DESIGN OF A SWITCHING MODE POWER SUPPLY WITH UPS FEATURES

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Abstract

The proposed circuit integrates a flyback converter and a buck converter to provide a switch-mode power supply (SMPS) with uninterruptible power supply (UPS) features. It can accept a high voltage of main power input and a low voltage of backup battery input. It uses ONE PWM IC-controller for the normal and backup modes of operation so that it does not require a synchronization and a detection circuit for power failure. Therefore, the cost and circuit size will be reduced together. High efficiency can be obtained due to the use of a single DC-DC conversion topology from input to output over the conventional UPS. It can also provide full isolation among the high voltage main power input, the low voltage backup battery input and the voltage output. The prototype circuit was built, and the circuit operation and the experimental results of this converter are presented.

1. Introduction

Computer system has become very important all over the world. They are capable of doing complicated work such as calculation of mathematics, word processing. When the main power is failed, the computer system cannot support normal operation and shut down. As a result, all working data will be lost if they were not saved previously. Therefore, a UPS system is designed to protect data loss and prevent any output interruption after the main power input is failed suddenly.

Many UPS systems have been developed to include a conventional UPS and a uninterruptible SMPS. A conventional UPS [1] is often built with at least two converters. It provides standard AC output voltage either from the main power input or from the backup power input. Consequently, the size of the conventional UPS is often bulky because it consists of many converters in the UPS system. It also reduces the overall efficiency and increases the total cost of production.

Uninterruptible SMPS is designed to form high frequency UPS. They can use any SMPS topology with a high frequency operation to provide good performance and reduce size. Many high frequency UPS have been presented in [2] [3] [4] [5]. These designs have some limitation in the practical aspect such as narrow range between high input voltage and the low input voltage and [2], a synchronization required [3], a non-zero switch-over time and detection circuit required [4], more than one DC-DC conversion [5] and non-fully isolation. Based on these reviews, there is a need for a good performance of high frequency UPS. This high frequency UPS need to provide uninterruptible power supply within a single SMPS with the addition of the backup battery. It will have the following properties :

(1) Small size, Low cost and High efficiency ,
(2) Zero switch-over time from the main power failure to the backup battery 'ON',
(3) Use of ONE PWM IC-controller for switching component of both inputs, and
(4) Good isolation between the main power input and the backup power input .

2. Overview of the proposed UPS

This methodology mainly consists of a flyback converter, a buck converter and a special construction of isolation transformer. The isolation transformer is constructed with two different sets of winding arrangement to separate the main power input and backup battery input, so that the input range can be adjusted which is controlled from two different sets of winding arrangement. Therefore, this methodology allows the matching of the main power voltage and the backup battery voltage by careful adjustment of the transformer turns ratio. The block diagram of this methodology is shown in Fig. 1. This methodology will adopt a simpler topology (flyback) of SMPS than other topology (such as buck converter, boost converter, flyback converter, C'uk converter etc..). In addition, a PWM IC-controller with isolated feedback amplifier has been available to make an isolated closed-loop feedback control to provide a good performance (e.g. line and load regulation).

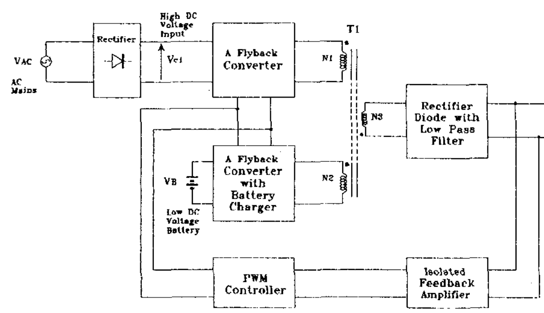

Fig. 1 Block diagram of proposed UPS

As show in Fig. 2, this proposed UPS circuit mainly uses two flyback converters and a buck converter providing following features :

a. A built-in UPS features in Switching Mode Power Supply (SMPS)
b. An Isolated Closed-loop Feedback Circuit
c. Use of ONE PWM IC-controller for switching component of both inputs
d. A nearly constant current battery charger

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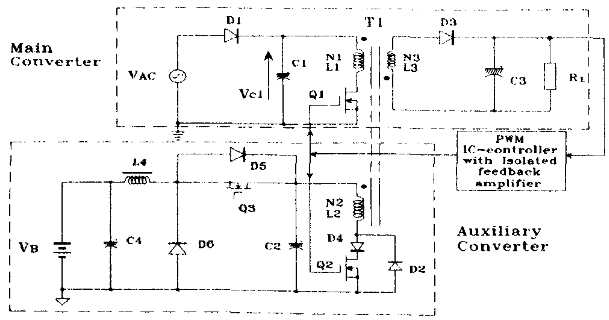


Fig. 2 Circuit of proposed UPS

3 Circuit Description

The proposed UPS can be divided into two independent circuit and shown in Fig. 2. Their grounds have been separated into a ground of earth and a common ground of circuit. Due to the separated grounds, the proposed UPS can achieve full isolation between the main power input (V_{AC}), the rechargeable backup battery input (V_B) and an output on the load. The two independent circuits are the main converter and the auxiliary converter. The main converter adopts a flyback converter. The auxiliary converter consists of a flyback converter and buck converter. Also, they operate in two different modes such as the "Normal Mode" and the "Backup Mode" of operation.

Mode Operation

The circuit diagram of normal mode and backup mode of operation illustrates to the Fig. 3. The status of switching components (MOSFET transistors) are shown in Table_1. The proposed UPS has a function of automatic power failure detection to control the mode of operation selection automatically between the two modes. Providing an output voltage on the load, the two modes have used a common ONE PWM IC-controller to adjust the change of duty cycle (D_1), so as to make a zero switch-over time for two differents mode selection and reduce the number of components on the proposed UPS.

Normal Mode of Operation

There are two operation in this mode working at the same time. The first one is a normal output operation. Power is delivered from the main power input to the output load through the main converter. The second one is a battery charging operation through the auxiliary converter. The power is also delivered from the main power input to the backup rechargeable battery through a part of step-down transformer T1 and a buck converter.

For normal output operation, the circuit function as a flyback converter delivering power from the main power input (V_{C1}) is switched across the primary winding (N1) of transformer T1 by a MOSFET Q1. The control circuit with a fixed frequency and duty cycle (D_1) of MOSFET Q1 is adjusted to maintain a constant output voltage on the load. The duty cycle (D_1) can be adjusted by a current mode control of closed-loop feedback to improve the load and line regulation.

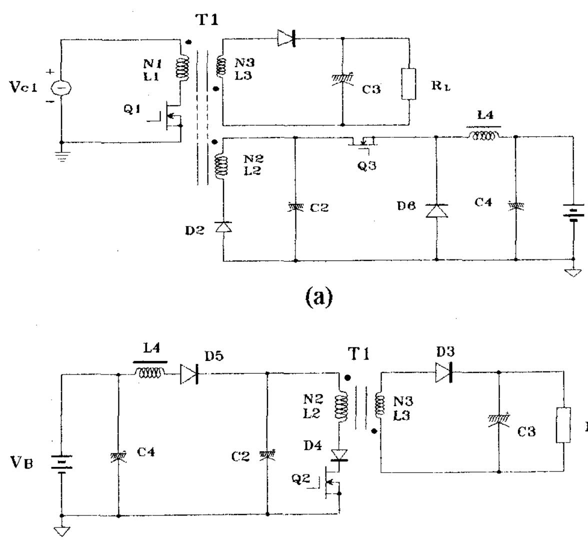
In the battery charging operation, the circuit functioning as a part of step-down transformer T1 and buck converter delivers power from the mains input V_{C1} to the capacitor C2 and store it , in order to satisfy the condition of $V_{C1}>V_{C2}$. The power flow is controlled by duty cycle (D_1) of MOSFET Q1. Then, the input voltage of battery charger refers to the voltage (V_{C2}) across the capacitor C2, so that the power transfers from that input to backup battery. The battery charging current (I_4) is independently controlled by duty cycle (D_2) of MOSFET Q3. The buck converter is established as a current source to convert the voltage V_{C3} into a nearly constant current (I_4) for charging purpose, in order to meet the condition of $V_{C2} > V_B$.

Backup Mode of operation

In this mode of operation, the DC voltage of backup rechargeable battery must be higher than the DC voltage (V_{C2}) across the capacitor C2. This condition indicates that the main power has failed to turn "OFF". During $V_B>V_{C2}$, the diode D5 has been turned to "ON" which has disabled the operation of MOSFET Q3. Then, its circuit function as a flyback converter transfers power from the backup battery V_B to the load. This power flowing is controlled by the duty cycle (D_1) of MOSFET Q2. This control method for duty cycle (D_1) of MOSFET Q2 is similar to the duty cycle (D_1) of MOSFET Q1 providing a common output voltage constant. It is because MOSFET Q1 and Q2 have used a common current mode control closed-loop feedback on the proposed UPS.

	Q1	Q2	Q3
Normal mode	PWM	don't care	PWM
Backup mode	don't care	PWM	don't care

Table_1 Status of switching components



(b)

Fig. 3. Circuit of mode operation. (a) Normal mode of operation, (b) Backup mode operation.

4. Design and Analysis

This proposed UPS is mainly equivalent two simple flyback converters parallel (Fig. 2). The transformer is concerned important for this design consideration (Using a engineering approach method to design it). The minimum number of turns is estimated from the equation(1).

$$N_{min} = \frac{V \cdot t}{\Delta B_{ac} \cdot A_e} \quad (1)$$

where N_{min} is a minimum primary turns, V is a minimum of applied DC voltage, t is a maximum DT, ΔB_{ac} is a maximum ac flux density (mT), A_e is a minimum cross-sectional area of core (mm^2).

The value of ΔB_{ac} and A_e depend on the material and dimensional of the core. The minimum secondary turns is calculated from a simple equation (2).

$$N_{3(min)} = \frac{V_{L3}}{V_{L1(min)}} \cdot N_1 = \frac{V_{L3}}{V_{L2(min)}} \cdot N_2 \quad (2)$$

For the Discontinuous Mode (complete energy transfer), all input energy is stored in the transformer during 't_{ON}' period. The stored energy in the transformer is transferred to the load at the output during the 't_{OFF}' period. The equation of output on the load voltage will be expressed as following.

The output voltage (Vo) can be calculated from equation(3).

$$Vo = V_{CI} \cdot t_{ON} \sqrt{\frac{R_L}{2 \cdot L_1 \cdot T}} = V_B \cdot t_{ON} \sqrt{\frac{R_L}{2 \cdot L_2 \cdot T}} \quad (3)$$

For the special construction of the transformer, the main input voltage requires

$$V_{L1} \geq \frac{N_1}{N_2} \cdot V_{L2}$$

Using equation (3) finds out the theoretical curve comparing with the practical curve at the measurement between the input DC voltage (V_{C1}, V_B) and the duty cycle (D) for an single output (5V, 1A). These curves are shown in Fig. 9. In this figure, the input voltage operates at the backup mode from 20V to 40V and the normal mode from 70V to 200V.

4. Experimental Results

The experimental prototype of the proposed UPS as shown in Fig. 2 was built. It has an single output (5V, 1A) operating with the DC input mains (100V to 200V) and the DC backup battery input (20V to 30V). However, the DC backup battery input is inputted from the DC rechargeable battery (21.6V). The battery charger operates at nearly constant charging current (110mA). The switching frequency is chosen to be 100K Hz. The following components are used:

Q1 = IRF 840 ; Q2, Q3 = IRF 520 ;
D1-6 = MUR 460 ; L4 = 350 μH , 1.056Ω ;
C1 = 120 μF ; C2, C4 = 1000 μF ;
C3 = 6800 μF ; IC1, IC2 = Uc 3842 ;
T1 = TDK H7C4 PQ2620 with 0.5mm air gap
L1, N1 = 463.4 μH, 2.5, 38T (SWG 28) ;
L2, N2 = 28.9 μH, 0.36, 10T (SWG 28) ;
L3, N3 = 6.8 μH, 0.2, 4T (0.2mm Copper foil) ;

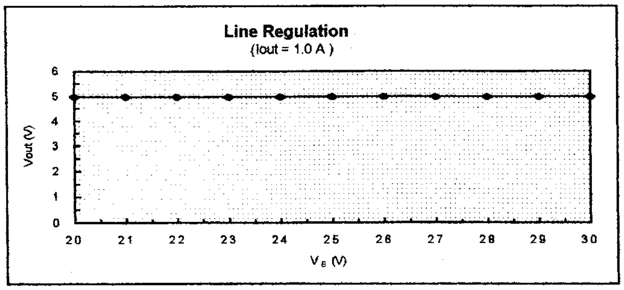
Results of measurement are shown in Figs. 5 for line regulation of maximum. The load regulation is shown in the Figs. 6. The efficiency illustrates in Fig. 7 and then the mode transition characteristic is presented in Fig. 8.

5. Conclusion

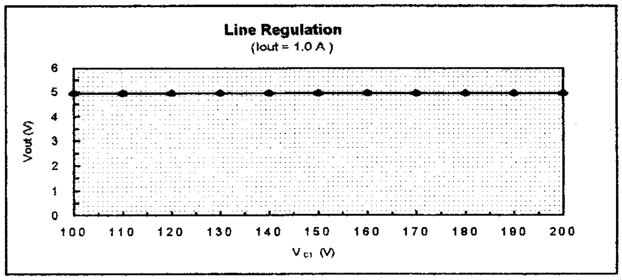
The proposed UPS has been built with small size. It makes use of an opto-coupler to form an isolated closed-loop feedback. The closed-loop feedback also contains a control method of the current mode control. It controls the duty cycle of PWM for the required input voltage range. Therefore, the output voltage can be regulated with a high-voltage DC input mains (200V) and a low-voltage backup battery (21.6V). Also, good line regulation and load regulation are achieved.

The opto-coupler also isolates a portion of the input from the output for safety and good performance. The transformer separates all parts including main power, backup battery input and the output and ensures full isolation for all parts so that fully isolation is achieved in the proposed UPS circuit.

The proposed UPS has a special feature which only uses a single PWM IC-controller to control two different MOSFETs operation in the 'Normal ' and 'Backup' mode simultaneously. The common PWM IC-controller can provide a zero switch-over time function and make the PWM control simple and eliminate the detection circuit of mode selection (normal or backup mode of operation). As a result, the synchronization problem can be solved and the detection circuit of main input failure is saved. All other proposed features are also achieved.

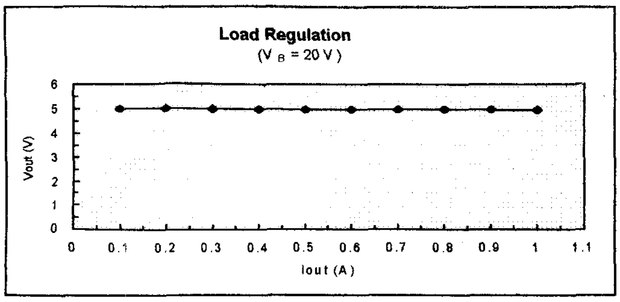


(a)



(b)

Fig. 5 Line regulation for maximum load at (a) backup mode and (b) normal mode.



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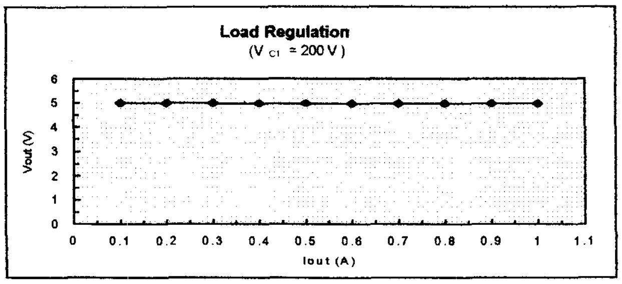
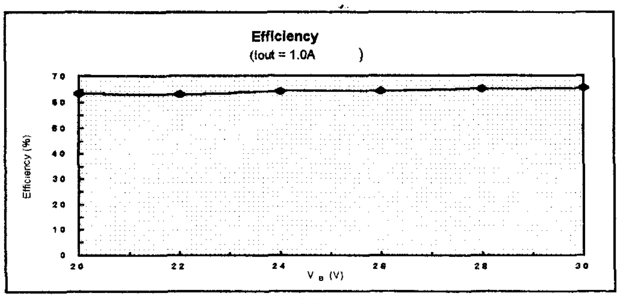
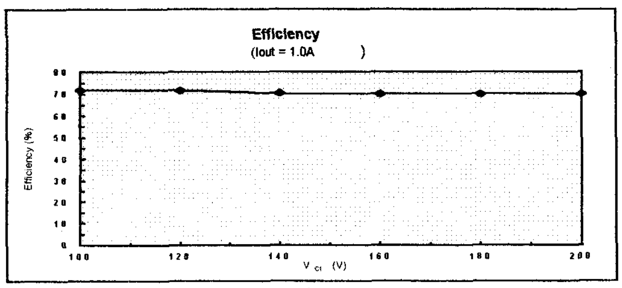


(b)

Fig. 6 Load regulation for (a) low input backup battery voltage, and (b) high input main voltage.



(a)



(b)

Fig. 7 Efficiency for maximum load at (a) backup mode, (b) normal mode

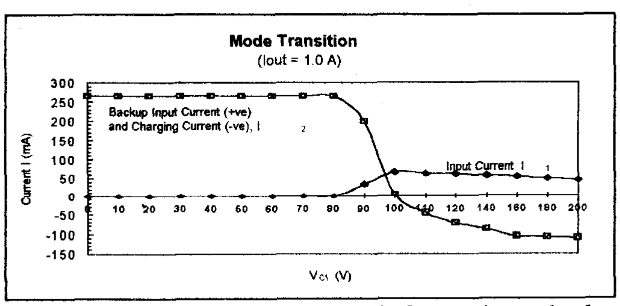
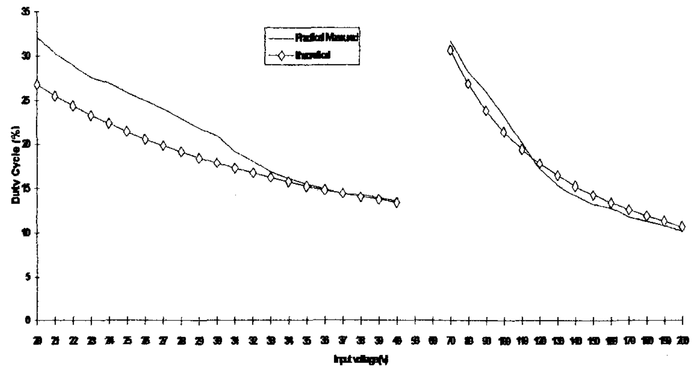


Fig. 8 Mode transition characteristic for maximum load



REFERENCES

[1] Joseph Perkinson, "UPS Systems - A Review", Conference Proceedings of Third IEEE Applied Power Electronics Conference and Exposition 1988 (APEC '88), pp. 151-154.

[2] Kwok-Wai Ma and Yim-Shu Lee, " A Novel Uninterruptible DC-DC Converter for UPS Applications". IEEE Transactions on Industry Applications, Vol.28, No.4, Jul/Aug 1991, pp.808-815.

[3] B. Fuld, "A Cost-Effective DC/DC-Converter with Integrated UPS-Function". Fifth European Conference on Power Electronics and Applications (EPE '93), Vol.3, Sept. 1993, No.377, pp. 237-239.

[4] Kwok-Wai Ma and Yim-Shu Lee, " A Integrated Flyback Converter for DC Uninterruptible Power Supply". Internal paper, Department of Electronic Engineering, H.K.Polytechnic.

[5] D.K.W. Cheng and W. Chan, "Design of a Switching Mode Power Supply with UPS Features", Proceding, PEDS '95, 21-24 Feb. 1995 Singapore, pp.341-346.