Design and Implementation of 5-Phase 5-Level Cascaded Inverter for Electric Vehicle Applications

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Abstract: *This paper presents the design and implementation of a 5-phase 5-level cascaded inverter for electric vehicle (EV) charging applications. The proposed inverter topology offers improved power quality, reduced harmonic distortion, and increased efficiency compared to traditional 2-level inverters. The 5-phase configuration enables reduced current stress on individual switches, while the 5-level cascaded structure provides a higher voltage output with reduced total harmonic distortion (THD). The design is suitable for high-power EV charging applications, supporting the widespread adoption of electric vehicles.*

Keywords: *Electric Vehicle Charging, Cascaded Inverter, 5-Phase 5-Level, Power Quality, Harmonic Distortion.*

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has led to an increased demand for efficient and reliable charging infrastructure. The charging process requires a high-power conversion system to supply the necessary energy to the vehicle's battery. Traditional 2-level inverters have limitations in terms of power quality, efficiency, and reliability. To address these challenges, this paper proposes a novel design and implementation of a 5-phase 5-level cascaded inverter for EV charging applications.The 5-phase configuration offers reduced current stress on individual switches, while the 5-level cascaded structure provides a higher voltage output with reduced total harmonic distortion (THD). This topology enables improved power quality, reduced harmonic distortion, and increased efficiency.

A two-level inverter has two different output voltages and is the simplest one. But the ac output is rectangular with high total harmonic distortion (THD) whereas the load needs sinusoidal voltage. Multilevel inverter (MLI), a step ahead of the two-level inverter tends to reduce this effect. It does so by using many low rated dc voltage sources as input for the desired ac voltage output. So, in a multilevel inverter, the output voltage is stepped more than twice. As the level increases in the multilevel inverter, the waveform is smoother than the two-level inverter. MLI has two classes; current source inverter and voltage source inverter. In the former, a short circuit in the circuit can cause a very high fault current which will damage any other types of equipment connected to the circuit. Hence, multilevel voltage source inverters are preferred [2]. There are four types of MLI topologies; neutral point clamped (NPC), diode clamped (DC), flying capacitor (FC), and cascaded H-bridge (CHB) multilevel inverter. Cascaded H-bridge multilevel inverters have preferably low THD [1]. The difference between several topologies of MLI lies in the source of input voltage and the mechanism of switching.

MLI is used in power intense and high voltage applications. The industry demands additional solutions of high dv /dt resulting in voltage doubling in motor output, compliance of % THD, high electromagnetic interference (EMI) and high common-mode voltages which trigger research of inverters [3] [4]. Baker and Banister [5] pioneered the series H-bridge inverter. The demerits of DC and FC topologies, for instance, additional clamping diodes and capacitors are overcome by a proposed CHB inverter [6]. It can give high output power from a medium-voltage source. Higher voltage can be generated using the lower rating devices. The control of switches in this converter is simple and easy to construct. A survey on multilevel inverter configuration, control, and application, and an MLI with reduced number switches is described [6]. Because of its isolated dc sources, cascaded inverters are appropriate to interface photovoltaic generation to an ac grid for power quality management [7]. They are suitable for regenerative type motor drive applications, fuel cell-based electric vehicles. Potential applications include electric and hybrid power trains. A review of MLI configuration was brought by Pharne [8]. An MLI with a reduction in the number of switches was described by Ebrahimi et al [9].

II. TOPOLOGY AND DESIGN OF INVERTER

In power electronics, multilevel inverters react as a promising device and mostly applied in medium and high voltage industrial applications such as industrial drives, laminators, blowers, fans, and surveyors. Since two-level inverters have some limits in terms of the variety of power applications, multilevel inverters with modulation techniques have been proposed in recent years to address this issue [1][2]. Several literatures mentioned, there were three well-known configurations of multilevel inverter called cascaded H-bridge, diode-clamped, and flying capacitors. Due to the simple switch configurations and have easy way to be controlled, H-bridge inverter was used in many industrial applications. This kind of inverters involved with high switching frequency of PWM and their □□/□□ stress result was in low efficiency. Thus, as a means to resolve these problems, multilevel inverters (MLI) was proposed as an alternative to reduce the voltage stress on power-switching devices and also produce high-quality output voltages [3][4].Multilevel inverter gets as far as much attention nowadays when it comes to in a range from medium to high power applications because of its great advantages and abilities. The most popular topologies are Diode-Clamped Multilevel Inverter (DCMLI), Flying Capacitor Multilevel Inverter (FCMLI), and Cascaded H-Bridge Multilevel Inverter (CHBMLI). The classification is shown in Figure 1.

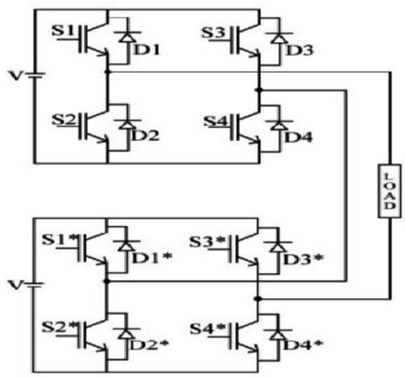

Fig.1: 5-Level Cascaded Inverter

Five level cascaded H-bridge multilevel inverter. The converter consists of two series connected H-bridge cells which are fed by independent voltage sources. The outputs of the H-bridge cells are connected in series such that the synthesized voltage waveform is the sum of all of the individual cell outputs. The output voltage is given by V=V1 +V2 Where the output voltage of the first cell is labeled V1 and the output voltage of the second cell is denoted by V2. There are five level of output voltage ie 2V, V, 0, -V, -2V.The main advantages of cascaded H-bridge inverter is that it requires least number of components, modularized circuit and soft switching can be employed. But the main disadvantage is that when the voltage level increases, the number of switches increases and also the sources, this in effect increases the cost and weight. The cascaded H-bridge multilevel inverters have been applied where high power and power quality are essential, for example, static synchronous compensators, active filter and reactive power compensation applications, photo voltaic power conversion, uninterruptible power supplies, and magnetic resonance imaging. Furthermore, one of the growing applications for multilevel motor drive is electric and hybrid power trains.The applicability of multiphase systems is explored in electric power generation, transmission, and utilization. The research on six-phase transmission system was initiated due to the rising cost of right of way for transmission corridors, environmental issues, and various stringent licensing laws. Six phase transmission lines can provide the same power capacity with a lower phase-to-phase voltage and smaller, more compact towers compared to a standard double-circuit three-phase line. The geometry of the six-phase compact towers may also aid in the reduction of magnetic fields as well. The research on multiphase generators has started recently and only a few references are available.

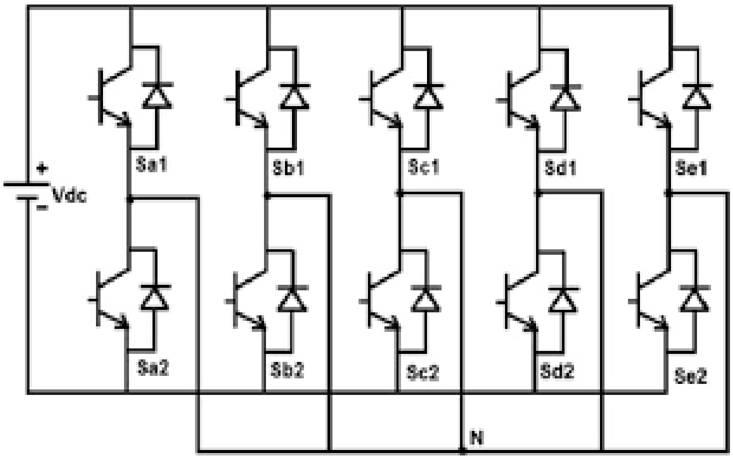

Fig.2: 5-Phase 5-Level voltage source Inverter

Five phase ten-switch inverters are used in five phase VSI and CSI inverters [1]-[8]. For this reason, many researchers have been recently investigating different types of fault that commonly occur in these inverters. Of these, the improvement of the output waveform and reduce harmonic distortion is very important. Therefore, using electronic devices, various excitation of inverters are presented, which can reduction harmonic and can lead to improve the output voltage too. Although, this inverters increase the quality of output voltage and current, but leads to other disadvantages, including increased size, weight and price [9]-[12]. In this paper, a new method for selecting conductive angle based on the power factor of load is presented. The conductive angle can vary from 36° to 180° according to these parameters. To achieve low THD and high RMS of output voltage, the conductive angle is changed from 36° to 180° for different power factor of lead and lag loads with simulation. There are five leg for five phase supply. Each leg has two switches with antiparallel diodes across each switch. The load considered here may be resistive or inductive or a motor load. The gating signal of five phase inverters should be advanced or delayed by 72°. With respect to each other to obtain a five phase balanced (fundamental) voltages. If the five phase output voltages are not perfectly balanced in magnitudes and phases, there are not balanced. A five phase output can be obtained from a configuration of ten transistors and ten diodes as shown in Fig. and the Simulink view of the topology is shown in Fig. Control signals can be applied to the switches at 36°, 72°, 108°, 144° and 180°. Their performances are compared in this paper.

Table.1: Switching Sequence for Five Phase Five Leg

phase	36	72	108	144	180	216	252	288	324
Ph1	S1					S6			
Ph2			S3					S8	
Ph3					S5				S10
Ph4		S2					S7		
Ph5				S4					

III. SIMULATION RESULTS

Simulation studies using tools like MATLAB/Simulink will model and validate the inverter's performance under various operating conditions, optimizing design parameters for the best performance-to-complexity ratio. The hardware implementation phase involves designing and assembling a prototype, followed by rigorous testing to confirm the simulation results. Integration with actual EV charging setups will assess real-world performance, focusing on metrics such as charging efficiency, power quality, and thermal management.

This innovative system aims to significantly reduce charging times and improve the user experience, with a modular design that allows scalability to meet future demands. By advancing control strategies and exploring integration with renewable energy sources, this project addresses current EV charging challenges and lays the groundwork for sustainable and efficient future charging solutions.

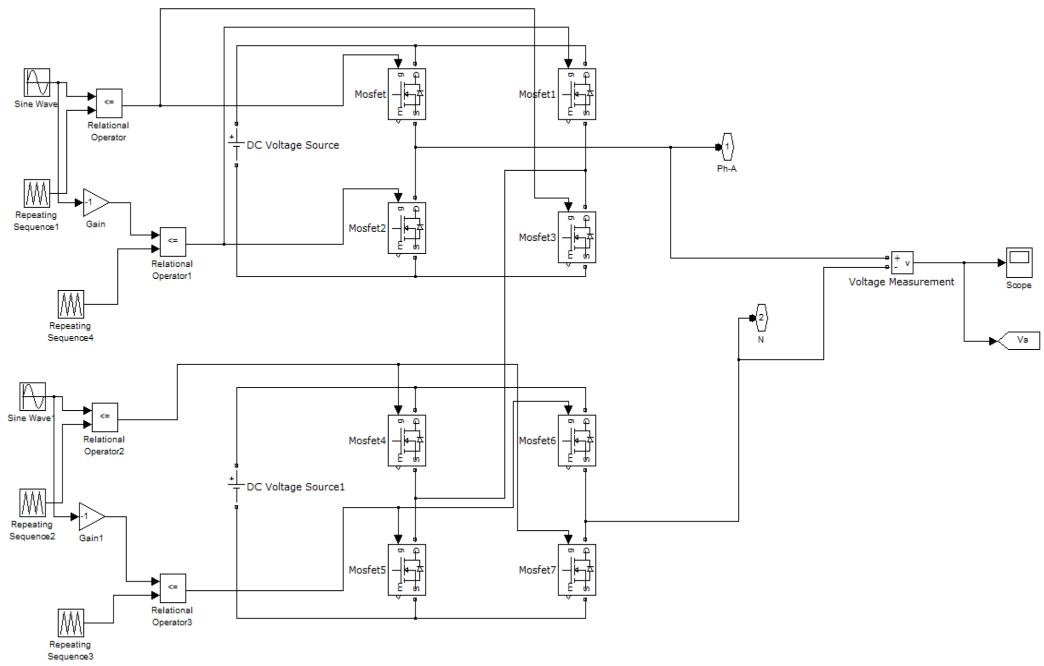

Fig.3: Simulation diagram of 5-level cascaded Inverter

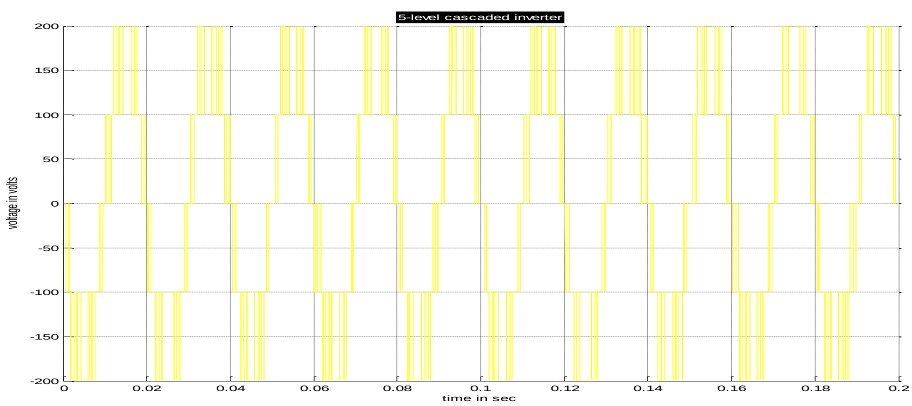

Fig.4: Output waveform of 5-level cascaded Inverter

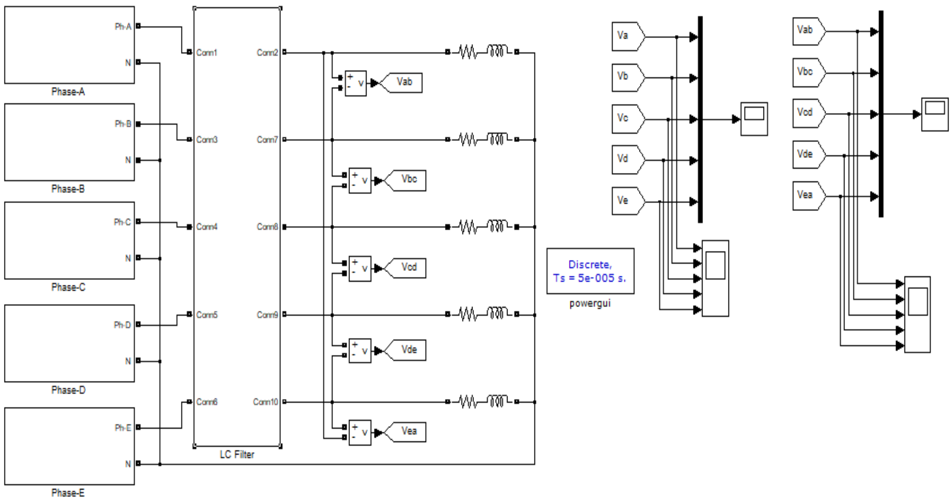

Fig. 5: Simulink diagram for 5-Phase 5-level Inverter with and without filter

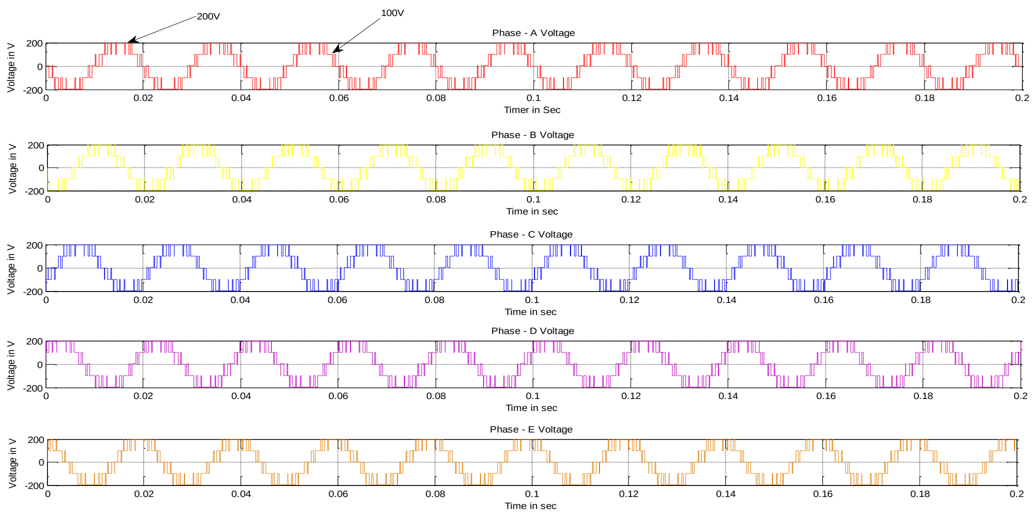

Fig. 6: 5-phase 5-level phase voltages without filter

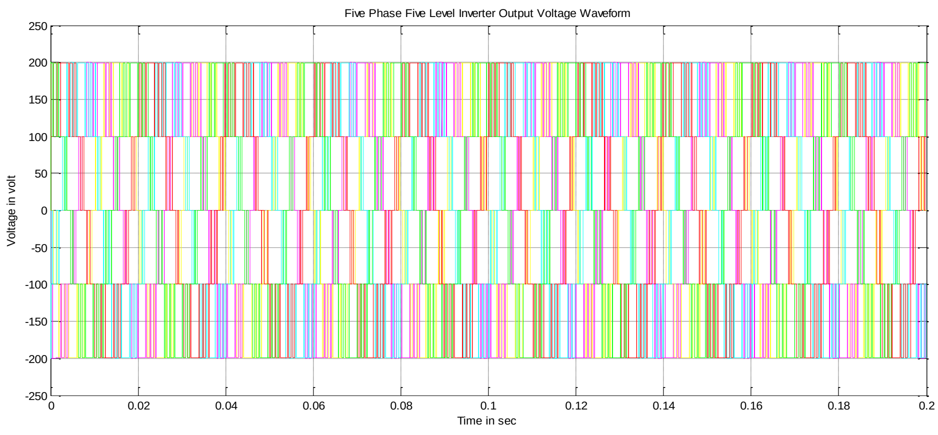

Fig. 7: 5-phase 5-level inverter output voltage waveform without filter

IV. CONCLUSION

The design and implementation of a 5-phase 5-level cascaded inverter for electric vehicle (EV) charging applications have yielded significant improvements in power quality, efficiency, and reliability of EV charging systems.The 5-phase 5-level cascaded inverter architecture effectively reduces Total Harmonic Distortion (THD) and enhances voltage regulation, leading to superior power quality compared to traditional inverter designs.The integration of the proposed inverter with EV charging infrastructure showed significant improvements in charging efficiency and reduced charging times, providing a better user experience for EV owners. The future scope of the 5-phase 5-level cascaded inverter for electric vehicle charging applications is vast and promising. Hardware implementation and testing will validate its performance and reliability. The technology's potential in other applications like renewable energy systems and energy storage will be explored. Collaboration with industry partners and further research will drive innovation and widespread adoption.

V. REFERENCES

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