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H-Bridge Multi Level Inverter with Reduced THD for Automotive application

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ABSTRACT

This paper presents a compact inverter-battery combination for automotive application as a replacement for DCAC converter. A 9 level H-bridge inverter is introduced for this purpose with a reduced amount of Total Harmonic Distortion. When compared to the conventional inverter multilevel inverters have an advantage on Total Harmonic Distortion reduction; by increasing the levels THD can be reduced without changing efficiency. Relevance of H-bridge inverter, change in THD with respect to multi level inverter levels and comparison in THD values , working principle circuit design, THD analysis, simulation results of the power circuit using MATLAB-SIMULINK, simulation of control circuit using Proteus-ISIS schematic capture and Hardware

Index Terms— *Multilevel Inverter, Total Harmonic Distortion, Automotive application*

I. INTRODUCTION

Pollution is an issue of this era; fossil fuel vehicles are having a major role in polluting the environment. To overcome this issue electric vehicles can be used Which can be called as a lesser pollutant. General motor's president put forward the idea of electric vehicle with two seats in 1990. Leading car manufacturers like Ford, Honda, Nissan and Toyota followed German Motors in manufacturing electric cars by the end of 90's [1][16].When coming to the building blocks of electric vehicles they are composed of motors, batteries and semiconductor converters. The semiconductor converters will liberate the heat. In order to overcome the heat cooling fans are used along with pumps and radiators. EVs can be classified on the basis of the usage of them. On-Off road EVs, rail borne EVs, Space rover vehicles, Air borne EVs.

The switching devices in the proposed H-bridge inverter are selected in such a way the whole system have minimized switching loss. These semiconducting switches are feeding different motors in an electric vehicle such as 3-phase induction motor, stepper motor, servomotor depending on the use of the motors ,such as serving the main drive and some auxiliary motors which are driving power steering power windows etc. By considering the use motor and converters are selected. Converters are selected depending on the input of the motor or in other words DC/DC converter if the motor input is DC and DC/AC converter if the input of the motor is AC.

Block Diagram of Electric Vehicle

The block diagram comprises of a battery which is feeding energy to the engine of the car. The battery is

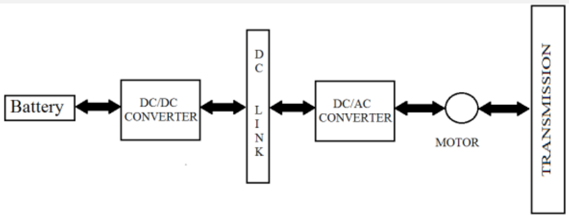

Figure 1.Block diagram of Electric vehicle

Followed by a DC-DC converter in order to boost up the voltage level connected to dc link and thereby a DC-AC converter in [23]. This DC-AC converter is connected to the motor which is adjusting input voltage of the motor which result in the speed control of the vehicle. The block diagram of the electric vehicle is shown in figure.1.It shows the connection of DC-AC (Proposed H-bridge multi level inverter) with the transmission system. Here the DC-AC converter or the proposed H-Bridge multilevel inverter is used to feed the main drive of the electric vehicles; this can be successfully used with other motors also.

1.2. Literatures review

INVERTERS

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source.

A power inverter can be entirely electronic or may be a combination of mechanical effects (such as a rotary apparatus) and electronic circuitry. Static inverters do not use moving parts in the conversion process. Inverters can be broadly classified into two types based on their Voltage Source Inverters (VSI) Current Source Inverters (CSI)

Voltage Source Inverters is one in which the DC source has small or negligible impedance. In other words VSI has stiff DC voltage source at its input terminals. A current source inverter is fed with adjustable current from a DC source of high impedance, i.e.; from a stiff DC current source. In a CSI fed with stiff current source, output current waves are not affected by the load.

1.1.1 CONVENTIONALOR TWO LEVEL INVERTER

The smallest number of voltage levels for an inverter using cascaded inverter is two. The voltage source inverters produce an output voltage or a current with levels either $+V_{dc}$ or $-V_{dc}$. They are known as two level inverter. To achieve a two level waveform, a single full-bridge inverter is employed. Basically, a full-bridge inverter is known as an H-bridge cell. The inverter circuit consists of four main switches and four freewheeling diodes.

1.1.2 MULTILEVEL INVERTER

A multilevel inverter is a power electronic device which is capable of providing desired alternating voltage level at the output using multiple lower level DC voltages as an input. The concept of multilevel Inverter (MLI) is kind of modification of two-level inverter. The multilevel inverters create a smoother stepped output waveform. In this more than two voltage levels are combined together and the output waveform obtained in this case has lower dv/dt and also lower harmonic distortions.

1.1.3 TYPES OF MULTILEVEL INVERTER

- Diode clamped multilevel inverter
- Flying capacitor multilevel inverter
- Cascaded H-bridge multilevel inverter

1.1.4 DIODE CLAMPED MULTILEVEL INVERTER

The main concept of this inverter is to use diodes and provides the multiple voltage levels through the different phases to the capacitor banks which are in series. A diode transfers a limited amount of voltage, thereby reducing the stress on other electrical devices. The maximum output voltage is half of the input DC voltage. It is the main drawback of the diode clamped multilevel inverter. This problem can be solved by increasing the switches, diodes, capacitors. Due to the capacitor balancing issues, these are limited to the three levels. This type of inverters provides the high efficiency because the fundamental frequency used for all the switching devices and it is a simple method of the back to back power transfer systems.

1.1.5 APPLICATIONS

1. Static VAR compensation
2. Variable speed motor drives
3. High voltage system interconnections
4. High voltage DC and AC transmission lines

1.1.5 FLYING CAPACITOR MULTILEVEL INVERTER

The main concept of this inverter is to use capacitors. It is of series connection of capacitor clamped switching cells. The capacitors transfer the limited amount of voltage to electrical devices. In this inverter switching states are like in the diode clamped inverter. Clamping diodes are not required in this type of multilevel inverters. The output is half of the input DC voltage. It is drawback of the flying capacitors multi-level inverter**.** An electric battery is a device consisting of one or more electrochemical that converts stored chemical energy into electrical energy. Each cell contains a positive terminal, or cathode and a negative terminal, or anode. Electrolyte flow ions to move between the electrodes and terminals, which allows current to flow out of the battery to perform work.

1.1.6. APPLICATIONS

1. Induction motor control using DTC (Direct Torque Control) circuit
2. Static var generation
3. Both AC-DC and DC-AC conversion applications
4. Converters with Harmonic distortion capability
5. Sinusoidal current rectifiers

1.1.7 CASCADED H-BRIDGE MULTILEVEL IN INVERTER

The cascaded H-bride multilevel inverter is to use capacitors and switches and requires less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridge and gives the separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages. One of the advantages of this type of multi-level inverter is that it needs less number of components compared with diode clamped and flying capacitor inverters. The price and weight of the inverter are less than those of the two inverters. Soft-switching is possible by the some of the new switching methods.

Multilevel cascade inverters are used to eliminate the bulky transformer required in case of conventional multi-phase inverters, clamping diodes required in case of diode clamped inverters and flying capacitors required in case of flying capacitor inverters. But these require large number of isolated voltages to supply the each cell.

1.1.8. APPLICATIONS

1. They are commercialized in standard products such as compressors, pumps, fans, grinding mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, high-voltage direct-current (HVDC) transmission.
2. The power quality in particular is very good because of EMI/EMC issues, which impose strong requirements in the automotive industry.
3. It is used in some aircraft systems to convert a portion of the aircraft DC p It is used in some aircraft systems to convert a portion of the aircraft DC power to AC. The AC power is used mainly for electrical devices like lights, radar radio, motor and other devices.
4. They are also used in Motor drives, Active filters, Electric vehicle drives, DC power source utilization. They are also used in Motor drives, Active filters, Electric vehicle drives, DC power source utilization, Power factor compensators, Back to back frequency link systems, Interfacing with renewable energy resources.

2.1 THREE LEVEL INVERTER

To achieve a three-level waveform, a single full-bridge inverter is employed. A full-bridge inverter is known as an H-bridge cell, which is illustrated. The inverter circuit consists of four main switches and four freewheeling diodes. The Fig.3.1 shows a single phase cascaded three level inverter.

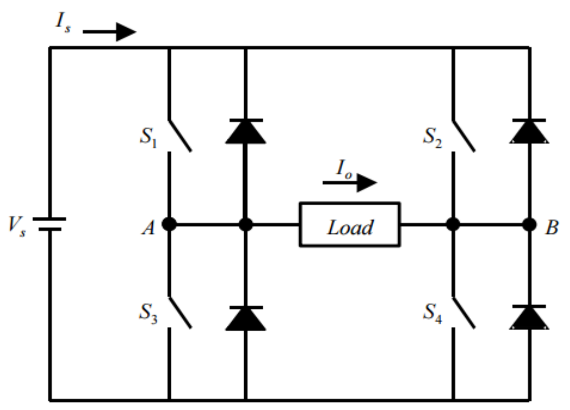

Fig 2.1 Three level inverter

According to the switching pattern, three output voltage levels, +V, -V, and 0 can be synthesized for the voltage across A and B from the switching pattern shown in Table 3.1 and the waveform is shown in Fig.3.2.

Table 2.1 Switching pattern of 3 level inverter

Switches Triggered	Voltage level (in volts)
S3,S4	0V
S1,S4	+Vdc
S1,S2	0V
S1,S2	0V
S2,S3	-Vdc
S3,S4	0V

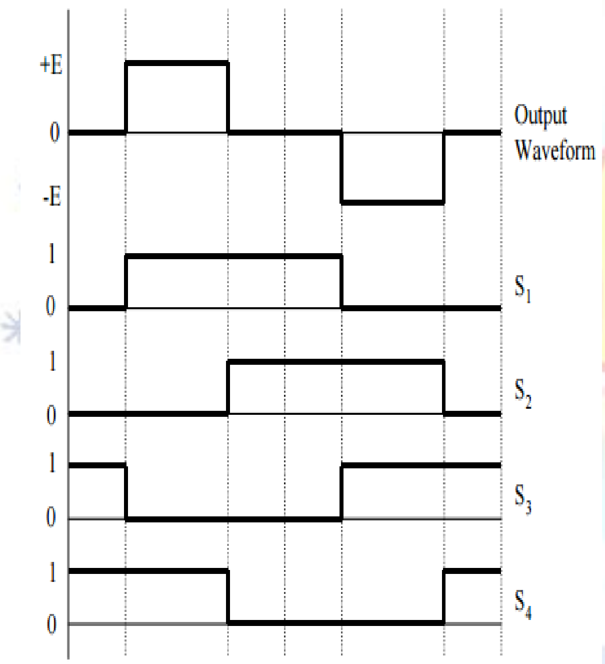

Fig.2.2 Three level inverter switching signals

2.2 FIVE LEVEL INVERTER

A five level inverter is designed by cascading two H-bridges and connecting a load across it. Separate dc supply is given to both the H-bridges. A combination of eight switches is used for designing the five level inverter. The switching sequence is such that +Vdc is obtained for the first step and +2Vdc for the second step during positive cycle. Similarly, -Vdc and -2Vdc is obtained for negative cycle. .The figure 3.3 shows a single phase cascaded five level inverter.

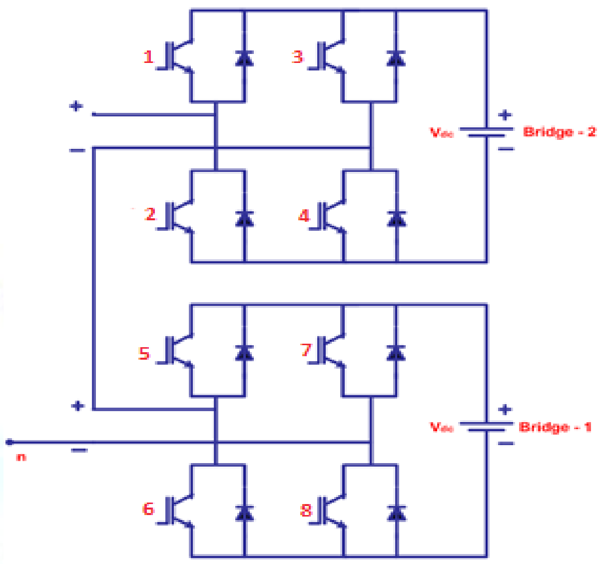

Fig. 2.3 Five level inverter

The five level output waveform is obtained according to the switching pattern as shown in Table 3.2

Table 2.4 Switching patternof5 level inverter

Switches Triggered	Voltage level (in volts)
S1,S4,S6,S7	0V
S1,S4,S5,S7	+Vdc
S1,S4,S5,S8	+2Vdc
S1,S4,S6,S8	+Vdc
S1,S4,S6,S7	0V
S2,S3,S5,S8	-Vdc
S2,S3,S6,S8	-2Vdc
S2,S3,S6,S7	-Vdc
S2,S3,S5,S7	0V

The waveform for five level inverter is as shown in the Fig.2.5

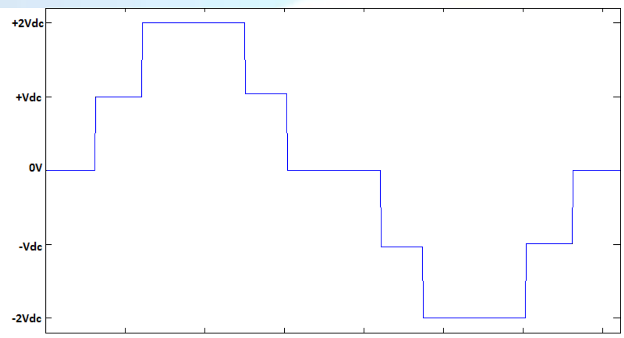

Fig.2.5 Five level inverter voltage waveform

2.3 FORMULAE

The formulae used for the calculation of the output voltage, fundamental voltage and the total harmonic distortions are given

1. m = 2s +1

Where, m = no. of levels

s = no. of DC

V_{dc} = the dc voltage source across the H-bridge

α_1, α_2 and α_3 = the switching angles for three H-bridges

V_1 = the fundamental

2. $$\frac{4V_{dc}}{\pi}(\cos(\alpha_1)+\cos(\alpha_2)+\ldots+\cos(\alpha_s))=V_1$$

Where,

V_{dc}= the dc voltage source across the H-bridge

α_1, α_2 and α_3 = the switching angles for three H-bridges

V_1 = the fundamental

3. $$v_{an}(wt)=\sum_{k=1,3,5,\ldots}^{\infty}\frac{4V_{dc}}{k\pi}(\cos(k\alpha_1)+\cos(k\alpha_2)+\ldots+\cos(k\alpha_s))\sin(k\omega t)$$

Where,

Van = the output voltage

k = the order of the harmonic component

4. $$THD=\frac{\sqrt{\sum_{n=x}^{n=25} V_n^2}}{V_1}\times 100$$

Whe...,

x = the no. of stages in the waveform

n= square of no. of levels

Hence, x=7 and n=25

2.4 PROPOSED H-BRIDGE MULTI LEVEL INVERTER FOR AUTOMOTIVE APPLICATION

In multi level inverter the input voltage is vdc and its different levels [28] are forming the output voltage levels of the inverters following. Consider Vm is the output voltage levels and the input voltages vdc Then the output voltage level is given by Vm = vdc/m-1 Where m is the number levels of the multilevel inverter. An H-bridge multilevel inverter consist of m number of single phase full bridge inverter cascaded connected .In cascaded inverter voltage-clamping diodes or voltage balancing capacitors are not used. For real power conversion (AC-DC-AC) separate dc input voltage is required which is from fuel cell, solar cell or battery. Components required for cascade inverter are lesser compared to other form of multilevel inverters. Soft switching can be performed if required. Circuit design is done as follows: number of single phase full bridge inverter can be calculated using the equation given below by considering the number of voltage levels and input voltage.

N=m-1/2

Where,

N=number of DC voltage source

M=output phase voltage level.

2.5 SINUSOIDAL PWM

SPWM output is generated by intersection between sine signal and triangle signal. Sine signal is the reference waveform and triangle waveform is the carrier waveform. When magnitude of sine signal is larger than triangle signal, the pulses generated will be high. And then when the triangular signals higher than sine signal, the The pulses near the edges of the half cycle are always narrower than the pulses near the centre of the half cycle such that the pulse widths are proportional to the corresponding amplitude of a sine wave at that portion of the cycle. To change the effective output voltage, the widths of all pulses are increased or decreased while maintaining the sinusoidal proportionality.

With pulse width modulation only the widths (on-time) of the pulses are modulated. The amplitudes (voltage) during the "on-time" are constant unless a multi-step circuit is used. The line-to neutral voltage of a 3-phase inverter has two voltage levels. Fig.2.6 shows the generation of a sinusoidal PWM signal. The gating signal can be generated by comparing a sinusoidal reference signal with a triangular carrier wave and the width of each pulse varied proportionally to the amplitude of a sine wave evaluated at the centre of the same pulse.

The output frequency of the inverter can be found by using the frequency of the reference signal. The RMS output voltage (V_0) can be controlled by modulation index M and in turn modulation index is controlled by peak amplitude. The voltage can be calculated by V_0 V/s S_1, S_4 . The number of pulses per half cycle depends on the carrier frequency. The gating signal can be produced by using the unidirectional triangular carrier wave

2.6 TOTAL HARMONIC DISTORTION (THD) ANALYSIS

The total harmonic distortion is defined as the measure of closeness of the obtained waveform to the shape of its fundamental waveform. And is given by the equation

THD=(1/V1(E v2n))1/2

N=1,2,3

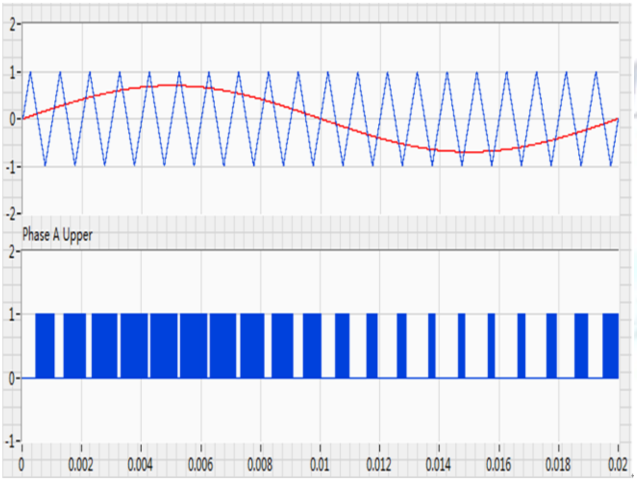

Fig 2.6 Generation of SPWM

Sinusoidal PWM is a type of "carrier-based" pulse width modulation. Carrier based PWM uses pre-defined modulation signals to determine output voltages. In sinusoidal PWM, the modulation signal is sinusoidal, with the peak of the carrier signal.

2.7 SIMULATION MODEL OF POWER CIRCUIT

The simulation model of power circuit for the five level and three level inverter is done in MATLAB/SIMULINK using SPWM technique for generating the pulses fed to the MOSFETs.

2.7.1 SIMULINK MODEL OF 3 LEVEL INVERTER (WITH R= 100 Ω)

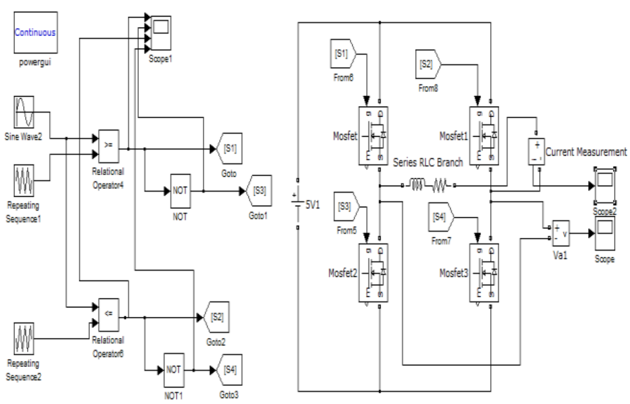

Fig2.7 SIMULINK model of three level inverter

2.7.2 SIMULATION RESULT FOR 3 LEVEL INVERTER

The simulation result for 3 level inverter is obtained and the THD value is verified using the formulas.

SWITCHING PULSES FOR 3 LEVEL INVERTER

The switching pulses for 3 level inverter is obtained by placing scope after relational operator. The pulses are as shown in Fig.2.8

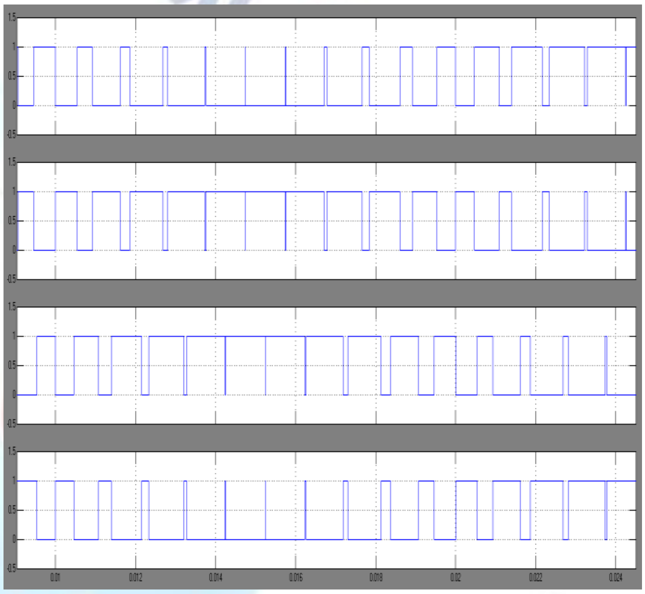

Fig 2.8 switching pulses for three level inverter

2.8 SIMULINK MODEL OF 5 LEVEL INVERTER (WITH R=100Ω)

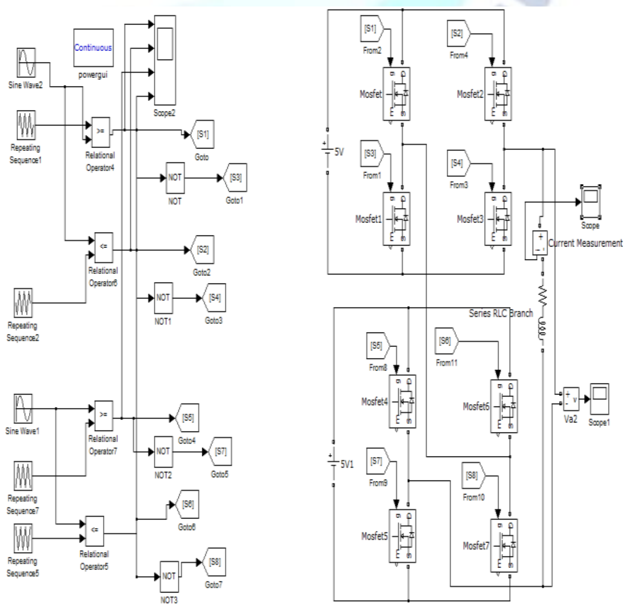

Fig 2.9 SIMULINK model of five level inverter

2.8.1SIMULATION RESULT FOR 5 LEVEL INVERTER

The simulation result for 5 level inverter is obtained and the THD value is verified using the formulas.

SWITCHING PULSES FOR 5 LEVEL INVERTER

The switching pulses for 5 level inverter is obtained by placing a scope after relational operator. The pulses are as shown in Fig.3.0

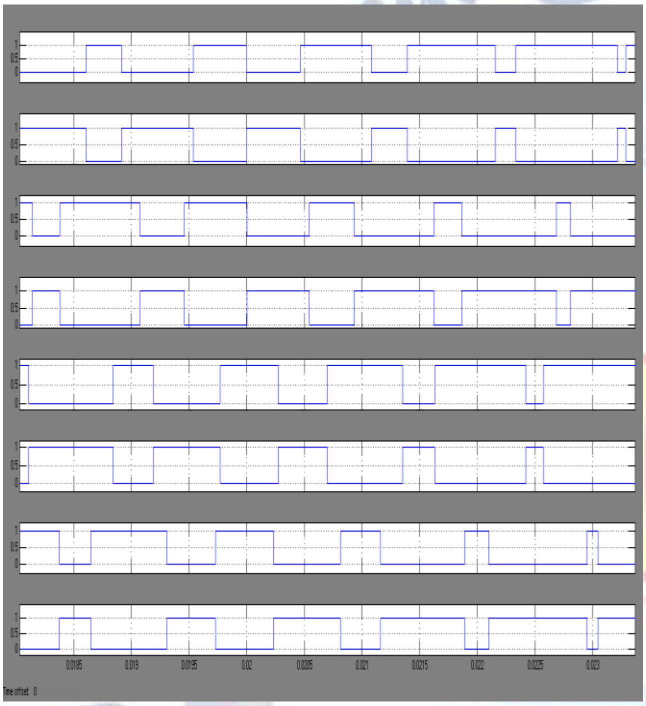

Fig 3.0 switching pulses for five level inverter

III THD USING FFT ANALYSIS

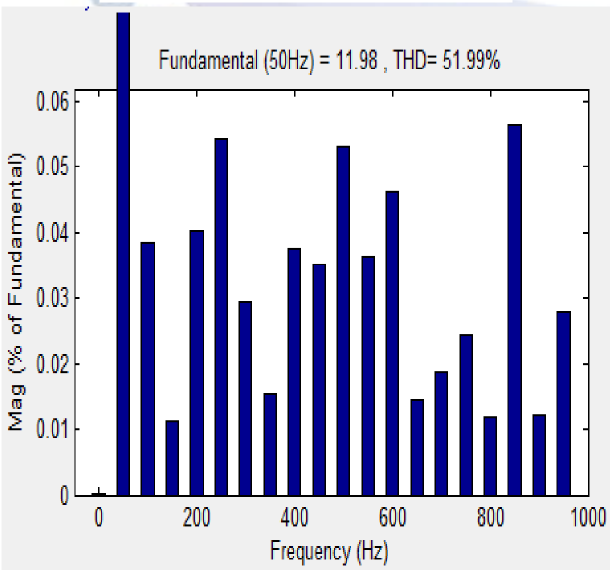

Fig 3.1 THD For 3 Level Inverter

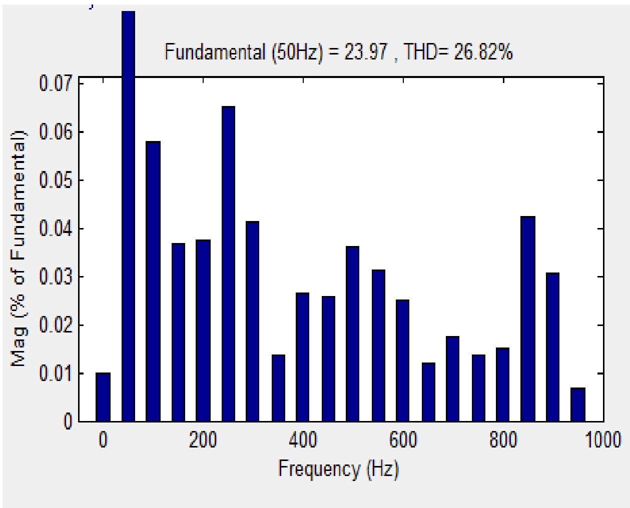

Fig 3.2 THD FOR 5 LEVEL INVERTER

3.1 ARDUINO

Arduino is a software company, project, and user community that designs and manufactures computer hardware, open, and <u>microcontroller</u> based kits for building digital devices and interactive objects that can sense and control physical devices.

The project is based on microcontroller board designs, produced by several vendors, using various microcontrollers. These systems provide sets of digital and analog I/O pins that can interface to various expansion boards (termed shields) and other circuits. The boards feature serial communication interfaces, including Universal Serial Bus (USB) on some models, for loading programs from personal computers. For programming the microcontrollers, the Arduino project provides an integrated development environment(IDE) based on a programming language named Processing, which also supports the languages C and C++.

The first Arduino was introduced in 2005, aiming to provide a low cost, easy way for novices and professionals to create devices that interact with their environment using sensors and actuators. Common examples of such devices intended for beginner hobbyists include simple robots, thermostats, and motion detectors

3.2DRIVER CIRCUIT

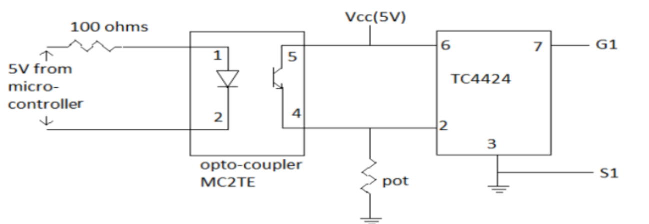

Fig 3.3 Driver circuit of MOSFET

3.3 SOFTWARE DESCRIBTION

ISIS provides the development environment for PROTEUS VSM, our revolutionary interactive system level simulator. This product combines mixed mode circuit simulation micro-processor models and interactive component models to allow the simulation of complete micro-controller based designs. ISIS provides the means to enter the design in the first place, the architecture for real time interactive simulation and a system for managing the source and object code associated with each project. In addition, a number of graph objects can be placed on the schematic to enable conventional time, frequency and swept variable simulation to be performed.

Major features of PROTEUS VSM include:

- True Mixed Mode simulation based on Berkeley SPICE3F5 with extensions for digital simulation and true mixed mode operation.
- Support for both interactive and graph based simulation.
- CPU Models available for popular microcontrollers such as the PIC and 8051ATMEGA 32 series.
- Interactive peripheral models include LED and LCD displays, a universal matrix keypad, an RS232 terminal and a whole library of switches, pots, lamps, LEDs etc.
- Virtual Instruments include voltmeters, ammeters, a dual beam oscilloscope and a 24channel logic analyzer.
- On-screen graphing - the graphs are placed directly on the schematic just like any other object. Graphs can be maximized to a full screen mode for cursor based measurement and so forth.
- Graph Based Analysis types include transient, frequency, noise, distortion, AC and DC sweeps and fourier transform. An Audio graph allows playback of simulated waveforms.
- Direct support for analogue component models in SPICE format.
- Open architecture for ‘plug in’ component models coded in C++ or other languages. These can be electrical, graphical or a combination of the two.
- Digital simulator includes a BASIC-like programming language for modeling and test vector generation.
- A design created for simulation can also be used to generate a net list for creating a PCB- there is no need to enter the design a second time.

Full details of all these features and much more are provided in the PROTEUS VSM

3.4 Simulation of the control circuit

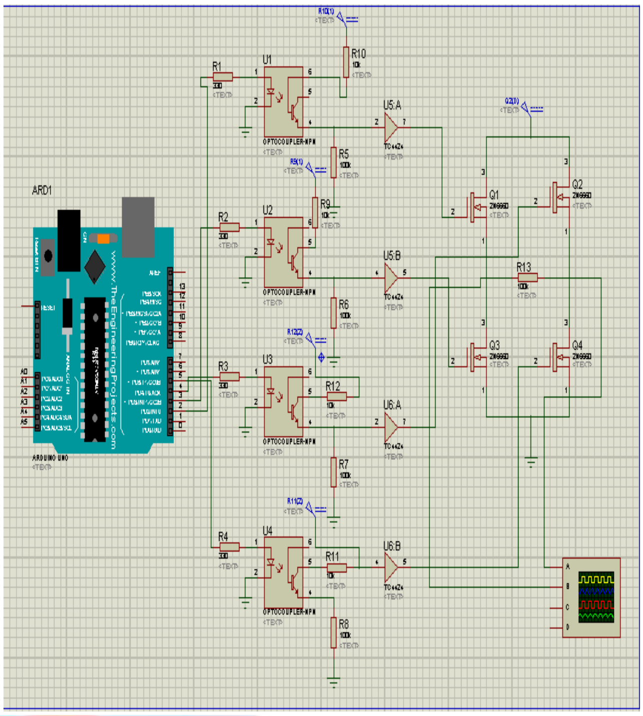

Fig 3.4 simulation of the control circuit

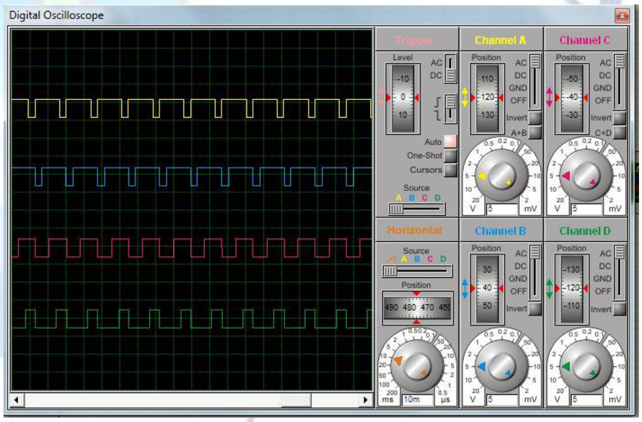

Fig 3.5 pulses of control circuit

IV.CONCLUSION

Multilevel concept provides an efficient reduction of total harmonic distortion. The benefits of multilevel converter include lower transient power loss due to low frequency switching, reduced ac filters and thereby providing compact power conversion. In this project, the prototype of 3 level inverter using microcontroller ATmega328 is implemented. It can be concluded that, in order to maintain the good quality of power, it is necessary to replace the conventional drives with 2 level inverters by multilevel inverters. It is concluded that as the levels of voltage increases, the THD value decreases.

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