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Development of 15 Level Cascaded H-H-T Multilevel Inverter

R. Ramaprabha*[1], V. Aadhavan[2], K. Arun[2], V. Arun[2]

*[1]Associate Professor, Department of Electrical and Electronics Engineering Sri Sivasubramaniya Nadar College of Engineering, Chennai, Tamil Nadu, India

[2]UG Students, Department of Electrical and Electronics Engineering Sri Sivasubramaniya Nadar College of Engineering, Chennai, Tamil Nadu, India

ABSTRACT

In recent years, multilevel inverters have emerged as a very important alternative in the area of high power medium voltage energy control. Multilevel inverters (MLI) have been receiving increased attention for their capability of high voltage operation, low electromagnetic interference (EMI) and higher efficiency. The inverter plays a vital role in any renewable based power generation system, as the power extracted from the renewable source is dc. MLI uses power semiconductor devices and dc sources (batteries/capacitors) to synthesis staircase output voltage waveform. By increasing number of levels improving its spectral quality. Numerous topologies and modulation strategies have been introduced and studied extensively in recent literature for utility and drive applications. Although there are a large number of multilevel inverter topologies in the literature, in this work, the most common cascaded topology with H-H-T structure is implemented and tested.

Keywords- MLI, H-H-T, levels, Mat Lab.

I. INTRODUCTION

Multilevel inverter technology has emerged recently as a very important alternative in the area of high-power medium-voltage energy control. The prominent type of inverters includes diode-clamped inverter (neutral-point clamped), capacitor-clamped (flying capacitor), and cascaded multicell with separate dc sources [1]-[2]. Each type has its own set of advantages and applications. Based on the requirement, the inverters are employed in places of need. Multilevel inverters have an array of power semiconductors and capacitor voltage sources. Its output generates voltage with stepped waveforms. The most relevant types of modulation methods, which can be used, are multilevel sinusoidal pulse width modulation, multilevel selective harmonic elimination, and space-vector modulation. Cascade Multilevel Inverters are very popular and have many applications in electric utilities and for industrial drives. When these inverters are used for industrial drives directly, the THD in the output voltage of inverters is very significant as the performance of drive depends very much on the quality of voltage

applied to drive. A multilevel inverter in high power ratings improves the performance of the system by reducing harmonics. This work presents the simulation and hardware implementation of fifteen level inverter. The most significant features of multilevel inverters include, low distorted output voltage generation, less distorted current, reduced stress on the load, etc. In this paper, 15-level inverter that utilizes lesser number of switches than the conventional topologies is implemented and to the performance is evaluated through MATLAB based simulation and experimentation. Firstly, 15 level H-H-T cascaded multilevel inverter is implanted using MATLAB. Then, it is tested through hardware implementation with pulse generation using Arduino processor.

II. CIRCUIT DESCRIPTION AND EXPLANATION

The structure of the proposed basic unit is presented in the Fig 1. This circuit consists of six unidirectional switches (K1, K2, K3, K4, Sx, Sy), two bidirectional switches (S1, T1), and four dc sources. Two of the dc sources have the same magnitude of V1 and the value of the two other sources is V2.

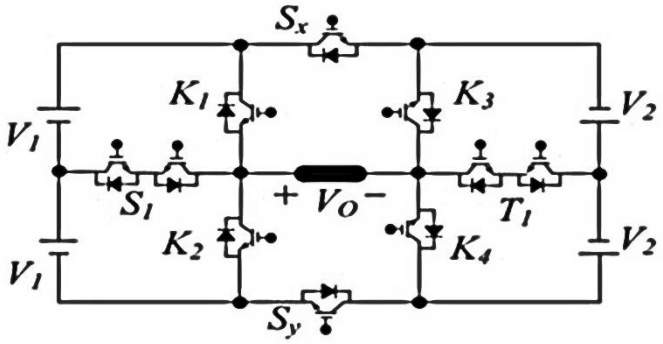

Fig. 1. Basic Structure Unit

The modulation methods used in multilevel inverters can be classified according to the switching frequency. Modulation techniques that work with high switching frequencies have many commutations for the power semiconductors in a cycle of the fundamental output voltage. Multilevel inverters generate sinusoidal voltages from discrete voltage levels, and pulse width modulation (PWM) strategies accomplish this task of generating sinusoids of variable voltages and frequencies. Several techniques for the implementation of PWM for multilevel inverters have been developed. The well-known high switching frequency methods are classic carrier based sinusoidal PWM (SPWM) was presented in [8]-[9] and space vector PWM. The popular methods for low switching frequency methods are space vector modulation (SVM) method and selective harmonic elimination method [10]-[16]. In this project, one of the fundamental type i.e. Half - Height PWM technique is used.

The main idea of half-height (HH) method is that when the fundamental value increases to the half-height of the level, the switch angle is set and thus a better output waveform obtained. The main switching angles are determined by the formula:

$$\theta_i = \sin^{-1}\left(\frac{2i-1}{N-1}\right), \text{ where } i=1, 2, 3, \ldots \left(\frac{N-1}{2}\right)$$

where, N= Number of output levels (1)

Calculation of Switching Angles- HH PWM

For a 15-level inverter the switching angles calculated for Half Height PWM are: θ1 = 7.18, θ2 = 22.02, θ3 = 38.68, θ4 =
61.04. The harmonics eliminated are 3, 5, 7.

Calculation of Switching Angles- SHE PWM

For a 15-level inverter the switching angles calculated for SHE PWM are: θ1 = 10.01, θ2 = 22.14, θ3 = 40.75, θ4 =
61.75. The harmonics eliminated are 5, 7, and 11.

Switching Modes of Operation

Fig 2 explains the modes of operation of a fifteen level multilevel inverter. The switching states for each mode are different to obtain a stepped waveform. In each mode the ON switches are mentioned with the voltage across the switch.

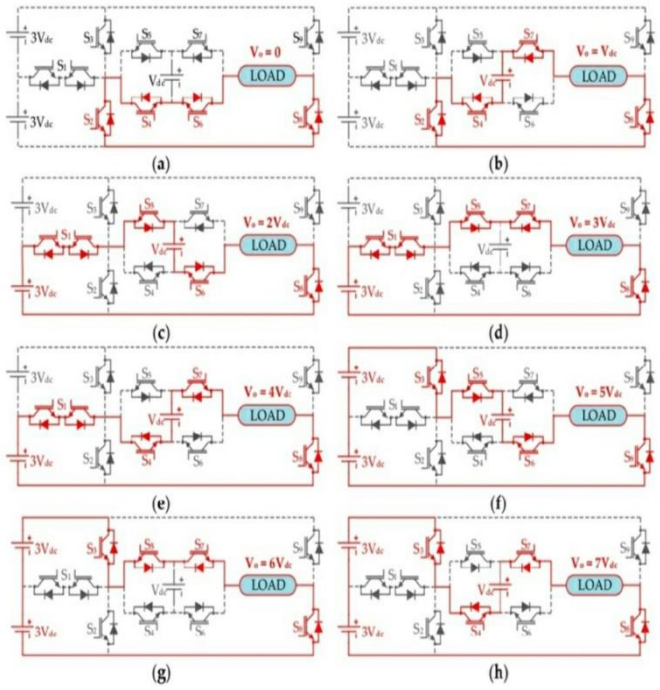

Fig. 2. Switching Modes of Operation

Switching States of Basic Unit of MLI

Table 1 shows the switching states of basic structure of multilevel inverter and the output voltage for each state is mentioned.

Table 1 Switching states of basic unit of MLI

S1	S2	S3	S4	S5	S6	S7	S8	S9	Output Voltage (Vo)
0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	0	1	1	0	Vdc
1	0	0	0	1	1	0	1	0	2 V_{dc}
1	0	0	0	1	0	1	1	0	$3V_{dc}$
1	0	0	1	0	0	1	1	0	$4V_{dc}$
0	0	1	0	1	1	0	1	0	$5V_{dc}$
0	0	1	0	1	0	1	1	0	$6V_{dc}$
0	0	1	1	0	0	1	1	0	$7V_{dc}$
0	1	0	1	0	1	0	1	0	0
0	0	1	0	1	1	0	0	1	$-V_{dc}$
1	0	0	1	0	0	1	0	1	$-2V_{dc}$
1	0	0	1	0	1	0	0	1	$-3V_{dc}$
1	0	0	0	1	1	0	0	1	$-4V_{dc}$
0	1	0	1	0	0	1	0	1	$-5V_{dc}$
0	1	0	1	0	1	0	0	1	$-6V_{dc}$
0	1	0	0	1	1	0	0	1	$-7V_{dc}$
0	0	1	0	1	0	1	0	1	0

III. IMPLEMENTATION & HARDWARE REALIZATION

MATLAB Implementation

Fig 3 and Fig 4 show the Simulink model for level multilevel inverter with sub-circuits.

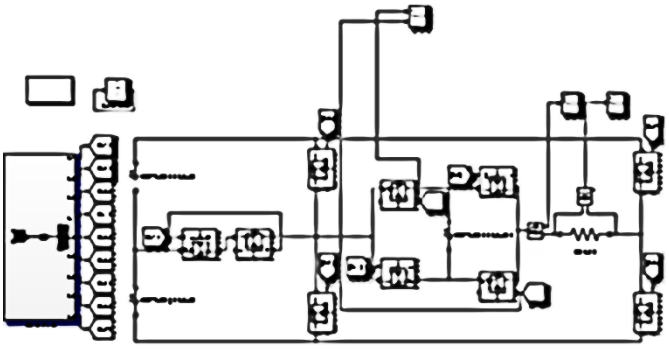

Fig. 3. MATLAB Circuit for T-type 15 level MLI

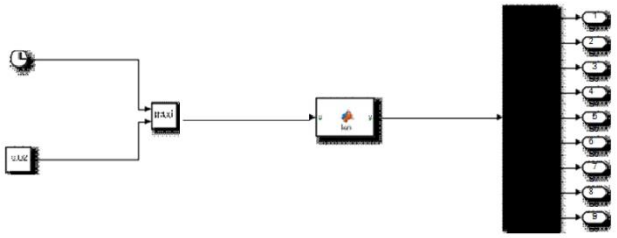

Fig. 4. Sub-circuit for T-type 15 level MLI

The simulation output of 15-level multilevel inverter is obtained and shown in Fig 5.

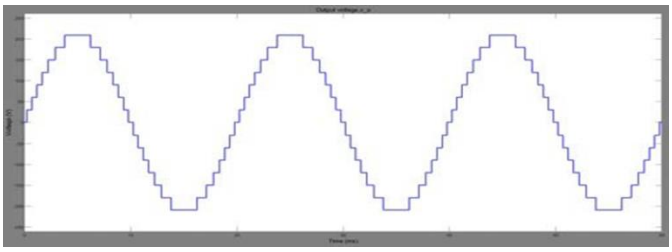

Fig. 5. Output voltage of T-type 15 level MLI

The switching pulse of each switch is shown vide Figs 6 to 8.

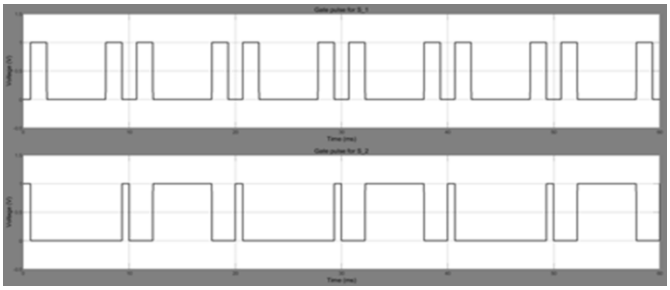

Fig. 6. Pulses for S1 and S2

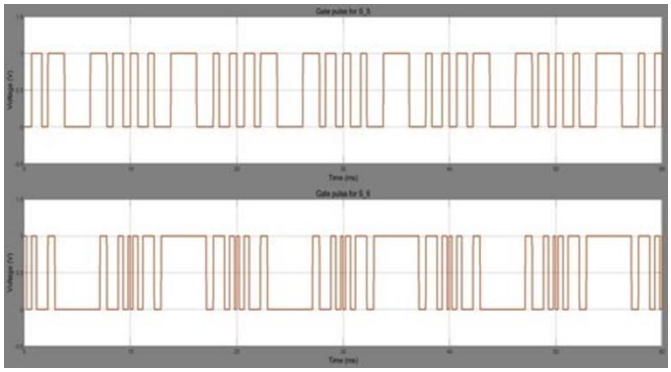

Fig. 7. Pulses for S3, S4 S5 and S6

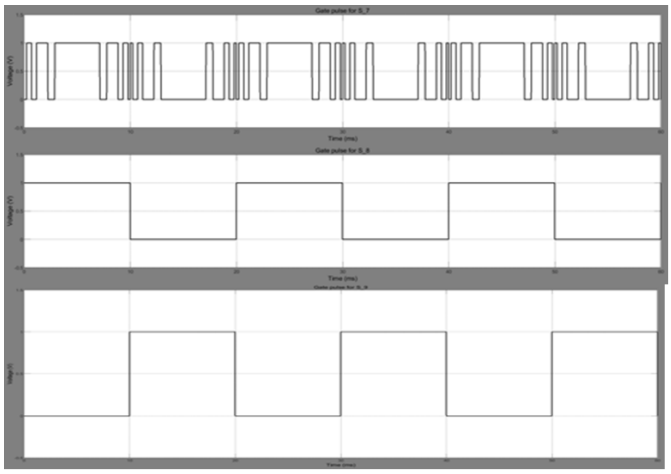

Fig. 8. Pulses for S7, S8 and S9

Fig 9 shows the THD percentage and the harmonics of 15 level multilevel inverter. The results show the 15-level

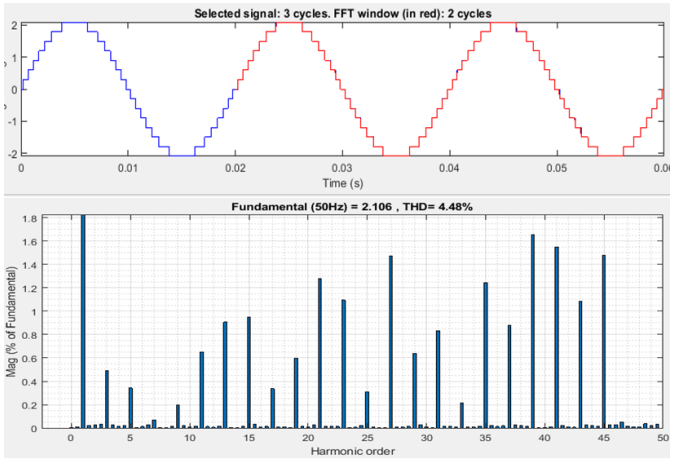

Fig 9 THD percentage and harmonic order

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Sampling time       = 9.7688e-06 s
Samples per cycle   = 2047
DC component        = 7.253e-05
Fundamental         = 2.106 peak (1.489 rms)
THD                 = 4.48%

     0 Hz   (DC):          0.00%    270.0°
    25 Hz                  0.01%    -19.5°
    50 Hz   (Fnd):       100.00%     -0.1°
    75 Hz                  0.02%    213.9°
   100 Hz   (h2):          0.03%    208.2°
   125 Hz                  0.03%     78.4°
   150 Hz   (h3):          0.49%    178.6°
   175 Hz                  0.03%    129.8°
   200 Hz   (h4):          0.02%    260.4°
   225 Hz                  0.02%     57.3°
   250 Hz   (h5):          0.34%     -0.1°
   275 Hz                  0.01%    149.3°
   300 Hz   (h6):          0.01%    243.9°
   325 Hz                  0.03%     60.3°
   350 Hz   (h7):          0.07%    172.6°
   375 Hz                  0.01%     86.1°
   400 Hz   (h8):          0.00%    130.8°
   425 Hz                  0.02%     66.4°
```

Fig 10 Sampling time

Hardware Implementation

Table 2 shows the hardware specifications and Table 3 shows the parameters.

Table 2 Hardware specifications

Components	Specification	Quantity
MOSFET	IRFP460	9
Optocoupler	MC2TE	10
Arduino	UNO	01

Table 3 Parameters

Parameters	Values
Output voltage (V_o)	210 V
Supply frequency (f_s)	50 Hz
DC voltage (V_{dc})	30 V
Total number of switches	9
Number of unidirectional switches	8
Number of bidirectional switches	1

The power supply circuit for the opto-couplers are shown in the Fig 11 and complete gate driver circuit is shown in Fig 12. The power circuit is shown in Fig 13.

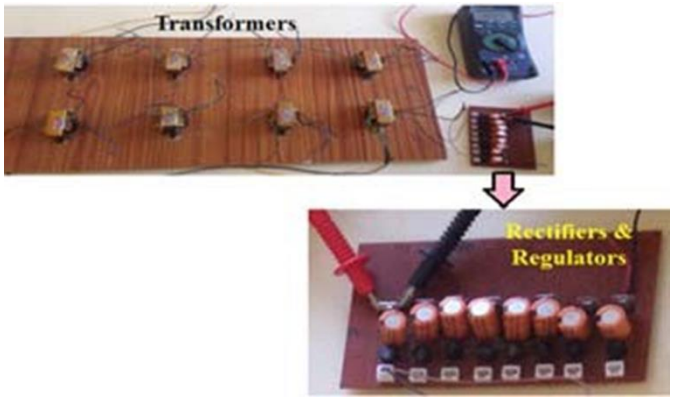

Fig 11 Power supply circuit for opto-coupler

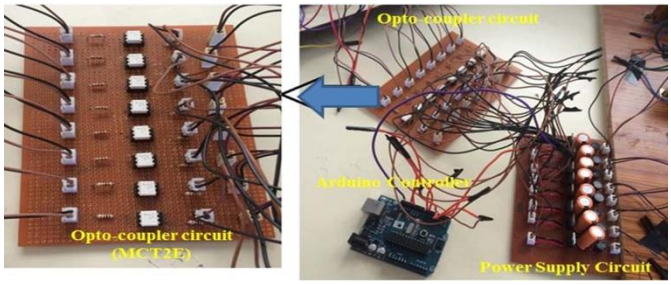

Fig 12 Opto-coupler Circuit

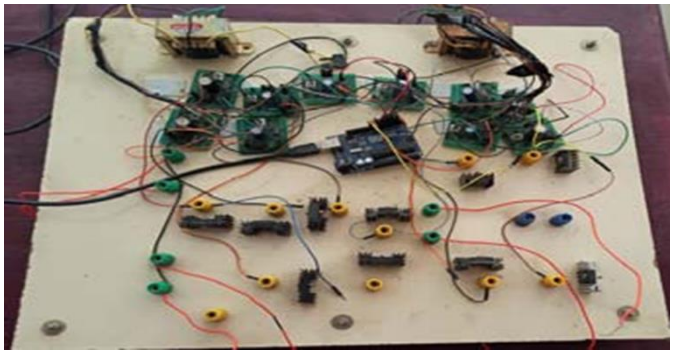

Fig 13 Power circuit

The complete hardware circuit along with the optocoupler circuit, Arduino controller, power supply circuit are shown in the Fig 13.

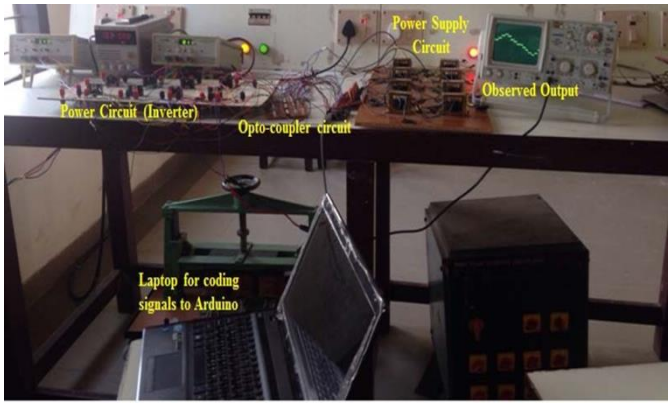

Fig 13 Complete hardware circuit

The pulse generated for each switches is shown in the Fig 14. The switching pulses generated using Arduino board for each switch are presented and the output voltage is shown in Fig 15.

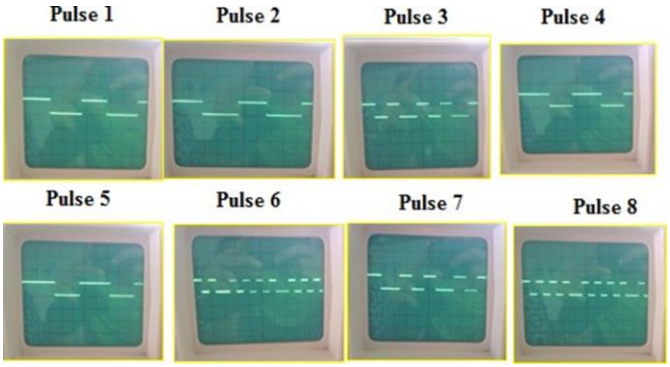

Fig 14 Pulse generated for each switch

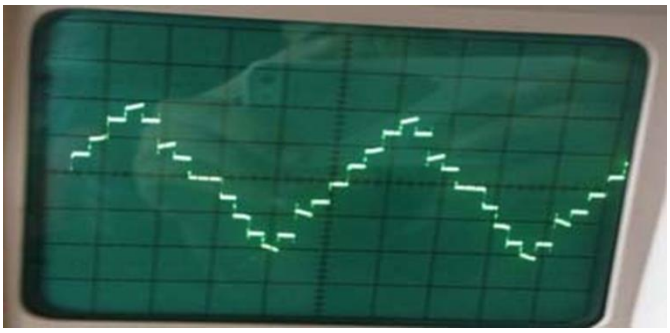

Fig 15 Output voltage (15 level)

IV. CONCLUSION

In this project, a 15-level cascaded HHT Multilevel inverter using half height technique and equally spaced method has been proposed. In the solution, expected 15 level output voltage level is achieved with reduced switches. Experimental results have verified the performance of the proposed solution. The performance of the 15-level inverter is also compared for different low frequency PWM schemes and the results showed that HH-PWM results in lesser distortion.

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