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A New Topology of Multiple-Input Converter with Embedded Controller Based Power Management

S. Saravanan, A. Sureshkumar, S. Thangavel

***Abstract*— This paper presents a new power conditioner topology that integrates multiple renewable energy sources to make best use of their operating characteristics and obtain better reliability than that could be obtained by single renewable energy based power supply. The proposed power conditioner uses three sources, one storage device and isolated load outputs. The proposed multiple-input converter uses intelligent closed loop control for efficient power control. The proposed power conditioner uses very limited number of switches and promises significant savings in component count and reduced losses in renewable energy power-harvesting system by reducing the on-state conduction loss and switching loss in comparison to topology like H-Bridge converters. The power conditioner houses a battery bank which is suitably connected by the controller to sink or source the input power based on the load requirement..**

***Index Terms*— Fuel cell, Multiple - Input Converter, PV panel, Power Conditioner, Renewable Energy Integration, Wind Turbine Generator.**

I. INTRODUCTION

The world is facing severe energy crisis and it is expected to increase in the forthcoming years. Worldwide, the power generation is majorly done using conventional energy sources and its energy reserve is very much limited, expected to disappear after few decades. The shortage of conventional energy resources (e.g. coal, oil, uranium, etc.) and the necessity to reduce the environmental impact (e.g. emission of CO_2) have lead to significant interest in renewable energy resources and their efficient utilization. Hence there is a renewed interest in the power generating technologies based on renewable energy resources as it is everlasting and eco-Friendly (as it gives out extremely less magnitude of greenhouse gases). Therefore photovoltaic (PV) power and wind power generation are the most promising ways for future power generation. However, the photovoltaic panel can only generate power when there is sunshine and wind turbine generator can generate power.

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When the wind speed is at least 5 to 7 m/sec, which is the cut-in speed of large wind power generators. Also the Fuel cell have received great deal of attention recently, because of its property of zero emission of greenhouse gasses and high power density, also have unique features such as high efficiency, diversity of fuels and reusability of the exhaust heat. But the output voltage from a fuel cell stack is usually low, and the fuel cells have very slow response due to the natural electrochemical reactions required for the balance of enthalpy.

In General, electrical systems are supplied by single energy source, which may be PV panel, a wind turbine generator and mostly utility, etc. where the reliability in continuity of supply is less. In certain special cases when the loads are critical, it is powered by two sources, such as uninterruptable power supplies. Here an effort has been made to integrate three renewable energy sources (solar energy, wind energy and fuel cell stack) that can maintain an interruption less supply of power for the load which can be mainly used for the electrification of remote military installations and rural electrification. An ideal multiple-input power supply could accommodate a variety of sources and combine their advantage automatically, such that the inputs are interchangeable [1]-[4],[6]-[9]. The multiple-input converter with fly back converter topology has been proposed to combine different types of clean energy to obtain the regulated DC output and AC output voltage as shown in figure 1.

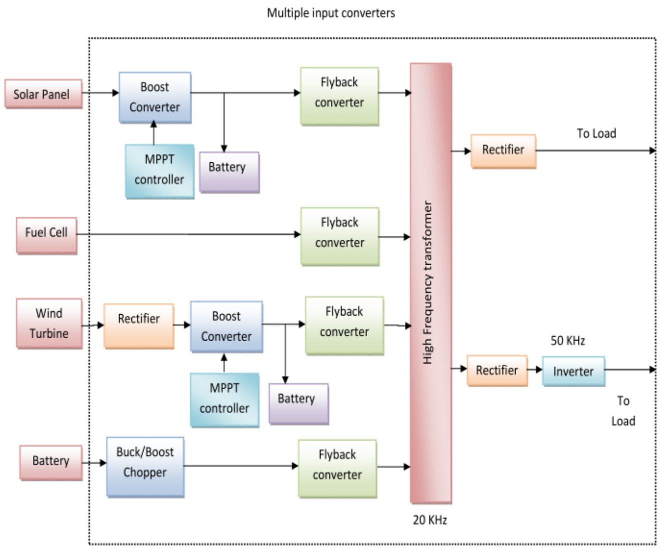

Figure 1. Schematic of proposed multiple-Input converter

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A. Magnetic Flux Additivity

The concept of energy integration is done by magnetic flux additivity by adding up the magnetic flux produced by the sources in the core of the coupling transformer[5], instead of combining the produced DC or AC in the electric form which alleviates the need for controllers to maintain the bus voltage constant in case of DC based coupling and voltage along with frequency at the point of common coupling (PCC) in AC. In the multiple-input converter, high frequency AC voltages are generated from the DC sources, and the corresponding flux produced is connected in series to form a composite magnetic circuit to sum up all the powers in the primary windings.

The concept of flux additivity is better explained with the figure 2. The primary of the transformer is connected with four sources through a single switch inverter. Let Is1, Is2, Is3 and Is4 be the primary currents. The total MMF produced is given by the expression

$$MMF = N_1 I_{S1} + N_2 I_{S2} + N_3 I_{S3} + N_4 I_{S4}$$
$$MMF = H_1 L_m + H_2 L_m + H_3 L_m + H_4 L_m \quad (1)$$

as H = NI/L Where N1, N2, N3, N4 are the number of turns of the primary winding H1, H2, H3 and H4 were the magnetic field intensity produced by the primary currents and Lm the length of the core.

From the basics of composite magnetic circuit, the total MMF can be written as the MMF is the product of flux and reluctance.

$$MMF = (\varphi_1 + \varphi_2 + \varphi_3 + \varphi_4) \times \left| \frac{L_m}{A\mu_o \mu_r} \right| \quad (2)$$

The power conditioner can be operated as a standalone power supply or the grid interactive power supply with the utility as one of the input to the converter, where the converter is suitably operated by a suitable intelligent controller to achieve the maximum usage of green energy rather than grid energy. For the stand-alone system, if the demand is greater than the sum of generation the excess power requirement will be met with the battery. When the sum of generation is in excess than load demand, then the excess power shall be stored in battery for further usage. The stand-alone system can also be designed with backup generators. In the grid connected system the excess demand required is met with the grid supply.

II. SIMULATION

The simulation of the multiple-input converter and the modeling of the sources such as solar panel, wind turbine are done in is done in Simulink /MATLAB.

A. Solar Panel

Solar photovoltaic (PV) energy is one of the most important resource because it is free, abundant, pollution free and available all over the world. The daily average solar energy incident over India varies from 4 -6 kWh per square meter per day depending upon the location which can be used to generate power to meet the growing demand.

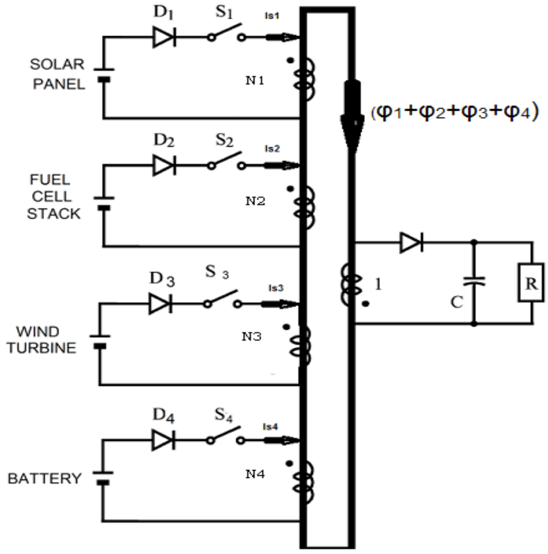

Figure 2. Concept of Magnetic Flux Additivity

A Single diode model based PV module [5]-[7] with varying insolation and temperature developed in Simulink is shown in figure.3.

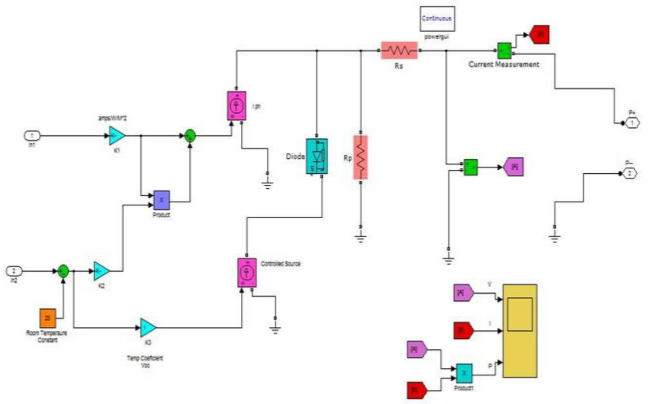

Figure 3. Simulink model of PV cell (with varying insolation and temperature)

Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is low (in general less than 17%, especially under low irradiation conditions), and the amount of electric power generated by solar arrays changes continuously because of variations in the insolation due to unpredictable shadows cast by clouds, birds, trees, etc.

Moreover, the I-V characteristic of a PV array is nonlinear and varies with irradiation and temperature. The insolation change affects the photon generated current and has very little effect on the open circuit voltage. Whereas the temperature variation affects the open circuit voltage and the short circuit current varies very marginally. In general, there is a unique point on the I-V or V-P curve, called the Maximum Power Point (MPP), at which the entire PV system (array, converter, etc.,) operates with maximum efficiency and produces its maximum output power. The power-voltage characteristics of a photovoltaic module at different irradiance levels are shown in figure 4.

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The location of the MPP is not known, but can be located, either through calculation models or by search algorithms. However, by incorporating maximum power point tracking (MPPT) algorithms[8], the photovoltaic system's power.

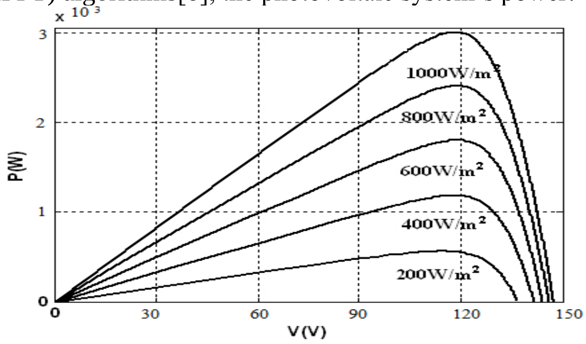

Figure 4. Power-voltage characteristics of Photovoltaic module at different irradiance levels

transfer efficiency and reliability can be improved significantly as it can continuously maintain the operating point of the solar panel at the MPP pertaining to that irradiation and temperature. The solar radiation data of a typical sunny day shown in figure 5 is collected from solar centre, KEC, Erode, Tamilnadu, India and the data points

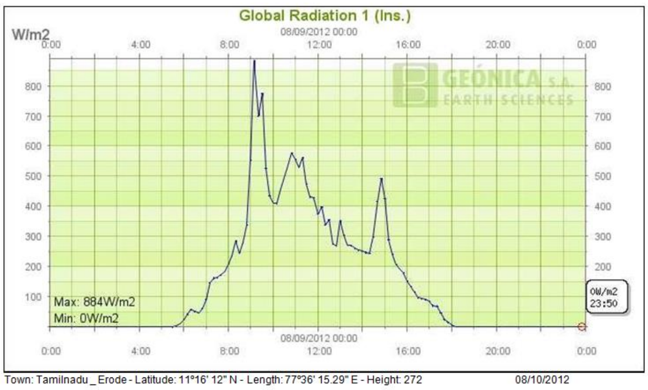

Figure 5. Variation of solar insolation in a typical sunny day

extracted from the same is fed as the insolation data input to the developed PV panel[5]-[7] along with the measured panel temperature. The voltage, current and power output of the PV panel is shown in the figure.6.

B. *VSS-INC MPPT Technique*

Maximum Power Point Tracking (MPPT) system is embedded for solar and Wind turbine generator to have an index of instantaneous power generated by the sources which is required by the power management controller. Of the various MPPT techniques[8]-[9] Variable Step-Size Incremental Conductance (VSS-INC) method[10] is employed because of improved dynamic response, accuracy and enhanced suitability for practical operating conditions due to a wider operating range. Flowchart of the VSS-INC MPPT technique is shown in the figure 7. And the power output of the MPPT converter is shown in the figure 8.

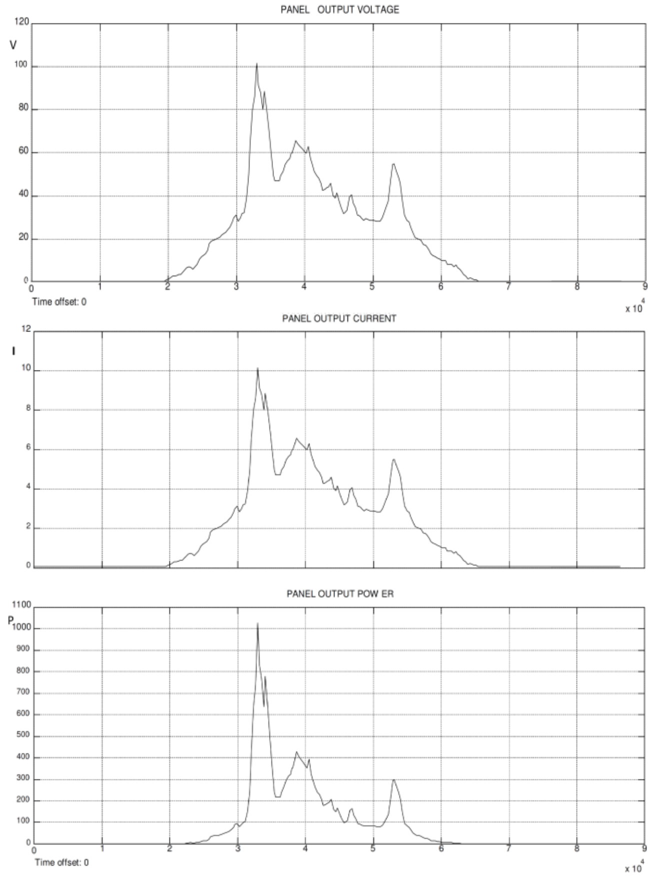

Figure 6. Output voltage, current and power of simulated solar panel

C. *Wind Turbine*

The wind turbine generator[11]-[17] using asynchronous generator is developed in Simulink is shown in figure 9.

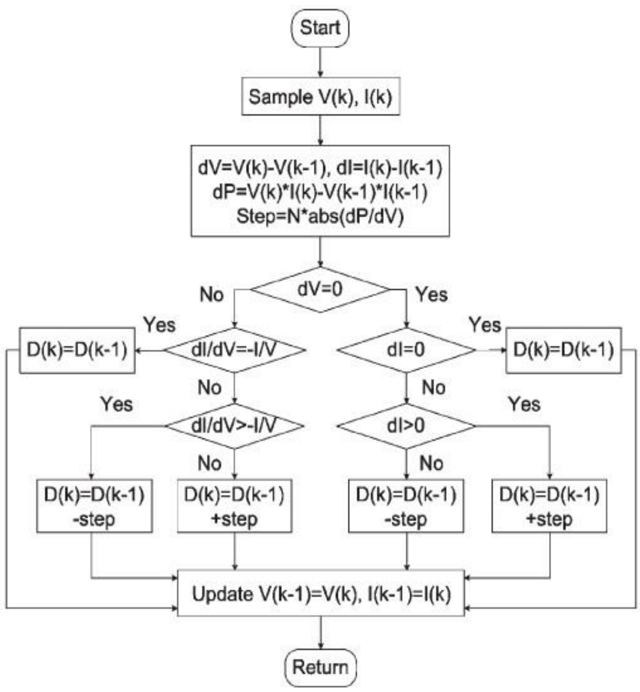

Figure 7. Flowchart of VSS-INC MPPT Technique.

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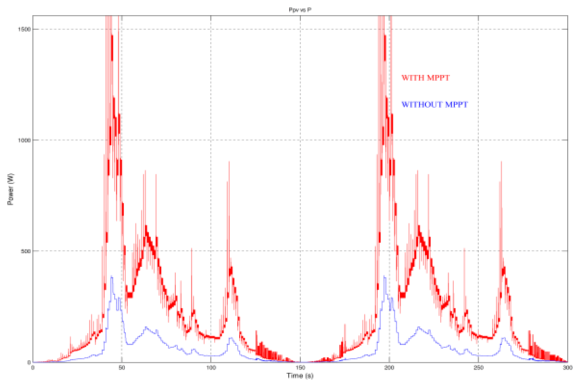

Figure 8. Output of MPPT Converter.

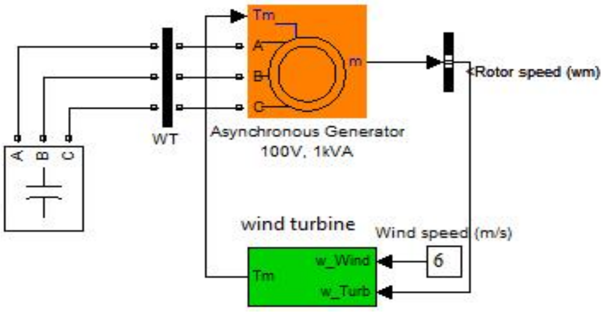

Figure 9. Wind Turbine Generator Model

The Wind Turbine block developed based on mathematical equations is shown in figure 10. The wind turbine output is made to drive the asynchronous generator and the rotor is kept slightly above the synchronous speed to deliver active power. In practical systems, the systems with cut-in speed as low as 2.8m/s are commercially available in markets which are very much viable for low power stand-alone operation.

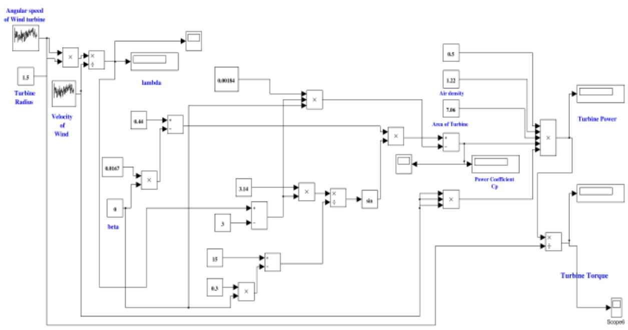

Figure 10. Model of Wind Turbine

The torque of the wind turbine is estimated from the basic electromechanical equation i.e., the torque is power upon generator speed as in (6).

$$T_m = \frac{Cp(\lambda,\beta)\rho A V^3}{\omega_m} \qquad (6)$$

Where 'ω_m' is the generator speed. As the system is a standalone system, a capacitor bank is connected at the output of the asynchronous generator in order to supply the reactive power required by the asynchronous generator for generation of electrical energy. The wind speed data for 24 hours of a day at KEC, Perundurai, TN, India and the simulated torque output of the wind turbine for the wind data input is given in the figure 11&12 respectively.

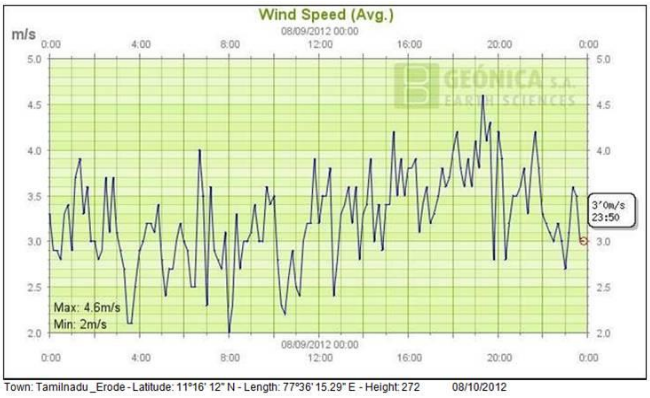

Figure 11. Wind speed data of a typical day at KEC, Perundurai, TN, India

The voltage, current and power output of wind turbine generator is shown in figure 13.

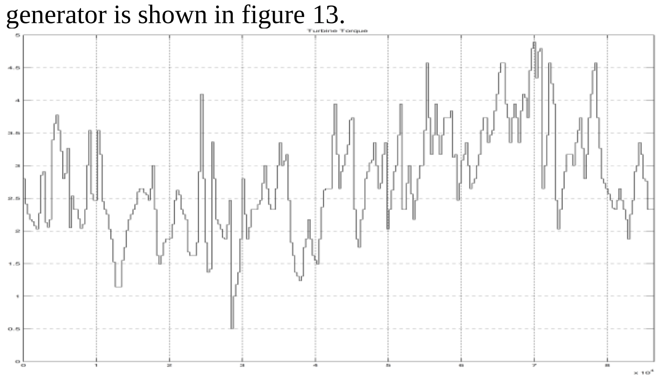

Figure 12.Torque output of simulated wind turbine

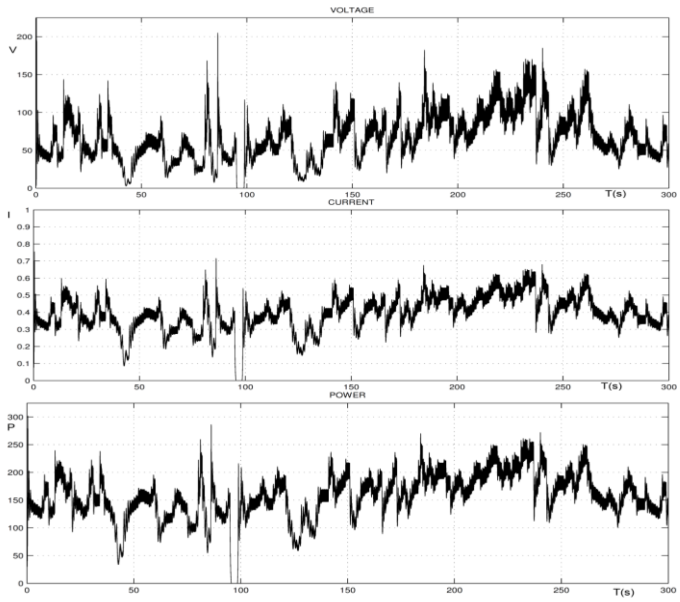

Figure 13. Voltage, current and power output of WTG

D. Fuel Cell

Fuel cells produce direct current electricity using an electromechanical process similar to battery. As a result, combustion and the associated environmental side effects are avoided. In order to have the output voltage near 120V, three fuel cell stacks, with the voltage rating of 24V each with the voltage profile of 42V at 0Ampere and 35V at 1Ampere, are connected in series as shown in figure 14.

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III. BATTERY

Battery is used as the external leveling agent to sink / source the power based on the instantaneous load condition. The lead acid batteries are preferred for

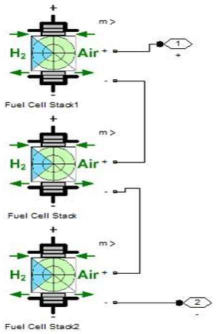

Figure 14. Fuel Cell Stack

standalone applications as the maintenance and the initial costs are less. The rate of charging and the discharging of the battery are done based on the standard specifications of the battery handbook. The lead acid battery handbook illustrates that the charging current of the battery should be less than 0.1CB. Where 'CB' is capacity of battery. For a 150Ah battery the charging current (7) should not exceed,

$$I_{BattCh} = 0.1 \times 150 = 15A \tag{7}$$

Also according to the battery handbook, the discharge current in tens of the seconds should not exceed (0.5 – 0.7) CB and the nominal discharge is 0.1CB. Here (CB/5) is selected as the maximum discharge current. The capacity of the battery needed for delivering the power of 1.5 kW even at minimum battery voltage of 99V and the efficiency of the boost converter being 95% ($\eta_{Boost-Conv} = 0.95$) shall be calculated as in (8)

$$C_B = \frac{P_o}{0.1 \times \eta_{Boost-Conv} \times V_{Bat-min}} \tag{8}$$

$$C_B = \frac{1500}{0.1 \times 0.95 \times 99}$$

$$C_B = 159.489\text{Ah}$$

Hence a 150 Ah battery is selected.

The maximum battery discharge current (9) at the output of the boost converter to deliver a power of 1.5kW at the battery voltage of V Bat -min = 99V is

$$I_{BattDch} = \frac{P_o}{\eta_{Boost-Conv} \times V_{Bat-min}} \tag{9}$$

$$I_{BattDch} = \frac{1500}{0.95 \times 99}$$

$$= 15.94\text{A}$$

A. *Slip-In and Slip- Out*

The slip-in and slip-out of the battery from conduction is an imperative function which is performed by the power management controller. The point of slip-in and slip-out of battery from conduction is generally done based on the instantaneous load demand and power available in the sources. The battery is allowed to discharge only when the state of charge (SOC) of battery is set at 40% as DoD to about 70 – 80% of its capacity shall damage the battery even if it is a deep cycle battery. In this paper online estimation of SOC is done by measuring the terminal voltage and current of the battery.

IV. FLYBACK CONVERTER

The renewable energy sources such as photovoltaic panel, wind turbine, fuel cell are connected to the multi-winding transformer through a fly back converter which uses only one switch for inverter operation, so as to reduce the component count in the power conditioning circuit and highly suitable for low power applications.

The schematic of a fly back converter and the nature of output voltage are shown in the figure 15(a)&15(b). When the switch is ON the primary of the transformer is directly connected to the input voltage source. This results in an increase of magnetic flux in the transformer. The voltage across the secondary winding is negative, so the diode is reverse-biased (i.e., blocked). The output filter capacitor supplies energy to the load. Simulink model of overall system is shown in figure 16.

When switch is ON,

$$I_{m(T\_on)} = I_{mo} + \left(V_s / L \right) T_{on} \tag{10}$$

When switch is OFF, the energy stored in the transformer is transferred to the output of the converter.

$$I_{m(T\_off)} = I_{m1} - \left(\frac{N_1}{N_2} \right) V_0 \left((T - T_{on}) / L \right) \tag{11}$$

Where 'K' is the transformer ratio. The operation of storing energy in the transformer before transferring to the output of the converter allows the topology to easily generate multiple outputs with little additional circuitry, although the output voltages have to be able to match each other through the turns ratio.

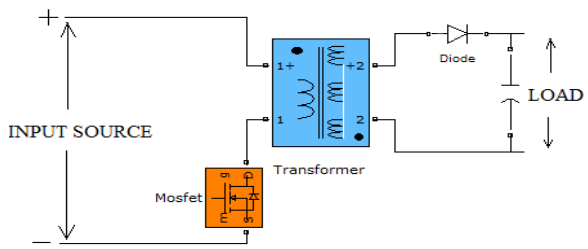

Figure 15 (a). Fly back Converter

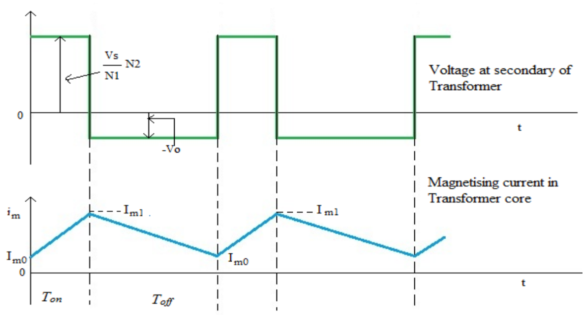

Figure 15(b). Voltage and Current Waveform.

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A. *Power Management Controller*

The embedded controller based power management control is developed in the proposed system to control the power flow from sources to load. The inputs to the controller are power from solar panel, wind turbine generator (WTG), fuel cell and SOC of the battery and the outputs are the control pulses that connect and disconnect the power sources which is shown in the figure 17. The decision on inclusion of the sources for delivering the power to the load is done based on the instantaneous power available in the solar panel, WTG, fuel cell and SOC of the battery and follows the priority order given below.

- Solar and wind power are given higher priority for consumption as it is freely available.
- When the load demand (LD) is less than the sum of the power generated by solar and wind, it supplies load and the excess power is used to charge the battery.

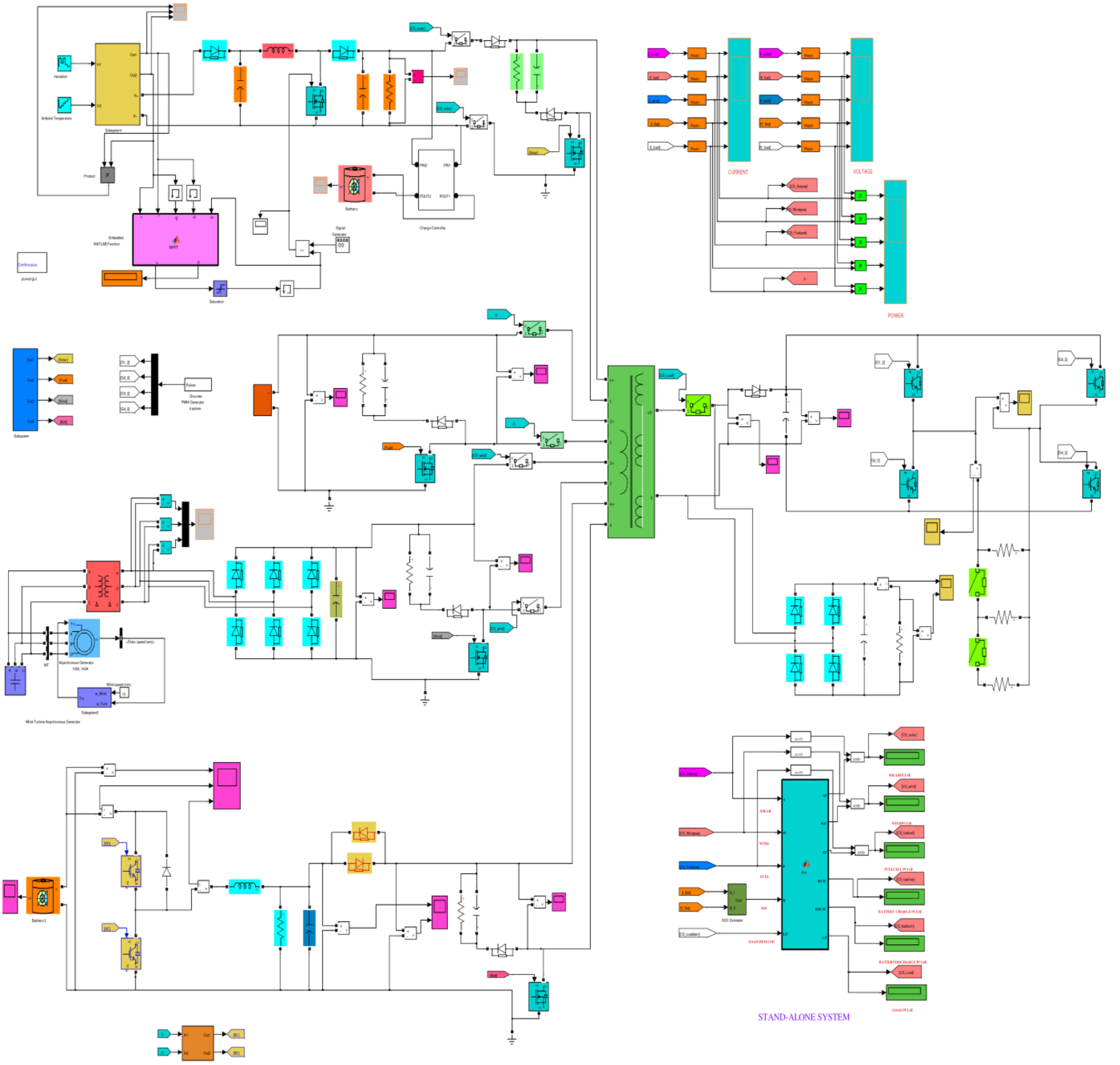

Figure 16. Overall Simulation Diagram

- If the load demand is more the sum of power generated by solar and wind the battery is made to discharge, if the SOC of the battery is more than 40%
- If the load demand is further more that if it could not be met by the above sources, fuel cell is made to discharge along with the others to meet the load demand.
- When the LD is very much higher than the power delivered by the sources and the SOC being less, the controller disconnects the load and charges the battery with the available power.
- Excess power in any mode is used to charge the battery.

The flowchart representation of control logic is shown in the figure 18. Based on the input power and LD the embedded controller operates in any of the 25 modes possible to meet the LD which is shown in the figure 19.

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B. Simulation Results

The DC output voltage of the simulated solar panel shown in the figure 20. Also the AC output voltage of the asynchronous generator is shown in figure 21. As the input

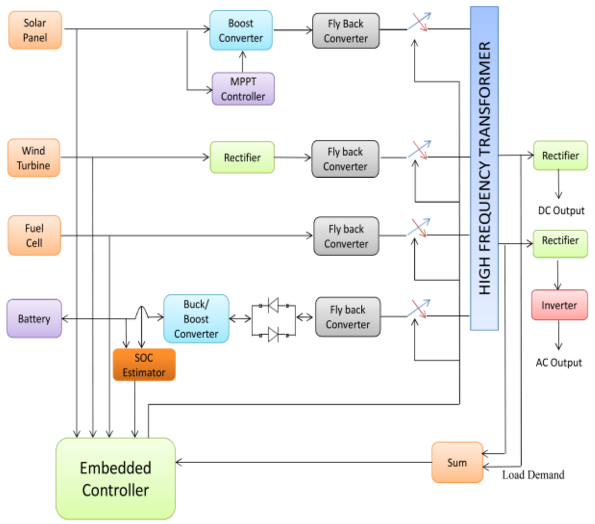

Figure 17. Control signal flow

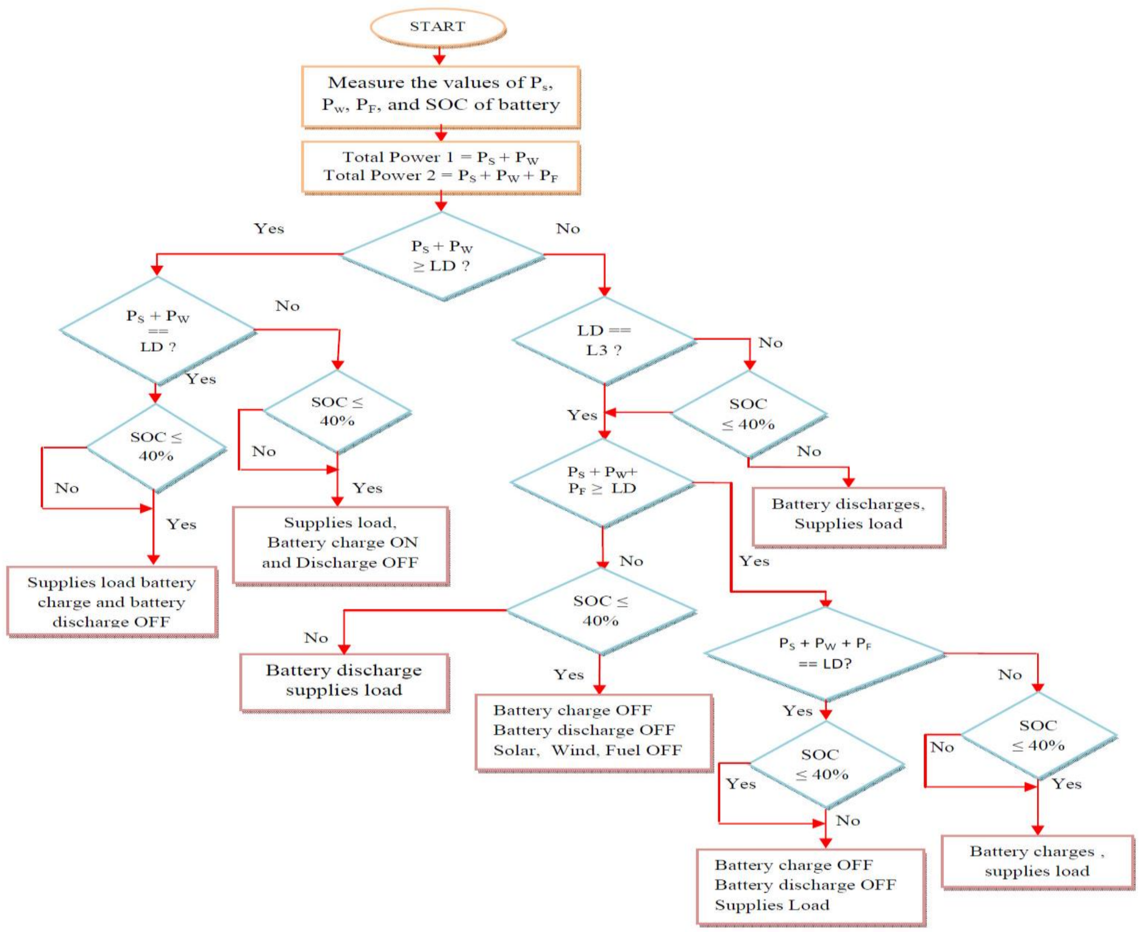

Figure 18. Flowchart of control logic

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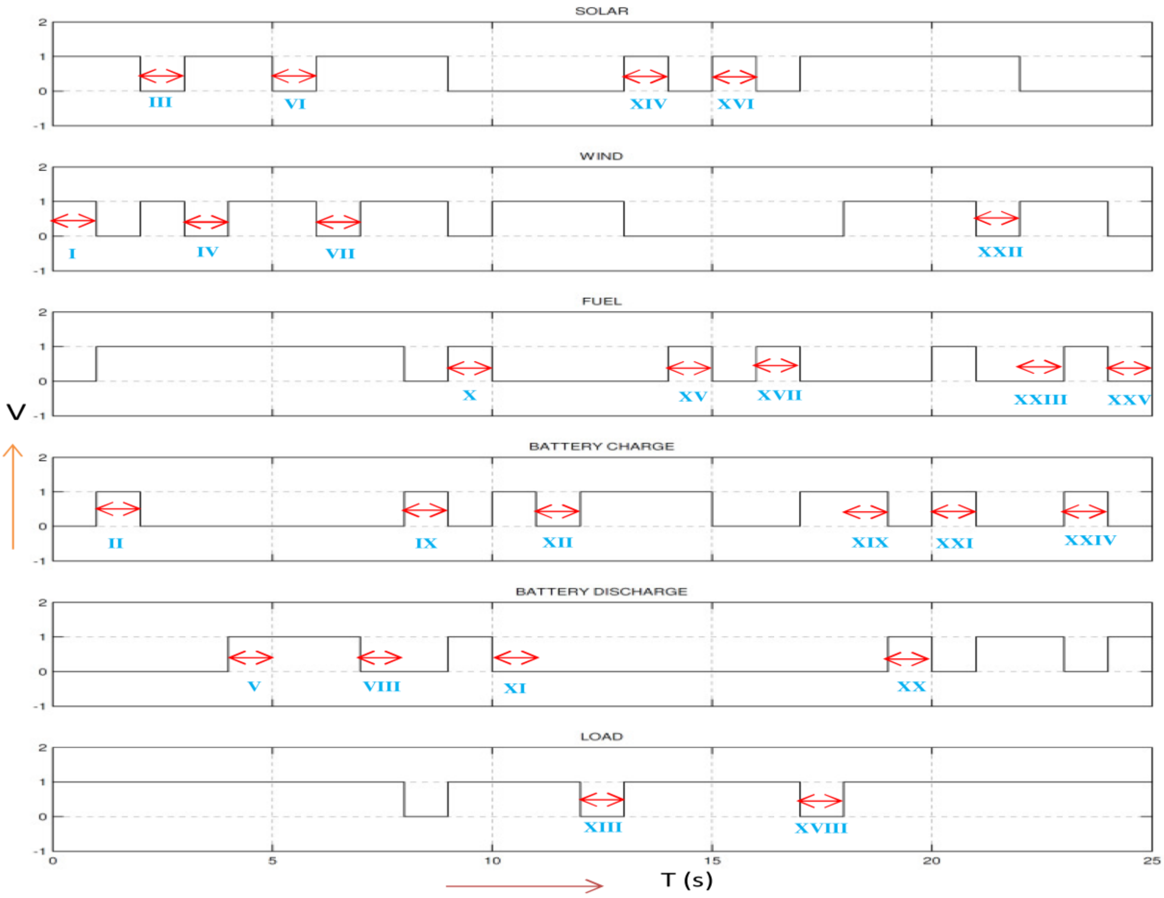

Figure 19. Control pulses developed by Embedded controller (25 modes)

to the multiple-input converter is a high frequency AC, the output voltage of the asynchronous generator which is at varying frequency or at power frequency is rectified and applied as input to the inverter (shown in figure 22) where it is converted to high frequency AC of 50 kHz frequency shown in figure 23.

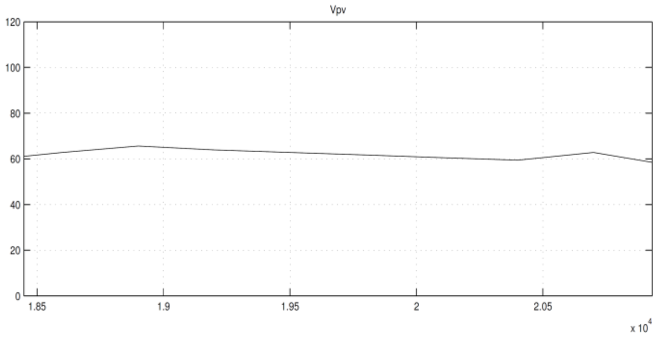

Figure 20. Output of solar panel

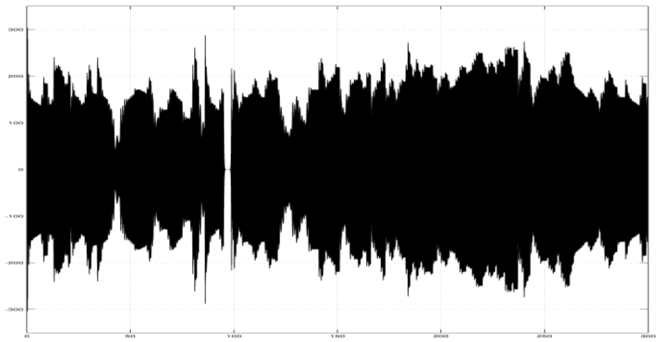

Figure 21. Output of Asynchronous Generator

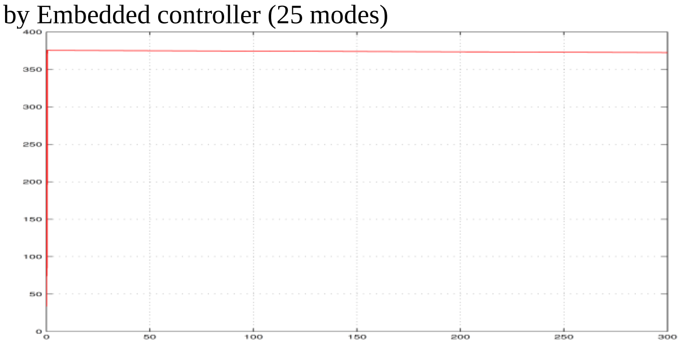

Figure 22. Rectified Output of Asynchronous Generator

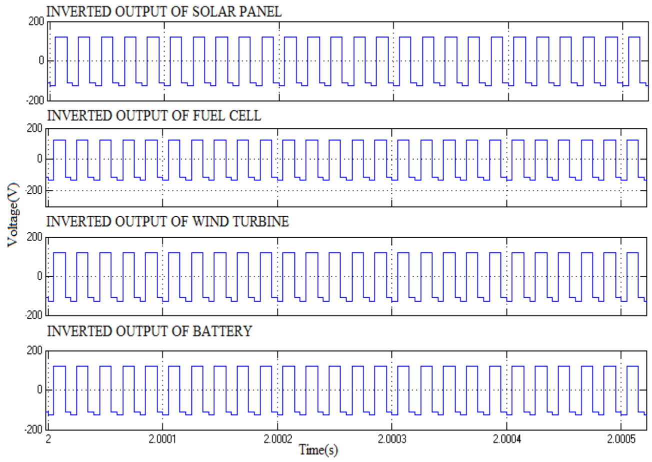

Figure 23. Input of Multi -Winding Transformer

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The integrated high frequency voltage at the secondary of the high frequency transformer is rectified using a half wave rectifier and the ripples in the DC output are removed using a capacitive filter. The DC output voltage and the current variations are shown in the figure 24(a)&(b) respectively.

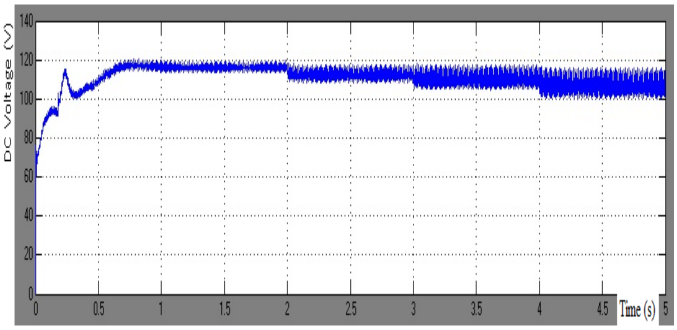

Figure 24(a). DC output voltage variations with load

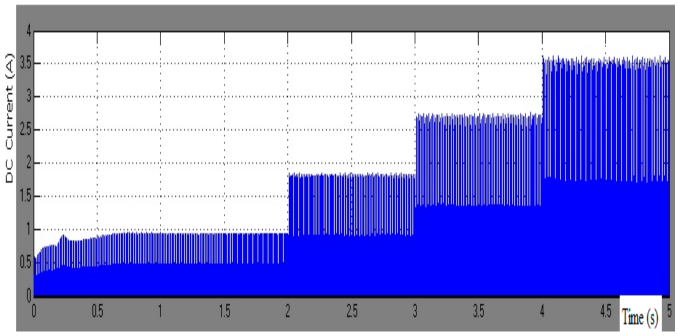

Figure 24(b). DC output current variations with load

The load connected to the inverter is increased in steps to verify the mode selection by the controller. The voltage and current variation at the output of the inverter is shown in figure 25(a)&(b) respectively.

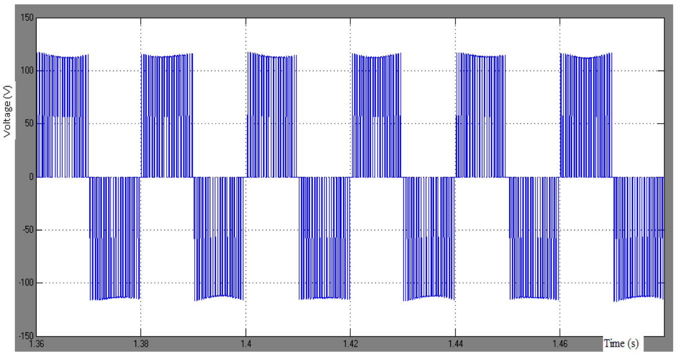

Figure 25(a). output voltage of inverter on varying load

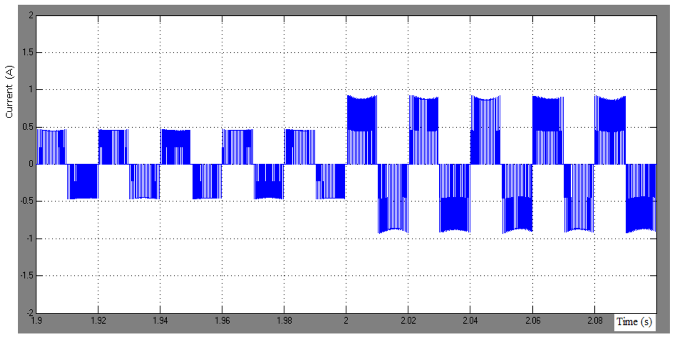

Figure 25(b). output current of inverter on varying load

C. Simulation Results

When the sum of generation is higher than the load demand, the excess energy is used in charging the battery. A charger circuit using boost chopper is used. The duty cycle of the boost chopper is adjusted based on the amount of excess energy which controls the charging rate of the battery. The operation of the charger circuit can be visualized from the figure 26 which applies a higher voltage at the terminals of the battery, allows the current to flow inside (negative polarity of battery current), increase the state to charge of the battery. Similarly, when the load demand is high, the battery discharges to supply the load which is shown in figure 27.(positive battery current augurs the battery is discharging)

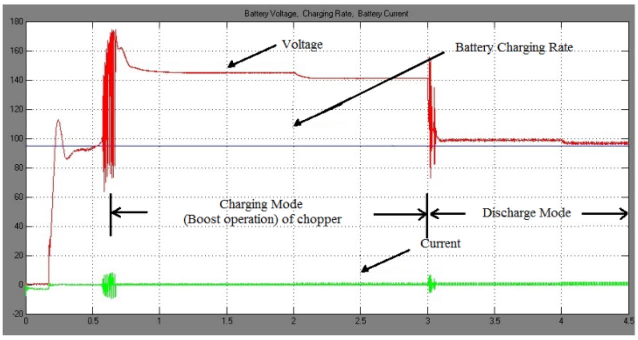

Figure 26. Battery characteristics

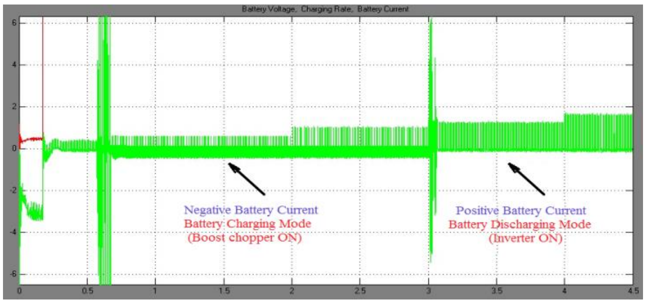

Figure 27. Battery Current Charging and Discharging Mode

V. CONCLUSION

The simulation and performance analysis of multiple-input converter is done and the analysis shows a better performance which can be authenticated from the waveforms. The scope of the above work is immense in the area of renewable energy based power supply for rural electrifications and remote installations. Also the further work such as implementation of maximum power point tracking (MPPT) can be implemented for photovoltaic panel and wind power generators. Also the neuro – fuzzy based controller can be tried for precise tuning of the duty cycle of the charging/ discharging circuit for better power management.

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