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MATHEMATICAL MODELLING AND PERFORMANCE ANALYSIS OF HIGH BOOST CONVERTER WITH COUPLED INDUCTOR

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Abstract- *In this work, High boost converter is analyzed mathematically modeled, designed with given parameters. This paper explains the mathematical modeling of high boost converter for continuous and discontinuous mode of operation for low power application. Input to the high boost converter is the unregulated supply which is obtained by rectifying AC supply. In the proposed model, DC battery fictitiously represents the unregulated supply.*

Keywords: Coupled Inductor, High boost converter, MOSFET, Diode, Power Electronics, Filter.

1. INTRODUCTION

The high gain DC-DC converter with coupling inductor is design to boost low voltages to voltages into high range of 30 to 50 times input voltage [1]. It is especially useful in boosting low solar panel voltage to high voltage, so that 230V ac can be generated. At the time the efficiency is also high and it is cost effective [2-3]. It is a transformer less topology. This converter will work with input voltage of 25V dc, and generate constant output voltage of 440 V dc with the help of PI controller. To achieve high voltage output, gain the converter output terminal and boost output terminal are connected in serially with the isolated inductor with less voltage stress on controlled power switch and power diodes. PSIM software has been used for simulation [4-5]. To verify the performance of the proposed converter, a 345-W prototype sample is implemented with an input voltage range of 20–40 V and an output voltage of up to 440 V. The upmost efficiency of 93.3% is reached with high-line input; on the other hand, the full-load efficiency remains at 89.3% during low-line input. High boost dc-dc converter operating at high voltage regulation is mainly required in many industrial applications. High gain dc-dc boost converter play an important role in renewable energy sources such as solar energy system, fuel energy system, DC back up energy system of UPS, High intensity discharge lamp and automobile applications. For battery-powered systems, electric vehicles, fuel cell systems, and photovoltaic systems, where low-voltage sources need to be converted into high voltages, the demand for non-isolated high step-up dc–dc conversion techniques are gradually increasing [7-8]. This paper presents a cascaded high step-up dc–dc converter to increase the output voltage of the micro source to a proper voltage level for the dc interface through dc–ac inverter to the main electricity grid [9-10]. The proposed converter is a quadratic boost converter with the coupled inductor in the second boost converter. The circuit diagram of the proposed converter is shown in Fig.1

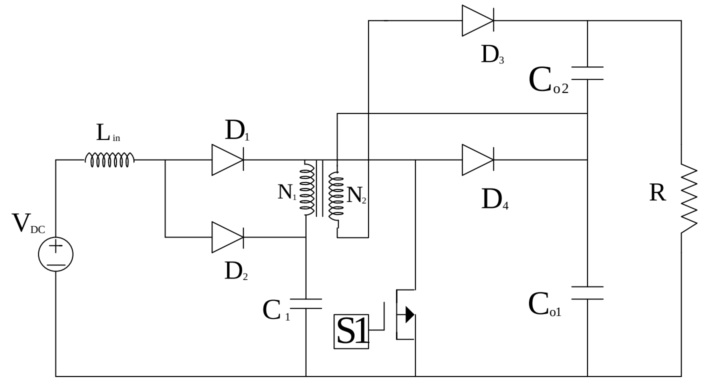

Fig.1: High boost converter topology

2. PRINCIPLE OF OPERATION

The simplified circuit model of the proposed converter is shown in Fig.2. The dual-winding coupled inductor consisted of a magnetizing inductor L_m, primary leakage inductor L_{k1}, secondary leakage inductor L_{k2}, and an ideal transformer, which constituted the primary and secondary windings, N_1 and N_2, respectively. In order to simplify the circuit analysis of the proposed converter, some assumptions are stated as follows.

- All components are ideally considered except the leakage inductor of the coupled inductor. The ON-state resistance *RDS* (ON) and all parasitic capacitors of the main switch *S*1 are neglected; in addition, the forward voltage drop of the diodes D_1–D_4 is ignored.
- All capacitors are sufficiently large, and the voltages across capacitors are considered as constant during one switching period.
- The ESRs of all capacitors C_1, C_{01}, and C_{02} are neglected.

- The turn ratio η of dual-winding coupled inductor T_1 is equal to $\frac{N_1}{N_2}$.

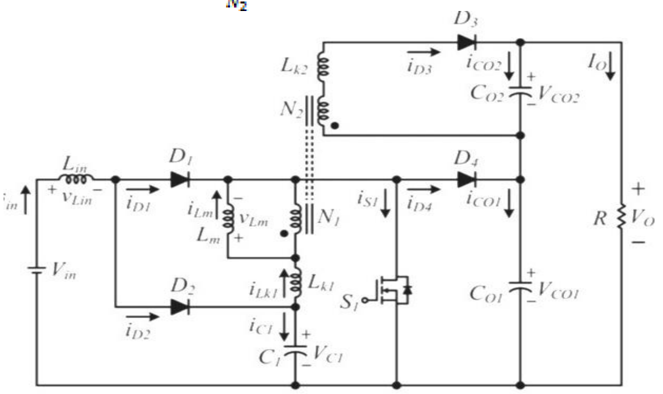

Fig.2: Simplified circuit model of the proposed converter

2.1 CONTINUOUS CONDUCTION MODE:

Fig.3 shows several typical waveforms during five operating modes at one switching period T_S while both the input inductor L_{in} and the magnetizing inductor L_m are operated in CCM. The operating modes are described as follows.

2.1.1 MODE 1 $[t_0, t_1]$:

In this transition interval, switch S_1 is turned ON. Diodes D_1 and D_3 are conducted but diodes D_2 and D_4 are turned OFF .The path of the current flow through the conduction element. The energy of the dc source V_{in} is transferred to the input inductor L_{in} through the diode D_1, and the voltage across the input inductor L_{in} is V_{in} ; the input current i_{in} is equal to i_{D1} and is increased. The capacitor C_1 delivers its energy to the magnetizing inductor L_m and the primary leakage inductor L_{k1}.The voltage across the magnetizing inductor L_m and the primary leakage inductor L_{k1} is V_{C1}, but the magnetizing inductor L_m keeps on transferring its energy through the secondary leakage inductor L_{k2} to the charge capacitor C_{01} so that both currents i_{Lk2} and i_{Lm} decrease, until the increasing i_{Lk1} reaches and equals to decreasing i_{Lm} in the meantime, the current i_{Lk2} is down to zero at t= t_1 this mode is ended. The energies stored in capacitors C_{01} and C_{02} are constantly discharged to the load *R*.

2.1.2 MODE 2 $[t_1, t_2]$:

During this interval, the switch S_1 is remained ON. Only the diode D_1 is conducted and rest of other diodes D_2, D_3, and D_4 are turned OFF .The path of the current flow through the conduction element. The energy of the dc source V_{in} is still stored into the input inductor L_{in} through the diode D_1 .The energy that has charged the capacitor C_1 is still delivered to the magnetizing inductor L_m and primary leakage inductor L_{k1} .The voltage across magnetizing inductor L_m and primary leakage inductor L_{k1} is V_{C1} .Thus, currents i_{in}, i_{D1}, i_{Lm}, and i_{Lk1} are increased. The energies stored in capacitors C_{01} and C_{02} are still discharged to the load R. This mode is ended when switch S_1 is turned OFF at t= t_2.

2.1.3 MODE 3 $[t_2, t_3]$:

During this interval, switch S_1 and diode D_1 are turned OFF; the diodes D_2, D_3, and D_4 are conducted . The path of the current flow through the conduction element .The dc source V_{in} and input inductor L_{in} are connected serially to the charge capacitor C_1 with their energies. Meanwhile, the primary leakage inductor L_{k1} is in series with capacitor C_1 as a voltage source V_{C1} through magnetizing inductor L_m then delivered their energies to the charge capacitor C_{01} .The magnetizing inductor L_m also transferred the magnetizing energy through coupled Inductor T_1 to secondary leakage inductor L_{k2} and to charge capacitor C_{02} .Thus, currents i_{in}, i_{D2}, i_{D4}, i_{Lm}, and i_{Lk1} are decreased, but currents i_{C1}, i_{Lk2}, and i_{D3} are increased. The energies stored in capacitors C_{01} and C_{02} are discharged to the load R. This mode is ended when the current i_{C01} is dropped till zero at t= t_3.

2.1.4 MODE 4 $[t_3, t_4]$:

During this transition interval, switch S_1 and diode D_1 are remained OFF; and diodes D_2, D_3, and D_4 are still conducted .The path of the current flow through the conduction element. Almost statuses are remained as Mode 3 except the condition of primary leakage inductor L_{k1} is in series with capacitor C_1 as a voltage source V_{C1} through magnetizing inductor L_m then discharged or released their energies to load. Thus, currents i_{in}, i_{D2}, i_{D4}, i_{Lm}, and i_{Lk1} are persistently decreased, but currents i_{C02}, i_{Lk2}, and i_{D3} are still increased. The energy stored in capacitors C_{01} and C_{02} is discharged to the load R. This mode is ended when current iLk1 is decreased until zero at t= t_3.

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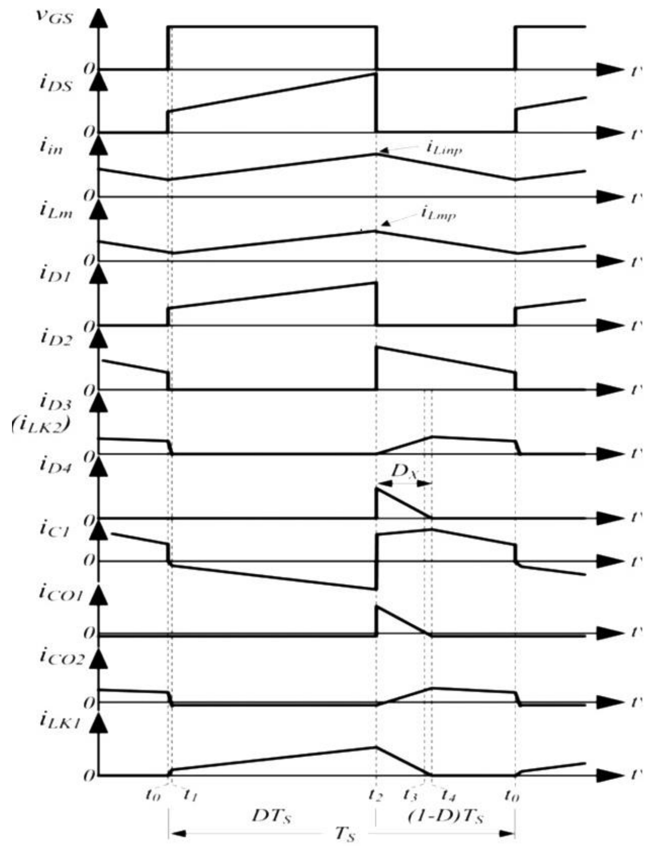

Fig.3: Some typical waveforms of the proposed converter both L_m and L_{in} are CCM operation

2.1.5 MODE 5 [t_4 , t_5]:

During this interval, switch S_1 and diode D_1 are remaining OFF; diode D_4 is turned OFF and diodes D_2 and D_3 are keep conducted the path of the current flow through the conduction element .The path of the current flow through the conduction element. The dc source V_{in} and input inductor L_{in} are connected serially and still charged to capacitor C_1 with their energies. The magnetizing inductor L_m continuously transferred its own magnetizing energy through coupled inductor T_1 and diode D_3 to the secondary leakage inductor L_{k2} and to the charge capacitor C_{02}.Thus, currents i_{in} ,i_{D2},i_{D3},i_{Lk2} , and i_m are decreased. The energies stored in capacitors C_{01} and C_{02} are discharged to the load. This mode is end when switch S_1 is turned ON at the beginning of the next switching period.

3. MATHEMATICAL EXPRESSION

Mathematical expression of boost converter has been explained for Continuous conduction mode of operation .For steady-state analysis of proposed converter.

3.1 CCM OPERATION:

Since the time durations of Modes 1 and 4 are transition periods, only Modes 2, 3, and 5 are considered at CCM operation for the steady-state analysis. During the time duration of Mode 2, the main switch S_1 is conducted, and the coupling coefficient of the coupled inductor k is considered as $L_m/(L_m) + L_{k1}$. The following equations can be written from Fig. 5.3.1:

$$vL_{in}=V_{in} \quad (1)$$

$$vL_m=\frac{L_m}{L_m+L_{k1}}V_{C1}=kV_{C1} \quad (2)$$

$$vL_{K1}=VC_1 - VL_m = (1-K)VC_1 \quad (3)$$

$$vL_{K2}= \eta . vL_m \quad (4)$$

During the period of Modes III and V that main switch S_1 is turned OFF, the following equations can be found as

$$vL_{in}=V_{in} - V_{C1} \quad (5)$$

$$vL_m= V_{C1} - V_{C01} - V_{Lk1} \quad (6)$$

$$vL_{K2} = - \eta . vL_m - V_{C02} \quad (7)$$

Where the turn ratio of the coupled-inductor η is equal to N_1/N_2.The voltage across inductor L_{in} by the volt-second balance principle is shown as

$$\int_0^{DT_s} V_{in}\,dt + \int_{DT_s}^{T_s}(V_{in} - V_{C1})\,dt = 0 \quad (8)$$

$$VC_1 = \frac{1}{1-D}V_{in} \quad (9)$$

$$\int_0^{DT_s} kV_{C1}\,dt + \int_{DT_s}^{T_s}(V_{C1} - V_{C01} - V_{Lk1})\,dt = 0 \quad (10)$$

$$\int_0^{DT_s} kV_{C1}\,dt + \int_{DT_s}^{T_s}\frac{(-V_{C02} - V_{Lk2})}{\eta}\,dt = 0 \quad (11)$$

Substitute (9) into (10) and (11), and assume that L_{k2} is equal to ηL_{k1}; thus V_{CO1} and V_{CO2} can be obtained from the following equations:

$$V_{CO1} = \frac{1-D+kD}{1-D} V_{C1} - V_{Lk1} \quad (12)$$

$$= \frac{1-D+kD}{(1-D)^2} V_{in} - V_{Lk1} \quad (13)$$

$$V_{CO2} = \frac{\eta kD}{1-D} V_{C1} - V_{Lk2} \quad (14)$$

$$= \frac{\eta kD}{(1-D)^2} V_{in} - \eta V_{Lk2} \quad (15)$$

The output voltage V_0 can be express as

$$V_0 = V_{CO1} + V_{CO2} \quad (16)$$

By substituting (3), (13), and (15) into (16), we can obtain the voltage gain M_{CCM}:

$$M_{CCM} = \frac{V_0}{V_{in}} \quad (17)$$

$$= \frac{k(\eta + 1) + \eta(D-1)}{(1-D)^2} \quad (18)$$

Fig.4 shows a line chart of the voltage gain versus the duty ratio D under three different coupling coefficients of the coupled inductor while η = 4.4 is given. It revealed that the coupling coefficient k is almost unaffected. By substituting k = 1 into (18) and (15), the input–output voltage gain can be simplified

$$M_{CCM} = \frac{V_0}{V_{in}} = \frac{1+\eta D}{(1-D)^2} \quad (19)$$

$$M_{CCM} = \frac{V_{CO2}}{V_{C1}} = \frac{\eta D}{1-D} \quad (20)$$

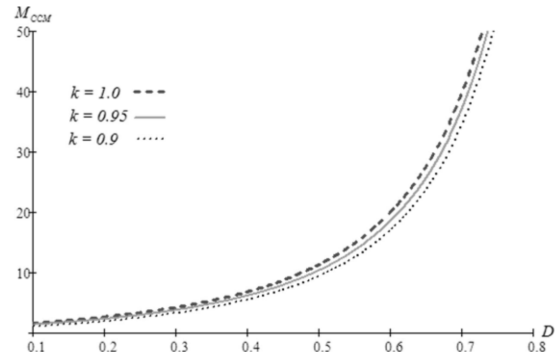

Fig.4: Voltage gain versus duty ratio at CCM operation under n = 4.4 and Diverse k

Fig.5 demonstrates the voltage gain versus the duty ratio of the proposed converter and other converters in [19], [21], and [22] at CCM operation under k = 1 and η = 4.4. As long as the duty ratio of the proposed converter is larger than 0.55, the voltage gain is higher than the converters in [19], [21], and [22]. Referring to the description of CCM operating modes, the voltage stresses on S_1 and D_1 –D_4 are given as

$$V_{DS} = V_{D4} = \frac{V_0}{1+\eta D} \quad (21)$$

$$V_{D1} = \frac{DV_0}{1+\eta D} \quad (22)$$

$$V_{D2} = \frac{(1-D)V_0}{1+\eta D} \quad (23)$$

$$V_{D3} = \frac{\eta V_0}{1+\eta D} \quad (24)$$

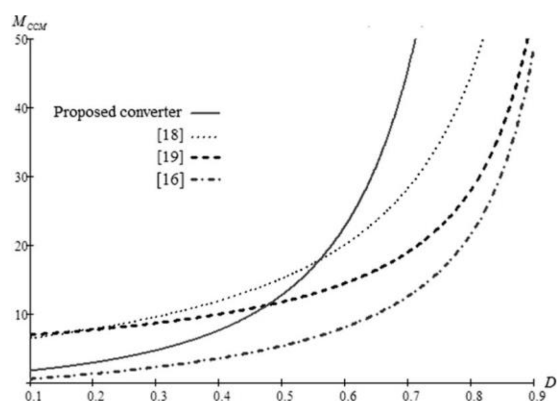

Fig.5: Voltage gain versus duty ratio of the proposed converter, the converters in [19], [21], and [22] at CCM operation under n = 4.4 and k = 1

4. DESIGN ANALYIS

The functions of main components of high gain DC-DC boost converter power stage are discussed and the individual values are determined to meet the project specification. The conduction mode of power stage is determined by input voltage, output voltage, output current and value of inductor. The input voltage, output voltage, load current is defined by project specification.

In project specification the input voltage 25 V generates the output voltage of 440 V with output current of 0.789 Amp. The calculation for output current is shown below, given the requirement for 440 V output voltage and 345 W output power. The power equation is:

$$P=V\times I$$

The calculation of output current requires to supplying 345 W powers to the load.

$$I_{out} = P_{out} V_{out}$$

The load resistor is calculated by ohm's low:

$$V=I\times R$$

$$R_{out} = \frac{V_{out}}{I_{out}}$$

The turn ratio of coupling inductor is:

$$\sqrt{\frac{L_2}{L_1}} = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

Time period during switch is ON condition i.e.

$$T_{ON} = \alpha T$$

Time period during switch is OFF condition i.e.

$$T_{OFF} = T - T_{ON}$$

Duty cycle (D):

$$D = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

The value of inductor L1 is calculates as follow:

$$L_1 \frac{dI_{L1}}{dt} = V_S$$

$$L_1 = V_S \frac{dt}{dI_{L1}}$$

The value of inductor L2 is

$$\sqrt{\frac{L_2}{L_1}} = \frac{N_2}{N_1}$$

Considering coupling coefficient K. The mutual inductance (M) between two coupling inductors is:

$$K= \frac{M}{\sqrt{L_1 \times L_2}}$$

4. CONCLUSION

A high boost converter is successfully used as a quadratic boost converter driven by a single switch and achieved high step-up voltage gain; the voltage gain is up to 20 times more than the input. The leakage energy of coupled-inductor can be recycled, which is effectively constrained the voltage stress of the main switch S_1 and benefits the low ON-state resistance R_{DS} (ON) can be selected. As long as the technology of active snubber, auxiliary resonant circuit, synchronous rectifiers, or switched-capacitor-based resonant circuits employed in converter are able to achieve soft switching on the main switch to reaching higher efficiency. The simulation of the high boost converter open loop operation in continuous conduction mode has been implemented. The results have been compared for open loop control for pulse generator and sin PWM generator. Along with this is a closed loop operation in continuous conduction mode has been implemented and results have been plotted.

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