A. Maheswari

Abstract—A method is presented that a cascaded H-Bridge multilevel inverter can be implemented using unequal DC power sources. A standard cascade multilevel inverter requires n DC sources for 2n + 1 level. Proposed scheme allows the use of unequal DC power source without the requirement of transformers. Cascaded H-Bridge multilevel inverter which uses the unequal DC source shows the better performance and also significantly decreases the number of required switches. High quality output power due to its high number of output levels, results in high conversion efficiency and low thermal stress as it uses fundamental frequency switching scheme. This paper mainly discusses about the control of seven level multilevel converters with fundamental frequency switching control. The performance of single phase cascaded H-Bridge multilevel inverter with unequal DC source is simulated by using MATLAB/Simulink. A detailed harmonic analysis is done on cascaded H-Bridge seven level inverter and experimental results are presented to demonstrate the superiority of the proposed system.

II. CASCAD ED H-BRIDGE MULTILEVEL INVERTER TOPOLOGY

Multilevel inverters have received more and more attention because of their capability of high voltage operation, reliable operation, high efficiency, and low electromagnetic interference (EMI). The desired output of a multilevel converter is synthesized by several sources of DC voltages [1], [2]. With an increasing number of DC voltage sources, the converter voltage output waveform approaches nearly sinusoidal waveform while using a fundamental frequency switching scheme.

Transformerless multilevel inverters are uniquely suited for this application because of the high VA ratings possible with these inverters [1]. Unique structure of the multilevel voltage source inverters allows them to reach high voltages with low harmonics without the use of transformers or series-connected synchronized switching devices. The general function of the multilevel inverter is to synthesize a desired voltage from several levels of DC voltages [3], [4], [5], [6], [7]. Multilevel inverters also have several advantages with respect to hard switched two level pulse width-modulation (PWM) adjustable-speed drives.

Motor damage and failure have been reported by industry as a result of some adjustable-speed drives (ASD) operated by the inverters which has high voltage change.

I. Gnanambal

2 Department of Electrical and Electronics Engineering, Government College of Engineering, Salem, India. E-mail: ignanam@yahoo.com

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In this work, a method is given to compute the switching angles for a multilevel converter so as to produce the required fundamental voltage while at the same time cancel out specified higher order harmonics. In particular, a complete analysis is given for a seven level converter and validated the performance with hardware.
With enough levels, using this fundamental frequency switching technique results in an output voltage of the inverter that quasi-square waveform by phase shifting its positive and is almost sinusoidal. Each H-bridge unit generates a quasi-square waveform by phase shifting its positive and negative phase legs’ switching timings. Note that each switching device always conducts for 180 (or 1/2 cycle) regardless of the pulse width of the quasi-square wave. This switching method makes all of the active devices’ current stress equal.

Ideally, given a desired fundamental voltage $V_1$, one wants to determine the switching angles $\theta_1$, $\theta_2$ and $\theta_3$ so that (2) becomes $V(\omega t) = V_1 \sin(\omega t)$ . In practice, one is left with trying to do this approximately. In this case, the desire is to cancel the $5^{th}$ and $7^{th}$ order harmonics as they tend to dominate the total harmonic distortion. The mathematical statement of these conditions is then

$$\frac{4}{\pi} V_{DC} \left( \cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) \right) = V$$

$$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) = 0 \quad \text{(3)}$$

$$\cos(7\theta_1) + \cos(7\theta_2) = 0$$

This is a system of three transcendental equations in the three unknown’s $\theta_1$, $\theta_2$, and $\theta_3$. There are many ways one can solve for the angles. One approach to solve the set of nonlinear transcendental (3), is to use an iterative method such as the Newton-Raphson method [12]. In contrast to iterative methods, the approach here is based on solving polynomial equations using the theory of resultants which produces all possible solutions [13], [14]. The transcendental equations characterizing the harmonic content can be converted into polynomial equations. Then the resultant method is employed to find the solutions when they exist. These sets of solutions have to be examined for its corresponding total harmonic distortion (THD) in order to select the set which generate the lowest harmonic distortion (mostly due to the $11^{th}$ and $13^{th}$ harmonics). The computed THD in percent is defined by

$$\text{THD}\% = \frac{\sqrt{V_2^2 + V_2^2 + \ldots + V_{19}^2}}{V_1^2} \times 100 \quad \text{(4)}$$

### IV. SIMULATION STUDY

The simulation of single phase seven level cascaded H-Bridge multilevel inverter using unequal dc sources was done using Simulink. In this proposed multilevel inverter, only eight switches are required to obtain the output voltage. More switches are required to achieve the same output voltage in the symmetrical type where equal dc sources are used. The main advantage of the multilevel inverter over conventional two level inverter is the voltage stress on each switch is reduced due to series connection of the switches. In case of the symmetrical type, the voltage of each switch is limited to the value of DC source. Since the proposed multilevel inverter uses unequal dc sources the voltage stress among the switches will be asymmetrically distributed. Hence care should be taken while selecting power switches for this type of configuration.

The simulation diagram of seven level cascaded H-Bridge multilevel inverter is shown in Fig.3. The spectrum of the output current is taken to determine the Total Harmonic Distortion (THD). The simulation results of output voltage, Load current and FFT spectrum of Load current were presented for various RL loads are shown in
Fig. 4, Fig. 5 and Fig. 6. From the normalized FFT analysis shown in Fig. 4(c), Fig. 5(c) and Fig. 6(c), it can be derived that the magnitude of lower order harmonics are very low and the magnitude of higher order harmonics are nearly equal to zero. A detailed THD for the different load is tabulated in the Table I. It is seen that the percentage of harmonics in the proposed multilevel inverter is less compared to classical inverter system.

![Fig. 3: Simulation diagram of seven level cascaded H-Bridge inverter](image)

**Table I: Specifications adopted for the simulated parameters $V_{dc1}=12$ V and $V_{dc2}=6$ V**

<table>
<thead>
<tr>
<th>$R$ value</th>
<th>$L$ value</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$11$ $\Omega$</td>
<td>$125$ mH</td>
<td>$5.75$</td>
</tr>
<tr>
<td>$11$ $\Omega$</td>
<td>$30$ mH</td>
<td>$7.07$</td>
</tr>
<tr>
<td>$22$ $\Omega$</td>
<td>$30$ mH</td>
<td>$9.38$</td>
</tr>
</tbody>
</table>

![Fig. 4: Simulation results for $R=11\Omega$, $L=125$mH.](image)

(a) Output voltage (b) Load current (c) FFT Analysis
Fig. 5: Simulation results for \( R = 11 \Omega, L = 30 \text{mH} \).
(a) Output voltage (b) Load current (c) FFT Analysis

Fig. 6: Simulation results for \( R = 22 \Omega, L = 30 \text{mH} \).
(a) Output voltage (b) Load current (c) FFT Analysis

V. EXPERIMENTAL RESULTS

To experimentally validate the proposed multilevel inverter output voltage, hardware of single phase cascaded H bridge multilevel inverter has been built using MOSFET as the switching devices. A multi conversion cell consists of three 6 V batteries. One stage is supplied by 6 V and the other stage is supplied by 12 V (two 6 V batteries are connected in series). A real time variable output voltage, variable frequency inverter controller based on ATmega16 Microcontroller is used to implement the control algorithm. An ATmega16 Microcontroller is used as the main processor, which provides gate signals.

According to microcontroller control signal, MOSFET gate terminal is turned on and off. Output of the inverter terminal is connected to RL load. The hardware block diagram and experimental setup of seven level Cascaded H Bridge Multilevel Inverter shown in Fig. 7 and Fig. 8. Hardware result of proposed multilevel inverter is exposed in Fig. 9 and Fig. 10. The output voltage of seven level cascaded multilevel inverter is 15 volt, with frequency of 50 Hz.
VI. CONCLUSION

The proposed cascaded H-Bridge multilevel inverter uses unequal dc power source for producing desired multilevel voltage is simulated and validated by hardware. A fundamental frequency switching control algorithm was developed and implemented in the microcontroller. The total harmonic distortion is very low compared to that of classical inverter. The simulation results of load current waveform shows that the lower order harmonics have been reduced considerably and also higher order harmonics are eliminated.

The proposed multilevel inverter can be used for industries where the adjustable speed drives are required and significant amount of energy can be saved as the proposed system has less harmonics.

REFERENCES


A. Maheswari et. al: Harmonic Analysis of Cascaded H-bridge…

**BIOGRAPHIES**

**A. Maheswari** was born in Tamilnadu, India, on April 7, 1983. She received her B.E degree in Electrical and Electronics Engineering from V.M.K.V Engineering College, Salem, in 2004, the M.E degree in Power Electronics and drives from Government college of Engineering, Salem, in 2008. Currently she is doing Ph.D.

She has presented 4 papers in various National and International conferences. She also published one paper in international journal. Her current research interests include simulation and control techniques of AC drives, Inverters topologies and harmonic suppression. Ms.Maheswari is an ISTE life member.

**I. Gnanambal** was born in Tamilnadu, India. She received her B.E degree in Electrical and Electronics Engineering from Government college of Engineering, Salem, in 1981, the M.E degree in Applied electronics in Government college of technology, Coimbatore, in 2002 and the Ph.D. degree in networking from Anna university, Chennai, in 2008.

She has presented more than 50 papers in various National and International conferences. She also published more than 20 papers in various National and International journals. Her research interests include power electronics, solid state drives, networking and special electrical machines. Dr. Gnanambal is an ISTE, IE and IETE life member.