref} is attained from the active power*Pref*and Reactive power*Qref*. The *Pref&Qref* powers are used for computing of Im and Ө.

The equations are given by:

$$I_m = \frac{(P_{ref}+Q_{ref})}{\frac{V_{pk}}{2}} \qquad (8)$$

$$\theta = \tan^{-1}(\frac{Q_{ref}}{P_{ref}}) \qquad (9)$$

$$Q_{ref} = 0$$

Hv(s) is voltage sensor gain. This compensates feedback voltage V_{AC} from grid. Phase Locked Loop gives voltage angle (ωt) at grid. By adding θ to ωt a reference current is generated. This compares introduced current *iac*. Based on this error is generated by P-R controller and pulses are generated by PWM to A1 & A2.

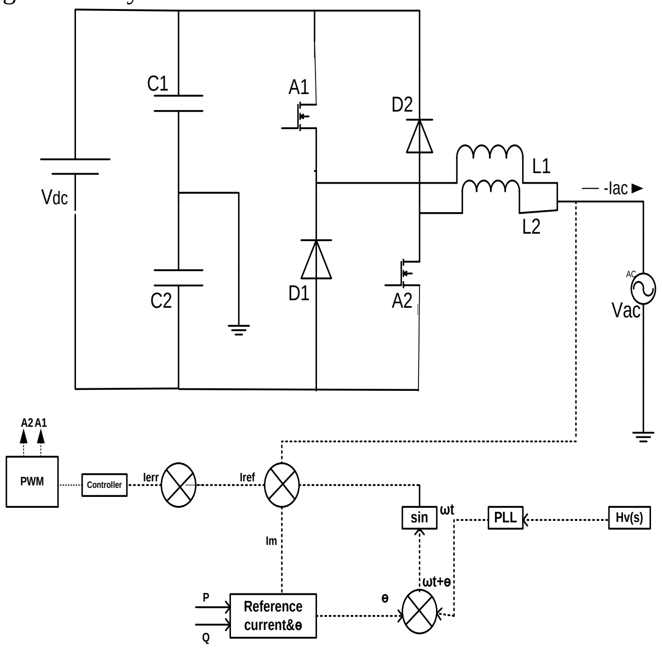

Fig.15: Controller circuit for generating pulses to A1&A2

IV. SIMULATION RESULTS

The hybrid system with bi-directional converter connected to grid system simulation diagram is shown in figure15.

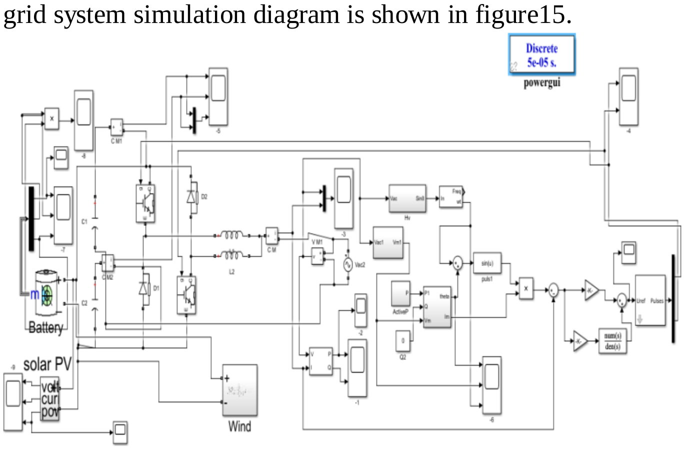

Fig.15: Simulink model of the system

The operation of the hybrid system connected to the grid is analysed by considering a load curve. The working of bi-directional converter is carried out by different loads. Each load is considered for 0.1sec duration of time. The output patterns are shown in figures.

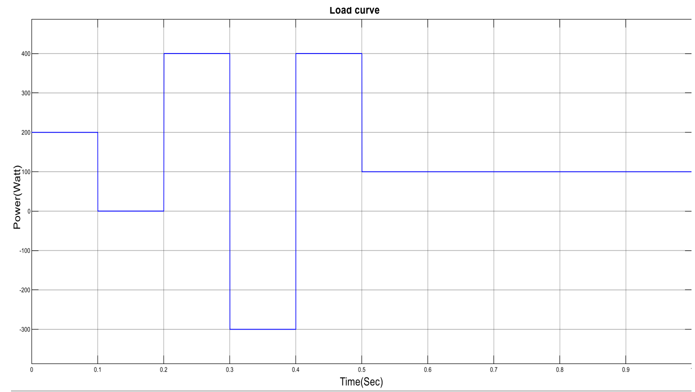

Fig.16: Considered Load Curve

Modes of operation:

*Case1(0to0.1sec):*Here, the load demandonthegridis 200wasshowninFig.16.The output from the hybrid system is zeroassolarirradianceiszero. So, this power demand is satisfied by Battery. The bi-directional converter will act as inverter. The SOC of the battery is decreasing.

Case2 (0.1 to 0.2sec): Here, the load demand on the grid is zero as shown in Fig. 16. The PV system generates 380W as the Solar irradiance is around 0.8 W/m^2 shown in Fig. 16. The generation from wind is 50W.This entire 430W is recharged to battery. In this duration the converter action is absent. The SOC of battery is increasing.

Case3 (0.2 to 0.3 Sec): Here, the load demand on grid is at its maximum value. The PV system generates 470W as the solar irradiation is high. The generation from wind is 50W. So, 400W is supplied to load and remaining 120W is supplied to battery. Bidirectional converter will now act as an inverter. The SOC of battery is increasing.

Case4 (0.3 to 0.4 Sec): Here, the load demand on the grid is less than the base load. During this period the cost of electricity is low so, power can be consumed from the Grid. The power generation from the PV System is 430W and wind is 150W.So, this entire power is charged to battery. Bidirectional converter is acting as a rectifier; the grid voltage and current are in 180^0 phase difference with each other as shown in Fig. 21.The SOC of battery increases.

Case5 (0.4 to 0.5 Sec): Here, the load demand on the grid is maximum. The PV system generation is zero as solar irradiation is zero and wind generation is 150W. So, the wind and battery systems combinedly satisfy the load demand. The SOC of battery is decreasing.

Case6 (0.5 to 0.6 Sec): Here, the load demand on the grid is 100W. The PV system generation is zero and wind generation is 150W. So, the load demand is satisfied by wind system and the remaining power is recharged to battery. The SOC of battery is increasing.

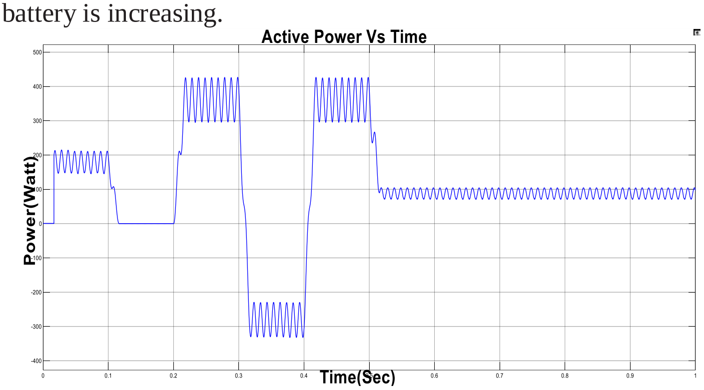

Fig.17: Active power transferring to grid Vs time

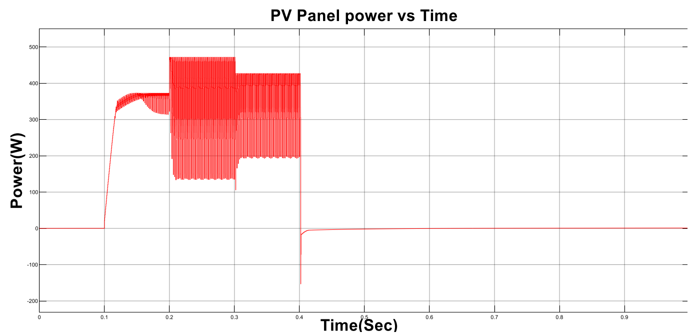

Fig.18: Power generated by PV panel Vs time

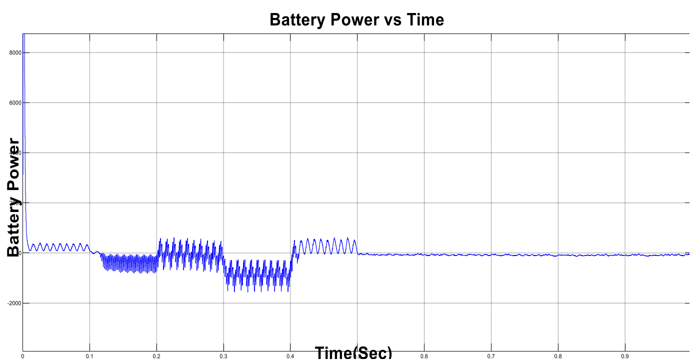

Fig.19: Battery Power Vs time

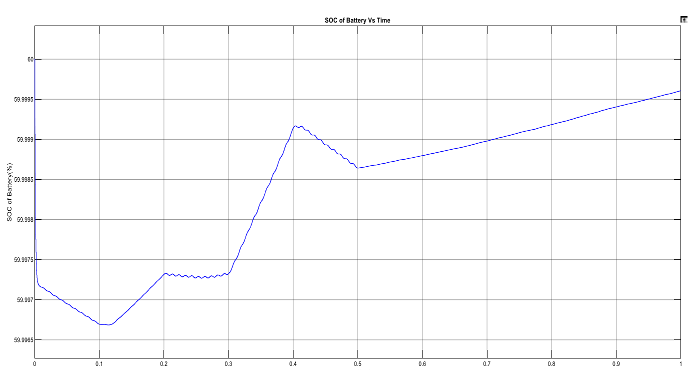

Fig.20: State of charge of battery Vs time

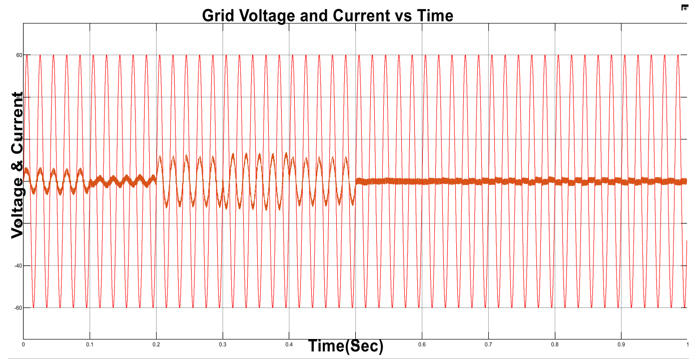

Fig.21: Grid voltage and sending current Vs time

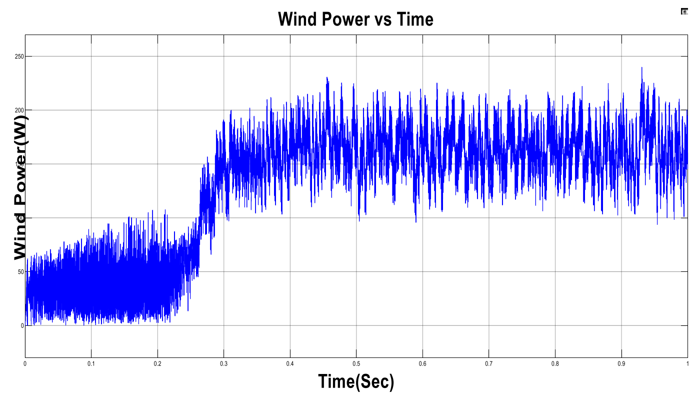

Fig.22: Power generated by wind system Vs time

V. CONCLUSION

In this paper, Hybrid system with solar, wind and battery connected to the grid. The working of a Bi-directional AC-DC converted is discussed by considering Load Curve. If the power is flowing from Ac-Dc then it is acting as Rectifier. If the power is flowing from Dc-Ac it is acting as Inverter. For various combinations of power generated by the PV panel, available grid power, SOC of battery and load demand, the operation of the converter is analyzed in detail. With this it can be concluded that the algorithm works fine for varying load and power availability conditions.

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