A HIGH POWER FACTOR SYMMETRICAL SWITCHED-MODE POWER SUPPLY

Fernando Lessa Tofoli
Universidade Federal de Uberlândia
fernandolessa@pop.com.br

Carlos Alberto Gallo
Universidade Federal de Uberlândia
gallo@eel.ufu.br

Resumo

Este trabalho propõe a concepção de uma fonte chaveada com correção de fator de potência, obtida através de uma integração de soluções, ou seja, a associação de um conversor ca/cc e dois conversores cc/cc. Um estágio ca;cc pré-regulador do tipo boost é utilizado, obtendo-se tensão de alimentação universal e conteúdo harmônico reduzido da corrente de entrada. Dois conversores forward são empregados na conversão cc/cc de forma a se obter dois estágios na forma de fonte simétrica.

Palavras-chave: *correção de fator de potência, fontes chaveadas.*

Abstract

This paper proposes a switched-mode power supply (SMPS) with power factor correction. A pre-regulator boost converter is employed in order to obtain universal line voltage and reduced harmonic content of the input current. Two dc/dc forward converters are used so that two symmetrical output stages are obtained. The association of the aforementioned ac/dc and dc/dc converters results in a high power factor SMPS.

Keywords: *power factor correction, SMPS.*

1. Introduction

Power supplies have been intensively used in several types of electronic loads (e.g. computers and telecommunication devices). They provide the necessary voltages to the accurate operation of electronic circuits. As they have become more sophisticated (STAFFIERE et al., 2001; MANKIKAR, 2001), their weight and size have decreased significantly, increasing their functionality and efficiency. Generally, such loads use AC voltages as primary power sources, which must be converted to dc voltages, since most of the systems require high quality dc power.

Linear power supplies are adequate for low power applications, but are uneconomical and inefficient as more power is demanded. Then, 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 when compared to linear power supplies. However, the input stages of switched-mode power supplies 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) (LEE et al., 2001). 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 converter has been widely used due to the dc voltage gain characteristics, lower inductor size and weight, and reduced losses in the power devices (ZHANG et al., 1995; MIWA et al., 1992 and FROEHLEKE et al., 1992). It is a prominent choice since such characteristics affect cost, efficiency, and power density directly.

This paper presents the application of a boost converter as a pre-regulator stage in order to provide power factor correction in a dc/dc converter, where the combination of both stages results in a switched power supply composed of two symmetrical units that operate at 100kHz. The output voltages of the units are equal to +200V and -200V, the total output voltage is 400V, and the total output power is 500W, as UC3854 power factor correction IC is employed in the control strategy of the boost stage.

2. The proposed symmetrical switched power

The boost PFC stage and the dc/dc stages are shown in Figures 1 and 2, respectively. The dc/dc converters are two Forward topologies that provide output voltages equal to +200V and -200V, and can be associated so that the total output voltage is equal to 400V. In Figure 2 (a), one can see that multiple secondary windings exist, which act as auxiliary power supplies to control circuitry.

A high power factor is obtained by employing the average current control waveshaping technique using UC3854 IC. The association of the aforementioned stages is depicted in Figure 3.

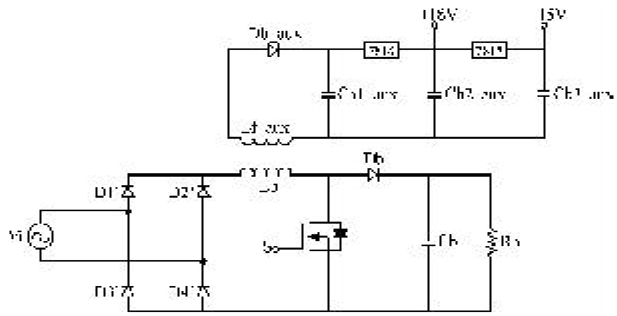
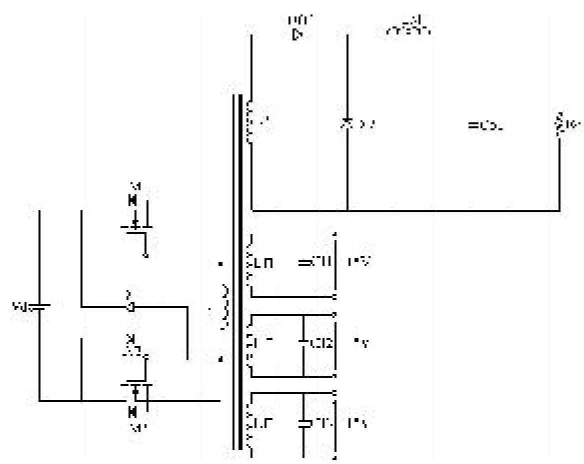
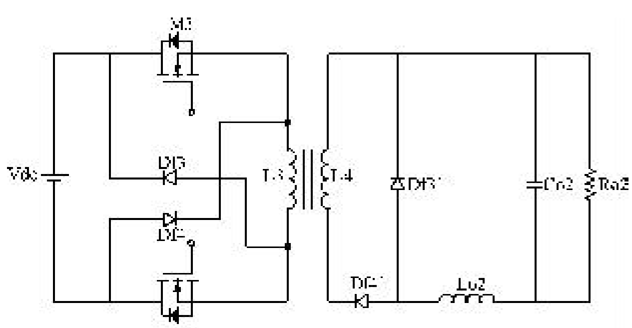


Figure 1: Ac/dc boost converter.



(a) Forward converter: output voltage = +200V



(b) Forward converter: output voltage = -200V

Figure 2: Dc/dc Forward converters.

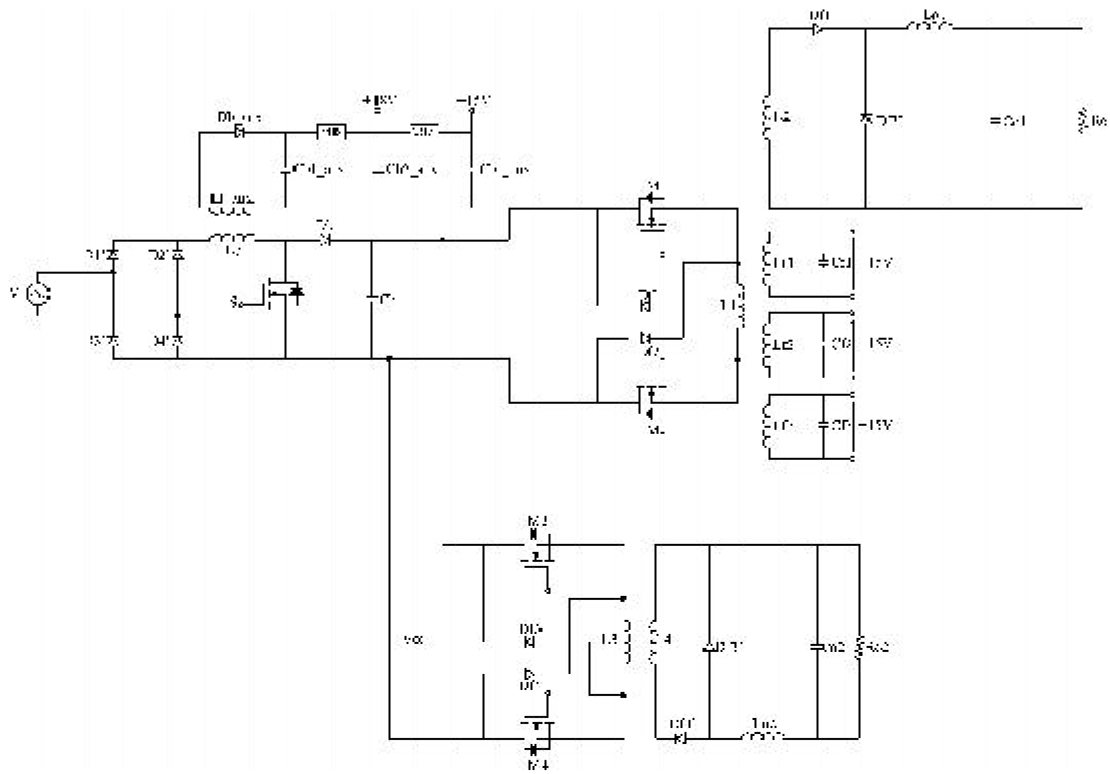


Figure 3: Proposed switched-mode power supply.

3. Control strategy

The Boost stage operates with constant switching frequency and high power factor, using the average current mode control (DIXON, 1992) (Figure 4), which eliminates many serious problems, such as poor noise immunity, a need for slope compensation, and peak-to-average current errors which the inherently low current loop gain can not correct (ROSSETTO et al., 1994).

The block diagram of the control circuit of the Boost power stage is shown in Figure 5. The input current and line voltage samples are obtained from sensors, as the voltage sample is rectified by a precision rectifier. The PI controller is implemented to provide the control signal which is multiplied by the reference voltage. Then, this signal is added to the sawtooth signal, what generates the reference current signal. Drive signals are provided comparing the current feedback signal, obtained in a sensor, with the reference current signal. In this case, this process is implemented by UC3854 (TODD, 2005).

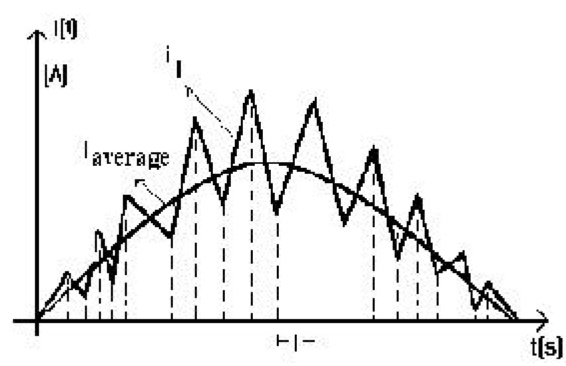


Figure 4: Principle of the average current mode control.

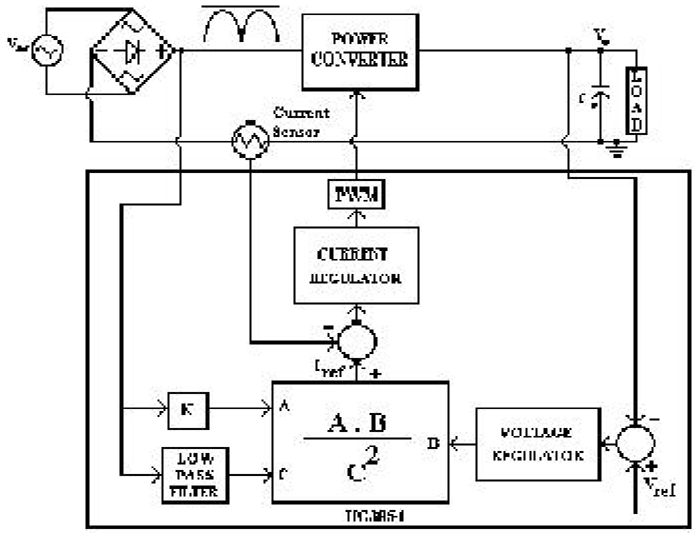


Figure 5: Control strategy applied to the Boost converter.

4. Experimental results

Experimental tests were performed on the proposed SMPS as the parameter set shown in Table 1 was employed.

Table 1: Parameters set used in experimental tests.

Boost Converter: AC/DC Stage	
Parameter	**Value**
Input ac voltage	V_{in}=127/220V_{ac}
Switching frequency	f_s=100 kHz
Boost diode	MUR860
Switch *S*	IRFP460
Boost inductor	*Lb*=600mH
Output capacitor	*Cb*=2100mH
Auxiliary diode	MUR860
Auxiliary inductor	*Lf_aux*=30mH
Auxiliary capacitors	*Cf1_aux*=*Cf2_aux*=*Cf3_aux*=10mF
Forward Converters: DC/DC Stages	
Parameter	**value**
Input DC voltage	V_{DC}=300V
Switching frequency	f_s=100kHz
Diodes *Df1*, *Df2*, *Df1'*, *Df2'*, *Df3*, *Df4*, *Df3'*, *Df4'*	MUR1560
Switches *M1*, *M2*, *M3*, *M4*	IRFP460
Primary windings	*L1*=*L3*=310mH
Secondary windings	*L2*=*L4*=730mH
Auxiliary windings	*Lf1*=*Lf2*=*Lf3*=50mH
Output capacitors	*Co1*=*Co2*=330mF
Output inductors	*Lo1*=*Lo2*=50mH
Filter capacitors	*Cf1*=*Cf2*=*Cf3*=10mF
Output voltages	V_{o1}=V_{o2}=200V
Output power	500W

Figure 6 presents the ac input voltage and gating signal applied to switch *S*. The gating signals are obtained from IC UC3854, which is responsible for unity power factor.

Figures 7 and 8 depict power factor correction when the input voltage is 127V and 220V, respectively. Additionally, the harmonic contents of the input voltage and input current are also presented. One can see that the displacement power factor is near unity, and the reduced harmonic content of the input current is evidenced as well.

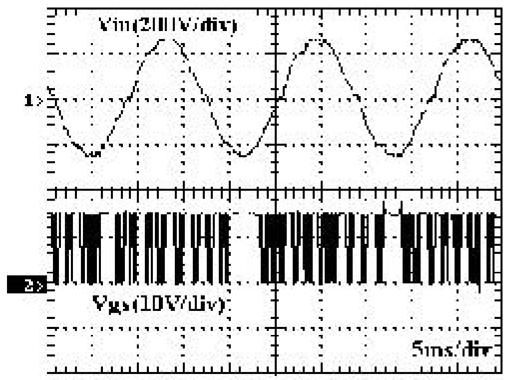
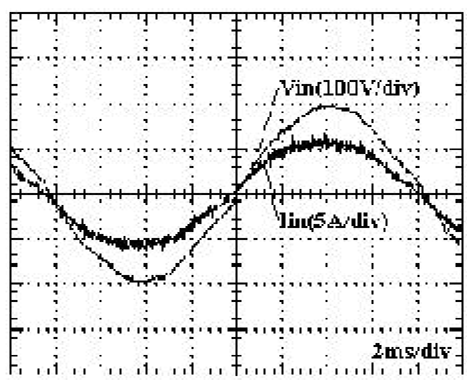
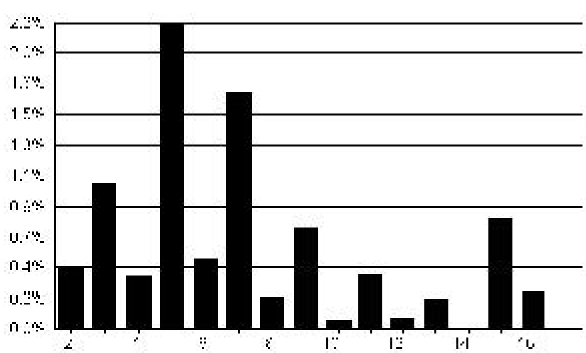


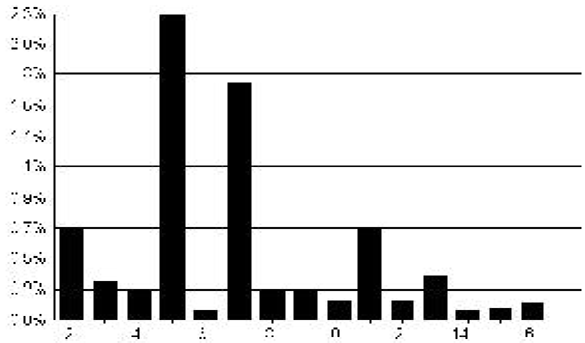
Figure 6: Input voltage and gate signal in switch S.



(a) Input voltage and input current

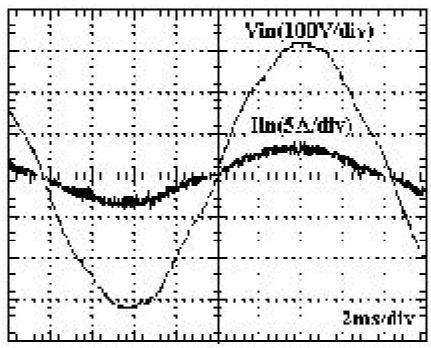


(b) Harmonic content of the input voltage

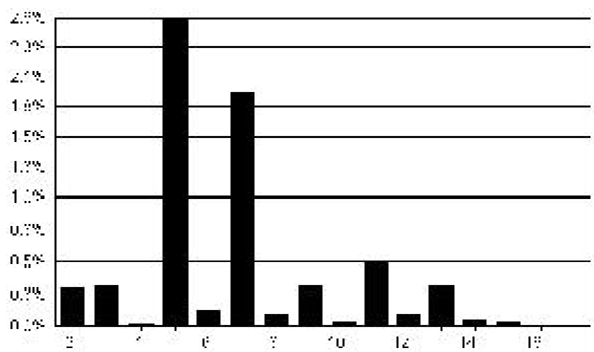


(c) Harmonic content of the input current

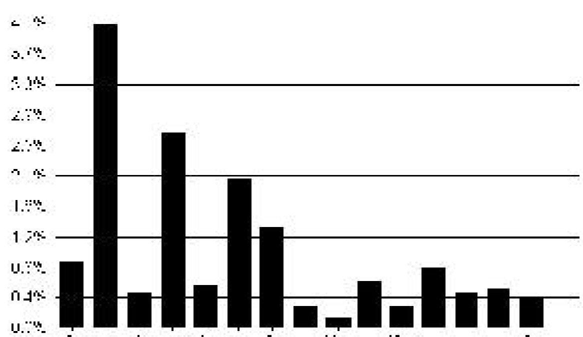
Figure 7: Experimental results: V_{in}=127V.



(a) Input voltage and input current



(b) Harmonic content of the input voltage



(c) Harmonic content of the input current

Figure 8: Experimental results: V_{in}=220V.

Tables 2 and 3 show some relevant experimental results obtained when the input voltage is 127V and 220V, respectively. One can see that the input power factor is almost unity, and that the current total harmonic distortion rate is low if compared to conventional diode rectifiers.

Table 2:. Measured results – V_{in}=127V.

Parameter	Value
Input voltage	V_{in}=127V
Input current	I_{in}=4.56A
Displacement power factor	cos ϕ_1=0.990
Input power	P_o=570W
Voltage distortion	THD_V=3.11%
Current distortion	THD_I=3.33%

Table 3: Measured results – V_{in}=220V.

Parameter	Value
Input voltage	V_{in}=220V
Input current	I_{in}=2.36A
Displacement power factor	cos ϕ_1=0.993
Input power	P_o=523 W
Voltage distortion	THD_V=3.34%
Current distortion	THD_I =5.79%

Additional tests were carried out in order to evaluate the converter dynamics, when the input voltage is 220V. In Fig. 9, the converter is evaluated at nominal load and no load condition, as satisfactory output voltage regulation is observed. In Fig. 10, short circuit in the output side of the power supply occurs, as the output current becomes null due to control system action in order to minimize damage.

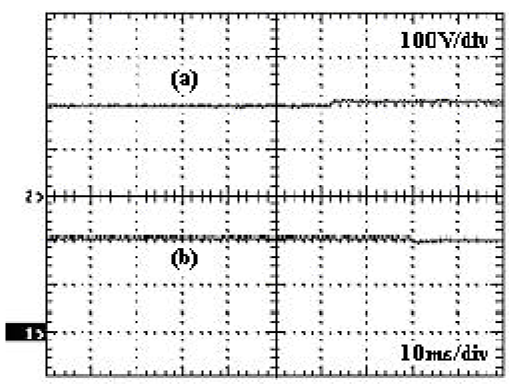


Figure 9: Output voltage control response

(a) Positive load step;

(b) Negative load step.

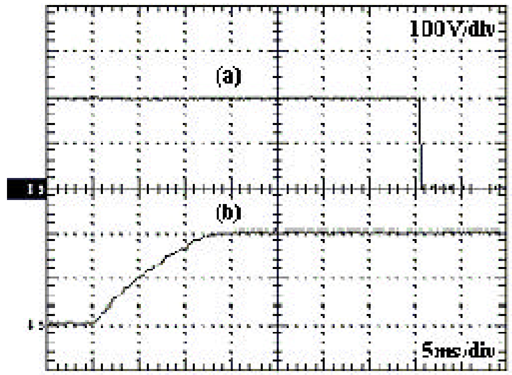


Figure 10: Output current control response

(a) Beginning of the fault;

(b) End of the fault.

Finally, Figure 11 shows the efficiency of the proposed system, which is about 86% at nominal load. It must be considered that the SMPS presented in this paper is composed of two stages, and efficiency tends to be lower than that in a single stage structure.

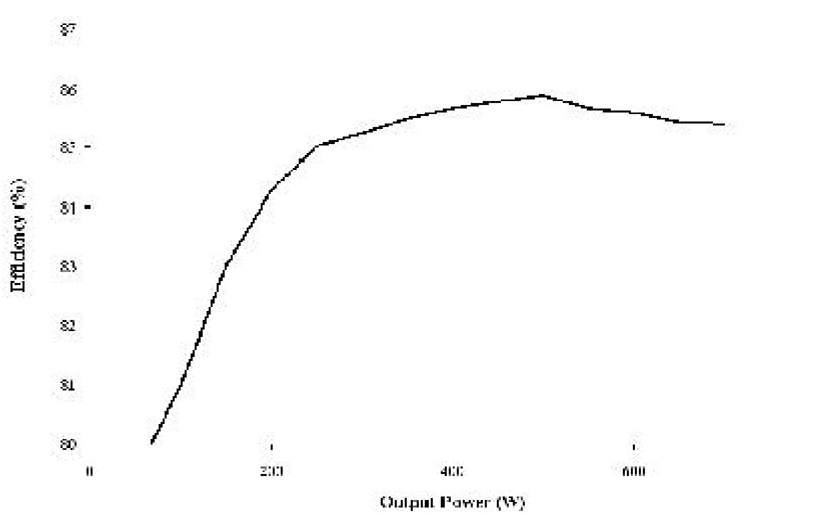


Figure 10: Efficiency as a function of output power.

5. Conclusion

This paper has reported 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 good performance in high frequencies. The proposed SMPS employs two forward structures as dc/dc stages, so that an output voltage equal to 400V can be obtained. The current total harmonic distortion rates obtained experimentally is considered low if compared with conventional diode rectifiers, and near unity input power factor is achieved. Furthermore, experimental tests demonstrate satisfactory output voltage regulation and protection against short circuit condition.

References

DIXON, L. *Average current mode control of switching power supplies.* Colorado: University of Colorado, 1990. UNITRODE. Application Note U140.

FROEHLEKE, N. et al. CAE-Tool for optimizing development of switched mode power supplies. In: APPLIED POWER ELECTRONICS CONFERENCE, 2001, Anaheim. *Proceedings...* Anaheim, 2001. p. 752-758.

LEE, F. C. et al. Evaluation of input current in the critical mode boost PFC converter for distributed power systems. In: APPLIED POWER ELECTRONICS CONFERENCE, 2001, Anaheim. *Proceedings...* Anaheim, 2001. p. 130-136.

MANKIKAR, M. Analysis of various power supply business models. APPLIED POWER ELECTRONICS CONFERENCE, 2001, Anaheim. *Proceedings...* Anaheim, 2001. p. 54-57.

MIWA, B. A.; OTTEN, D. M.; SCHLECHT, M. F. High efficiency power factor correction using interleaving techniques. In: APPLIED POWER ELECTRONICS CONFERENCE, 1992, Boston. *Proceedings...* Boston, 1992. p. 368-375.

ROSSETTO, L.; SPIAZZI, G; TENTI, P. Control techniques for power factor correction converters. In: POWER ELECTRONICS, MOTION CONTROL (PEMC), 1994, Kosice. *Proceedings...* Kosice, 1994. p. 1310-1318.

STAFFIERE, D.; MANKIKAR, M. Power technology roadmap. In: ANNUAL IEEE APPLIED POWER ELECTRONICS, 16., 2001, Amherst. *Proceedings...* Amherst, 2001. p. 49-53.

ZHANG, M.T.; JIANG, Y. LEE, F. C.; JOAVANOVIC, M. M. Single-phase three-level boost power factor correction converter. In: IEEE APPLIED POWER ELECTRONICS CONFERENCE, 1995, Dallas. *Proceedings...* Dallas, 1995. p. 434-439.

ABOUT THE AUTHORS

Carlos Alberto Gallo
He received the BSc and MSc degrees in Electrical Engineering from the Federal University of Uberlândia, Brazil, in 2000 and 2002, respectively. He is now PhD student at the Power Electronics Research Group of the same university.. His research interests include high-frequency power conversion, microprocessor-based control of power converters, power factor correction topologies and UPS systems.

Fernando Lessa Tofoli
He received the BSc and MSc degrees in Electrical Engineering from the Federal University of Uberlândia, Brazil, in 1999 and 2002, respectively. Nowadays he is PhD student at the Power Electronics Research Group of the same university. His research interests include power quality related issues, high power factor rectifiers and soft switching techniques applied to static power converters.