A High Power Factor Power Supply Employing A Self-Oscillating Converter to Supply Control Circuitry

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Abstract— **This paper proposes a symmetrical switched-mode power supply which employs a self-oscillating converter as auxiliary power to supply control and drive circuits. It is composed of a preregulator Boost converter applied to two dc-dc Forward converters in order to provide power factor correction. They operate at 100kHz and the individual output voltages are equal to +200V_{dc} and -200V_{dc}, as the total output voltage is 400 V_{dc} and the total output power is 500W. Power factor correction IC UC3854 is employed in the control strategy of the Boost stage.**

I. Introduction

Power supplies have been intensively used in several types of electronic loads e.g. computers and telecommunication equipments, for they provide the necessary voltages to the accurate operation of electronic circuits. As they have become more sophisticated [1] [2], their weight and size have decreased significantly, what increases the functionality and the efficiency. Generally, such equipments use ac voltages as a primary power supply, which must be converted to dc voltages, since most of the systems require high quality dc power.

The use of switched-mode power supplies (SMPS) is prominent, because they provide multiple output dc voltages, constant switching frequency and reduced size and weight. However, their input stages are well known to be harmonic sources. Recently, there has been great interest about the reduction of the input current harmonic content and power factor correction (PFC) [3]. Moreover, in many single-phase applications, mainly in power supplies, the power levels can reach several kilowatts and, in some cases, the input voltage can be quite high as well. For such types of application, the conventional Boost PFC converter has been mainly used due to the dc voltage gain characteristics, lower inductor size and weight, and losses on the power devices, which will affect cost, efficiency, and power density [4]-[6]. This converter behaves as a perfect preregulator stage, but it presents considerable commutation and conduction losses, bringing reduction in the overall efficiency.

This paper presents a symmetrical power supply that employs a self-oscillating auxiliary converter to supply drive and control circuits. It is composed of two symmetrical units that operate at 100kHz, and a Boost converter is used as a preregulator circuit to provide power factor correction. The output voltages of the units are equal to +200V_{dc} and -200V_{dc}, the total output voltage is +400 V_{dc}, and the total output power is 500W, as UC3854 power factor correction IC is employed in the Boost stage control strategy.

II. The Self-Oscillating Auxiliary Converter

Most of converters require a small amount of auxiliary power to supply control and drive circuits, as the auxiliary requirements are often derived from low frequency line transformers. This is not quite efficient, once the transformer size will be determined according to the need to meet VDE and UL creepage distance specifications rather than by the power needs. Therefore the transformer size will be larger than is required to meet the power requirements alone.

Highly efficient low-cost transformers can be produced using self-oscillating techniques in order to overcome this problem. In self-oscillating converters, switching is maintained by positive feedback from a winding on the main transformer. The frequency is controlled either by saturation of the main transformer or a subsidiary drive one, or in some cases by a drive clamping action that responds to the increase in magnetizing current during the conduction period.

Fig. 1 shows a one-switch self-oscillating power supply. This converter operates in flyback mode, and is useful for low-power, constant-load applications, such as auxiliary supplies for control circuits. The operation principle is described as follows.

At the startup, the current in *R2* turns on *Q*, as positive regenerative feedback is developed by drive winding *L1* and applied to *Q* via *C2* and *D1*, so that it turns on rapidly. The current in the collector, and hence in the emitter, will then increase linearly at a rate defined by the primary inductance and the supply voltage.

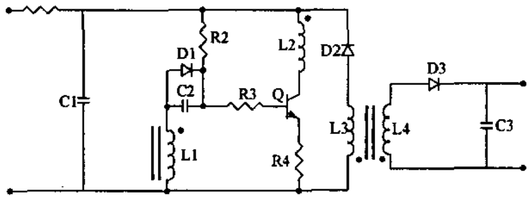


Fig. 1. Primary voltage-regulated self-oscillating flyback converter for low-power auxiliary supplies

As the emitter current increases, the voltage across *R4* will also increase, until it reaches the value generated by the feedback winding *L1*. At this point, the base current to *Q* will be "pinched off" and *Q* will start to turn off. By normal flyback action, the voltages on all windings will now reverse, and regenerative turn-off will be applied to the base of Q by the drive winding L1 and capacitor *C2*.

This "off" state will now continue until all the energy that was stored in the transformer during the "on" period is transferred to the input circuit. At this point, the voltage across all windings will begin to fall toward zero. Now, as a result of the charge that has been developed across *C2* by the current in *R2* as the drive winding *L1* returns to zero, the base of *Q* will, once again, be taken positive, and *Q* will be turned on again, as a new cycle begins.

The operation frequency is controlled by the primary inductance, the value of *R4*, the reflected load current and voltage, and the selected feedback voltage on *L1*.

To minimize the frequency change resulting from load variations, the turn-off time must be maintained nearly constant, what is achieved by storing sufficient energy during the "on" period to keep the energy recovery diode *D2* in conduction mode during the complete flyback period. By this means, the flyback voltage is maintained constant. This requires that the flyback energy considerably exceeds the load requirements, so that the spare energy will be returned to the supply line during the complete flyback period, keeping *D2* in conduction. The transformer inductance will be selected to obtain this condition by adjusting the core gap size.

III. The Proposed Symmetrical Switched Power Supply

The Boost PFC stage and the dc-dc stages are shown in Fig. 2 and Fig. 3, respectively. The dc-dc converters consist of two Forward topologies that provide symmetrical output voltages, and can be associated so that the total output voltage is equal to 400 V_{dc}. A high power factor is obtained by employing the average current control waveshaping technique using UC3854. The association of the aforementioned stages provides the proposed switched power supply presented in Fig. 4.

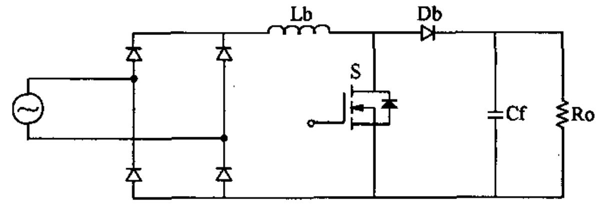
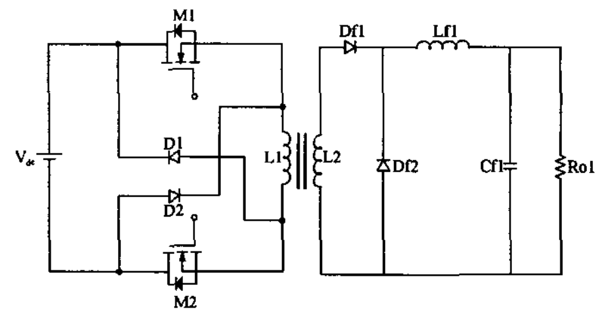
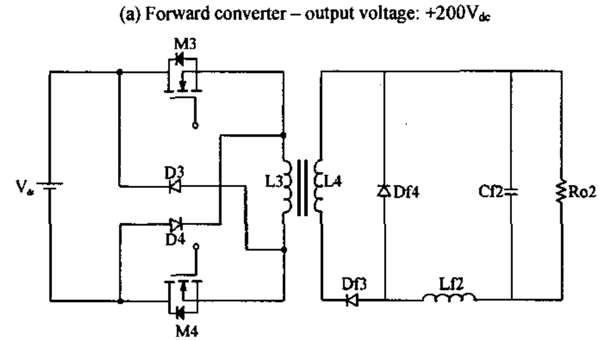


Fig. 2. Conventional Boost converter



(a) Forward converter – output voltage: +200V_{dc}



(b) Forward converter – output voltage: -200V_{dc}

Fig. 3. Conventional dc-dc Forward converters

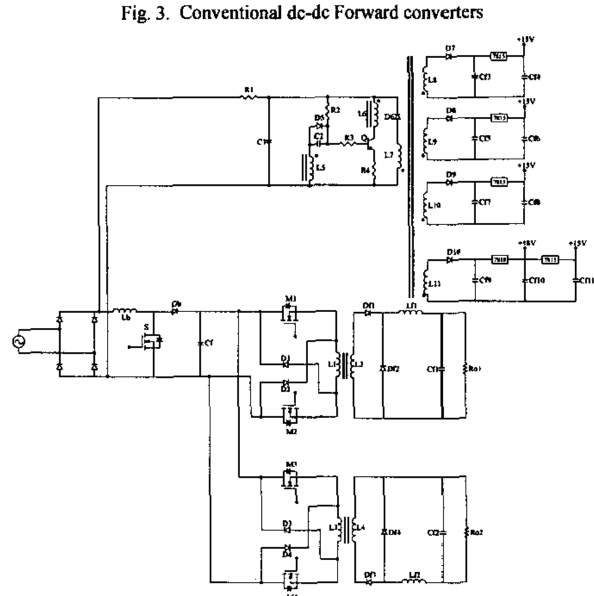


Fig. 4. Proposed switched power supply

IV. EXPERIMENTAL RESULTS

Experimental tests have been performed on the proposed SMPS shown in Fig. 4, as the following parameters set was employed. Diodes are MUR1560, switches *S*, *M1*, *M2*, *M3*, *M4* are MOSFETs IRFP460 and *Q* is bipolar transistor BC337.

Fig. 5 presents the ac input voltage and the gate signal in switch *S* waveforms obtained experimentally.

Fig. 6 and Fig. 7 evidence the power factor correction when the input voltage is $127V_{ac}$ and $220V_{ac}$, respectively, and also show the harmonic content of the input voltage and input current.

TABLE I. PARAMETERS SET EMPLOYED IN TESTS

Parameter	Value
C1	50μF
C2	500nF
Cf	330μF
Cf1, *Cf2*	10μF
Cf3,...*Cf11*	10μH
L1, *L3*	730μH
L2, *L4*	310μH
L6, *L7*	10mH
L8, *L9*, *L10*	30mH
L11	35mH
Lb	600μH
Lf	30μH
Lf1, *Lf2*, *Lf3*	50μH
R1	2kohms
R2	100kohms
R3	36ohms
R4	10ohms
f_s	100kHz
V_{o1}	$+200V_{dc}$
V_{o2}	$-200V_{dc}$
P_o	500W
I_o	1.5A

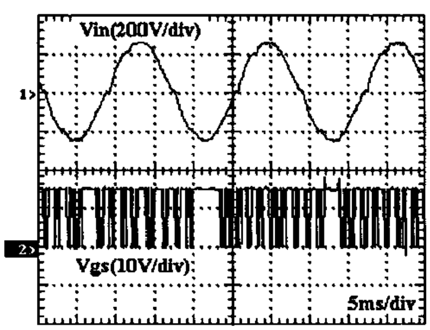
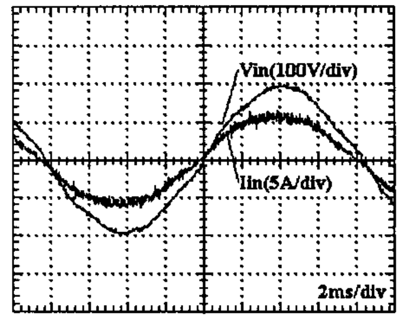
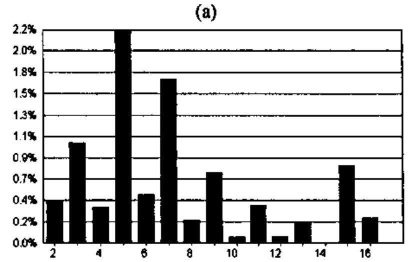


Fig. 5. Input voltage and gate signal in switch *S*



(a)



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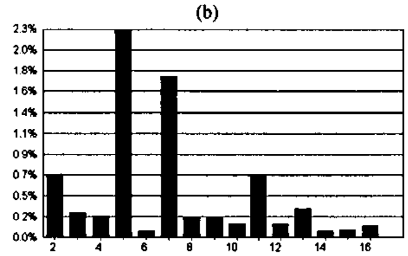
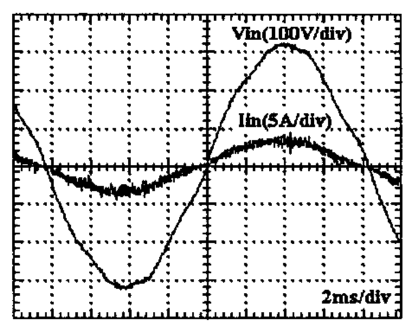
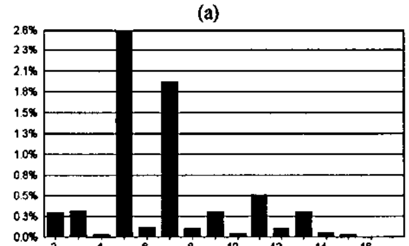


(c)

Fig. 6. Experimental results: $V_{in}=127V_{ac}$
(a) Input voltage and input current
(b) Harmonic content of the input voltage
(c) Harmonic content of the input current



(a)



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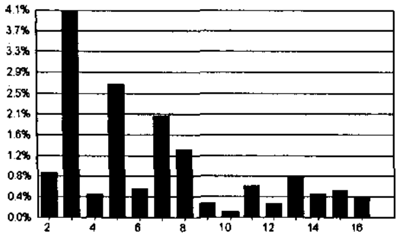

(c)

Fig. 7. Experimental results: V_{in}=220V_{ac}
(a) Input voltage and input current
(b) Harmonic content of the input voltage
(c) Harmonic content of the input current

TABLE II. MEASURED RESULTS – V_{IN}=127V_{AC}

Parameter	Value
Input voltage	127V_{ac}
Input current	4.56A
Input power factor	0.990
Input power	570W
THD_V	3.11%
THD_I	3.33%

TABLE III. MEASURED RESULTS – V_{IN}=220V_{AC}

Parameter	Value
Input voltage	220V_{ac}
Input current	2.36A
Input power factor	0.993
Input power	523W
THD_V	3.34%
THD_I	5.79%

Table II and Table III show some relevant experimental results obtained when the input voltage is 127V_{ac} and 220V_{ac}, respectively. One can see that the input power factor is almost unity, and that the voltage and current total harmonic distortion rates are relatively low.

Additional tests were carried out in order to evaluate the dynamics of the converter, when the input voltage is 220V_{ac}. Fig. 8 depicts the output voltage control performance with and without load. Fig. 9 illustrates the output current control performance when a short circuit in the output side of the power supply occurs.

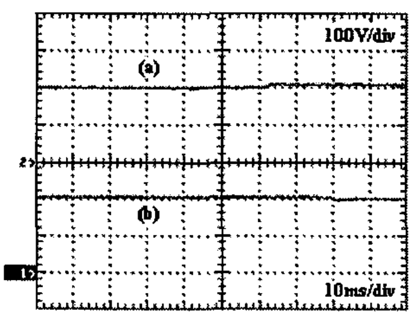

Fig. 8. Output voltage control response
(a) Positive load step
(b) Negative load step

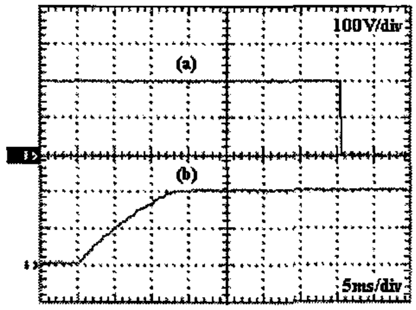

Fig. 9. Output current control response
(a) Beginning of the fault
(b) End of the fault

V. CONCLUSION

This paper reports results concerning the development of a symmetrical switched power supply using the PFC ac/dc Boost converter. It has been demonstrated that the use of the average current waveshaping control technique implies a highly efficient power factor correction, allowing a good performance in high frequencies. The presented SMPS employs two Forward structures as dc-dc stages, so that an output voltage equal to 400V_{dc} can be achieved. The current and voltage total harmonic distortion rates obtained experimentally are considered low, and an almost unity input power factor is achieved.

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