Novel forward mode AC/AC converters with high frequency link

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Abstract: A circuit configuration and a circuit topologic family of the novel forward mode AC/AC converters with high frequency link are presented. The circuit configuration is constituted of input cycloconverter, high frequency transformer, output cycloconverter, input and output filters. The circuit topologic family includes eight circuit topologies, such as full-bridge-full-wave mode, etc. The bi-polarity phase-shifted control strategy and steady principles are thoroughly investigated. The output characteristics are obtained. By using the bi-polarity phase-shifted control strategy with phase-shifted control between the output cycloconveter and the input cycloconverter, commutation overlap period of the output cycloconverter, and polarity selection of the output filtering inductance current and the input voltage, the leakage inductance energy and the output filtering inductance current are naturally commutated, and surge voltage and surge current of the cycloconverters are overcome. The converters have such advantages as simple topology, two-stage power conversions(LFAC/HFAC/LFAC), bi-directional power flow, high frequency electrical isolation, good output waveforms, and strong ability to stabilize voltage. The converters lay key technical foundation on a new-type of regulated sinusoidal AC power supplies and electronic transformers. The correction and advancement of the converters are well verified by a principle test.

Key words: forward mode; high frequency link; AC/AC converter; bi-polarity phase-shifted control; cycloconverter

The high frequency link DC/DC converters[1], the high frequency link AC/DC converters[2], and the high-frequency link DC/AC inverters[3] have been deeply investigated and well known. However, the study on AC/AC converters has been mainly limited to the thyristor phase-controlled cycloconverters[4] and the matrix converters[5]. So far, only a push-pull-full-wave mode AC/AC converter with high frequency electrical isolation has been presented[6]. In Ref.[6], the simple operational principle and test results are given, but surge voltage and surge current of the cycloconverters are not investigated, and the push-pull-full-wave mode AC/AC converter is only suitable for low input voltage and low output voltage.

This paper presents and thoroughly investigates a family of the bi-polarity phase-shifted controlled forward mode AC/AC converters with high frequency link. The converters lay key technical foundation on a new-type of regulated sinusoidal AC power supplies and electronic transformers. The steady principles are thoroughly investigated and the output characteristics curve is obtained. A principle test is provided to verify the correction and advancement of the converters.

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1 Circuit Topologic Family and Control Strategy

1.1 Circuit configuration and circuit topology family

The circuit configuration of the converters comprises constituted an input cycloconverter, high frequency transformer, output cycloconverter, input and output filters. The circuit topologic family includes eight circuit topologies, such as single forward mode, interleaved-forward mode, push-pull-full-wave mode, push-pull-full-bridge mode, half-bridge-full-wave mode, half-bridge-full-bridge mode, full-bridge-full-wave mode, and full-bridge-full-bridge mode, etc. The full-bridge-full-wave mode and the half-bridge-full-wave mode circuit topologies are shown in Fig.1.

1.2 Bi-polarity phase-shifted control strategy

The bi-polarity phase-shifted control principle of the full-bridge-full-wave mode circuit topology is shown in Fig.2. There is a phase difference θ ($\theta = 0-180°$) between the output and the input cycloconverters. As θ varies sinusoidally and the voltage across the output filter u_{AB} is a bi-polarity SPWM voltage, the control strategy is called bi-polarity phase-shifted control strategy. By controlling θ, the output voltage u_o can be

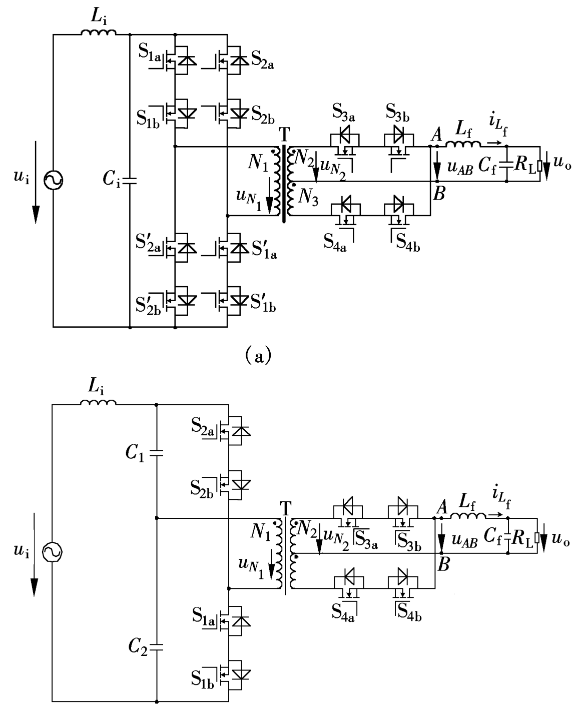

Fig.1 The full-bridge-full-wave mode and the half-bridge-full-wave mode circuit topologies. (a) Full-bridge-full-wave mode; (b) Half-bridge-full-wave mode

kept stable when the input voltage u_i or the load R_L varies.

The common conduction time T_{com} while the power switches $S_{3a}(S_{3b})$ and $S_{1a}(S_{1b})$, $S_{4a}(S_{4b})$ and $S_{2a}(S_{2b})$ are both on during one switching period T_s is

$$T_{com} = \frac{T_s(180° - \theta)}{2 \times 180°} \tag{1}$$

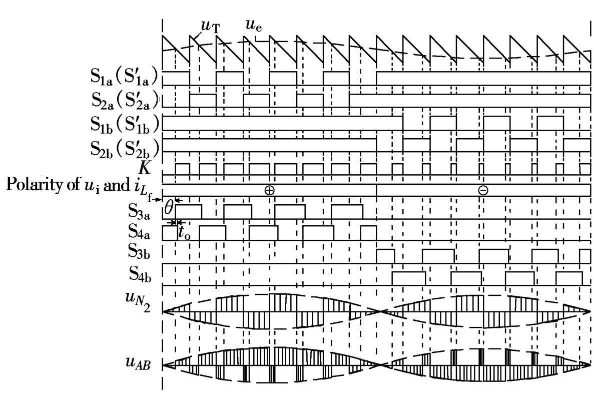

Fig.2 The bi-polarity phase-shifted control principle

By using a phase-shifted control between the output cycloconveter and the input cycloconverter, a commutation overlap period t_o of the output cycloconverter, and polarity selection of the output filtering inductance current i_{L_f} and the input voltage u_i, the bi-polarity phase-shifted control strategy has the following advantages: the leakage inductance energy and the output filtering inductance current are naturally commutated, and surge voltage and surge current of the cycloconverters are overcome.

2 Steady Principle and Output Characteristics

Take the full-bridge-full-wave mode converter in CCM during one T_s as an example. When the power switches S_{1a}, S_{1b}, S'_{1a}, S'_{1b}, S_{3a} and S_{3b} are on, or S_{2a}, S_{2b}, S'_{2a}, S'_{2b}, S_{4a} and S_{4b} are on, the voltage across the output filter $u_{AB} = u_i N_2/N_1$. When S_{2a}, S_{2b}, S'_{2a}, S'_{2b}, S_{3a} and S_{3b} are on, or S_{1a}, S_{1b}, S'_{1a}, S'_{1b}, S_{4a} and S_{4b} are on, $u_{AB} = -u_i N_2/N_1$. The switching state equivalent circuits are shown in Fig.3, where r includes the equivalent resistance of the transformer, the on-resistance of the power switches and the parasitic resistance of the filtering inductance and so on.

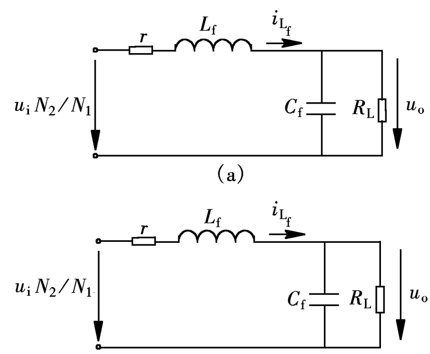

Fig.3 The switching state equivalent circuits in CCM during one T_s. (a) $u_{AB} = u_i N_2/N_1$; (b) $u_{AB} = -u_i N_2/N_1$

From the switching state equivalent circuits, the state-space averaging method is used to get output characteristics. The output characteristics in actual state ($r \neq 0$) and CCM are

$$U_o = \frac{U_i(2D-1)N_2}{N_1} \frac{1}{1+\frac{r}{R_L}} \tag{2}$$

where D is the duty cycle of the SPWM voltage across the output filter during one T_s, i.e. $D = 2T_{com}/T_s = (180° - \theta)/180°$ $(0 < D < 1)$. From Eq.(2), the output characteristics in ideal state ($r = 0$) and CCM are

$$U_o = \frac{U_i N_2(2D-1)}{N_1} \tag{3}$$

Similarly, output characteristics in ideal state ($r = 0$) and critically CCM are

$$I_o = 4I_{omax}D(1-D) \tag{4}$$

and output characteristics in ideal state ($r = 0$) and DCM are

$$\frac{U_o}{U_i} = \frac{4D^2 - \dfrac{I_o}{I_{omax}}}{4D^2 + \dfrac{I_o}{I_{omax}}} \frac{N_2}{N_1} \tag{5}$$

In Eqs.(4) and (5), I_o is the load current, and I_{omax} is the maximum value of I_o.

From Eqs.(2) - (5), normalized output characteristics of the AC/AC converter are shown in Fig.4.

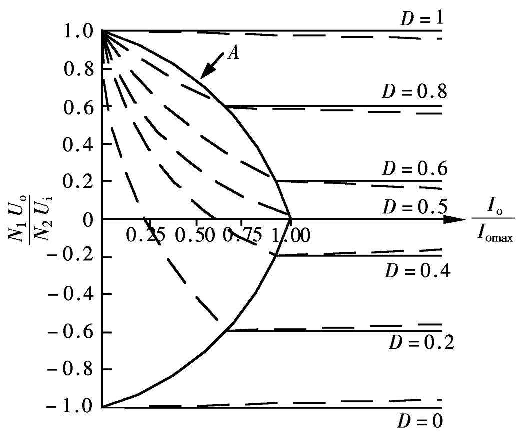

Fig.4 Normalized output characteristics of the AC/AC converter

3 Principle Test

The designed example: the half-bridge-full-wave mode circuit topology, the bi-polarity phase-shifted control strategy, the AC input voltage U_i = (220 ± 10%) V (50 Hz), the AC output voltage U_o = 110 V (50 Hz), the switching frequency F_s = 50 kHz, the turn ratio of the transformer $N_1 : N_2 : N_3$ = 14 : 18 : 18, the input filtering inductance L_i = 10 μH, the input capacitance C_1 = 50 μF, C_2 = 50 μF, the output filtering inductance L_f = 0.5 mH, the output filtering capacitance C_f = 20 μF.

Fig.5 shows principle test waveforms of the AC/AC converter. Principle test results agree well with theoretical analyses.

4 Conclusions

From the discussions presented above, the following conclusions are obtained.

1) The circuit configuration of the forward mode AC/AC converters comprises input cycloconverter, high frequency transformer, output cycloconverter, input and output filters. The circuit topologic family includes eight circuit topologies, such as full-bridge-full-wave mode, etc.

2) The converters have such advantages as simple topology, two-stage power conversions(LFAC/HFAC/LFAC), bi-directional power flow, high frequency

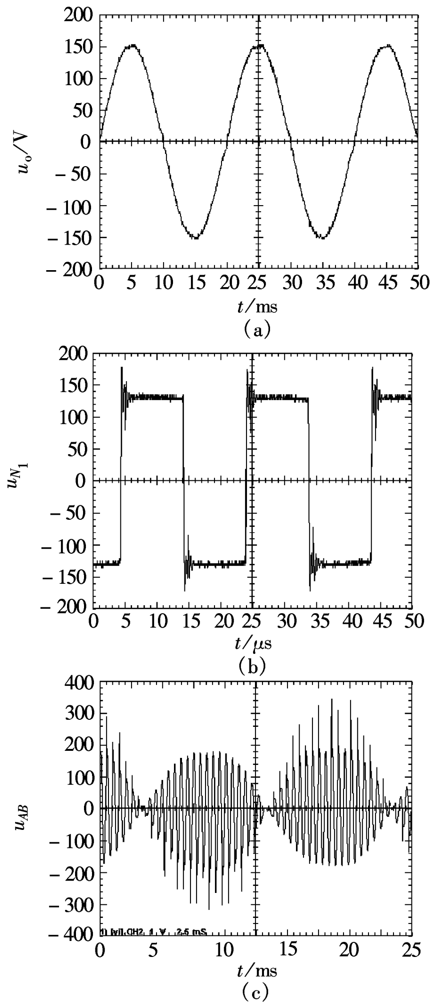

Fig.5 Principle test waveforms. (a) Output voltage u_o; (b) Voltage across transformer's primary winding u_{N_1}; (c) Voltage across output filter u_{AB}

electrical isolation, good output waveforms, and strong ability to stabilize voltage.

3) By using the bi-polarity phase-shifted control strategy, the leakage inductance energy and the output filtering inductance current are naturally commutated, and the surge voltage and surge current of the cycloconverters are overcome.

4) The principle test well verifies the correction and advancement of the converters.

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新颖的正激式高频环节交-交变换器

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摘　要　提出新颖的正激式高频环节交-交变换器电路结构和电路拓扑族,这类电路结构由输入周波变换器、高频变压器、输出周波变换器以及输入、输出滤波器构成,电路拓扑族包括全桥全波式等8种电路.深入研究了这类变换器的双极性移相控制策略和稳态原理,获得了外特性曲线.采用具有输出周波变换器与输入周波变换器之间移相、输出周波变换器换流重叠、输出滤波电感电流和输入电压极性选择的双极性移相控制策略,这类交-交变换器的周波变换器上的尖峰电压和环流得到抑制.这类变换器具有电路拓扑简洁、两级功率变换(低频交流/高频交流/低频交流)、双向功率流、高频电气隔离、输出波形质量好和稳压能力强等优点,为实现新型的正弦交流稳压器和电子变压器奠定了关键技术基础.原理试验很好地证实了这类变换器的正确性和先进性.

关键词　正激式; 高频环节; 交-交变换器; 双极性移相控制; 周波变换器

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