# MODELING AND SIMULATION OF A NOVEL SOLAR PV/ BATTERY HYBRID ENERGY SYSTEM WITH A SINGLE PHASE FIVE LEVEL INVERTER

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**Abstract - In current global energy scenario, renewable energy sources can play an important role in meeting the ever increasing energy demand. This is due to exhaustive nature of fossil fuels and the environmental pollution caused by other conventional energy sources. Among renewable energy sources, solar photo-voltaic system is the most popular one as solar energy is available in abundance without paying any cost. The output voltage generated from the solar panels depends on solar irradiance level and temperature. This paper intends to present a novel solar PV/battery hybrid energy system with a single phase five level inverter. The battery is used as a backup source when in case solar power is absent. The power flow through the battery is controlled using a bidirectional converter so that the optimum usage of the battery is ensured. The proposed configuration uses a modified single phase five level inverter topology for converting DC voltage generated from solar photovoltaic/battery energy sources to AC voltage for feeding to the load. The usage of five level inverter reduces Total Harmonic Distortion (THD) in output voltage and thus eliminates the use of bulk filters at the output side. Simulation study of the proposed system is carried out using MATLAB Simulink. Simulation results for different cases are provided in this paper.**

***Keywords—photovoltaic system; renewable energy; multilevel inverter; hybrid energy system; bidirectional converter***

## I. INTRODUCTION

Nowadays renewable energy generation systems are gaining more attraction due to the exhaustive nature of fossil fuel resources and its increased prices. Also the need for pollution free green energy has created a keen interest towards alternate energy sources. Solar power is the most common and available renewable power source to meet our rapidly increasing energy requirements [1].

Peak power from the solar pv maodule is to be tracked for its efficient implementation. Various algorithms are available in the literature for tracking maximum power from solar panels. In this paper Perturbation and Observation algorithm is considered due to its simplicity. A boost converter is used to implement maximum power point tracking algorithm [2].

The output power generated from the solar panels is intermittent in nature and varies with the irradiance level. Hence to make the system more reliable, a battery is included in the system. A bidirectional converter is also used to adjust the flow of power from and into the battery [3].

A five level inverter is used to convert the dc voltage from the solar pv array to ac voltage and connect feed to the load. In this paper a novel topology for single phase five level inverter is suggested [4]. This topology uses reduced number of switches compared to conventional five level inverter topologies. Multilevel inverters produce a desired output voltage from different levels of direct current voltages as inputs. As the number of levels increases, the synthesized output waveform is staircase wave which approximates a sine wave with more number of steps.

Thus the output voltage approaches the desired sinusoidal waveform [5]. The basic idea of a multilevel converter is to obtain higher operating voltage using a series connection of power semiconductor switches with much lower voltage rating compared to power switches used in conventional two-level inverter. These power switches are controlled in such a way that more number of voltage levels is generated in the output using many dc sources. The rated voltage of the power semiconductor switches depends upon the rating of the input voltage sources to which they are connected and it is much less than the output voltage [6].

The main advantages of a multilevel inverter are that they can generate the output voltages with very less THD, can draw input current with very low distortion, lower EMI effects, lower dv/dt across each switch and can operate at wide range of switching frequencies from fundamental frequency to very high frequency. The most common topologies for multilevel inverters are diode clamped, flying capacitor and cascaded H- bridge multilevel inverter. The paper presents a modified topology for multilevel inverter which uses less number of switches compared to conventional topologies [7].

## II. PROPOSED SYSTEM ARCHITECTURE

The block diagram of the proposed architecture is shown in Fig. 1. The output of the solar panel is given to the multilevel inverter through a boost converter. The switching pulse generated from the MPPT algorithm is given to the boost converter. This topology is suitable for interfacing with renewable energy sources since the output from the different solar panels can be fed to the multilevel inverter as input dc sources [8]. The power from the battery is given to the multilevel inverter through a bidirectional dc-dc converter so that power flow through either direction can be controlled.

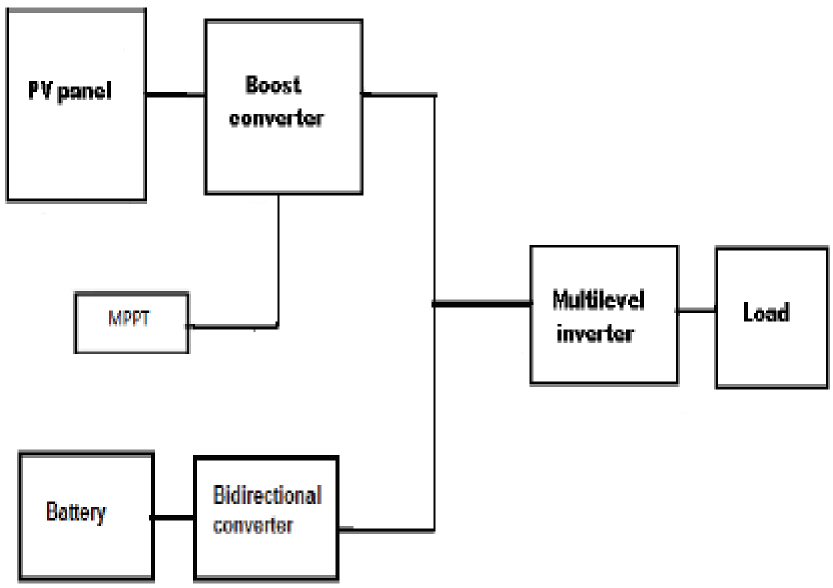


Fig. 1.Block diagram of proposed architecture

## III. PV CELL MODELING

The equivalent circuit of a PV cell is shown in Fig. 2.

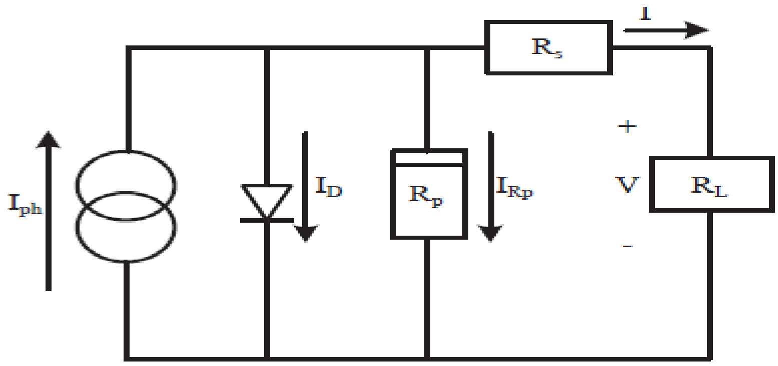


Fig. 2 Equivalent circuit of PV cell

An ideal solar cell is modeled by a current source and a parallel diode. However no solar cell is ideal there by shunt and series resistance are added to the model as shown in Fig.
2. Rs is the series resistance whose value is very small. Rp is the equivalent shunt resistance whose value is very high. Applying Kirchoff's current law at the node where current source (Iph), diode, Rp and Rs meet, we get,

$$I_{ph} = I_d + I_{Rp} + I$$

We get the following equation for the PV cell current

$$I = I_{ph} - (I_d + I_{Rp})$$

$$I = I_{ph} - \left(I_o\left[e^{\left(\frac{V+IR_s}{V_T}\right)} - 1\right] + \frac{V + IR_s}{R_p}\right)$$

where Iph is insolation current, I is the cell current, Io is the reverse saturation current, V is the cell voltage, Rs is the series resistance, Rp is the parallel resistance, and VT is the thermal voltage.

### *A.Modeling of PV array*

The main building block of PV array is a solar cell. It is basically a p-n junction which converts light energy into electrical energy. The equivalent circuit is shown in fig3.

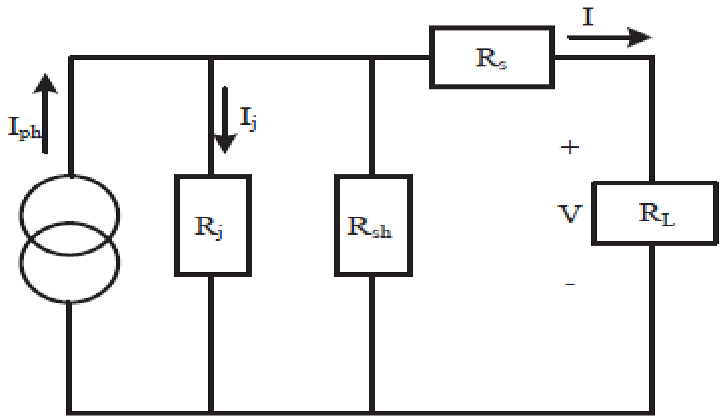

Fig.3 Equivalent circuit of PV array

The current source Iph represents the cell photovoltaic current, Rj is used to represent the nonlinear resistance of the p-n junction, Rsh and Rs are used to represent the intrinsic shunt and series resistance respectively. Normally value of Rsh is very large and Rs is very small. Hence both of them can be neglected to simplify the analysis. PV cells are grouped in larger units to form PV modules. They are further interconnected in series-parallel combination to form PV arrays. The mathematical model used to simplify the PV array is represented by the equation

$$I = n_p I_{ph} - n_p I_{rs} \left[ e^{\left(\frac{q}{kTA} * \frac{V}{n_s}\right)} - 1 \right]$$

Where I is the PV array output current, V is the PV array output voltage, ns is the number of series cells, np is the number of parallel cells, q is the charge of an electron, k is the Boltzman constant, A is the p-n junction ideality factor, T is the cell temperature, and Irs is the cell reverse saturation current. The factor A decides the deviation of solar cell from the ideal p-n junction characteristics. Its value ranges from one to five. The photo current Iph depends on the solar irradiance and cell temperature as below

$$I_{ph} = [I_{scr} + K_i(T - T_r)] \frac{S}{100}$$

Where Iscr is the cell short circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient and S is the solar irradiance in mW/cm2.The Simulink model of PV array is shown in Fig. 4. The model includes three subsystems. One subsystem to model PV module and two more subsystems to model Iph and Irs [9].

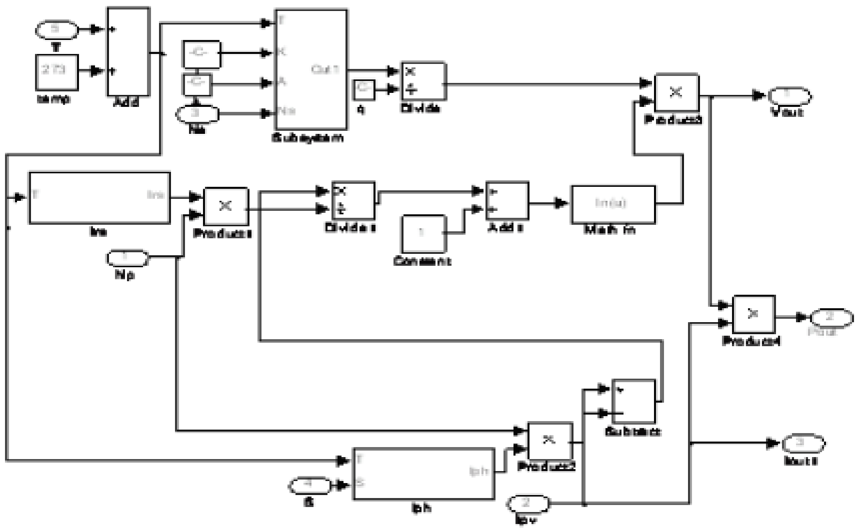


Fig.4. simulink model of solar pv module

## IV. MAXIMUM POWER POINT TRACKING

Maximum power point tracking technique (MPPT) is to be implemented for tracking maximum power from solar array. There are different techniques available in the literature for tracking maximum power from solar panel. Here P&O algorithm is adopted considering its simplicity. The simulink model of P&O algorithm is shown in Fig. 5.

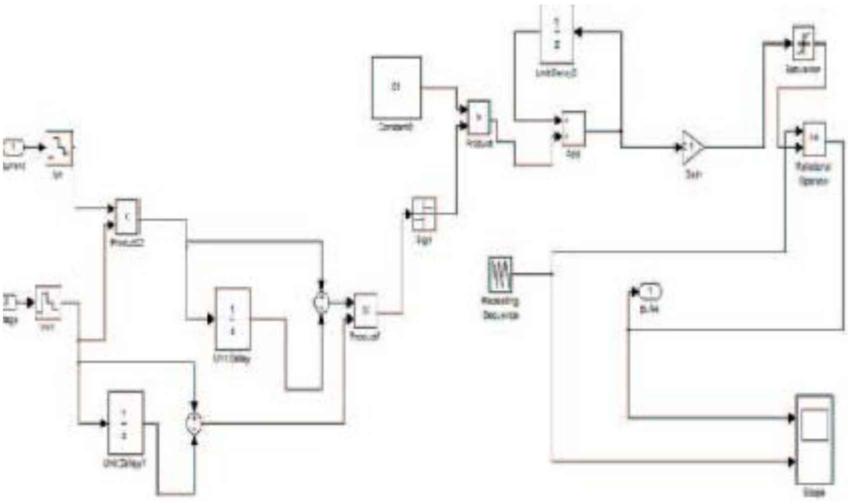

Fig.5. simulink model of P&O algorithm

## V. DC-DC CONVERTER

The solar PV/battery hybrid system is connected to the multilevel inverter through a DC-DC converter. A boost converter is used to implement MPPT algorithm. Output voltage of the boost converter is Vo = D Vd where Vd is the input voltage and D is the duty ratio. The pulse generated from the MPPT algorithm is given to the boost converter. The output of the boost converter is given as the input to the multilevel inverter.

## VI. BIDIRECTIONAL CONVERTER

The circuit diagram of a bidirectional dc-dc converter is shown in fig.6. The main purpose of the bidirectional converter is to maintain the dc link voltage constant. When charging, switch S1 is activated and the converter works as a boost circuit. When discharging, switch S2 is activated and the converter works as a buck circuit.

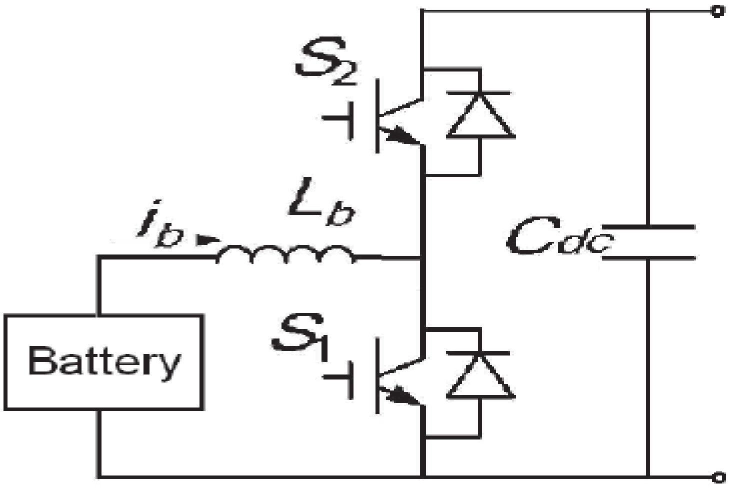


Fig 6. Bidirectional dc-dc converter

The control scheme of the bidirectional converter is shown in fig7. When the voltage at the dc link is lower than the reference voltage, switch S2 is activated. When the dc link voltage is higher than the reference voltage, switch S1 is activated. Ib is the reference current generated by the PI controller and Ib, ref is the battery current.

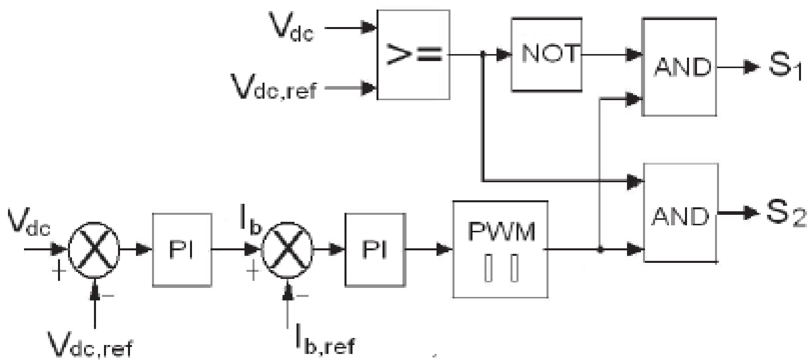


Fig.7. Control of the bidirectional converter

## VII. MULTILEVEL INVERTER

The modified single phase five-level inverter uses a full bridge configuration and an auxiliary circuit. The circuit diagram is shown in Fig. 8.

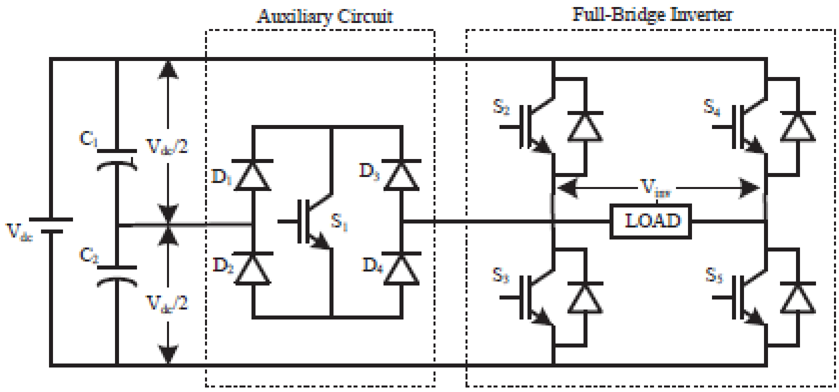


Fig. 8 Circuit diagram of five level inverter

Here an auxiliary circuit consists of one switch and four diodes are used along with a full bridge configuration. The principle of operation of the proposed inverter is to generate five levels of output voltage, V/2, V, 0, -V/2 and –V. Using proper switching sequence in this modified circuit, five levels in output voltage is generated [10]. Table 1 shows the switching sequence used for generating five levels in the output voltage.

Table1:

Switching sequence

| $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $V_{inv}$ |
|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 1 | $V_{dc}$ |
| 1 | 0 | 0 | 0 | 1 | $V_{dc}/2$ |
| 0 | 1 | 0 | 1 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 | |
| 1 | 0 | 0 | 1 | 0 | $-V_{dc}/2$ |
| 0 | 0 | 1 | 1 | 0 | $-V_{dc}$ |

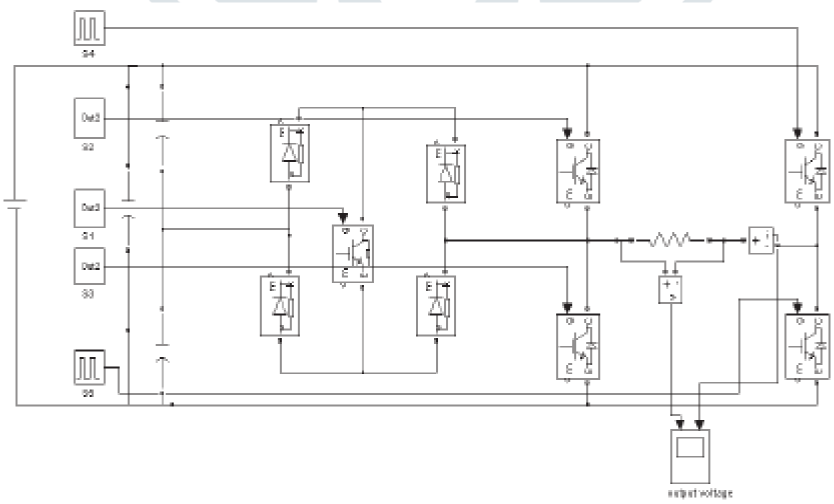


Fig.9. simulink model of five level inverter

## VIII. PWM STRATEGY

In this paper, the switching technique adopted to generate the gate signals is obtained by comparing a reference signal with two carrier signals. The reference signal is a rectified sinusoidal signal and the two carrier signals are triangular waves having the same frequency and phase angle, but with different offset voltage magnitudes. The PWM strategy is shown in fig:10 The switching patterns of the five level inverter are shown in Fig. 11.

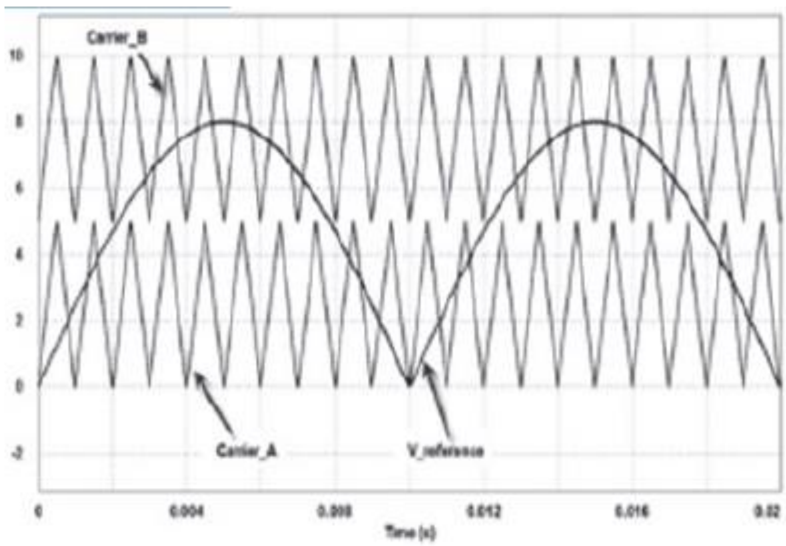


Fig.10. Sine-triangle PWM

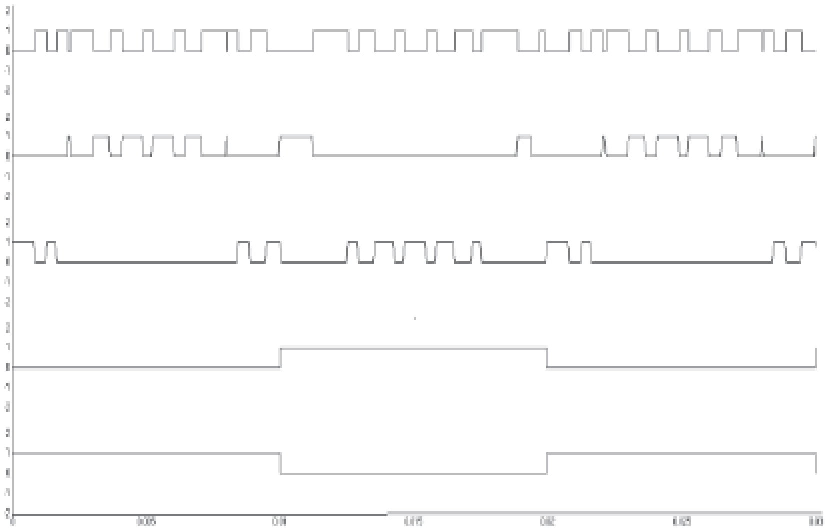

Fig.11. switching patterns of the five level inverter

## IX. SIMULATION RESULTS

The output voltage of the pv array is shown in Fig. 12.

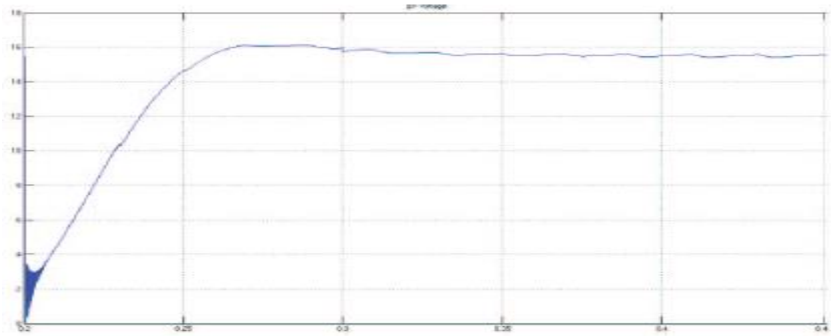

Fig.12. output voltage of the pv array

The output voltage of the five level inverter when fed from PV for a load resistance of 10 ohms is shown in Fig.

13.

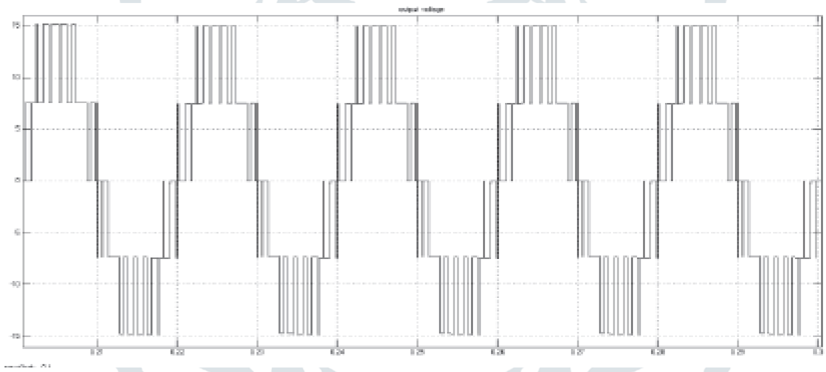

Fig.13. output voltage of the five level inverter for R load

The output current of the five level inverter when fed from PV for a load R= 10 ohms L= 1 mH is shown in Fig. 14. It is seen that five levels are generated in the output for different loads using a single input.

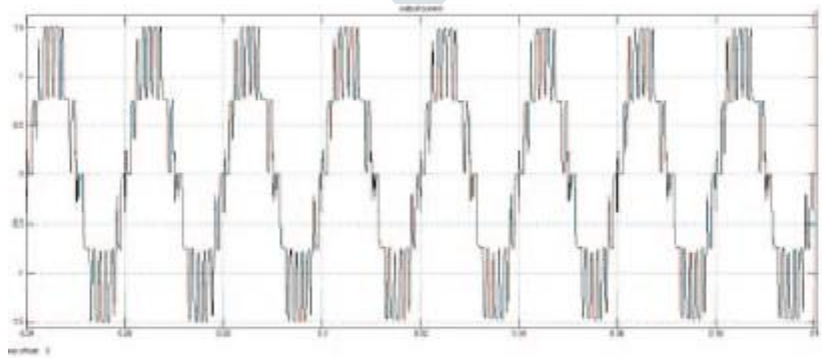

Fig.14. output current of the five level inverter for RL load

## X. CONCLUSION

In this paper, the modelling and simulation of a solar PV/battery hybrid energy system with a five level inverter has been presented. The proposed system reduces both voltage & current THD and implements a reliable hybrid renewable energy system. The five-level inverter topology used in proposed system has less number of switches compared to conventional cascaded H-bridge configuration. Detailed simulation analysis is carried out to evaluate the dynamic performance of the proposed system under different worse case conditions. It is found from simulation results that the performance of the proposed renewable hybrid energy system is good for all the tested conditions.

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