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 DC-AC 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 prototype are included in this paper.

Keywords: Multilevel Inverter, Total Harmonic Distortion, Automotive application, 9-level H-bridge inverter.

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 vehicles 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 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 born EVs, Space rover vehicles, Air borne EVs are some among them analysed in [2]-[7].

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.

A. 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 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.

![Block diagram of Electric vehicle](image)

Figure 1.Block diagram of Electric vehicle

The function of the H-bridge multilevel inverter is to collect energy from the dc-link capacitor and transfer to the motor. The inverter can be used in order to give supply for the motor as well as the speed control.

B. Relevance of H-bridge multi level Inverter in Automobile Application

DC to AC conversion is done using H-bridge MLI in order to provide feed appropriate supply to the motors. Apart from DC to AC conversion H-bridge multi level inverter can take part in the speed control of the main drive motor 3-phase induction motor. Speed of main drive motor can be controlled in two methods they are i) by stator voltage control and ii) by v/f control by varying the output voltage of the H-
bridge multi level to a desired voltage level. Also the different levels of multi level inverter can be used for feeding motors of different input voltage specifications. Like stepper motor in power steering, servomotor used in power windows, glass wiper driving motors etc.

II. PROPOSED H-BRIDGE MULTI LEVEL INVERTER FOR AUTOMOTIVE APPLICATION

In multi level inverter the input voltage is \( v_{dc} \) and its different levels [28] are forming the output voltage levels of the inverter as following. Consider \( V_m \) is the output voltage levels and the input voltage is \( v_{dc} \).

Then the output voltage level is given by

\[ V_m = \frac{v_{dc}}{m-1} \]

Where \( m \) is the number levels of the multi level 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 multi level 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.

\[ N = \frac{m-1}{2} \]

Where,

\( N \) = number of DC voltage source

\( M \) = output phase voltage level

For a 9 level cascade inverter 4 individual batteries and 4 single phase full bridges are required. As the level of the output phase voltage is 9 voltage waveform is almost sinusoidal and the Total Harmonic Distortion (THD) is a small value.

A. Working Principle

The output voltage is obtained between first and fourth H-bridge end terminals. The phase output voltage is the sum of individual H-bridge outputs. Each H-bridge consist of a DC source of \( V_{dc} \). In a single H-bridge inverter it is generating three output voltage levels and they are \( + V_{dc} \), \(- V_{dc} \) and zero. The switching combinations of switches \( S_2 \) and \( S_4 \) yields output voltage of single H-bridge as \( + V_{dc} \) and combination of switches \( S_2 \) and \( S_4 \) yields \( - V_{dc} \). Zero voltage level when all the switches are OFF.

The circuit diagram for a 9 level H-bridge multi level inverter with 4 single phase full bridge along with switching patterns table are given in the below.

![Figure 2.Circuit diagram of 9 level H-bridge MLI](image)

### Table 1 switching patterns

<table>
<thead>
<tr>
<th>( S_1 )</th>
<th>( S_2 )</th>
<th>( S_3 )</th>
<th>( S_4 )</th>
<th>Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>0</td>
</tr>
<tr>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>( + V_{dc} )</td>
</tr>
<tr>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
<td>( - V_{dc} )</td>
</tr>
</tbody>
</table>

The pulses given to each single phase full bridge inverter are shown in figure.3 as the input DC
voltage of each inverter are equal the voltage levels are symmetrical and are equally divided as \(4V_{dc}, 3V_{dc}, 2V_{dc}, 1V_{dc}, 0, -1V_{dc}, -2V_{dc}, -3V_{dc}, -4V_{dc}\) as the sum sum with corresponding triggering pulses. These equally divided voltage level forms the 9 voltage levels as mentioned earlier.

### III. 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

\[
\text{THD} = \frac{1}{V_1} \sqrt{\sum_{n=2}^{N} V_n^2}
\]

Where,

\(V_1\) = voltage of the fundamental voltage  
\(V_n\) = voltage of the \(n^{th}\) wave

For the purpose of calculating the THD of a 9 level H-bridge inverter. The proposed circuit diagram is simulated with the help of MATLAB R2014a SIMULINK with appropriate triggering pulses. From the simulation result it is clear that the 9 level H-bridge multi level inverter has a THD value of 8.54% which is a low value as shown in figure.4. A 7 level H-bridge inverter has a THD of 12.13 greater than that of 9 level from figure.5, 5 level has a THD value of 16.89 obtained from figure.6.

From this comparison it is clear that as the level of the H-bridge increases the THD value decrease by using lesser number of switching components and control circuits for these semiconducting switches. As a result of lesser number of switching devices and control circuit the system is compact as well as it can be designed easily. In other multi level inverters switching devices like diode clamped multilevel inverter and flying capacitor multi level inverter the number of switches clamped diodes voltage balancing capacitors are high and a complex controlling unit which result in a high value of THD [21]-[26]. This drawback is overcome by the usage of H-bridge of high voltage levels without sacrificing the efficiency.

Table 2. Comparison of THD values

<table>
<thead>
<tr>
<th>INVERTER LEVELS</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>8.54</td>
</tr>
<tr>
<td>7</td>
<td>12.13</td>
</tr>
<tr>
<td>5</td>
<td>16.89</td>
</tr>
</tbody>
</table>

H-Bridge Multi Level Inverter With Reduced THD For Automotive Application
IV. SIMULATION RESULTS

The power circuit of the proposed H-bridge multi level inverter is simulated using MATLAB R2014a version SIMULINK. And the simulation diagram is shown in figure 7.

![Simulation diagram of proposed 9 level H-bridge Multi level inverter](image1)

**Figure 7. Simulation diagram of proposed 9 level H-bridge Multi level inverter**

![Output phase voltage of proposed 9 level H-bridge Multi level inverter](image2)

**Figure 8. Output phase voltage of proposed 9 level H-bridge Multi level inverter**

Here IGBTs are used as power switches of inverter and gate is triggered using individual pulses named subsystem 1 to subsystem 8 (set of 2). Output terminals are connected to a R-load followed by voltage measurement block and scope. The output of this circuit is obtained as shown in figure 8. A sine wave is also included along with the output phase voltage in order to show the closeness to the fundamental wave.

Control circuit simulation done using PROTEUS ISIS schematic capture. The controller used to generate pulses are explained in the hardware session.

![PROTEUS ISIS schematic capture of control circuit](image3)

**Figure 9. PROTEUS ISIS schematic capture of control circuit**

The corresponding pulses as the simulation result of the PROTEUS ISIS schematic capture is shown in figure 10. These pulses are same as that of the pulses shown in figure 3.

![Pulses of control circuit](image4)

**Figure 10. Pulses of control circuit**

V. EXPERIMENTAL RESULT

The 9 level H-bridge Multi level inverter is shown in figure 11. The switching devices are commercially available 600-V IGBT/IPM modules. The microcontroller used for generating control pulses are ATMEGA328P which is a 32-bit microcontroller available in market. This microcontroller is selected for the construction of
VI. FUTURE SCOPE

The THD of the multi level can be further reduced by increasing the levels. Or in other words this 9 level H-bridge MLI can be replaced with 15 level H-bridge MLI without sacrificing the efficiency. This replacement can also be used for electric vehicle and automobile application.

CONCLUSION

In this paper the flying capacitor multi level inverter is replaced with 9 level H-bridge multi level inverter in order to overcome the demerits of the existing system. Analysis has shown that the proposed 9 level H-bridge Multi level inverter requires a lesser number of switching devices and a compact and easy method is used for the control circuit. Moreover it reduces the THD levels compared to other MLIs.

REFERENCES


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