Asymmetrical Multilevel Inverter Using Fuzzy with Low Switching Frequency Topology With Reduced Switch Count

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ABSTRACT:

The inceptions of multilevel inverters (MLI) have caught the attention of researchers for medium and high power applications. However, there has always been a need for a topology with a lower number of device count for higher efficiency and reliability. A new single-phase MLI topology has been proposed in this thesis to reduce the number of switches in the circuit and obtain higher voltage level at the output with fuzzy. The basic unit of the proposed topology produces 13 levels at the output with three dc voltage sources and eight switches. Three extensions of the basic unit have been proposed with fuzzy. A detailed analysis of the proposed topology has been carried out to show the superiority of the proposed converter with respect to the other existing MLI topologies. Power loss analysis has been done using MATLAB software, resulting in a maximum efficiency of 98.5%. Nearest level control (NLC) pulse-width modulation technique has been used to produce gate pulses for the switches to achieve better output voltage waveform.

INDEX TERMS: DC–AC converter, multilevel inverter, reduce switch count, nearest level control (NLC)

INTRODUCTION

Nowadays, multilevel inverters are getting more attention in many industrial and renewable energy applications. Compare to its two-level counterparts, multilevel inverter have superior power quality feature with low total harmonic distortion (THD). The conventional MLI topologies which include neutral point clamped or diode clamped MLI (NPCMLI), flying capacitor MLI (FCMLI) and cascaded H-bridge MLI (CHBMLI) are being used in industries for varied applications. The high power application include HVDC transmission system, solar PV generation system, wind energy generation system and traction in railways while lower power level MLI is used in grinding mills, pumps, conveyor belts reactive power compensation, propulsion of marine system and starter of turbines etc. [1]–[4]. But these conventional topologies have some limitations. There is a requirement of large number of isolated DC power supply in CHB topology which increases with the number of levels in the output voltage waveform while FC-MLI requires a complex control mechanism to ensure that the voltage across the capacitor is maintained constant. This control becomes more challenging when the number of capacitor increases exponentially with the higher output voltage level generation. Over the last few years, the research has been focused on developing topologies to overcome the shortcomings of the conventional multilevel inverter [5], [6]. Researchers are trying to further reduce the number of switches for overcoming the cost constraint and improving the quality of output voltage waveform by increasing the number of levels at the output voltage. With a higher number of levels, the advantages possessed by the topology includes the increase in efficiency, reliability, power density, reduced filter size, and increased range of applications [7]. Designing newer MLI topology derive its motivation to reduce the count of isolated DC power supply, switch and gate driver requirement. Based on these parameters several topologies have been presented in the literature [6]–[8]. In [9], a topology based on developed H-bridge produces both polarities (negative & positive) in the output voltage waveform. But the requirement of blocking maximum output voltage by two switches in the topology limits its use for high voltage application. The authors of [10] have tried to resolve this problem by modifying circuit topology. Several other MLI topologies have been proposed in [11]–[15] each having some advantages and shortcomings.

The topology proposed in [16] has a structure as a sub multilevel module which can be connected in series. However, the use of backend H-bridge limits its applications for high voltage applications. The work done in [16] has been modified, and a newer topology has been proposed in [17]. In [17], the cascaded topology is based on the half-bridge configured dc voltage sources. The modified single unit structure has switches in one leg instead of the dc voltage sources and every unit has a different H-bridge for obtaining the voltage polarity. The modified structure has lesser voltage stress on the H-bridge switches due to cascade connection but the number of switches increases as compared to [16]. A bidirectional multilevel inverter topology has been proposed in [18] which has asymmetric as well as symmetric configurations having a fewer number of...
DC power supply and lesser driver circuits and power electronic switches requirement. But, the use of backend H-bridge increases the total standing voltage (TSV) of the topology. Many topologies incorporating modified H-Bridge (MHB) configuration has been employed by various topologies to enhance the level of voltage generated manifold [10], [19]-[25]. Apart from generating the polarity of voltage level, a MHB also generates voltage level corresponding to the addition of the voltages on the two sides of the MHB. In all of the above topologies, at least two switches need to block the peak of the output voltage. Similarly, a new category of multilevel inverter topologies has been based on the reduced voltage stress across the switches. In this kind of topologies, the maximum voltage stress across any switch is less than the peak output voltage [26]-[30]. In this paper, a novel MLI topology has been proposed with the aim of reduced switch count, reduced TSV and individual voltage stress for the higher number of levels. This paper has been organized as follows: a detailed analysis of the proposed topology is carried out in section II. Section III discusses the nearest level control pulse width modulation techniques for producing pulses for the gate driver circuit. Section IV provided the comparative study for the proposed topology considering various circuit parameters. Section V gives a detailed analysis of the power loss using PLECS software.

II. DC-DC CONVERTER

A DC-DC converter with a high step-up voltage, which can be used in various applications like automobile headlights, fuel cell energy conversion systems, solar-cell energy conversion systems and battery backup systems for uninterruptable power supplies. Theoretically, a dc-dc boost converter can attain a high step-up voltage with a high effective duty ratio. But, in practical, the step-up voltage gain is restricted by the effect of power switches and the equivalent series resistance (ESR) of inductors and capacitors.

Generally a conventional boost converter is used to get a high-step-up voltage gain with a large duty ratio. But, the efficiency and the voltage gain are restricted due to the losses of power switches and diodes, the equivalent series resistance of inductors and capacitors and the reverse recovery problem of diodes. Due to the leakage inductance of the transformer, high voltage stress and power dissipation effected by the active switch of these converters. To reduce the Voltage spike, a resistor-capacitor –diode snubbed can be employed to limit the voltage stress on the active switch. But, these results in reduction of efficiency. Based on the coupled inductor; converters with low input ripple current are developed. The low input current ripple of these converters is realized by using an additional LC circuit with a coupled inductor.

Power engineering is the method used to supply electrical energy from a source to its users. It is of vital importance to industry. It is likely that the air we breathe and water we drink are taken for granted until they are not there.

III. MULTI LEVEL INVERTER

An inverter is an electrical device that converts direct current (DC) to alternating current (AC) the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Static inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries. The electrical inverter is a high power electronic oscillator. It is so named because early mechanical AC to DC converters were made to work in reverse, and thus were "inverted", to convert DC to AC.

3.1 Cascaded H-Bridges inverter

A single phase structure of an m-level cascaded inverter is illustrated in Figure 4.1. Each separate DC source (SDCS) is connected to a single phase full bridge, or H-bridge, inverter. Each inverter
level can generate three different voltage outputs, \( +V_{dc} \), 0, and \( -V_{dc} \) by connecting the DC source to the ac output by different combinations of the four switches, \( S_1, S_2, S_3, \) and \( S_4 \). To obtain \( +V_{dc} \), switches \( S_1 \) and \( S_4 \) are turned on, whereas \( -V_{dc} \) can be obtained by turning on switches \( S_2 \) and \( S_3 \). By turning on \( S_1 \) and \( S_2 \) or \( S_3 \) and \( S_4 \), the output voltage is 0. The AC outputs of each of the different full bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels \( m \) in a cascade inverter is defined by \( m = 2s + 1 \), where \( s \) is the number of separate DC sources. An example phase voltage waveform for an 11 level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 4.2.

### IV. INTRODUCTION TO FUZZY

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision support systems, and portfolio selection. To understand why use of fuzzy logic has grown, you must first understand what is meant by fuzzy logic.

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalued logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalued logical systems.

The fuzzy logic toolbox is highly impressive in all respects. It makes fuzzy logic an effective tool for the conception and design of intelligent systems. The fuzzy logic toolbox is easy to master and convenient to use. And last, but not least important, it provides a reader friendly and up to date introduction to methodology of fuzzy logic and its wide ranging applications.

#### 4.1 What is fuzzy logic?

Fuzzy logic is all about the relative importance of precision is how important is it to be exactly right when a rough answer will do?

You can use Fuzzy Logic Toolbox software with MATLAB technical computing software as a tool for solving problems with fuzzy logic. Fuzzy logic is a fascinating area of research because it does a good job of trading off between significance and precision something that humans have been managing for a very long time. In this sense, fuzzy logic is both old and new because, although the modern and methodical science of fuzzy logic is still young, the concept of fuzzy logic relies on age old skills of human reasoning.

**Fig. Fuzzy descriptions**

**V. PROJECT DISCRIPTION AND CONTROL DESIGN**

#### 5.1 DETAILED ANALYSIS OF THE PROPOSED TOPOLOGY

The basic unit of the proposed multilevel inverter topology is shown in Fig 1. The circuit consists of three dc voltage sources of magnitude \( V_{dc} \), \( 2V_{dc} \) and \( 3V_{dc} \) and eight power semiconductor switches. The switch pair \( (S_1, S_2) \), \( (S_3, S_4) \), \( (S_5, S_6) \), and \( (S_7, S_8) \) are connected to the topology such that their conduction at the same time leads to short circuit of dc voltage sources. Therefore these switch pairs need to be operated in complementary mode. Table 1 gives the switching modes of the proposed basic unit. Fig 2. Shows various switching states of the proposed topology as per the switching states shown in Table 1. One of the important aspect in the designing of MLI topology is the total standing voltage. It is defined as the sum of highest voltage stress appearing across switch for all the levels generated at the output. For the basic unit of the proposed MLI topology, the maximum voltage stress across each switch is given as:

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\begin{align*}
V_{S1} &= V_{S2} = 3V_{dc} + 2V_{dc} = 5V_{dc} \\
V_{S3} &= V_{S4} = 2V_{dc} \\
V_{S5} &= V_{S6} = V_{dc} \\
V_{S7} &= V_{S8} = V_{dc} + 3V_{dc} = 4V_{dc}
\end{align*}
\]

where \( V_{S1}, V_{S2}, V_{S3}, V_{S4}, V_{S5}, V_{S6}, V_{S7}, \) and \( V_{S8} \) are the voltage stress of switches \( S_1, S_2, S_3, S_4, S_5, S_6, S_7, \) and \( S_8 \) respectively. Therefore, the TSV of the basic unit sum to be
VI. RESULTS AND DISCUSSION

The basic unit of the proposed topology has been simulated and the simulation results have been verified using the experimental results. In this section, both simulation and experimental results are discussed.

A. SIMULATION RESULTS

The basic unit of the proposed topology has been simulated using PLECS software. For simulation, the Vdc is selected as 50V. This results in the magnitude of three input dc voltage sources as 50V, 100V and 150V. The resultant 13 level output voltage has a peak voltage of 300V with a step voltage magnitude of 50V. Fig. 11 (a) shows the waveforms of output voltage and current of a series connected resistive-inductive load of \( Z = 10 + 100 \text{mH} \) with a change of modulation index. The different dynamic and steady state response of the output voltage and current waveforms are also depicted in Fig. 11 (a). The harmonic spectrum of the output voltage and current has been depicted in Fig. 11 (b). The THD of voltage and current has a value of 6.3% and 0.35% respectively. Furthermore, a step change of load type from purely resistive load i.e., \( Z = 50 \) to a series connected RL load with \( Z = 50 + 100 \text{mH} \) has been also been depicted in Fig. 11 (c).
VII. CONCLUSION
The thesis presents a novel MLI topology with multiple extension capabilities. The basic unit of the proposed topology produces 13 levels using eight unidirectional switches and three dc voltage sources. Three different extension of the basic unit has been proposed. The performance analysis of the basic unit of the proposed topology has been done and the comparative results with some recently proposed topologies in literature have been presented in the paper. The power loss distribution in all the switches for different combination of loads have also been demonstrated in the paper. The performance of the proposed topology has been simulated with dynamic modulation indexes and different combination of loads using MATLAB software.

FUTURE SCOPE:
Further, a power loss analysis of the dynamic losses (switching and conduction) in the MLI has also been presented, which gives the maximum efficiency of the basic unit as 98.5%.

REFERENCES