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Multi-level Inverters for Electric Vehicles

[1]Prof.Shivanand Konade, [2]Mr.Sarvadnya Satish Nimbalkar

[1]Assistant Professor, Electrical Engineering Department, Smt. Indira Gandhi College of Engineering. [2]Research Scholar student, University 0f Mumbai.

Abstract

Present-day electric vehicles employ conventional two-level inverters. However, the usage of multi-level inverters as the propulsion inverter in electric vehicles has gained popularity in recent years. Thus, this thesis examines the performance of several topologies of multi-level inverters as traction inverters, and a comparison with conventional two-level inverters is made. Multiple output voltage levels can be achieved with a multi-level inverter, which contributes to a decrease in THD and losses. The majority of this work's implementation and analysis is done using the PLECS software, which models and simulates several multi-level inverter topologies and compares them in a number of ways, including losses, THD, Investigations are being conducted on a two-level and a three-level multi-level inverter. Four distinct topologies (i.e., T-type neutral point clamped inverter, Flying capacitor inverter, Neutral point clamped inverter, and Cascaded H-bridge inverter) through simulation, analysis, and modeling. For the inverter models, two distinct switching strategies—Sine wave PWM and Space vector PWM—are used. However, phase-shifted sine wave PWM is employed for the multi-level inverter versions. The inverter's size, cost, and modulation technique complexity all rise with the number of levels. Thus, choosing an inverter involves balancing all of the aforementioned factors.

Keywords: Electric cars, DC link voltage, thermal model, PLECS, traction inverter, and electrical losses.

I. INTRODUCTION

For nearly a century, internal combustion engines dominated the personal transportation industry. However, in recent years, demand for electric vehicles (EVs) has increased dramatically in both the transportation industry and the automotive industry globally. globe [1]. With the widespread adoption of electric vehicles, society may see a substantial shift in terms of not only personal transportation technology but also the economy's shift away from petroleum, which lowers the environmental impact of transportation.

1.1 Overview

Multilevel inverters are becoming more and more well-known in the market as one of the best tools for power electronic conversion in high power applications. applications [2]. As of right now, the most popular power electronic converter for usage in electric car applications is the two-level inverter [3]. However, there have been studies and research on Multi-Level Inverters (MLI), which show to be a cost-effective solution with an increase in power quality within acceptable standards, in response to the on going rise in voltage and power levels [4]. It is named an MLI because the voltage level of the output can be increased stepwise by adding a few additional components. The fundamental topologies that are most frequently mentioned are: Point of Neutrality Clamped. According to recent studies and research, all MLIs significantly reduce switching losses and overall harmonic distortion; nevertheless, as the number of components increases, prices and power loss increase as well. Regarding FCMI, As the number of levels rises, bigger capacitors are utilized, which also raises the control's complexity [5].Because independent dc sources are required for each phase leg in the case of CHMI, its use in the electric vehicle sector is restricted. Therefore, the purpose of this thesis work is to examine several MLI topologies and evaluate them against Two-Level Inverters (TLI) and each other on a range of characteristics, including losses, THD, semiconductor device temperature, etc.

II.Background Theory

The theories of MLI and TLI are covered in this chapter. Based on their circuit topology, the various MLI topologies that will be examined in this thesis will be discussed. Design and quantity of parts utilised. Following that, several modulation methods that will be used for these topologies will be seen. Next, the power electronic device utilized to switch the MLIs will be observed, along with the losses caused by both them and other components of the inverter. Lastly, a discussion of the thermal factor that will be included in the inverter model will be held.

2.1 Two inverter levels

The most popular and straightforward inverter topology utilized in electric car applications is the three-phase TLI. This device's input is a DC voltage source, and transforms it into AC voltage, which powers the electric machine that is the load. Six semi-conductor switches make up this architecture, and each switch incorporates an anti-parallel diode to allow current to flow in the other way. This inverter may produce two output voltage levels, +Vdc and −Vdc, depending on the phase to ground voltage. Figure 2.1 shows the circuit schematic for a three phase, two level inverter.

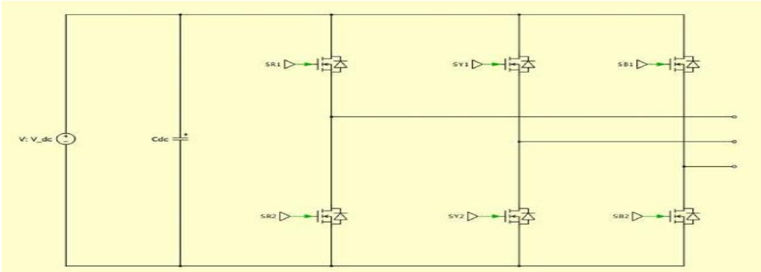


Figure 2.1: Circuit diagram of two level inverter

2.2 Multiple inverter levels

Since 1975, the idea of MLI has existed [6]. It is a power electronic gadget that offers a way to increase power by using more switching. devices that generate a voltage from the output phase to the ground that has more than two levels. In its phase to ground output voltage waveform, a n level MLI can generate n number of voltage levels. It is superior to the TLI in a number of ways. When compared to the TLI, a more sinusoidal voltage waveform can be realized at a lower switching frequency as the number of levels increases. This contributes to a lower THD. Each switch experiences a decrease in voltage as the number of levels rises.

2.2.1 Clamped Multi-level Inverter with Neutral Point

Clamping diodes are used by the Neutral point Clamped Multi-level Inverter (NCMI), also known as the diode clamped multi-level inverter, to enable the additional voltage levels in relation to ground voltage at the output. Figure 2.2 shows the circuit diagram for a three phase, three level NCMI.

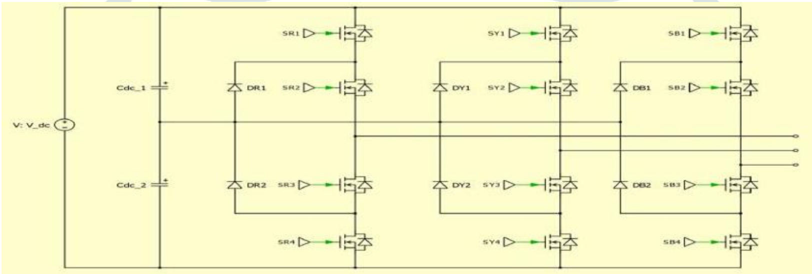


Figure 2.2: Circuit diagram of three level, three phase NCMI

(n−1)(n−2) clamping diodes are utilized across each phase leg of a n level NCMI. It is composed of (n-1) DC link capacitors, or capacitors on the DC bus. When the DC link capacitors reach their appropriate voltage levels of charge, they offer the extra voltage levels by implementing the appropriate switching technique. Clamping diodes are used to create the extra zero level in a three level NCMI. Figure 2.3 displays the circuit diagram for the NCMI for a single phase leg.

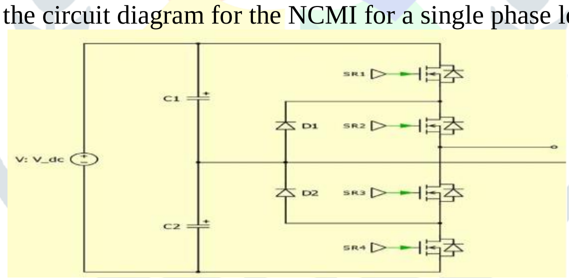


Figure 2.3: Single phase leg of the NCMI

Table 2.1 and Fig. 2.4 show all of the NCMI's switching states with a positive current output. The DC link capacitors divide the DC voltage, or Vdc/2, in half. Switches SR1 and SR2 are turned on in instance 1 to generate the positive voltage. The two zero level switching states are displayed in Case 2. Depending on the direction of the current, either the switch SR2 or SR3 conducts in this situation. The switch SR2 conducts for a positive current, and the switch SR3 conducts for a negative current. Switches SR3 and SR4 are activated in case 3 to generate the negative voltage. In every instance, the conductivity of the switch or the anti-parallel diodes is determined by the direction of current. As an illustration, for

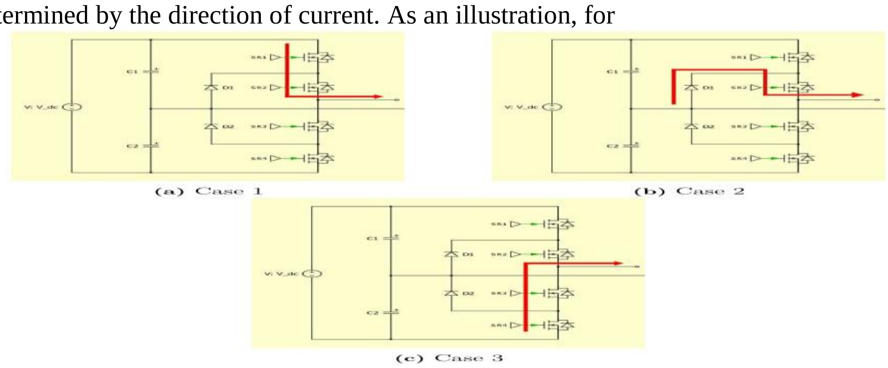


Figure 2.4: Switching states for the three phase three level NCMI

Table 2.1: NCMI - Switching states

Switching State	Phase Voltage	S1	S2	S3	S4
Case 1	$V_{dc}/2$	On	On	Off	Off
Case 2	0	Off	On	On	Off
Case 3	$-V_{dc}/2$	Off	Off	On	On

2.2.2 Multi-level Inverter with Neutral Point Clamped T-type

Similar to the conventional NCMI, the T-type Neutral point Clamped Multi-level Inverter (TNCMI) uses two switches in lieu of clamping diodes. every phase leg that contributes to the reduction of conduction loss [7]. Figure 2.5 shows the circuit schematic for a three phase, three level TNCMI.

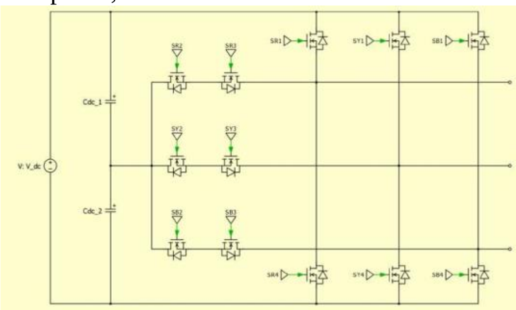


Figure 2.5: Circuit diagram of three level, three phase TNCMI

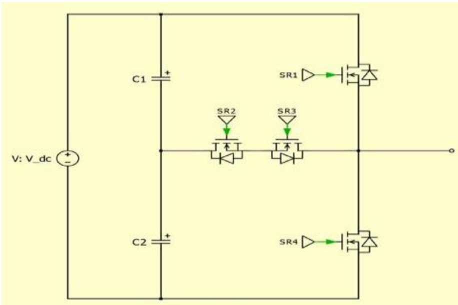
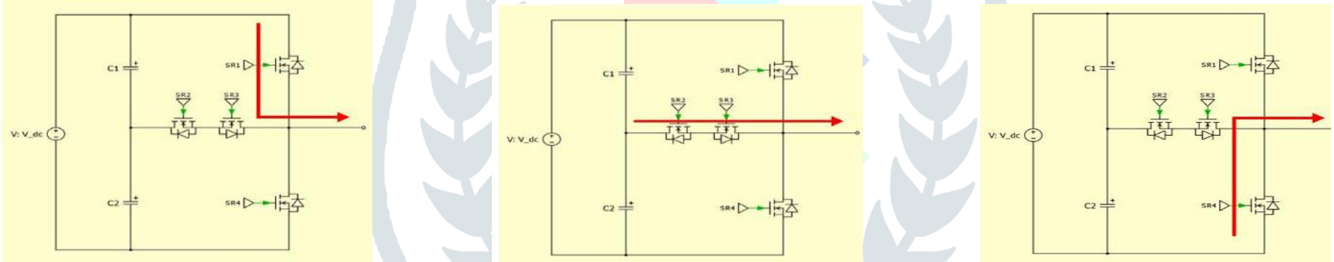


Figure 2.6: Single phase leg of the TNCMI

The TNCMI has (n−1) DC link capacitors, just like the NCMI. The additional voltage levels are provided by the DC link capacitors by using the appropriate switching method once they are charged to their respective voltage levels. The extra zero level in a three-level TNCMI is accomplished by the connections made between the switches in each phase leg. Figure 2.6 displays the circuit diagram for the TNCMI for a single phase leg.

Table 2.2 and Fig. 2.7 show all of the TNCMI's switching states with a positive current output. The DC link capacitors divide the DC voltage in half, or Vdc/2, in accordance with the NCMI topology. In the first scenario, flip SR1 and SR2 or to produce the positive voltage, just SR1 is turned on. The two zero level switching states are displayed in Case 2. Depending on the direction of the current, either the switch SR2 or SR3 conducts in this situation. Both the switch SR2 and the anti-parallel diode of SR3 conduct when there is a positive current flowing through them, and vice versa when there is a negative current. Switches SR3 and SR4 (or simply SR4) are turned on in instance 3 to generate.



(a) Case 1 (b) Case 2 (c) Case 3

Figure 2.7: Switching states for the three phase three level TNCMI

Table 2.2: TNCMI - Switching states

Switching State	Phase Voltage	S1	S2	S3	S4
Case 1	$V_{dc}/2$	On	On	Off	Off
Case 2	0	Off	On	On	Off
Case 3	$-V_{dc}/2$	Off	Off	On	On

2.2.3 Multi-level inverter with flying capacitors

Each phase leg of the Flying Capacitor Multi-level Inverter (FCMI) contains a capacitor connected in parallel. We refer to these capacitors as "flying capacitors." They make it possible to attain the additional voltage levels in relation to the ground voltage at the output. When compared to the NCMI, the FCMI operates in quite similar ways. Figure 2.8 shows the circuit diagram for a three phase, three level FCMI.

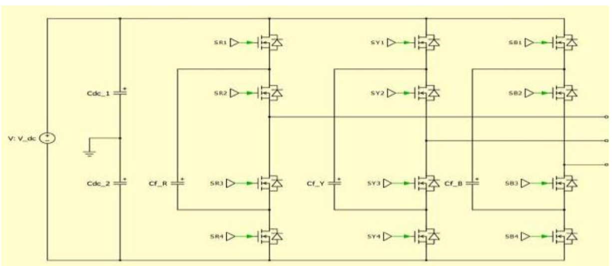


Figure 2.8: Circuit diagram of three level, three phase FCMI

The voltage across each flying capacitor for a n level FCMI is (Vdc)/(n−1), and (n−1)(n−2)/2 flying capacitors are utilized across each phase leg [8] [9]. The additional voltage is provided by the flying capacitors once they are charged to their corresponding voltage levels. levels by using the appropriate switching technique. Therefore, the number of capacitors will likewise increase dramatically as the number of levels increases, which could result in the device being large. In order to have less voltage ripple for

the flying capacitors, it is crucial to additionally take their size into account. Using f lying capacitors allows for the addition of a zero level to a three level FCMI. Figure 2.9 displays the circuit diagram for the FCMI for a single phase leg.
Table 2.3 and Fig. 2.10 show all of the FCMI's switching states with a positive current output. Here, the production of the positive and negative voltages has similarities with the NCMI topology's operation. The The DC link capacitors divide the DC voltage, or Vdc/2, in half. Additionally, the flying capacitors must have a voltage of Vdc/2. Switches SR1 and SR2 are turned on in instance 1 to generate the positive voltage. The two states of zero level switching are displayed in Cases 2 and 3. These two switching states must occur alternately for the FCMI. This automatically balances the voltage to the flying capacitors in every phase leg. In instance number two, the voltage generated.

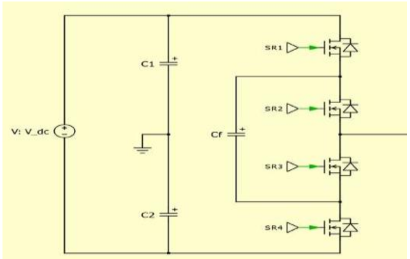
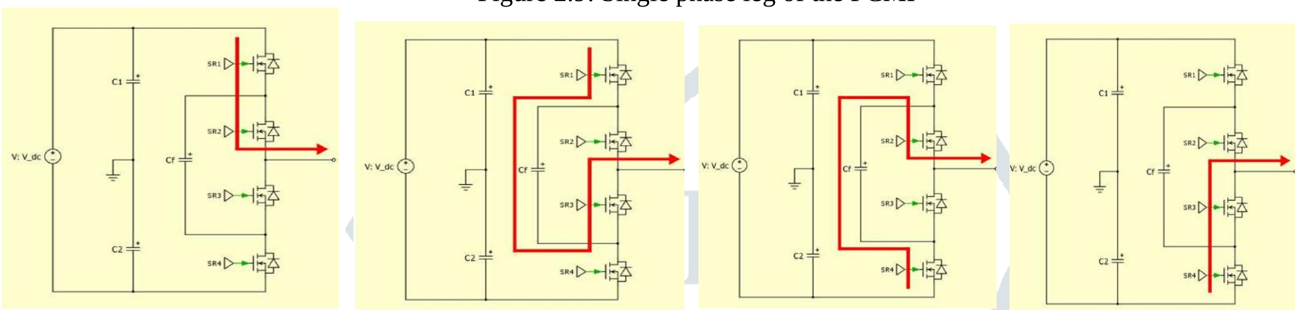


Figure 2.9: Single phase leg of the FCMI



(a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4

Figure 2.10: Switching states for three phase three level FCMI

Table 2.3: FCMI - Switching states

Switching State	Phase Voltage	S1	S2	S3	S4
Case 1	$V_{dc}/2$	On	On	Off	Off
Case 2	0	On	Off	On	Off
Case 3	0	Off	On	Off	On
Case 4	$-V_{dc}/2$	Off	Off	On	On

2.2.4 H-bridge Multi-level Cascaded Inverter

An H-bridge inverter with distinct DC sources for each phase leg is a sub-module of the Cascaded H-bridge Multi-level Inverter (CHMI). This makes it possible to accomplish the phase to ground voltage's three distinct voltage levels. Figure 2.11 shows the circuit schematic for a three phase, three level CHMI.

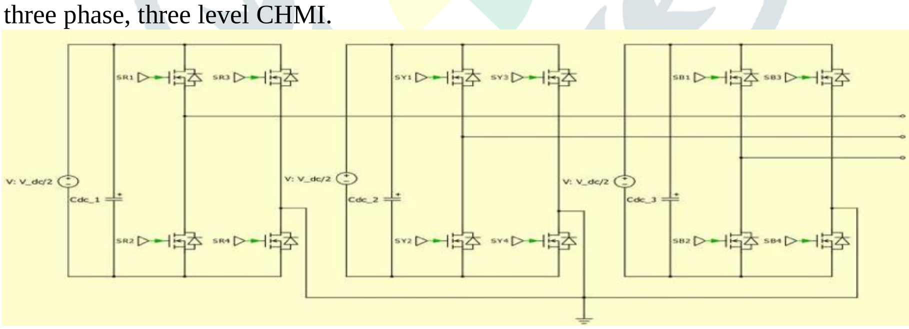


Figure 2.11: Circuit diagram of three level, three phase CHMI

For every phase, n sub-modules must be used in series, and 2(n − 1) switches are needed, in order to obtain a n level CHMI. Each switch's voltage stress is determined by the sub-module's DC supply. It can be expanded to higher levels with ease because of its modular design. With this structure, every sub-module needs its own DC source. Additional parts, like the diodes and capacitors used in the earlier topologies, are not required. The extra zero level for a three-level CHMI is produced by using separate DC sources in each of its phase legs to create the three distinct voltage levels. The voltage of each individual DC source is VDC/2, or half .

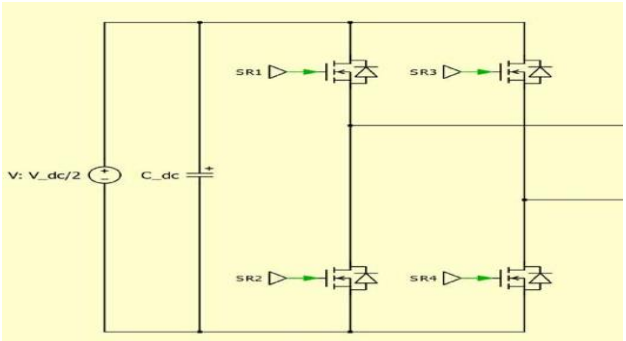


Figure 2.12: Single phase leg of the CHMI

Table 2.4 and Fig. 2.13 show all of the CHMI's switching states with a positive current output. Every phase leg that contains a DC source will also have DC link capacitors. Switches SR1 and SR4 are activated in instance 1 to generate the voltage that is positive. The DC link capacitor is connected in parallel to the output. The two zero level switching states are displayed in Cases 2 and 3. To do this, the output can be in short circuit condition, producing zero voltage, by closing either the top two switches or the bottom two switches. In example 4, the negative voltage level is produced by turning on switches SR2 and SR3. The output is linked within.

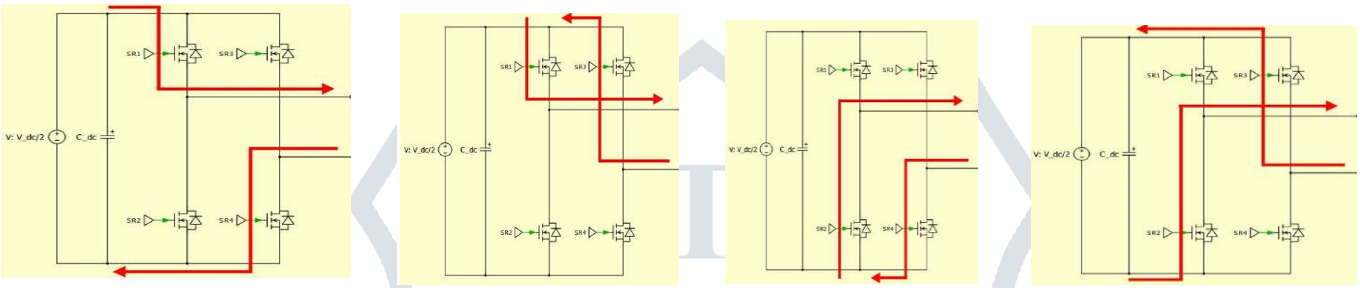

(a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4

Figure 2.13: Switching states for the three phase three level CHMI

Table 2.4: CHMI - Switching states

Switching State	Phase Voltage	S1	S2	S3	S4
Case 1	$V_{dc}/2$	On	Off	Off	On
Case 2	0	On	Off	On	Off
Case 3	0	Off	On	Off	On
Case 4	$-V_{dc}/2$	Off	On	On	Off

Conclusion

This work examined and analyzed the performance of the inverter models using various MLI and TLI inverter topologies that were modeled and simulated. Additionally, a comparison of all the topologies was done on a number of factors. such as power loss, temperature for three distinct test situations, efficiency, and THD for both current and voltage. To sum up, the MLIs fared better overall, with the TNCMI performing better overall in the majority of categories. This was anticipated given that MLIs have lower conduction and switching losses than TLIs. The primary reason for this is the switches' nearly halving of operating voltage when compared to TLI switches.

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