A Soft Switching Voltage Boosting Converter for High Power applications

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Abstract— **A soft switching voltage boosting converter for high power applications is proposed. It consists of voltage boosting converter and a half bridge resonant converter and the two stages are merged in to a single stage. The voltage boosting converter stage provides a continuous input current and soft switching operation of power switches. The Half bridge converter stage provides the high voltage gain. The principle of operation and the system analysis are proposed in this project. The simulink results are obtained for proposed circuits by using MATLAB/Simulink.**

Index Terms— **voltage boosting converter, coupled inductor, soft switching, high voltage gain, low reverse recovery loss.**

I. INTRODUCTION

In many industrial areas DC converters with high voltage gain are required. In renewable energy resources like wind turbines, fuel cells, photo voltaic generators, small hydro systems a front end boost converter is connected to step up the voltage.[1], [2]. In addition to high voltage gain DC-DC converters also required low reverse recovery losses, [3], low voltage stress across the switches, and constant input current.

In [4] a high-step-up converter with coupled inductors is suggested to provide high voltage gain and a continuous input current. However, its operating frequency is limited due to the hard switching of the switches. Their switching frequencies are limited due to the hard-switching operation. The converters proposed [5]-[7] are also have same drawbacks.

In order to solve these problems, a soft switching voltage boosting converter is proposed .It consists of a Voltage boosting converter with coupled inductor to make the input current continuous and a resonant Zero voltage switching half-bridge converter stage to provide high voltage gain.

Manuscript received Aug, 2015.

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II. CONVERTER IMPLEMENTATION AND OPERATION

The circuit diagram for proposed converter is shown in Fig: 1. The two stages voltage boosting converter and half bridge resonant converter are merged in to a single stage.

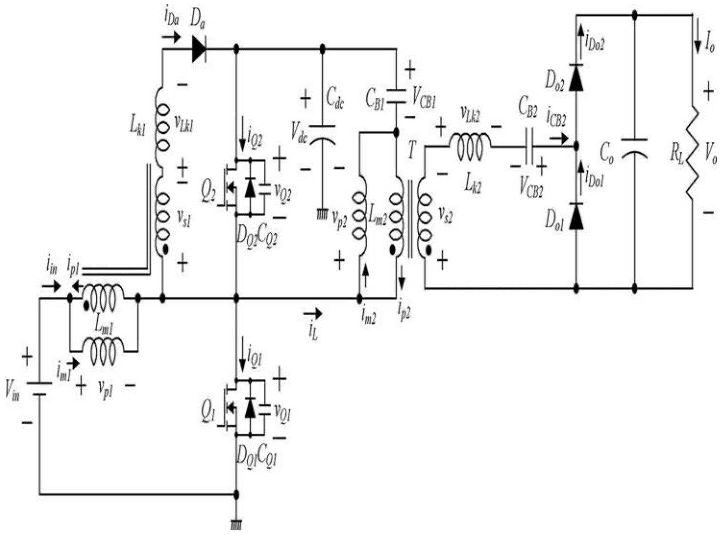

Fig: 1 Equivalent circuit of the proposed soft-switching voltage boosting converter

The voltage boosting converter consists of two switches Q_1 and Q_2, coupled inductor $L_{C,}$ leakage inductance L_{K1}, Magnetizing Inductance L_{M1}, auxiliary diode D_a and dc link capacitor C_{dc}. The ideal transformer with turn's ratio $1{:}n_1$ is used in the circuit.

The diodes D_{Q1} and $D_{Q2,\text{ and}}$ capacitances C_{Q1} and CQ2 are body diodes and parasitic capacitances of Q1 and Q_2.

The half bridge zero voltage switching resonant converter consists of MOSFET switches Q_1 and Q_2, Output diodes D_{o1} and D_{o2}, transformer T, dc blocking capacitors C_{B1} and C_{B2}, Leakage inductance L_{K2}, Magnetizing Inductance L_{M2}, output capacitor C_o.

OPERATION:

In one switching period T_s the operation of the converter is divided in to seven parts. Initially the upper switch Q_2 is conducting and the capacitor C_{Q2} is charging. At input side the magnetizing current decreases to its minimum value and the current through auxiliary diode D_a increase to maximum value.

The current I_L increases to its maximum value and the output diode D_{o1} is conducting.

ISSN: 2278 – 7798

Mode 1:

The upper switch Q_2 is turned OFF at t_0. Then the capacitor C_{Q2} starts charging to its input voltage V_{dc}. The initially charged capacitor CQ1 starts discharging its voltage to zero. Now assume that the inductor currents are not changed and the output capacitors are small the transition time interval is given by

$$T_{t1} = t_1 - t_0 = \frac{(C_{Q1} + C_{Q2})V_{dc}}{I_{L1} + (n_1 + 1)I_{Da} - I_{m12}} \dots\dots\dots\dots\dots\dots (1)$$

Mode 2:

Now the voltage across switch Q_1 becomes zero, and the current through it is bypassed through diode D_{Q1}. Therefore Zero voltage switching of Q_1 is possible to decrease the voltage stress across the switches. As the voltage across Magnetizing inductance is V_{in} (i.e.$V_{p1}=V_{in}$) its current increase from minimum value to its maximum value as follows:

$$i_{m1}(t) = I_{m12} + \frac{V_{in}}{L_{m1}}(t - t_1) \dots\dots\dots\dots\dots\dots (2)$$

Since the voltage V_{LK1} across the leakage inductance L_{K1} is $-(n1\ V_{in}+V_{dc})$, the auxilary diode current i_{Da} linearly decreases from its maximum value I_{Da} as follows:

$$i_{Da}(t) = I_{Da} - \frac{n1\ V_{in} + V_{dc}}{L_{K1}}(t - t_1) \dots\dots\dots\dots\dots\dots (3)$$

From (2) and (3), the input current i_{in} is determined as follows:

$$i_{in}(t) = i_{m1}(t) - i_{p1}(t) = i_{m1}(t) - n_1 i_{Da}(t)$$
$$= I_{m12} - n_1 I_{Da} + \frac{V_{in}}{L_{m1}}(t - t_1) + n_1 \frac{n1\ V_{in} + V_{dc}}{L_{K1}}(t - t_1) \dots\dots\dots\dots\dots\dots (4)$$

Since V_{p2} is $-(V_{dc}\ \text{-}V_{CB1})$ and V_{LK2} is V_{CB2}+ n_2V_{in} , the magnetising current i_{m2} and the diode i_{DO1} are given by

$$i_{m2}(t) = I_{m21} - \frac{V_{dc} - V_{CB1}}{L_{m2}}(t - t_1) \dots\dots\dots\dots\dots\dots (5)$$

$$i_{Do1}(t) = -i_{CB2}(t) = I_{Do1} - \frac{V_{CB2} + n_2\ V_{in}}{L_{K2}}(t - t_1) \dots\dots\dots\dots\dots\dots (6)$$

In this mode , the primary current i_{p2} , the coupled inductor current i_L, and the switch current i_{Q1} can be obtained from the following relations:

$$i_{p2}(t) = n_2\ i_{CB2}(t) \dots\dots\dots\dots\dots (7)$$
$$i_L(t) = i_{m2}(t) - i_{p2}(t) \dots\dots\dots\dots\dots\dots (8)$$
$$i_{Q1}(t) = i_{in}(t) - i_{Da}(t) - i_L(t) \dots\dots\dots\dots\dots\dots (9)$$

Mode 3:

At this mode the output diode current I_{Do1} decreases to zero the current i_{CB2} changes its direction. There the diode D_{o2} comes in to conduction. The sudden change in current through diode D_{o1} is controlled by the leakage inductance of transformer T. Therefore the reverse-recovery characteristics of the diode were improved.

$$i_{m2}(t) = I_{m2}(t_2) - \frac{V_{in}}{L_{m2}}(t - t_2) \dots\dots\dots\dots\dots\dots (10)$$

$$i_{Do2}(t) = i_{CB2}(t) = \frac{V_{CB2} + n_2\ V_{in} - V_o}{L_{K2}}(t - t_2) \dots\dots\dots\dots\dots\dots (11)$$

The remaining components currents and voltages are same as in Mode 2.

Mode 4:

The current through the auxiliary diode I $_{Da}$ becomes zero and the diode stops conducting. . The sudden change in current through diode D_a is controlled by the leakage inductance of the ideal transformer. Therefore the reverse-recovery characteristics of the diode were improved. But the voltage across magnetizing inductance is V_{in} its current increases with same slope as in Mode 2 and 3.

$$i_{m1}(t) = I_{m1}(t_3) + \frac{V_{in}}{L_{m1}}(t - t_3) \dots\dots\dots\dots\dots\dots (12)$$

The voltages V_{p2} and V_{Lk2} and the slopes of the current i_{m2}, i_{CB2}, and i_L are not changed.

Mode 5:

The lower switch Q_1 is turned OFF at t_4. Then the capacitor C_{Q1} starts charging to its input voltage V_{dc}. The initially charged capacitor CQ2 starts discharging its voltage to zero. Now assume that the inductor currents are not changed and the output capacitors are small the transition time interval is given by

$$T_{t2} = t_5 - t_4 = \frac{(C_{Q1} + C_{Q2})V_{dc}}{I_{L2} + I_{m11}} \dots\dots\dots\dots\dots\dots (13)$$

Mode 6:

Now the voltage across switch Q_2 becomes zero, and the current through it is bypassed through diode D_{Q2}. Therefore Zero voltage switching of Q_2 is possible to decrease the voltage stress across the switches. As the voltage across Magnetizing inductance is – (Vdc–Vin) its current starts decreasing from maximum value as follows:

$$i_{m1}(t) = I_{m11} - \frac{V_{dc} - V_{in}}{L_{m1}}(t - t_5) \dots\dots\dots\dots\dots\dots (14)$$

Since the voltage V_{LK1} across the leakage inductance L_K is (V_{dc} - V_{in}), the auxilary diode current i_{Da} linearly increases from zero as follows:

$$i_{Da}(t) = \frac{n1\ (V_{dc} - V_{in})}{L_{K1}}(t - t_5) \dots\dots\dots\dots\dots\dots (15)$$

From (14) and (15), the input current i_{in} is determined as follows:

ISSN: 2278 – 7798

$$i_{in}(t) = I_{m11} - \frac{V_{dc} - V_{in}}{L_{m1}}(t - t_5) - n_1 \frac{n1\,(V_{dc} - V_{in})}{L_{K1}}(t - t_5)$$

$$\dots\dots\dots\dots\dots\dots (16)$$

Since V_{p2} is V_{CB1} (D V_{in} / (1-D)) and V_{LK2} is -(Vo-V_{CB2}+ n_2 D V_{in} / (1-D)) , the magnetising current i_{m2} and the diode i_{DO2} are given by

$$i_{m2}(t) = I_{m22} + \frac{D\,V_{in}}{L_{m2}\,(1-D)}(t - t_5) \dots\dots\dots\dots\dots (17)$$

$$i_{Do2}(t) = i_{CB2}(t) = I_{Do2} - \frac{V_{CB2} + \left(\frac{n_2 DV_{in}}{1-D}\right)}{L_{K2}}(t - t_5)$$

$$\dots\dots\dots\dots\dots\dots (18)$$

Mode 7:

At this mode the output diode current I_{Do2} decreases to zero the current i_{CB2} changes its direction. There the diode D_{o1} comes in to conduction. The sudden change in current through diode D_{o2} is controlled by the leakage inductance of transformer T. Therefore the reverse-recovery characteristics of the diode were improved.

The current i_{m2} and the diode current i_{Do2} are given by

$$i_{m2}(t) = I_{m2}(t_6) - \frac{DV_{in}}{L_{m2}(1-D)}(t - t_6) \dots\dots\dots\dots\dots (19)$$

$$i_{Do1}(t) = -i_{CB2}(t) = \frac{V_{CB2} - (n_2 D \frac{V_{in}}{1-D}))}{L_{K2}}(t - t_6)$$

$$\dots\dots\dots\dots\dots\dots (20)$$

The currents i_{p2} , the coupled inductor current i_L are obtained from the same relations of mode 2.

The voltages V_{p1} and V_{Lk} are equal to those in mode 6. Therefore the magnetising current i_{m1}, the auxiliary current i_{Da} changes and the input current change with Same slopes as in Mode 2.

III. SIMULATION RESULTS

The proposed soft switching voltage boosting converter for high power application was simulated in SIMULINK (Fig: 1) and the results obtained are shown to verify the operation of the converter. The values of various components are shown in Table 1.

A DC voltage with amplitude of 24V is applied for simulation of proposed scheme. The voltage boosting converter stage provides a continuous input current and soft switching operation of power switches. The output voltage from the bridge converter is boosted to 393V.The MATLAB/SIMULINK diagram for proposed converter is shown in Fig 2.

TABLE 1
Circuit components

Parameter	**Value**
Switching frequency	108kHz
Leakage Inductance L_{K1}	16.75μH
Magnetizing Inductance L_{m1}	800μH
Leakage Inductance L_{K2}	170μH
Magnetizing Inductance L_{m2}	474μH
Dc-blocking capacitor C_{B1}	6.6μF
Dc-blocking capacitor C_{B2}	2.2μF
Dc-link capacitor C_{dc}	470μF/100V
Output capacitor C_o	47μF/450V

SIMULATION DIAGRAM

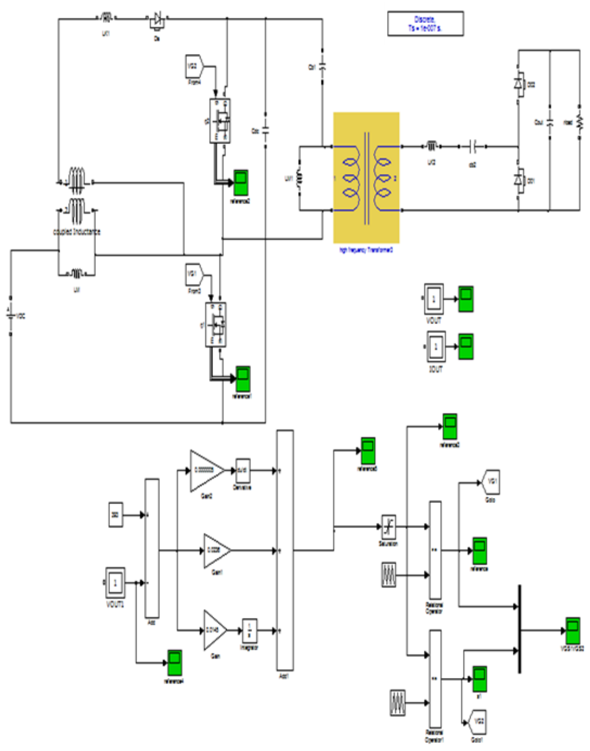

Figure 2: MATLAB/SIMULINK model of proposed converter . for closed loop system

ISSN: 2278 – 7798

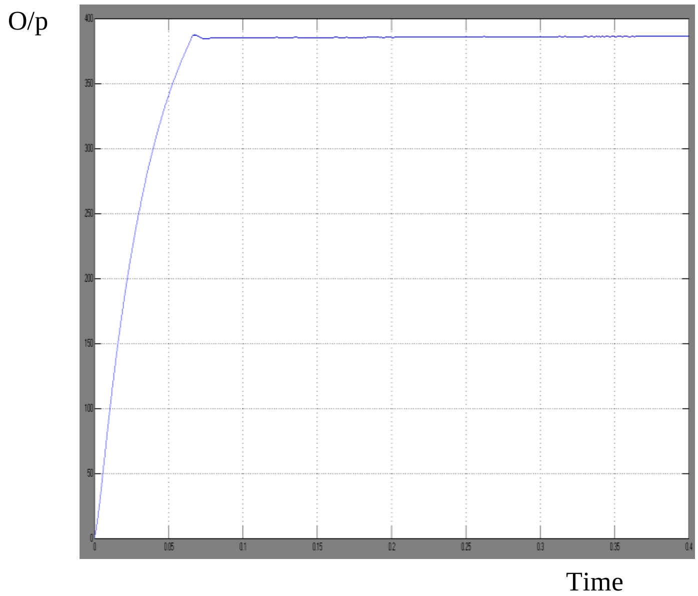

Fig 3: Output voltage waveform

The output voltage from half bridge converter is shown in Fig 3. The output voltage boosted to 393V.Since the input current does not change its direction, the converter operates in Continuous Current mode.

The output voltage is compared with its reference value and the error is modified by using PI controller. According to this the pulses are given to power switches to step up voltage.

IV.CONCLUSION

This paper has presented a Soft switching voltage boosting converter for high power applications. It can achieve by turning on the switches at zero voltage while maintaining the circuit in continuous current mode (CCM). The current changing rate of the output diodes was controlled by leakage inductance of the transformer. Therefore the reverse –recovery characteristics were significantly improved.

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