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An Advanced Control Method for Inductive Load of Z-Source Inverter

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Abstract
In this paper, the operation principle of the Z-source inverter is analysed in detail. According to the characteristics of allowed short–shrougt zero state in the Z-source inverter, SPWM control method of the Z-source inverter is obtained by inserting fixed short–shrougt zero state into zero state of SPWM. It is simple and easily implemented in practice. However, in inductive load condition the output voltage and current of Z-source inverter have serious distortion and affect the inverting quality. The cause of this distortion is analysed in detail and an improved SPWM control method is proposed, which can better solve the output voltage and current distortion problem of the Z-source inverter under the condition of inductive load. Matlab simulation results verify that the improved SPWM control method not only eliminates distortion caused by inductive load, but also decreases the switch times and quantities in each cycle. Therefore, it decreases the THD of AC output effectively and improves the efficiency of the inverter, and its theoretical analysis is verified to be effective.
Keywords-Z-source, inverter, SPWM, the shoot–shrougt zero state, inductive load, voltage distortion

I. INTRODUCTION

More concerns have been paid to Z-source inverters as a novel topology proposed in 2002, which has a excellent input voltage bandwidth, a buck-boost function, and decrease the impact current and the gird harmonic current. Also this inverter can switch on the both the upper and the lower switches in the same phase legs. Generally PWM techniques are adopted for one phase Z-sourece inverter, while SPWM is widely applied for low THD, constant switching frequency, and easy implementation etc. Compared with conventional SPWM, some novel modulation techniques can suppress the low frequency voltage fluctuation,. The photovoltaic power Inverters connected to the AC grid should have a low harmonic output, while the high harmonic not only affects the quality, but also leads to power grid fluctuation and harmonic pollution. Therefore, SPWM is ideal for photovoltaic inverters to solve the high harmonic damage problem.

Different inverter topologies using different SPWM control methods can effectively improve the inverting efficiency and the output quality.

Because the shoot-through states of the upper and the lower switches in the same phase legs the of the Z-source inverters are used to improve voltage, the improved maximum SPWM control method is proposed in and its basic principle is described as follows: since the shoot-through zero state and the conventional zero state of SPWM have the same effect to the load, in the given modulation factor condition, the conventional zero state of SPWM should be replaced by the shoot-through state to the greatest extent so that to decrease the device stress in the same gain factor. Therefore, the optimal effect is that the conventional zero state of SPWM should be replaced by the shoot-through state wholly, which has a extreme design condition. Firstly, the operation principle is analysed. According to the Characteristics of the Z-source inverter, injecting the specified duty ratio during the state of SPWM is zero can achieve the shoot-through states based on the conventional SPWM control method. A simple SPWM control method of the Z-source is obtained by improving the conventional SPWM control method. This control method has only two switches operating with a high-frequency state in each cycle so that to decrease during inverting, but the output voltage and current of the Z-source inverter of condition leads to serious distortion, which affects the power quality. Subsequently, according to the cause of distortion, the Improved SPWM control method is used, which not only overcomes the output voltage and current distortion of inductive load but also decreases the switch times and switching loss in one cycle. The Simulation carried out with Matlab / Simlink verifies the validity and effectiveness of the proposed control method.

II. THE OPERATION PRINCIPLE OF Z-SOURCE

Fig 1 shows Z-source inverter in which tow capacitors and inductors are used to link a full-bridge resonant converter. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. Thus, Z-source inverter is divided into two kind of operating situations: the shoot-through state and the nonshoot-through state.

Fig 2 shows the shoot-through state. The diode D1is off because of withstanding reverse voltage. Assuming that the time of the shoot-through state is T0. From the equivalent circuit in Fig. 2, the inductance voltage has

VL-SHOOT=VC

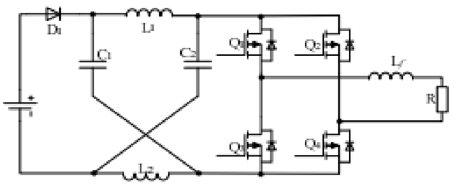


Figure 1. Z-source inverter structure

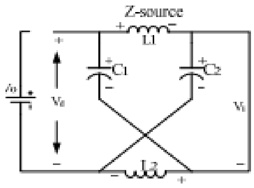


Figure 2. The shoot-through state of Z-source inverter

Fig 3 shows the nonshoot-through state. The diode D1is on. Assuming the time of the nonshoot-through state is T1, From the equivalent circuit in Fig. 3,

The inductance voltage has

VL-nshoot=Vd-nshoot-Vc (2)

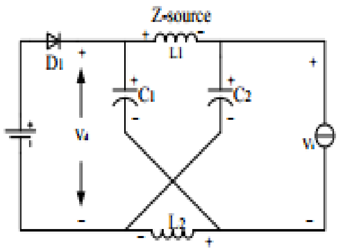


Figure 3. The nonshoot-through state of Z-source inverter

The average voltage of the inductors over one switching period should be zero in steady state, from (1) and (2), thus

$$V_{L-shoot} = \frac{T_0 * V_C + T_i * (V_0 - V_C)}{T} = 0 \quad (3)$$

$$\frac{V_C}{V_0} = \frac{T_i}{T_i - T_0} \quad (4)$$

Where D=T0/T，T= T0+ T1
The peak DC-link voltage across the inverter bridge can be written as

$$V_i = V_c - V_{L-shoot} = 2V_c - V_0 = B * V_0 \quad (5)$$

Where B—the boost factor resulting from the shoot-through
Zero state，B>=1
The output peak phase voltage from the inverter can be
Expressed as：

$$V_{ac} = M * \frac{V_i}{2} = M * B * \frac{V_0}{2} \quad (6)$$

Where M is the modulation index，and M≤1
Because the value of M*B is from zero to ∞, the output voltage of the Z-source can be stepped up and down by choosing an appropriate buck–boost factor M*B.

III. THE SPWMCONTROL METHOD OF Z-SOURCE INVERTER

For inverters of photovoltaic power example. the new energy sources, the power switches used should be as few as possible, which can meet the requirement of decreasing the switching loss, increasing efficiency, and easily controlling. It's ideal choice is Z-source inverters in Fig. 1. From the above working principle analysis of Z-source Inverters, the biggest difference between the Z-source and conventional converters is that the former can gate on the both upper and lower switches in the same phase legs, whereas the shoot-through states are forbidden in the latter. Therefore, to inject the specified boost duty cycle when the duty cycle of SPWM in switching period is zero can achieve the shoot-through states based on the conventional SPWM control method, which is simple and easily controlled and implemented. From the Figure 4 we can get the intervals of the switching period.

SPWM COMMAND	THE ZERO STATE	SHOOT THROUGH

Figure 4.Intervals of the switching period

Figure 5 shows the trigger states of four switches in one period. According to the Z-source converter in Figure 1, the SPWM control method is analyzed in details, while Q1and Q2are the AC frequency controlling switches to generate 50 Hz AC sinusoidal waveform and Q3and Q4are the high-frequency modulating switches. When Q1is switched on and Q2 is switched off, Q4is modulated by SPWM, while Q3 injects specified duty cycle being the zero of SPWM maintaining the shoot-through state of the Z-source converter. So doing this can modulate the output AC sinusoidal positive waveform. When Q2 is switched on and Q1is switched off, Q3 is modulated by SPWM, while Q4injects specified duty cycle being the zero of SPWM maintaining the shoot-through state of the Z-source converter. So doing this can modulate the output AC sinusoidal negative waveform.

Fig. 6 and Fig. 7 show the load current and voltage waveforms implemented by using the above SPWM control scheme.

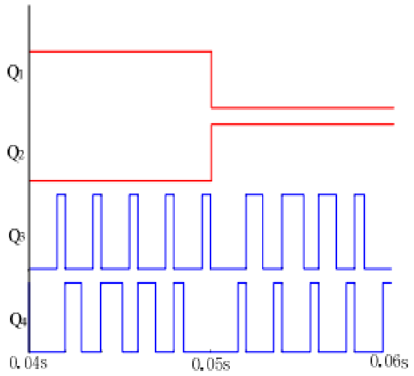


Figure 5. Switching pattern for the Z-source inverter

Because of inductive load, the current is rapidly taken to the zero state in the commutation of Q1and Q2getting the distortion of current waveform, which can be seen from the part amplified of Figure 6. Also the voltage distortion waveform can be seen from Figure 7.

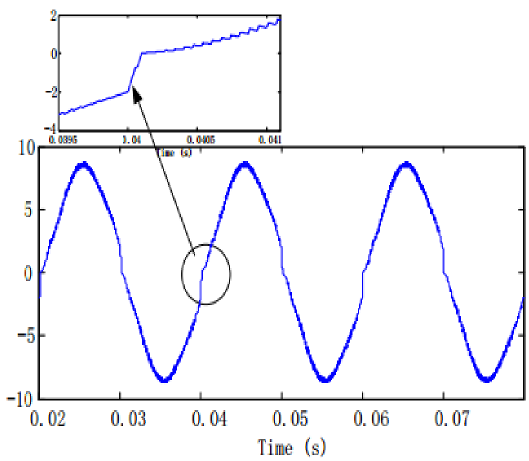


Figure 6. Output current of Z-source inverter

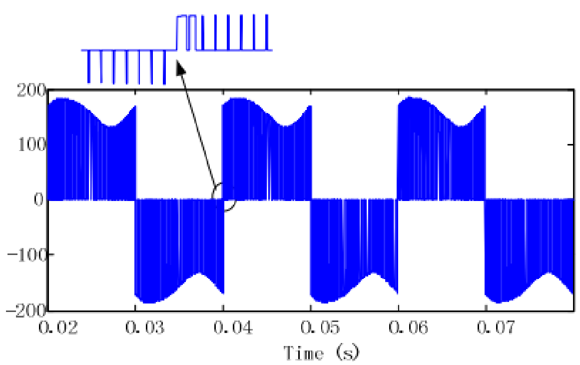


Figure 7. Output voltage of Z-source inverter

Figure 8 shows the THD of the output voltage is 9.96%, while the qualities of voltage and current are seriously influenced giving severe interference to power supply equipments and the grid.

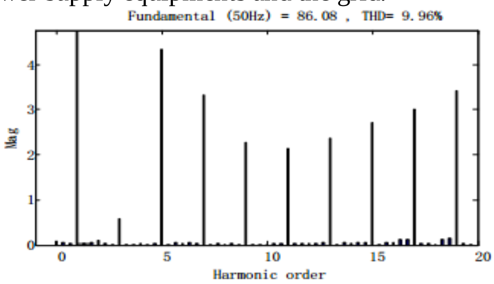


Figure 8. THD of output voltage

IV. THE IMPROVED PWM CONTROL METHOD

From the above analysis, using SPWM control can implement the converting of the Z-source topology, but the THD is quite big and the converting quality is seriously influenced. In order to avoid the above problem, firstly analyzing the cause of this distortion is necessary. The reasons are as follows: before it is at 0.04s, the output voltage is negative and the output current is negative too; when it is at 0.04s, the switch Q2is off and Q1is on. Therefore, the output voltage becomes positive. In the Condition of turning off Q3 and Q4 (the zero state of Fig. 4), the voltage of load R should be naught according to normal SPWM control method.

However, because of inductive load, the output current is still negative. The direction of the current is flowing from the diode of switch Q4, the load R, output filter Lf, to switch Q1, show in Fig. 9. In this way, the voltage of load R becomes the voltage of DC-bus, but not naught, and the distortion of output voltage occurs. Due to the effects of distorted voltage, the positive current of the load R increase with the increase of the voltage The subtract result between this positive current and Freewheeling current makes the current of the load get to be zero quickly and the distortion of output current occurs.

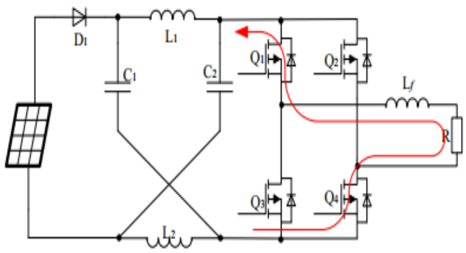


Figure 9. Current direction when distortion occurred

On the basis of the cause of the distortion, when SPWM control method operates commutation and zero state((the zero state of Fig. 4), the suitable freewheeling path should be provided to get to the zero voltage of The load after the output voltage change direction and avoid the above distortion.

Therefore, when switch Q1is on, and .Q1, Q1is off at 0.04s, switch Q2is on. Namely negative current of the load flows from Q1, Q2, the load R Lf to Q1and the voltage of load R is naught. SPWM control method can be satisfied, the freewheeling path shows in Fig.10. After the current of l the load becomes positive, the current may flow from Lf, the load R, the diode of switch Q2to switch Q1.These components Form the freewheeling path , and switch Q2 can be off and do not operate at high frequency always. The same as above, when the current of the load changes from positive to negative, switch Q1 is on in condition of turning-off state of witch Q3and switch Q4.

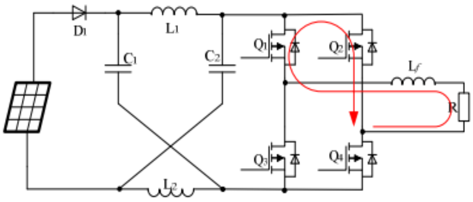


Figure 10. Current direction after using improved SPWM

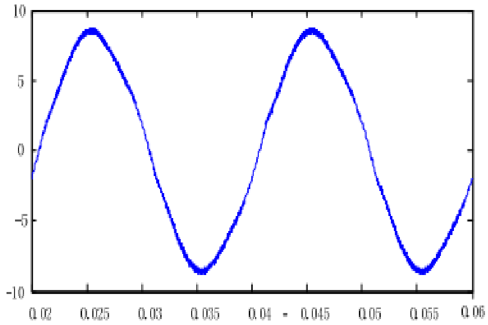
This improved control method is simple and easily realized in practice. There are few switch times and switching times at period cycle and decreasing loss of the switch and then improve the efficiency and life of the inverter

V. SIMULATION RESULTS

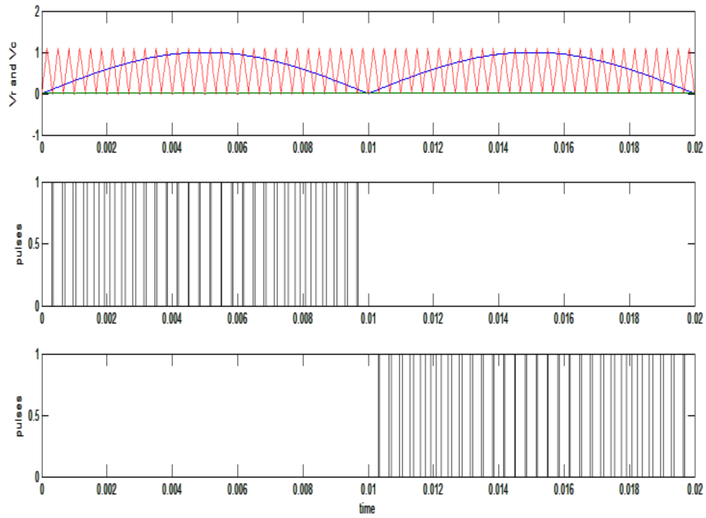
In order to verify the validity and effectiveness of the proposed control method for inductive load of the Z-source inverter, Mat lab simulation is used. Fig. 1 shows the Z-source inverter Authorized licensed use limited to: Bharat University. Downloaded on June 22, 2010 at 11:38:01 UTC from IEEE Explore. Restrictions apply. of simulation circuit. Main requirements and parameters are as follows: the input voltage Vin=80V; the output voltage Vout=220V; the switching frequency f=15KHz; The Z-source has two 2.7mH inductors L1=L2=2.7mH, capacitors C1=C2=340μF; D=0.33; Lf=7.6 mH ; R=10Ω. The proposed Improved SPWM control method is used. Switching pattern after using improved SPWM is shown in Fig.

Figure 11. Switching pattern after using improved SPWM

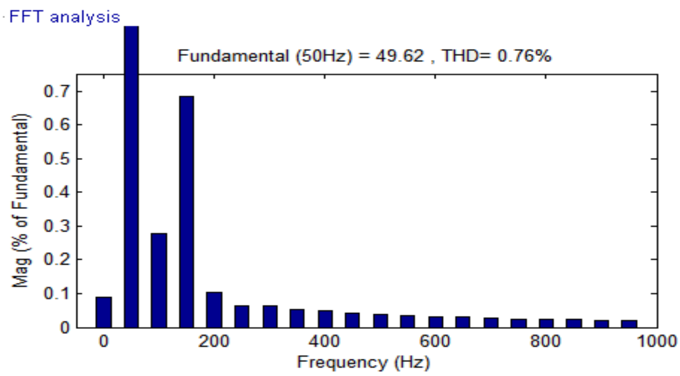
Fig. 12 and Fig. 13 show the output voltage and output current respectively with improved SPWM control method. It is obvious that the output current is no longer drop quickly to naught by comparing Fig. 6 with Fig. 12. It becomes smooth and has no distortion. The out voltage keeps normal modulating voltage and has no distortion which fig.7 shows. The improved SPWM control method can commendably solve distortion of the output voltage and the output current for inductive load by comparing Fig. 6 and Fig. 7 with Fig. 12 and Fig. 13.



The THD of the output voltage with improved SPWM control method decreases to half of
Fig. 8.



THD of voltage after using improved SPWM



VI. CONCLUSION

The conventional SPWM is used widely for its simplicity and easy implementation in practice, but under the condition of inductive load the output voltage and current of the Z-source inverter have serious distortion and the power inverting quality is affected. Based on the principle of the Z-source inverter, the control method is applied to DC-AC by inserting a fixed D into zero state of the SPWM. According to the cause of the output voltage and current distortion, the improved SPWM control method is proposed, which provide paths for the current commutation untill conventional SPWM after the current of commutation is naught and decreases the switch times in each cycle. Although it adds the detection and sampling circuit of the output current, the improved SPWM control method is still feasible for existing MPPT (maximum power point tracking) circuit of Photovoltaic. Finally, Mat lab simulative results verify that the improved SPWM control method not only solves the problem of the output voltage distortion well and smooth's the output current but also decreases the THD of the output voltage and improves the inverting quality effectively.

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