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Hardware Implementation of 31-Level Inverter using Arduino Uno Controller

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ABSTRACT-
This paper presents the hardware implementation of the single phase multilevel inverter using the Cascaded H-Bridge using Separated DC sources. The main objective of this paper is to increases the number of levels with a lower number of switches at the output without adding any complexity to the power circuit. The main advantages of the proposed method are to reduce the Total Harmonic Distortion, lower order harmonics and electromagnetic interference and to get high output voltage. To minimize the total harmonic distortion equal area criteria (EAC) switching technique is presented and it can enhance the output voltages from proposed work. Before the hardware implementation the simulation analysis has been performed using Matlab software. The Inverter is operated by using ATMEGA328 controller which generates PWM pulses. The use of Arduino makes the process of using electronics in multidisciplinary projects more accessible. It is well suited for processing control parameters such as speed of an Induction Motor.
Keywords-Multi Level Inverter (MLI), Equal Area Criteria (EAC), Arduino Uno, Total Harmonic Distortion (THD).

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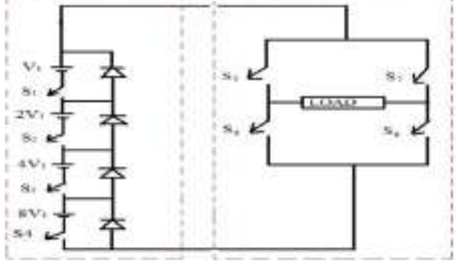
I. INTRODUCTION

Multilevel converters are mainly utilized to synthesis a desired single- or three-phase voltage waveform. The desired multi-staircase output voltage is obtained by combining several dc voltage sources. Solar cells, fuel cells, batteries and ultra-capacitors are the most common independent sources used. One important application of multilevel converters is focused on medium and high-power conversion nowadays, there exist three commercial topologies of multilevel voltage source inverters: neutral point clamped (NPC), cascaded H-bridge (CHB), and flying capacitors (FCs)[5]. Among these inverter topologies, cascaded multilevel inverter reaches the higher output voltage and power levels and the higher reliability due to its modular topology. Diode-clamped multilevel converters are used in conventional high-power ac motor drive applications like conveyors, pumps, fans, and mills. They are also utilized in oil, gas, metals, power, mining, water, marine, and chemical industries. They have also been reported to be used in a back-to back configuration for regenerative applications. Flying capacitor multilevel converters have been used in high-bandwidth high-switching frequency applications such as medium-voltage traction drives. Finally, cascaded H-bridge multilevel converters have been applied where high power and power quality are essential [1][10], for example, reactive power compensation applications, photovoltaic power conversion, uninterruptible power supplies, and magnetic resonance imaging. Furthermore, one of the growing applications for multilevel motor drives is electric and hybrid power trains.

II. MULTILEVEL INVERTER

The proposed multilevel inverter has a set of asymmetrical voltage sources and combination of level generating and polarity generating cell. to get 31-level with less THD, we require only four power switches in level generation cell (LGC) and four in polarity generation cell ((PGC) i.e., H-bridge)) i.e, with eight switches we can generate 31-levels. The proposed 31-level inverter is shown in below Figure 2.1,



Level generating cell Polarity generating cell
Figure 2.1. Proposed 31-level inverter

Here, V_1 is step voltage and the voltage ratio of asymmetrical voltage sources is given by,
$V_1 : 2V_1 : 4V_1 : 8V1$

Here, we have two cells, they are level generating cell and polarity generating cell. The LGC generates number of output levels with the help of switching sequence and PGC generates +Ve and –Ve half waves for AC operation. The voltage across LGC is 31-level pulsating DC [6].

In this paper the simple technique called EAC is implemented to finding the initial values and these initial switching angles are enough to get minimum THD for any number of levels. The EAC is a natural method of finding the best switching angles [6], [7]. By dividing half of fundamental sine wave horizontally and vertically with step voltage and time (ms) respectively.

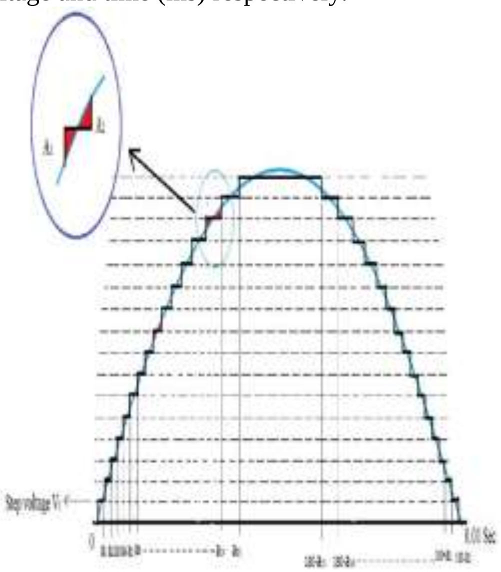


Figure 2.2. Equal Area Criteria (EAC) switching technique

Here, A_1 and A_2 are the areas shown in above figure. To get minimum THD the areas of A_1 and A_2 should be equal. The fundamental switching frequency is taken as 50Hz [6].
Here, $a_1, a_2, a_3, \ldots a_n$ are the switching angles for N-level MLI. All the angles should be $<90^0$.

$0<a_1<a_2<a_3<a_4<a_5<a_6<a_7 - - - - a_n<90^0$
Number of switching angles for N-levels = [(Number of levels-1)$_{/2}$]

Mathematical formula for angle calculation:
N^{th} switching angle a_n (deg.) = [Time at which the N^{th} vertical line touches the time axis (x-axis)] x [2 x fundamental frequency]] x 180^0
The switching angles for 31-level is given below,
$a_1=2^0$, $a_2=6^0$, $a_3=10^0$, $a_4=14^0$, $a_5=18^0$, $a_6=22^0$, $a_7=26^0$, $a_8=30^0$, $a_9=35^0$, $a_{10}=40^0$, $a_{11}=45^0$, $a_{12}=51^0$, $a_{13}=57^0$, $a_{14}=64^0$ $a_{15}=74^0$.

By using above formula we can calculate switching angles for N number of levels. These angles can also be useful for initial guess in NR. With the above switching angles the THD of 31-levels is 2.85%. Here the sinusoidal pulse width modulation technique (SPWM) can be used for controlling H-bridge switches [6].

In order to obtain integral multiple of +Vdc levels in the output voltage, switches S5 and S6 should be turned ON and for –Vdc levels switches S7 and S8 should be turned ON. For zero level simultaneously either S5&S6 or S7&S8 should be turned ON..

THD Calculation:
In general, the Fourier series expansion of the staircase output voltage waveform is given by

$$Van = \sum_{K=1,3,5,\ldots}^{\infty} {}^{4Vdc}/k\pi \; (\cos(k\alpha_1) + \cos(k\alpha_2) + \ldots + \cos(k\alpha_s))\sin(kwt) \quad \text{(i)}$$

Where s is the n^{th} switching angle and k is order of harmonic components. Among s number of switching angles, generally one switching angle is used for fundamental voltage selection and the remaining (s-1) switching angles are used to eliminate certain predominating lower order harmonics.
From equation (i), the expression for the fundamental voltage in terms of switching angles is given by

$$^{4Vdc}/\pi \; (\cos(\alpha_1) + \cos(\alpha_2) + \ldots\ldots\ldots + \cos(\alpha_s)) = V_1 \quad \text{(ii)}$$

From the above two equations (i) and (ii), the percentage value of THD is given by

$$\%THD = \frac{\sqrt{\sum_{n=2,3\ldots}^{\infty} V_n^2}}{V_1} \times 100$$

III. ARDUINO UNO

Figure 3.1 Arduino Uno board

Arduino Uno consists of an 8-bit Atmel AVR microcontroller with complementary components to facilitate programming and incorporation into other circuits. An important aspect of the Arduino is the standard way that connectors are exposed, allowing the CPU board to be connected to a variety of interchangeable add-on modules known as shields. Some shields communicate with the Arduino board directly over various pins, but many shields are individually addressable via an I²C serial bus, allowing many shields to be stacked and used in parallel. Official Arduino's have used the mega AVR series of chips, specifically theATmega8, ATmega168, ATmega328, ATmega1280, and ATmega2560.

A handful of other processors have been used by Arduino compatibles. Most boards include a 5 volt linear regulator and a 16 MHz crystal oscillator (or ceramic resonator in some variants), although some designs such as the Lily Pad run at 8 MHz and dispense with the on board voltage regulator due to specific form factor restrictions. An Arduino's microcontroller is also pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory, compared with other devices that typically need an external programmer.

Features:

- ATmega328 microcontroller
- Input voltage - 7-12V
- 14 Digital I/O Pins (6 PWM outputs)
- 6 Analog Inputs
- 32k Flash Memory
- 16Mhz Clock Speed

IV. MATLAB SIMULATION

The Proposed 31-level inverter simulation circuit with resistive load is as shown below,

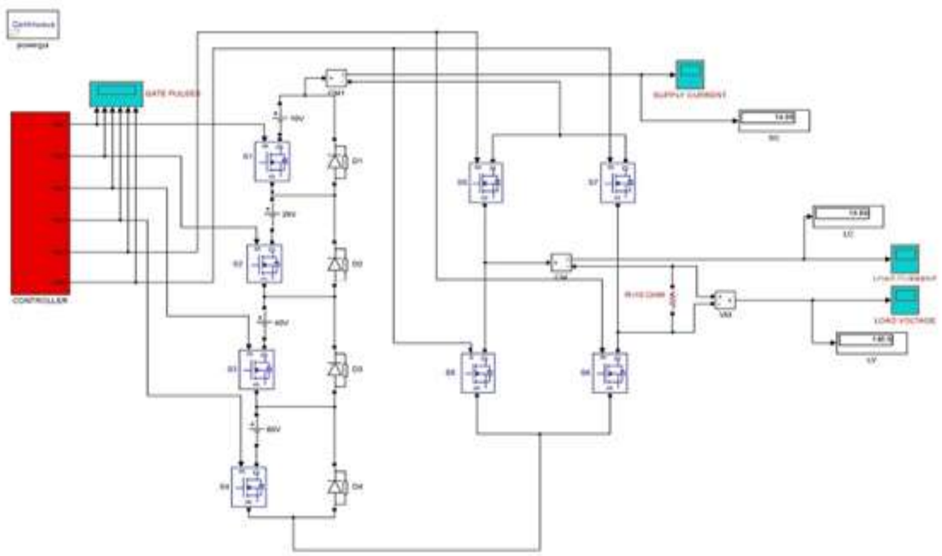


Figure 4.1. Simulink model of proposed 31- level inverter

After calculation of switching angles we used pulse generators for LGC to Switch ON the switches at calculated switching angles and for H-bridge SPWM. The value of THD is observed with the help of FFT analysis using MATLAB/Simulink software for 31-level with resistive load of 10ohms. We achieved The THD value of the above levels is 2.85%. The output voltage wave form and FFT analysis of output voltage are shown in below figures.

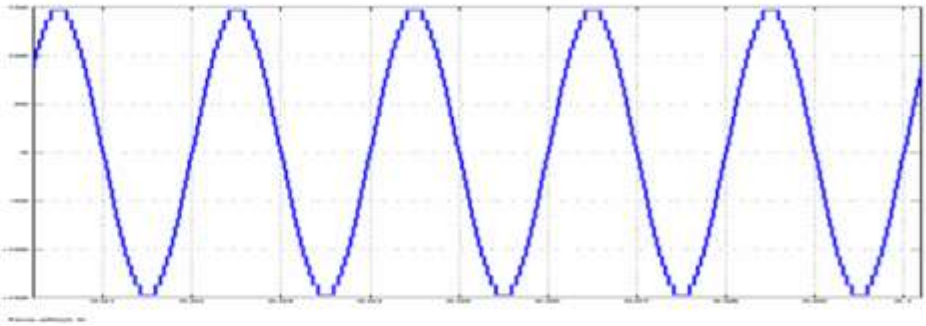


Figure 4.2. Output voltage wave form of 31-level inverter

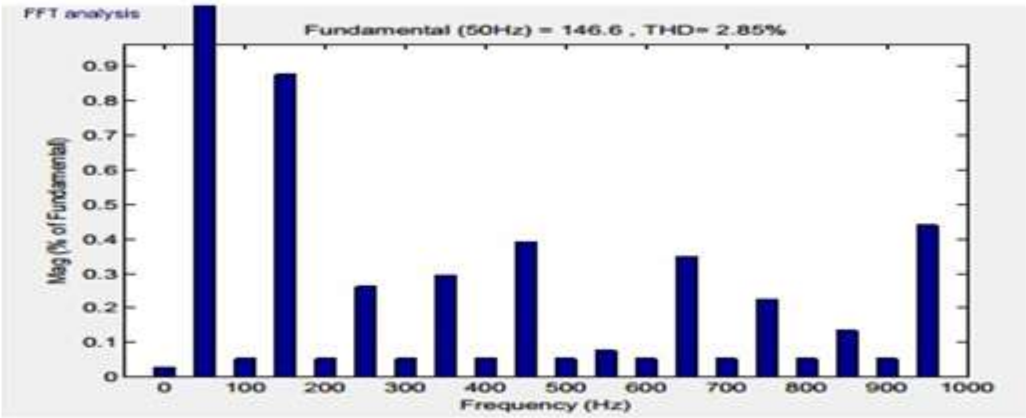


Figure 4.3. FFT analysis of 31-level inverter output voltage

IV. HARDWARE

The hardware implementation of a 31 level inverter has the triggering circuit and bridge circuit and are shown in figures 5.1 & 5.2. The components used in this topology are MOSFETS (IRF540), diodes (1N4007), Op amps (LM358P), resistors (10 ohm), capacitors (0.1 uf), batteries (9V), heat sinks (PI49) and Arduino Uno. Op amps are used as the driver circuit for MOSFETs. The output from driver circuits is given across the gate and source of the MOSFETs. The output can be seen in a cathode ray oscilloscope (CRO).

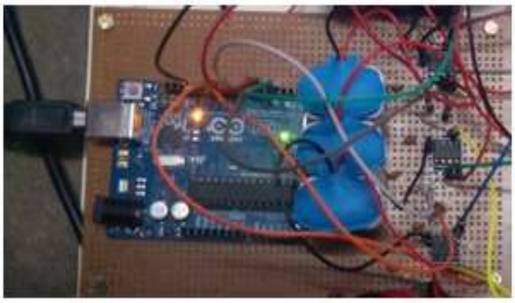


Figure 5.1. Triggering circuit

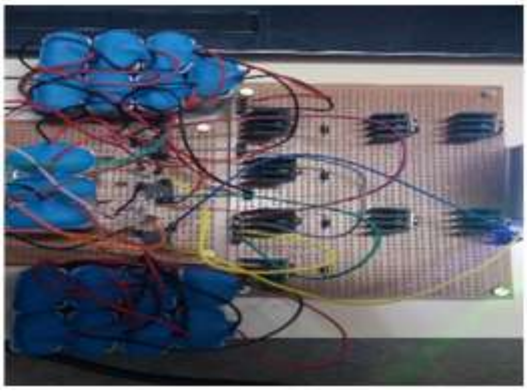


Figure 5.2. Bridge circuit

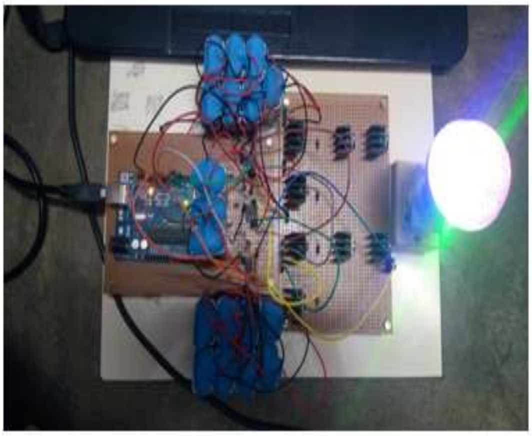


Figure 5.3. Hardware design of 31 level invedrter

The hardware has been interfaced to the Arduino as shown in figure 5.3 for giving the PWM pulses to the MOSFETS. It is interfaced to the laptop in order to provide the power supply to the Arduino. When the circuit is ON the following output wave forms have been obtained when the CRO is connected across the load.

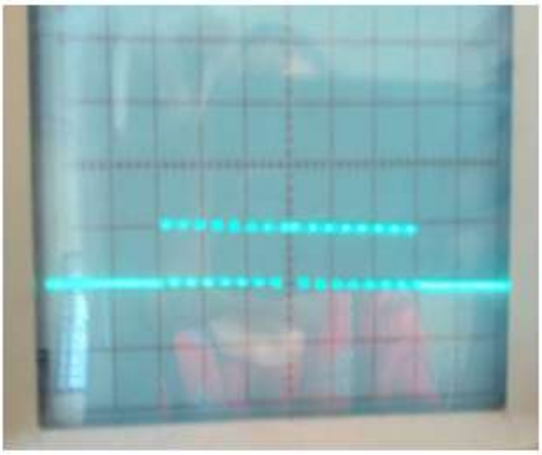


Figure 5.4 Gate pulse for switch S1

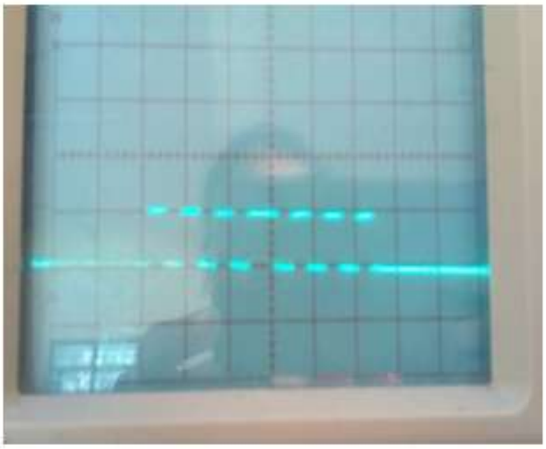


Figure 5.5 Gate pulse for switch S2

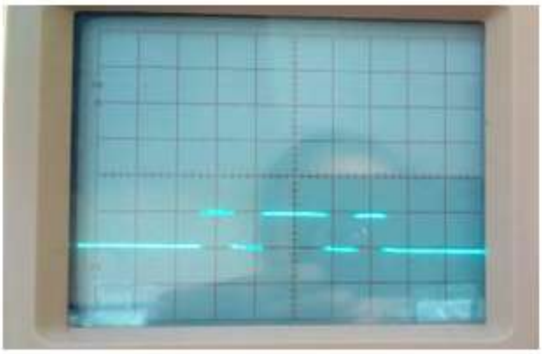


Figure 5.6 Gate pulse for switch S3

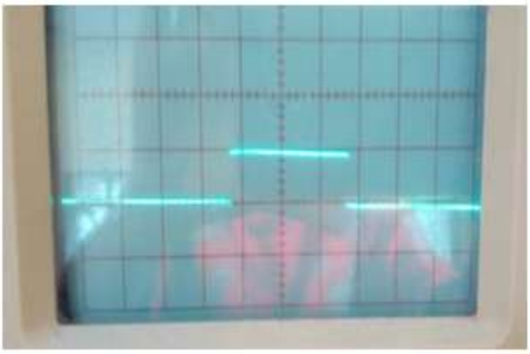


Figure 5.7 Gate pulse for switch S4

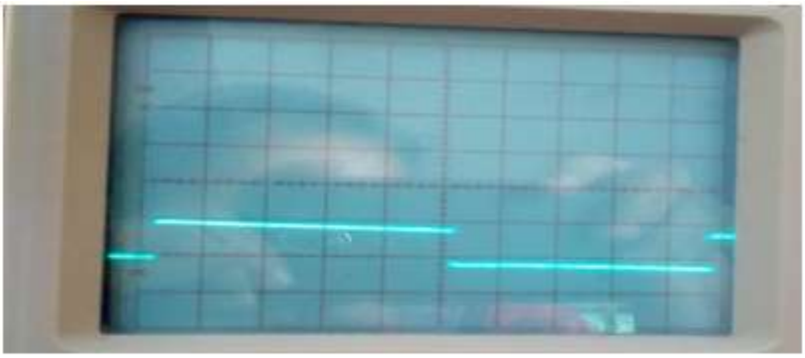


Figure 5.8 Gate pulses for switches S5 & S6

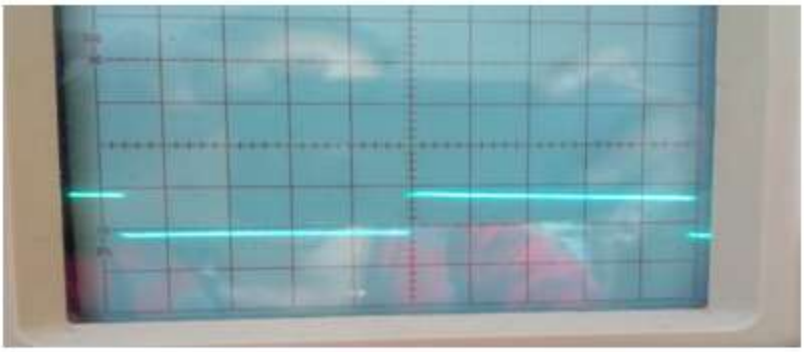


Figure 5.9 Gate pulses for switches S7 & S8

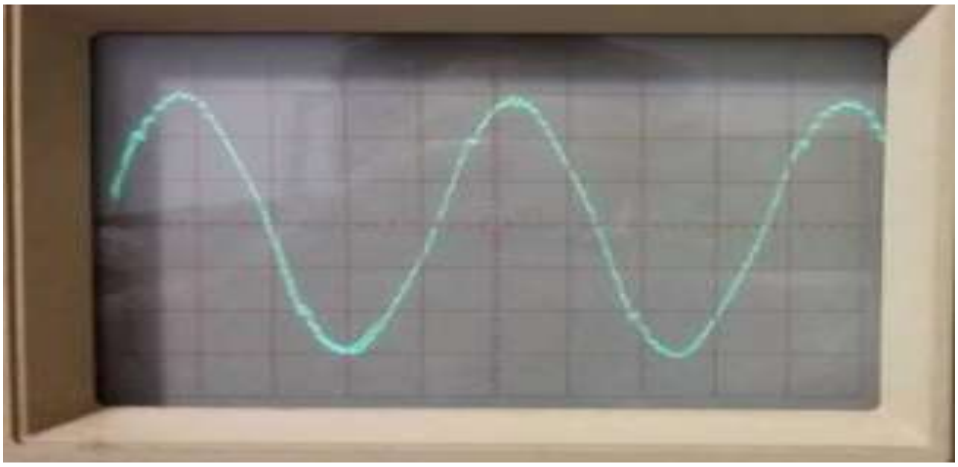


Figure 5.10 output voltage of 31- level inverter

VI. CONCLUSION

In this paper a new switching technique for 31level inverter is presented. With this simple method we can easily calculate the best switching angles. No need of solving complex non-linear equations and without writing the MATLAB program for GA and NR. No need of guessing initial angles [6]. With this EAC technique we achieved 2.85% THD with resistive load for 31-level.

The MATLAB simulation and the hardware implementation for the single phase 31 Level Inverter has been performed. The simulation and hardware results have been obtained. It is observed that in multilevel inverter using cascaded H-Bridge stepped output is obtained with reduced code and hardware design complexity using Arduino controller. Modifying the program written in microcontroller, using additional filter circuits the number of steps in the output waveform can be varied, resulting in better sinusoidal output.

VII. FUTURE SCOPE

The voltage levels obtained in the output can be improved by using high rated batteries which would enable the inverter to run industrial loads. In future there is scope to extend the number of levels as the process complexity is reduced for achieving the desired output which reduces the total harmonic distortion.

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