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Paper Authors

N.HARSHAVARDHAN REDDY, N.HANUMAN NAYAK

Sri Chundi Ranganayakulu Engineering College, Ganapavaram; Guntur (Dt); Andhra Pradesh, India

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SIMULATION OF HYBRID ENERGY SYSTEM WITH SINGLE PHASE SEVEN LEVEL INVERTER

[1]N.HARSHAVARDHAN REDDY, [2]N.HANUMAN NAYAK
[1]M-tech Student Scholar,Department of Electrical & Electronics Engineering, Sri Chundi Ranganayakulu Engineering College, Ganapavaram; Guntur (Dt); Andhra Pradesh, India.
[2]Assistant Professor,Department of Electrical & Electronics Engineering, Sri Chundi Ranganayakulu Engineering College, Ganapavaram; Guntur (Dt); Andhra Pradesh, India.
[1]hharshareddy227@gmail.com,[2]naikbuddi @gmail.com

Abstract- Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Multilevel inverter structures have been developed to overcome shortcomings in solid-state switching device ratings so that they can be applied to high voltage electrical systems. The multilevel voltage source inverters unique structure allows them to reach high voltages with low harmonics without the use of transformers. This makes unique power electronics topologies suitable for Flexible AC Transmission Systems and custom power applications. The use of a multilevel converter to control the frequency, voltage output including phase angle, real and reactive power flow at a dc/ac interface provides significant opportunities in the control of distributed power systems. In this concept, new system architecture for 7-level MLI system is proposed. This method allows the renewable energy sources to deliver the load together or independently depending upon their availability. The proposed inverter uses less number of switches when compared with the conventional multilevel inverter.

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 module 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

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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, and 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.

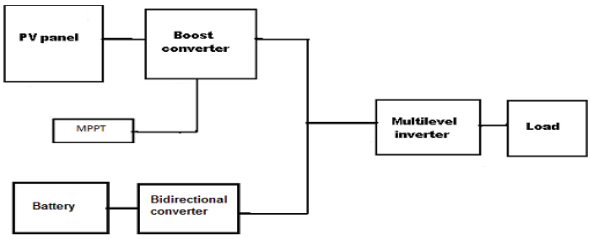

Fig.1.Block diagram of proposed architecture

III. PV CELL MODELING

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

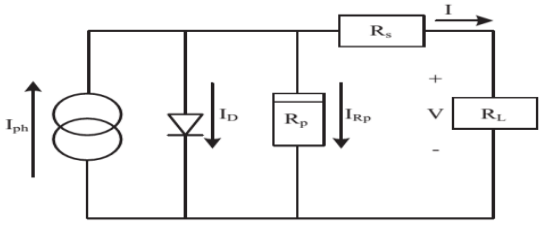

Fig.2 Equivalent circuit of PV cell

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. R_s is the series resistance whose value is very small. R_p is the equivalent shunt resistance whose value is very high. Applying Kirchhoff's current law at the node where current source (Iph), diode, Rp and Rs meet, we get,

$$I_{ph} = I_d + I_{Rp} + I \quad (1)$$

We get the following equation for the PV cell current

$$I = I_{ph} - (I_d + I_{Rp}) \quad (2)$$

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$$I = I_{ph} - \left(I_o \left[e^{\left(\frac{V+IR_s}{V_T}\right)} - 1 \right] + \frac{V + IR_s}{R_p} \right) \quad (3)$$

Where I_{ph} is insolation current, I is the cell current, I_o is the reverse saturation current, V is the cell voltage, R_s is the series resistance, R_p 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 fig 3.

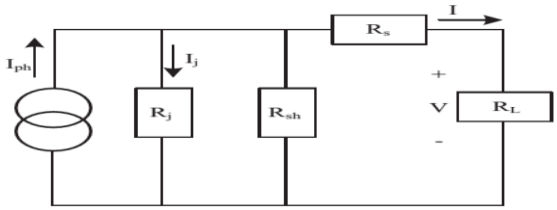

Fig.3 Equivalent circuit of PV array

The current source I_{ph} represents the cell photovoltaic current, R_j is used to represent the nonlinear resistance of the p-n junction, R_{sh} and R_s are used to represent the intrinsic shunt and series resistance respectively. Normally value of R_{sh} is very large and R_s 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

$$I = n_p I_{ph} - n_p I_{rs} \left[e^{\left(\frac{q}{kTA} \cdot \frac{V}{n_s}\right)} - 1 \right] \quad (4)$$

Where I is the PV array output current, V is the PV array output voltage, ns is the number of series cells, n_p 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 I_{rs} 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 I_{ph} depends on the solar irradiance and cell temperature as below

$$I_{ph} = [I_{scr} + K_i(T - T_r)] \frac{S}{100} \quad (5)$$

Where I_{scr} is the cell short circuit current at reference temperature and radiation, K_i is the short circuit current temperature coefficient and S is the solar irradiance in mW/cm^2. 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 I_{ph} and I_{rs} [9].

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.

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 $V_O = D_{Vd}$ 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

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discharging, switch S2 is activated and the converter works as a buck circuit.

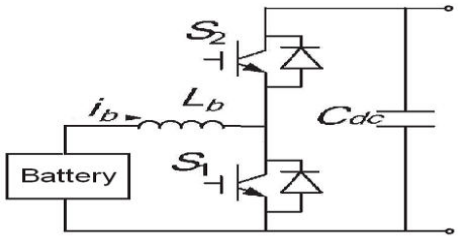

Fig.6. Bidirectional dc-dc converter

The control scheme of the bidirectional converter is shown in fi.7. When the voltage at the dc link is lower than the reference voltage, switch S_2 is activated. When the dc link voltage is higher than the reference voltage, switch S_1 is activated. I_b is the reference current generated by the PI controller and I_b, ref is the battery current.

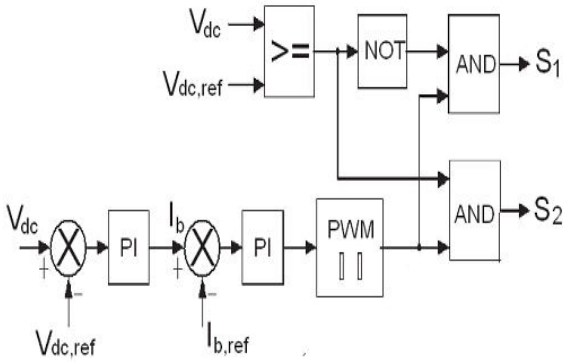

Fig.7. Control of the bidirectional converter

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.

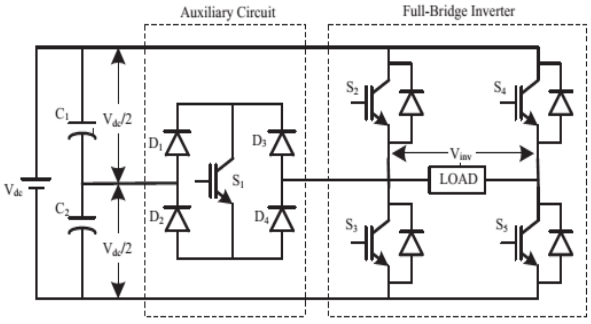

Fig. 8 Circuit diagram of five level inverter

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	$-V_{dc}$

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.9.

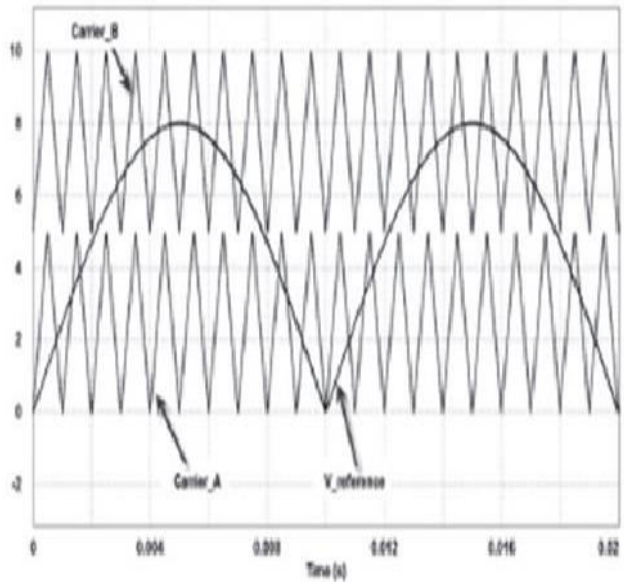

Fig.9. Sine-triangle PWM

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The switching patterns of the five level inverter are shown in Fig. 11.

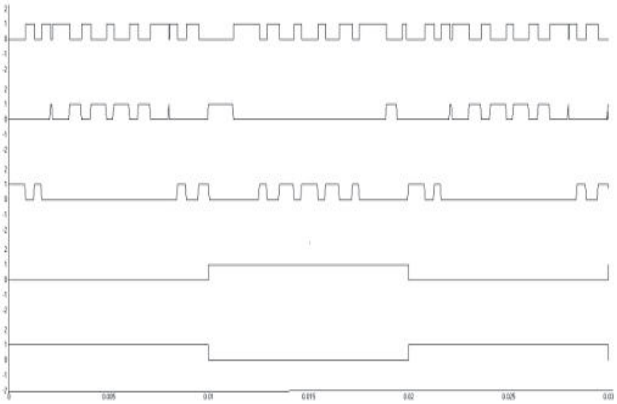

Fig.10. switching patterns of the five level inverter Cascade Multilevel Inverter

The cascade multilevel inverter consists of a number of H-bridge inverter units with separate dc source for each unit and is connected in cascade or series Each H-bridge can produce three different voltage levels: +Vdc, 0 and –Vdc by connecting the dc source to ac output side by different combinations of the four switches S1, S2, S3, and S4. The ac output of each H-bridge is connected in series such that the synthesized output voltage waveform is the sum of all of the individual H-bridge outputs. By connecting sufficient number of H-bridges in cascade and using proper modulation scheme, a nearly sinusoidal output voltage waveform can be synthesized

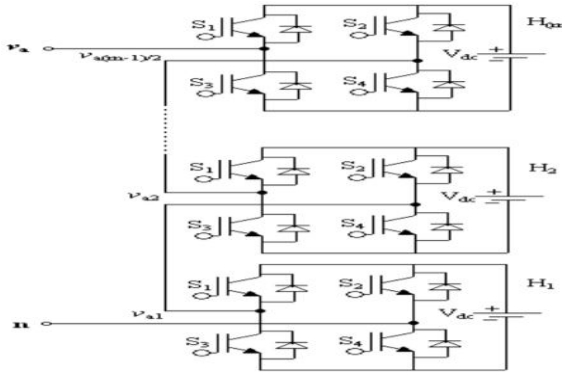

Fig.11 Single -phase cascade multilevel inverter topology.

The number of levels in the output phase voltage and line voltage are $2s+1$ and $4s+1$ respectively, where s is the number of H-bridges used per phase. For example, three H-bridges, five H-bridges and seven H-bridges per phase are required for 7-level, 9-level and multilevel inverter respectively. a typical waveform produced by 7-level CMLI. The magnitude of the ac output phase voltage is the sum of the voltages produced by H-bridges.

IX. SIMULATION RESLUTS:

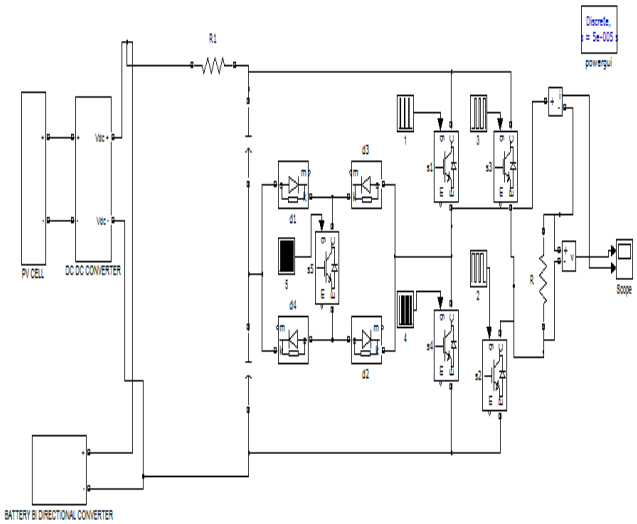

Fig.12 Simulink model of five level inverter

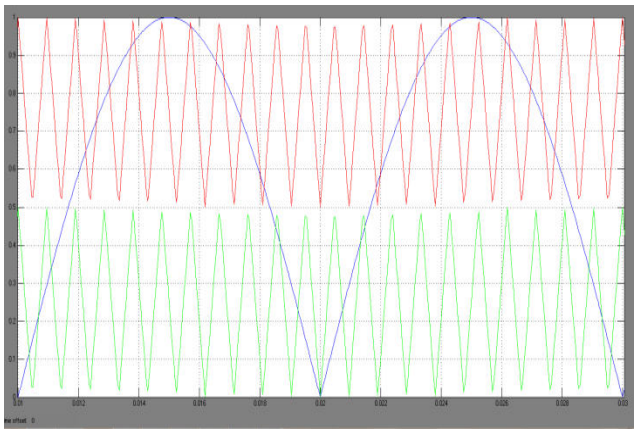

Fig.13 Sine-triangle PWM

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

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are triangular waves having the same frequency and phase angle, but with different offset voltage magnitudes. The PWM strategy is shown in Fig.13.

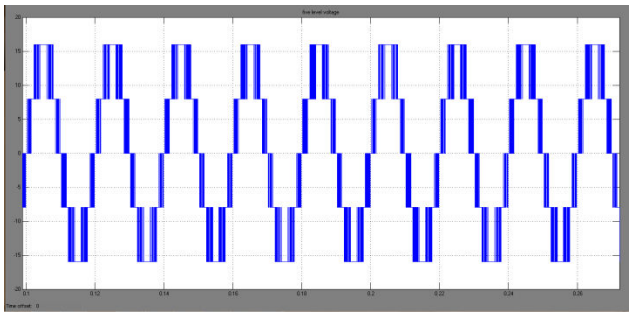

Fig.14 Output voltage of the five level inverter

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

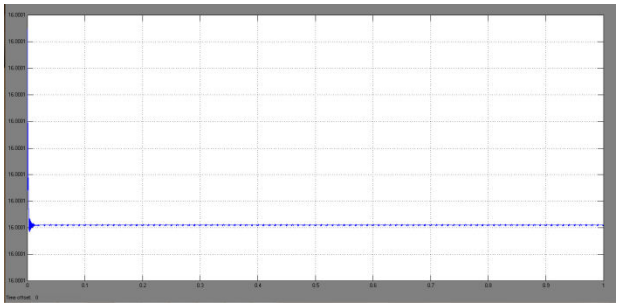

Fig.15 output voltage of the PV array

The output voltage of the five level inverter when fed from PV for a load resistance of 10 ohms is shown in Fig.15.

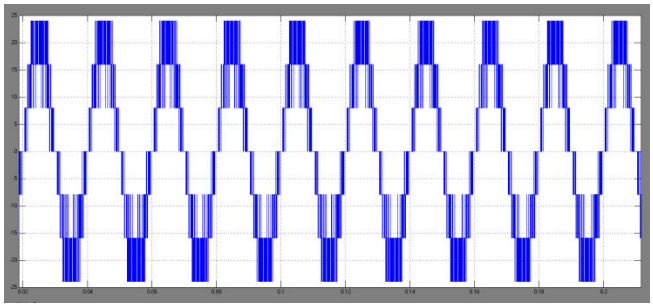

Fig.16 Output voltage of the seven level inverter

The output current of the seven level inverter when fed from PV for a load R= 1 ohm is shown in Fig.16. It is seen that five levels are generated in the output for different loads using a single input.

X. CONCLUSION

In this project, the modeling 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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