

Three Phase Switched Coupled 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 circuit. 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-Z-source 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 antiparallel 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.

Keywords – *Quasi Z-Source Inverter, Space Vector Modulation, Zero-voltage Switching Rectifier.*

I. INTRODUCTION

Onboard 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-Z-source 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 three-phase 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 dc-side 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 load range soft-switching technology applies this technology to three-phase inverter and proposes a modified modulation.

II. EXISTING SYSTEM

The Z-source concept can be applied to all dc-to-ac,ac-to-dc,ac-to-ac,dc-to-dc power conversion. To describe the operating principle and control, 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.

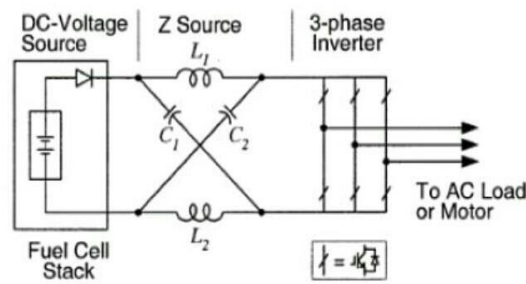


Fig1: Existing Proposed switched coupled-inductor quasi-Z-source inverter

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.

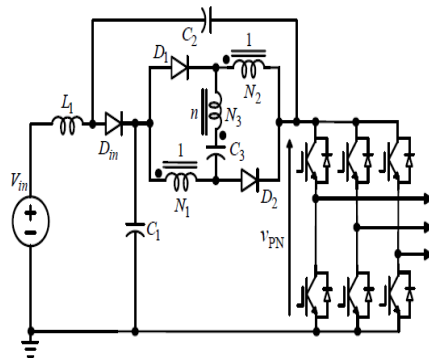


Fig 2: Proposed switched-coupled inductor quasi-Z-source inverter (SCLqZSI)

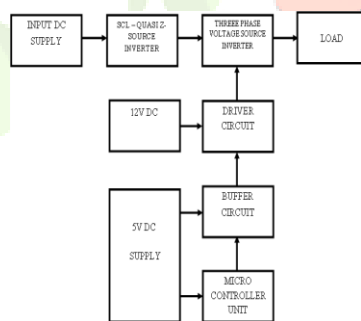


Fig 3: block diagram for proposed switched-coupled-inductor quasi-Z-source inverter

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 three-phase 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 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.

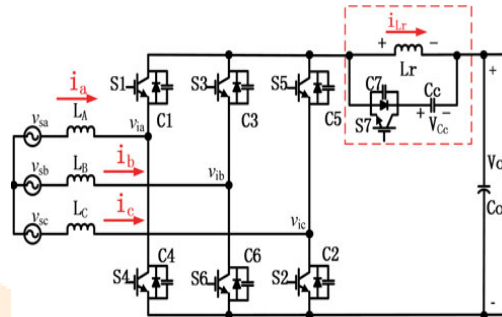


Fig. 4. Topology of the ZVS-SVM controlled three-phase PWM rectifier proposed.

IV. CONVERTER TOPOLOGY AND OPERATION ANALYSIS

Converter Topology Derivation

The topology of the ZVS-SVM-controlled three phase PWM rectifier proposed in which consists of a standard PWM rectifier and an auxiliary resonant branch. The auxiliary Branch consists of an auxiliary active switch S7, a resonant. Inductor Lr, and a clamping capacitor Cc. The auxiliary switch S7 is conducting for most of the switching period. When the auxiliary switch S7 is turned OFF, the energy stored in the resonant inductor Lr will discharge the parallel capacitors of the main switches. When the voltage of the capacitors paralleled with the main switches is discharged to be zero, the main switches can be turned ON under ZVS condition. Meanwhile, the current of the antiparallel diodes can be linearly decreased with the existence of Lr . Therefore, the reverse recovery current of the antiparallel diodes is effectively suppressed. For the topology shown in Fig. 2, the voltage stress of the Main and auxiliary switches is clamped to $V_o + V_{Cc}$, which will increase with the load power. With circuit parameter optimization, the voltage stress can be confined within 1.1 times of the dc-link voltage. To further decrease the voltage stress of the main and auxiliary switches, a novel active clamping ZVS three-phase boost PWM rectifier, as shown in Fig. 3 controlled by minimum voltage active clamping SVMmethod, is proposed in. Compared with the topology shown in Fig. 2, only the position of the clamping capacitor Cc is changed, which will decrease the device voltage stress to the dc-link voltage. In the existing ZVS-SVM control method proposed in is adopted to control the rectifier shown in Fig. 3. But there still exists some problems in the soft-switching condition. This paper will further discuss the rectifier shown in Fig. 3 and find the solution. B. Operation Analysis with Existing Modulation SchemeSince the novel topology shown in Fig. 3 is very similar to the topology shown in Fig.2; this paper will first discuss the operation principle of the novel ZVS rectifier adopting the existing ZVS-SVM control method proposed in.

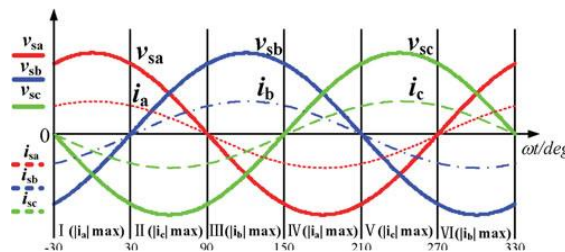


Fig. 7. Grid voltage and current waveforms.

V. PROPOSED MODULATION SCHEME AND OPERATION ANALYSIS

A. Proposed Suitable Modulation Scheme: In order to realize the ZVS condition, the energy stored in the resonant inductor Lr must be increased. The solution proposed in this paper is shown in Fig. 9, in which one additional stage (t_4-t_5) is inserted after stage 4 to make the current of Lr decrease linearly to a minus value $-I_{add}$. To realize the additional stage (t_4-t_5), one additional switch S8 is paralleled across the main switch bridge, as shown in Fig. 10(a), which can be simplified as shown in Fig. 10(b). At t_4 , the additional switch S8 is turned ON and the voltage of the resonant inductor is clamped to $V_{Cc} - V_o$. Then, the energy

stored in the resonant inductor L_r can be increased. SECT1-1 is taken as an example to analyze. The additional stage is numbered stage 5 (t_4-t_5) as shown in Fig. 11(e). The Fig. 10. Novel ZVS rectifier and its equivalent circuit. (a) Novel ZVS rectifier with one additional switch. (b) Equivalent circuit of the novel rectifier. stage analysis based on the equivalent circuit of the novel rectifier is shown in Figure. 4 (t_3-t_4). (e) Stage 5 (t_4-t_5). (f) Stage 6 (t_5-t_6). (g) Stage 7 (t_6-t_7). Stage 7 (t_6-t_7): At t_6 , the main switches S_1 , S_3 , S_5 and the auxiliary switch S_7 are ON. The resonance between L_r , $C_4 + C_6 + C_2$ and C_7 stops and then the rectifier enters switching state $U_7(1\ 1\ 1)$. Looking at Fig. 10, the additional switch S_8 can be replaced by making the main switch bridge in short circuit. Then, the traditional modulation scheme should be modified as shown in Fig. 13. At t_4 , turning ON one or two or all of the three main switches S_4 , S_6 , S_2 can make the main switch bridge in short circuit to replace the function of the additional switch S_8 .

B.Operation Principle With the Proposed Modulation Scheme: With the proposed modulation scheme shown in Fig. 13, the three-phase rectifier stage analysis is given as follows. SECT1-1 is still taken as an example to analyze. The operation stages and key waveforms of the novel three-phase ZVS rectifier during a whole switching cycle are shown in Figs. 12 and 13 separately. It is assumed that the voltage of the clamping capacitor C_c is constant during one switching cycle. From Fig. 12, the complete circuit operation in one switching cycle can be divided into ten stages. Stage 1 (t_0-t_1): The rectifier is in switching state $U_1(1\ 0\ 0)$. The main switches S_1 , S_2 , S_6 and the auxiliary switch S_7 are conducting. The voltage of L_r is clamped by V_{C_c} and its current increases at the rate of This stage ends when the auxiliary switch S_7 is turned OFF. $U_7(1\ 1\ 1)$. The resonant inductor is clamped by V_{C_c} , and its current increases at the rate of (1). This stage ends when the main switch S_5 is turned OFF. Stage 8 (t_7-t_8): At t_7 , S_5 is turned OFF. Because of the existence of C_5 and C_2 , the voltage of C_5 is slowly rising. When the voltage of C_5 increases to V_o , this stage ends. switch S_7 are ON. The circuit enters the state $U_2(1\ 1\ 0)$. The resonant inductor is clamped by V_{C_c} and its current increases at the rate of (1). This stage ends when the main switch S_3 is turned OFF. Stage 10 (t_9-t_{10}): At t_9 , S_3 is turned OFF. Because of the existence of C_3 and C_6 , the voltage of C_3 is slowly rising. When the voltage of C_3 increases to V_o , this stage ends and the circuit enters state $U_1(1\ 0\ 0)$, which repeats the next switching cycle.

VI. CONCLUSION

To enhance the efficiency of the three-phase $qZSR$, 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 S_7 can be turned on with ZCS. The value of the quasi-Z-source inductor can 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 S_7 using ZSVM3 is just 3 times the switching frequency of S_1-S_6 , 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 S_7 is higher than ZSVM2 and ZSVM6 because of system working in BCM or DCM.

VII. REFERENCES

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