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A futuristic digital interface with a glowing Earth globe in the center. The background is dark blue with various data visualizations including bar charts, line graphs, and network diagrams. Text elements like 'BUSINESS', 'NETWORK SEARCH', and 'LORDING 100%' are visible. The overall aesthetic is high-tech and data-driven.

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# Single Phase Multilevel Grid Connected Inverter for Photovoltaic System

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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 behavior 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 7level inverter output is compared with design of a 11level inverter.

**KEYWORDS:** PI&PID Controllers, H-Bridge inverters, Photo voltaic effect, Choppers, Pulse width modulation

## I. INTRODUCTION

### 1.1 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.

The D.C. power to the inverter may be battery, fuelcell,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.

### 1.2 Classification of Inverters

Inverters can be classified on the basis of a number of factors:

(a) **Classification according to the Nature of Input Source**

- Voltage Source Inverters (VSI)
- Current Source Inverters (CSI)

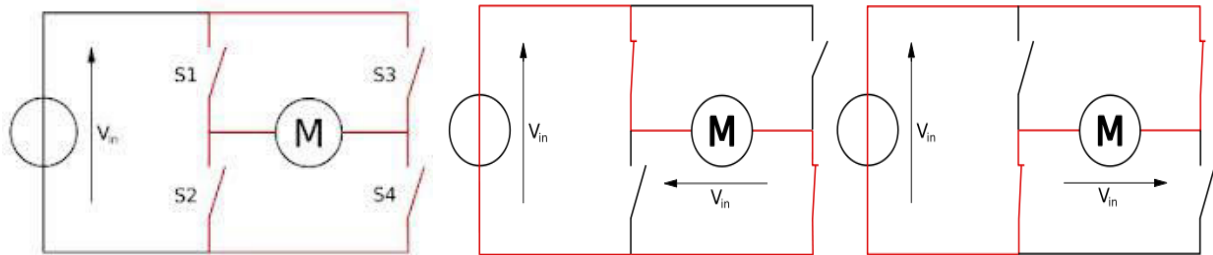
(b) **Classification according to the Wave shape of the Output voltage**

- Square-wave Inverter
- Pulse-width modulated (PWM) Inverter

### 1.3. H-Bridge Inverters

An H bridge is an electronic circuit that enables a voltage to be applied across a load in either direction. These circuits are often used in robotics and other applications to allow DC motors to run forwards and backwards.

The term H bridge is derived from the typical graphical representation of such a circuit. An H bridge is built with four switches (solid-state or mechanical).



**Fig.1.1. Block diagram of H-bridge Inverter. Fig 1.2. Operational diagram of H-Bridge inverter**

When the switches S1 and S4 (according to the first figure) are closed (and S2 and S3 are open) a positive voltage will be applied across the motor. By opening S1 and S4 switches and closing S2 and S3 switches, this voltage is reversed, allowing reverse operation of the motor.

**Fig 1.2. Operational diagram of H-Bridge inverter**

The following table summarizes operation, with S1-S4 corresponding to the diagram.

S1	S2	S3	S4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor free runs
0	1	0	1	Motor brakes
1	0	1	0	Motor brakes
1	1	0	0	Shoot-through
0	0	1	1	Shoot-through
1	1	1	1	Shoot-through

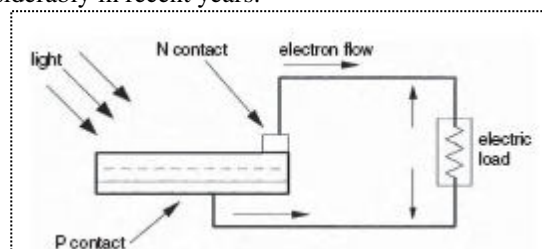
**Table.1.1. switching operation of H-bridge Inverter**

The arrangement is sometimes known as a single-phase bridge inverter. The H bridge with a DC supply will generate a square wave voltage waveform across the load.

## II. PHOTOVOLTAIC SYSTEM

### 2.1 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.[1] Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.



**Fig 2.1: PV effect converts the photon energy into voltage across the pn junction**



III. CHOPPERS

A chopper is a static device which is used to obtain a variable dc voltage from a constant dc voltage source. A chopper is also known as dc-to-dc converter. The thyristor converter offers greater efficiency, faster response, lower maintenance, smaller size and smooth control. Choppers are widely used in trolley cars, battery operated vehicles, traction motor control, control of large number of dc motors, etc.

Choppers are of two types:

- > Step-down choppers
- > Step-up choppers

1 Principle Of STEP\_DOWN Chopper:

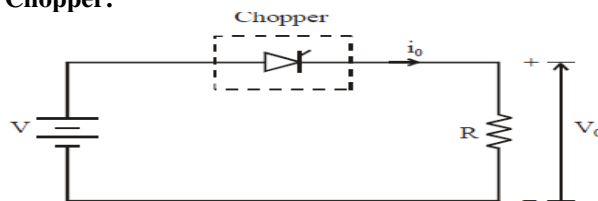


Fig. 3.1: Step-down Chopper with Resistive Load

The thyristor in the circuit acts as a switch. When thyristor is ON, supply voltage appears across the load and when thyristor is OFF, the voltage across the load will be zero. The output voltage and current waveforms are as shown in figure 3.2.

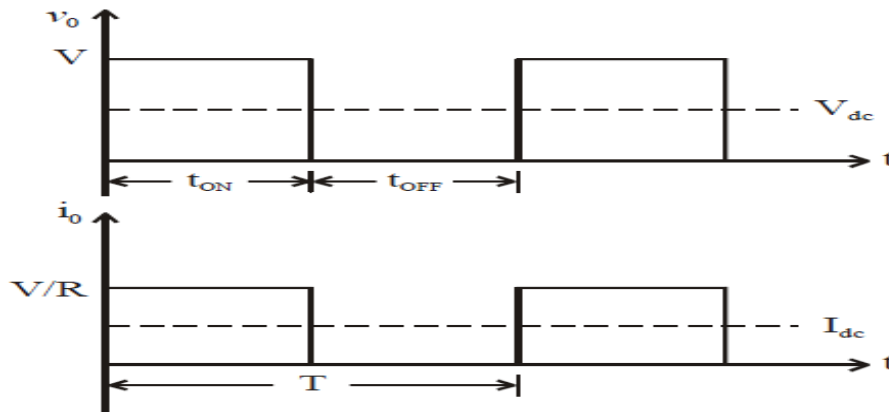


Fig. 3.2: Step-down choppers — output voltage and current waveforms

3.1.1 Expression For Output Voltage:

$V_{dc}$  = average value of output or load voltage

$I_{dc}$  = average value of output or load current

$t_{ON}$  = time for which SCR is ON

$t_{OFF}$  = time interval for which SCR is OFF

$T = t_{ON} + t_{OFF}$  = period of switching or chopping period

$f = 1/T$  = frequency of chopper switching or chopper frequency

Average output voltage

$V_{dc} = V(t_{on}/t_{on}+t_{off})$  ..... 3.1

$V_{dc} = V(t_{ON}/T) = Vd$  ..... 3.2



But  $(t_{ON}/T)=d$ =duty cycle ..... 3.3

Average output current

$$I_{dc}=V_{dc}/r \quad \dots\dots\dots 3.4$$

$$I_{dc}=(v/r)d \quad \dots\dots\dots 3.5$$

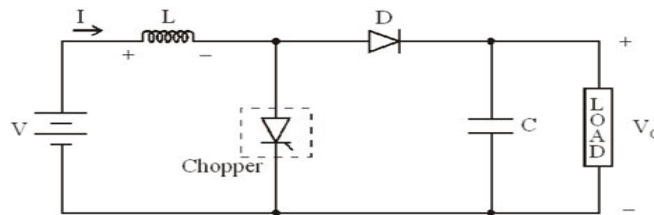
RMS value of output voltage

$$V_0 = \sqrt{\frac{1 \int_0^{t_{ON}} v^2 dt}{T}}$$

$$V_0 = \sqrt{\frac{V^2 t_{ON}}{T}}$$

$$V_0 = \sqrt{d} \cdot V$$

**3.2 Principle Of STEP UP Chopper:**



**Fig.3.3 Step up chopper**

**3.2.1 Expression For Output Voltage:**

Where T=Chopping period or period of switching

$$T=t_{on}+t_{off}$$

$$V_0 = V \left( \frac{1}{1 - \frac{t_{ON}}{T}} \right)$$

Therefore  $V_o=V(1/1-d) \quad \dots(2.29)$

Where  $d=t_{ON}/T$  =duty cycle.

For variation of duty cycle ‘d’ in the range of  $0 < d < 1$ , the output voltage  $V_o$  will vary in the range  $V < V_o < \infty$

**IV. PULSE WIDTH MODULATION:**

**4.1 Two-Level PWM**

The most common and popular technique of digital pure-sine wave generation is pulse-width-modulation (PWM). The PWM technique involves generation of a digital waveform, for which the duty-cycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave. The simplest way of producing the PWM signal is through



comparison of a low-power reference sine wave with a triangle wave. Using these two signals as input to a comparator, the output will be a 2-level PWM signal. This PWM signal can then be used to control switches connected to a high-voltage bus, which will replicate this signal at the appropriate voltage. Put through an LC filter, this PWM signal will clean up into a close approximation of a sine wave. Though this technique produces a much cleaner source of AC power than either the square or modified sine waves, the frequency analysis shows that the primary harmonic is still truncated, and there is a relatively high amount of high-level harmonics in the signal

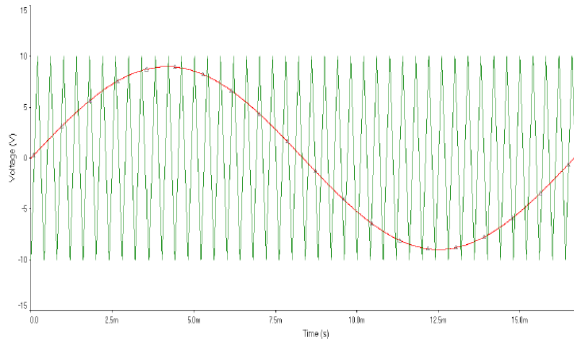


Figure 4.1: 2-Level PWM Comparison Signals

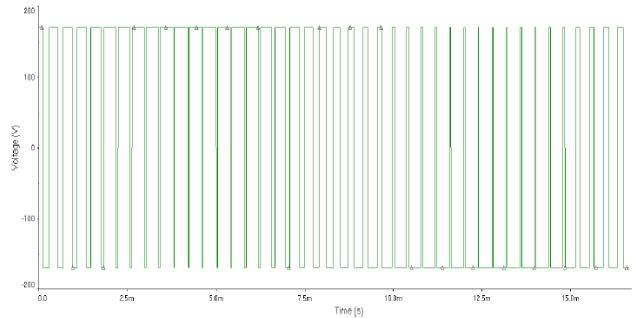


Figure 4.2: 2-Level PWM Output (Unfiltered)

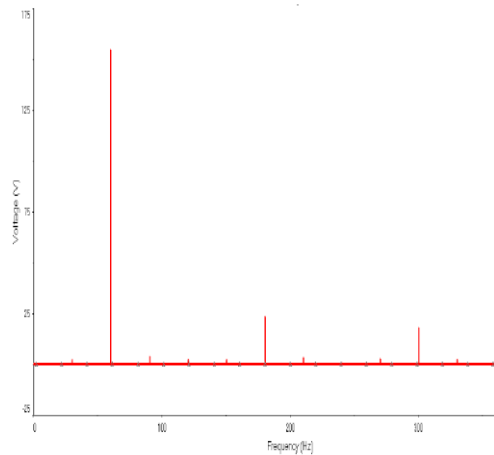


Figure 4.3: 2-Level PWM Harmonic Analysis

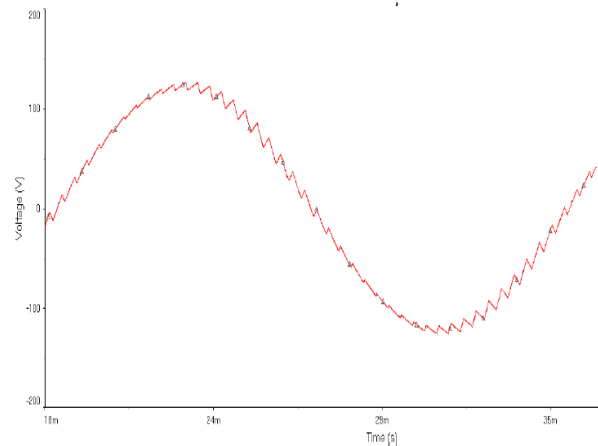


Figure 4.4: 2-Level PWM Output (Filtered)

## 4.5.CONTROLLERS

### 4.5.1..PI Controller

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used. The controller output is given by

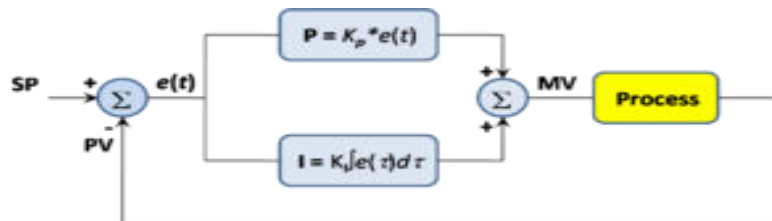


Fig 5.3 Block Diagram of PI Controller

$$K_p \Delta + K_I \int \Delta dt$$

where  $\Delta$  is the error or deviation of actual measured value ( $PV$ ) from the setpoint ( $SP$ ).

$$\Delta = SP - PV$$

A PI controller can be modeled easily in software such as Simulink or Xcos using a "flow chart" box involving Laplace operators:

$$C = \frac{G(1 + \tau s)}{\tau s}$$

where

$G=K_p$  = proportional gain

$G/\tau = K_i$  = integral gain

**4.5.2.PID Controller:** A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs.

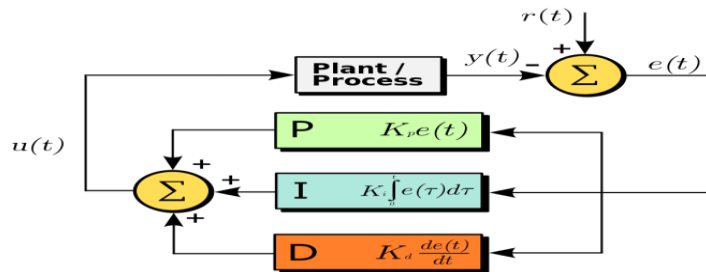


Fig 5.4 Block diagram of a PID controller

$$u(t)=MV(t)=K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$$

where

$K_p$ : Proportional gain, a tuning parameter

$K_i$ : Integral gain, a tuning parameter

$K_d$ : Derivative gain, a tuning parameter

e: Error  $SP - PV$

t: Time or instantaneous time (the present)

$\tau$ : Variable of integration; takes on values from time 0 to the present t.

**CIRCUIT DIAGRAM OF SEVEN LEVEL INVERTER:**

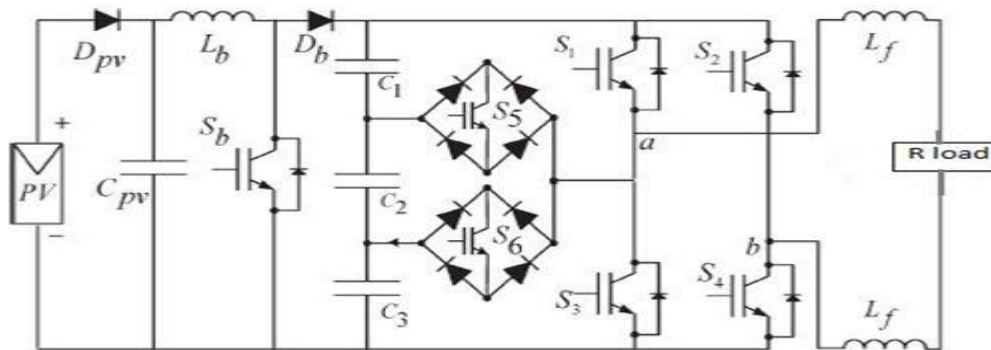


Fig: Single phase seven-level grid-connected inverter for photovoltaic system

**Operation:**

- Operates in seven modes to give seven level outputs.

The seven voltage levels are  $V_{dc}$ ,  $V_{dc}/3$ ,  $2V_{dc}/3$ ,  $0$ ,  $-V_{dc}/3$ ,  $-2V_{dc}/3$ ,  $-V_{dc}$ .

OUTPUT VOLTAGE ACCORDING TO THE SWITCHES' ON-OFF CONDITION

$v_0$	$S_1$	$S_2$	$S_3$	$S_4$	$S_5$	$S_6$
$V_{dc}$	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

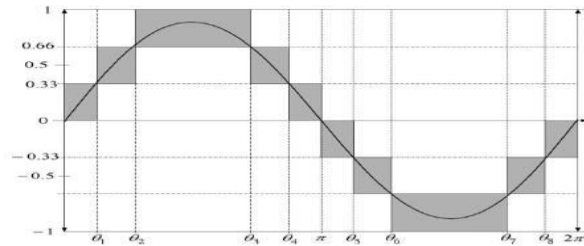


Fig: output waveform

**V. CONTROL SYSTEM**

**5.1 Controlling in Seven Level Inverter**

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.

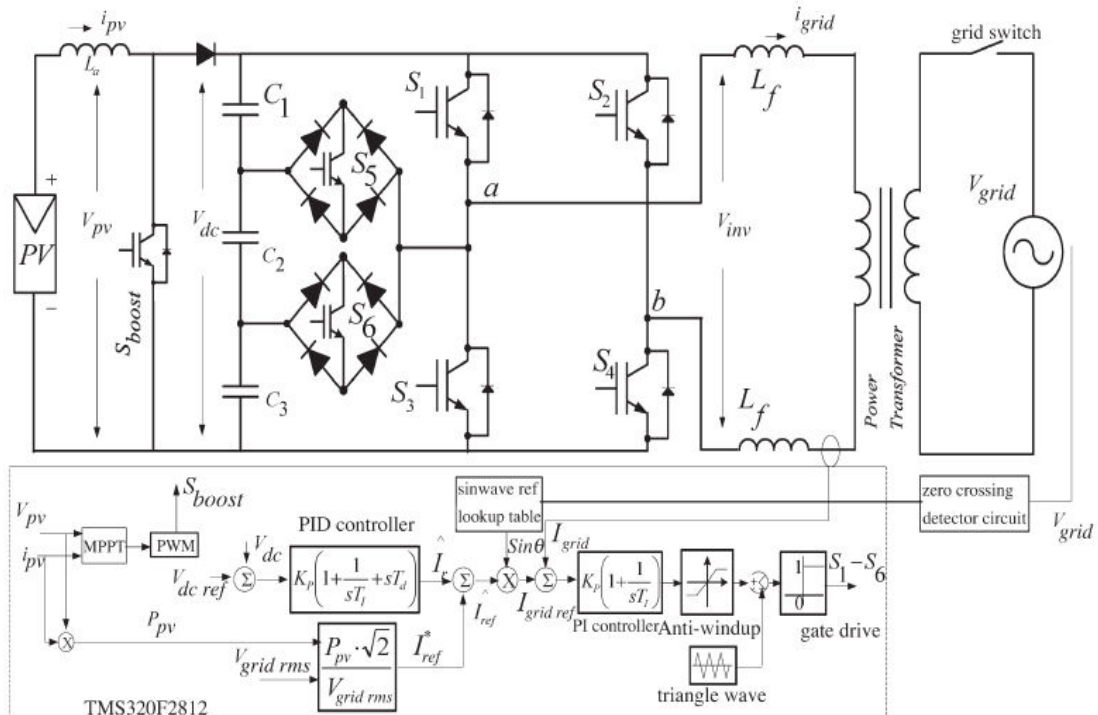
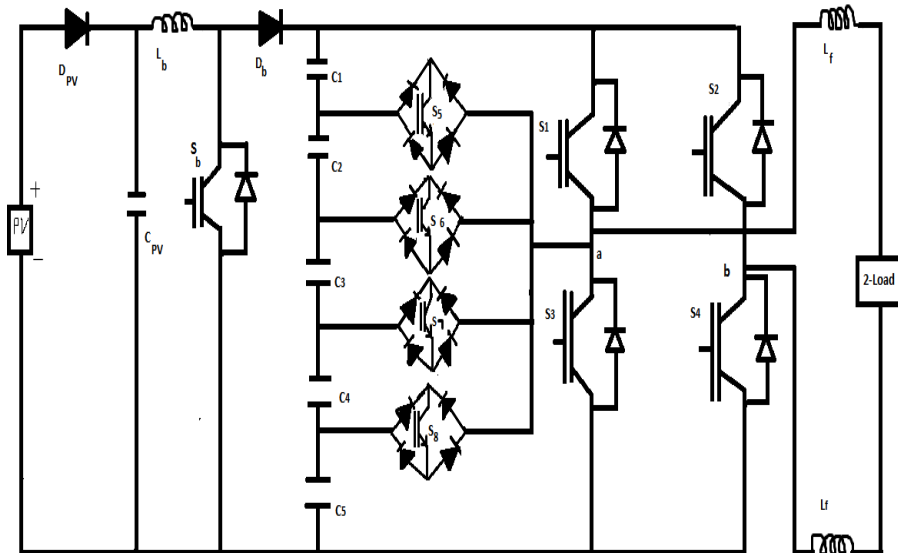


Fig. 5.1. Seven-level inverter with closed-loop control algorithm.





Circuit Diagram of Proposed 11 Level Inverter



Switching Operation

S1	S2	S3	S4	S5	S6	S7	S8	V0
1	0	0	1	0	0	0	0	$V_{dc}/5$
0	0	0	1	1	0	0	0	$4V_{dc}/5$
0	0	0	1	0	1	0	0	$3V_{dc}/5$
0	0	0	1	0	0	1	0	$2V_{dc}/5$
0	0	0	1	0	0	0	1	$V_{dc}$
0or1	1or0	0or1	1or0	0	0	0	0	0
0	0	1	0	0	0	0	1	$-V_{dc}$
0	0	1	0	0	0	1	0	$-2V_{dc}/5$
0	0	1	0	0	1	0	0	$-3V_{dc}/5$
0	0	1	0	1	0	0	0	$-4V_{dc}/5$
0	1	1	0	0	0	0	0	$-V_{dc}/5$

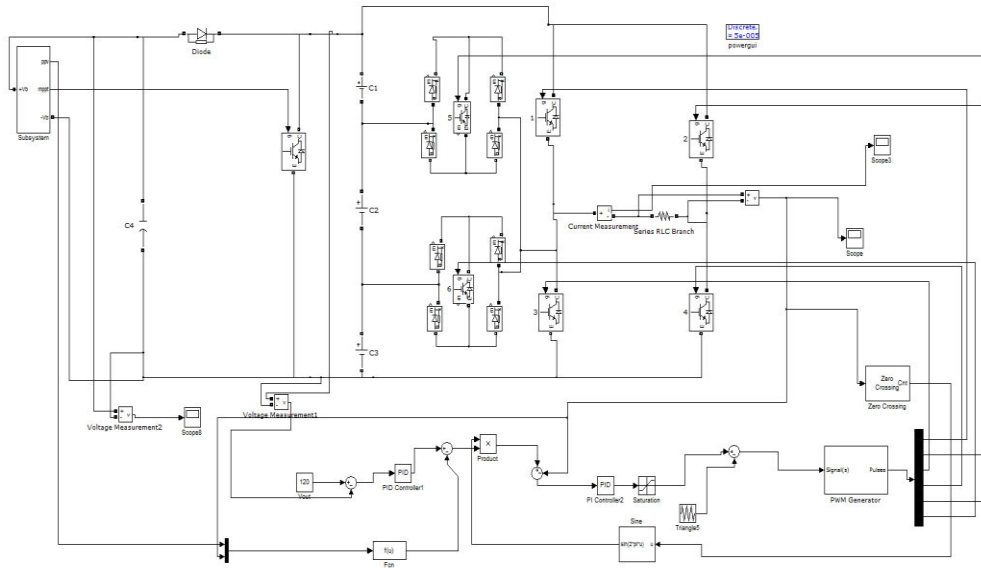


Fig. 6.1. Block diagram of single phase seven level grid connected inverter for photovoltaic system.

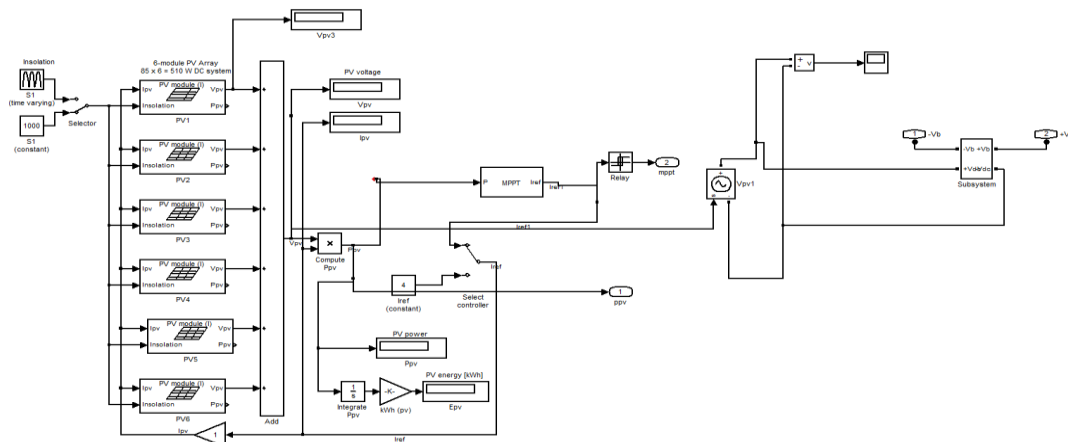


Fig. 6.2. System of PV module.

Subsystem of PV module

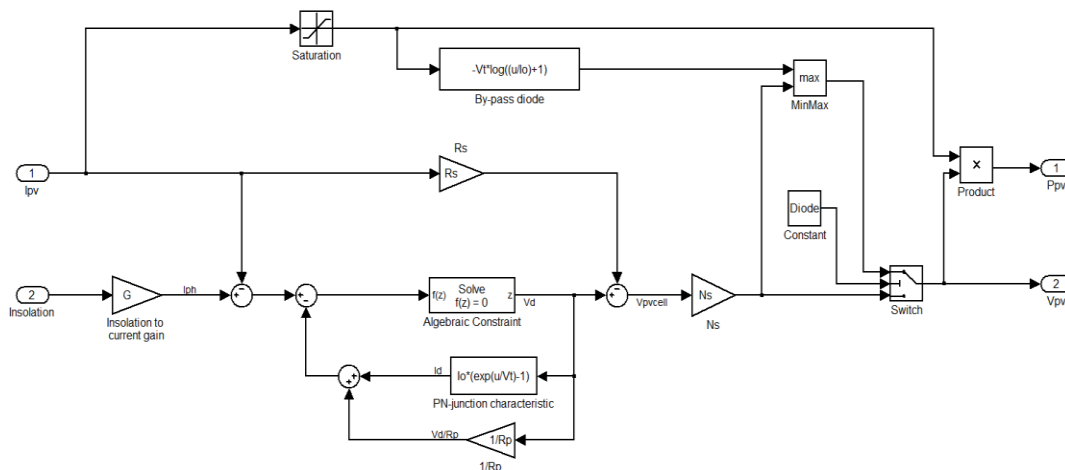


Fig. 6.3. Sub system of PV module.

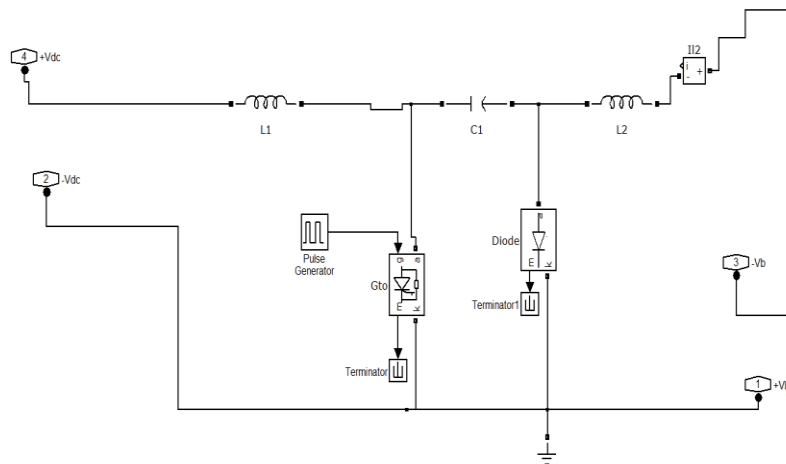


Fig. 6.4. System of chopper.

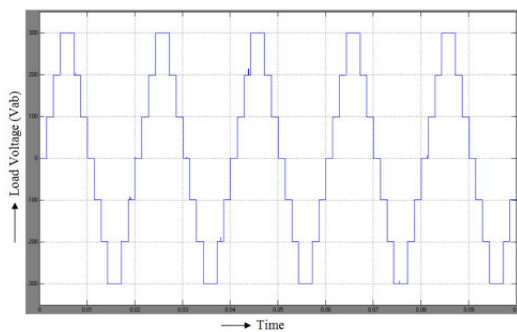


Fig.6.5.seven levels of Inverter output voltage

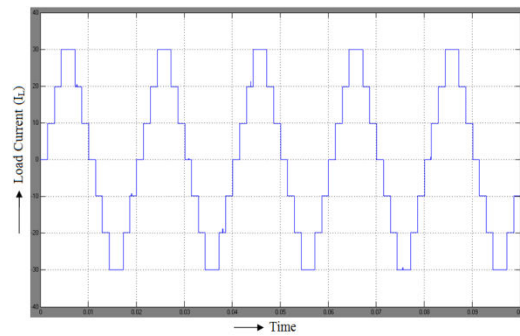


Fig.6.6. seven levels of Inverter output

( $V_{inv}$ ). current ( $I_{inv}$ ).

For  $R=10\Omega$

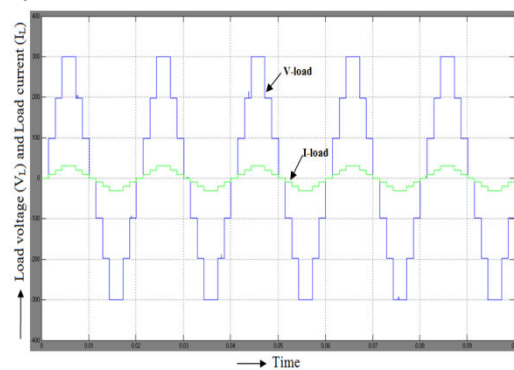


Fig.6.7. Load voltage ( $V_{Load}$ )

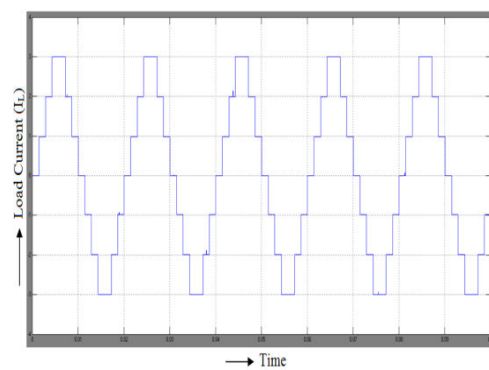


Fig. 6.8. Inverter output current ( $I_{inv}$ ).

Load current ( $I_{Load}$ ) that are in phase for  $R=100\Omega$

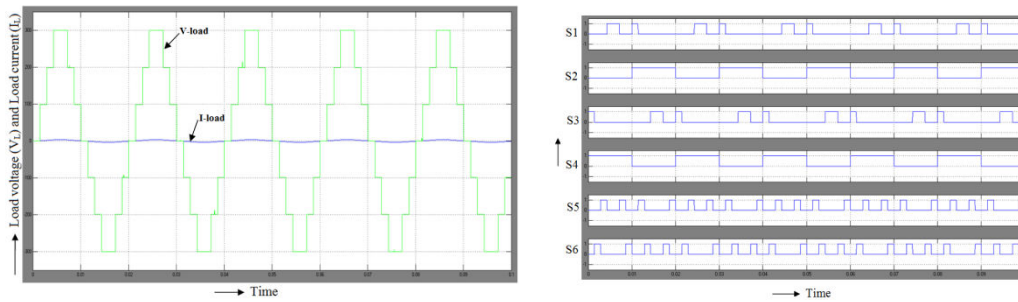


Fig. 6.9. Load voltage ( $V_{Load}$ ) and Load current Fig.6.10. Switching pattern for the single- $(I_{Load})$  that are in phase phase seven-level inverter.

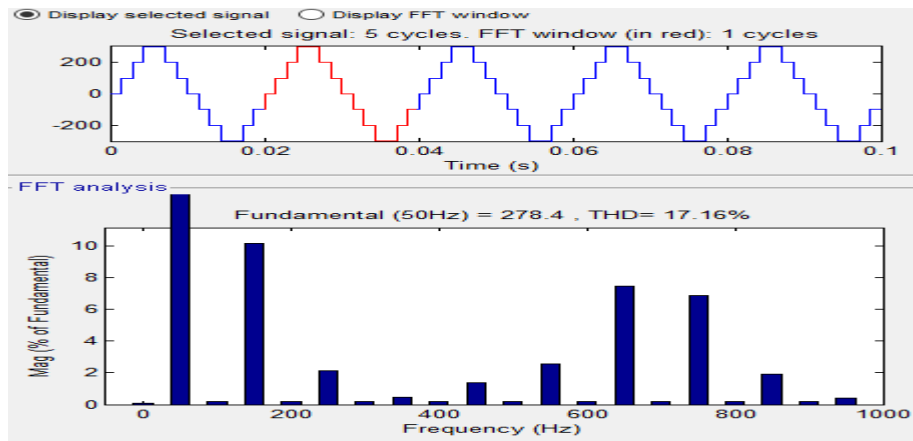


Fig. 6.11. THD for seven level inverter

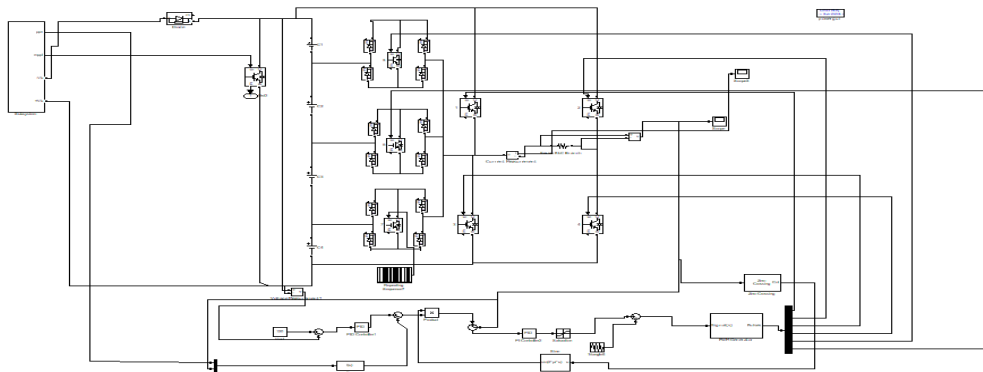


Fig 6.12. Nine level inverters

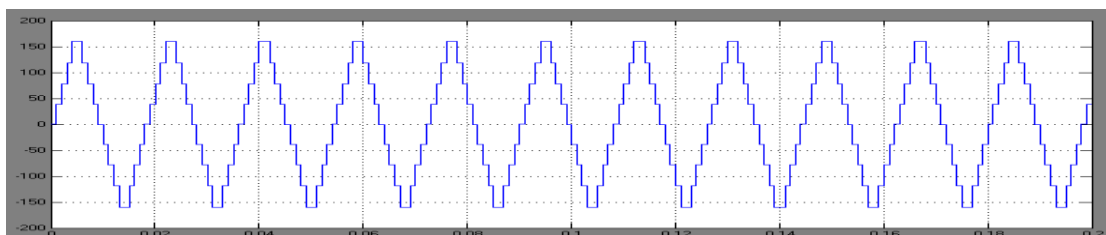


Fig 6.13 Nine level inverter output voltage

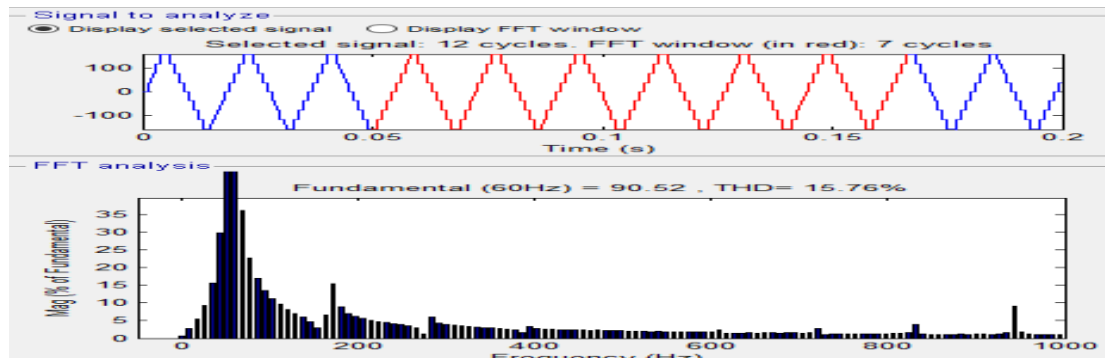


Fig. 6.14. THD for nine level inverters

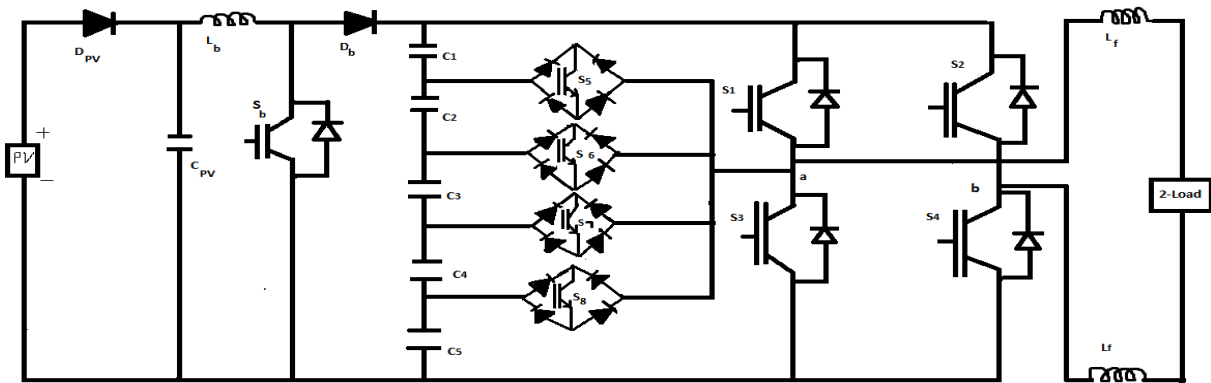


Fig 6.15 Circuit Diagram of Proposed 11 Level Inverter

Switching Operation:

S1	S2	S3	S4	S5	S6	S7	S8	V0
1	0	0	1	0	0	0	0	Vdc/5
0	0	0	1	1	0	0	0	4Vdc/5
0	0	0	1	0	1	0	0	3Vdc/5
0	0	0	1	0	0	1	0	2Vdc/5
0	0	0	1	0	0	0	1	Vdc
0 or 1	1 or 0	0 or 1	1 or 0	0	0	0	0	0
0	0	1	0	0	0	0	1	-Vdc
0	0	1	0	0	0	1	0	-2Vdc/5
0	0	1	0	0	1	0	0	-3Vdc/5
0	0	1	0	1	0	0	0	-4Vdc/5
0	1	1	0	0	0	0	0	-Vdc/5

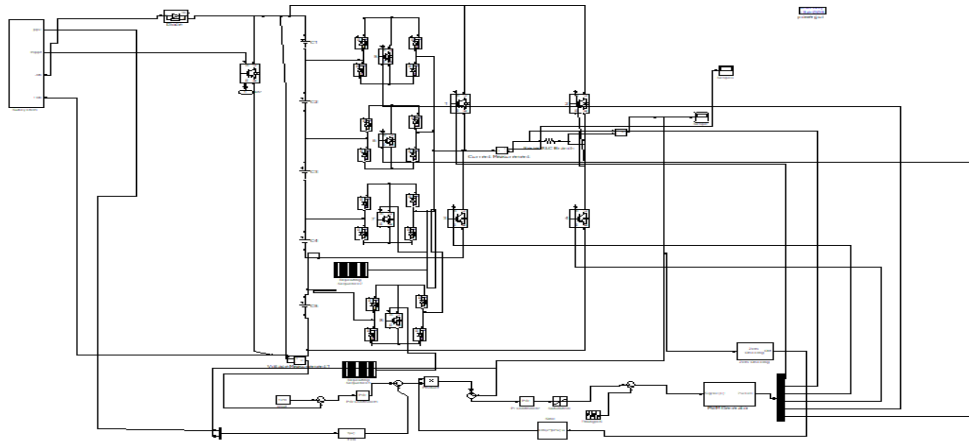


Fig 6.12. Eleven level inverters

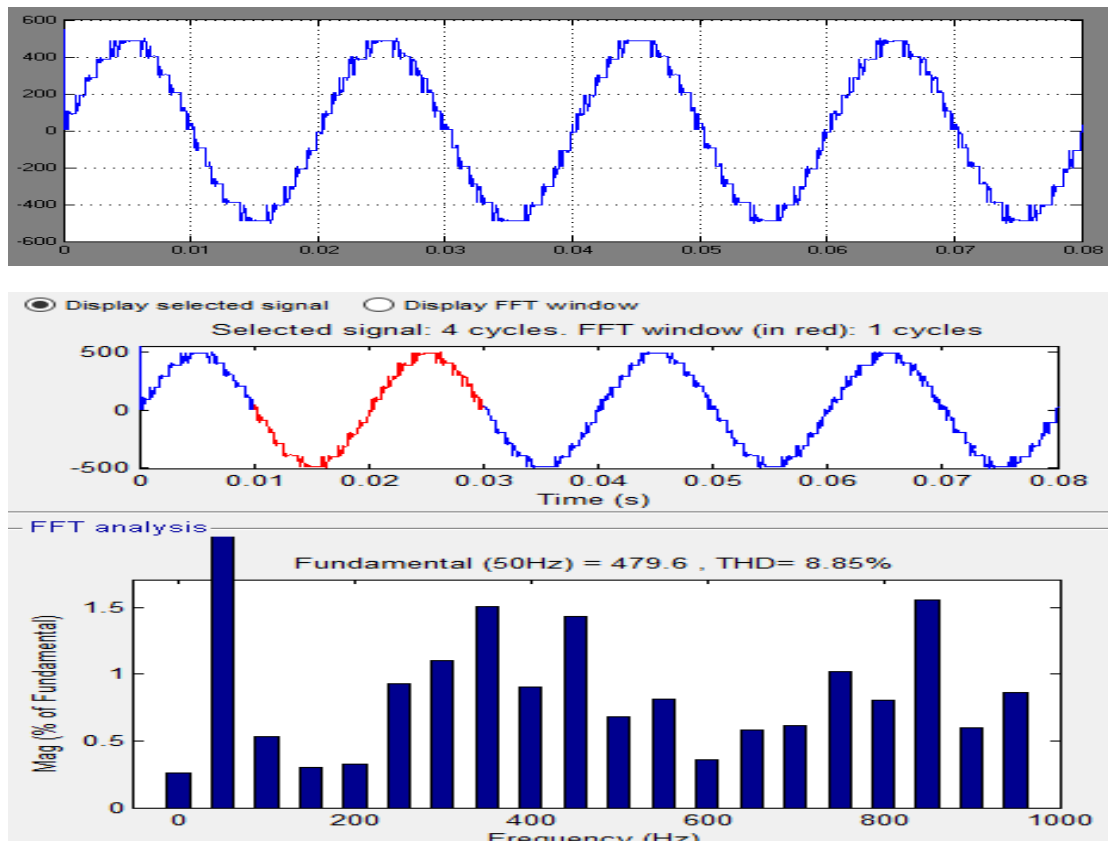


Fig 6.13.Eleven level inverter output voltage andTHD for Eleven level inverter

## VI. CONCLUSION AND FUTURE SCOPE

### 6.1 conclusion

In the field of high-power, high-performance applications the multi-level inverters seem to be the most promising alternative. In multilevel inverters, as the switching involves several small voltages, the rapid change in voltage is smaller. Further, switching at the fundamental frequency will also result in decreasing the number of times these voltage changes occur per fundamental cycle. But harmonic elimination is the major issue for multilevel inverters.



The results have been presented and analyzed. On the other hand, from the results, it is observed that as the modulation index is increased the total harmonic distortion (THD) decreases and also the fundamental RMS value increases linearly. By using this method, the results obtained for THD in two-level and three-level inverters are 54.02% and 28.60% respectively. But the level of inverter increases, the complexity of control algorithm and execution time increases. From the results, it is observed that the inverter performance is highly improved. The output voltage total harmonic distortion for three-level and five-level inverters is 5.7% and 3.61% respectively. The total harmonic distortion (THD) is highly reduced as the level of inverter is increased. By comparing the THD of seven, nine and eleven level we can conclude that by increasing the level the harmonics can be reduced.

## 6.2 Future Scope

This thesis work focuses on novel pulse width modulation for multilevel inverters. Analytical evaluation of harmonic distortion for multilevel inverters can also be carried out. More techniques can be developed for inverter switching at much higher frequencies and hardware implementation can also be done. All the proposed algorithms in this thesis are time-invariant systems. Therefore, it is recommended to eliminate harmonics for time-variant systems. Further to reduce the switching losses of the inverters, discontinuous pulse width modulation algorithms have to be proposed.

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