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Three Phase Switched Inductor Quasi-Z-Source Inverter

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ABSTRACT:A new space vector modulation, for three-phase quasi-Z-source rectifier (qZSR) is proposed. All switches in the three-phase bridge can be turned on and turned off with zero-current or zero voltage using the proposed ZSVM3 without any auxiliary ciruit. The current through the inductors of the quasi-Z source network operates in boundary conduction mode or discontinuous conduction mode to achieve all freewheeling diodes turned off with zero current- switching (ZCS). At the same time, the switch in the quasi-Z-source network can be turned on with ZCS. Besides, the voltage stress of all switches is equal to dc-link voltage. The operation principle of the qZSR is analyzed in detail and the calculated value of the quasi-Zsource inductor is given. The proposed theory in this paper is verified by a 2-kW prototype. Novel active clamping zero-voltage switching three phase boost pulse width modulation (PWM) rectifier is analyzed and a modified minimum-loss space vector modulation (SVM) strategy suitable for the novel zero-voltage switching (ZVS) rectifier is proposed in this paper. The topology of the novel ZVS rectifier only adds one auxiliary active switch, one resonant inductor, and one clamping capacitor to the traditional hard-switched three phase boost PWM rectifier. With the proposed SVM strategy, the novel ZVS rectifier can achieve ZVS for all the main and auxiliary Switches. In addition, the anti parallel diodes can be turned OFF softly, so the reverse recovery current is eliminated. Besides, the Voltage stress of all the switches is equal to the dc-link voltage. The Operation principle and soft-switching condition of the novel ZVS Rectifier is analyzed. The design guidelines of the soft switched Circuit parameters are described in detail. A DSP controlled 30 kW Prototype is implemented to verify the theory.

KEYWORDS: Quasi-Z-source rectifier, space vector modulation,

I. INTRODUCTION

On board charger plays a very important role in electric vehicles (EVs). While it increases space occupation, weight and costs of EVs, especially when quick charge is needed. Integrated charger solves these problems. It uses the traction hardware including an inverter, circuits, and motor windings, as the rectifier and grid-side filter inductors of the charger. Since the quasi-Z-source network can realize bi-directional energy flow and some electrical vehicle drives use quasi-Zsource network, three-phase qZSR is very suitable for integrated charger. Enhancing the efficiency of integrated charger is important. The switching loss and the freewheeling diode reverse recovery loss lower the efficiency of integrated charger. So it's necessary to realize the soft switching for a three-phase rectifier. Many researches on soft-switching for threephase rectifier have been done in recent years. In most soft-switching technologies, an auxiliary circuit is added to make switches turned on and turned off under zero-voltage-switching (ZVS) or ZCS condition. The resonant dc-link (RDCL) is one kind of dc-side soft-switching technologies. The auxiliary circuit of RDCL only needs one small capacitor and inductor. But the voltages across the switches will reach about 2.5 times the dclink voltage. The active clamped resonant dc-link (ACRDCL) is another dcside soft-switching technology. Compared to RDCL, the voltages across the switches are lower (about 1.4 times the dc-link voltage) using ACRDCL. However, the auxiliary circuit of ACRDCL needs one more power switch. Quasi-ACRDCL (qACRDCL) is proposed in. All switches can be turned on with ZVS and the reverse recovery loss of freewheeling diodes also can be eliminated. The auxiliary circuit of qACRDCL is simpler than ACRDCL and the grid-side harmonic current can be reduced by specific modulation, while the voltages across all switches are still higher than dc-link voltage. Modified qACRDCL uses a modified SVM to make the voltages across all switches equal to the dc-link voltage. The zero-voltage-transition (ZVT) and zero-current-transition (ZCT) converter proposed in use a small switch, a small inductor and a small diode to realize a wide

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load range soft-switching technology applies this technology to three-phase inverter and proposes a modified modulation. A high-power threephase rectifier using six auxiliary switches to achieve full zero-current switching for all switches is proposed. the simplified three-phase ZCT inverter only uses three auxiliary switches and LC resonant tanks and it can achieve soft switching with normal PWM algorithms. All these technologies are only for singlestage rectifier. Since the Z-source converter was first proposed by Peng it has been widely used in three-phase rectifier and inverter. Many researchers have been done to solve the hard-switching of Z-source converter. presents a full soft-switching technology for a galvanically isolated quasi-Z-source converter. It only uses two snubber capacitors. But the high inductor current ripples increase the conduction losses. A new shoot-through control for qZSI is proposed. This control method makes the switching losses more balanced, but it can't realize full soft switching. A switched coupled-inductor is used in unidirectional Z-source inverter. This configuration can make the transistors of inverter work with soft switching and the reverse-recovery of diodes is alleviated. A ZVS Z-source three-phase rectifier is proposed. This structure doesn't use any additional circuit. It uses the freewheeling diode to clamp the voltage across the switch to zero in the shoot-through state. So the switches in the three-phase bridge can be turned on with ZVS. While the switch in the Zsource network will suffer high voltage and is in hard switching.

II. EXISTING SYSTEM

The Z-source concept can be applied to all dc-to-ac,ac-to-dc,ac-to-ac,dc-todc power conversion. To describe the operating principle andcontrol,this paper focuses on an application example of the Z-source converter:a Z-source inverter for dc-ac power conversion needed for fuel cell application. Because fuel cells are usually produce a voltage that changes widely.(2.1 ratio) depending on current drawn from the stacks. For fuel-cell vehicles and distributed power generation, a boost dc-dc converter is needed because the V-source inverter cannot produce an ac source.

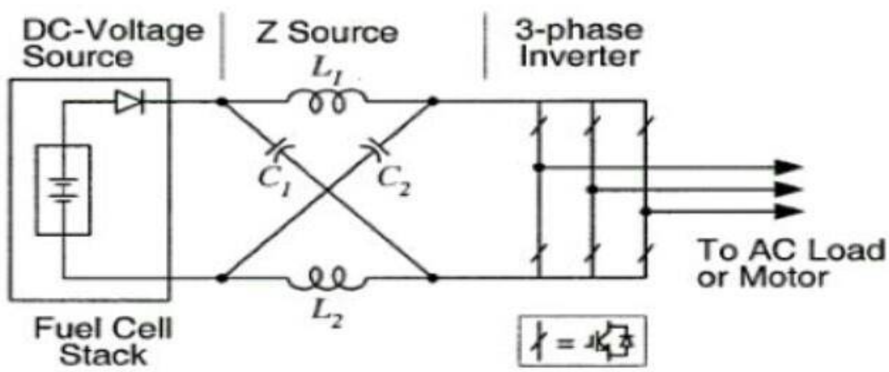

Fig1: Existing Proposed switched coupled-inductor quasi-Z-source inverter

III. PROPOSED SYSTEM

We propose, a combination of switched-capacitor (SC) and a three winding switched-coupled-inductor (SCL) is applied to the qZSI, and the topology obtained is termed as SCL-qZSI. The proposed SCL-qZSI retains all of the advantages of the classical qZSI topology such as continuous input current and a common ground between the dc-voltage source and the inverter-bridge; it can also suppress the start up inrush current. The integration of the SC with SCL is beneficial in that it significantly enhances the boost ability of the SCL-qZSI with a smaller component count and lower turn ratio. The proposed inverter adds only one capacitor and two diodes to a classical qZSI, and even with a turns ratio of 1, its voltage boost ability is higher than that of the existing high-voltage boost (q) ZSI and trans-ZSI, which were discussed before. Therefore, for the same input and output voltages, it can use lower and higher, which results in lower component-voltage stresses, a better output power quality, and a lower input current ripple.

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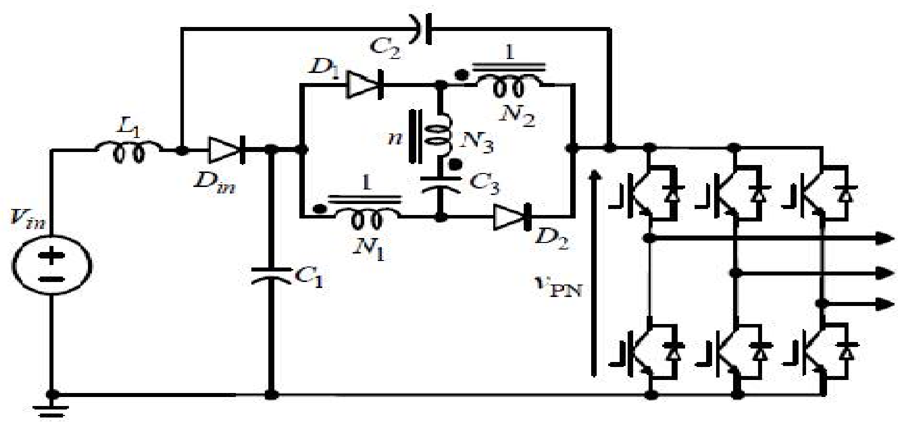

Fig 2: Proposed switched-coupled inductor quasi-Z-source inverter (SCLqZSI).

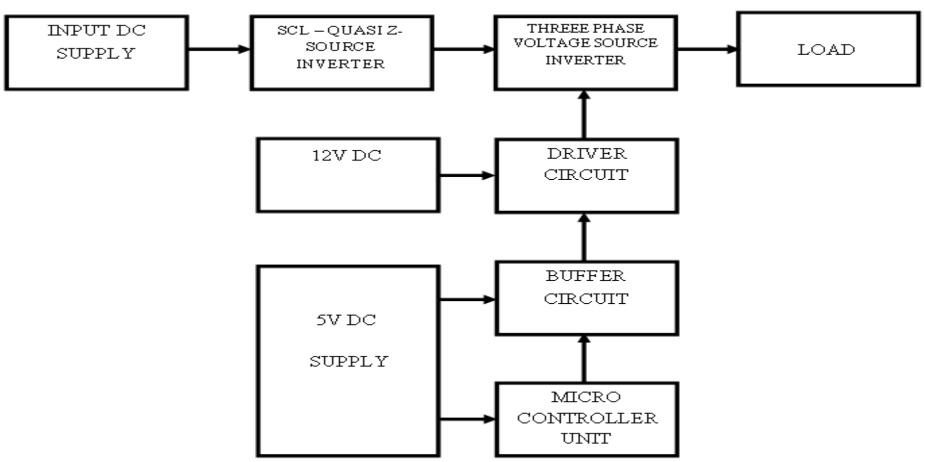

Fig 3: block diagram for proposed switched-coupled-inductor quasi-Z-source inverter.

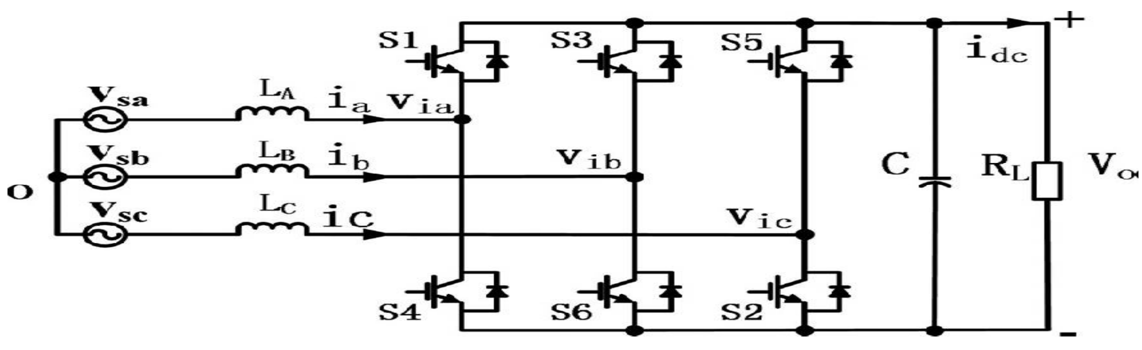

Fig. 4. Topology of the three-phase boost PWM rectifier.

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The three-phase six-switch boost pulse width modulation (PWM) rectifier as shown in Fig. 1, due to its remarkable features of high power quality and low electromagnetic interference (EMI) emissions, is widely chosen for medium and high power industrial applications. However, during the commutation from diode to transistor, the antiparallel diodes of the rectifier experience reverse recovery process, which will cause severe switching losses and EMI problems due to high di/dt and dv/dt. Considering these problems, the switching frequency of PWM converters is usually confined, which may result in higher current total harmonic distortion, larger passive components, and high switching noise. The soft-switching technique can make switches be turned ON and OFF under zero-voltage or zero-current condition, which will resolve the diode reverse recovery problems and reduce switching losses. Meanwhile, the rising and falling edges of switch current and voltage waveforms can be shaped so the di/dt and dv/dt are reduced as well. Many soft-switching techniques for three-phase PWM converter have been investigated. The general methodology is to add auxiliary resonant circuit to decrease or eliminate the overlap between voltage and current at switching transitions. According to the placement of auxiliary circuit, the soft-switching threephase PWM converters can be divided into two classes: the dc-side soft-switching converter and the ac-side soft-switching converter. The dc-side soft-switching converter uses one group of auxiliary circuits placed on the dc-side of the converter to produce high-frequency pulsating voltage across the main switch bridge. The switches are commutated at the instants when the bridge Voltage is zero so the corresponding devices can be zero-voltage switching (ZVS) switched. Among the various dc-side soft-switching topologies in the resonant dc-link (RDCL) converter in has the simplest topology, but it imposes 2–2.5 times voltage stress on all the switches. The active clamped RDCL (ACRDCL) converter in added one extra auxiliary clamping switch to decrease the device voltage stress by times. However, the RDCL and ACRDCL converters are both controlled by discrete pulse modulation (DPM), which will produce sub harmonics in the ac-side current waveforms. A partial PWM control technique for heRDCLand ACRDCL converters has been proposed in to overcome the drawbacks of the DPM but the device turn-off loss is increased and meanwhile the PWMrange is limited. To apply real PWM control techniques, many approaches have been presented in . These converters provide zero voltage intervals in the switch bridge of the PWM converter whenever the switch transition is needed but the circuits are much more complex compared to the ACRDCL converter. The parallel resonant dc-link (PRDCL) converter with unity voltage stress proposed in needs three additional switches. The quasi-resonant dc-link (QRDCL) converter proposed in requires only two auxiliary switches and the auxiliary switch can be turned off under zero-current condition. The QRDCL inverter with coupled inductive feedback proposed in further simplifies the circuit, which only needs one auxiliary switch, one diode, and one coupled inductor with two additional coils. The drawback is the voltage stress of the clamping diode is too high (4.3–11 p.u.). To overcome this problem, a new QRDCL inverter with some changes to the circuit in is proposed in which still only needs one auxiliary switch and can ensure soft-switching for all the switches. The device voltage stress is (1.01–1.10) times the dc-link voltage under all load conditions but the circuit requires a separate low-voltage dc source. The dcrail zero-voltage-transition (ZVT) and zero-current-transition (ZCT) three-phase voltage source inverter proposed in can be controlled by a modified SVM and provides ZVT or ZCT for the switches. However, the converter topology consists of three additional switches. On the other hand, the ac-side soft-switching converters usually have much more complex topology compared to dc-side soft-switching converters, which can offer the advantages of PWM control and soft-switching without additional voltage or current stress in primary devices. The auxiliary resonant circuit is added at the ac side for each phase and the resonant transitions occur separately when the corresponding main switch needs switching. The auxiliary resonant commutated pole converter proposed in features zero-voltage switching for main switches and zero-current switching for auxiliary switches without affecting the standard PWMcontrol. However, the midpoint voltage provided by split capacitors is susceptible to drift which may affect the operation of the resonant circuit. A transformer-assisted PWM ZVS pole inverter proposed in adds one transformer for each phase leg to avoid using split capacitors but the auxiliary transformer may cause manufacturing penalty and complexity. A new ZVS PWM single-phase full-bridge inverter using a simple ZVS-PWM commutation cell without floatingmid-point voltage is proposed in. The main switches operate at ZVS and the auxiliary switches operate at ZCS. The ZVS inverters using coupled magnetics proposed in can also avoid the capacitor voltage unbalance issue with the advantage of less current stress of the auxiliary switch and faster demagnetization. The ZVS timing requirement is also satisfied over the full load range by using the variable timing control . The ZVT topology with six auxiliary switches and three coupled resonant inductors achieves zero-voltage turn-on for main switches and zero-current turn-off for auxiliary switches. Three-phase can be independently controlled without any modification of SVM technique and the auxiliary switches only need to carry half of the phase current. However, the circuit topology is

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complicated and requires much more space. There have been several research works devoted to developing ZVT topologies with less than six switches . These topologies decrease the cost and space with fewer components but lead to some critical disadvantages which are not in the ZVT topology with six auxiliary switches. The ZCT converter proposed can achieve zero-current switching for all of the main and auxiliary switches and their antiparallel diodes, so the turn-off loss and diode reverse recovery related loss are almost eliminated. The only drawback is the requirement of six auxiliary switches and three LC resonant tanks.

A simplified three-phase ZCT converter proposed in uses only three auxiliary switches and can achieve zero-current turn-off for all the main and auxiliary switches and provide soft commutation for the diodes. The execution of ZCT requires no modifications to normal PWM algorithms but the resonant tank current stress is higher. A novel frequency inverter with a "sinus switch" to solve the EMI noise in conventional PWM inverter is proposed in. A special ZVS control scheme with a variable switching frequency is proposed to control the inverter. To combine the advantages of both dc-side and ac-side soft-switching converters, the authors proposed a ZVS-SVMcontrolled three-phase PWM rectifier in which has a similar topology to the ACRDCL converter. In contrast, the rectifier can be controlled by a modified SVM scheme proposed by the Authors and can realize ZVS for both the main and auxiliary switches and soft turn-off of their antiparallel diodes. The auxiliary switch has the same fixed switching frequency as the main switches. However, the voltage stress of all the switches is still a little higher than the dc-link voltage. Nowadays, SiC power electronic devices have superior performance. The SiC Scotty diode has almost no reverse recovery process compared to Si diodes. The Si insulated gate bipolar transistor (IGBT) with ant paralleled SiC diode has been shown with very high efficiency. In the future, SiC MOSFET will be used to realize higher efficiency converter. Soft-switching converter is one alternative. Besides the efficiency, soft-switching is also helpful for lower EMI.
In this paper, a novel active clamping ZVS three-phase boost PWM rectifier is analyzed and a modified SVM strategy suitable for the novel ZVS rectifier is proposed. With the proposed SVM strategy, the novel rectifier can achieve ZVS for both the main and auxiliary switches. All the antiparallel diodes can be turned OFF softly, so the reverse recovery current is eliminated. Moreover, the voltage stress of both main and auxiliary switches is equal to the dc-link voltage. The turn-on losses of IGBTs and reverse recovery losses of antiparallel diodes can be avoided. But for ZVS switching, the turn-off losses of IGBTs can only partly be avoided because of the existence of the tail current.

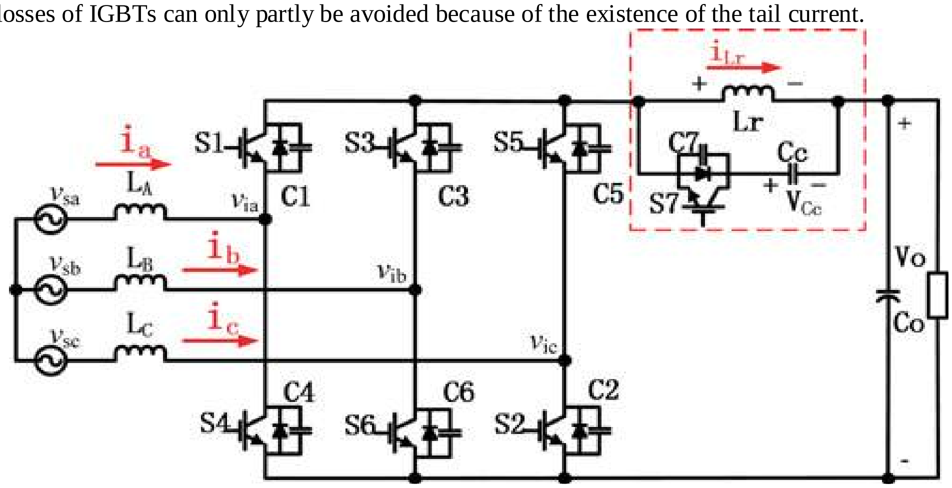

Fig. 5. Topology of the ZVS-SVM controlled three-phase PWM rectifier proposed.

IV.SIMULATION & EXPERIMENTAL VERIFICATION

The battery voltage of the electric vehicle usually vary from 360-V to 550-V according to different bands. And the input voltage is a three-phase 50-Hz 380-V. As the experimental platform is limited, a 2-kW scaling-down system is designed in this example. The parameters are: The input filter inductance is L=3mH. The capacitances of the quasi-Z-source network are c1=c2=550 uF. The switching frequency is 10-kHz. The input phase voltage amplitude is Vm=78V. The output voltage is Vout=120V. The output load resistance is R=7.5Ω

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Design for 2-kW Full-load

The voltage of 2 C is 295 V when output voltage is 120 V. So the buck factor is B = 0.593 . According to (18), 86 can be chosen as k V and it has K= 0.708 . The value of the quasi-Z-source inductor with BCM can be calculated by substituting the parameters into (29), one has L = 209uH.The relationship L versus theta based onabove parameters is shown in Fig. 7.

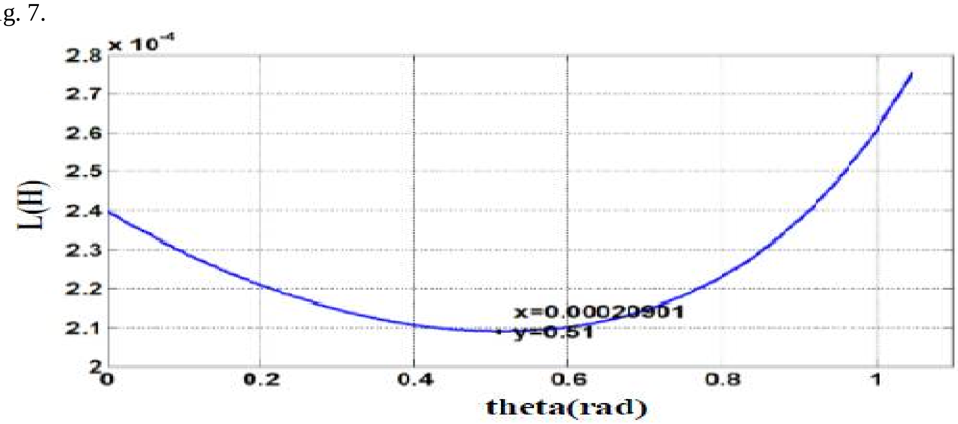

Fig 6. The relationship L versus theta

V.SIMULATION RESULTS

A MATLAB simulation model was built with above parameters and the quasi- Z-source inductances are L1=L2=209uH. The simulation results are shown in Fig. 8. From the simulation results, it can be seen that the 4S is turned on with ZCS condition and turned off with ZVS condition. In addition, the freewheeling 4 d is turned off with ZCS. The simulation results correspond to the theoretical waveforms presented in Fig. 4.through 4 d and 4 S (Iigbt, I4d), the voltage across 4S , the driving signal of 4S and 7.

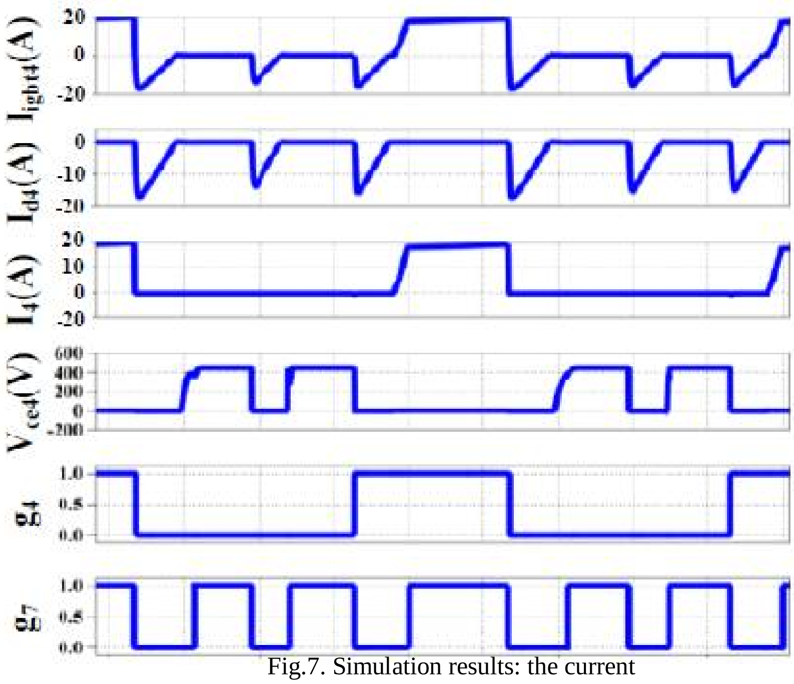

Fig.7. Simulation results: the current

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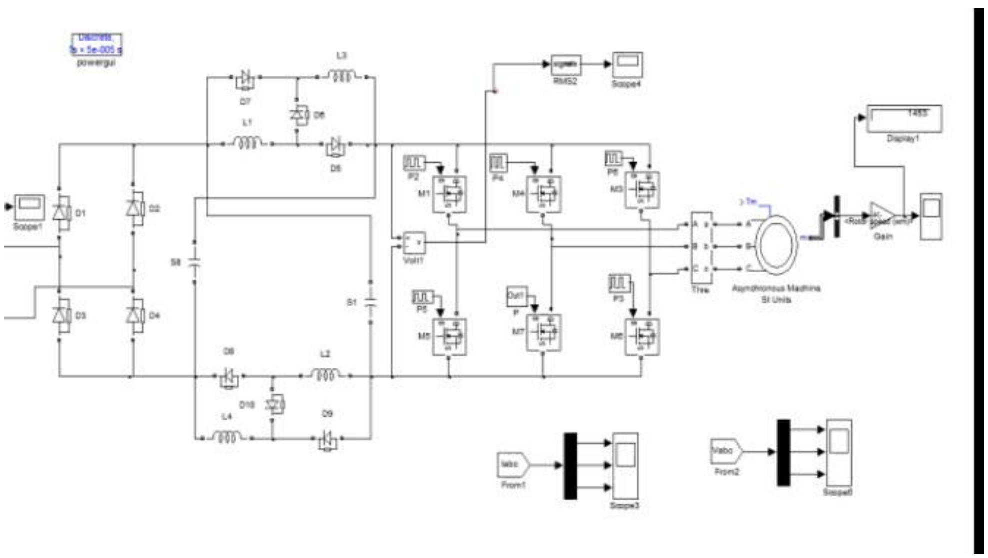
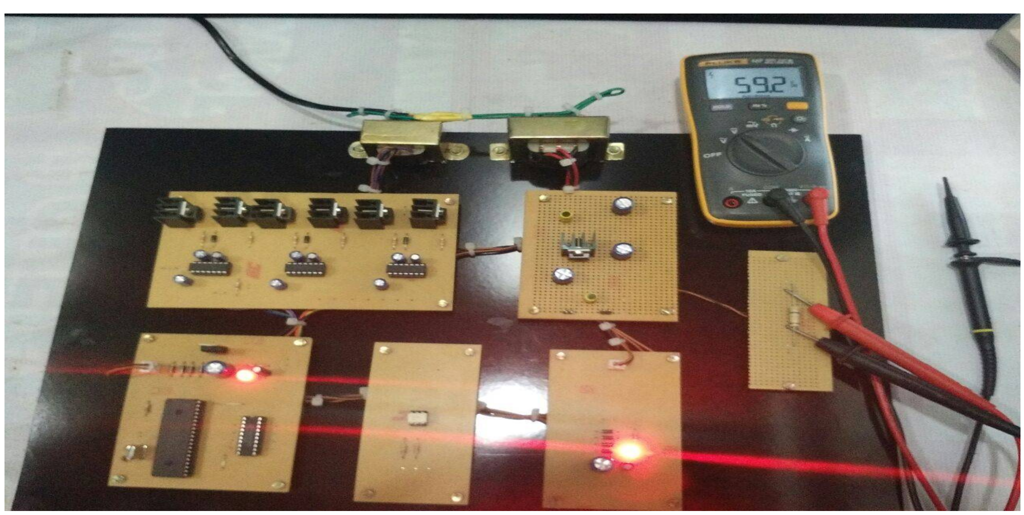
VI. SIMULATION OUTPUT



VII. REAL TIME OUTPUT



VIII. CONCLUSION

To enhance the efficiency of the threephase qZSR, a ZSVM3 is proposed. The switches in a three-phase bridge can be turned on and turned off under softswitching condition. When the quasi-Zsource inductor current operates in BCM or DCM, the current through freewheeling diode has enough time to decrease to zero, so all the freewheeling diode reverse recovery can be suppressed. And S7 can be turned on with ZCS. The value of the quasi-Z-source inductor can

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be fit for a wide range of load power. Besides, the voltage stress of the main switches is equal to dc-link voltage. Compared with ZSVM2 and ZSVM6, the proposed ZSVM3 can realize full softswitching and the efficiency of system increases significant. And the switching frequency of S7 using ZSVM3 is just 3 times the switching frequency of S1-S6, while using ZSVM2 is 4 times and using ZSVM6 is 6 times. However, ZSVM3 has its disadvantages. Because ZSVM3 is asymmetric, the THD of grid-side current is a little high. And the peak current through S7 is higher than ZSVM2 and ZSVM6 because of system working in BCM or DCM.

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