

# POWER RECYCLER FOR DC POWER SUPPLIES BURN-IN TEST: DESIGN AND EXPERIMENTATION

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**Abstract** - Conventionally the burn-in test of DC power supplies uses resistors as load. Consequently, all the energy involved is lost by heating, provoking still an additional energy waste with the air conditioning system. The power recycler is a power converter that replaces the resistors load banks in the burn-in test of DC power supplies with the advantage that most of the energy is sent back to the utility grid with low THD and quasi-unitary power factor. The economical benefits due to energy savings are evident and contribute in reducing the final cost of the equipment. Besides, the power recycler is totally agreeable to the world concern about ecology and energy conservation.

This paper analyses the proposed solutions in recent literature and presents a new architecture for the implementation of a power recycler for DC power supplies burn-in tests.

The proposed circuit is regulated by conventional integrated circuits: PWM and power factor controllers.

Circuit operation, design characteristics, simulation and experimental results of a 2kW prototype are provided in the paper.

## I. INTRODUCTION

The burn-in test of DC power supplies, UPS's (Uninterruptible Power Supplies) and other power sources generally takes 24 to 72 hs [1]. Traditionally, resistors are used as load and all this energy is lost by heating, causing an additional energy waste in the refrigeration system. The estimates of the amount of electric energy wasted in testing of power sources runs into hundreds of millions of kilowatt hours annually [2]. To reduce these energy losses, the power recycling concept is applied to the burn-in test of power sources. The power recycler replaces the resistor load bank

in the burn-in test of DC power supplies, draining the necessary load current with the great advantage that most of the involved electric energy is sent back to the utility grid. Consequently, the test can be accomplished consuming only a small part the energy if the resistor load bank is used. The amount of recycled energy depends on the efficiency of the power recycler, and the use of non dissipative converters is preferable. As the power recycler is connected to the utility grid some safety and power quality requirements are necessary [3].

By using the power recycler, the cost of the burn-in test is reduced, decreasing the final cost of the equipment and therefore offering more competitive prices for consumers. The initial investment can be amortized in less than a year by the energy savings [2]. Another important characteristic that should be emphasized is the total alignment of the power recycler with the great world concern of today about ecology and energy conservation.

## II. STATE OF THE ART

In recent literature, there have been some proposals following the power recycling principles for DC power supply burn-in tests [2,4]. In both solutions, the power supplies under test are connected in series to obtain an adequate voltage level to implement a DC/AC converter. Fig. 1 shows the basic block diagram for the two cases.

In [2], the amount of recycled power is controlled by adjusting the amplitude of the imposed sinusoidal output current of the DC/AC converter. The control is performed by a digital controller, a sampled control system, containing a microprocessor and an application specific integrated circuit (ASIC).

In [4], the power transference from the DC power supplies to the utility grid is controlled by varying the amplitude and the phase of the inverter sinusoidal output voltage in relation to the grid. A digital signal processor (DSP) is responsible for the system control.

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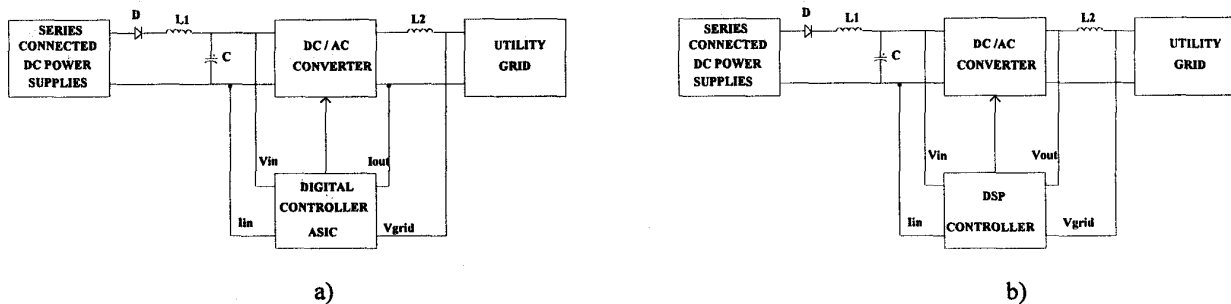


Fig. 1. a) Block diagram for DC load bank in [2].  
b) Block diagram for DC load bank in[4].

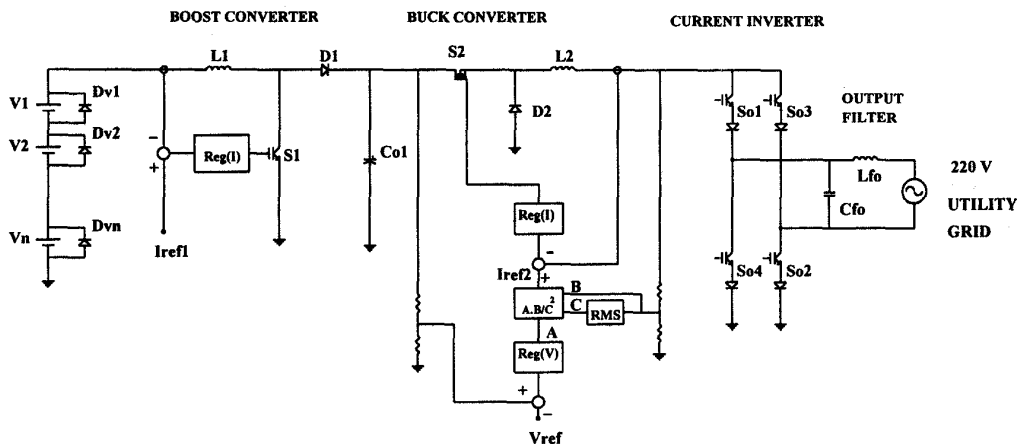


Fig. 2. Basic block diagram of the proposed structure.

### III. THE PROPOSED ARCHITECTURE

Fig. 2 shows the circuit diagram for the proposed architecture. The control is accomplished by analog integrated circuits: traditional PWM and power factor controllers commonly used in switching power supplies, that are cheaper and easier to implement than the digital control proposed in [2,4].

The proposed structure is composed by three stages:

The first stage is a boost converter that is responsible for draining the desired load current from the power supplies and for providing the adequate voltage level (around 400V) for the next stage. This stage has a controlled input current using a traditional PWM controller and its output voltage is controlled by the next stage.

The second stage is a buck converter that imposes a 120 Hz rectified sinusoidal shape in its output current. The amplitude of the imposed current is controlled by the energy in its input voltage bus.

The third and last stage is a current inverter that converts its rectified sinusoidal input current in a sinusoidal output current, synchronized with the utility. An inverter bridge is used and each pair of switches is alternately active every 120 Hz.

An output filter must be used to eliminate the high frequency harmonics in the grid injected current.

Though the proposed structure is composed by three stages, high efficiency can be obtained by using non-dissipative converters in the first and second stages. The third stage operates in low frequency and hard switching can be used.

### IV. THE POWER RECYCLER APPLIED TO THE MICROCOMPUTER POWER SUPPLIES BURN-IN TEST

To use the proposed power recycler in the burn-in test of microcomputer power supplies some considerations must be

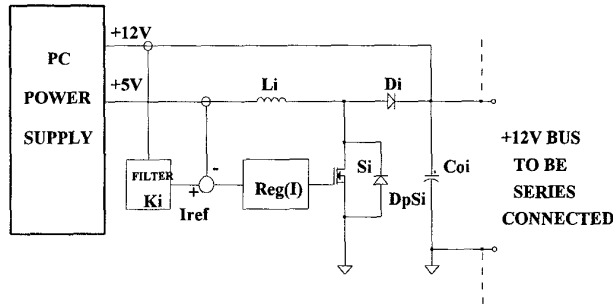


Fig. 3. Adaptation of the +5V and +12V power in a single bus.

taken into account. As the microcomputer power supplies have multiple outputs which are commonly referred to the same ground, an adaptation is necessary to make the series connection possible. The microcomputer power supply has four output voltages:  $\pm 5V$  and  $\pm 12V$ . According to preliminary economical studies, only the positive outputs (+5V and +12V) should be recycled since they represent more than 95% of the total power. The structure utilized for the adaptation consists of a boost converter between the +5V and +12V outputs as shown in Fig. 3. The +5V to +12V boost converter is responsible for draining the adequate current from the +5V output and for transferring the energy of the +5V output to the +12V output. As the output of the boost converter is connected to the +12V output of the microcomputer power supply, its output voltage is imposed. Using one power processing stage, we have obtained the +5V and +12V power in a +12V voltage bus. Now, using this adaptation in each microcomputer power supply to be tested, the series connection of the +12V outputs can be achieved and the recycling of the positive outputs power can be accomplished.

Using a set of ten microcomputer power supplies, the series connection results in a 120V voltage bus. The next stage is a 120V to 400V boost converter

## V. CONTROL STRATEGY

Comparing the two last stages of Fig. 2 with a power factor correction pre-regulation stage, one can notice the duality between the two systems. The latter one is a AC/DC converter which drains from the utility a high power factor sinusoidal current. The power recycler is a DC/AC converter and injects into the utility a high power factor sinusoidal current. So, a power factor controller IC with a small external adaptation can be used to control the buck converter. This necessary adaptation is only to change the polarity of the voltage loop input error. In power factor correction, when the pre-regulator output voltage has a tendency of increasing, it means that the grid drained power is higher than the load power, and the controller acts to reduce the

reference of the current loop to control the output voltage. In a power recycler, when the input voltage of the buck converter is increasing, it means that the energy to be recycled has increased and the reference of the current loop must increase. The UC3854 [5,6], a power factor controller IC, with an external adaptation was used.

The amount of recycled power is controlled by the 120V/400V boost converter of the preceding stage by imposing its input current.

For obtaining the adequate drained current of +5V and +12V outputs of the microcomputer power supplies, only a current loop at the +5V/+12V boost converter input is used. A current sensor for monitoring the +12V power supply output current generates the current reference for the current loop of the +5V/+12V boost converter. So, the current drained from the +5V output is proportional to the current furnished by the +12V output. The proportionality factor is given in (1):

$$K_i = \frac{I_5}{I_{12}} \quad (1)$$

Where:

- $I_5$  : nominal current of the +5V microcomputer output;
- $I_{12}$  : nominal current of the +12V microcomputer output.

By using this method the input current of the 120V/400V boost converter is imposed and the drained currents of the +5V and +12V outputs are naturally imposed by using the +5V/+12V boost converter current loop and proportionality factor. So, if another load condition is required it is necessary only to change the current reference of the 120V/400V boost converter current loop, and the drained currents of the +5V and +12V power supplies outputs will be adapted to this new situation.

### A. The Control Loops Analysis

The input current loop analysis of the boost converter was based on a simplified model of the PWM switch [7] and results:

$$\frac{I_m(S)}{V_c(S)} = \frac{V_o R_{sh}}{S L V_{osc}} \quad (2)$$

Where:

- $V_c(S)$  : comparison voltage with the sawtooth of PWM controller.
- $R_{sh}$  : "shunt" resistor for current sampling.
- $V_{osc}$  : sawtooth voltage amplitude of PWM controller.

To guarantee the stability of the current loop a two poles (one placed at the origin to assure low static error) and one zero compensator was used as in [5,6].

The output current loop of the buck converter was analyzed using the same model and is given in (3):

$$\frac{I_o(S)}{V_c(S)} = \frac{V_{in} R_{sh}}{S L V_{osc}} \quad (3)$$

The transfer function obtained in this case is similar to (2) and the same compensator is used. The input voltage loop has very low bandwidth compared with the current loop and it is compensated only by the low frequency distortion requirements in the power factor controller integrated circuit [5,6]. As mentioned before, to use the UC3854, a small external adaptation is necessary. It was accomplished using an operational amplifier.

## VI. DESIGN CHARACTERISTICS

A power recycler for ten 200W microcomputer DC power supplies (+5V/20A, +12V/8A, -5V/0.5A, -12V/0.5A) was designed, simulated and implemented. The power of the positive outputs that will be recycled represent about 96% of the total power (1960W).

The characteristics of the 5V/12V boost converter are:  $V_{in} = 5V$ ,  $V_o = 12V$ ,  $f_s = 50 \text{ kHz}$ ,  $I_{in} = 20A$ .

The 5V/12V boost converter current loop utilizes a low cost and low power magnetic current sensor based on [8]. A shunt resistor was used to sample the +12V output current because in this case the current level is lower. The TL494 PWM controller was used. A current limitation and a special protection to allow the converter to operate with no load were implemented. This protection acts in the current loop to limit the output voltage around 15V when the converter has no load. The measured efficiency of the 5V/12V boost converter was around 86%. So, the available power in the 12V bus of each microcomputer power supply is 182W.

The 120V/400V boost converter was designed using the ZCS structure proposed in [9]. Its characteristics are:  $V_{in} = 120V$ ,  $V_o = 400V$ ,  $f_s = 20 \text{ kHz}$ ,  $I_{in} = 15A$ . The current loop was implemented like the 5V/12V converter using the same magnetic current sensor and protections.

The buck converter is controlled using the UC3854 with a small external adaptation. In this first prototype hard commutation was used but soft commutation can be obtained using [9]. Its characteristics are:

$V_{in} = 400V$ ,  $V_o = 220V(\text{rms})$ ,  $f_s = 20 \text{ kHz}$ ,  $I_o = 7.5A(\text{rms})$ .

The current inverter operates at 120 Hz, enabling one pair of the inverter switches (So1/So2) during the positive half cycle of the grid voltage and the other pair (So3/So4) in the negative half cycle.

The output filter used in the laboratory was:  
 $L = 6.4\text{mH}$  and  $C = 1\mu\text{F}$ .

A dead time of  $\pm 400\mu\text{s}$  around the zero crossing of the grid voltage was introduced in the drive signal of the buck

converter switch. If this dead time is not used great current peak near the zero crossing occurs during the initialization of this stage. On the other hand, the drive signal of the current inverter switches So1/So2 and So3/So4 have a superposition of  $\pm 200\mu\text{s}$  around the zero crossing of the grid voltage. So, the current inverter is always enabled.

As the boost converters can operate with no load, the start-up of the power recycler can be accomplished by using different soft-start times in each power stage. First the 5V/12V boost converter is turned on, after a few seconds the 120V/400V boost converter is activated and, finally, some seconds later, the buck converter. The inverter must be turned on before the buck converter, to allow the power transference to the utility.

## VII. SIMULATION RESULTS

Fig. 4 shows some simulation results.

In Fig. 4.a, the current loop response of the 120V to 400V boost converter is illustrated. In Fig. 4.b, the input current loop response of the 5V to 12V boost converter is shown. In Fig 4.c illustrates the current of the +12V power supply output. In this case, an ideal voltage source was used in the simulation and a large current ripple can be noticed in the +12V output current. In the real circuit this current ripple is smaller due the power supply output filter as shown in Fig. 6.a.

## VIII. EXPERIMENTAL RESULTS

Fig. 5 shows the implemented circuit.

Fig. 6 shows the practical results obtained in the laboratory.

Fig. 6.a illustrates the +5V and +12V microcomputer power supply output currents using the +5V to +12V boost converter submitted to a resistive load.

The 120V to 400V boost converter input current is shown in Fig.6.b.

Fig. 6.c shows the drive signal of each pair of the inverter switches in relation to the grid voltage reference. It is possible to notice the superposition of  $\pm 200\mu\text{s}$  around the zero crossing of the grid voltage of the current inverter switches drive signal. The pulse of  $\pm 400\mu\text{s}$  around the zero crossing of the grid voltage was used to inhibit the buck switch drive signal. Fig. 6.d shows the 120 Hz rectified current in the buck converter inductor. Fig. 6.e shows the inverter output current. Fig. 6.f shows the grid injected current, already filtered. The inverter output current is plotted at  $180^\circ$  shifted from the grid voltage because the power flow is from the power recycler to the grid.

Fig. 7 shows the harmonic analysis of the grid voltage and injected current for the practical results presented in Fig. 6.f.

The grid voltage presented a THD of 3.2% and the injected

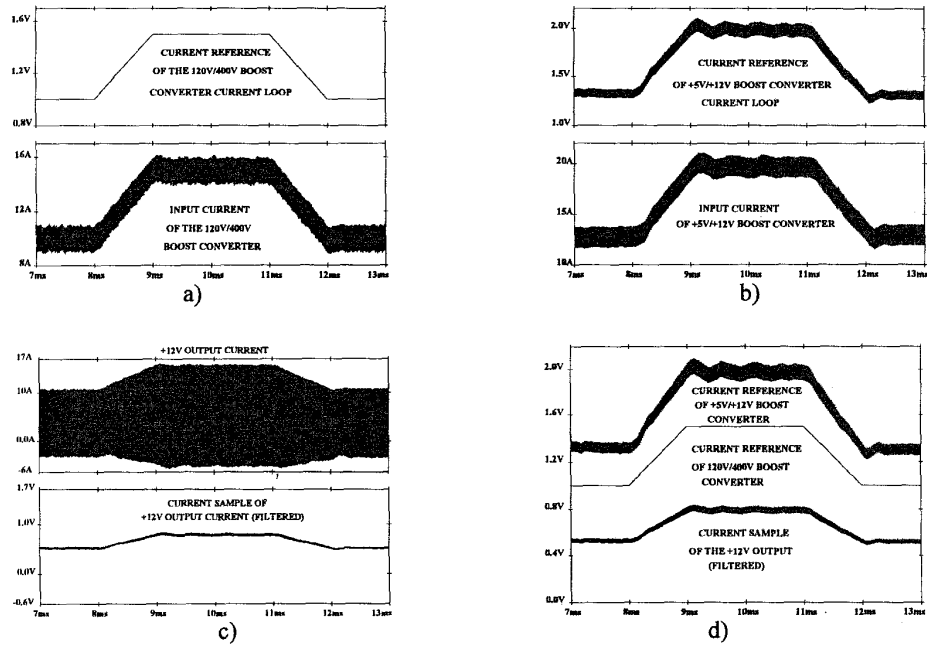


Fig. 4. Simulation results.

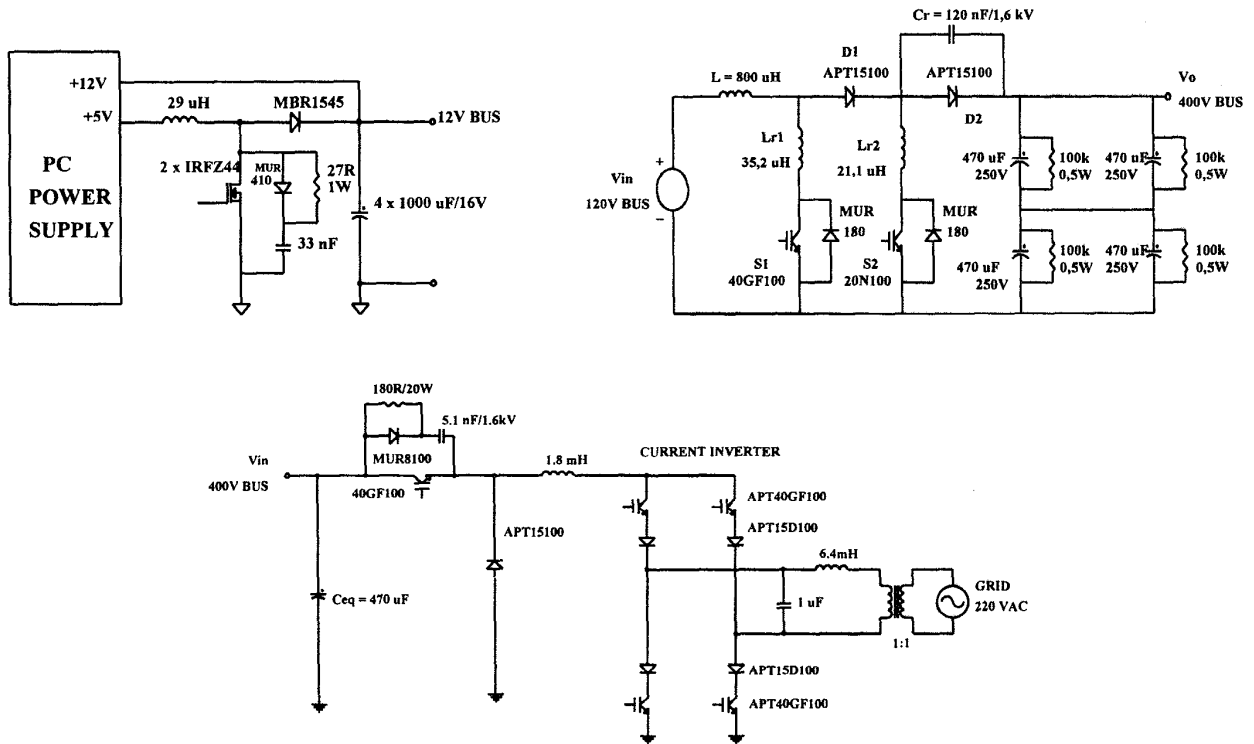


Fig. 5. The implemented circuit.

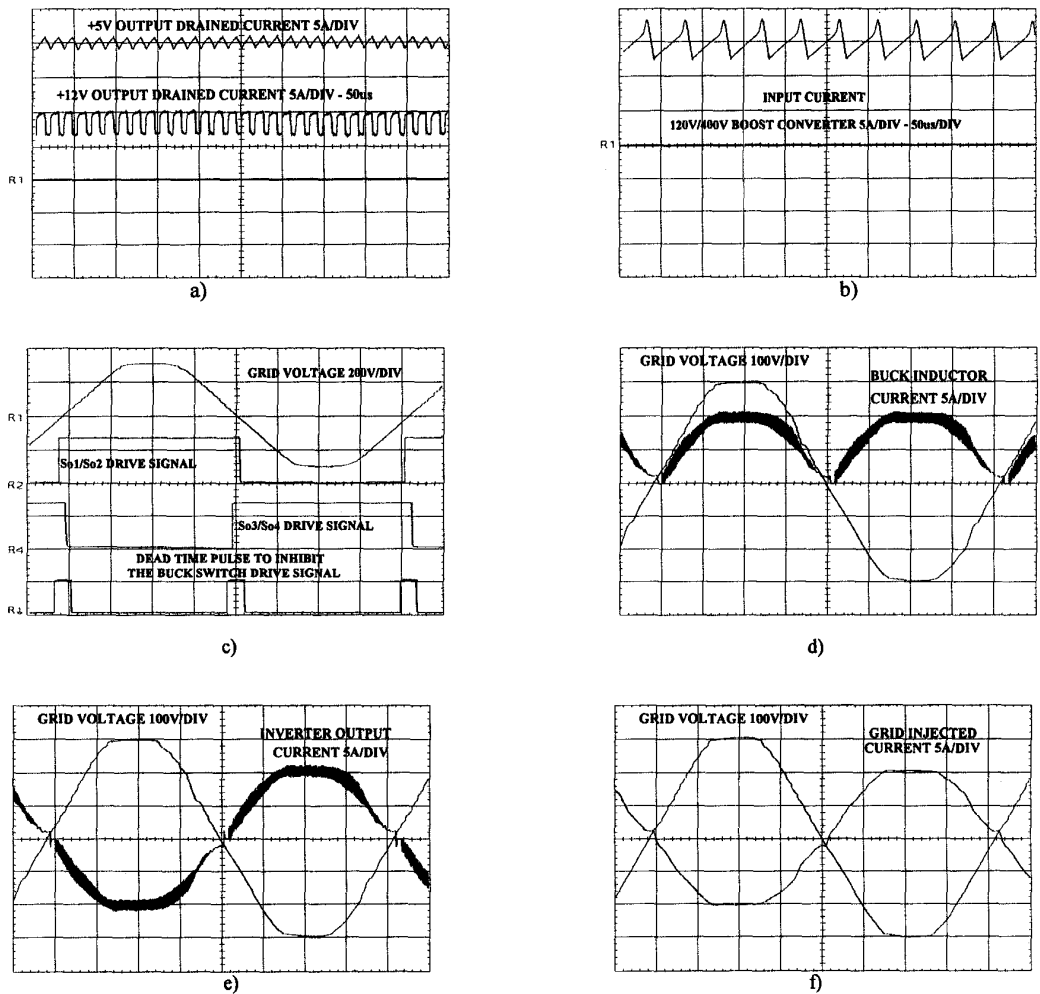


Fig. 6. Experimental results.

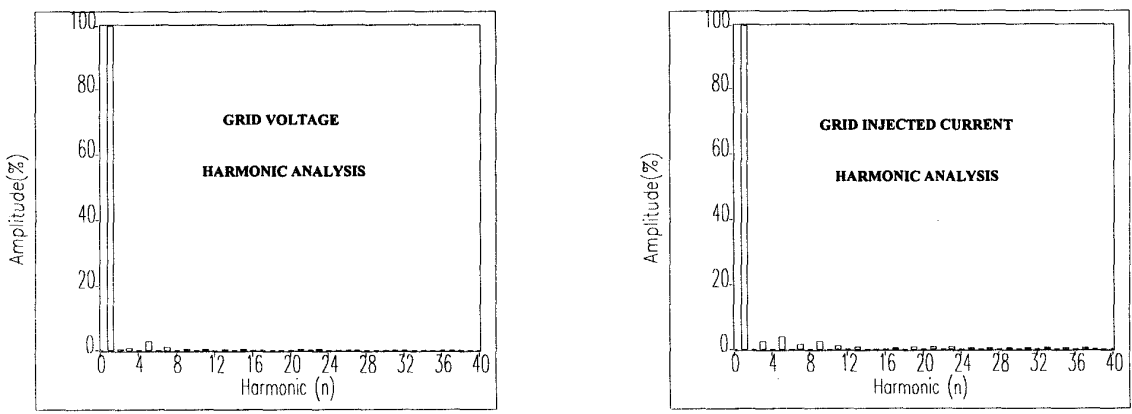


Fig. 7. Harmonic Analysis.

current, a THD of 5.6% with a displacement angle of  $-3^\circ$ . This results in an almost unitary power factor and 1650W of recycled power. The resulting efficiency of the power recycler is around 82%. If the first stage (the 5V/12V boost converters) was not considered the efficiency is 88%. The efficiency can be improved using soft commutation in the buck converter stage.

### IX. ECONOMICAL ANALYSIS

The savings obtained by using the power recycler during a year can be described in (4) and illustrated in Fig. 8.

$$E_s = P_t \cdot \eta \cdot F_u \cdot 8760 \cdot 0.12 \quad (4)$$

where:  $E_s$  : annual electrical energy savings in US\$;  
 $P_t$  : power involved in the test in kW;  
 $\eta$  : efficiency of the power recycler;  
 $F_u$  : utilization factor of the power recycler;  
 8760 : number of hours in a year;  
 0.12 : cost of the kWh in USA in US\$.

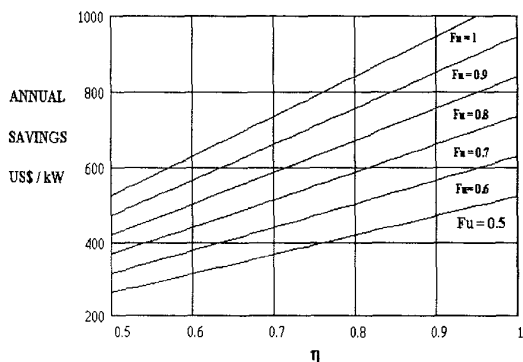


Fig. 8.- Annual savings of electrical energy of the power recycler.

The economical benefits due to the use of the power recycler depends on its utilization factor: the more it is used the more energy savings are obtained.

### X. CONCLUSION

In this paper a power recycler for DC power supplies burn-in test is described. Circuit operation, design characteristics, simulation and experimental results of a 1.96kW prototype were presented. The proposed structure uses only traditional PWM and power factor controllers integrated circuits with low cost and easy implementation.

The power recycler replaces the resistor load bank, draining the correct current from the DC power supplies and

injecting into the utility grid a current with low THD and high power factor.

The use of the DC power recycler in burn-in tests of DC power supplies results in great energy savings and contributes in reducing the final price of the product. The time for amortizing the initial investment of the power recycler depends strictly on its utilization factor. Besides the economical point of view, another interesting characteristic is that the power recycling concept and the concern about energy conservation is totally agreeable to the ecological thoughts of today.

### ACKNOWLEDGMENT

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