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A Novel Circuit Configuration of UPS with Auxiliary Inverter and Its Specific Control Implementations

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ABSTRACT

The rapid expansion of small computers over the last 10-odd years has brought about great changes in the circumstances affecting UPSs. There are strong demands that UPSs become much smaller and lighter, and more economical, which has resulted in the wide application of the circuit topology without transformer A disadvantage of such UPS topology is that the DC link voltage is very high, which invites decreased reliability and increased cost of battery bank Some circuit configurations were proposed to eliminate this disadvantage, but they still had problems In this paper, a novel circuit configuration which eliminates these problems is proposed and evaluated by the experimental results of prototype UPS.

Keywords: UPS, Without transformer, Half-bridge Inverter, PFC converter

1. Introduction

Nowadays, rapid growth in the use of computers and its systems has brought great changes to the circumstances of UPS (Uninterruptible Power Supply) Although UPS was originally a typical kind of industrial electrical equipment, in the last few years they are increasingly used as a peripheral device for small computers. For that reason, UPS has been strongly demanded to become smaller, lighter, and more economical To be economical, UPS must not only be cheaper but also have high efficiency

Major changes have come about in UPS circuit topologies in response to these demands Over the last 10-odd years the dominant circuit configurations in on-line UPSs have changed from the topology with low-frequency transformer to with high-frequency transformer and to without transformer[1][2] These changes led to substantially better UPS economy, and also made them far smaller and lighter[3][4] Nowadays the topologies without transformer are most popular for on-line UPS[5][6] In this paper a novel on-line UPS topology without transformer and its specific control strategy are presented and evaluated on the basis of experimental results

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2. Conventional Circuit Configuration

Fig. 1 shows the basic circuit configuration of the UPS without transformer It combines a half-bridge, PFC (Power Factor Correction) converter composed of T1, T2 and L1, and a half-bridge inverter comprising T3, T4, and L2[7][8]. In this configuration, the input S phase and the output V phase have the same potential, which makes it possible to eliminate the transformer because the voltage potential of load is stable[9].

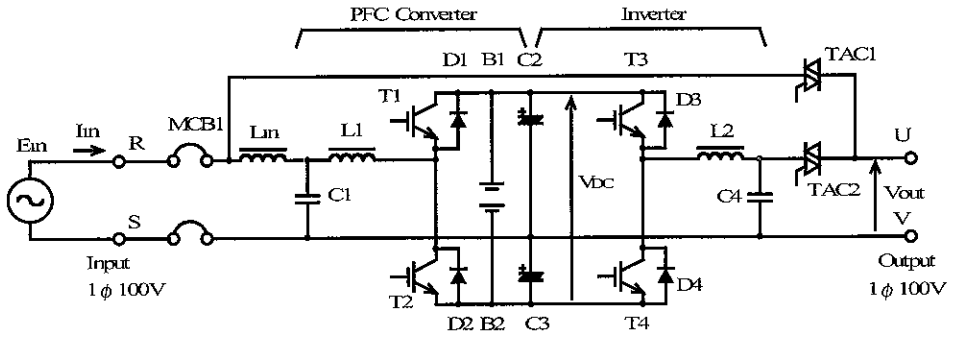


Fig 1 Basic circuit configuration of on-line UPS without transformer

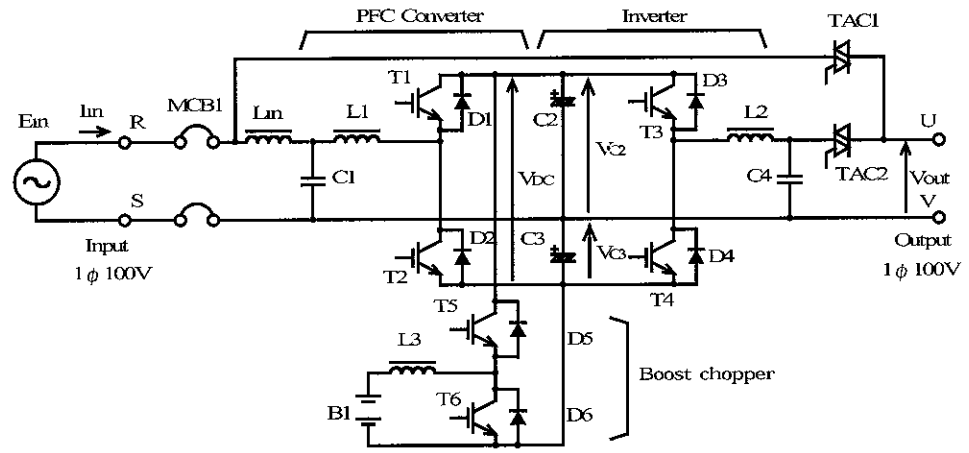


Fig 2 Conventional circuit configuration of on-line UPS with boost chopper

Because the circuit configuration of Fig. 1 needs no transformer, it is not only much smaller, lighter, and more economical, it is also easy to achieve high efficiency But because this circuit topology employs a half-bridge inverter, it needs a high voltage of about 340 V for DC link voltage VDC in order to obtain the output voltage of 100V This necessitates connecting a very large number of small capacity battery cells in series, which invites decreased reliability and increased cost.

Fig 2 shows the circuit topology which is proposed by the authors previously to overcome these problems[9] To the basic circuit in Fig 1 it adds a chopper circuit comprising T5, T6, and L3, which boosts the voltage of battery B1 and supplies it to DC link voltage VDC. This makes it possible to keep battery voltage low, thereby ensuring the reliability and low cost of the battery B1 However, this circuit topology requires the addition of two switching elements and the inductor L3, which made it less economical especially because inductor is expensive Additionally, chopper circuit have no capability to balance the high-voltage side (VC2) and low-voltage side (VC3) of its output voltage For example, if a half-wave rectification circuit is connected to the load, the unbalance between VC2 and VC3 will increase and prevent the generation of a normal output voltage of inverter

3. Proposed Circuit Configuration

In order to improve the problem mentioned above, a novel circuit configuration with an auxiliary inverter shown in Fig 3 is proposed Battery bank is connected to the AC input side through a simple auxiliary inverter which operates at a commercial frequency

When receiving commercial power, T5-T8 are off and battery bank B1 is disconnected from the UPS circuit. When a power failure is detected, TAC1 is instantaneously turned off and the UPS circuit is disconnected from the commercial power grid At the same time, auxiliary inverter starts the operation.

T5 and T8 turn on and off simultaneously. T6 and T7 are also switched simultaneously T5/T8 and T6/T7 are turned on and off alternately As a result, battery voltage is changed to the square-wave AC voltage of the commercial power frequency and supplied to the PFC converter circuit, which receives this square-wave AC voltage and continues the operation in the same way as when using commercial power

In this circuit configuration, the voltage of battery bank is boosted by the PFC converter and supplied to the inverter It means that the battery bank with low voltage can provide the power to the inverter which needs the high input voltage of 340V The battery bank whose rated voltage is 96V have been adopted to the 1kVA UPS prototype

PFC converter has two active switches of T1 and T2 By controlling the duty ratio of T1 and T2 respectively, PFC converter output voltage VC2 and VC3 are controlled individually It means that the proposed circuit configuration can keep the voltage balance of VC2 and VC3, and overcomes the disadvantage of conventional circuit

4. Control Implementation of the PFC Converter

The PFC converter circuit shown in Fig 3 is regulated through the current-mode control circuit shown in Fig 4 so as to obtain an unity power factor and a sinewave line current shaping effects The current of reactor L1 is compared to a reference wave of the same phase as commercial power, and amplified Its error signal Ver is modulated with a 40 kHz triangular wave, and the PWM signal that drives transistors T1 and T2 is obtained In this way, the current wave form of reactor L1 becomes equal to the reference wave Input current of PFC converter has the same phase as AC input voltage and a sinusoidal waveform with no distortion, because reference wave is a sinewave The offset voltage of the reference wave is controlled so as to keep the voltage balance of VC2 and VC3

The control circuit operates in the same manner whether commercial power is available or not, so even though the input voltage waveform of the PFC converter is square, its input current waveform is a sinusoidal With the minimum AC input voltage of 90V, the input current of the UPS is 10 6Arms which means 15.0Apeak At power failure, as mentioned above, input power of the PFC converter is supplied by the battery bank through the auxiliary inverter Battery bank is consist of 48 cells of read acid batteries and the rated voltage of the battery bank is 96V and

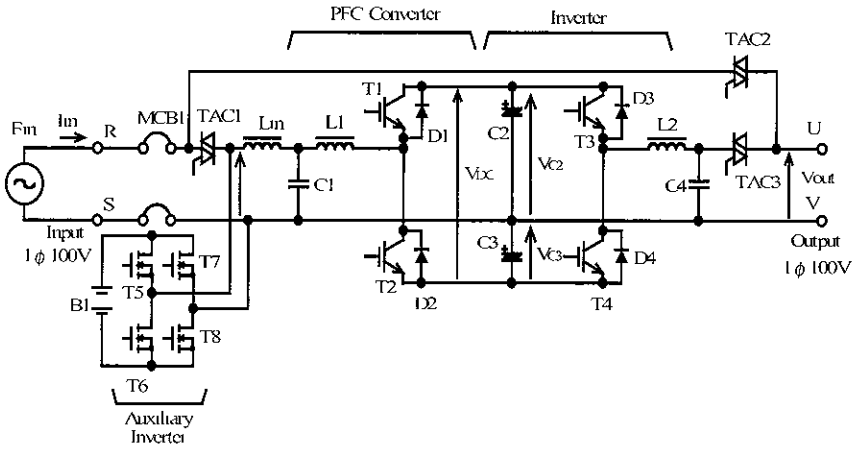


Fig 3 Proposed circuit configuration of on-line UPS with auxiliary inverter

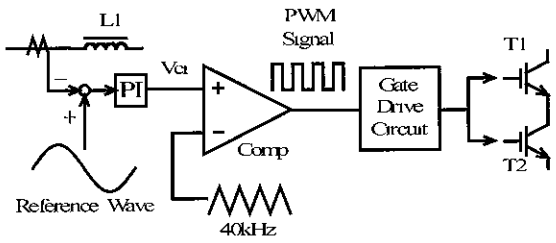


Fig 4 Control circuit block diagram of PFC converter

minimum voltage is 77V at the end of discharge period Consequently, the maximum input current of the PFC converter at power failure is calculated to be 12.4A by the following formula

Maximum input current
= 10 6Arms × 90V − 77V = 12 4Arms

The peak value of 12 4Arms is 17 5Apeak It means that the peak current of the inductor L1 at power failure is about 17% larger than that in normal operation and it brings the increase of size and cost of inductor L1

Because input current waveform must be shaped to be sinusoidal in normal operation, the current waveform of L1 must be changed into a sinusoidal waveform, but this restriction does not apply during power failure. The authors therefore developed a new control strategy in which, at power failure, the peak value of L1 current is suppressed by changing the reference wave provided by the microcomputer circuit into a trapezoidal wave as shown in Fig 5 The trapezoidal reference wave brings the trapezoidal current to L1 and the peak current of L1 is reduced to the value of 14 5A which is small enough to prevent the increase of size and cost of inductor L1

Fig 6 shows the current waveforms of inductor L1 It is shaped to the sinusoidal wave in normal operation and trapezoidal wave at power failure

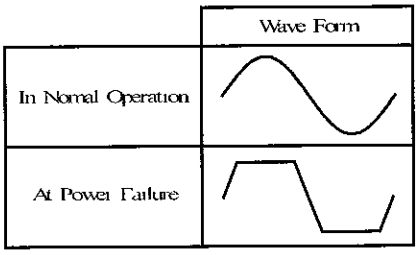
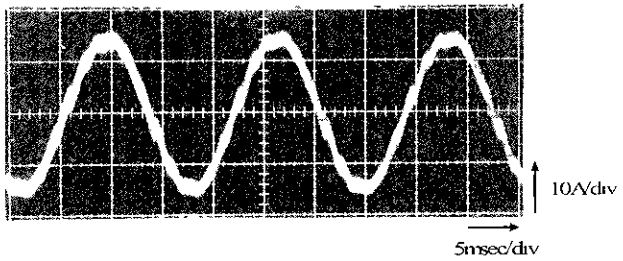
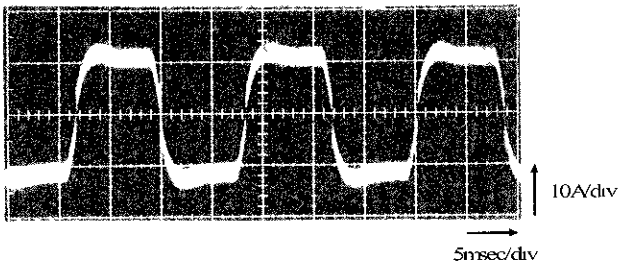


Fig 5 Reference Wave of Control Circuit of PFC Converter



(a) In normal operation



(b) At power failure

Fig 6 Current waveforms of inductor L1

5. General Description of the 1kVA UPS Prototype

1kVA UPS prototype incorporating the auxiliary inverter shown in Fig 3 is developed Fig. 7 shows the waveforms of the input voltage and input current of the developed 1kVA UPS. Input current is undistorted sine wave of the same phase as input voltage Fig 8 shows the output voltage and output current waveforms with a rectifier load As the figure shows, even if the current waveform is distorted with a large crest factor, the output voltage is a sine wave with little distortion

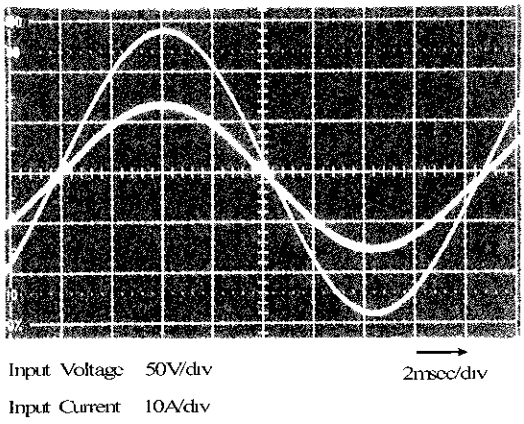


Fig 7 Waveforms of input voltage and current at rated input and output

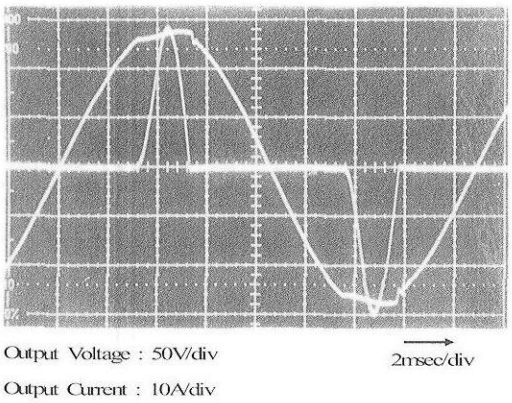


Fig. 8. Waveforms of output voltage and current at rectification load.

Table 1 shows the characteristics of the UPS. As shown in Fig. 7, input current is sine wave of the same phase as input voltage, so the input power factor is 99%, and input current distortion is 3%. Output voltage distortion is under 5% even with a rectifier load (non linear load). Because of the high efficiencies of 84.2% with the 1kVA UPS, a small cooling fan is sufficient, and acoustic noise is less than 40 phons.

Fig. 9 shows the photograph of the UPS. It is small and light: the volume and weight of the 1kVA UPS is 21.9 liters and 24 kg.

Table 1. Characteristics of the 1kVA UPS prototype.

Items	Characteristics
Input Voltage	1 ϕ 100V 50/60Hz
Input Power Factor	99%(at full load)
AC Input Current THD	3%(at full load)
Output Capacity	1kVA 800W
Output Voltage	1 ϕ 100V 50/60Hz
Voltage Accuracy	within $\pm$2%
Frequency Accuracy	within $\pm$0.5%
Output Voltage Distortion	1.8% (at linear load) 4.0% (at non linear load)*
AC/AC Efficiency	84.2% (at full load)
DC/AC Efficiency	82.2% (at full load)
Battery Type	Sealed Lead-Acid
Back up Time	7 minutes
Audible Noise	less than 40 dB
Dimensions	330W 190H 350L
Weight	24kg

* Full bridge rectification circuit with large smoothing capacitor is used for non linear load.

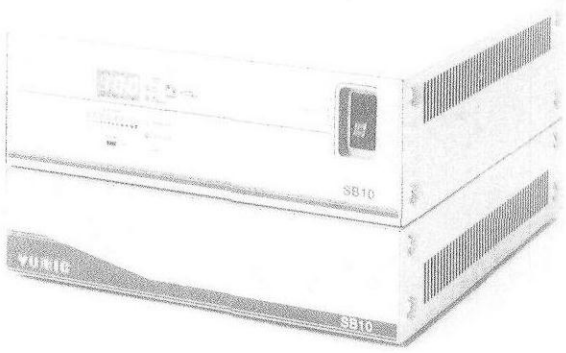


Fig. 9. Exterior overview of 1kVA UPS prototype.

6. Conclusion

The state-of-the art UPS incorporating simple half-bridge PFC converter and half-bridge PWM inverter circuits with no electrical isolation power stage has attracted special interest recently. However, this attractive UPS topology has significant disadvantage that storage batteries have to be connected to the high voltage DC link bus. The authors were able to overcome this shortcoming without any substantial cost increase by employing the circuit of auxiliary inverter. The 1kVA UPS prototype developed using the circuit configurations made it possible to achieve excellent performance including small size, light weight, high efficiency, high power factor and low distortion.

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