DOUBLE FORWARD CONVERTER WITH SIMETRICAL OUTPUT VOLTAGE AND SOFT SWTICHING

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***Resumo.** This paper presents a new topology of soft-switching two-switch Forward converter associated to a quadratic Boost converter, which provides large voltage step-up (from 12Vdc to 80Vdc). The combination of the stages results in a switched-mode power supply (SMPS), whose output voltages are +200Vdc and -200Vdc. The inverter put in these converter is very fast and simple, because it has a little components quantity, and this form can be said that this control is very robust, and in the other side, the control presents a low cost. The little volume presented in this converter present other important thing, because it has a small volume and this form, have a big energy density. The operation of this converters are analyzed, as some results concerning the proposed SMPS with output AC are presented.*

***Palavras-chave:** Double Forward, PWM Half-Bridge Inverter.*

1. INTRODUÇÃO

The main goal of this work consists in the development of a switched-mode power supply (SMPS) where the dc input voltage is low and the dc output voltage is quite high. In dc/dc conversion applications that demand a large range of input or output voltages, conventional PWM converters must operate at extremely low duty cycle ratios, what limits the operation to lower switching frequencies because of the minimum on-time of the transistor switch [1].

To obtain an isolated power supply, two-switch Forward converters consist in one of the most suitable topologies since the power switches need to block only the supply voltage instead of twice or more times the supply voltage as in flyback or single-ended Forward converters [3] [4]. This is a particularly interesting benefit for power MOSFET's once that their on-resistance increase exponentially with breakdown voltage. Further, at turning off, there is no leakage inductance spike.

Although there are a number of bipolar transistors and MOSFETs with high voltage ratings which can take that stress, it is a far more reliable design to use the double-ended Forward converter with half the off-voltage stress. Reliability is of overriding importance in a power supply design, and in any weighing of reliability versus initial cost, the best and, in the long run, least expensive choice is reliability. Therefore, two-transistor forward converter is more reliable and attracted attention of great research, but this topology has drawback of hard switching and single quadrant operation of transformer [5]

A new topology of two-transistor Forward converter, shown in Fig. 1, using two primary windings, is proposed in this paper. It employs an additional switch that operates with twice the switching frequency of the main switches, in order to promote the transformer reset, as a reset winding is not necessary, reducing weight and volume of the proposed SMPS with output AC.

Additionally, a conventional snubber, shown in Fig. 2, is added in parallel with switches S1 and S2 in order to limit di/dt and dv/dt rates in the devices, keeping them within their safe operating areas and reducing the switching power losses. In this specific case, conventional snubbers are preferable instead of non dissipative ones, because of the simplicity of design and implementation, once that the high efficiency issue is not the main propose of this work. Since no inductors are employed in the snubber, the weight and volume are reduced and the power density is increased considerably.

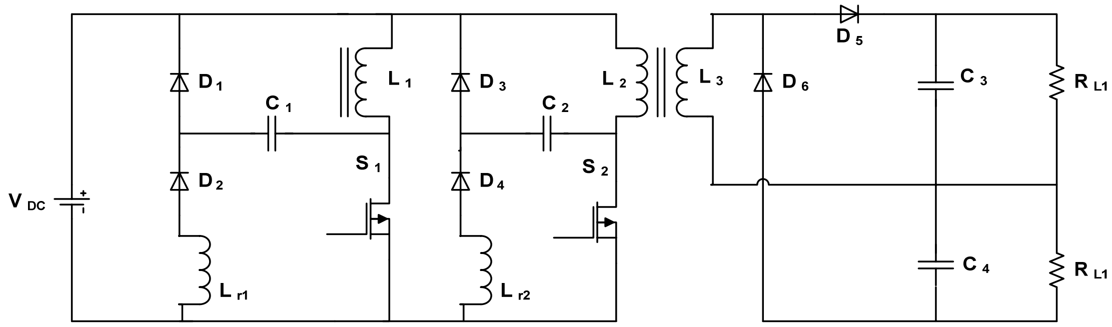


Fig. 1 – Two-switch Forward converter.

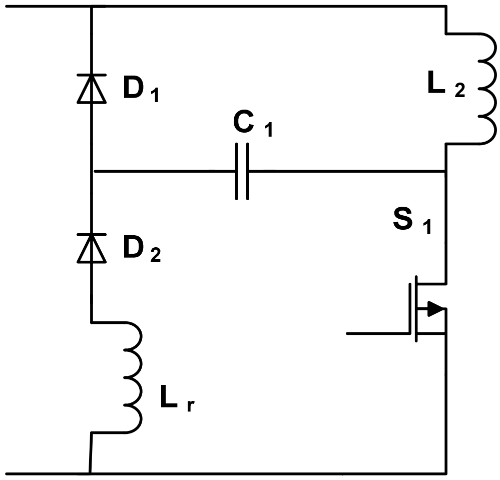


Fig. 2 – Snubber LDDC employed in switches *S1* and *S2*.

In order to have real appreciable efficiency improvement for practical designs, one needs soft switching (zero current or/and zero voltage switching) techniques that eliminate switching losses while preserving minimum voltage and current stresses on switching devices (i.e., in the same level as those in PWM converters). Converters with this unique feature can be called the soft-PWM converters, since their waveforms are square-wave-like (similar to those in PWM converters), but with soft edges (i.e., without switching losses).

Soft-PWM converters are more efficient than resonant and quasi-resonant converters, since the voltage and current waveforms are basically square waveforms. Soft-PWM converters can also switch much faster than PWM converters since there is no switching loss associated with the switching devices. In short, soft-PWM switching combines good features from both the PWM and the resonant worlds to deliver much improved performance.

Hence, soft-PWM is a preferred switching technique. The PMAD development should be focused on finding a switching scheme that is close to the forward converter, but with soft switching provided for both the primary and the secondary devices.

Circuit Fig. 1 is a scheme that recovers part of the magnetizing energy while resetting the transformer (see, for example, [6], [7] . At turn-off, the diode and capacitor clamp the voltage in the same manner as in the case of the RCD snubber. Reset of the capacitor is accomplished through an LC resonance when the MOSFET is on. Typical voltage stress is twice the maximum input voltage, 2 Vgmax.

Since a resonance is involved, there are four modes of operation as discussed in [6] for the case of a flyback converter (but it can be used for a forward with minor modifications). Because of this, careful designs are needed to ensure efficiency benefit. In practice, designers often find that this technique does not bring notable efficiency improvement as it is supposed to. However, it does clamp the drain-source voltage well.

Another disadvantage is that the resonant tank needs a high Q factor in order to be able to recycle part of the magnetizing energy back to the input. This requires the inductor to have a certain value. The size of the inductor is proportional to the input voltage level. This limitation is particularly severe if the input voltage is high.

The LDDC Double Converter circuit shows a circuit that eliminates a few remaining undesirable features associated with a switching snubber [8], [9] and [10]. This circuit behaves the same as the forward converter when the main MOSFET is on. Energy is forwarded to the output via the main forwarding diode. This is called the main power forwarding. A second winding is introduced to the transformer to allow the magnetizing energy to be forwarded to the output (instead of the input as in previous cases) via the auxiliary forwarding diode and the low-pass filter. This is called auxiliary power forwarding. Since this converter forwards two power pulses to the output within one switching cycle, it is called naturally the double forward converter.

On the primary side, the converter behaves like that of a switching snubber. However, a significant departure is that the switching snubber is designed in such a way that all the magnetizing energy is transferred into the capacitor during the brief switching dead time. Then the energy is forwarded to the secondary during the time duration when the auxiliary switch is on.

The soft switching mechanism for the main and the auxiliary MOSFETs is similar to the one in the case of the switching snubber. A significant diparture, though, is that the notorious subharmonic oscillation or the lock-up mode is prevented from happening. This improves the reliability of the technique significantly and, more importantly, paves the way for its wide application in industry.

For a design with input voltage range of two, the duty ratio can be controlled to be from 0.25 to 0.50. Voltage stress for both the main and the auxiliary switches (MOSFETs) stays relatively constant at 1:3 Vg,max over line and load changes. For example, for a 48 V bus with a range of 36—60 V, the double forward allows 150 V parts to be used with about 50% derating; whereas the forward converter normally requires 300 V parts for 50% derating. Reduced voltage rating enables designers to use MOSFETs with lower on-resistance Rds,on and lower total gate charge Qg.

On the secondary side of the converter, a freewheeling diode is used in front of the low-pass filter. This prevents the secondary of the transformer from being short-circuited during the dead time. A small saturable reactor is inserted in series with the main and the auxiliary diode, respectively. This saturable reactor eliminates the reverse recovery current of the diode and hence further improves efficiency. Also, the freewheeling, the main, and the auxiliary forward diodes work together to ensure zero-current switching. Hence, all the secondary switching devices of the converter are also soft-switched. By its double forwarding nature, the output inductor size is typically a half of that of a forward. In fact, the inductor current ripple can actually be nullified for a particular input line voltage. In this regard, the double forward actually outperform a double-ended converter such as a full bridge.

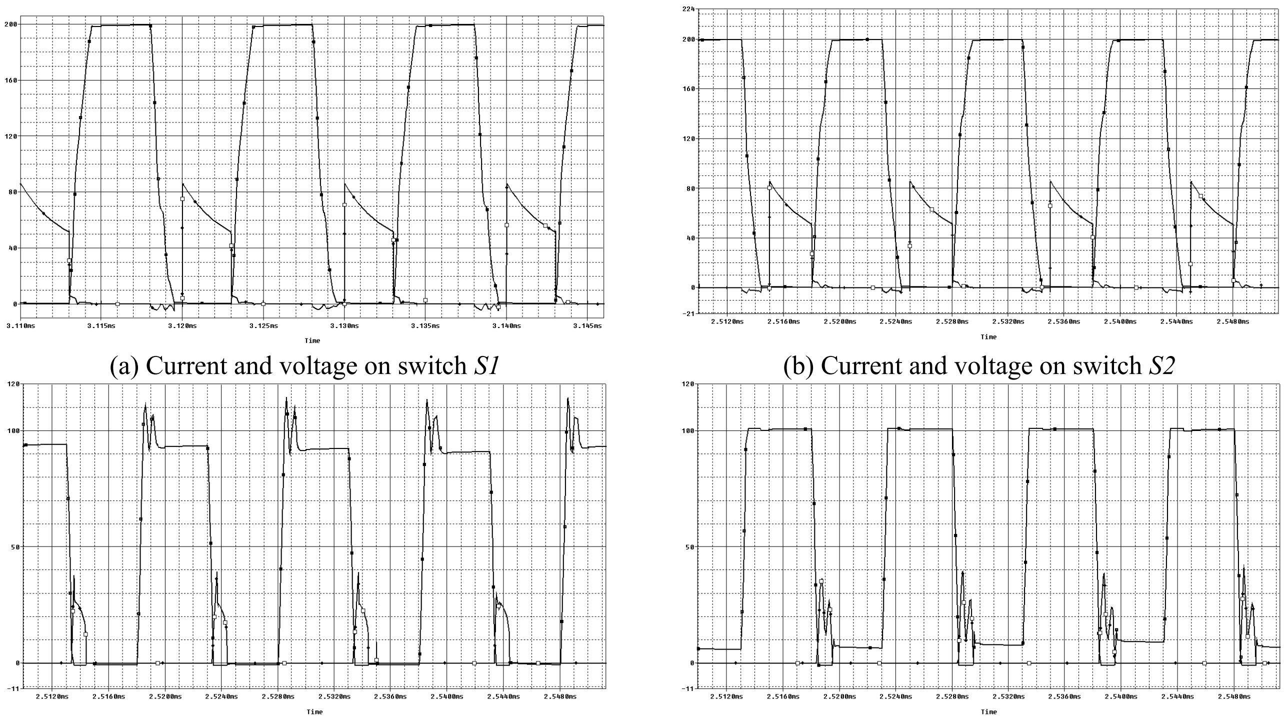
2. SIMULATION RESULTS

Simulation tests have also been performed on the two-switch Forward converter using snubber shown in **Fig. 2**. The parameter specifications are summarized in **Table 1**.

Fig. 3 shows some simulation results regarding the operation of the converter under the conditions stated below. In **Fig. 3** (a) and (b), one can see the zero-current switching (ZCS) at the switches turning on, and the zero-voltage switching (ZVS) at the switches turning off. In **Fig. 3** (c), one can see the that switch *S3* operates at twice the switching frequency of switches *S1* and *S2*. Finally, **Fig. 3** (d) represents the output voltages.

Table 1 – Parameter set employed in the two-switch Forward converter.

Parameter	**Value**
L_{r1}, L_{r2}	5μH
L_1, L_2	500μH
L_2	500μH
C_1, C_2	2.2nF
C_3, C_4	100μF
Co1, *Co2*	30μH
Diodes D_1, D_2, D_3, D_4	Ideal
Switches S_1, S_2	Ideal
Switching frequency – S_1 and S_2	100kHz
Input voltage	$48V_{dc}$
Output voltages	$+200V_{dc}$, $-200V_{dc}$
Output power	500W

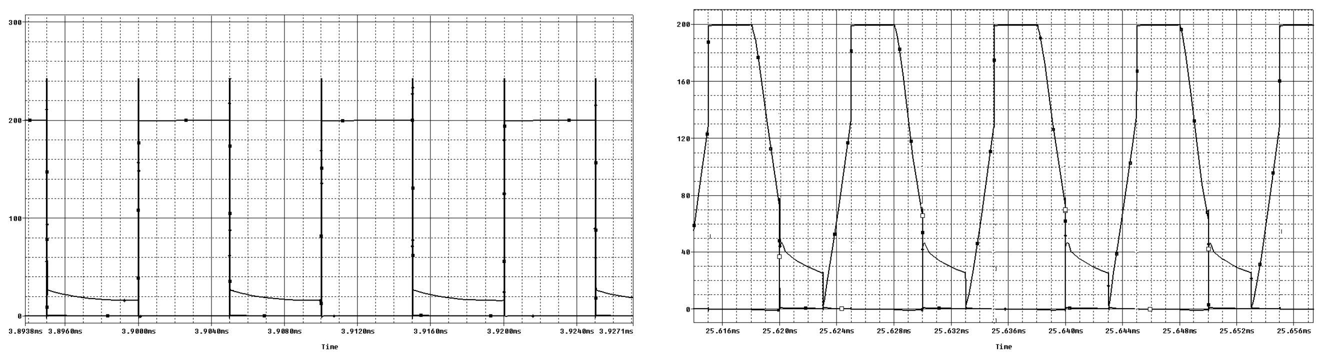


(a) Current and voltage on switch *S1* (b) Current and voltage on switch *S2*

(c) Current (0,1A/div) and voltage on Diode *D1* (d) Current (0,1A/div) and voltage on Diode *D2*

Fig. 3 – Simulation results obtained for the two-switch Forward converter.

Fig. 4 shows the switching detail with and without the use of the conventional RC snubber, where it can be seen in **Fig. 4** (a) that the power dissipation area corresponding to the conduction losses is much greater than that in **Fig. 4** (b).



(a) Without snubber (b) With snubber

Fig. 4 – Switching detail.

Even though the converter has already been built in laboratory, an experimental prototype of the two-switch Forward converter is yet to be fully implemented and associated to the aforementioned topology, constituting the proposed SMPS with output AC. Therefore additional experimental results will be presented at the final version of this paper.

3. CONCLUSION

This paper reports some results regarding a switched-mode power supply with reduced weight, size and complexity. A quadratic Boost converter is associated to a new topology of a soft-switched double-ended Forward converter in order to obtain output voltages equal to $+200V_{dc}$ and $-200V_{dc}$. Both structures have been studied and the operating principles of the Forward topology have been analyzed theoretically.
This work presents an active auxiliary commutation topology for three level PWM TRHEE LEVEL HALF BRIDGE INVERTER, based on resonance principle.

This controller is very fast and simple, because it has a little components quantity, and this form can be said that this control is very robust, and in the other side, the control presents a low cost. The little volume presented in this converter present other important thing, because it has a small volume and this form, have a big energy density. It is important to high light that the proposed permits the ZVS half bridge inverter works at three level without the need of auxiliary sources, differently of some counterparts. The proposed circuit assure soft switching to al main loads, since capacitor loads until inductive loads, with low current stress and high efficiency.

The operation and performance are verified by simulation results using software models. Theoretical results have been verified. A laboratory prototype this converter will be implemented and the experimental results will be presented in the final version of this work.

ACKNOWLEDGEMENT

The authors gratefully acknowledge CNPq and FAPEMIG for the financial support to this work (Proc. Nb. 574001/2008-5 - INCT-EIE) and also Texas Instruments and ON Semiconductor for sending us free samples.

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