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A Single Stage High Voltage Gain ZVS Boost Converter Feasible to Photovoltaic Battery Charger Systems

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***Abstract*- In order to give support to the growing technology demand of renewable energy applications, this paper presents a new converter topology for battery charging feasible to photovoltaic systems. The proposed converter presents in a single stage a large voltage step-up, high efficiency, and reduced voltage stress on switches due to the transformer. Also ZVS soft switching is naturally achieved a lowing high frequency operation and low commutation losses. Following, it will be shown the topology, its operation principle, and the preliminary results for a 500W load.**

I. INTRODUCTION

Renewable energy systems using, as main energy source, photovoltaic panels and/or fuel cells have an intrinsic characteristic of producing low voltage levels, requiring a DC converter with large voltage step-up in order to produce a high voltage DC bus in order to feed an AC DC converter.

Though conventional boost converter can theoretically be used for this purpose, obtaining such high voltage gain implies that it would operate with duty cycles greater than 0.9, which is not feasible due to the great variations on the output voltage caused by small variations on the duty cycle, leading the boost converter to instability. Also, the main switch would be under high voltage and current stress.

To overcome this drawback, a large number of large voltage step-up converters have been proposed, as in [1-14].

In [3] and [4], the use of an interleaved boost converter associated with an isolated transformer was introduced, using a high frequency AC link. Despite of the good performance, this topology uses three magnetic cores. In [5], the converter presents low input current ripple and low voltage stress across the switches. However, high current flows through the series capacitors at high power levels. In [6-8], converters with high static gain based on the boost-flyback topology are introduced, which presents low voltage stress across the switches, but the input current is pulsed, as it needs an LC input filter. The step-up switching-mode converter with high voltage gain using a switched-capacitor circuit was proposed in [9]. This idea is only adequate for low power converters as it results in a high voltage stress across the switches and many capacitors are necessary. In [10-12] the three-state switching cell is shown. In [12] a voltage doubler rectifier is employed as the output stage of an interleaved boost converter with coupled inductors.

In [13] the converter has some advantages compared to the others: possibility to operate in large voltage range, high efficiency, and high power capability. It can be seen in [13] that the number of semiconductor devices is the same as in the traditional interleaved boost arrangement, though two coupled inductors L1 and L2 are added, resulting in higher output voltage. The main drawback of this topology is the hard switching mode, which causes power losses.

The structure presented in [14] is an alternative of [13], where a commutation cell is associated to the main topology in order to reduce the current stress on the switches. Despite of achieving higher efficiency, this solution leads to a more complex control and structure, due to the presence of an extra auxiliary circuit for each switch. Nevertheless, most of solutions include different stages to perform battery charging and step up goals.

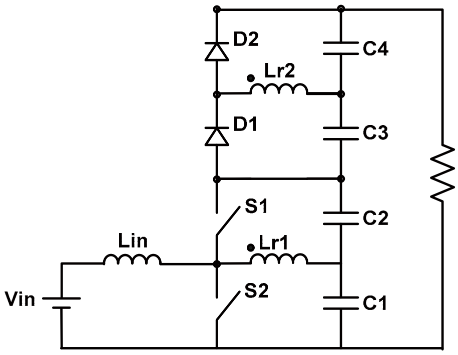

Fig .1. Proposed topology.

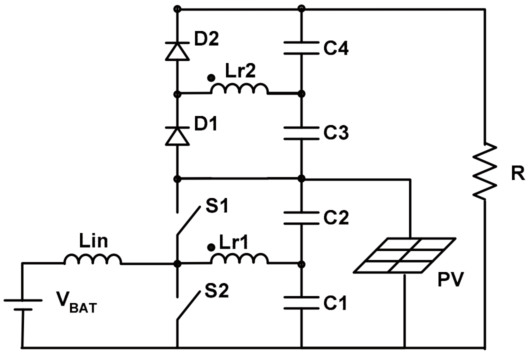

Fig .2. Proposed topology using a PV system.

This paper presents a new high voltage gain DC/DC converter, as can be seen in Figure 1 and Figure 2. The main advantage of the proposed structure is the low voltage stress across the switches, which is naturally achieved by the converter characteristic, without the need of inserting an extra auxiliary circuit for achieving ZVS operation. A single-stage

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converter with high step-up gain then results, while an integrated system with battery charging from a photovoltaic panel is also obtained. The duty cycle allows the MPPT control and the battery absorbs or delivery energy automatically according to the load condition and maintaining acceptable output voltage regulation.

II. OPERATION PRINCIPLE

This section presents the operation principle from the high voltage gain boost converter. For the theoretical analysis, it will be considered that the input voltage (Vin) and output current (Io) are ripple free and all devices are ideal.

From Figure 7, it can be observed the main theoretical waveforms, which illustrate the details of the operation principle stages explained above.

First Stage [t_0 – t_1] - At t_0, S_1 is turned-off and S_2 is maintained turned-on, as presented in Figure 3. On this stage, the difference between the conduced current due to the transformer leakage and the input current flows through the anti-parallel diode of S2 and decreases linearly. This stage ends when the current on the primary side of the transformer is zero.

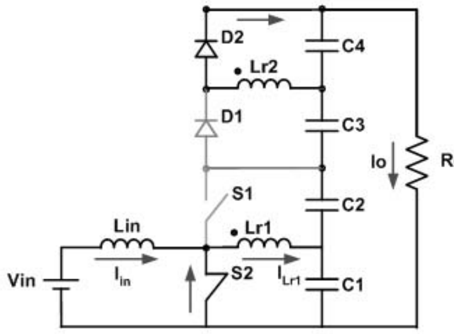

Fig .3. First Stage.

Second Stage [t_1 – t_2] – On this stage, the current through the primary side is added to the input current and conduced through the switch S2. The secondary circuit charges the capacitor C3 through diode D1.

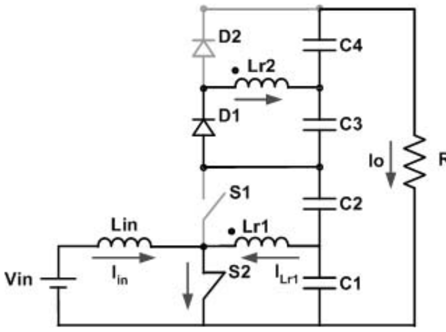

Fig .4. Second Stage.

Third Stage [t_2 – t_3] – This stage begins when S2 turns-off and S1 turns-on. The current that flows through S1 is the sum of the input current and the one through the transformer primary side, and increases linearly. This stage ends when the current on the primary reaches zero.

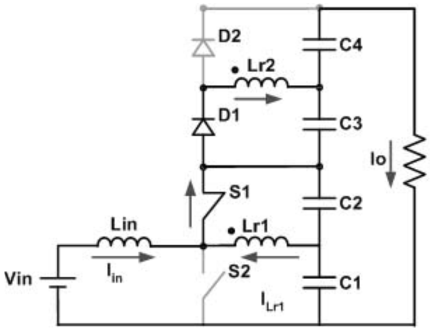

Fig .5. Third Stage.

Fourth Stage [t_3 – t_4] – On this stage, the current on the transformer primary side is the sum of the input current and the one that flows through C2. The secondary circuit charges C4 through diode D2. This stage ends when S2 turns-on and S1 turns-off.

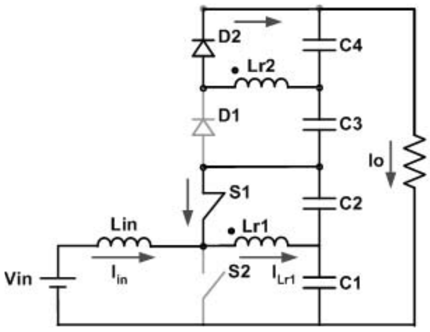

Fig .6. Fourth Stage.

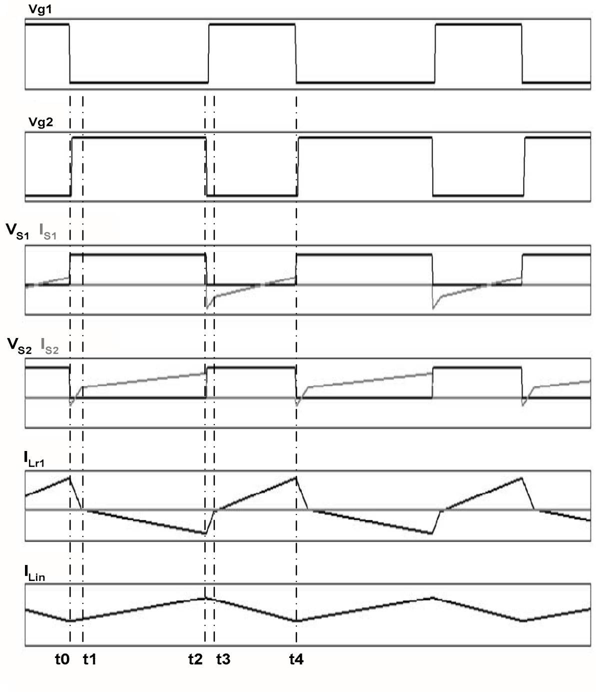

Fig .7. . Main theoretical waveforms.

III. STATIC GAIN

The output voltage at any given moment can be expressed as the sum of the voltages across each output capacitor, C_1, C_2, C_3 e C_4, as presented in equation (1).

$$Vo = V_{C1} + V_{C2} + V_{C3} + V_{C4} \tag{1}$$

Relation (2) can be obtained observing that the voltage across the inductors L_{r1} and L_{r2} must be null during a switching cycle period, the voltage across the capacitor V_{C2} can be expressed by (2).

$$V_{C2} = \frac{D.Vin}{1-D} \tag{2}$$

Due to the transformer relation (n), it must be noticed that the voltage across C1are related to the voltage across C3 according 4 and.

$$V_{C1} = Vin \tag{3}$$

$$V_{C3} = n.Vin \tag{4}$$

Similarly to the condition presented on equation (3), the voltage across C4 has an direct relation to the voltage across C2 and the transformer relation (n), as shown in (6).

$$V_{C4} = n.\frac{D.Vin}{1-D} \tag{6}$$

Substituting (3)-(6) in (1), it can be determined the static gain, as shown in equation (7).

$$G = \frac{Vo}{Vin} = \frac{1+n}{1-D} \tag{7}$$

Figure 8 presents the curves relating the static gain (G) with the duty cycle (D) for different values of (n).

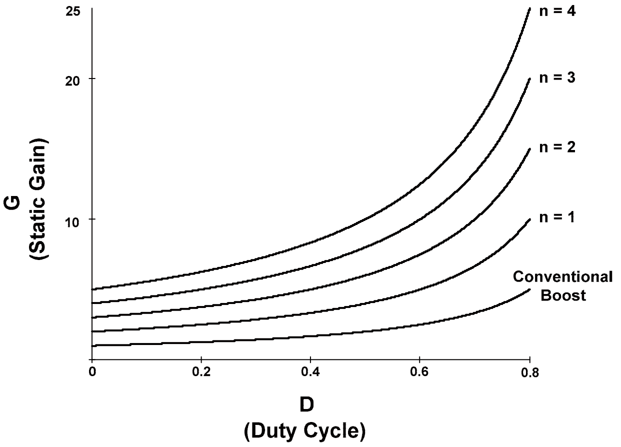

Fig .8. Relation G x D for different values of n.

IV. EXPERIMENTAL RESULTS

This section presents the experimental results. The wave forms showed certify the obtained simulation results, as can be seen in figure 7.

The specifications are presented on tables I. The choice of large output capacitors was made based on predicting the use of an inverter connected to the converter output, which would require large capacitors in order to attenuate the low frequency ripple.

Figure 9 shows the input voltage waveform (Vin = 24V) and the output voltage (Vo = 200V) for the nominal load, proving the correct operation.

TABLE I
Converter Specifications

Input Voltage	24 Vdc
Output Voltage	200 Vdc
Nominal Power	500 W
Switching Frequency	50kHz
Transformer turns ratio (n)	3
Inductance of L_{in}	120µH
Capacitances of C_1, C_2, C_3 and C_4	680µF

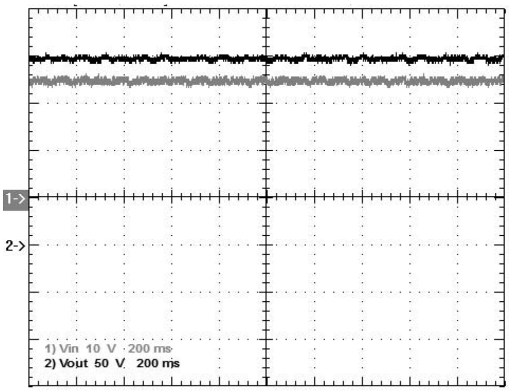

Fig .9. Input and output voltages.

Figure 10 presents the input current waveform (Iin). As can be observed, the average value is 12A with a ripple of 10% for a 300W load.

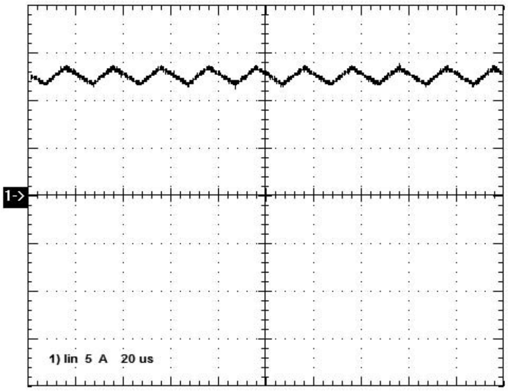

Fig .10. Input current.

Figure 11 presents the voltage and the current during the turn-on period through the switch S1. It must be observed from these figures that the switch S1 start to conduct in ZVS mode. Figure 12 presents the voltage and the current during the turn-on period through the switch S2.

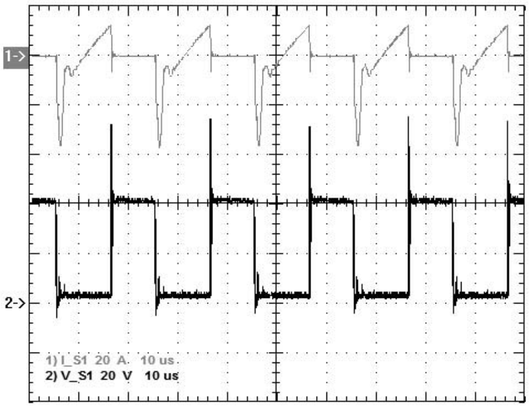

Fig .11. Voltage and current through S1.

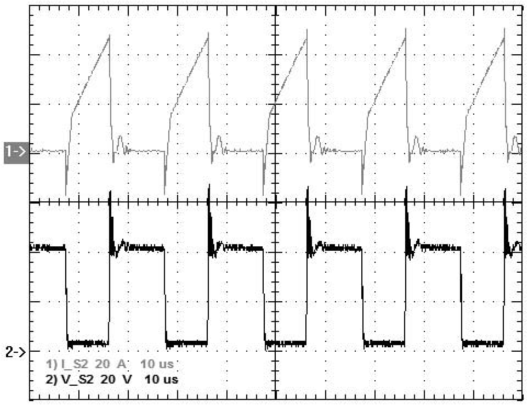

Fig .12. Voltage and current through S2.

Figure 13 presents the voltage across each output capacitor, which are equilibrated. Measured V_{C1} is 25V, while V_{C2} is 18.1V, V_{C3} is 90V, and V_{C4} is 74.2V. With a transformer relation of 1:3, it is expected that the voltage across C3 should be three times the voltage across C1, and the same relation between C2 and C4.

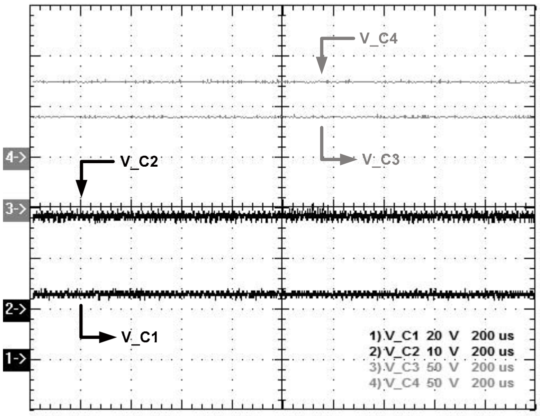

Fig .13. Voltage across C1, C2, C3 and C4.

However these relations are not observed on the simulation results, due to the presence of the leakage inductance, which is responsible for the ZVS commutation.

Figure 14 shows the voltage and current waveforms through the primary side of the transformer for a 300W load.

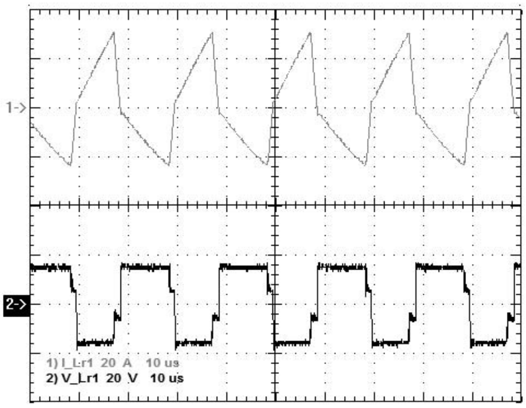

Fig .14. Voltage and current through Lr.

Figure 15 shows the output voltage waveform response considering an insulation step up from 0% to 100% of the rated condition. One can see an acceptable static and dynamic voltage response, considering the load as the dc link of an inverter. Figure 16 presents the prototype developed in laboratory.

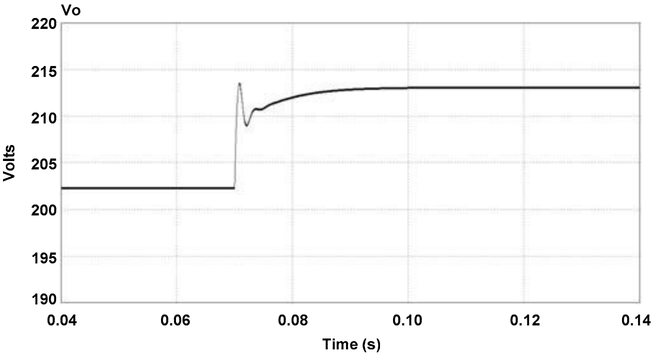

Fig .15. Output voltage waveform for zero to full load step-up.

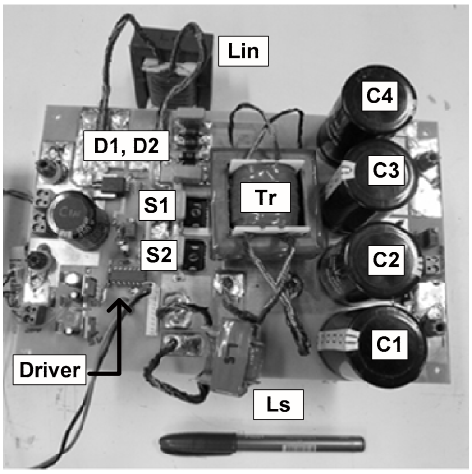

Fig .16. Prototype.

V. CONCLUSION

A boost converter with high voltage gain was presented, and its equations, operation principle, and main theoretical waveforms were all detailed. The topology presents, as main feature, a large voltage step-up with reduced voltage stress across the main switches, important when employed in grid-connected systems based on battery storage, like renewable energies systems.

Other characteristics of the converter are: voltage balancing between output capacitors, low input current ripple, high switching frequency, which reduces the structure volume and weight, simple switching control, as just a simple voltage loop control based on the conventional boost was implemented, and the possibility to make the voltage gain even higher by increasing the transformer turns ratio.

One of the main advantages of this topology is the ZVS commutation of the switches, which is a natural characteristic of the proposed topology, reducing the switching losses.

In this paper only the battery mode was analyzed. The experimental results obtained are very similar to the converter simulation. The prototype had 88% of efficiency, however, changing the switches and redesigning the magnetic elements, the converter efficiency can be improved to 94%. The operations considering the PV are object of another paper.

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