창 립
40주년학술대회
논문 87-A-20-1

RECENT DEVELOPMENT OF DC-TO-AC CONVERTERS FOR SMALL UPS SYSTEMS

Koosuke Harada, Hiroshi Sakamoto, and Masahito Shoyama

Kyushu University, Japan

Abstract

A novel type of the sinusoidal dc-to-ac converter is presented, where a pair of switches is placed in each side of the primary and the secondary of the isolation transformer. This converter is controlled by the phase difference between the two pairs of switches. As a result, the transformer is miniaturized by making the switching frequency high and the reactive energy can be easily recovered to the dc-source. This converter is especially suitable for small UPS systems.

1. Introduction

For the recent electronic equipments including computers, actuators etc., an interruption of the power source will cause a serious damage to the system. And so an uninterruptible power supply (UPS) is requested to be inserted between the commercial power line and the electronic equipment. The market of UPS has been greatly increased in accordance with the spreads of the field of electronics. A number of types of UPS have been developed for various applications. Among them, a small UPS less than several KVA is required for micro-computers and other electronic devices concerning office and home automations. For these applications, UPS should be especially of small size and low cost. In any type, dc-to-ac converter plays a key role for determining the size of the UPS. We will discuss in this paper the difficulties of the size reduction in dc-to-ac converters and present a new circuit as a solution of these problems.

2. Size Reduction in DC-to-AC Converters

In order to reduce the size of the dc-to-ac converter, the PWM process with semiconductor switches will be most suitable. The basic circuit is shown in Fig.1. In this circuit, the size of the L-C filter becomes small enough by increasing the switching frequency and the transient response becomes quicker due to miniaturized L-C filter. However, the size of the isolation transformer connected to the output is almost independent of the switching frequency, because the flux change in the transformer is mainly determined by the modulation signal of the commercial ac-line frequency of 50-60Hz. Therefore the high frequency switching in the converter does not contribute to reduce the size of the transformer.

Fig.2 shows the case where the isolation is made in the dc-to-dc converter followed by the PWM inverter. The isolation transformer can be miniaturized by increasing the switching frequency. However, two control circuits with different switching process are necessary and the loss may become large due to the cascade connection of the two high frequency switching power stages. Further the reactive energy cannot be recovered to the dc-supply through the dc-to-dc converter.

In order to solve these problems, we present a novel type of dc-to-ac converter suitable for small UPS, where the isolation transformer is extremely miniaturized by the high frequency switching. The power can flow bidirectionally through this converter. The operation of this converter and its applications to UPS are shown in the following.

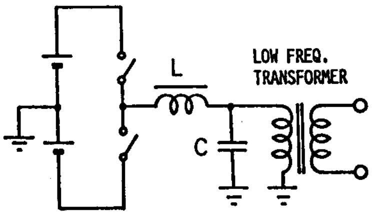


Fig.1 Conventional PWM DC-AC converter.

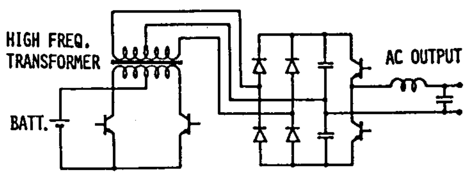


Fig.2 PWM inverter preceded by dc-to-dc converter for isolation.

3. Basic Principle of the New Circuit [1]

The basic circuit of the new dc-to-ac converter is shown in Fig.3. Switch S1 and S2 in the primary side of the transformer repeat ON and OFF alternately with 50% duty ratio as shown in Fig.4(a). Switches S3 and S4 in the secondary side also repeat ON and Off in the same way as those in the primary side as shown in Fig.4(b). However, the primary switches and the secondary switches operate with the phase difference DT. Where, D corresponds to the duty ratio of this converter. Fig.4(c) is the PWM voltage appeared at the point A of Fig.3. When D is changed sinusoidally, the sinusoidal voltage Eo appears at the output terminal by removing the high frequency components with L-C filter. In this circuit, the voltage across the transformer seen from the primary side or the secondary side are of rectangular waveform with the duty ratio 50%. Because the core flux being changed by high frequency carrier signal with period 2T, the size of the transformer is miniaturized.

The circuit operation is analyzed with the aid of the state space averaging method to derive the averaged equivalent circuit as shown in Fig.5. When the energy flows from the primary to the secondary of the transformer (normal flow mode), the circuit acts as a buck converter. On the other hand, when the energy flows from the secondary to the primary (reverse flow mode), the circuit acts as a boost converter. The equivalent turns ratio of the transformer is a function of the duty ratio D, which is controlled sinusoidally by the external signal (error signal). The power being able to flow bidirectionally through the equivalent dc transformer, the wattless power can be recovered to the primary source Ei for an inductive load. Fig.6 and Fig.7 show the calculated and experimental results of the voltage controlled by D. Fig.6 is for the normal flow mode, and Fig.7 is for the reverse flow mode. In the case of the reverse flow mode, the resistance R' is connected across the input terminal.

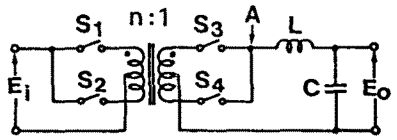


Fig.3 Basic circuit of new dc-to-ac converter.

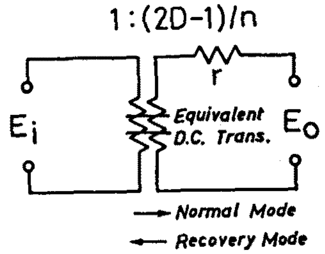


Fig.5 Averaged equivalent circuit.

4. Practical Circuit

Fig.8 shows the practical circuit of the dc-to-ac converter. A pair of MOS-FETs are used for the switches. In order to avoid the high voltage surge across the switching element due to the stored energy in the reactor, the time gap between on-times of the secondary switches should be zero. On the other hand, if the on-times

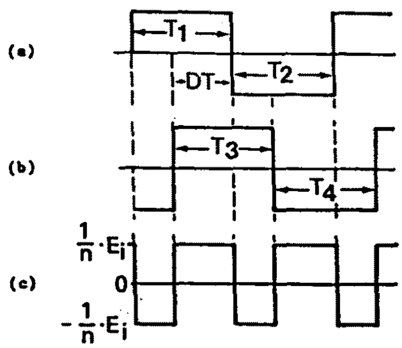


Fig.4 Switching sequence and PWM waveform.

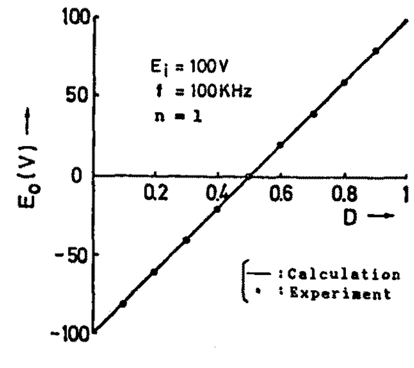


Fig.6 Eo vs. D for normal flow mode.

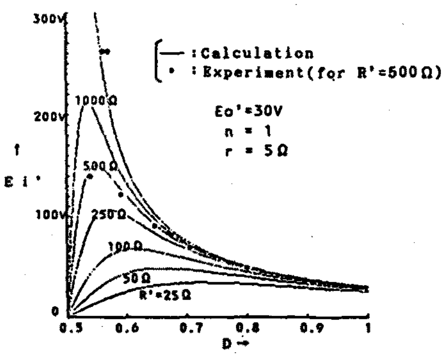
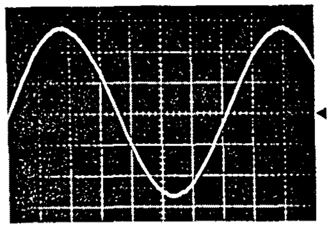


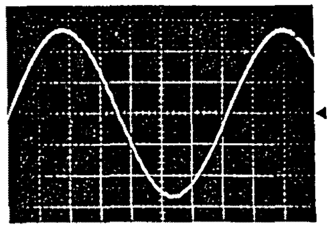
Fig.7 Ei' vs. D for reverse flow mode.

of the secondary switches overlap in the basic circuit shown in Fig.3, a short circuit current will pass through the switches S3 and S4. For blocking this rush current, the reactor L of the filter shown in Fig.3 is divided into L1 and L2 as shown in Fig.8. Small saturable cores SR1 and SR2 are used as a magnetic snubber to suppress the current surge due to excess charge in the diodes of D31, D32, D41, and D42. The signal to control the duty ratio D is produced in the control circuit. It consists of a phase shifter and a sinusoidal reference voltage generator. The phase shifter includes a high frequency oscillator and produces the switching signals for the MOS-FETs. The reference voltage Vref should have a sufficient accuracy in amplitude and be synchronized to the low-frequency commercial line.

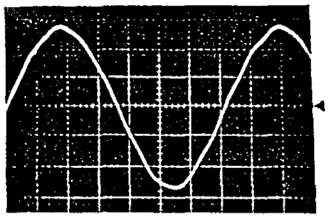
Fig.9 shows the oscillograms of the output voltage for three types of loads, when the output voltage is controlled to be sinusoidal waveform of 60Hz. Because the distortion in each waveform is very small, it is verified that this converter deals well with the wattless power. Fig.10 shows the oscillogram of the output voltage and the output current for a micro-computer load in which the full-wave rectifier followed by a capacitor-input filter is used. The output voltage is kept to change sinusoidally while the load current pulsating. Fig.11 shows the efficiency vs. the transferred power, where (a) is for the normal flow mode and (b) is for the reverse flow mode. The high efficiency of about 85% are obtained for the normal flow mode with the switching frequency of 100kHz.



(a) Resistive load of 100Ω.



(b) Inductive load of 0.1H.



(c) Capacitive load of 50μF.

Fig.9 Oscillogram of the output voltage. (50V/div, 20ms/div)

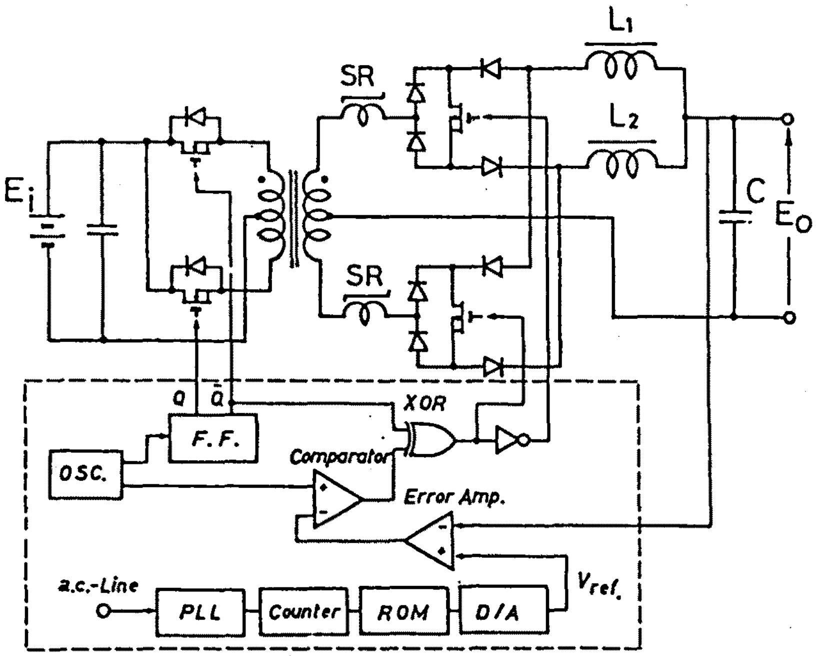


Fig.8 Practical circuit.

5. Applications to UPS

When this converter is used for the UPS, the battery charger can be removed by making use of the reverse flow mode. We show in Fig.12 and Fig.13 the UPS systems where this converter is used for a stand-by element.

Fig.12 is the case of interconnecting the commercial ac line and this converter with a set of thyristors. This system is very simple and constructed in small size. However, when the ac line voltage is lower than that of the converter, the battery can not be charged from the ac line. For charging the battery in this case, the reference voltage should be made lower for conducting thyristors, which sacrifice the accuracy of the regulation as the UPS system.

Fig.13 is the case of inserting a reactor between the ac commercial line and the output of the converter. When the voltage of the commercial ac line is lower than that of the converter, the battery is charged by making the phase angle of the reference ac voltage lag behind that of the ac commercial line. Inversely, if the voltage of the commercial ac line is higher than that of the converter, and if we wish to prevent the inverse power flow from the ac output to the battery, the phase angle of the reference voltage should be lead from the ac commercial line. Therefore, the output ac voltage is well regulated to give a precise ac-voltage. However, the reactor for the interconnection should be designed for the low-commercial frequency. Hence the size reduction of the reactor may not be expected.

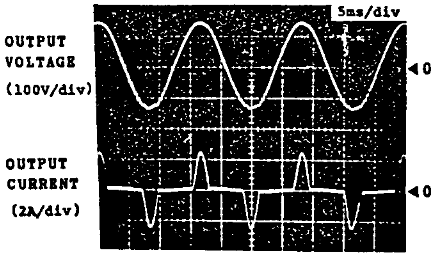
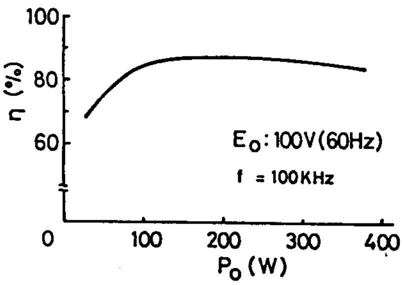
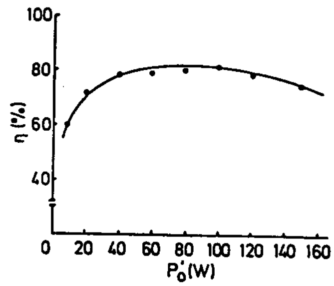


Fig.10 Oscillogram for micro-computer load.



(a) Normal flow mode.



(b) Reverse flow mode.

Fig.11 Efficiency vs. transferred power.

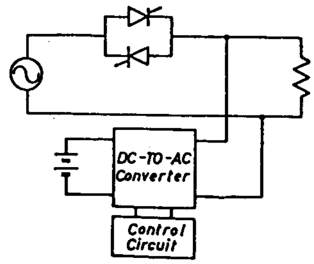


Fig.12 Interconnection with ac line using thyristor.

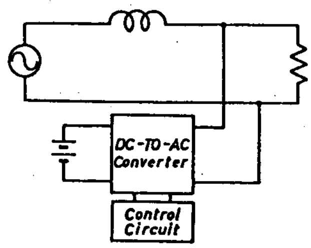


Fig.13 Interconnection with ac line using reactor.

6. Conclusions

About the novel type of the dc-to-ac converter the followings are clarified. The isolation transformer is extremely miniaturized by the high frequency switching. The power can flow bidirectionally through the converter. Therefore the reactive power is well recovered to the dc-source. The current surge due to the commutation of the secondary switches is removed by dividing the reactor for filtering into two separate ones. By making use of this converter, a small and simple UPS system is constructed, where the battery is charged directly through the converter.

Reference

[1] K.Harada, H.Sakamoto and M.Shoyama, "Phase Controlled DC-AC converter with High Frequency Switching," IEEE PESC Record, pp.13-19, 1987.