A COMPARISON BETWEEN THE BOOST AND THE DOUBLE BOOST CONVERTERS WITH INDUCTIVE COUPLING

C. A. Petry and I. Barbi
Power Electronics Institute - INEP
Dept. of Electrical Engineering - EEL
Federal University of Santa Catarina – UFSC
P. O. box 5119 – 88040-970 – Florianópolis – SC- Brazil
petry@inep.ufsc.br and ivobarbi@inep.ufsc.br

Abstract **– This work presents a comparative study between the two converters: Conventional Boost and the Double Boost with Inductive Coupling. Principle of operation, comparative analytical study and experimental results are shown. 120W converters with a range of input voltage from 9 to 16V and 60V of output voltage were implemented and the results are presented.**

KEYWORDS

Boost, Double Boost, DC-DC and inductive coupling.

I. INTRODUCTION

The development of DC-DC and PFCs converters applied in telecommunication, solar energy conversion, domestic equipments, among others, is a current subject of research in power electronics. These structures can operate with low and high powers, many times with small voltages and high currents at the input side [1,4]. Conventional Boost (BC) converters, with one inductor and one switch only, exhibit good performance when the output voltage is not very greater than the input voltage [2].

Double Boost Converters with a Coupling Inductor (DB) are used to reduce the switching currents and the volume of the magnetic and capacitive elements. These converters operating at the boundary of continuous-conduction mode and discontinuous-conduction mode improve the efficiency. However, they can require a variable switching frequency [2].

A Boost converter that used two inductors and one auxiliary transformer was presented in [2]. The voltage across the switches has half the value of the output voltage and the static gain is multiplied by four in relation with the conventional Boost Converter. However, the output and the switches aren't at the same ground. Current-Fed Converters with one and two inductors are analyzed in [3]. That paper appoints that the Boost Converter with two inductors was better.

Families of DC-DC converters were proposed in [4]. The complete theoretical and experimental study was realized for the Double Boost Converter with Inductive Coupling. The switches and the output voltage have the same ground.

In this work, we will realize a comparative study between the BC and DB converters operating in continuous-conduction mode, because in discontinuous-conduction mode the effort over the switches and the emission of EMI are bigger.

II. CONVERTER STRUCTURE AND PRINCIPLE OF OPERATION

The Double Boost Converter is shown in Fig. 1. L_i is the Boost inductor and T_1 is the coupling transformer, which has the finality of distributing the current between the two commutation cells. S_1/D_1 forms a commutation cell and S_2/D_2 forms another one. The output filter capacitor is C_o and R_o represents the load.

The Double Boost Converter has four operation stages, distinct for operation with duty cycle above or below 0.5.

Operation stages for D≤0.5 are shown in Fig. 3 and Fig. 4 shows the main waveforms for this operation mode. The energy is storage in L_i and transferred to output for the first and third stages. In the second and fourth stages the energy is only transferred to the output.

Fig. 5 shows the operation stages for D≥0.5 and the main waveforms are shown in Fig. 6. In the first and third stages the energy is stored in L_i, which is transferred to the output in the second and fourth stages.

Following, we will make an analytical study between the BC and DB converters. Static gain, output characteristics, current and voltage ripple will be compared.

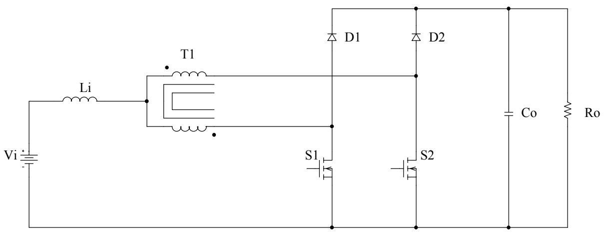

Fig. 1 – Double Boost Converter structure.

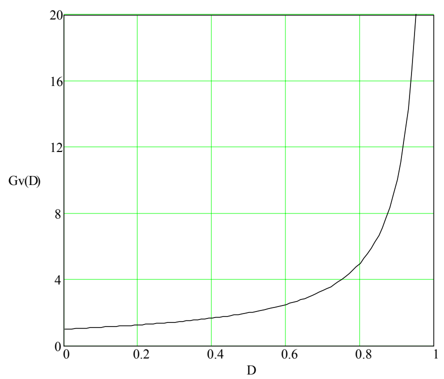

Fig. 2 – Static gain as a function of duty cycle.

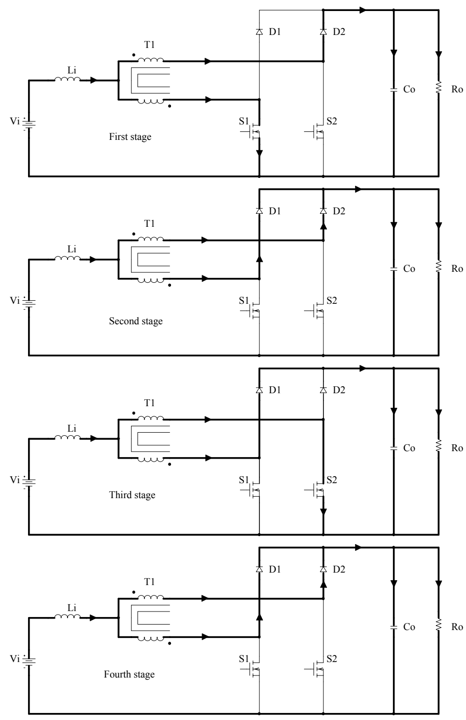

Fig. 3 – Stages for D≤0.5.

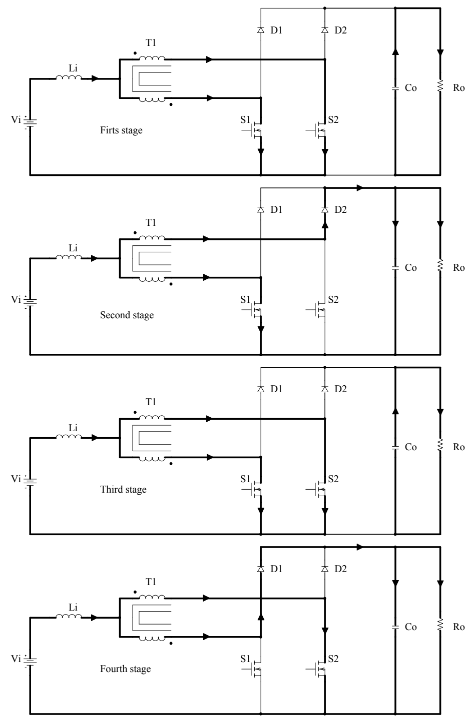

Fig. 5 – Stages for D≥0.5.

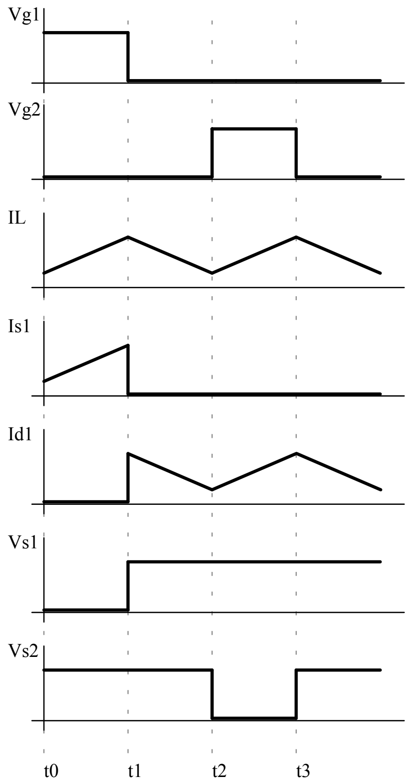

Fig. 4 – Main waveforms for D≤0.5.

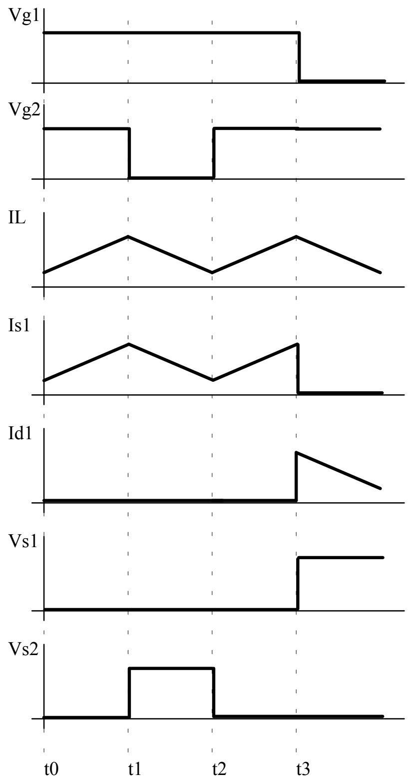

Fig. 6 – Main waveforms for D≥0.5.

III. COMPARATIVE AND ANALYTICAL STUDY

The static gain of the converters in function of the duty cycle is given by (1) and shown by Fig. 2. The BC and DB converters have the same expression. However, the DB converter needs a more elaborate circuit to implement the switches command, because the mode of command is distinct for D<0.5 or D>0.5.

$$Gv = \frac{V_o}{V_i} = \frac{1}{1-D} \tag{1}$$

The output characteristics for the DB converter are given by expressions (2) and (3), for D<0.5 and D>0.5, respectively. Fig. 7 and Fig. 8 shown expressions (2) and (3).

$$Gv = \frac{2 \cdot D^2 + \gamma}{\gamma + D^2} \quad (2)$$

$$Gv = \frac{(2 \cdot D - 1)^2}{\gamma} + 2 \quad (3)$$

$$\gamma = \frac{4 \cdot L_i \cdot I_o}{V_i \cdot T_s},\ T_s = \frac{1}{f_s} \quad (4)$$

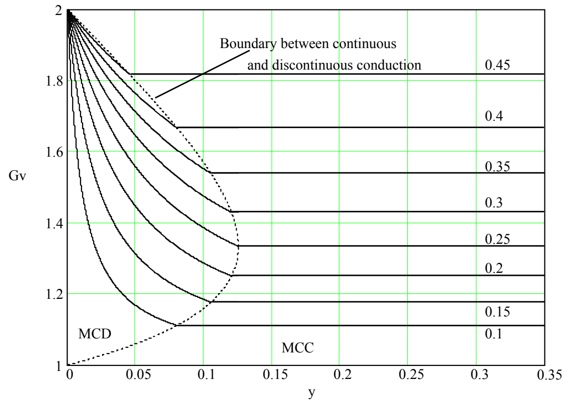

Fig. 7 – Output characteristic for D<0.5 – DB.

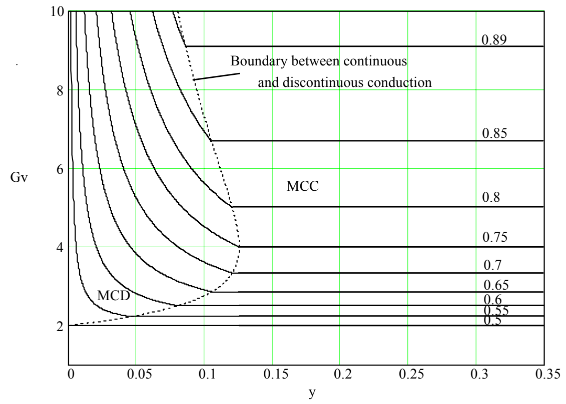

Fig. 8 - Output characteristic for D>0.5 – DB.

For the BC converter, the output characteristics are given by expressions (5) and (6) and shown by Fig. 9.

It's verified by Fig. 7, Fig. 8 and Fig. 9 that the band of continuous conduction of the converter DB is greater than the same band of the BC converter. Therefore from (4) and (6) we have $\gamma_{BC}=\gamma_{DB}/2$.

Expressions (7) and (8) give the normalized current ripple of inductor L_i for the BC and DB converters and Fig. 10 shows its curves.

$$Gv = \frac{\gamma + D^2}{\gamma} \quad (5)$$

$$\gamma = \frac{2 \cdot L_i \cdot I_o}{V_i \cdot T_s},\ T_s = \frac{1}{f_s} \quad (6)$$

$$\beta_{DB} = \frac{L_i \cdot \Delta I_{L_i}}{T_s \cdot V_o} = \left| \begin{array}{ll} \frac{(1-2 \cdot D) \cdot D}{2} & \to D < 0.5 \\ \frac{(2 \cdot D - 1) \cdot (1-D)}{2} & \to D > 0.5 \end{array} \right. \quad (7)$$

$$\beta_{BC} = \frac{L_i \cdot \Delta I_{L_i}}{T_s \cdot V_o} = (1-D) \cdot D \quad (8)$$

We can note that for the same values of L_i, V_o and f_s, the current ripple of the BC converter is four times bigger than the DB converter's.

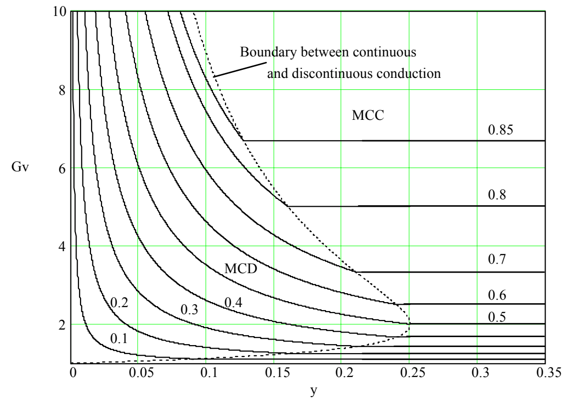

Fig. 9 - Output characteristic for BC.

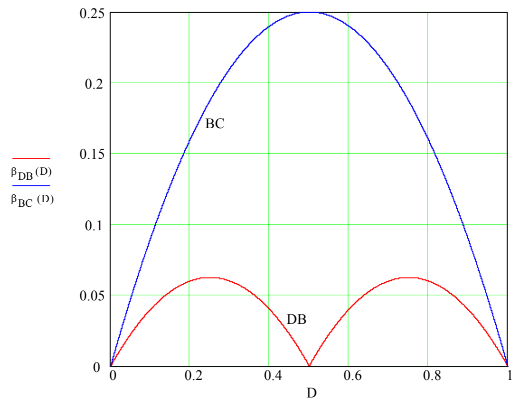

Fig. 10 – Normalized current ripple.

The boundary inductance is given by expressions (9) and (10) for the DB and BC converters, respectively. Fig. 11 shows the result of expressions (9) and (10).

$$\gamma_{DB} = \frac{2 \cdot L_i \cdot I_o}{T_s \cdot V_i} = \left| \begin{array}{ll} \frac{(1-2 \cdot D) \cdot D}{2} & \to D < 0.5 \\ \frac{(2 \cdot D - 1) \cdot (1-D)}{2} & \to D > 0.5 \end{array} \right. \quad (9)$$

$$\gamma_{BC} = \frac{2 \cdot L_i \cdot I_o}{T_s \cdot V_i} = (1-D) \cdot D \quad (10)$$

In the same way as the current ripple, the necessary inductor in the BC converter is four times bigger than the same in the DB converter.

Expressions (11) and (12) give the normalized voltage ripple for the DB and BC converters. The curves regarding (11) and (12) are shown in Fig. 12.

$$\alpha_{DB} = \frac{C_o \cdot f_s \cdot \Delta V_{Co}}{I_o} = \begin{cases} \dfrac{(1-2\cdot D)\cdot D}{(1-D)\cdot 2} & \rightarrow D < 0.5 \\ \dfrac{(2\cdot D-1)}{2} & \rightarrow D > 0.5 \end{cases} \qquad (11)$$

$$\alpha_{BC} = \frac{C_o \cdot f_s \cdot \Delta V_{Co}}{I_o} = (1-D) \qquad (12)$$

It's verified that for the same values of C_o, I_o and f_s, the voltage ripple is two times bigger in the BC converter, in comparison with the DB converter.

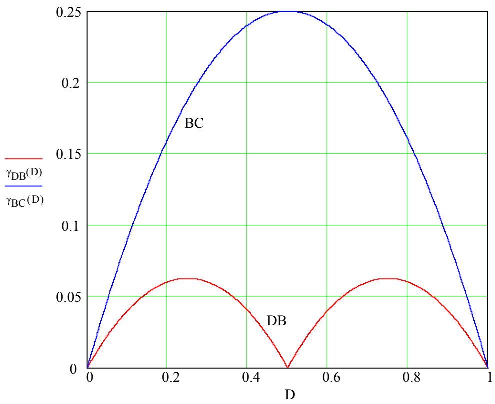

Fig. 11 – Normalized boundary inductance.

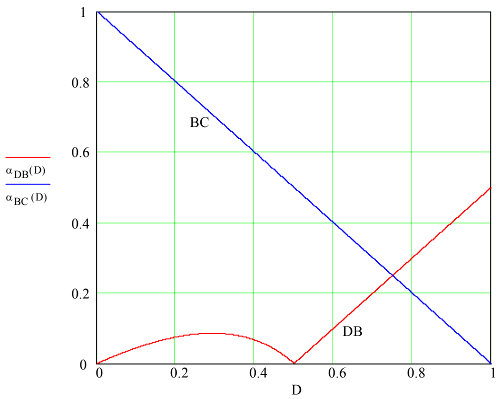

Fig. 12 – Normalized voltage ripple.

III. DESIGN EXAMPLE AND EXPERIMENTAL RESULTS

For a comparative study between the Double Boost (DB) Converter with Inductive Coupling and the Conventional Boost (BC) converter, the following parameters were designed:

- $V_i = 9...16V$ Input voltage;
- $V_o = 60V$ Output voltage;
- $P_o = 120W$ Output power;
- $\Delta V = \begin{cases} 6\% \rightarrow BI \\ 1.5\% \rightarrow BC \end{cases}$ Voltage ripple;
- $\Delta I_{L_i} = 15\%$ Current ripple;
- $f_s = 30\,kHz$ Switching frequency.

Applying the previous expressions for the DB and BC converters and using the classical methodology for inductor design, we can obtain Table 1 and Table 2.

It can be verified that the inductor of the DB converter is relatively small compared to the inductor of the BC converter. In this way, since using a coupling transformer (T_1), the magnetic elements for the DB converter are smaller than the ones of the BC converter. If the same output voltage ripple is adopted, the filter capacitor of the DB converter will have 26μF, while for the BC converter the capacitor will have 63μF. These values do not take in account the capacitor series resistance.

A disadvantage of the DB converter is the necessity of a clamper, because the transformer T_1 leakage inductances can cause spike voltages over the switches.

For the BC converter two switches in parallel were used aiming to decrease the conduction losses. Fig. 13 and Fig. 14 show the implemented converters diagrams.

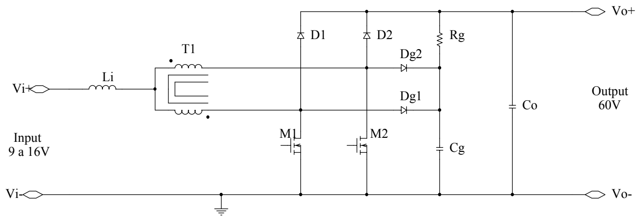

Fig. 13 – Double Boost.

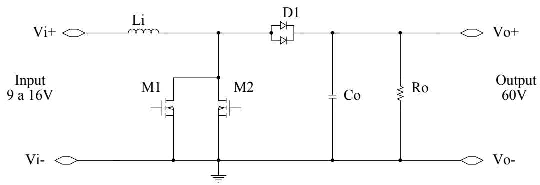

Fig. 14 – Boost Conventional.

Fig. 15 and Fig. 16 show the output voltage and the voltage over the switch S_1 for the DB and BC converters, respectively.

Fig. 17 shows the voltages over switches S_1 and S_2 for the DB converter. It can verified that the converter is operating with a duty cycle above 0.5

The waveforms from Fig. 15 to Fig. 17 were obtained for the converter operating with 120W and input voltage of 9V.

The efficiency of the Double Boost converter operating at rated power and input voltage of 9V was 86%. For the Conventional Boost converter operating at the same conditions the efficiency was 84%. It can be noted that the DB converter has a better performance than the BC converter.

Fig. 18 shows the efficiency in function of the load for the two converters. In the figure it can be observed that the Double Boost is better than the Conventional Boost. If the BC utilizes only one switch, than the difference between the two converters will be greater, evidencing the superiority of the DB converter.

Table 1

Double Boost

L_i	Inductance of 56µH Ferrite core EE 4220 Thornton 13 turns of 22 wires 22AWG in parallel Air gap of 0,091mm
C_o	2 x 3,3 µF
T_1	Ferrite core EE 4215 Thornton 10 turns of 14 wires 22AWG in parallel RT = 1
S_1 e S_2	IRL2910S – IR
D_1 e D_2	MUR820 – IR
C_g	22 nF
D_{g1} e D_{g2}	MUR120 – IR
R_g	1.5kΩ

Table 2

Conventional Boost

L_i	Inductance of 160µH Ferrite core EE 55 Thornton 27 turns of 18 wires 22AWG in parallel Air gap de 0,202mm
C_o	470 µF
S_1 e S_2	IRL2910S – IR
D_1	MUR1020 – IR

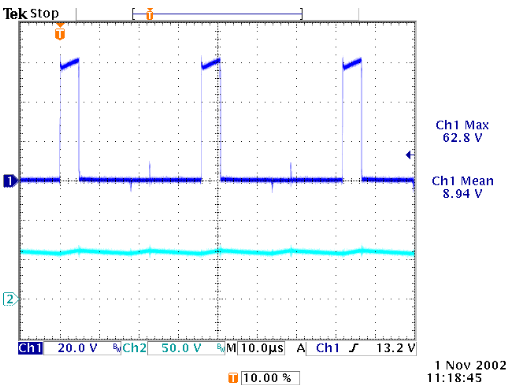

Fig. 15 – Output voltage and voltage over S_1 for the DB converter.

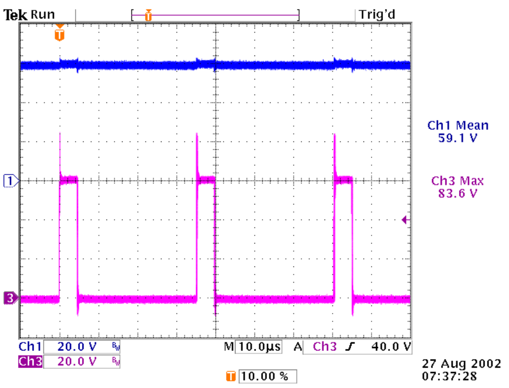

Fig. 16 - Output voltage and voltage over S_1 for the BC converter.

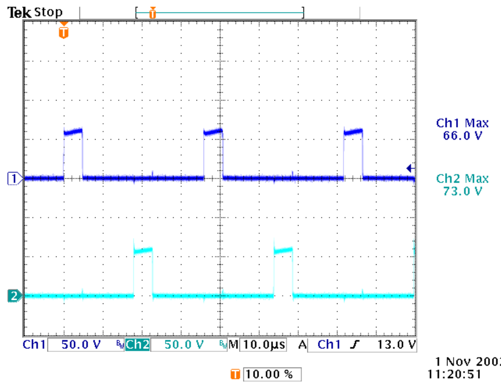

Fig. 17 – Voltages over S_1 and S_2 for the DB converter.

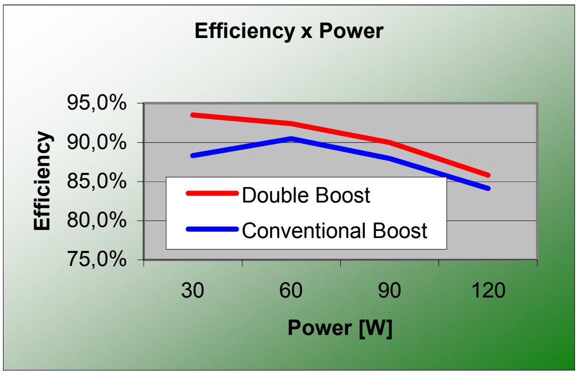

Fig. 18 – Converters efficiency as function of the power.

III. CONCLUSIONS

This paper presents a comparative study between the Conventional Boost (BC) Converter and the Double Boost (DB) Converter with Inductive Coupling. The operation stages and main waveforms for the Double Boost were shown.

By means of a comparative and analytical study between the converters we can conclude that:

- The static gain as function of the duty cycle of the two converters are the same;
- The continuous-conduction region of the DB is greater than that as the BC converter;
- The current ripple of the BC converter is four times greater than that of the DB converter, leading to a bigger inductor, in the same ratio;
- The voltage ripple of the DB converter is the half of the BC converter's, leading to a smaller capacitor, in the same ratio;

In relation to the efforts, we notice that:

- The voltage over the switches is the same for the two converters. However, for the DB converter, the voltage can provoke spikes because of transformer T_1's leakage inductances;
- Switch currents (peak, average and rms) are greater in the BC converter, even if it operates with two switches in parallel;

- Therefore, the BC converter has more switching losses that the DB converter.
- The currents (peak and average) in the BC converter are bigger when compared to the DB converter's, leading to more losses.

The conclusions about the efforts are valid for the DB converter operating with a duty cycle above 0.5. In this converter, the energy is transferred to the output at the same time that it is stored in the inductor. Therefore, the currents are small. The BC converter needs a stage to transfer energy to the output and a stage to store it in the inductor.

The Double Boost converter uses a more elaborate circuit to command the switches, since the command is distinct for a duty cycle above or below 0.5. For $D<0.5$ the command signals don't overlap, but when $D>0.5$, the signals must overlap. The experimental results for a Conventional Boost and a Double Boost with Inductive Coupling operating with an input voltage of 12V and output of 60V and 120W of power were presented. The efficiency of the Double Boost was better than that of the Conventional Boost, even if two switches in parallel had been used in the latter.

The coupling transformer has a small leakage inductance; therefore, a clamp circuit must be used in the Double Boost.

The control of the converters is identical. So, the Double Boost converter can be used for power factor correction.

ACKNOWLEDGEMENT

The authors would like to thank CNPq for their financial support and Marlos Gatti Bottarelli for his contributions in building the laboratory prototype.

REFERENCES

[1] BASCOPÉ, Grover V. Torrico and BARBI, Ivo. Generation of a family of non-isolated DC-DC PWM converters using new three-state switching cells. Power Electronics Specialists Conference, 2000. PESC 00. 2000. Pp: 858 –863. Vol. 2.

[2] JANG, Yungtaek and JOVANOVIÉ, Milan M. New Two-Inductor Boost Converter With Auxiliary Transformer. Applied Power Electronics Conference and Exposition, 2002. APEC 2002. Pp: 654 -660. Vol. 2.

[3] FILHO, W. C. P. and BARBI, Ivo. A Comparison Between Two Current-Fed Push-Pull DC-DC Converters-Analysis, Design and Experimentation. Telecommunications Energy Conference, 1996. INTELEC '96, 6-10 Oct 1996. Pp: 313 –320.

[4] BASCOPÉ, Grover V. Torrico. Nova Família de Conversores CC-CC PWM Não Isolados Utilizando Células de Comutação de Três Estados, SC – Brasil, 2001. Tese de Doutorado em Engenharia Elétrica – Centro Tecnológico, Universidade Federal de Santa Catarina.