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# 9-Level Inverter Using Pulse Width Modulation Technology

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## Abstract:

Single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10 kW. Types of single-phase grid-connected inverters have been investigated. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation. This project proposes a single-phase seven-level inverter for grid-connected photovoltaic systems, with a novel pulse width-modulated (PWM) control scheme. Three reference signals that are identical to each other with an offset that is equivalent to the amplitude of the triangular carrier signal were used to generate the PWM signals. The inverter is capable of producing seven levels of output-voltage levels ($V_{dc}$, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}/3$, $-2V_{dc}/3$, $-V_{dc}$) from the dc supply voltage. Multilevel inverters offer improved output waveforms and lower THD. The behaviour of the proposed multilevel inverter was analyzed in detail by using MATLAB. By controlling the modulation index, the desired number of levels of the inverter's output voltage can be achieved. The 7 level inverter output is compared with design of a nine level inverter. It requires an additional switch.

## I. Introduction:

The ever-increasing energy consumption, fossil fuels' soaring costs and exhaustible nature, and worsening global environment have created a booming interest in renewable energy generation systems, one of which is photovoltaic. Such a system generates electricity by converting the Sun's energy directly into electricity. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters. A single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10 kW. Types of single-phase grid-connected inverters have been investigated. A common topology of this inverter is full-bridge three-level. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence, also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation.

Multilevel inverters are promising; they have nearly sinusoidal output-voltage waveforms, output current with better harmonic profile, less stressing of electronic components owing to decreased voltages, switching losses that are lower than those of conventional two-level inverters, a smaller filter size, and lower EMI, all of which make them cheaper, lighter, and more compact. Various topologies for multilevel inverters have been proposed over the years. Common ones are diode-clamped, flying capacitor or multi cell, cascaded H-bridge and modified H-bridge multi level. This paper recounts the development of a novel modified H-bridge single-phase multilevel inverter that has two diode embedded bidirectional switches and a novel pulse width modulated (PWM) technique. The topology was applied to a grid-connected photovoltaic system with considerations for a maximum-power-point tracker (MPPT) and a current-control algorithm.

By using MPPT the maximum power point will be obtained and the simulated results are explained.

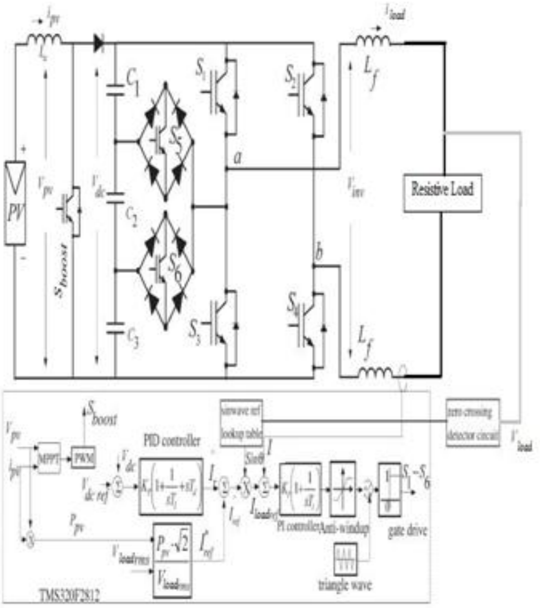

Figure 1.1: Seven-level inverter with closed-loop control algorithm

## II. PHOTOVOLTAIC SYSTEM:

### Photovoltaic Effect:

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels comprising a number of cells containing a photovoltaic material. Materials presently used for photovoltaic include mono crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride and copper indium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. As of 2010, solar photovoltaic generates electricity in more than 100 countries and while yet comprising a tiny fraction of the 4800 GW total global power-generating capacity from all sources, it is the fastest growing power-generation technology in the world. Between 2004 and 2009, Grid-connected PV capacity increased at an annual average rate of 60 percent, to some 21 GW. Such installations may be ground-mounted (and sometimes integrated with farming and grazing) or built into the roof or walls of a building, known as Building Integrated Photovoltaic's or BIPV for short. Off-grid PV accounts for an additional 3–4 GW. Driven by advances in technology and increases in manufacturing scale and sophistication, the cost of photovoltaic has declined steadily since the first solar cells were manufactured. Net metering and financial incentives, such as preferential feed-in tariffs for solar-generated electricity; have supported solar PV installations in many countries. The photovoltaic effect is the generation of a voltage (or a corresponding electric current) in a material upon exposure to light. Though the photovoltaic effect is directly related to the photoelectric effect, the two processes are different and should be distinguished. In the photoelectric effect, electrons are ejected from a material's surface upon exposure to radiation of sufficient energy. The photovoltaic effect is different in that the generated electrons are transferred between different bands (i.e. from the valence to conduction bands) within the material, resulting in the buildup of a voltage between two electrodes. In most photovoltaic applications the radiation is sunlight and for this reason the devices are known as solar cells. In the case of a p-n junction solar cell, illumination of the material results in the generation of an electric current as excited electrons and the remaining holes are swept in different directions by the built-in electric field of the depletion region. The photovoltaic effect was first observed by Alexandre-Edmond Becquerel in 1839.

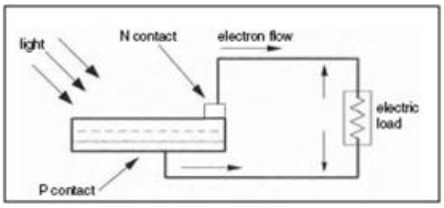

Fig 2.1: PV effect converts the photon energy into voltage across the p-n junction

As of October 2010, the largest photovoltaic (PV) power plants in the world are the Sarnia Photovoltaic Power Plant (Canada, 80 MW), the Olmedilla

Photovoltaic Park (Spain, 60 MW), the Strasskirchen Solar Park (Germany, 54 MW), the Lieberose Photovoltaic Park (Germany, 53 MW), the Puertollano Photovoltaic Park (Spain, 50 MW), the Moura photovoltaic power station (Portugal, 46 MW), and the Waldpolenz Solar Park (Germany, 40 MW).

## Equivalent Circuit:

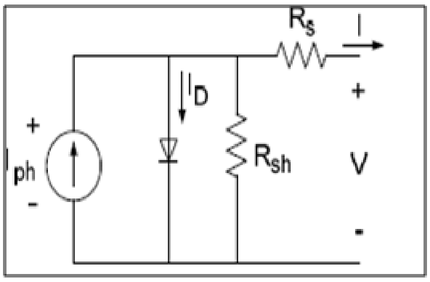

Fig 2.2: PV cell equivalent circuit

The complex physics of the PV cell can be represented by the equivalent electrical circuit. The circuit parameters are as follows. The series resistance $R_s$ represents the internal resistance to the current flow, and depends on the pn-junction depth, impurities, and contact resistance. The shunt resistance $R_{sh}$ is inversely related to the leakage current to ground. In an ideal PV cell, $R_s = 0\Omega$ (no series loss) and $R_{sh}=\infty$(no leakage to ground). In a typical high-quality silicon cell, Rs varies from 0.05 to 0.10 Ω and $R_{sh}$ from 200 to 300Ω. The PV conversion efficiency is sensitive to small variations in $R_s$, but is insensitive to variations in $R_{sh}$. A small increase in $R_s$ can decrease the PV output significantly

## III. INVERTER:

### Introduction to Inverters:

D.C.-A.C. inverters are electronic devices used to produce mains voltage A.C. power from low voltage D.C. energy (from a battery or solar panel). This makes them very suitable for when you need to use A.C. power tools or appliances but the usual A.C. mains power is not available. Examples include operating appliances in caravans and mobile homes, and also running audio, video and computing equipment in remote areas. Most inverters do their job by performing two main functions: first they convert the incoming D.C. into A.C., and then they step up the resulting A.C. to mains voltage level using a transformer. And the goal of the designer is to have the inverter perform these functions as efficiently as possible so that as much as possible of the energy drawn from the battery or solar panel is converted into mains voltage A.C., and as little as possible is wasted as heat**.** Square-wave or quasi- wave voltages may be acceptable for low and medium power applications, and for high applications low-distorted, sinusoidal waveforms are required. The output frequency of an inverter is determined by the rate at which the semi conductor devices are switched on and off by the inverter control circuitry and consequently, an adjustable frequency A.C. output is readily provided. The harmonic contents of output voltage can be minimized or reduced significantly by switching techniques of available high speed power semiconductor devices. The D.C. power to the inverter may be battery, fuel cell, solar cells or other D.C. source .But in most industrial applications it is fed by rectifier. This configuration of A.C. to D.C. converter and D.C. to A.C. inverter is called a D.C. link. The main objective of static power converters is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static var compensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications.

### Proposed Multilevel Inverter Topology:

The proposed single-phase seven-level inverter was developed from the five-level inverter. It comprises a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by $C_1$, $C_2$, and $C_3$. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitors for inverters of the same number of levels. Photovoltaic (PV) arrays were connected to the inverter via a dc–dc boost converter.

The power generated by the inverter is to be delivered to the power network, so the utility grid, rather than a load, was used. The DC–DC boost converter was required because the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the grid. A filtering inductance $L_f$ was used to filter the current injected into the grid. Proper switching of the inverter can produce seven output-voltage levels ($V_{dc}$, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}$, $-2V_{dc}/3$, $-V_{dc}/3$) from the dc supply voltage The proposed inverter's operation can be divided into seven switching states, as shown in Fig. 4.6 – 4.12. Fig.4.6, 9, and 12 shows a conventional inverter's operational states in sequence, while Fig.4.7, 8, 10, and 11 shows additional states in the proposed inverter synthesizing one- and two-third levels of the DC-bus voltage. The required seven levels of output voltage were generated as follows

### 3.1 Maximum positive output ($V_{dc}$):

$S_1$ is ON, connecting the load positive terminal to $V_{dc}$, and $S_4$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $V_{dc.}$ Fig. 4.6 shows the current paths that are active at this stage. Depending upon the switching operation the output voltage will be controlled and in any inverter topology any two switches will be operated for the required output voltage. And the current paths also shown in the figure and it will operated depending upon the required switching operation of the inverter circuit. The load voltage is positive so the output voltage also positive only depending upon the switching states of the inverter circuit.

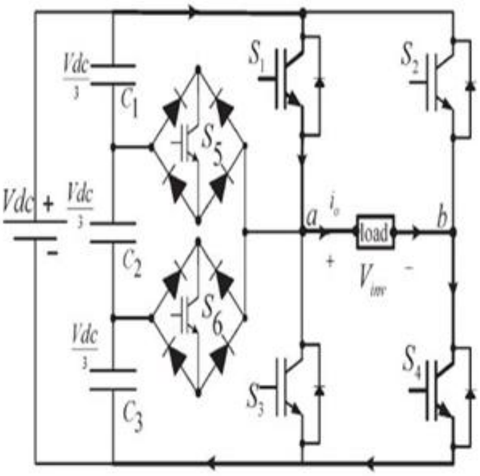

Fig 3.1 Inverter circuit for the output voltage ($V_{dc}$)

### 3.2 Two-third positive output ($2V_{dc}/3$):

The bidirectional switch $S_5$ is ON, connecting the load positive terminal, and $S_4$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $2V_{dc}/3$. Fig. 4.7 shows the current paths that are active at this stage.

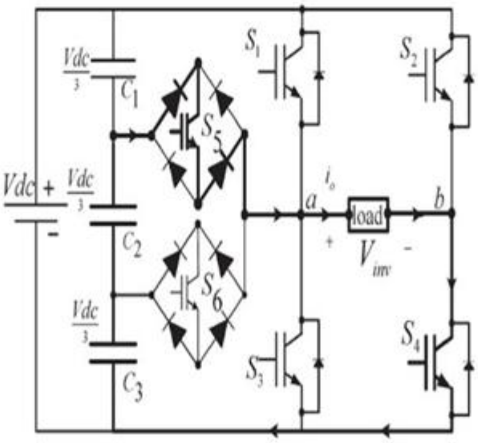

Fig 3.2 Inverter circuit for the output voltage ($2V_{dc}/3$)

### 3.3 One-third positive output ($V_{dc}/3$):

The bidirectional switch $S_6$ is ON, connecting the load positive terminal, and $S_4$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $V_{dc}/3$. Fig. 4.8 shows the current paths that are active at this stage.

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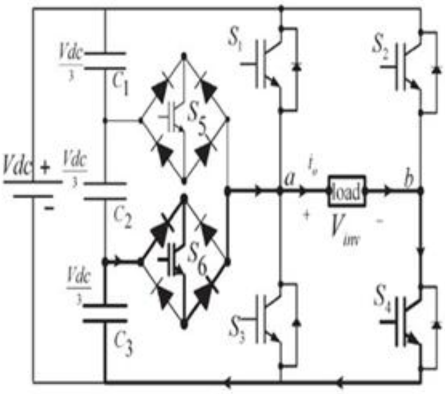

Fig 3.3 Inverter circuit for the output voltage ($V_{dc}/3$)

### 3.4 Zero output:

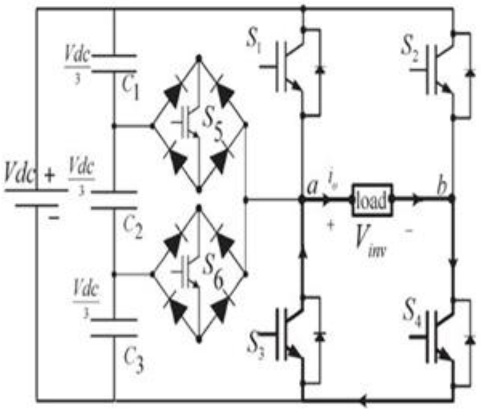

Fig 3.4 Inverter circuit for the output voltage (zero 0)

This level can be produced by two switching combinations; switches $S_3$ and $S_4$ are ON, or $S_1$ and $S_2$ are ON, and all other controlled switches are OFF; terminal ab is a short circuit, and the voltage applied to the load terminals is zero. Fig. 4.9 shows the current paths that are active at this stage. And the current paths also shown in the figure and it will operated depending upon the required switching operation of the inverter circuit. The load voltage is positive so the output voltage also positive only depending upon the switching states of the inverter circuit. Depending upon the switching operation the output voltage will be controlled and in any inverter topology any two switches will be operated for the required voltage becomes zero.

### 3.5 One-third negative output ($-V_{dc}/3$):

The bidirectional switch $S_5$ is ON, connecting the load positive terminal, and $S_2$ is ON, connecting the load negative terminal to $V_{dc}$. All other controlled switches are OFF; the voltage applied to the load terminals is $-V_{dc}/3$. Fig. 4.10 shows the current paths that are active at this stage.

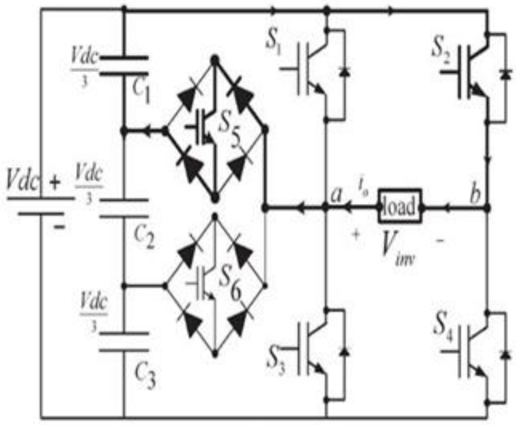

Fig 3.5 Inverter circuit for the output voltage ($-V_{dc}/3$)

### 3.6 Two-third negative output ($-2V_{dc}/3$):

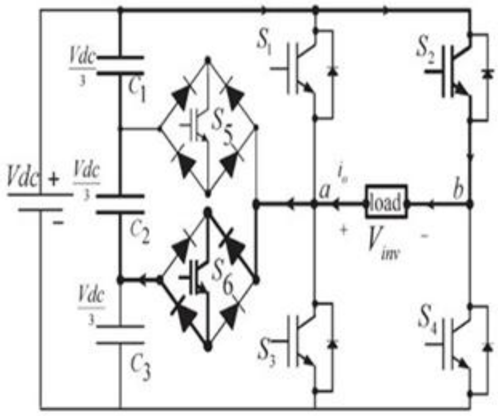

Fig 3.6 Inverter circuit for the output voltage ($-2V_{dc}/3$)

The bidirectional switch $S_6$ is ON, connecting the load positive terminal, and $S_2$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $-2V_{dc}/3$. Fig. 4.11 shows the current paths that are active at this stage.

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### 3.7 Maximum negative output ($-V_{dc}$):

$S_2$ is ON, connecting the load negative terminal to $V_{dc}$, and $S_3$ is ON, connecting the load positive terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $-V_{dc}$. Fig. 4.12 shows the current paths that are active at this stage. Depending upon the switching operation the output voltage will be controlled and in any inverter topology any two switches will be operated for the required output voltage. And the current paths also shown in the figure and it will operated depending upon the required switching operation of the inverter circuit. The load voltage is positive so the output voltage also positive only depending upon the switching states of the inverter circuit. Here the load current is the negative value so the output current also negative.

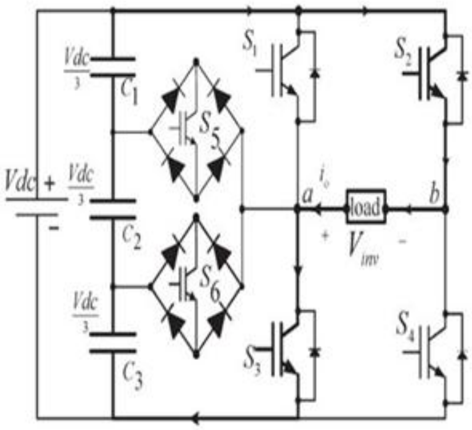

Fig 3.8 Inverter circuit for the output voltage ($-V_{dc}$)

| $v_0$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| $V_{dc}$ | on | off | off | on | off | off |
| $2V_{dc}/3$ | off | off | off | on | on | off |
| $V_{dc}/3$ | off | off | off | on | off | on |
| 0 | off | off | on | on | off | off |
| 0* | on | on | off | off | off | off |
| $-V_{dc}/3$ | off | on | off | off | on | off |
| $-2V_{dc}/3$ | off | on | off | off | off | on |
| $-V_{dc}$ | off | on | on | off | off | off |

Table 3.9 Output voltage according to the switches on–off condition

Table shows the switching combinations that generated the seven output-voltage levels ($0, -V_{dc}, -2V_{dc}/3, -V_{dc}/3, V_{dc}, 2V_{dc}/3, V_{dc}/3$).

## VI CONTROL STRATEGY:

### 4 Introduction:

As Fig. 5.1 shows, the control system comprises a MPPT algorithm, a dc-bus voltage controller, reference-current generation, and a current controller. The two main tasks of the control system are maximization of the energy transferred from the PV arrays to the grid, and generation of a sinusoidal current with minimum harmonic distortion, also under the presence of grid voltage harmonics. The proposed inverter utilizes the perturb-and-observe (P&O) algorithm for its wide usage in MPPT owing to its simple structure and requirement of only a few measured parameters. It periodically perturbs (i.e., increment or decrement) the array terminal voltage and compares the PV output power with that of the previous perturbation cycle. If the power was increasing, the perturbation would continue in the same direction in the next cycle; otherwise, the direction would be reversed. This means that the array terminal voltage is perturbed every MPPT cycle; therefore, when the MPP is reached, the P&O algorithm will oscillate around it.

The P&O algorithm was implemented in the dc–dc boost converter. The output of the MPPT is the duty-cycle function. As the dc-link voltage $V_{dc}$ was controlled in the AC-DC seven level PWM inverter, the change of the duty cycle changes the voltage at the output of the PV panels. A PID controller was implemented to keep the output voltage of the DC–DC boost converter ($V_{dc}$) constant by comparing $V_{dc}$ and $V_{dcref}$ and feeding the error into the PID controller, which subsequently tries to reduce the error. In this way, the $V_{dc}$ can be maintained at a constant value and at more than $\sqrt{2}$ of $V_{load}$ to deliver power to the load. To deliver energy to the grid, the frequency and phase of the PV inverter must equal those of the grid; therefore, a grid synchronization method is needed. The sine lookup table that generates reference current must be brought into phase with the grid voltage ($V_{load}$). For this, the grid period and phase must be detected.

The overall response is controlled under this block and the different PID controllers are used for the generation of the sinusoidal signal and the sine lookup table and zero crossing detector are used for the sinusoidal signal. The overall response is controlled under the closed loop conditions to get the accurate output.

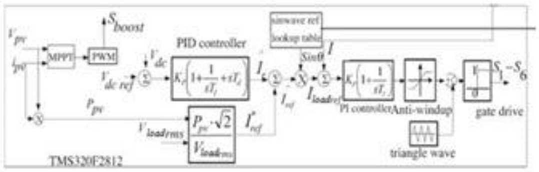

**Fig 4.1 closed-loop control algorithm**

## V SIMULATION RESULTS

### 5.1 Block Diagrams:

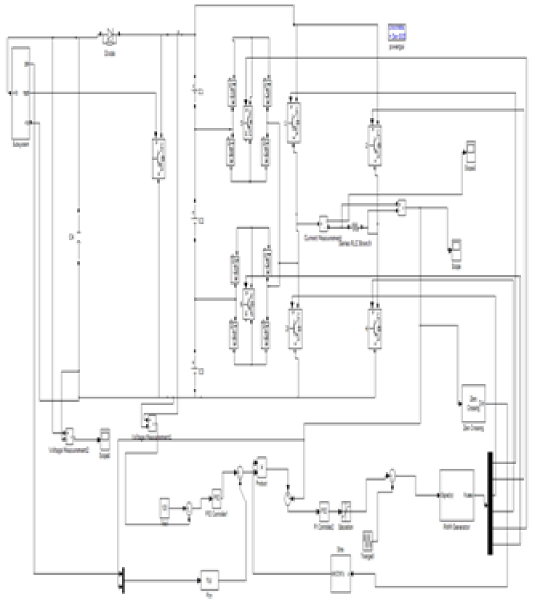

**Fig 5.1 Main MATLAB/SimuLink Block diagram**

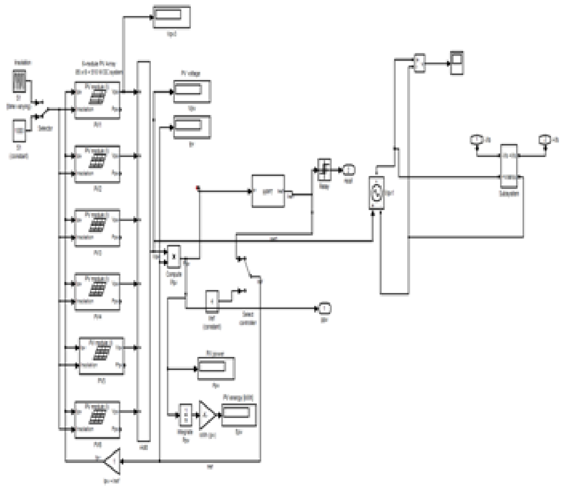

**Fig 5.2 Internal PV Block Diagram**

### 5.2 Subsystem of PV module:

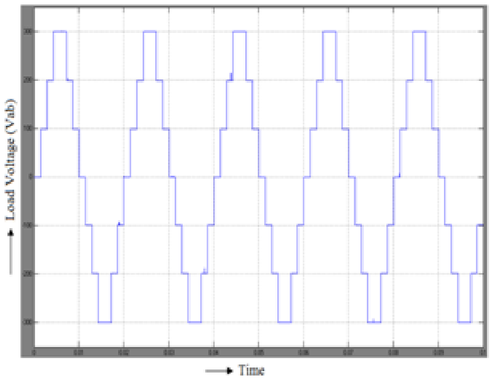

**Fig 5.2 Seven levels of Inverter output voltage ($V_{inv}$)**

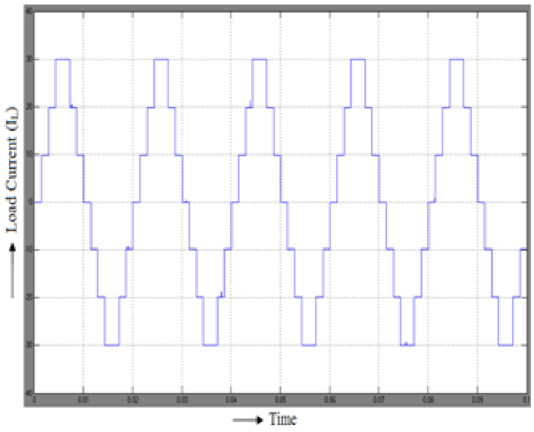

**Fig 5.4 Seven levels of Inverter output current ($I_{inv}$) For R=10Ω**

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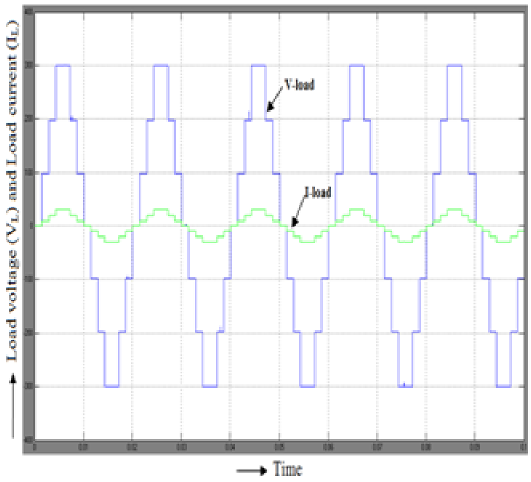

Fig 5.5 Load voltage ($V_{Load}$) and Load current ($I_{Load}$) that are in phase

**For R=100Ω**

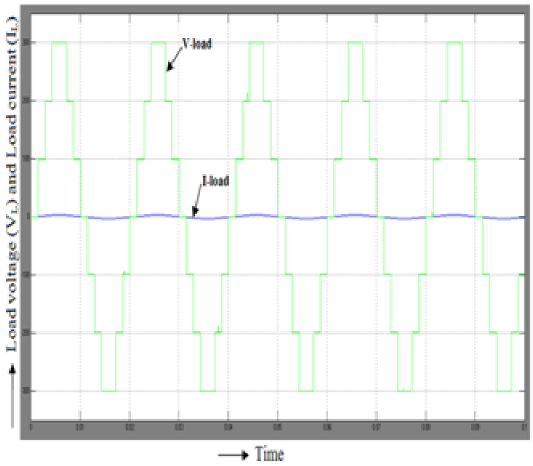

Fig 5.6 Load voltage ($V_{Load}$) and Load current ($I_{Load}$) that are in phase

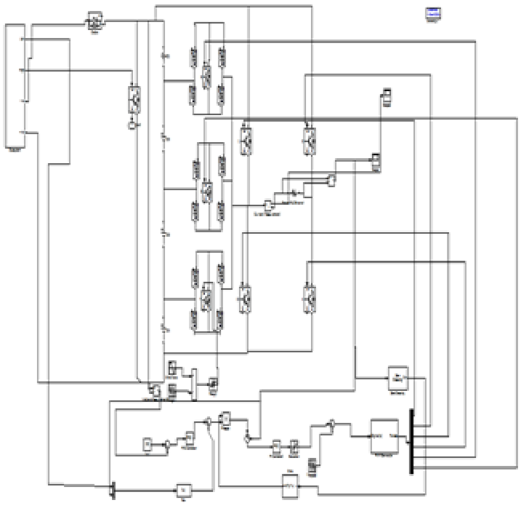

Fig 5.7 Nine level inverter

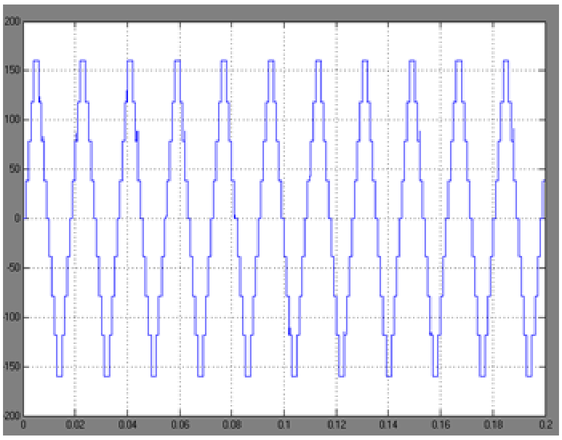

Fig 5.8 Nine level inverter output voltage

## VI CONCLUSION:

Multilevel inverters offer improved output waveforms and lower THD. This project has presented a novel PWM switching scheme for the proposed multilevel inverter. It utilizes three reference signals and a triangular carrier signal to generate PWM switching signals. The behavior of the proposed multilevel inverter was analyzed in detail. By controlling the modulation index, the desired number of levels of the inverter's output voltage can be achieved. The less THD in the seven-level inverter is an attractive solution for grid-connected PV inverters. By using this seven level inverter we can improve the overall response of the system with the less number of switching states and the reliable operation. By increasing the number of levels we can decrease the Total Harmonic Distortion (THD) and to get the exact sinusoidal output , and by using the less number of switches we can get the 9-level, 11-level, and 48-level output distortions less by this the THD will be minimized. Lower the THD means the output Efficiency is more.By comparing the thd of seven and nine level we can conclude that by increasing the level the harmonics can be reduced.

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