

A Different Approach to Build an Uninterruptible Power Supply System with Power Factor Correction.

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Abstract — In this paper a different approach to build an uninterruptible power supply (UPS) system is presented. The proposed scheme includes features such as high power factor, low total harmonic distortion and good dynamic response at the output voltage. This scheme has the desirable features of high efficiency, simple circuit and low cost compared to a traditional standalone multiple stages UPS with power factor correction. The circuit operation, analysis and experimental results of the proposed UPS scheme are presented. The UPS approach is a good solution for low power applications (≤ 500 W).

I. INTRODUCTION

To add an external UPS is the traditional approach used to provide uninterruptible power for applications such as personal computers, medical equipment, telecommunication systems, control systems, etc. On the other hand, it is desirable to include power factor correction (PFC) because of the well known advantages that this improvement represents. However, in order to get this capacity, it is necessary to add an extra power stage as it can be observed in Fig. 1.

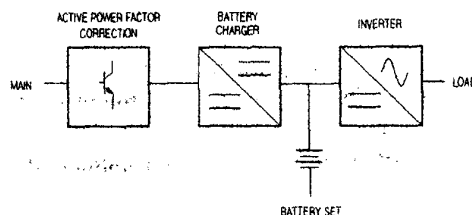


Fig. 1. Traditional uninterruptible power supply system with active PFC

Besides, the power inverter stage is done based on the full bridge buck inverter (FB-BI). In this case the output voltage is always lower than the DC input voltage, therefore it is necessary to add an extra stage to adequate its input voltage. There are two alternatives to achieve this objective:

The first possibility is to build the inverter stage throughout the FB-BI and the boosting function by using a heavy and bulky low frequency transformer (Fig 2a). The second possibility is to use a DC-DC boost converter in order to adequate the inverter input voltage (Fig 2b).

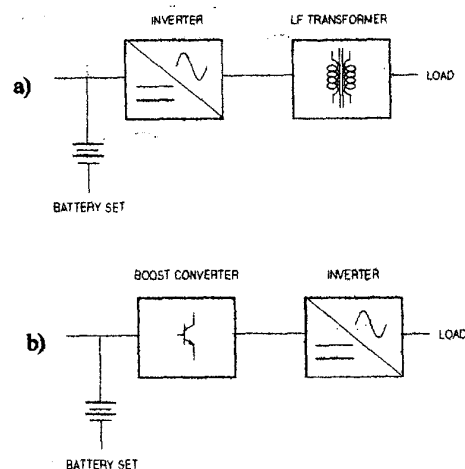


Fig. 2. Traditional alternatives to implement the inverter stage,
(a) low frequency AC link (b) high frequency DC link.

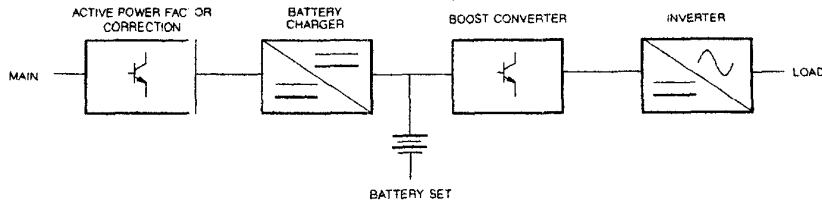


Fig. 3. Uninterruptible power supply system with active power factor correction and high frequency DC link.

The last option is more suitable due to benefits such as reduced size and low weight. The UPS using a two stage PFC-battery charger and a two-stage high frequency DC link-inverter is shown in Fig 3.

As it can be observed in Fig. 3, the UPS scheme consists of four power conversion stages resulting in poor efficiency, high cost and low reliability. In this paper, a novel scheme of an uninterruptible power supply system based on two power conversion stages is presented. The proposed configuration has high efficiency and low cost. Besides, it exhibits a close unity power factor.

II. PROPOSED SYSTEM

The proposed UPS based on two power conversion stages is shown in Fig. 4 (this approach was previously presented at PESC'97 by the authors [1]). The UPS offers excellent features, such as: simple structure, high power factor, low total harmonic distortion, fast dynamic response at the output voltage, high efficiency and low cost. These features make it a better solution than the classical approach.

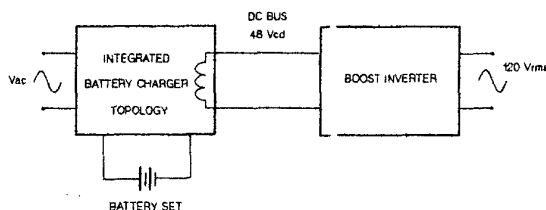


Fig. 4. Proposed uninterruptible power supply system.

The first stage of the proposed UPS consists of an integrated battery charger which was presented in [2]. This topology uses a discontinuous conduction mode (DCM) flyback converter in order to provide high power factor, battery charging, and high frequency isolation between both the main input and the battery set to the load. This structure does the functions of battery charging and power factor correction using just one magnetic structure, reducing the cost and accomplishing high reliability and simplicity of the converter. However, due to the use of the DCM flyback converter, it is suitable for low power applications (≤ 500 Watts).

The second stage is an integrated inverter topology with both boosting and inverting function. This topology was previously introduced in [3]. The boost DC - AC converter, referred to as *boost inverter*, has an excellent property: it naturally generates an output AC voltage lower or larger than the DC input voltage, depending on its duty cycle [3-5]. This property is not found in the classical voltage source inverter which produces an instantaneous AC output voltage always lower than the input DC voltage. In the next paragraphs the operation principles of each stage of the proposed UPS structure will be described.

III. BATTERY CHARGER-PFC STAGE

The basic circuit of the battery charger-PFC is shown in Fig. 5. As it can be seen in this figure, the converter accept two input powers: one through the AC line and the other through the

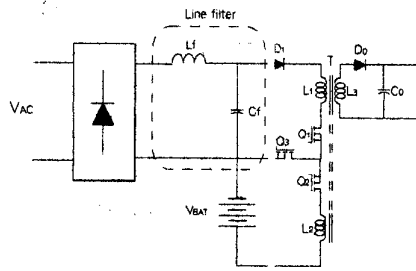


Fig. 5 Integrated battery charger topology as input stage of the proposed UPS.

battery set. The topology has three operation modes [2]: normal mode, backup mode, and charging mode. The switch Q_1 controls the energy transfer in normal and charging operation mode, whereas Q_2 modulates the power transference when the converter operates in backup operation mode. The main converter (V_{AC} , L_1 and Q_1) operates when the main utility line is working properly, whereas the backup converter (V_{BAT} , L_2 and Q_2) operates when the principal energy supply fails. The switch Q_3 selects between the normal or backup operation mode and the charging operation mode. At the same time, it controls the battery charging current. In addition, the switch Q_3 protects the battery from high current levels that overpass the specifications of the battery manufacturer.

In normal and charging operation modes, the equivalent circuit of the integrated battery charger topology is a flyback converter operating in DCM. Therefore, it behaves in a natural way as a linear load to the utility line

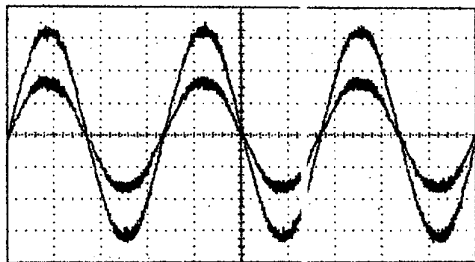


Fig. 6. Input voltage and current waveforms in normal operation mode.

[6]. In backup operation mode the equivalent circuit is a well know DC-DC flyback converter. However, as the battery voltage is low, the peak and average current are higher than these ones in normal and charging operation mode. Therefore, we must be careful during the selection of the battery voltage bus.

A. Experimental results

In order to verify the battery charger-PFC stage, an experimental prototype was designed and built. The specifications were the following: output power = 250 Watts, input voltage = 120 volts, $V_{BAT} = 48$ volts, and output voltage = 48 volts. The converter was implemented in DCM using a mixed device as power switch in order to increase the efficiency.

The experimental input voltage and current waveforms in normal operation mode are shown in Fig. 6. As it can be seen, the voltage and current waveforms are in phase. Therefore, a close to one power factor and low THD are obtained.

The converter was tested in charging operation mode too. The experimental input voltage and current waveforms during this operation mode are shown in Fig. 7. As it can be seen in this figure, the input current waveform has a dead time crossing during zero. This effect is due to the relatively high

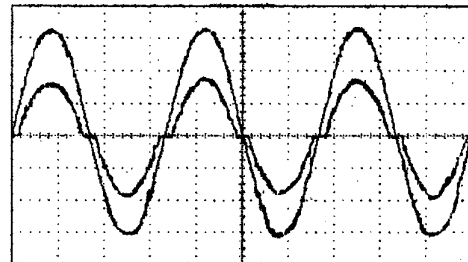


Fig. 7. Input voltage and current waveforms in charging operation mode.

battery voltage bus [7], causing a reduction of the power factor and higher THD than those in normal operation mode. However, a higher V_{BAT} voltage means a higher efficiency in backup operation mode.

IV. BOOST INVERTER STAGE

The boost inverter achieves DC - AC conversion as follows: the power stage consists of two current bi-directional boost converter and the load is connected differentially across them (see Fig. 8). These converters produce a DC - biased sinusoidal waveform, so that each converter produces an unipolar voltage. The modulation of each converter is 180 degrees out of phase with respect to the other, which maximizes the voltage excursion over the load (Fig. 9).

For the purpose of optimizing the boost inverter dynamics, while ensuring correct operation in any working condition, the sliding mode controller is one of the most suitable approaches [8,9]. The main advantage, over the classical control schemes is its robustness for plant parameter variations and invariant steady state responses in the ideal case.

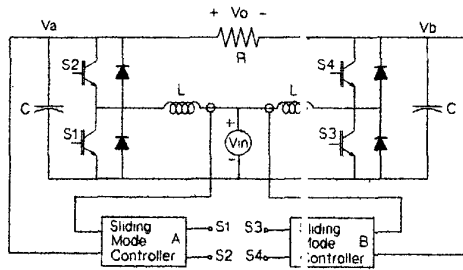


Fig. 8. Boost inverter with sliding mode control

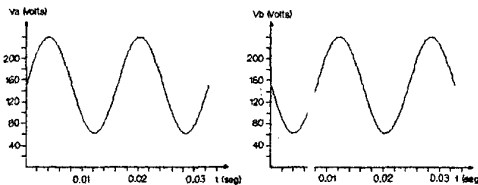


Fig. 9. Output voltage for each E.C-DC converter.

A. Sliding mode controller.

Two controllers are used, one for each boost converter, as a result of this an easier model of the system is obtained since one of them is modeled as an ideal source. The design steps [10-12] can be summarized as follow:

- i) Propose a sliding surface
- ii) Verify the existence of sliding mode
- iii) Verify stability into the sliding surface.

These points are explained in [12]. Therefore only some definitions are mentioned. The proposed sliding surface is:

$$s = SX - SX_r = SeX \quad (1)$$

Where:

$S = [s_1 \quad s_2]$, controller parameters

X = state variables

X_r = reference variables

$eX = [ex_1 \quad ex_2]^T$

The proposed control law is:

$$u = u_{eq} + u_N \quad (2)$$

Where: u_{eq} = equivalent control,

$u_N = - \text{sgn } \sigma$

B. Simulation results.

The system has been simulated with the following parameters: $L= 360 \mu\text{H}$, $C=28\mu\text{F}$, $R=32.4\Omega$, $V_{in} = 50$ Volts, $V_o = 180$ Vac, $f= 60$ Hz. In figure 10 and 11 is shown the capacitor voltage under resistive load and load variation respectively.

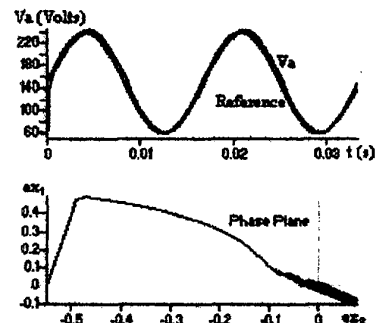


Fig. 10 .Simulations with resistive load.

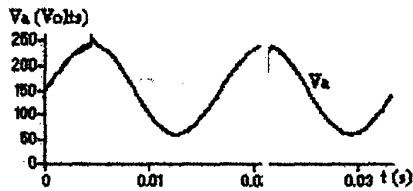


Fig. 11. Simulation with load variation $s_1=0.8$ y $s_2=1$.

C. Experimental results.

In order to validate the proposed idea, a 300W prototype of the boost inverter was implemented. The following parameters were adopted: $L = 360 \mu\text{H}$, $C = 28 \mu\text{F}$, $V_{in} = 48 \text{ V}$, $V_o = 120 \text{ Vac}$, $f_o = 60 \text{ Hz}$, $i_{s_{max}} = 30 \text{ kHz}$.

The inverter was tested under no load, linear, nonlinear and load variation conditions. The output voltage under no load condition with a THD = 0.7% is shown in figure 12.

The converter under resistive load is shown in figures 13 and 14. The output voltage and current is shown in figure 13, and the capacitor voltage is shown in figure 14.

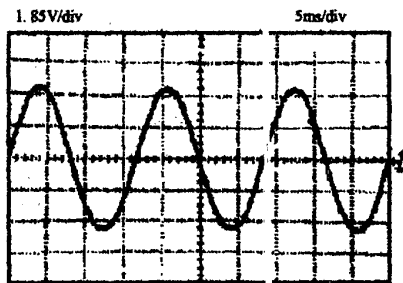


Fig. 12. Output voltage, unloaded inverter.

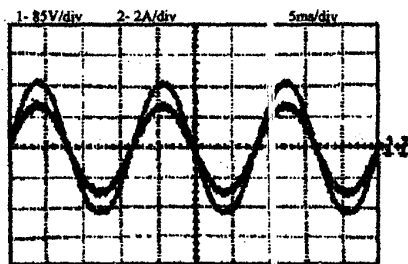


Fig. 13. Output voltage and current, $P_o=200\text{W}$.

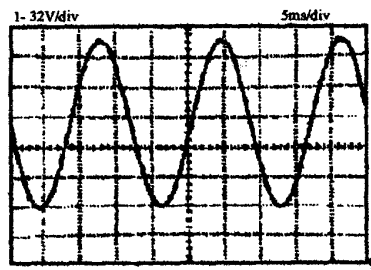


Fig. 14. Capacitor voltage, $P_o=200\text{W}$.

In order to show the system response, it was tested under non linear load and load variation. The output voltage and current under nonlinear load that demands 133 VA ($C=220\mu\text{F}$, $R=240\Omega$) is shown in figure 15. The THD obtained in this case is 3.61%.

In figure 16 is shown the output voltage and current under load variation, the settling time when the load decreases and after increases is $760\mu\text{S}$ and $980\mu\text{S}$ respectively.

In figures 17 and 18 are shown the efficiency and the THD versus the output power.

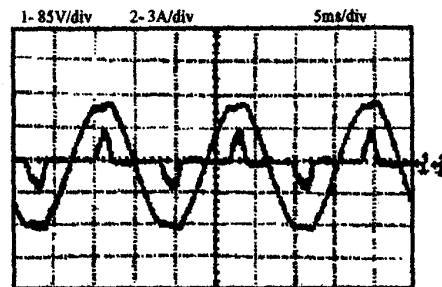


Fig. 15 Output voltage and current, nonlinear load

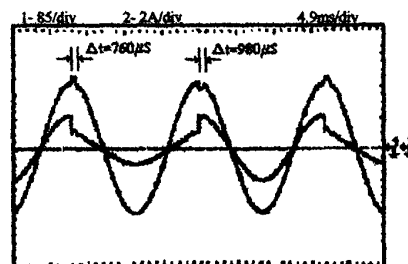


Fig. 16. Output voltage and current, load variation.

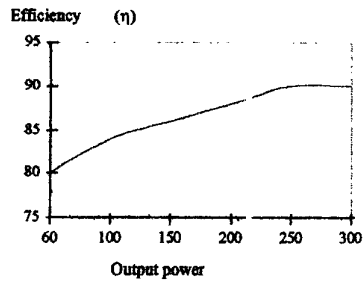


Fig. 17 Efficiency vs. output power.

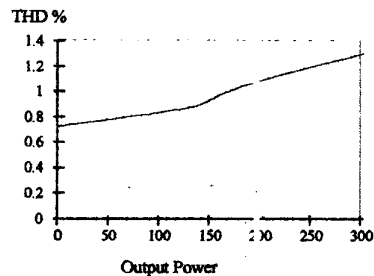


Fig. 18 THD vs. output power.

V. CONCLUSIONS

Nowadays, it is very important to achieve high efficiency, low cost and high reliability in UPS design, and at the same time to fulfill the power quality standard (concerning PF and THD characteristics). This paper presents a novel approach in order to meet these objectives which is based on the reduction of the power conversion stages in both the battery charger and the inverter stages.

A boost inverter topology used in applications such as UPS is analyzed. This converter is different from the traditional inverter because it is able to boost and invert a signal at the same time. This converter requires a fast response, robustness and stability properties in order to reduce the distortion of the output voltage.

In order to show the performance of the designed controller, some simulations and experiments have been made. It can be observed a good dynamic response, robustness and stability properties when the control based on sliding mode has been applied.

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