PERFORMANCE ANALYSIS OF CASCADED H-BRIDGE MULTILEVEL INVERTER

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Abstract: - The inverter is an electrical system that converts DC to AC electrical energy respectively. In early time output voltage of inverter is limited to two to three levels so that in megawatt power level parameter such as reliability reduces due to this reason need of introducing higher level inverter (Multilevel Inverter) become essential to overcome these limitations. In multilevel inverter, it is produce output AC voltage which have multiple level so that less switching loss, less harmonic distortion and output filter size reduce or sometimes not required. Multilevel inverter has many advantages over the two level inverter including handling medium and high power loads without causing any problem. It produces higher level output voltage with low voltage distortion. There are many multilevel inverter topologies have been invented but the most popular and widely used topology is the cascade H-bridge multilevel inverter (CHMI). Multilevel inverter is recommended not only for the use in high power applications but it can be used for industrial applications as alternative in high power and medium/high voltage applications. Aim of this paper is to simulate two/three levels of inverter and multilevel inverter then compare output characteristics for the same. Scope of paper includes understanding and analyzing the performance of two/three levels inverter with respect to multilevel inverter. Simulation done in MATLAB Simulink.

Keywords: - Inverter, CHMI, MLI, THD, etc.

1. INTRODUCTION

The DC to AC converter also known as the Inverter, it converts DC Electric power to AC Electric power at desired output voltage and frequency. The input DC power to the inverter is form as external power source like Battery, fuel cell and Photovoltaic array (Solar cell). The filter capacitor which connected across input side of the inverter provides a constant DC link voltage and low impedance energy source which provide instant energy during step load applied at output side load of the inverter. The inverter therefore is an adjustable frequency voltage source. The configuration of AC to DC converter and DC to AC inverter is called a dc-link converter. Inverters is typed by its supply source and topology relationship of the power circuit. It can be classified as voltage source inverter (VSI) and Current source inverter (CSI). In this paper only the voltage source inverter will be discussed.

The power inverter can produce different types of output wave form from such as square wave, modified sine wave and pure sine wave. These signal outputs represent different qualities of power output. Square wave inverters result in uneven power delivery that is not efficient for running most devices. Square wave inverters were the first types of inverters made but now a day these type of inverters are not used. Modified sine wave inverters deliver power that is consistent and efficient enough to run most devices normally. Some sensitive loads require a sine wave signal, like medical equipment and variable speed or rechargeable tools. Modified sine wave signal or quasi sine wave inverters were second generation of power inverter. These popular types of inverters represent a compromise between the low harmonics of a true sine wave inverter and the higher cost and lower efficiency of a true wave inverter. Modified sine wave inverters approximate a sine wave and have low enough harmonics that they do not cause problems with household equipment. They run stereos, induction motors, universal motors, computers, microwave, TVs and more quite well. The main disadvantage of a modified sine wave inverter is that the peak voltage varies with the battery voltage. Inexpensive electronic devices with no regulation of their power supply may behave erratically when the direct current voltage fluctuates. True sine wave inverters represent the latest inverter technology. The waveform produced by these inverter is the same as or better than the power delivered by the utility. Harmonics are virtually eliminated and all appliances operate properly with this type of inverter. They are significantly more expensive than their modified sine wave inverter.

The converter topology is based on the series connection of single-phase inverters with separate dc sources. The power circuit for one phase leg of a three-level, five-level and seven-level cascaded inverter. The resulting phase voltage is synthesized by the addition of the voltages generated by the different cells. In a 3-level cascaded inverter each single-phase full-bridge inverter generates three voltages at the output: +Vdc, 0, -Vdc (zero, positive dc voltage, and negative dc voltage). This is made possible by connecting the capacitors sequentially to the ac side via the power switches. The resulting output ac voltage swings from -Vdc to +Vdc with three levels, -2Vdc to +2Vdc with five-level and -3Vdc to +3Vdc with seven-level inverter.

The staircase waveform is nearly sinusoidal, even without filtering. For real power conversions, (ac to dc and dc to ac), the cascaded-inverter needs separate dc sources. The structure of separate dc sources is well suited for various renewable energy sources such as fuel cell, photovoltaic, and biomass, etc. Connecting separated dc sources between two converters in a back-to-back fashion is not possible because a short circuit will be introduced when two back-to-back converters are not switching synchronously.

2. PWM TOPOLOGY

With advances in solid-state power electronics devices and microprocessors, various inverter control techniques employing pulse width modulation techniques are becoming increasingly popular in AC motor drive applications. These PWM based dives are used to control both the frequency and the magnitude of the voltages applied to motors.

Many PWM strategies, control schemes and realization techniques have been developed nowadays. PWM strategy plays an important role in the minimization of harmonics and switching losses in converters, especially in three phase applications. The first modulation techniques were developed in the mid-1960s by kirnnich, Heinrick and Bowes. The research in PWM schemes has intensified in the last few decades. The main aim of any modulation technique is to obtain a variable output with a maximum fundamental component and minimum harmonics.

The advantages of PWM control are:
1. No additional components are required with this method.
2. Lower order harmonics are eliminated or minimized along with its output voltage control. Hence, the filtering requirements are minimized since higher order harmonics can be filtered easily.

Different schemes of Pulse width modulation:
1. Single pulse modulation
2. Multi pulse modulation
3. Sinusoidal pulse modulation

Since our paper deals with Sinusoidal Pulse Width modulated Inverters, the basic concepts of Sinusoidal PWM are explained below. In this method of modulation, several pulses per half cycle are used and the pulse width is a sinusoidal function of the angular position of the pulse in a cycle. A high frequency triangular carrier wave vc is compared with a sinusoidal reference wave vr of the desired frequency. The switching instants and commutation of the modulated pulse are determined by the intersection of vc and vr waves. The carrier and reference waves are mixed in a comparator. When the sinusoidal wave has higher magnitude, the comparator output is high, else it is low. The comparator output is processed in a trigger pulse generator in such a way that the output voltage wave has a pulse width in agreement with the comparator pulse width.

Unipolar and bipolar modulation
If the half-cycle sine wave modulation, the triangular carrier only in a positive or negative polarity range of changes, the resulting SPWM wave only in a polar Range, called unipolar control mode. If the half-cycle sine wave modulation, triangular carrier in continuous change between positive and negative polarity, the SPWM wave is between positive and negative changes, known as bipolar control. Unipolar and bipolar modulations are shown in Figure.

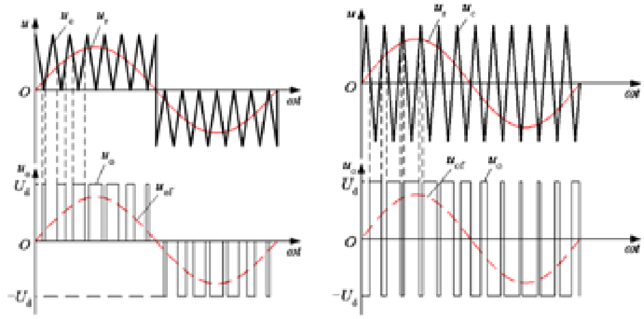


Fig 1- Unipolar PWM Topology

3. INVERTER TOPOLOGIES

Three phase Voltage Source Inverter (VSI)
Voltage Source Inverters especially three phase are widely utilized to drive AC motors with high motion control quality and energy efficiency to provide clean current waveform and regenerative operation in AC – DC power converter applications and to supply high quality AC power in uninterruptable power supply systems as AC-DC-AC power converter units.
Basic operation of single phase bridge

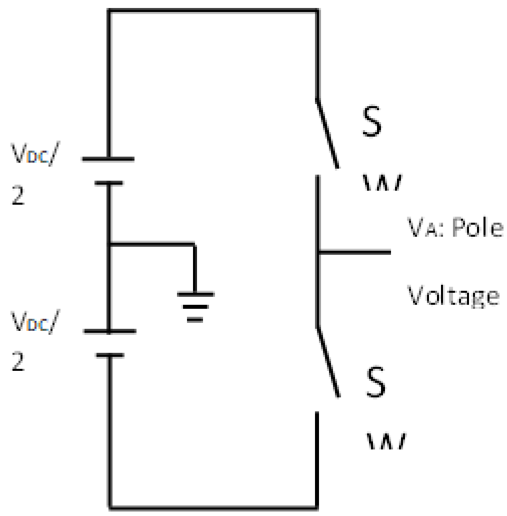


Fig 2- Circuit model of single pole inverter
As shown in figure 2, It is single phase bridge with two switches, input voltage is VDC and output voltage is VA with respect to ground as shown in figure.

Sr. No.	SW1	SW2	VA
1	OFF	OFF	Float
2	OFF	ON	-VDC/2
3	ON	OFF	VDC/2
4	ON	ON	Not Used

For Sr. No. 2 and 3, it is used for normal functions of Inverter.
For Sr. No. 1, During switching between Sr. No. 2 to 3 or 3 to 2 practically both switches must be OFF simultaneously for least time, otherwise dc link is short during transection this is due to turn On and turn Off delay time of Power Switches. This state called dead band. For Sr. No. 4, both switches are ON simultaneously the DC link will get short circuited and high current will flow through switches it may get damaged so that this condition is not used practically.

4. THREE PHASE INVERTER SWITCHES OPERATION

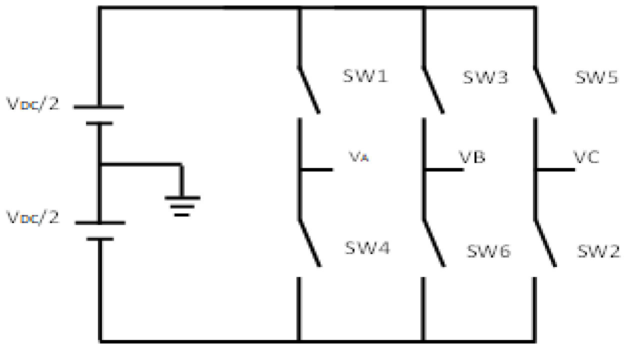


Fig. 3: Circuit model of three pole inverter

State	Switches ON	Switches OFF	VAB	VBC	VCA
1	1, 2 & 6	4, 5 & 3	VDC	0	-VDC
2	2, 3 & 1	5, 6 & 4	0	VDC	-VDC
3	3, 4 & 2	6, 1 & 5	-VDC	VDC	0
4	4, 5 & 3	1, 2 & 6	-VDC	0	VDC
5	5, 6 & 4	2, 3 & 1	0	-VDC	VDC
6	6, 1 & 5	3, 4 & 2	VDC	-VDC	0
7	1, 3 & 5	4, 6 & 2	0	0	0
8	4, 6 & 2	1, 3 & 5	0	0	0

Multilevel Voltage Source Inverter

A voltage level of three is considered to be the smallest number in multilevel converter topologies. Due to the bi-directional switches, the multilevel VSC can work in both rectifier and inverter modes. This is why most of the time it is referred to as a converter instead of an inverter in this dissertation. A multilevel converter can switch either its input or output nodes (or both) between multiple (more than two) levels of voltage or current. As the number of levels reaches infinity, the output THD approaches zero. The number of the achievable voltage levels, however, is limited by voltage-imbalance problems, voltage clamping requirements, circuit layout and packaging constraints complexity of the controller, and, of course, capital and maintenance costs. Three different major multilevel converter structures have been applied in industrial applications: cascaded H-bridges converter with separate dc sources, diode clamped, and flying capacitors. The multilevel inverter structures are the main focus of discussion in this chapter; however, the illustrated structures can be implemented for rectifying operation as well. Although each type of multilevel converters share the advantages of multilevel voltage source inverters, they may be suitable for specific application due to their structures and drawbacks. Operation and structure of some important type of multilevel converters are discussed in the following sections.
In general, multilevel power converter can be as voltage synthesizers in which the higher output voltage is generated from many discrete smaller voltage sources. The main advantages of this methods are as followed.

1) The voltage capacity of the existing device can be increased many times without the complications of static and dynamic voltage sharing that occur in series connected devices.
2) Performance of multilevel waveforms is better to that of their two-level counterparts.
3) Multilevel waveforms naturally limit the problem of large voltage transients that occurs due to the reflections on cables. Which can damage the windings of motor (insulation break) and cause other problems?

One more alternative for a multilevel inverter is the cascaded multilevel inverter or series H-bridge inverter. The series H-bridge inverter appeared in 1975. Cascaded multilevel inverter was not fully realized until two researchers, Lai and Peng. They patented it and presented its various advantages in 1997. Since then, the CMI has been utilized in a wide range of applications. With its modularity and flexibility, the CMI shows superiority in high-power applications, especially shunt and series connected FACTS controllers. The CMI synthesizes its output nearly sinusoidal voltage waveforms by combining many isolated voltage levels. By adding more H-bridge converters, the amount of Var can simply increase without redesign the power stage, and build-in redundancy against individual H-bridge converter failure can be realized. A series of single-phase full bridges makes up a phase for the inverter.

A three-phase CMI topology is essentially composed of three identical phase legs of the series-chain of H-bridge converters, which can possibly generate different output voltage waveforms and offers the potential for AC system phase-balancing. This feature is impossible in other VSC topologies utilizing a common DC link. Since this topology consists of series power conversion cells, the voltage and power level may be easily scaled.

V. SIMULATION & RESULTS

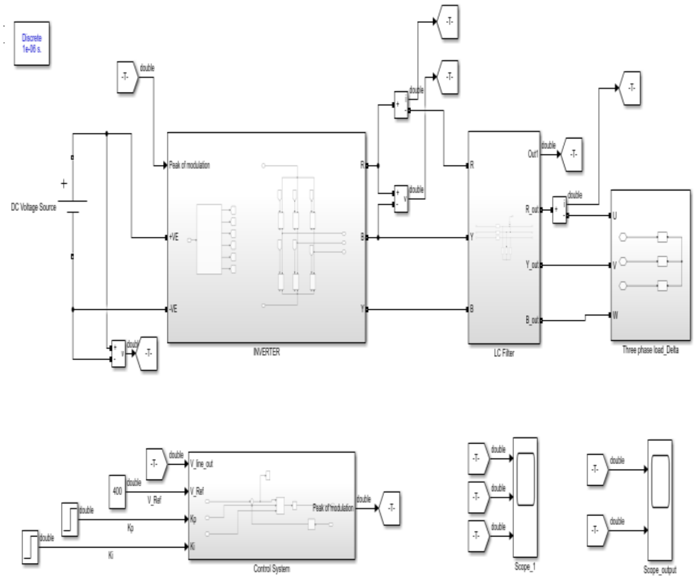


Fig. 4: Three Phase Inverter Model

There are major three subsystems as described below in detail

1) Inverter
2) LC Output filter
3) Control System

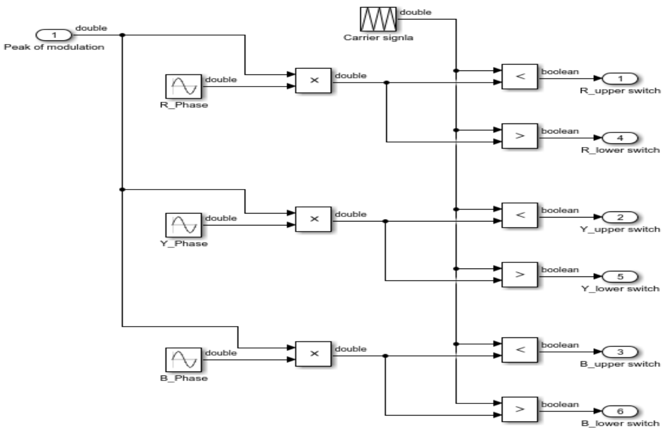


Fig. 5: Inside of PWM Subsystem

Sinusoidal Pulse Width Modulation technique is used in this module as shown in Fig.5.

Reference signal R-Phase, Y-Phase and B-Phase in fig.5 are sinusoidal in nature with unity magnitude and 50Hz frequency. Phase difference between all three signals is 120 degrees. Then these signals are individually multiplied with peak of modulation signal so that peak of these reference signals can be controlled to get desired output voltage magnitude of Inverter. Then it gets compared with Carrier signal as shown in fig. 5, Carrier signal is in triangular nature and peak to peak value is 2 with respect to 0 and frequency of carrier signal is 10 kHz. Gate signals for Top switches and Bottom switches are carried out.

Inputs:

I. Power Signal
1) DC Voltage source
Value of DC voltage is 600V.

II. Control Signal
1) Peak of modulation
This signal comes from Control system subsystem and goes to PWM Module which is subsystem of Inverter.

Outputs:

I. Power Signal
1) R, Y and B output

It is in form of raw PWM in nature.

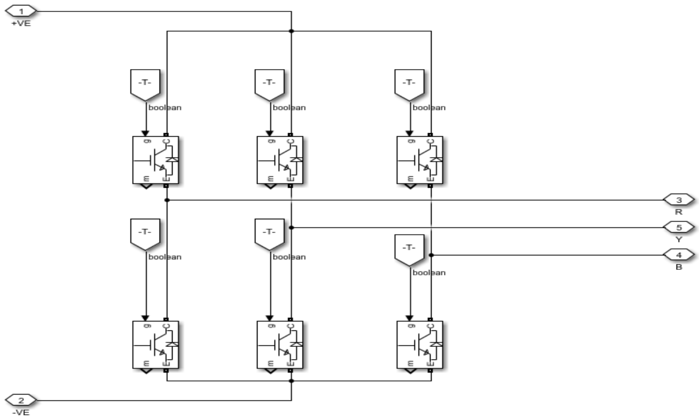


Fig. 5: Power Switches

Those gate signals are go to Six IGBTs as shown in Fig.6. IGBTs with free whiling diodes are used as Power switches.

Control System

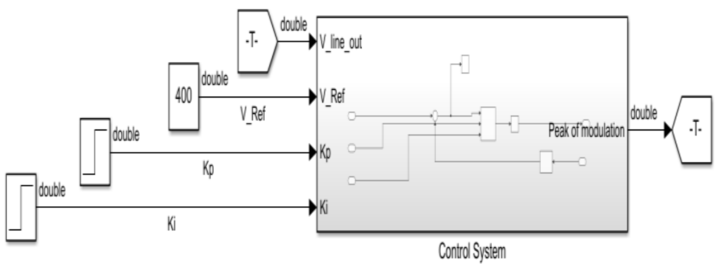


Fig. 6: Control System subsystem

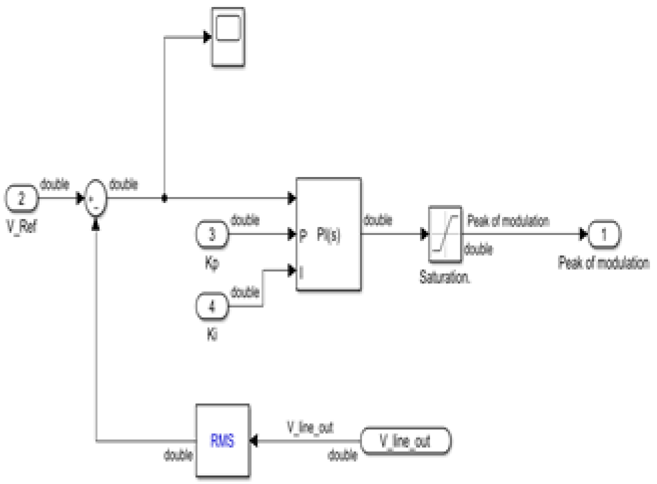


Fig. 7: Inside Blocks of Control System

Feedback of line to line voltage goes to RMS block, RMS block outputs RMS value of input signal. Then this feedback get difference with reference value. Difference is error which is goes to input of PI controller. Output of PI controller pass through saturation block. Upper limit is 5 and lower limit is 0. Then is signal being out as peak of modulation signal and goes to PWM module.

Five Level Voltage Source Inverter

In this paper simulation of three phase inverter model is done

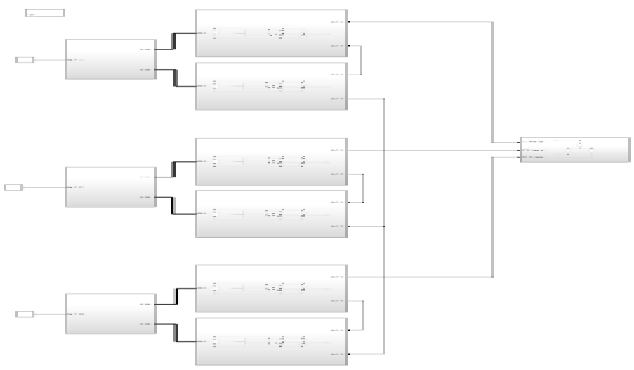


Fig. 8: 5 Level MATLAB Simulink Model

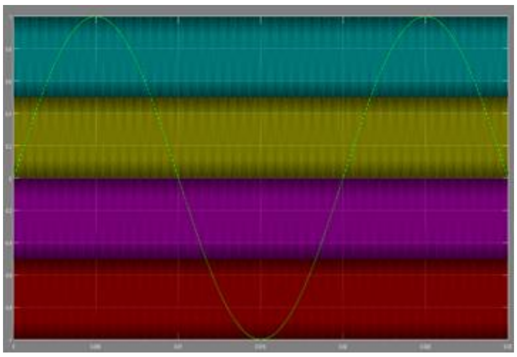


Fig.9: Gate pulses for H Bridge modules

In this simulation, PDPWM (Phase displacement pulse width

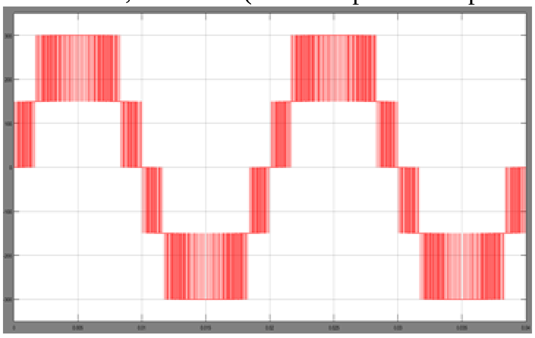
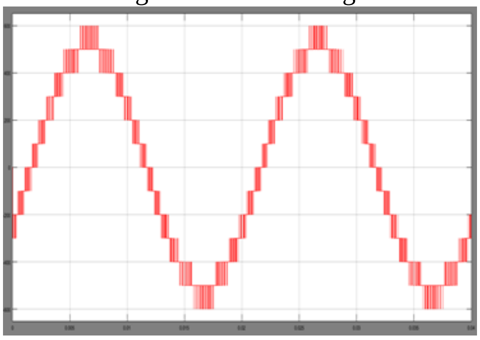
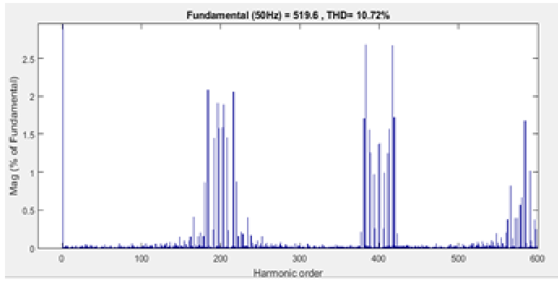
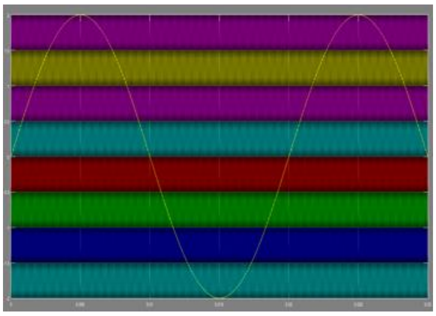
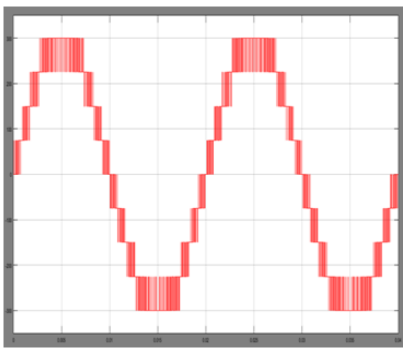


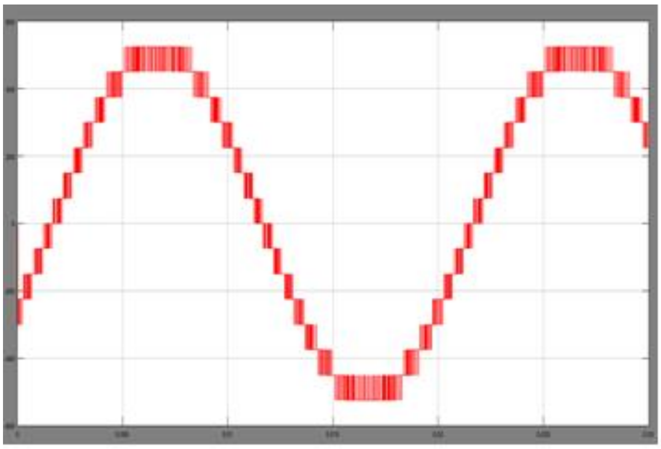
Fig.10: R Phase voltage

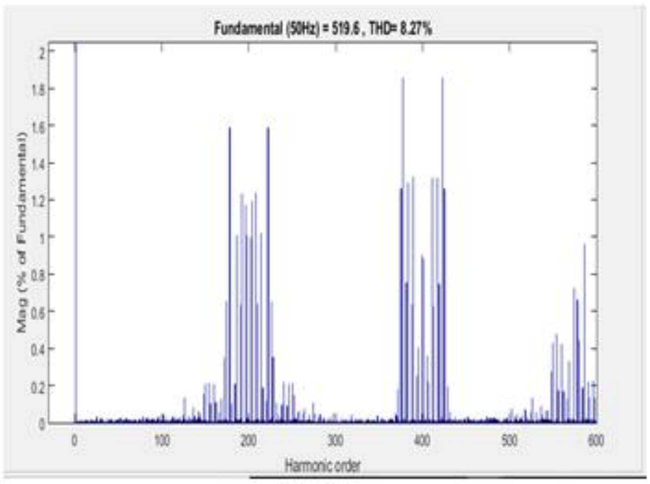












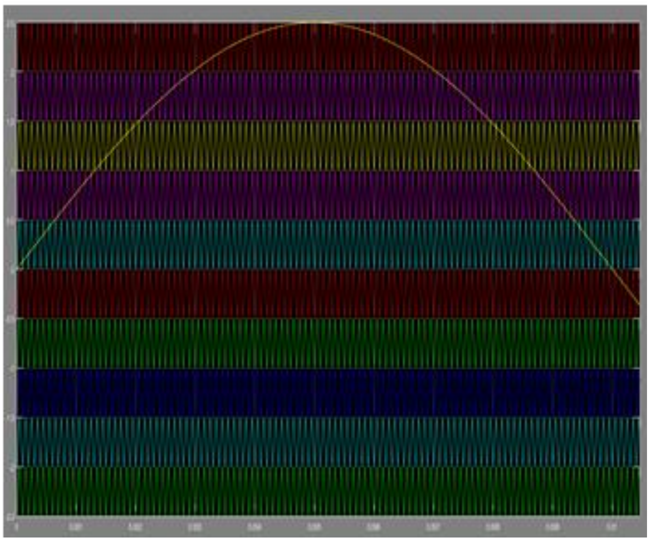


Fig. 22: Gate pulses for H Bridge modules

In this simulation, PDPWM (Phase displacement pulse width modulation) technique is used to drive IGBTs. Ten carrier waves are shifted by magnitude as shown in figure. Each carrier wave is for to drive single leg of H Bridge module. So that to drive ten leg of five H Bridge modules require four carrier wave.

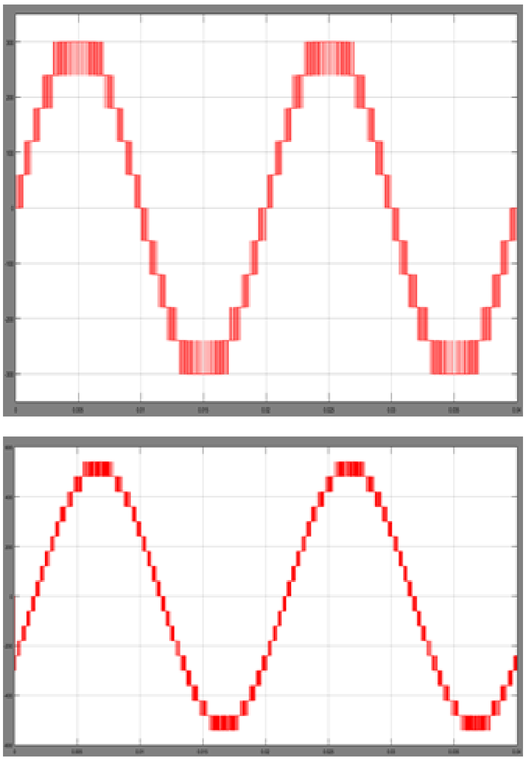


Fig. 24 Line voltage

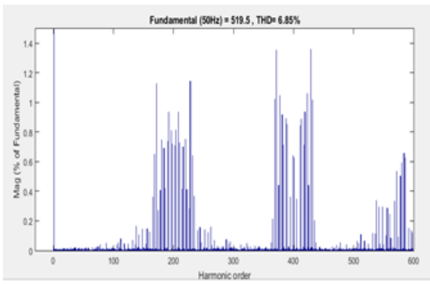


Fig. 25: FFT of Inverter output line to line Voltage

Comparison of all Results

Harmonic Order	% w.r.to Fundamental				
	3 Level	5 Level	7 Level	9 Level	11 Level
1	100	100	100	100	100
3	0.02	0.04	0.02	0	0.01
5	2.98	0.00	0.03	0.01	0.01
7	1.28	0.09	0.02	0.01	0.00
9	0.05	0.01	0.01	0.01	0.01
11	0.32	0.08	0.02	0.01	0.01
172 to 196	27.09	3.72	2.08	1.58	1.12
192 to 202	11.43	3.07	1.91	1.23	0.93

5. CONCLUSION

In this paper deals to say that in multilevel inverter, it is produce output AC voltage which have multiple level so that less switching loss, less harmonic distortion and output filter size reduce or sometimes not required. Multilevel inverter has many advantages over the two level inverter including handling medium and high power loads without causing any problem. We can clearly see from different tables that In 3 level inverter, Lower order harmonics (3, 5, 7, 9 and 11) is higher than all other higher level inverter line to line voltage, higher order harmonics (switching frequency) is also higher than all other higher level inverter line to line voltage. To filter this harmonics out large value and bulky passive filters require that cause extra cost, loss and space in system. For medium and high voltage application, voltage strass across power switches is very high some times that cause failure due to high dv/dt across power switches. In 5 level inverter, Lower order harmonics (3, 5, 7, 9 and 11) is very low of line to line voltage as compare to 3 level inverter and higher order harmonics (switching frequency) is also very lower than 3 level inverter. As level of inverter increase, lower order harmonics (3, 5, 7, 9 and 11) is near to zero and higher order harmonics (switching frequency) is getting lower in amplitude and THD also get low as level of inverter increase.

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