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## Solar Powered Simplified Multilevel Inverter

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**ABSTRACT:** In the area of distributed energy systems and industrial motor drives multilevel converters and inverters are the emerging trends. Single phase inverter is widely used for stand-alone systems and micro-grid application. The major limitation faced by multilevel inverters are, number of switches required large which leads to higher switching losses. A novel solar powered extended simplified multilevel inverter is proposed, in which a single phase multilevel output can be attained using less number of switches. This paper observes the feasibility of the proposed topology using Matlab/Simulink software. A seven level output voltage is obtained with less harmonic content and reduced switching losses.

**KEYWORDS:** Simplified multilevel inverter, solar PV system, MPPT, THD

### I. INTRODUCTION

For past few years, Multi-Level Inverters (MLI) has gained attention due to wide applications in distributed power systems and electrical drives. A better sinusoidal form of ac output from dc sources like batteries, solar cells, fuel cells etc can be attained from MLIs. Such ac output can be directly interfaced to the ac grid or a load with small filter circuit in its output.

A staircase waveform can be synthesized from multiple DC input sources fed to a MLI. MLI's stepped waveform depicts a better harmonic profile. The unwanted harmonics result in problems such as the electromagnetic interference, current pulsation, and additional power loss and may cause equipment damage. Renewable sources can be connected to the ac grid with the help of these MLIs, where high quality AC waveforms are essential. In other applications such as AC motor drives, the low-order harmonics are the main issue. The unwanted output harmonic contents can be considerably reduced by using Pulse Width Modulation (PWM) control techniques applied to the inverter switches.

The major limitations of MLIs are the requirement of a large number of power switching devices and associated gate driver circuits. The number increases with an increase in the number of output levels. Such a system will be expensive and complex. Therefore, practical implementation of MLI requires a minimized number of switches and gate driver circuits, without reducing its output level.

### II. MULTILEVEL INVERTER TOPOLOGIES

Following are the basically used MLI topologies to attain multilevel ac output for electrical drive and power engineering applications [1]-[3].

#### A. Diode clamped MLI

In diode clamped MLI proposed by Nabae *et al.*, intermediate voltage levels are attained with the help of capacitors and clamp diodes. Then the voltage across the switch becomes half of the input dc voltage, for a three level inverter. This MLI is limited due to its capacitor voltage balancing problems and is not suitable for solar (Photo-Voltaic) PV applications.

#### B. Flying Capacitor MLI

In this MLI, clamping voltages and multilevel output are achieved by floating capacitors and switches. Redundant switching states can be achieved without additional clamping diodes, which are used to balance the capacitor charge, even under a loaded condition and obtain the required dc level. As the number of output levels increases, the number of capacitors also increases.

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### C. Cascaded H-bridge MLI

In cascade H-bridge topology, the multilevel output can be achieved with symmetrical or asymmetrical dc voltage sources with comparatively less number of switches. Addition or subtraction of dc sources can be achieved easily, which in turn increase the number of levels in output waveform. But for each level addition, four controllable switches and additional control circuits are required.

### D. Modular MLI (half H-bridge)

Modular MLI is deduced from the cascaded H-bridge MLI. Instead of four switches, half numbers of switches are used to form a half H-bridge configuration, called a module. A module consists of a dc source and two switches. They are connected in cascade to obtain the required multilevel output.

## III. SIMPLIFIED MULTILEVEL INVERTER

Single phase simplified five level inverter was proposed by Y. H. Liao is shown in fig. 1. It is derived from two cascaded H-bridge configuration with two switches reduced from the circuit. It consists of six switches arranged in two strings, string A and string B. SA<sub>1</sub>, SA<sub>2</sub> and SA<sub>3</sub> are the switches in string A and SB<sub>1</sub>, SB<sub>2</sub> and SB<sub>3</sub> are the switches in string B. In string A, source of SA<sub>1</sub> is connected to drain of SA<sub>2</sub> and source of SA<sub>2</sub> is connected to drain of SA<sub>3</sub> and vice versa in string B [4].

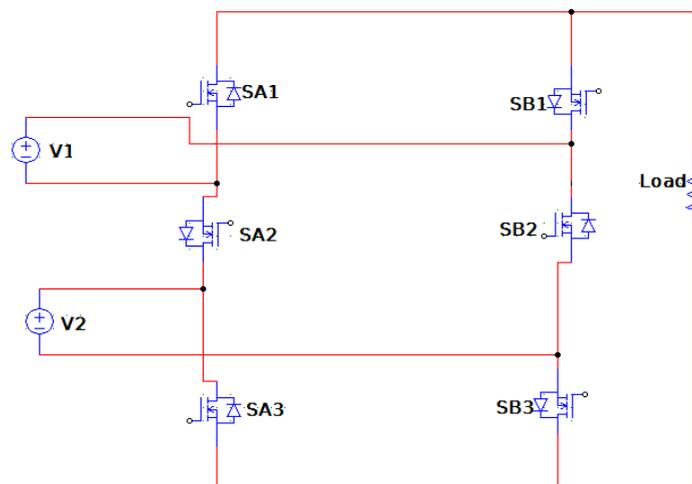


Fig. 1. Simplified five level inverter

## IV. SOLAR CELL MODELING

The solar cell equivalent circuit is shown in fig. 2, which consists of a current source giving photovoltaic current  $I_{ph}$ , a parallel diode  $D$ , shunt resistor  $R_{sh}$  and series resistor  $R_s$ . Current through the Diode is  $I_d$ ,  $R_{sh}$  is  $I_{sh}$ ,  $R_s$  is  $I$ .

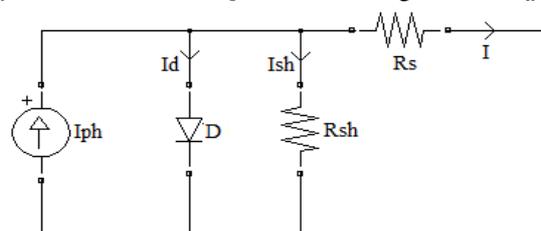


Fig. 2. Equivalent circuit of a solar cell

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Mathematical equations of a PV cell are given below.

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

$$I = I_{ph} - I_{drs} \left( e^{\frac{q(V+R_s I)}{AKT}} - 1 \right) - \frac{V+R_s I}{R_{sh}} \tag{2}$$

For short circuit condition,  $R_{sh}$  is assumed to be infinite then equation (2) becomes

$$I = I_{ph} - I_{drs} \left( e^{\frac{q(V+R_s I)}{AKT}} - 1 \right) \tag{3}$$

## V. PROPOSED SYSTEM

The proposed solar powered MLI consists of a simplified inverter and three solar powered DC sources. In order to connect three sources, the simplified inverter is extended by adding two more switches in the inverter proposed by Y. H Liao. The block and circuit diagrams are shown in fig. 3 and fig. 4 respectively.

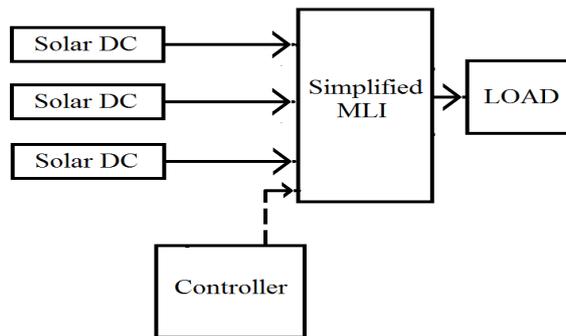


Fig. 3. Block diagram of the proposed system

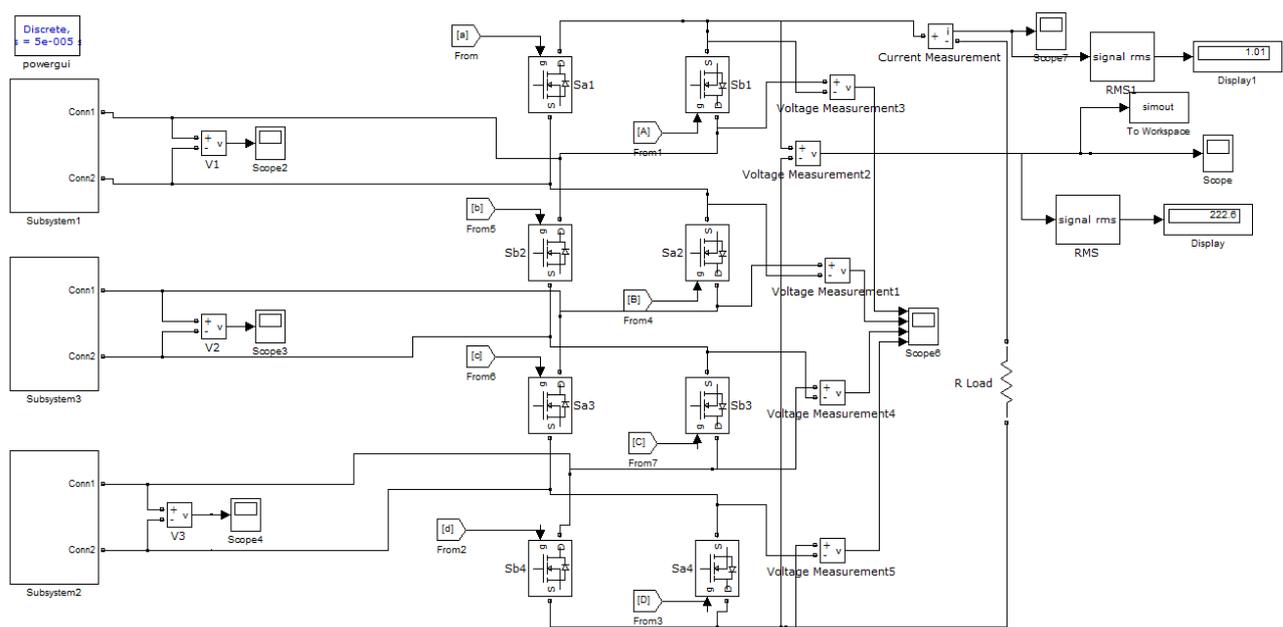


Fig. 4. Proposed MLI

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The inverter consists of eight switches arranged in two string format, string A and string B. Sa1, Sa2, Sa3 and Sa4 are the switches in A string and Sb1, Sb2, Sb3 and Sb4 are in B string. The adjacent switches in the string are connected in series with same sides, ie. source-source and drain-drain connections. The positive terminal of the DC source is connected to drain-drain of one string and its negative to source-source of next string.

### A. Boost Converter

Figure 5 shows the circuit diagram of a boost converter used in the solar subsystem, which contains an inductor L, controllable switch S/W, diode D, output capacitor C and load resistance R. Boost converter design equation are given below [6]-[7].

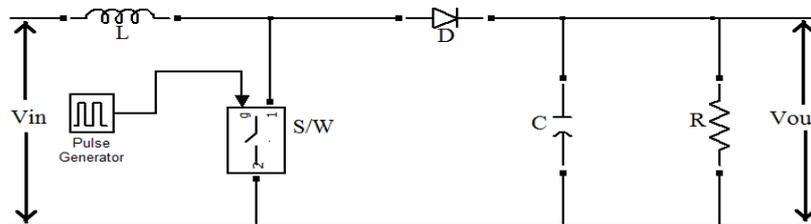


Fig. 5. Boost converter

Maximum duty cycle

$$L = \frac{V_{in}(V_{out}-V_{in})}{\Delta I_L f_s V_{out}} \quad (7)$$

Inductor value

$$D1 = 1 - \frac{V_{in(min)} D}{V_{out}} \quad (6)$$

Minimum Value of output capacitor

$$C = \frac{I_{out(max)} D}{f_s \Delta V_{out}} \quad (8)$$

Load current

$$I_{out} = \frac{V_{out}}{R} \quad (9)$$

### B. MPPT Technique

P & O algorithm or hill climbing technique is used for tracking MPP in the solar system. Figure 6 shows the flow chart of the P & O [8]-[9].

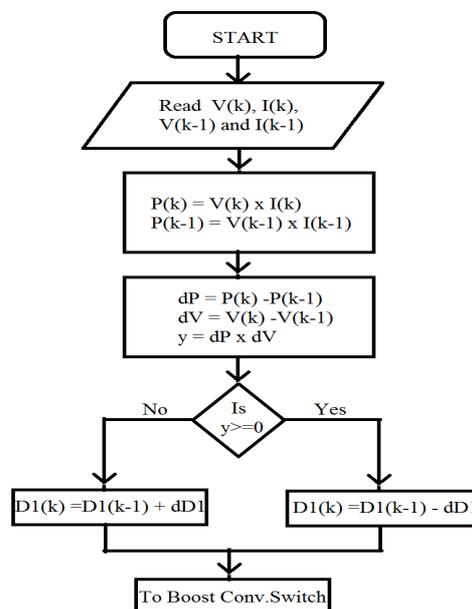


Fig. 6. Flow chart of P & O MPPT Algorithm

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### C. Inverter Controller

The PWM switching pulses are used for triggering inverter switches. They are generated using comparison of three triangular carrier waves with rectified sinusoidal modulating signal as shown in fig. 7 and the circuit diagram is shown in fig. 8.

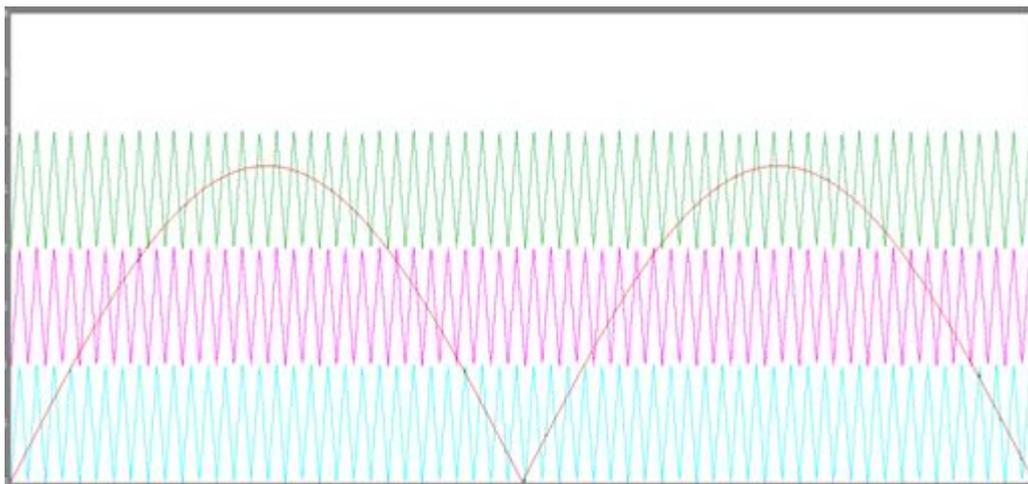


Fig. 7. Controller PWM generation: reference and modulating signals

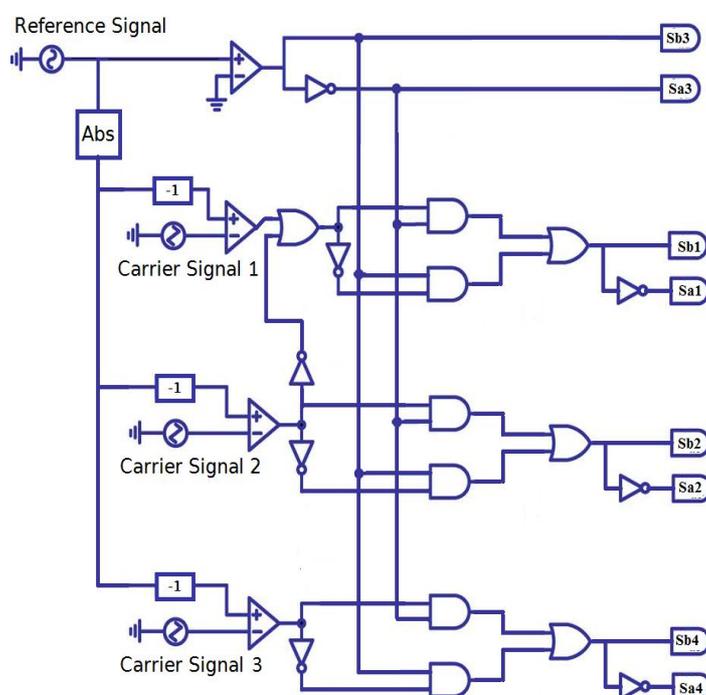


Fig. 8. Controller Circuit Diagram

### D. Simulation Results

The proposed system is modelled in MATLAB/SIMULINK software. A seven level ac output voltage is obtained from the proposed system is depicted in fig. 9.

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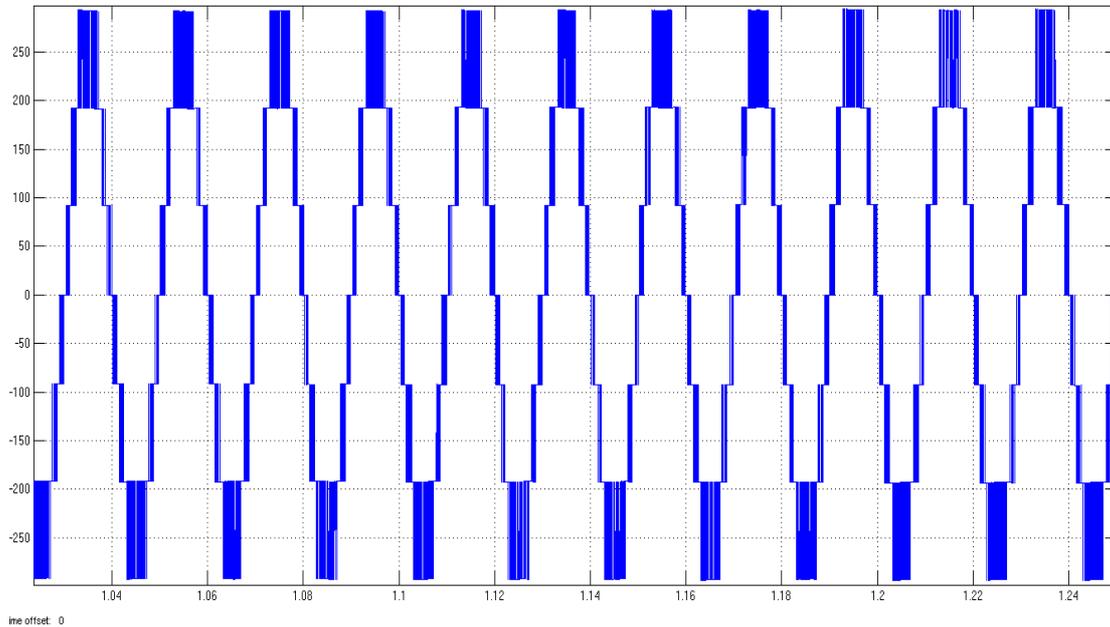


Fig. 9. Output AC Voltage Waveform

A 220 V, 50 Hz ac voltage is obtained from the proposed system, at 0.95 modulation index. Fast Fourier Transform (FFT) analysis was conducted on 20 cycles of the ac output voltage, shown in fig. 10, and obtained the fundamental component as 262.2 and THD as 3.27%.

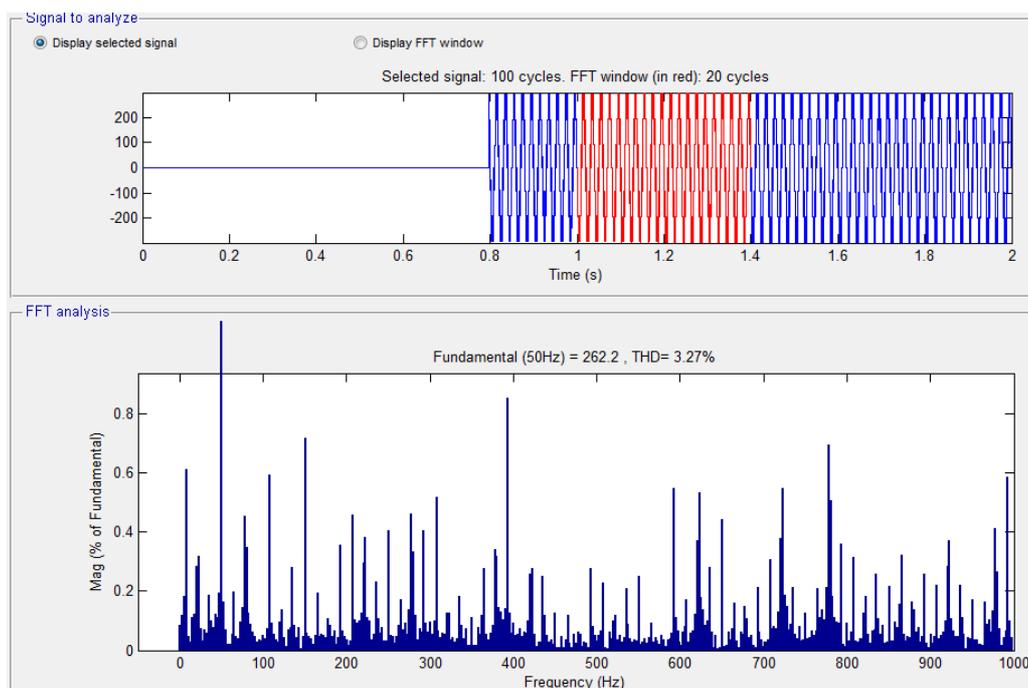


Fig. 10. FFT Analysis



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The current versus power, voltage versus current and voltage versus power characteristics for a variable resistive load are shown in fig. 11, fig. 12 and fig. 13 respectively. The voltage level is almost constant as power or load increases.

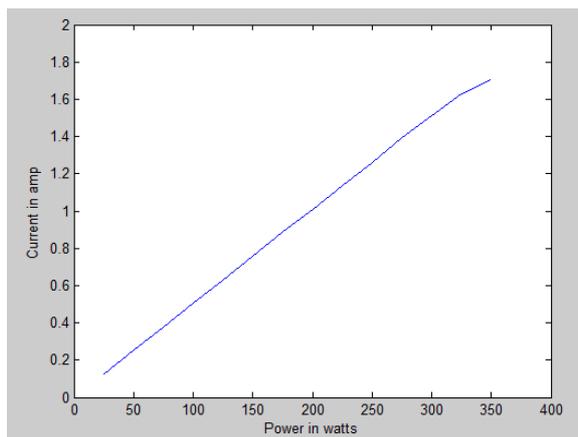


Fig. 11. I-P characteristics

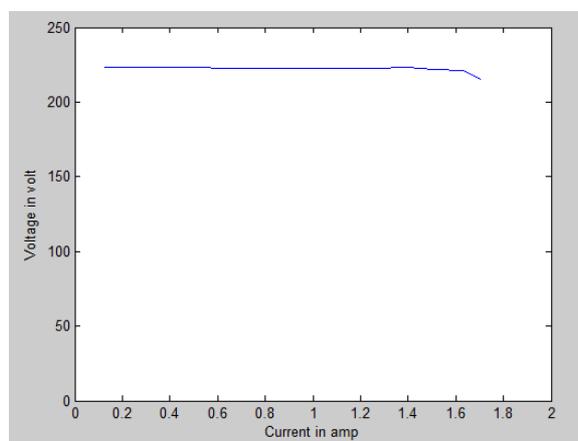


Fig. 12. V-I characteristics

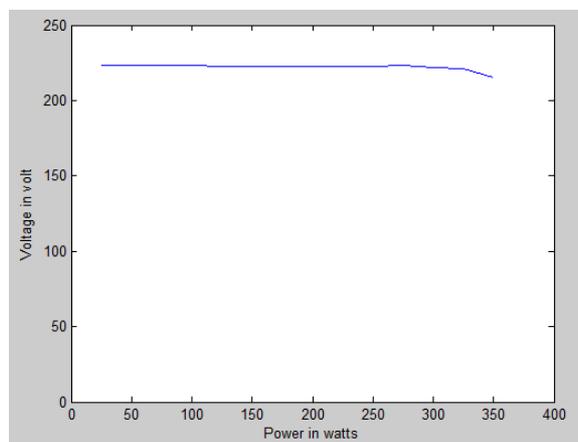


Fig. 13. V-P characteristics



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## VI. CONCLUSION

In this paper, a novel solar inverter system is proposed. A seven level ac output voltage is obtained with few numbers of switches. Size of the proposed 7 level inverter is reduced, in comparison with the existing conventional MLI for attaining same output level. The FFT analysis was conducted on the output ac voltage, which shows very low THD value. I-P, V-I and V-P characteristics shows the stability of this system for a variable resistive load.

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## BIOGRAPHY

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