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Research on a Novel Inverter Based on DC/DC Converter Topology*

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Abstract: The conventional inverters have the shortcomings of straightway conduction in transistors and the difficulty of realizing soft switching. A novel inverter based on the DC/DC converter topology is presented. The inverter is comprised of a combined Buck/Boost DC/DC converter and a bridge circuit. The front stage converter is controlled to output variable DC voltage and the bridge circuit is used to convert the DC voltage to AC output. The energy feedback technology and one-circle-control scheme are used to improve the dynamic characteristics of the DC converter. The power devices of the inverter bridge can conduct soft switching. The operation principle and the circuit topology of this inverter are analyzed. Simulations and experimental results demonstrate that the performance of the inverter is high.

Key words: inverter, DC/DC converter, PWM, one-circle-control, soft switching

Inverters can be categorized into inverter bridge based topology and DC/DC converter based topology.

Traditional inverters, using bridge circuit, have the advantages of simplicities in both circuit topology and control. However, the up and down transistors of the bridge have the risk of straightway conduction and the transistors are difficult to accomplish soft switching. The risk of straightway conduction lessens the reliability and limits the switching frequency.

Recently, inverters based on DC/DC converter are researched diffusely. The four-quadrant DC/DC converters can also be used as inverters. The four-quadrant DC/DC converter is controlled in certain rules, and the alternate output voltage can be obtained. Because of the diversity of four-quadrant DC/DC converters, the inverters topologies are enriched. Based on DC/DC topology, the performance of the inverter can be improved.

A novel inverter based on the DC/DC converter is presented in this paper. In this inverter, a Buck converter is cascaded with an inverse Boost converter as the first-stage while a simple inverter bridge is used as the second-stage. By this configuration, the risk of straightway conduction is eliminated and high frequency operation can be achieved. It has good load compatibility and it is easy to accomplish.

1 Operation Principle of the Novel Inverter Based on DC/DC Converter Topology

There are many combination styles of the inverters based on DC/DC converter topology. Fig.1 shows the circuit topology presented in Ref.[1].

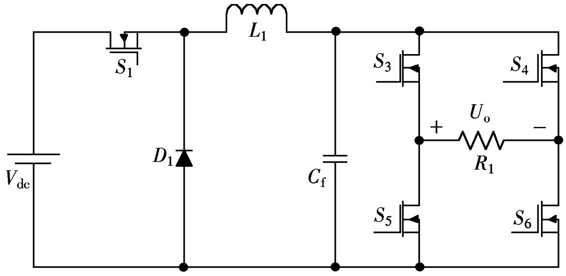

Fig. 1 An inverter based on DC/DC converter

This inverter circuit is combined by a Buck converter and an invert bridge. The first-stage Buck converter is operated at high switching frequency, and the output voltage is in the form of a fully rectified sine wave by using SPWM control scheme. Through the invert bridge which is operated at low switching frequency and is synchronized with the fully rectified waveform, the output voltage is "unfolded" into a sinusoidal waveform.

This circuit integrates the characters of the inverter based on bridge topology and the other based on DC/DC converter topology. It has several advantages. ① The circuit topology is terse and the control circuit is simple. ② The bridge circuit in the inverter operates at low frequency, the delay interval between the upper device and bottom device in each leg can be long, decreasing the risk of short-circuit. ③ The power devices of the bridge are switched when the output of the front-stage is near zero, so they are operated under ZVS condition. ④ The filter is small

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because the first-stage DC/DC converter is operated at high switching frequency. But, it also has some shortcomings. ① The load compatibility is not good because the first-stage DC/DC converter is a single quadrant converter which cannot transfer the energy in bi-direction way. When the load is light or not resistive, the energy of the filter capacity C_f cannot be released timely and the output is distorted seriously. ② The SPWM control scheme is a linear style and the influence of the voltage dropped on the inductor L_1 is ignored. In fact, Buck converter is a nonlinear system, and the influence of the voltage dropped on the inductor L_1 cannot be ignored. So the linearity of the system is not good, and the accuracy of output voltage is low.

On the basis of the circuit in Fig.1, a novel inverter is shown in Fig.2. A Buck circuit is selected as the first-stage converter because its output is directed ratio to the duty cycle D and it is of better linearity compared with the other DC converter and is easy to be controlled. At the same time, a Boost circuit is inversely parallel with the Buck circuit. When the output of the first-stage cannot run after the reference signal properly caused by the excessive energy on C_f, the Boost circuit operates, feeding back the excessive energy on C_f to the source. In this novel inverter the first-stage DC/DC converter is a two-quadrant DC/DC converter and the energy is transferred bi-directionally. The second-stage circuit mainly consists of a simple inverter bridge, and alternates the pole of the first-stage output.

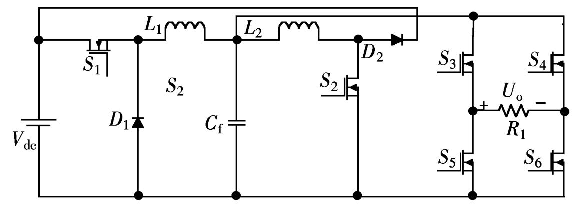

Fig.2 A novel inverter based on DC/DC converter

The circuit is controlled with negative feedback of the voltage transient magnitude. The Buck converter is controlled by one-circle-control scheme and the Boost converter is controlled by PWM technique. The architrave of the control circuit is shown in Fig.3.

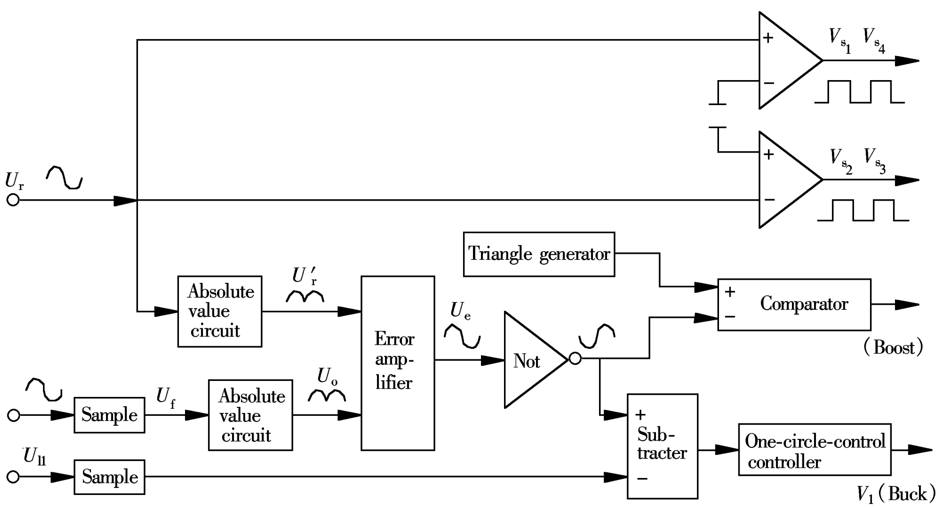

Fig.3 The control principle of system

Two switching signals synchronized with the reference signal are obtained from the cross-zero comparator. They are used to control the switches of the inverter bridge. The reference U'_r is obtained by the AC reference signal through an abstract value circuit. The voltage U_e is obtained by amplifying the error of U'_r and the feedback signal U_f. If $U_e > 0$, $(U_e + U_{l1})$ is used to control the one-circle-control circuit. The PWM signal to control the Buck circuit is generated and U_o is increased to follow U_r. If $U_e < 0$, compared with the triangular wave, the PWM signal obtained by $(-U_e)$ is used to control the Boost circuit and U_o is decreased to follow U_r.

Fig.4 shows the principle of the Buck circuit adopting one-circle-control scheme. The controller is comprised of integrator, comparator, and reset switch S_1 and R-S trigger. The goal of the output voltage magnitude running after the reference value in one circle can be fulfilled by this controller. The operating principle is explained below. When the R-S trigger is set by the up-edge of the clock pulse, V_t is on, and the reset switch S_1 is off, V_g equals to V_1, the integrator starts to operate, $-V_{int}$ is increased. While $-V_{int} = -V_{ref}$, the output of the comparator becomes high, the R-S trigger is reset, $Q = 0$, $\bar{Q} = 1$, V_t is off, the reset switch S_1 turns to be on, $-V_{int}$ and V_g equal to 0 until the next period. The function of the circuit can be generalized as

$$V_o = \bar{V}_g = \frac{1}{T_s}\int_0^{T_s} v_g(t)\,dt = \frac{1}{T_s}\int_0^{T_{on}} v_{dc}\,dt \qquad (1)$$

$$-V_{int} = \frac{1}{C_{int}}\int_0^{T_{on}} \frac{v_{dc}}{R_1}\,dt = -V_{ref} \qquad (2)$$

$$V_o = \bar{V}_g = -\frac{R_1 C_{int}}{T_s} V_{ref} \qquad (3)$$

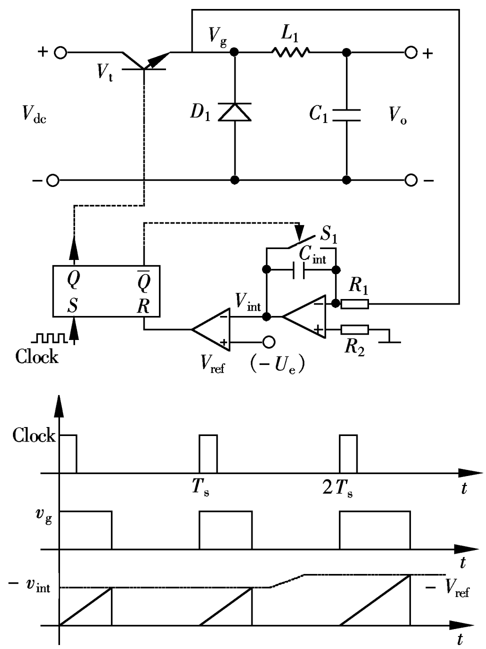

Fig.4 Principle of the Buck circuit adopting one-circle-control scheme

The advantages of the one-circle-control Buck circuit include that the output is linear with the reference, and is not relative with input voltage; the dynamic response is fast; anti-disturbance character is high; the nonlinear control is achieved and the system is robust.

2 Parameters Design

2.1 Design of the filter inductor L_f

The value of L_f is affected by input voltage V_{dc} and output voltage $|V_o|$. The ripple current on L_f is caused by V_{dc}. When the circuit is working at the worst condition, $D = 0.5$, the ripple current is maximum. So

$$\frac{4}{\sqrt{2\pi}}\frac{V_{dc}}{2} = 2\pi f_{sw} L_f I_{lripmax} \qquad (4)$$

$$L_f \geqslant \frac{4}{\sqrt{2\pi}}\frac{V_{dc}}{2}\Big/(2\pi f_{sw} I_{lripmax}) \qquad (5)$$

2.2 Design of the filter capacitor C_f

If the load ripple current is ignored, the ripple current of the filter inductor is flowed into C_f entirely. The ripple voltage V_{crip} of the capacitor is

$$V_{cripmax} = \frac{I_{cripmax}}{2\pi f_{sw} C_f} \qquad (6)$$

$$C_f \geqslant \frac{I_{lripmax}}{2\pi f_{sw} V_{cripmax}} \qquad (7)$$

2.3 The power of the Boost converter

At the condition of rated capacitive ($\cos\phi = -0.75$) load, the energy feedback is the most serious. The voltage and current on the load at this condition are shown in Fig.5.

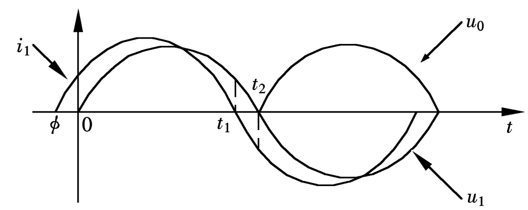

Fig.5 Voltage and current at lead load

When $t = t_1$ to t_2, load energy is fed back, the Boost circuit operates and extracts the energy from C_f. So

$$P_r = 2f_o(W_{cf} + W_{fb}) \qquad (8)$$

$$W_{cf} = \frac{1}{2}C_f\left(\sqrt{2}U_o\sin(\pi-\phi)\right)^2 \qquad (9)$$

$$W_{fb} = \int_{t_1}^{t_2} u_1 i_1\,dt = \int_{(\pi-\phi)/\omega_0}^{\pi/\omega_0} U_1 I_1 \cdot (\cos\phi - \cos(2\omega_0 t - \phi))\,dt \qquad (10)$$

where P_r is the design power of the Boost converter; W_{cf} is the storage energy of the capacitor; W_{fb} is the feed back energy.

3 Simulation Results and Analysis

As an example, one 300?V DC input and 500?V·A 115?V/400?Hz AC output inverter is developed using the presented circuit. The switching frequency of the DC converter is selected as 100 kHz; the circuit parameters are L_f = 1?mH, C_f = 2?μF and L_2 = 0.1?mH. The simulation is achieved by using the PSpice software.

Fig.6 – Fig.9 are the simulation waveforms of no load, rated resistive load, reactive and capacitive load, respectively.

From the simulation results, we can know that the output voltage waveforms are perfect, and the distortion of voltage takes place near the zero line. The distortion is that the result of the excessive energy on C_f cannot be released timely. We also can know from the figures that the operation time of the Boost converter is largest when the load is empty. That means the most energy is

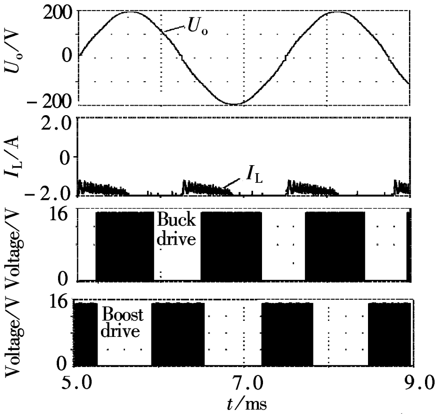

Fig. 6 Voltage waveforms at no load condition. (From up to down, they are the output voltage, the current of L_f, the drive signal of the Buck transistor and the drive signal of the Boost transistor)

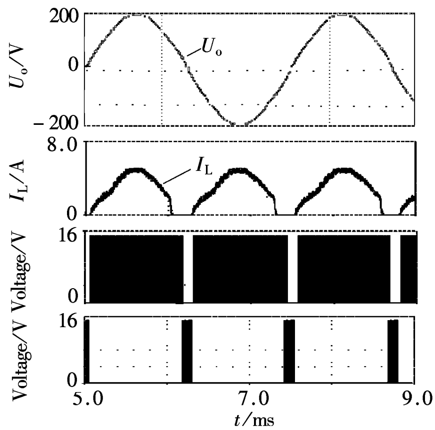

Fig. 7 Waveforms at rated resistive load

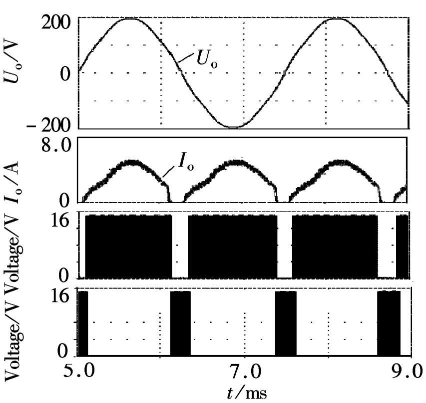

Fig. 8 Waveforms at rated lag load($\cos\phi = 0.75$)

extracted from C_f to source. And the operation time of the Boost converter is longer when the load is inductive or capacitive and is shorter when the load is resistive. So when the inverter is at no load condition, the distortion is most serious.

4 Experimental Results

With the parameters of f_{sw} = 100?kHz, L_f = 1?mH, C_f = 2?μF, L_2 = 0.1?mH, an inverter based on

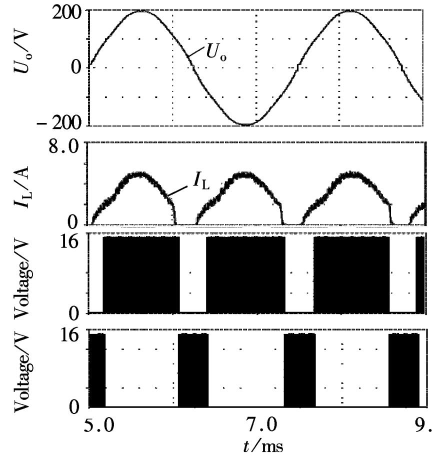

Fig. 9 Waveforms at rated lead load ($\cos\phi = -0.75$)

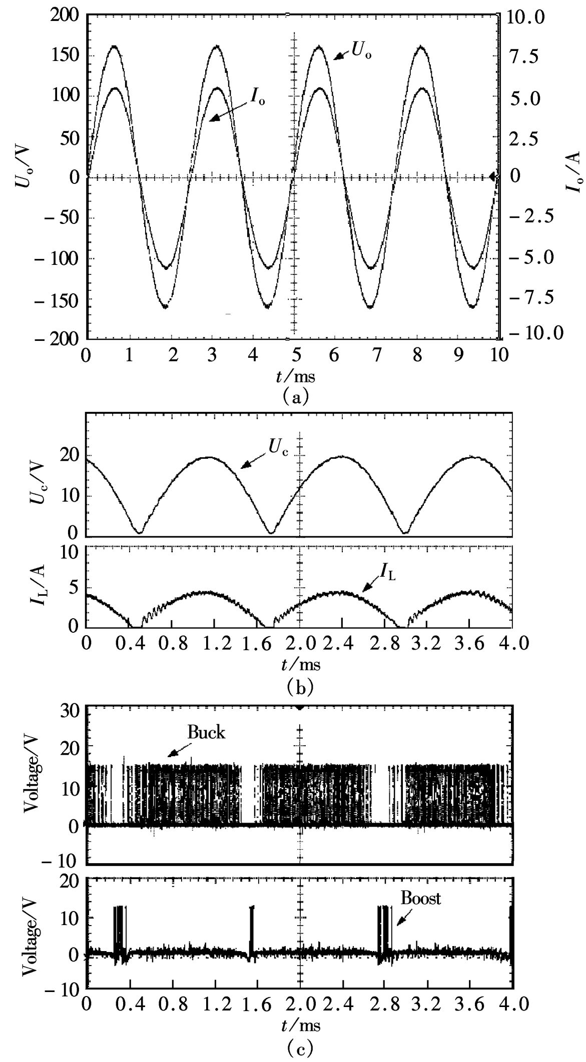

Fig. 10 Waveforms at rated resistive load. (a) Output voltage (THD = 1.45%) and current; (b) Voltage of C_f and current of L_f; (c) Drive signals of switches

DC/DC converter topology with 300?V DC input and 500?V · A 115?V/400?Hz output has been developed. The experimental results are shown in Fig.10 – Fig.12.

The practical output of the inverter is perfect and

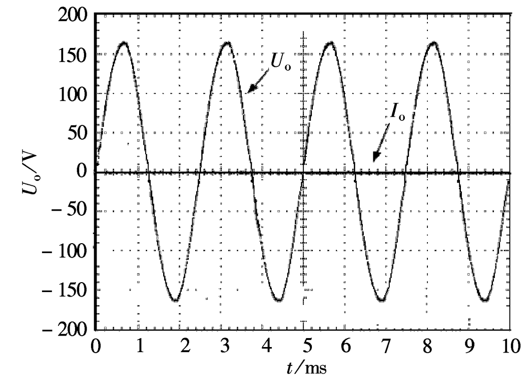

Fig.11 Waveforms of output voltage (THD = 1.92%) and current at no load

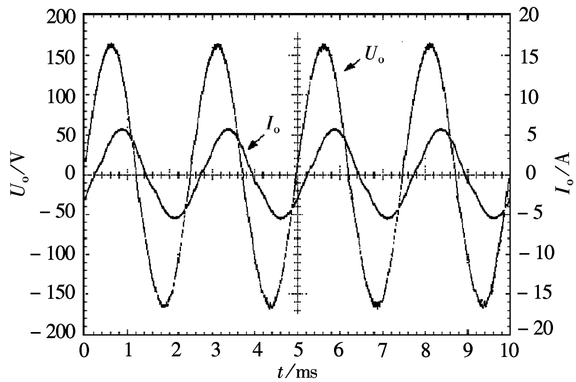

Fig.12 Waveforms of output voltage (THD = 1.84%) and current at rated lag load

the experimental results are accordance with the simulation results. The total harmonic contents (THD) of the output voltages under all conditions are less than 2%.

5 Conclusion

A novel inverter based on the DC/DC converter is presented and studied in this paper. The inverter is consisted of two power stages. The front stage converter amplify the signal in the absolute value mode. The converter has no risk of conduction straightway, so high switching frequency and nonlinear control scheme can be used. It can achieve fast dynamic response. The second stage converter is a bridge circuit. Because the voltage applied to the bridge is zero when the power devices are switching, the devices have achieved ZVS and low frequency operation, so the switch losses are very low. The simulation and experimental results demonstrate that the novel inverter has high performance, especially the advantages of fast response, good output linearity and high reliability and high efficiency.

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一种基于 DC/DC 变换器拓扑的逆变器研究

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摘　要　本文针对传统的逆变器存在功率管直通和难以实现软开关的缺点,提出了一种新颖的基于 DC/DC 变换器拓扑的逆变器.该逆变器由一个组合的 Buck/Boost 直直变换器和一个桥式电路构成,前级变换器输出可变的直流电压,后级电路将直流电压转换为交流输出.该逆变器可以实现逆变桥功率管的软开关.由于采用了能量反馈和单周期控制技术,变换器具有良好的动态性能.本文对该变换器的电路拓扑和控制原理进行了详细分析.电路仿真及样机实验结果表明该逆变器具有良好的性能.

关键词　逆变器，DC/DC 变换器，脉宽调制，单周期控制，软开关

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