Simulation and comparison of Standard Inverter Topologies

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A Project report submitted in partial fulfilment of the requirements for the degree of

B. Tech in Electrical Engineering

By

ABHIJIT BISWAS	**EE2017/049**	**11701617079**
HEMANTA JANA	**EE2017/048**	**11701617059**
MD SONU SOLANKI	**EE2017/046**	**11701617056**

Under the supervision of

Dr. SHILPI BHATTACHARYA

(Associate Professor of Dept. of Electrical Engineering, RCCIIT)

Department of Electrical Engineering

RCC INSTITUTE OF INFORMATION TECHNOLOGY

CANAL SOUTH ROAD, BELIAGHATA, KOLKATA - 700015, WEST BENGAL

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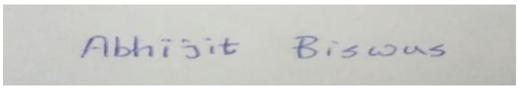
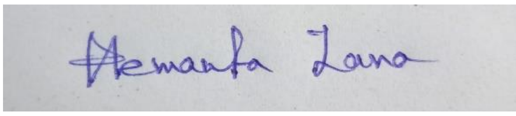


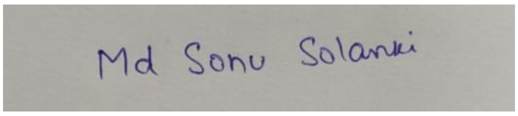
ABHIJIT BISWAS

Place: Date:

Kolkata
18/07/2021



HEMANTA JANA



Md SONU SOLANK

Department of Electrical Engineering
RCC INSTITUTE OF INFORMATIONTECHNOLOGY
GROUND FLOOR NEW BUILDING CANAL SOUTH ROAD, BELIAGHATA, KOLKATA – 700015, WEST BENGAL PHONE: 033-2323-2463-154, FAX:033-2323-4668
Email: hodeercciit@gmail.com, Website: http://www.rcciit.org/academic/ee.aspx

CERTIFICATE

To whom it may concern

This is to certify that the project work entitled Simulation and comparison of standard inverter topologies is the bona fide work carried out by Abhijit Biswas 11701617079, Hemanta Jana 11701617059, Md Sonu Solanki 11701617056 are student of B. Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year 2020-21, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and that this project has not submitted previously for the award of any other degree, diploma and fellowship.

Shilpi Bhattacharya

HoD, Dept. of EE
RCC Institute of Information Technology
Kolkata-700015

Signature of the Guide

Name:

Designation

Signature of the HOD

Name:

Designation

Signature of the External Examiner Name:

Designation:

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ABSTRACT

The project is to design and simulation of different kind of Voltage Source Inverter. In present time, the application of the voltage source inverter (VSI) is rapidly been increasing. Different designing methods are followed for the construction of VSI. The purpose of adopting for different techniques of inverter design is to decrease the harmonic contents from the output waves of VSI. Hence the comparison of three different voltage source inverters with their different techniques is discussed in this paper for the purpose of reduction in harmonics. Total harmonic distortion (THD) analysis of all three VSI has been done. THD analysis of sine pulse width modulation (SPWM) and third harmonic injection pulse width modulation (THIPWM) are further discussed in two manners – over modulation and exact modulation. A unique type of 7 level 5 switch voltage source multi-level inverter with phase disposition pulse width modulation (PDPWM) technique is also discussed and its comparison is made with earlier two techniques. In renewable energy systems, we need to control the power generation in a very efficient manner. Hence these inverters with low THD values can be utilized in that field for reduction in losses and increase in efficiency of the renewable system. Simulation of all three techniques based VSI is done on MATLAB platform and THD is compared. The project aims to use the MATLAB program to design, analyse and control switching for inverter circuits.

INTRODUCTION

We know that, in present time whole world is concerned in generation of energy without polluting the environment without wasting any amount of energy. Hence it is compulsory now to increase the efficiency of the devices that are working in a system. In the field of electrical, the efficiency analysis of any system can be done on the basis of system THD value. If it is low then system will be more efficient or vice-versa. Yet so many researches have been made in this field, but all studies contain THD value of above 20%. In this paper, an advance topologies of voltage source inverter (Multi Level Inverter) are analysed and also been compared with two conventional topologies that may help to decrease the THD of any electrical system.

The main function of voltage source inverter is to convert DC supply into AC supply of desired magnitude and frequency. Ideally, the output waveforms of inverter should be sinusoidal but in practical, the output waveforms are not pure sinusoidal and contains different harmonics. Harmonics in any system reduces the quality of electrical supply which can cause several negative effects in the system. RMS current will get increased when harmonic will increase which cause increase in loss. Electrical system starts getting premature ageing due to harmonics. For low and moderate power applications, square and quasi-square waves are allowed but for high power application, we need sinusoidal waveforms with very low harmonic content. That’s how, by using semiconductor-based devices and different methods of switches pulse generation (SPWM, THIPWM & PDPWM) the value of harmonic content can be minimized. Due to such design, system harmonics will get reduce or we get more pure quantity sinusoidal voltage which will help to reduce the losses of the system or that’s how we can manage or save the energy.

WORKING PRINCIPLE

Electrical system starts getting premature ageing due to harmonics. For low and moderate power applications, square and quasi-square waves are allowed but for high power application, we need sinusoidal waveforms with very low harmonic content. That's how, by using semiconductor-based devices and different methods of switches pulse generation (SPWM, THIPWM & PDPWM) the value of harmonic content can be minimized. The disadvantage possessed by this scheme is that the switching devices used in the inverter are expensive as they must possess low turn on and turn off times, nevertheless PWM operated are very popular in all industrial equipment's. PWM techniques are characterized by constant amplitude pulses with different duty cycles for each period. The width of these pulses is modulated to obtain inverter output voltage control and to reduce its harmonic content. There are different PWM techniques which essentially differ in the harmonic content of their respective output voltages, thus the choice of a particular PWM technique depends on the permissible harmonic content in the inverter output voltage.

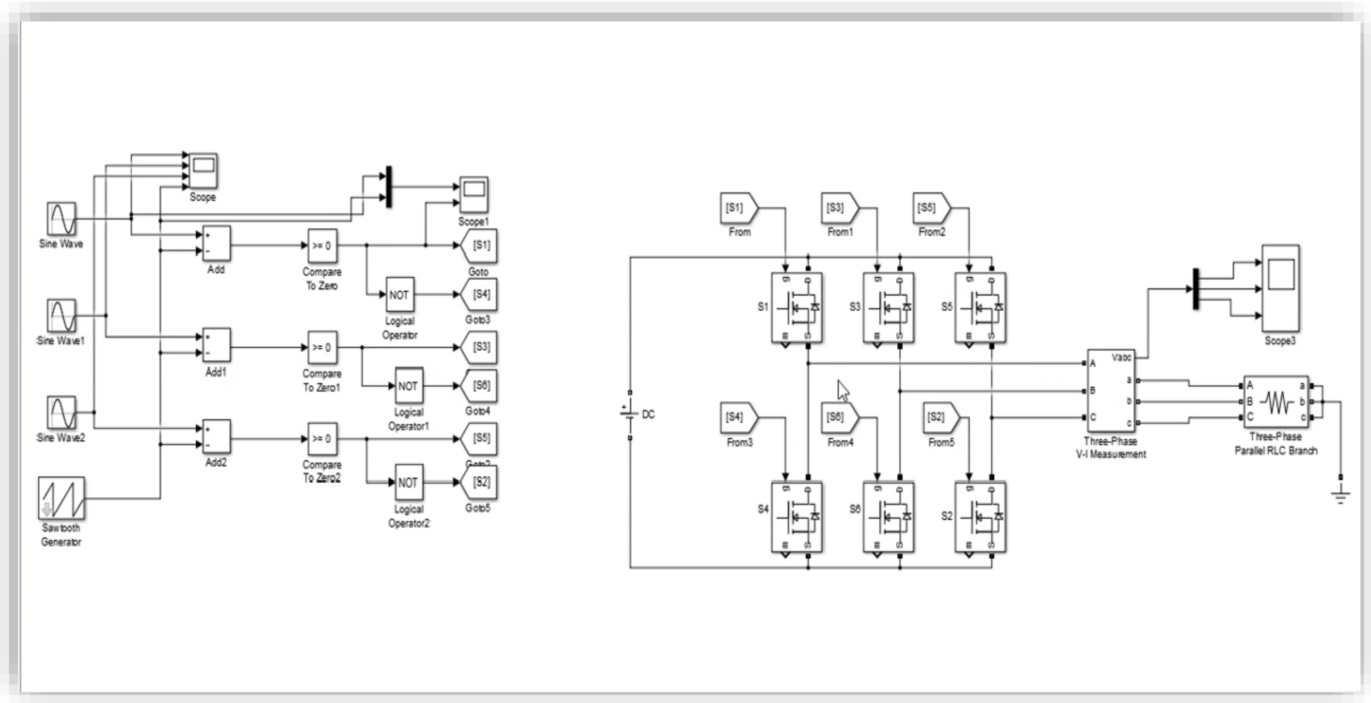
Pulse width modulation (PWM) is a strong method to control the Analog circuits with a processed digital output. PWM of power devices modulate its duty cycle to commit the control or amount of power delivered to the load. Single PWM is not suited for all type of applications. By the help of advanced technology, various methods of PWM are there for use in any application. The major aim of PWM is to maintain the output voltage and reduce the harmonic content from it. The different PWM techniques being used are:

Sinusoidal Pulse Width Modulation (SPWM)

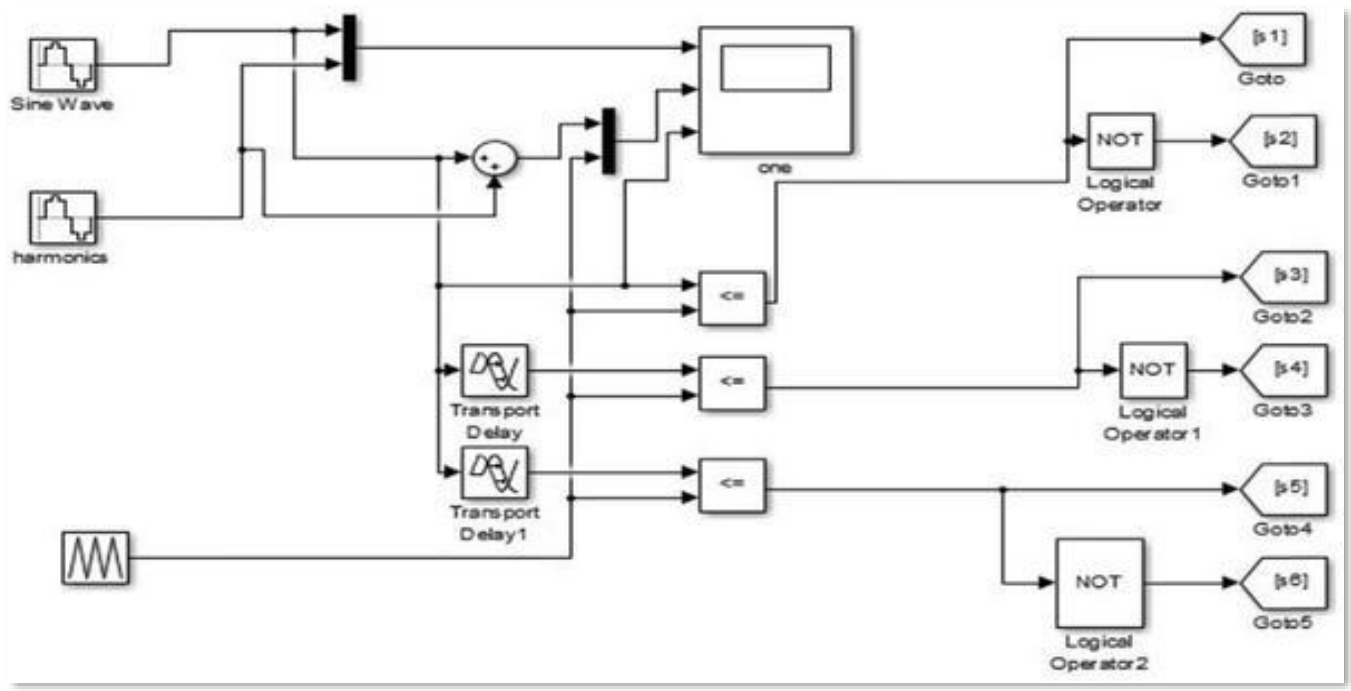
Third Harmonic Injection Pulse Width Modulation (THIPWM)

Phase Disposition Pulse Width Modulation (PDPWM)

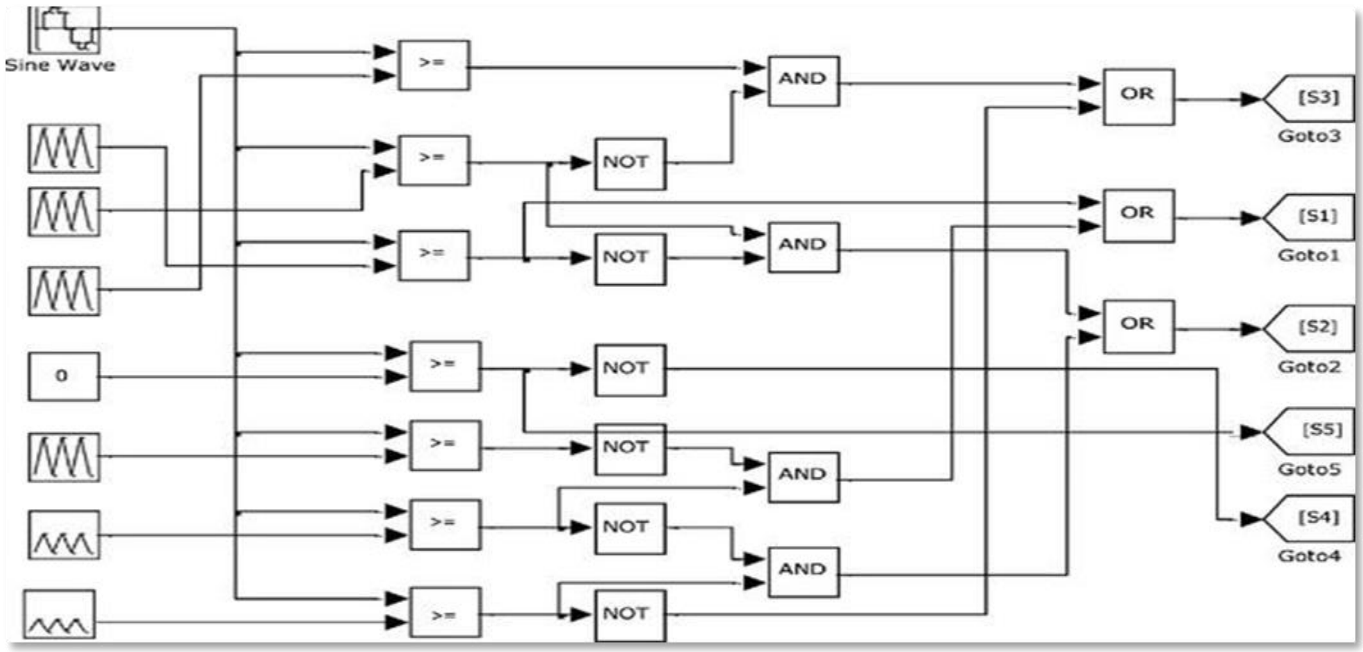
CIRCUIT DIAGRAM



10i SPWM CIRCUIT DIAGRAM



10iI THIPWM CIRCUIT DIAGRAM



11iii PDPPWM CIRCUIT DIAGRAM

COMPONENT LIST

SPWM:

1. Sine wave block.
2. Sawtooth generator block.
3. Add block.
4. Compare to zero block.
5. Mux.
6. Scope.
7. Goto block.
8. NOT block.
9. 100V DC source.
10. Upper switches s1,s3,s5.
11. Lower switches s2,s4,s6.
12. 3 phase v-I measurement.
13. De mux.
14. 3 phase parallel RLC branch.
15. Scope.
16. Continuous block.

THIPWM:

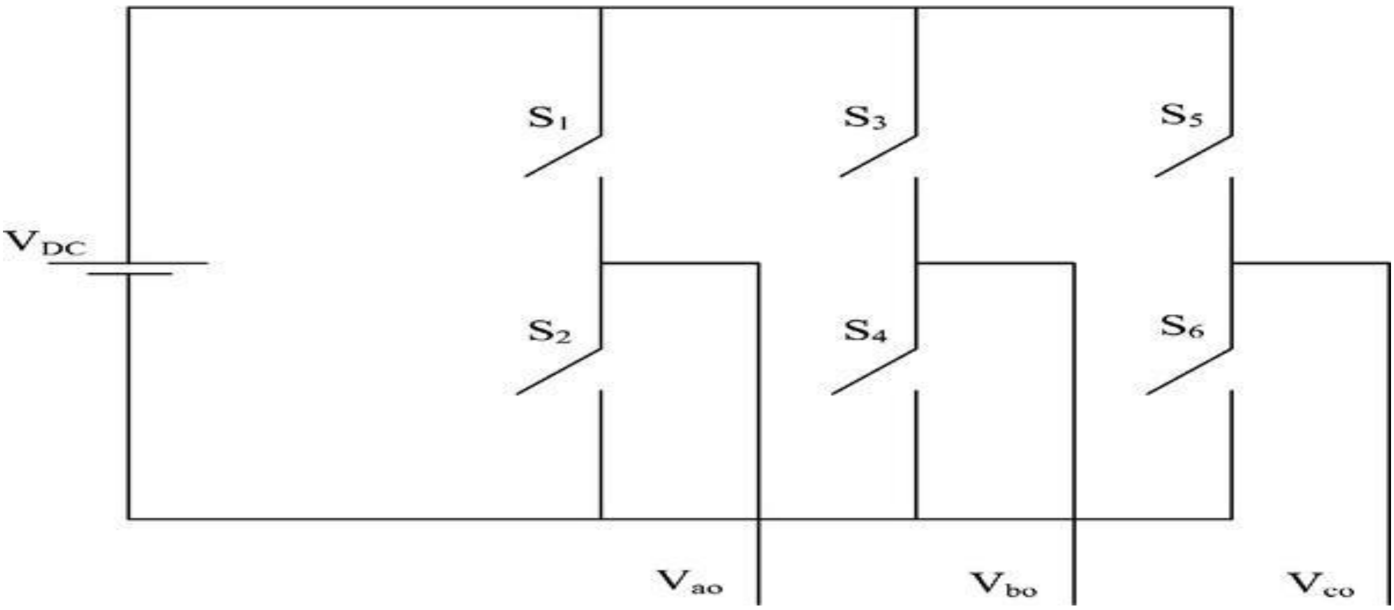
1. Sine wave block.
2. Sawtooth generator block.
3. Add block.
4. Compare to zero block.
5. Scope.
6. Goto block.
7. NOT block.
8. 100V DC source.
9. Upper switches s1,s3,s5.
10. Lower switches s2,s4,s6.
11. 3 phase v-I measurement.
12. mux.
13. 3 phase parallel RLC branch.
14. Scope.
15. Continuous block.
16. From block.

PDPWM:

1. Discrete
2. Repeating sequence
3. De mux
4. Scope
5. Relational operator
6. Levels
7. Or block
8. Goto block
9. From block
10. Switches
11. Series RLC
12. Voltage measurement
13. Scope

VOLTAGE SOURCE INVERTER (VSI)

VSI is mainly used to convert a constant DC voltage into an AC voltage with variable magnitude and frequency. VSI drives used capacitive storage in their DC link, which stores and smooths the DC voltage of the inverter. A schematic diagram of a three-phase VSI. The inverter is composed of six switches Sinv,1 through Sinv,6 with each phase output connected to the middle of each inverter leg. In the simplest form, three reference signals are compared to a high-frequency carrier waveform to control the output AC voltage of the inverter. The result of that comparison in each leg is used to turn the switches ON or OFF. It should be noted that the switches in each leg should be operated interchangeably, in order to avoid a dead short circuit of the DC supply. The name voltage source inverter actually is something of a misnomer. The inverter can change the frequency of the output waveforms by changing the length of time that



13i SPWM BASED VOLTAGE SOURCE INVERTER

the switches are turned on. However, the amplitude of the AC waveform is determined by the DC input voltage. Thus, changing the amplitude of the AC voltage requires a variable DC input to the inverter. This means a controlled rectifier will be required, i.e., SCRs rather than diodes. Usually a voltage-sourced PWM inverter is applied because this type can control both the frequency and amplitude of the AC output voltage. In inverters that are not PWM, any change in the output load directly affects the output voltage (when the load increases, the output voltage of the inverter decreases and vice versa) while output voltage of a PWM inverter can remain constant under a wide range of loads.

The controlling of voltage can be done by:

1. External control of inverter output voltage.
2. Internal control in inverter.

1. **External Control of Inverter Output Voltage**

Regulation of voltage input to AC load can be done by managing the firing angle of AC voltage controller. But this method is rarely used now, because it creates the high harmonic content in output voltage.

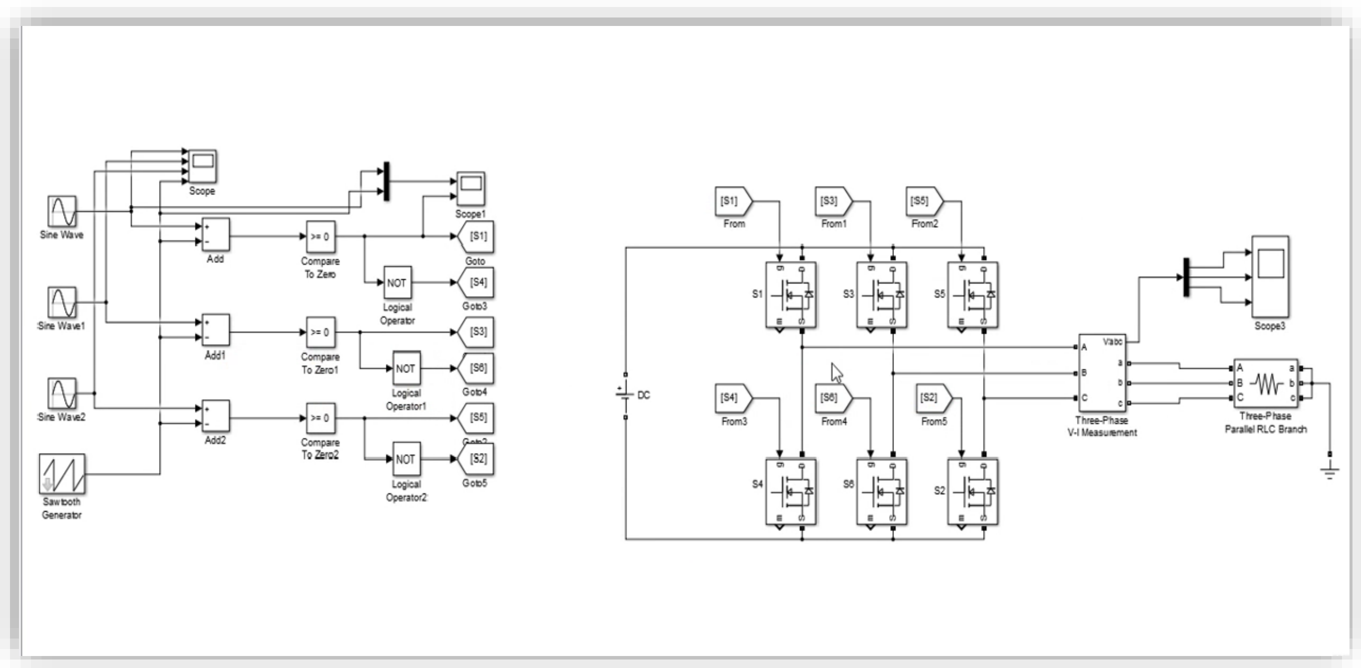
2. **Internal Control in Inverter**

The internal control of voltage in inverter enhances the output voltage very well. Pulse width modulation is the best way to achieve such control.

SINUSOIDAL PULSE WIDTH MODULATION (SPWM)

The term SPWM stands for "Sinusoidal pulse width modulation" is a technique of pulse width modulation used in inverters. An inverter generates an output of AC voltage from an input of DC with the help of switching circuits to reproduce a sine wave by generating one or more square pulses of voltage per half cycle. If the size of the pulses is adjusted, the output is said to be pulse width modulated. With this modulation, some pulses are produced per half cycle. The pulses close to the ends of the half cycle are constantly narrower than the pulses close to the centre of the half cycle such that the pulse widths are comparative to the equivalent amplitude of a sine wave at that part of the cycle. To change the efficient output voltage, the widths of all pulses are amplified or reduced while keeping the sinusoidal proportionality. Low frequency reference sinusoidal wave form is compared with high frequency triangular waves which are called carrier waves.

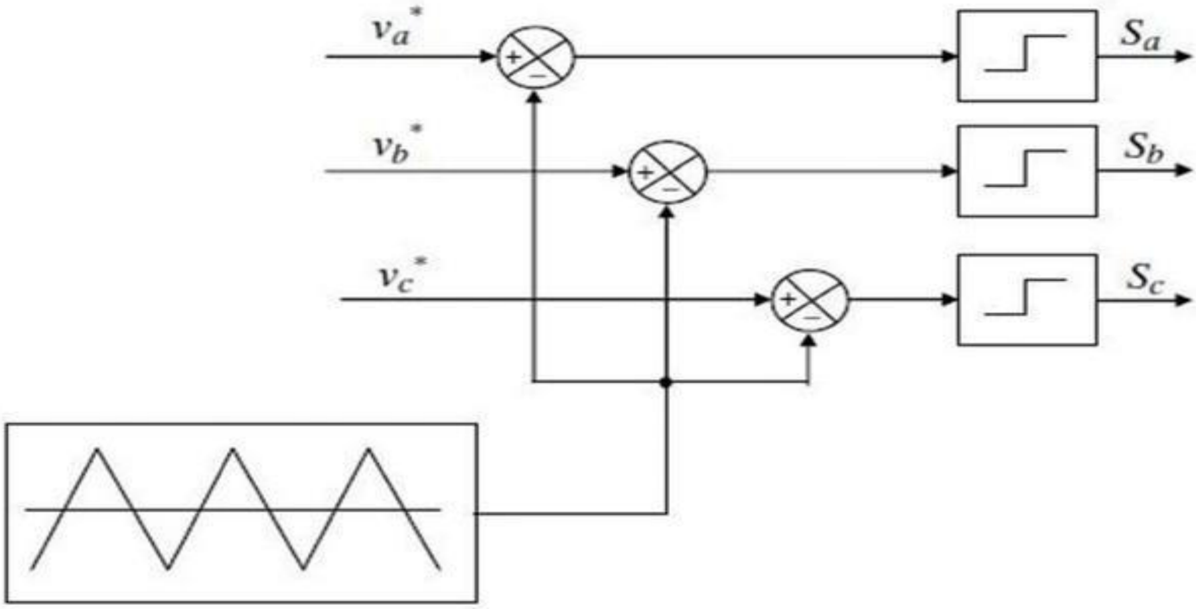
When crossing of sine and carrier waves are happen, the switching phase gets changed at that time. In three phases, three low frequency sinusoidal reference waves (Va, Vb, and Vc) which are 120· out of phase from each other, are compared with the triangular voltage waveform (Vt), as a result we get three



15i SPWM CIRCUIT MADE USING MATLAB

switching pulses for three different phases. A six-step voltage source inverter has six switches S1 to S6, out of these 6 switches, 2 switches will operate at a single time for one phase and are connected in series to form one leg of the inverter. Similarly, other switches will operate for other two phases. The output of each phase is connected to the centre of each inverter leg. The output of the comparator as shown in Figure 2 gives the controlling signal or pulses for the power devices connected on the three legs of the inverter. Two switches of one leg will operate in a complimentary manner it means when one is in on condition then other will be in off condition or vice-versa. The switching of outer pole voltages Vao, Vbo, Vco are done between –Vdc/2 and +Vdc/2 voltage levels. Vdc is the total DC voltage.

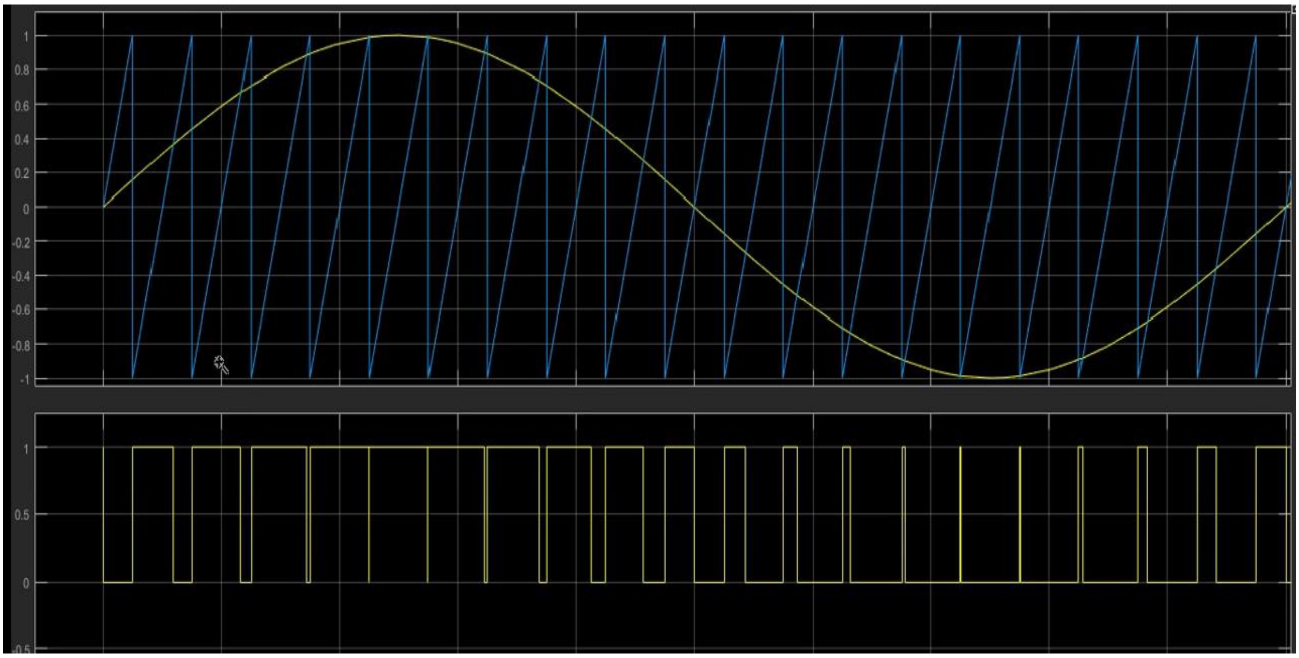
The comparator output is processed in a trigger pulse generator in such a manner that the output voltage wave of the inverter has a pulse width in agreement with the comparator output pulse width. The magnitude ratio of vr/ vc is called the modulation index (mi) and it controls the harmonic content of the output voltage waveform. The magnitude of fundamental component of output voltage is proportional to. The amplitude of the triangular wave is generally kept constant. The frequency–modulation ratio is defined as mf =fi/fm to satisfy the Kirchhoff's Voltage law (KVL) constraint, the switches on the same leg are not turned on at the same time, which gives the condition s11+s12 =1 for each leg of the inverter. This enables the output voltage to fluctuate between Vd/2 and -Vd/2



16i CONTROLLING SIGNAL OF SPWM

This is a technique that utilizes a triangular carrier wave modulated by a sine wave and the purposes of convergence decide the exchanging purposes of the power gadgets in the inverter. Despite the fact that this technique can't make full utilization of the inverter's supply voltage and the asymmetrical nature of the PWM switching characteristics delivers generally high harmonic distortion in the supply it is as yet prevalent for its effortlessness. The generation of switching gate pulse can be done by two methods, one is by over modulation method and other is by exact modulation method. For over modulation, the value of modulation index is taken 2, whereas, for the exact modulation method the value of modulation index is taken 1. In other manner, we can say that when the peak of low frequency sinusoidal reference wave is high compared to triangular waves then system is at over modulation and when peak is at same as triangular waves then it is called exact modulation. The formula of modulation index is

Modulation index (m)=vmvc



17i INPUT WAVEFORM TO THE INVERTER

Positive and negative DC bus voltage will apply on each phase according to the switching states. The switches are controlled in a combination of (S1, S4), (S3, S6), and (S5, S2)) and the logic behind this is

[S1 is ON when Va>Vt, S4 is ON when Va<VtS3 is ON when Vb>Vt, S6 is ON when Vb<VtS5 is ON whe n Vc>Vt, S2 is ON when Vc<Vt]

The width of pulse depends upon the crossing of the triangular and sinusoidal waves. The inverter output voltages can be as

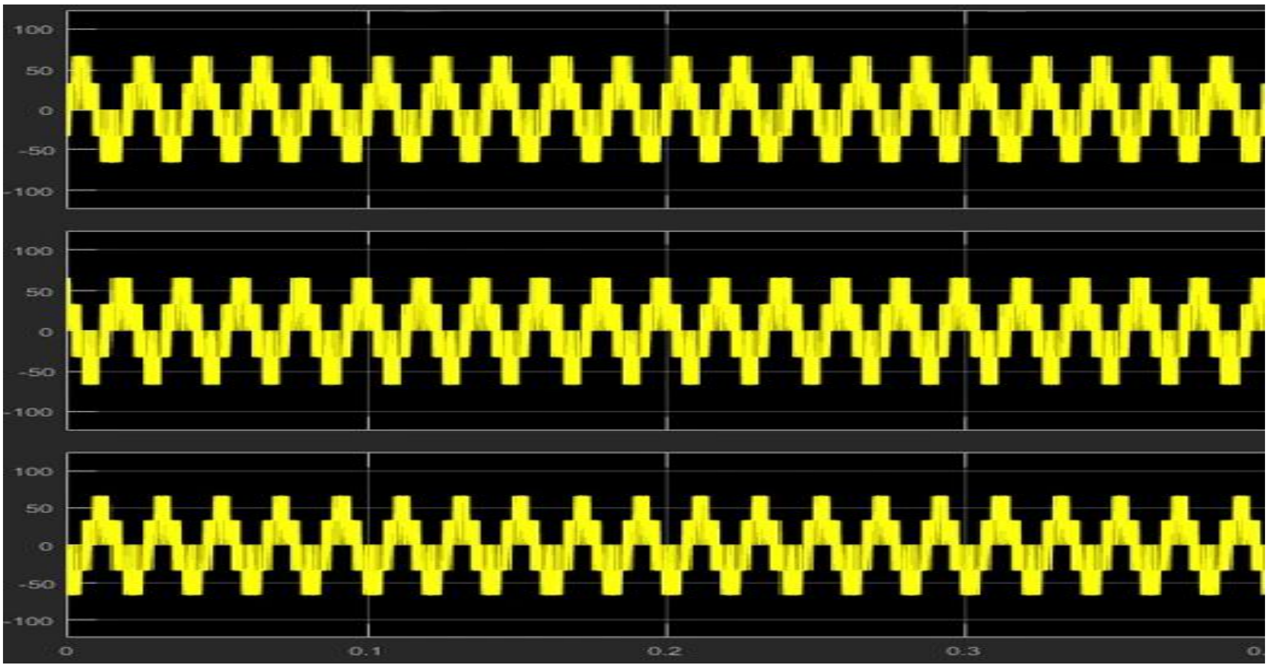
[Va>Vtri then Vao=0.5VdcVb>Vtri then Vbo=0.5VdcVc>Vtri then Vco=0.5Vdc]

And if

[Va<Vtri then Vao=−0.5VdcVb<Vtri then Vbo=−0.5VdcVc<Vtri then Vco=−0.5Vdc]

Calculation of line-to-line voltage from pole voltage can be done as

[Vab=Va0−Vb0Vbc=Vb0−Vc0Vca=Vc0−Va0]

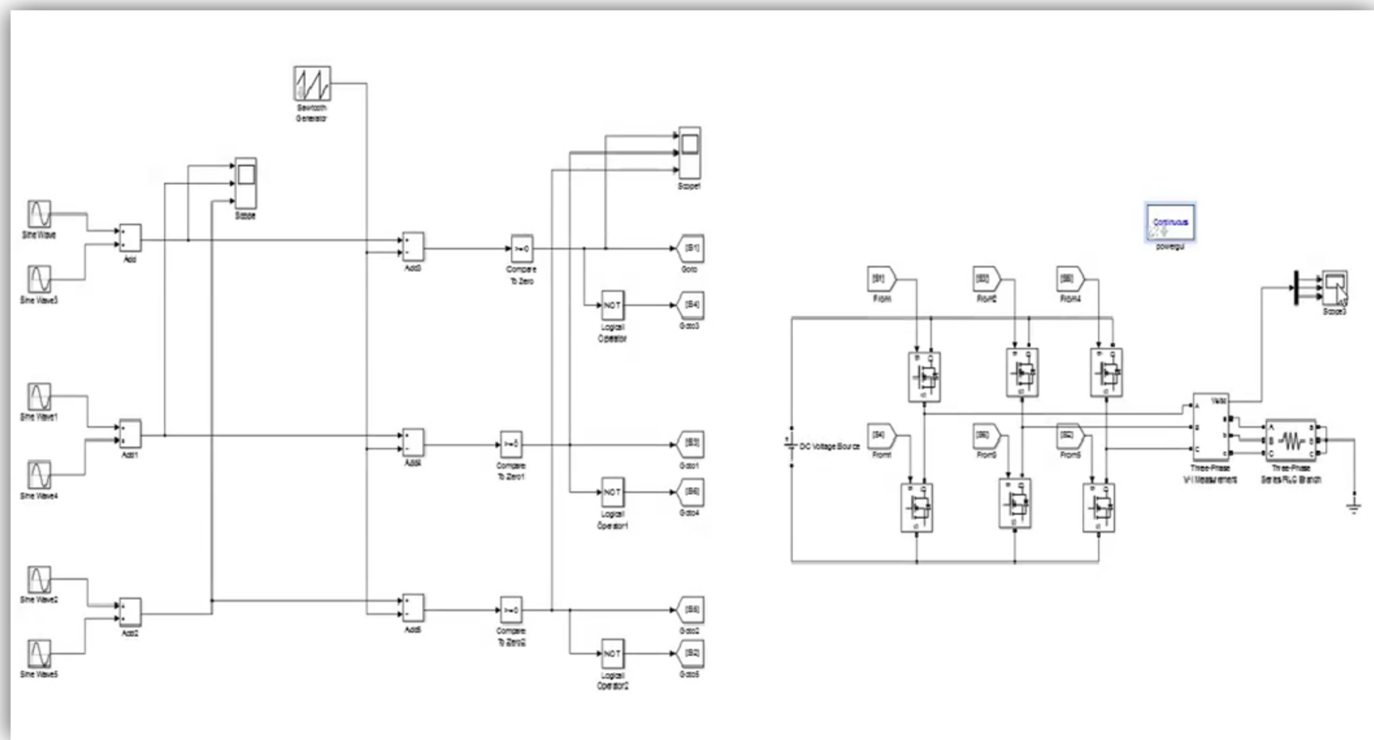


18i OUTPUT WAVEFORM OF SPWM INVERTER

To change the efficient output voltage, the widths of all pulses are amplified or reduced while keeping the sinusoidal proportionality. With PWM (pulse width modulation), only the on-time of the pulses are changed during the amplitudes.

THIRD HARMONIC INJECTION PULSE WIDTH MODULATION (THIPWM)

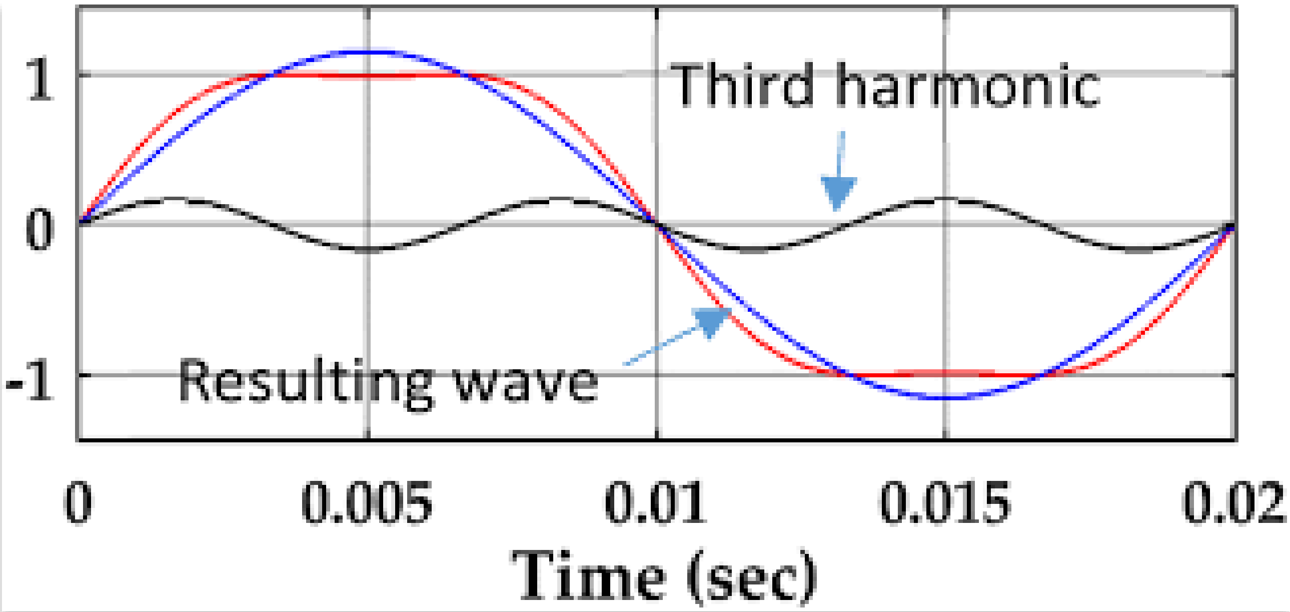
Sinusoidal PWM is easy to understand and in implementation but it is not able to fully occupy the available DC bus supply voltage. Due to such problem, third harmonic injection pulse width modulation (THIPWM) came in light. This method helps inverter in its performance enhancement. The sine PWM method approaches less of maximum achievable output voltage. Hence, by simply adding third harmonic signal in low frequency sinusoidal reference signal, we can achieve the amplitude increase in output voltage waveform. Similar to sine PWM the method of overmodulation and exact modulation can also be applied in third harmonic PWM method. In THIPWM, addition of third harmonic means that, in one cycle of sinusoidal wave, three cycles of harmonic should complete. The third harmonic injection to reference signal wave



19i THIPWM CIRCUIT DIAGRAM USING MATLAB

The sinusoidal PWM is the simplest modulation strategy to understand but the DC bus supply voltage is not completely utilized. Because of this issue, the THI PWM technique is employed to enhance the inverter execution. The sinusoidal PWM method causes diminish most extreme output voltage. For this situation, an expansion of most extreme achievable output voltage is studied. Subsequently, by essentially adding a third harmonic signal to each of the reference signals, it is conceivable to acquire a noteworthy adequacy increment at the output voltage without loss of quality, It is impressive that, the result of addition of the third and fundamental harmonic is less in amplitude than fundamental harmonic. On other side, the reference signal occupies two maxima at t = π/3 and t = 2π equals to 1. The fundamental harmonic and third harmonic equations can be written as

The THIPWM is implemented in the same manner as the SPWM, that is, the reference waveforms are compared with a triangular waveform. As a result, the amplitude of the reference wave forms does not exceed the DC supply voltage Vdc/2, but the fundamental component is higher than the supply voltage Vdc. As mentioned above, thiS is approximately 15.5% higher in amplitude than the normal sinusoidal PWM. Consequently, it provides a better utilization of the DC supply voltage. The one reference voltage and triangular waveform of a one phase THIPWM produce the following output pole voltage. Vao show in. Injection of harmonic of order three in the reference makes it possible to increase the zone of linearity of the fundamental one



20i THIRD HARMONIC INJECTION AND RESULTING WAVE

V1=V1maxsin.t

V3=V3maxsin3t

Hence at t = π/3, V bus/2 will be the voltage taken by the first harmonic of line to neutral output voltage. Now, the equations can be written as

Vbus2=V1maxsin(π/3)

Which yields,

V1max=Vbus2(0.86) = Vbus1.732

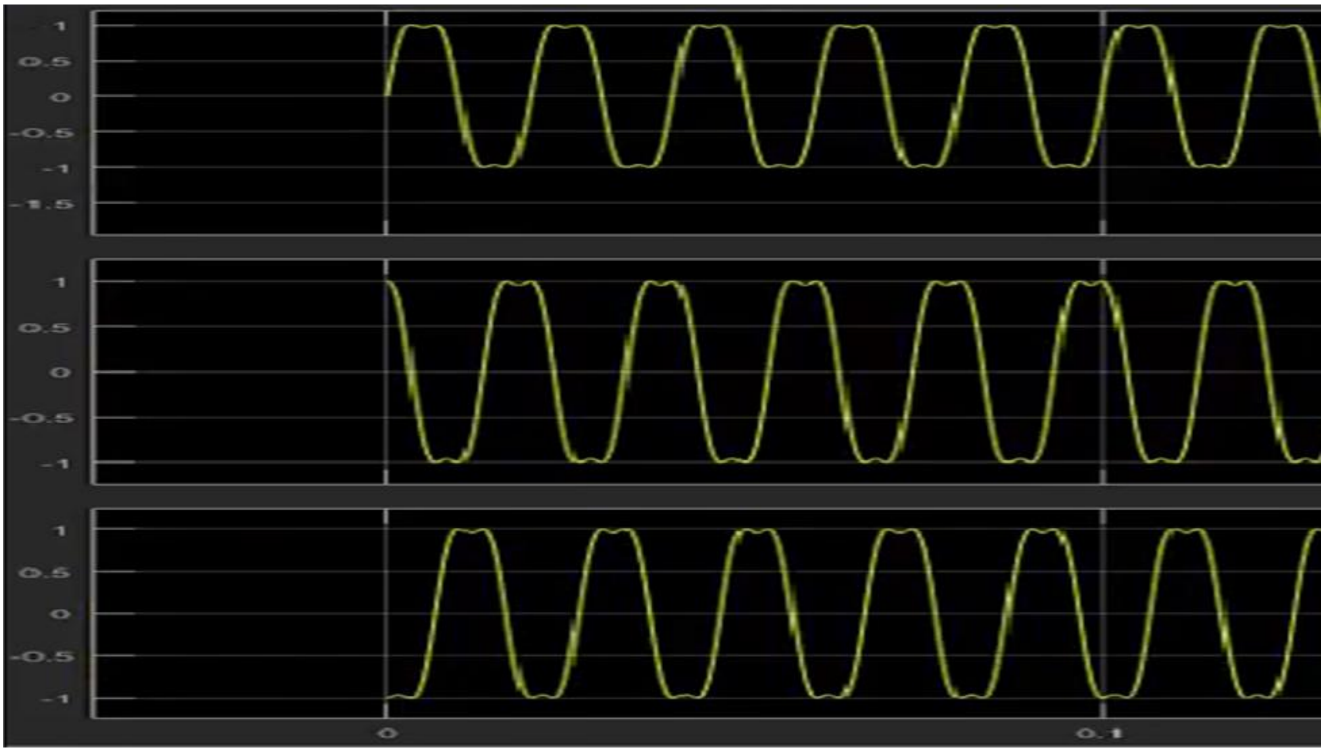
Accordingly, the amplitude of the first harmonic results

V1max = $Vbus$ 1.732

We see that the quality of the voltage waveform has not been significantly degraded. For each phase reference, the third harmonic injected is equal V1max sin wt + V3max sin 3wt

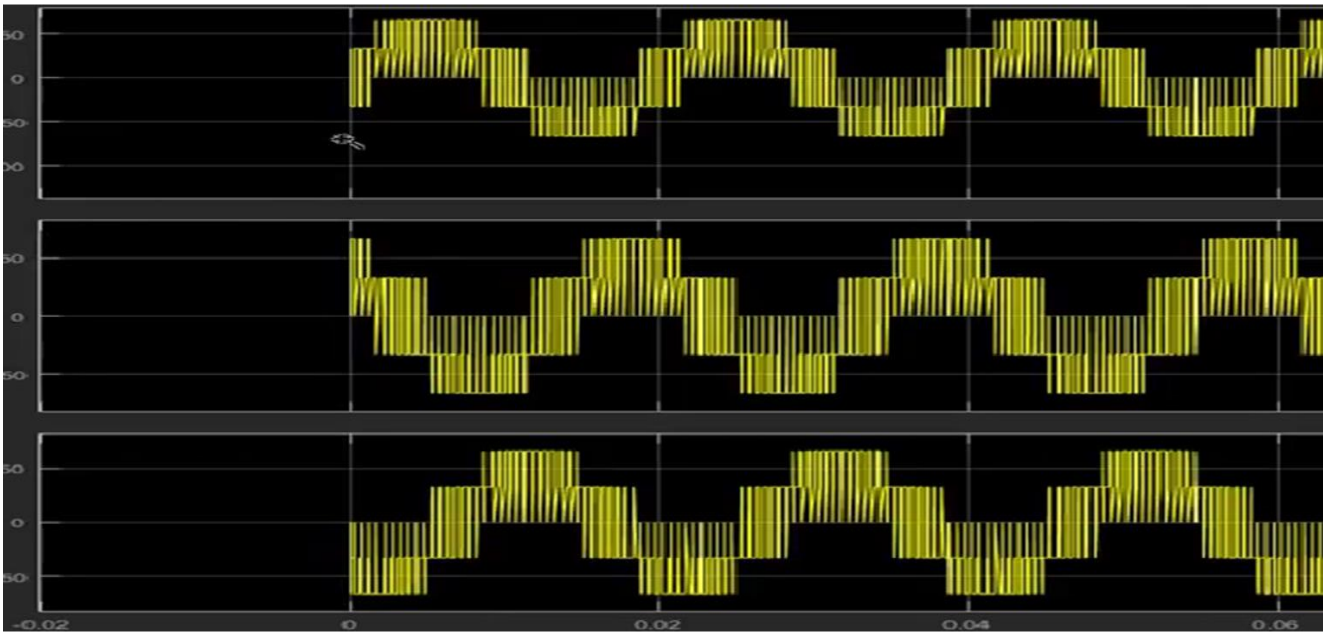
The equation represents the THI PWM for phase voltage injected into the PWM.

The generation of gate pulses through THI PWM strategy is represented in the above fig. The frequency of reference signal decides the frequency of inverter. The carrier signal frequency is higher than the reference signal by which the number of gate pulses is generated. The THI PWM strategy provides better output voltage than SPWM and the number of pulses is reduced due to which switching losses becomes low.



21i INPUT WAVEFROM TO THE THREE PHASE INVERTER (THIPWM)

The Simulink simulation result is given to verify the operation on the THIPWM three-phase inverter. The inverter was supplied by 100 V DC. Figure shows the THIPWM generation, where the third harmonic sine wave was imposed with another sine wave and resultant wave generated.



22i OUTPUT WAVEFORM OF THIPWM INVERTER

The output voltage waveform for each phase with third harmonic content can be written as

[V1maxsin(wt) +V3max Sin(3wt) V1maxsin(wt−2π3) +V3max Sin(3wt) V1maxsin(wt+2π3) +V3max Sin(3wt)]

PHASE DISPOSITION PULSE WIDTH MODULATION (PDPWM)

A new unique topology of voltage source multi-level inverter containing 7 levels and 5 switch is introduced. It is the modified form of existing 7 level 6 switches MLI which is now reduced in 5 switches. The output voltage levels can be calculated by the formula

$l=2*s-3$

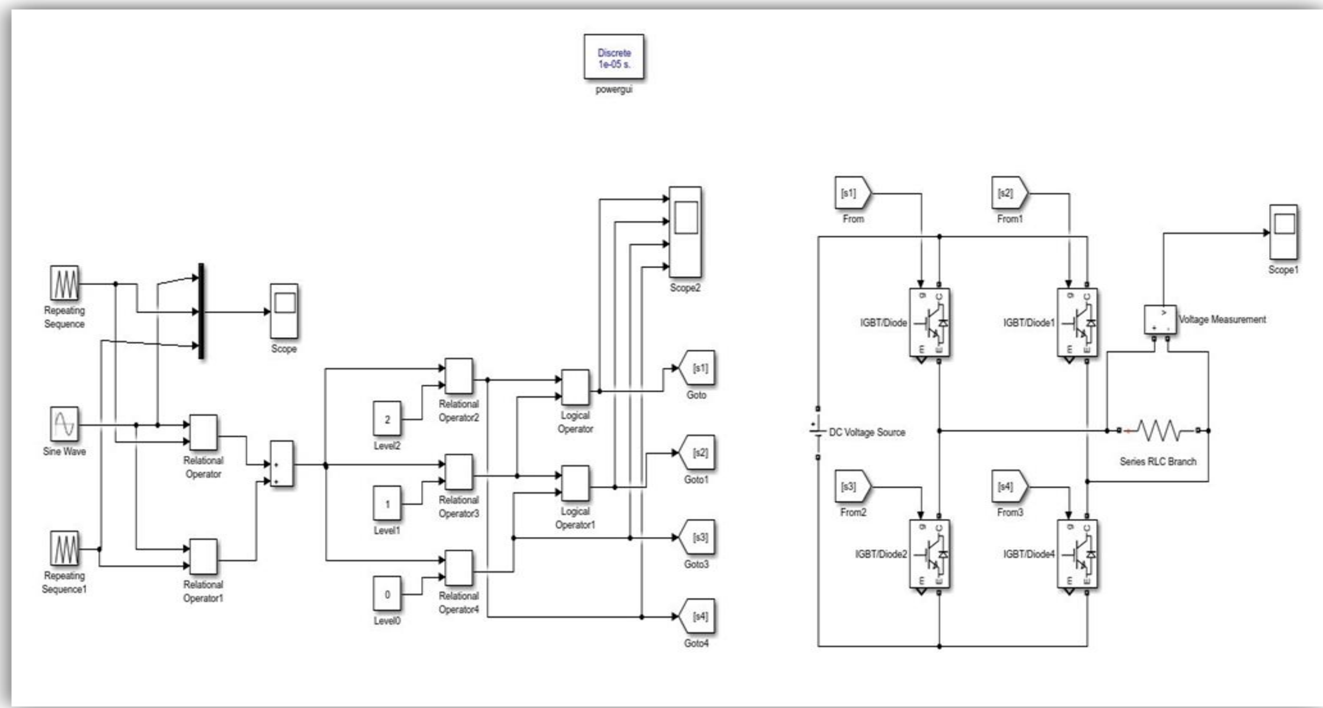
Where, l = voltage level count

S = switches count

And,

$l=2*d-1$

d = no. of DC sources

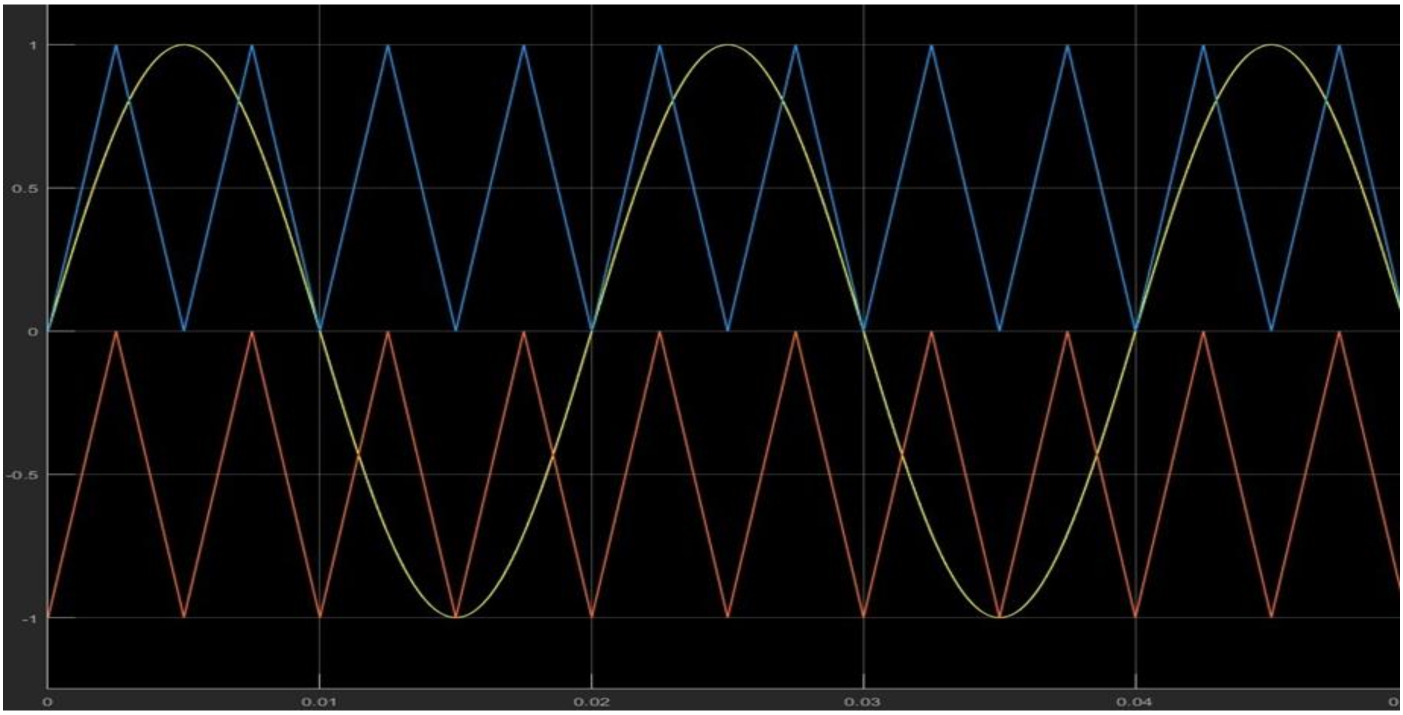


23i PDPWM CIRCUIT DIAGRAM USING MATLAB

This topology contains 4 DC voltage sources and 5 switches which helps to produce 7 level of output voltage waveform. The switching pattern of above VSI is also done in a unique manner. When, Switches S3 and S5 will operate in same time then it gives the output voltage equal to Vdc. Similarly, when switches S2 and S5 will operate they will give output voltage equal to 2 Vdc, when switch S1 and S5 will operate they will give the output voltage equal to 3 Vdc. When Switch S1 and S4 will operate, they will give output voltage equals to –Vdc and at the time when no switch is in operating mode the output voltage will be equal to zero.

Shift modulation technique is used here for the generation of pulses for switches. Four options are available in this modulating scheme, which are – phase disposition, phase opposition disposition, inverted phase disposition and alternative phase opposition disposition.

The comparison of sine and carrier waves is used in this method for generation of switching pulse.



24i INPUT WAVEFORM OF THE THREE PHASE INVERTER (PDPWM)

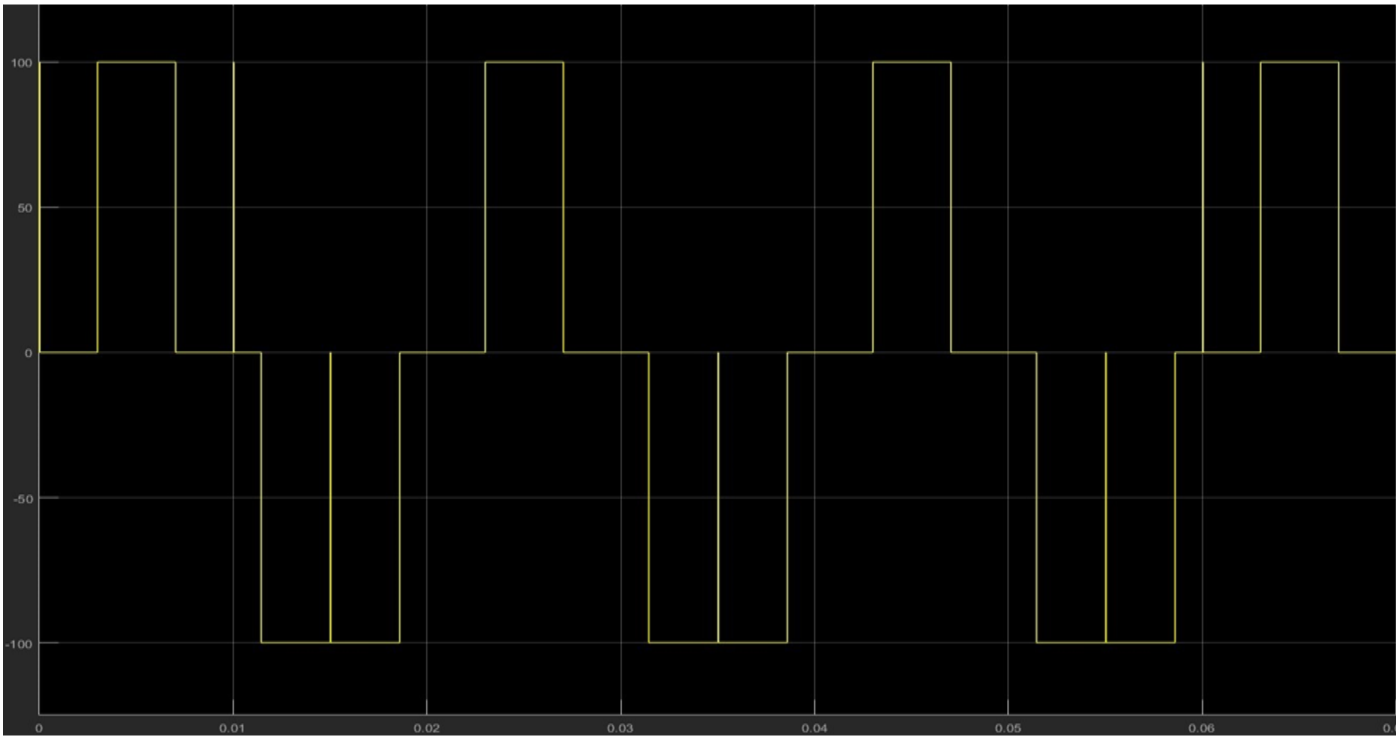
The output of the comparator is further provided to the appropriate switches that's how it can produce output voltage of 7 level in AC.

Switch S1 need a gate pulse to give output of –Vdc and +3 Vdc, switch S2 needs pulse to give output voltage of +2 Vdc and –2 Vdc, and switch S3 requires gate pulse to produce –3 Vdc and +3 Vdc. Rest switches, it means, switches S4 and S5 will operate regarding positive and negative half cycle. If we have to construct n level output waveform, then will need (n–1) carrier signals. It means for above proposed inverter we need 6 carrier signals

In PDPWM strategy, all the carrier waves have same amplitude, frequency and phase.

Since all carriers are selected with same phase. All carriers are having amplitude as 1.

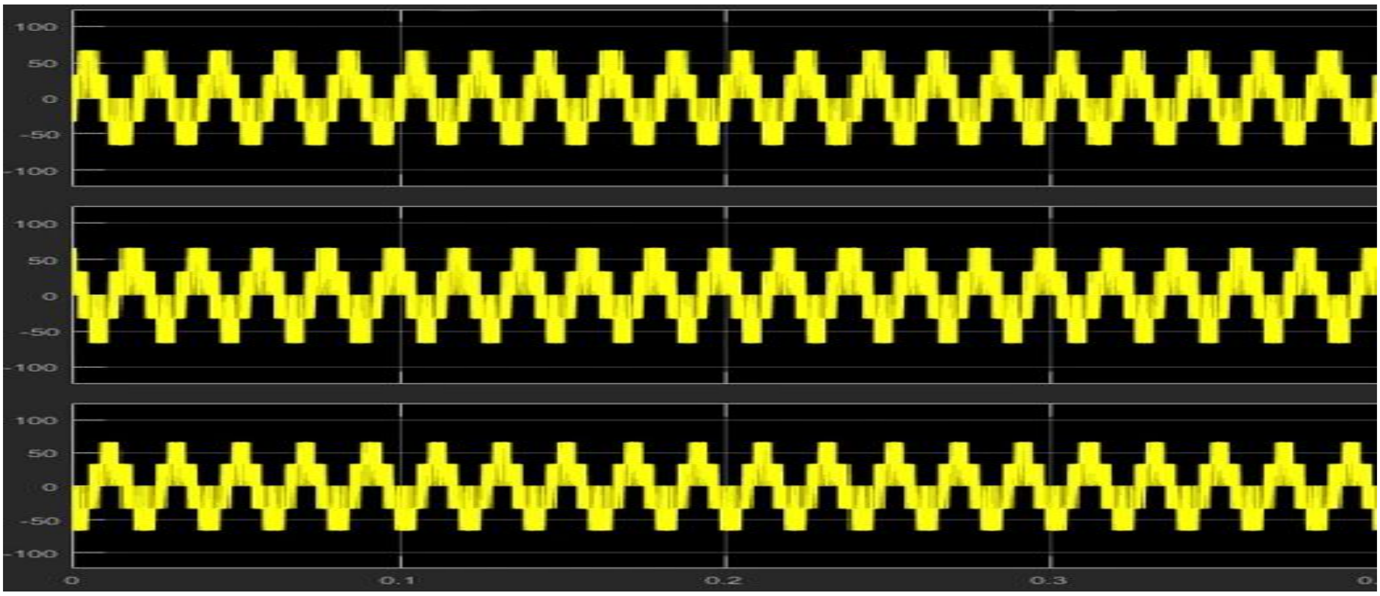
The carriers are equally divided into two groups based on positive/negative average levels. In this type the two groups are opposite in phase with each other while keeping in phase within the group



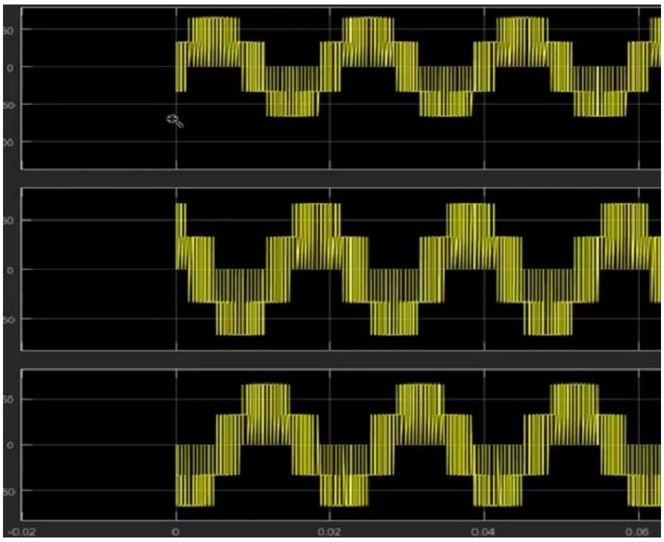
25i OUTPUT WAVEFORM OF PDPWM

OBSERVATION AND RESULT

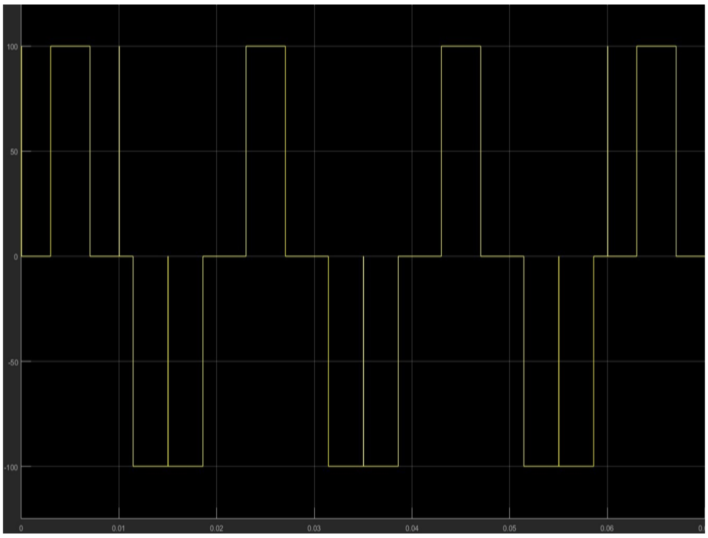
All three PWM techniques (SPWM, THIPWM and PDPWM) based voltage source inverter has been simulated on RL load in MATLAB software. The output of simulation of all three-voltage source inverter is shown only for single phase. The reference sinusoidal wave frequency is taken 50 Hz and carrier wave frequency is taken 35 kHz. Vdc is chosen 350 volts and the load is taken of 10-ohm resistance and 10mH inductance in each phase. The output voltage waveform is taken across one phase and neutral of load. The output voltage waveform of all three PWM techniques based VSI shown in the figure.



26i OUTPUT WAVEFORM OF SPWM INVERTER



26ii OUTPUT WAVEFORM OF THIPWM INVERTER



26iii OUTPUT WAVEFORM OF PDPWM

CONCLUSION

The THD comparison and analysis of various techniques (SPWM, THIPWM, PDPWM) based voltage source inverter has been carried out through MATLAB simulation. As the THD analysis is done above and results are simulated which results, reduction in THD of concluded techniques which may help in reduction in loss and increase in efficiency of system. This system of low THD can be applied in any renewable energy system so that efficiency of that renewable system can be increased. Hence, these voltage source inverters may be used in any application where reduction in system harmonics is required or reduction in losses is required so that we can increase the efficiency of the electrical system. Further, to decrease the value of THD power filter can be used in power circuits. By using such power filter, the final THD of the system can more be reduced to very low value. Unique contribution of this paper is that the 5 switch 7 level voltage source inverter topology is used or compared with other, SPWM and THIPWM technique for better power quality.

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