PWM Cuk AC-AC 컨버터를 위한 새로운 Commutation 회로

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A New Commutation Circuit for PWM Cuk AC-AC Converter

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ABSTRACT

This paper proposes a snubber circuit for a PWM AC-AC Cuk converter. The proposed snubber applies a modified Undeland snubber as a commutation aid. The snubber circuit has some good features such as reduction of voltage/current stress of the main switches, improved efficiency. The experiment results show the adaptability and feasibility of the proposed snubber circuit.

1. Introduction

PWM Cuk AC-AC converter has been the researching interest in constant frequency power conversion application, such as electronic transformer, phase shifter, line conditioner, and static var compensator and so on. The three phase PWM Cuk AC-AC converter topology has been dealt with in [1]. An modified Cuk converter circuit has also been proposed in [2]. The basic operation and characteristics are also dealt with in [1] and [2]. As to AC-AC converter, the current commutation is quite critical, many attempts have been made to solve this problem. In [3], a regenerative DC snubber for solving commutation problem was proposed for buck-boost converter. This paper proposes a snubber circuit for a PWM Cuk AC-AC converter. The proposed converter makes use of an modified Undeland snubber as commutation aids [4]. The snubber keeps such good features as reduction of voltage/current stress of main switching devices and improved efficiency. This paper shows experimental results to verify the adaptability and feasibility of the proposed snubber circuit.

2. PWM AC-AC Cuk converter

2.1 Converter circuit

Fig. 1 illustrates the three phase PWM Cuk AC-AC converter power circuit. The Cuk converter is capable of producing step-up and step-down voltage conversion. It also has the primary advantage that both the input and the output currents are non-pulsating, reducing the ripple seen at both the input and output sides. In Fig. 1, a group of IGBT switches Q_1, Q_3, Q_5 are turned on or off simultaneously. Meanwhile, the other group of switches Q_2, Q_4, Q_6 are also switched on or off simultaneously. And the on or off state of the two groups are complement. Hereby, the duty ratio d is defined as the ratio of turn-on duration of Q_1, Q_3, Q_5 over one switching period. Thus, it should be noted that there is only one control variable, d. C_t acts as energy transfer capacitor. And the C_t voltage is basically zero-centered AC waveform.

2.2 Commutation problem

For the described PWM Cuk AC-AC converter, the safe commutation of inductor current is critical. When dead time is used, all the switches are turned off for a short interval. Then there will be no path for both the input and output inductor currents. As the inductor current has to be continuous, an alternative current path has to be provided. On the contrast, overlapping in the PWM signal should also be avoided. Because in this case, the energy transfer capacitor will be short-circuited. And dramatic over current phenomena will occur. Hence, a proper circuit is needed as commutation aids. Since the energy transfer capacitor voltage implies AC value, an AC snubber has to be used to absorb the bidirectional turn-off spike energy and to perform the voltage clamp. The AC snubber is simple but inefficient. In this paper, the commutation problem is solved

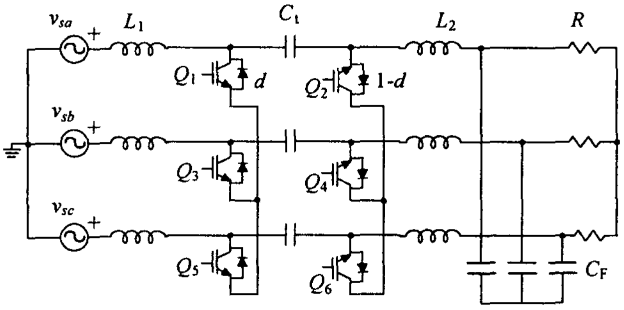

Fig. 1 Three phase PWM Cuk AC-AC converter: general topology

by introducing a modified Undeland snubber into the modified PWM Cuk AC-AC converter.

3. Proposed Cuk converter with commutation circuit

3.1 Modified Cuk converter topology

Compared with the circuit topology shown in Fig. 1, a modified three phase PWM Cuk AC-AC converter with an additional central connection is shown in Fig. 2. The operation of the circuit shown in Fig. 2 is almost similar to that in Fig. 1, but it has several differences or advantages over that of Fig. 1 as follows. In Fig. 1, six discrete IGBTs will be needed to construct the circuit. With the central connection, commercially available IGBT modules can be used. Totally, three modules will be utilized. The central connection will also help to make an easy circuit connection and compact structure. The voltage across the energy transfer capacitor has a DC offset. This critical difference makes it possible to apply DC snubbers to the converter circuit. There are some well-developed DC snubbers. Among them, the Undeland snubber could be a good choice. Due to this unidirectional voltage of the energy transfer capacitor, DC capacitor can be used instead of AC capacitor.

3.2 Proposed commutation circuit

The Undeland snubber is a complete turn-on/turn-off DC snubber. It consists of fewer components. Also, the snubber diodes do not cause difficulties due to their reverse recovery. Moreover, all the losses are dissipated in one resistor. Therefore, loss recovery is quite possible. It is worth noting that by introducing the Undeland snubber, it not only solves the commutation problem, but also helps to reduce the main switch stresses and improve efficiency.

For simplicity, a single phase PWM Cuk AC-AC converter with the proposed snubber as commutation aid is shown in Fig. 3. The snubber circuit applies Undeland snubber with symmetric structure. It consists of inductor L_s, capacitor C_s, resistor R_s, diode D_s , and an over-voltage capacitor C_o, the value of which is normally 10-15 times of that of C_s. S_1 and S_2, including D_1 and D_2, will be one commercial IGBT module. The turn-off capacitor C_s is used for limiting the switches' dv/dt value and L_s is used to limit the di/dt value. C_o is used to store the snubber energy and perform over voltage clamping, while R_s for loss dissipation. As to the power circuit, L_1 and L_2 are input and output inductors. C_t acts as energy transfer capacitors and C_F the output filter capacitor, R_L refers the load.

4. Experimental results

An experiment setup is made to verify the operation of the proposed PWM Cuk AC-AC converter with the proposed snubber. The power circuit accords with Fig. 3 and the actual values of the circuit elements are

$V_{s,RMS}$=110V, f=60Hz, L_1= L_2=1mH, C_t=C_F=45μF, R_L=5Ω, f_s=5KHz, L_s =10mH, R_s =5Ω, C_s=0.22μF, C_o=2μF.

where $V_{s,RMS}$ is the RMS value of the input voltage. f is the source frequency, and f_s is the switching frequency. As to the semiconductor devives, the IGBT module used is SKM 100GB 124D from Semikron, and snubber diode is DSEI 2*30-06C from IXYS. Also, a dead time of 1.3μs is introduced in the PWM gating signal.

Fig. 4 shows the overall converter operation when d=0.5. The most upper one is the input voltage waveform, while the middle one is the output voltage waveform. Energy transfer capacitor voltage is shown in the most lower waveform. As seen in Fig. 4, the converter operates well. There are little ripple injected into both the input and output voltage. Also, the energy transfer capacitor voltage has DC value as expected.

Fig. 5 shows the experimental voltage and current waveforms of switch S_1, the upper one for the turn-on transient and lower one for the turn-off transient. As seen in Fig. 5, the switch is turned on at zero voltage and turned

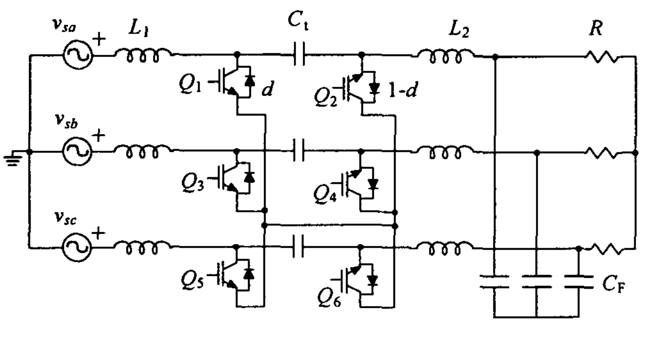

Fig. 2 Three phase PWM Cuk AC-AC converter: modified topology

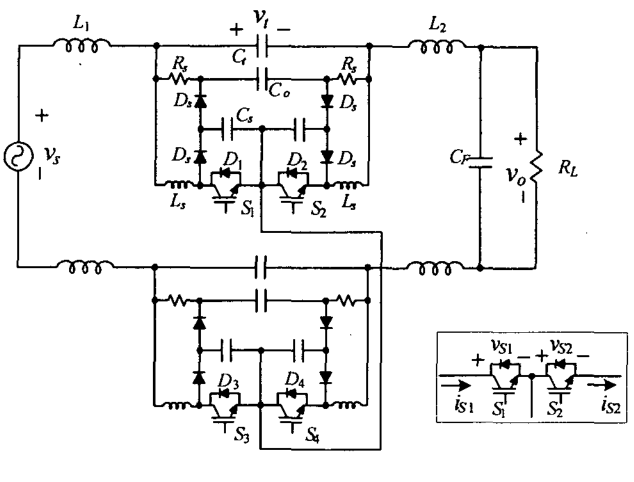

Fig. 3 Single phase PWM Cuk AC-AC converter with snubber

off at zero current. Therefore, soft switching operation is realized to reduce switching loss. Also the switch voltage is well clamped, hence introducing less stresses to the actual switches.

Fig. 6 is the experimental voltage and current waveforms of switch S_2 during turn-on and turn-off transient. The same good performance can be seen in Fig. 5 and Fig. 6.

As seen form the upper plots in Fig. 5 and Fig. 6, the current resonance occurs at turn-on transient. This is due to the reverse recovery phenomena of the IGBT's freewheeling diode. The spurious high-frequency oscillation can be excessively amplified due to in-circuit insertion of DC current probe and extension of lead wires in the process of measurement.

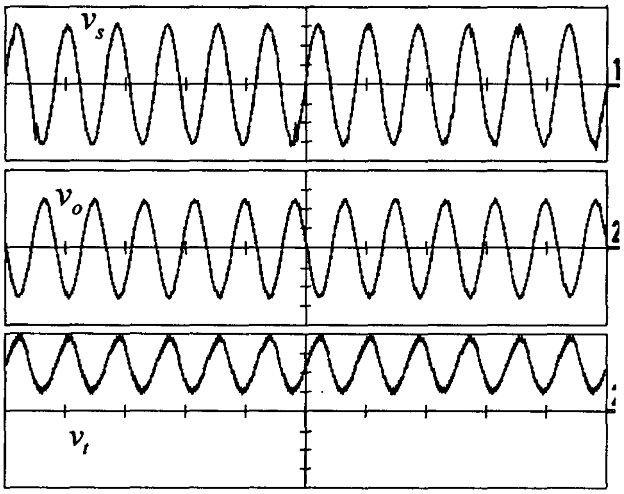

Fig. 4 Overall converter operation
vs(50V/div, 10ms/div);vo(50V/div, 10ms/div);
vt(100V/div, 10ms/div)

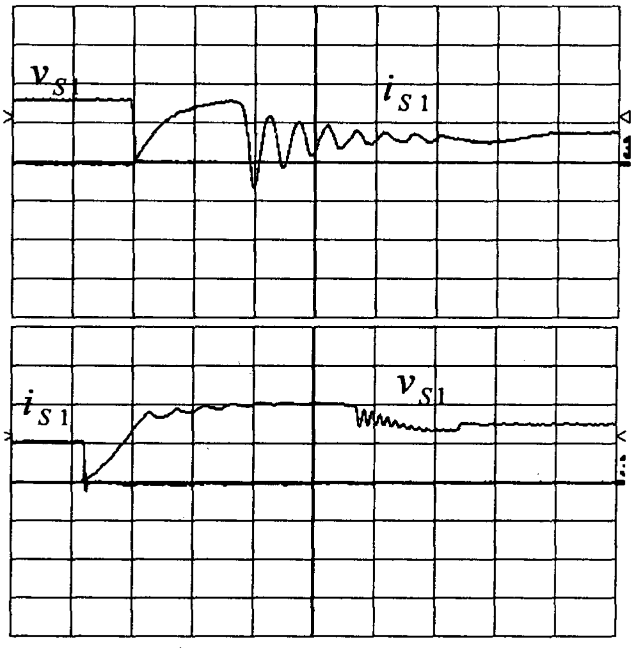

Fig. 5 Switch S_1 current and voltage waveforms
v_{S1}(250V/div, 5μs/div); i_{S1}(50A/div, 5μs/div)

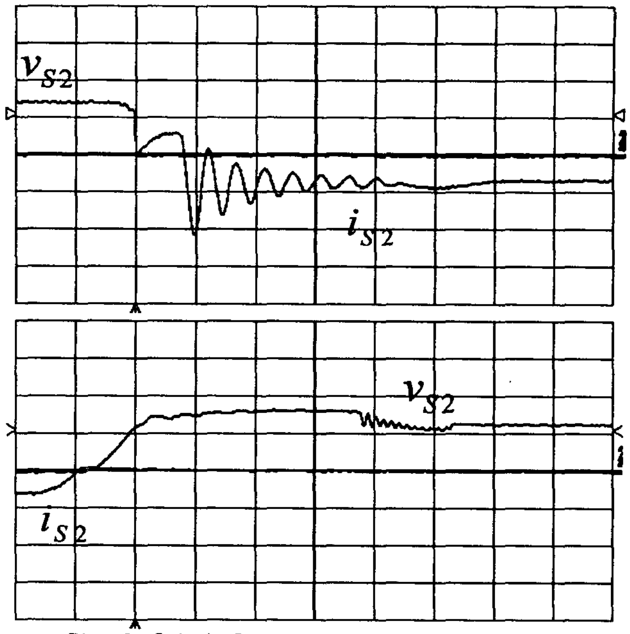

Fig. 6 Switch S_2 current and voltage waveforms
v_{S2}(250V/div, 5μs/div); i_{S2}(50A/div, 5μs/div)

5. Conclusions

A symmetric structure of Undeland snubber is adopted for a modified PWM AC-AC Cuk converter as a commutation aid. The proposed snubber circuit well facilitates the current commutation and performs good operation over voltage clamping for the main switches. The experiment results show the adaptability and feasibility of the proposed snubber circuit.

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