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Transformer less DC Converter with High Voltage Transfer Gain Achieving Voltage Regulation

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ABSTRACT:The increased demand for efficient lighting applications have led to the emergence of High Intensity discharge lamps. Their major applications are concerned about automotive lighting systems. Added to this they also find application in the field of wide area floodlighting systems, studios and entertainment lighting systems. But the starting stage of these lighting systems require adequate high level voltage which is generally not obtained from batteries or fuel cells that supply them. Hence high step up converters find an indispensable role in ballast of these high intensity discharge lamps. Step up converters boost the voltage of these sources possessing inherent low voltage characteristics. Moreover, efforts are being made to eliminate the drawbacks of these converters to develop a conceptual circuit for high efficiency dc-dc conversion to evolve next generation topologies for renewable energy systems. So a new transformer less voltage boost converter with high voltage transfer gain and reduced semiconductor voltage stress is introduced in this paper. It achieves a much higher voltage gain with reduced component count. The converter features uniform current sharing characteristic of two interleaved phases due to charge balance of blocking capacitors. A closed loop feedback is provided using P-I controller to achieve load voltage regulation. Finally the simulation results are presented to analyze the viability of this scheme in renewable energy applications.

KEYWORDS: Step up converter, Uniform current sharing, Transformer less DC converter.

I.INTRODUCTION

With the increasing demand for clean energy, renewable energy sources such as solar cells and fuel cells have found widespread usage in the modern energy scenario. However, a high step-up dc converter has become a necessity to compensate the effects of inherent low voltage characteristic of these sources. But the efficiency of conventional boost and Buck-boost converters is significantly low due to involvement of extremely large duty cycle[1]. Apart from large diode reverse recovery losses, step-up converter induces high voltage spikes and conduction losses[2],[3]. This acts as a hindrance for the fulfillment of application needs. Various topologies were introduced to solve the problems mentioned above thereby increasing the voltage gain of step-up converters[4]. Leakage inductance present in certain topologies with transformer isolation, were seen to cause large reverse recovery losses thereby increasing voltage stress across the semiconductor components. Active clamp techniques introduced were found to efficiently recycle the leakage inductance energy thereby minimizing the voltage stress across active switches[5]-[7].Certain topologies involving transformer isolation are capable of boosting the voltage gain by increasing the turns ratio but posses certain drawbacks like large input current ripple, increase in component number and size ,increase in cost etc. However, isolated current type converters overcome these drawbacks to certain extend thereby making them capable of being employed in high output voltage applications[8],[9]. But the start-up operation of such schemes paved way for further complications. Hence non-isolation topologies were suggested to offer much better solutions[10].Coupled inductor based converters were found to increase the voltage gain by improving the voltage conversion efficiency[16]-[18].Soft-switching techniques were also incorporated that reduced stress across semiconductor devices. Simplified coupled inductors were also introduced in some topologies to achieve effective voltage gain[22],[23].

In this paper a transformer-less interleaved boost converter is introduced which is capable of achieving high voltage gain with reduced semiconductor stress. It is capable of combining two-phase interleaved boost converters to realize a high voltage gain and maintain the advantage of an automatic current sharing capability simultaneously. This topology also offers advantages like reduced component count, less cost and simplified circuit. The remaining contents of this paper could be divided as follows. First, the circuit topology and operation principle are given in Section II. Then, the corresponding steady state analysis is made in Section III to provide some basic converter characteristics. A prototype is then constructed and some simulation and experimental results are then presented in Section IV for demonstrating the merits and validity of the proposed converter. Finally, some conclusions are offered at the ending section.

II.OPERATING PRINCIPLE

Interleaved converter with two phases forms the basis for the working principle of the proposed boost converter. The proposed converter is a modification of two-phase interleaved boost converter with parallel-input series-output configuration. The modification is brought about by adding two more capacitors and two more diodes to the basic interleaved topology. This leads to doubling of voltage gain of the converter topology. Reduction of voltage stresses across switches and diodes is also witnessed as a result of this. This topology also possess automatic uniform current sharing characteristic which signifies the importance of this scheme. No complex control scheme or extra circuitry is employed to realize automatic uniform current sharing property. The operating principle is illustrated below.

Achievement of high voltage gain is the main aim of this scheme. But to achieve this, it becomes mandatory to operate the converter in continuous mode at a duty cycle greater than 0.5. No sufficient energy transfer takes place between inductors to blocking capacitors, output capacitors and load side, if the converter is operated at a duty cycle below 0.5 or in discontinuous conduction mode. Even the automatic current sharing property could be achieved only when the duty cycle is greater than 0.5, due to charge balance of blocking capacitor. It also results in the loss of current balance between two phases of converter.

Mode 1 ($t_o \leq t < t_1$): In this operating mode both the switches namely S_1 and S_2 are turned on. The corresponding equivalent circuit is shown in Fig. 2(a).The diodes D_{1a}, D_{2a}, D_{1b} and D_{2b} are all in off position. Here currents in inductors L_1 and L_2 namely i_{L1} and i_{L2} store energy in their respective inductors. The voltages across diodes D1a and D2a are clamped to capacitor voltage VCA and VCB, respectively, and the voltages across the diodes D1b and D2b are clamped to VC2 minus VCB and VC1 minus VCA, respectively. The output capacitors C_1 andC_2 supply the necessary power to the load. Applying steady state, the state equations could be found as follows:

$$L_1\frac{diL1}{dt} = V_{in} \quad (1)$$

$$L_2\frac{diL2}{dt} = V_{in} \quad (2)$$

$$C_A\frac{dVCA}{dt} = 0 \quad (3)$$

$$C_B\frac{dVCB}{dt} = 0 \quad (4)$$

$$C_1\frac{dVc1}{dt} = -\frac{(Vc1+Vc2)}{R} \quad (5)$$

$$C_2\frac{dVc2}{dt} = -\frac{(Vc1+Vc2)}{R} \quad (6)$$

Mode 2 ($t_1 \leq t < t_2$): The corresponding equivalent circuit is shown in Fig. 2(b). For this operating mode switch S_2 is turned off while switch S_1 remains on or conducting. Diodes D_{2a} and D_{2b} begin to conduct in this mode of operation. From the figure Fig. 2(b), we could infer that that part of stored energy in inductor L_2 as well as the stored energy of C_A is now released to output capacitor C1 and load. Whereas part of stored energy in inductor L_2 is stored in C_B .The voltage across capacitor C_1 is the added sum of voltages across capacitors C_A and C_B. Here i_{L1} continues to increase whereas i_{L2} begins to decrease linearly. The state equations of this mode could be derived as follows:

$$L_1\frac{diL1}{dt} = V_{in} \tag{7}$$

$$L_2\frac{diL2}{dt} = V_{in} + V_{CA} - V_{C1} = V_{in} - V_{CB} \tag{8}$$

$$C_A\frac{dVCA}{dt} = i_{CB} - i_{L2} \tag{9}$$

$$C_B\frac{dVCB}{dt} = i_{CA} + i_{L2} \tag{10}$$

$$C_1\frac{dVC1}{dt} = -\, i_{CA} - \frac{(VC1+VC2)}{R} \tag{11}$$

$$C_2\frac{dVC2}{dt} = -\,\frac{(VC1+VC2)}{R} \tag{12}$$

Mode 3 ($t_2 \leq t < t3$): The corresponding equivalent circuit of this mode is same as that of mode 1. Both switches S_1 and S_2 are now conducting and rest of the operation is similar to mode1. The corresponding equivalent circuit turns out to be the same as Fig. 2(a).

Mode 4 ($t_3 \leq t < t_4$): In this operating mode, switch S_1 is turned off while switch S_2 continues to conduct. The equivalent circuit corresponding to this mode is shown in Fig. 2(c).

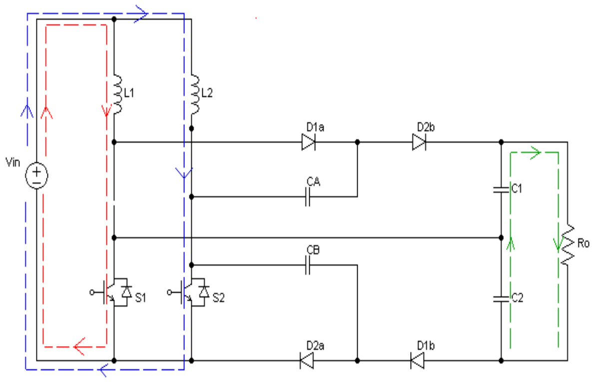

Fig. 2(a). Equivalent circuit of mode 1 operation

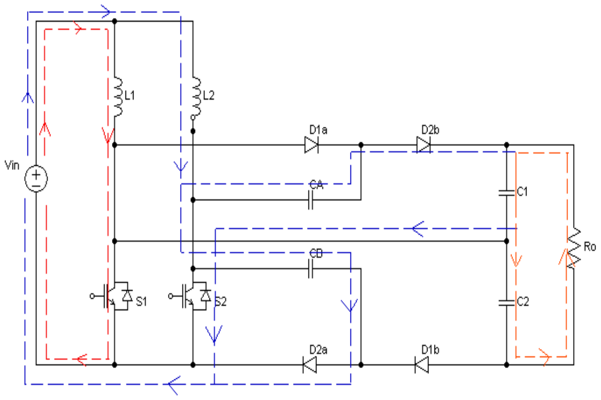

Fig. 2(b).Equivalent circuit of mode 2 operation.

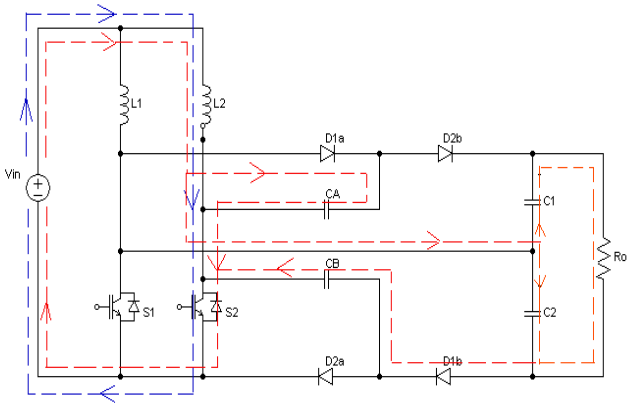

Fig. 2(c). Equivalent circuit of mode 4 operation

Diodes D_{1a} and D_{1b} begin to conduct here. From the figure it could be seen that the part of stored energy in inductor L_1 as well as the stored energy of C_B is now released to output capacitor C_2 and load. Whereas part of the stored energy in inductor L_1 , is stored in C_A.The voltage across capacitor C_2 is the added sum of voltages across capacitors C_A and C_B. Current i_{L2} continues to increase linearly while current i_{L1} begins to decrease linearly. The state equations corresponding to this mode are given as follows:

$$L_1\frac{diL1}{dt} = V_{in} - V_{C2} + V_{CB} = V_{in} - V_{CA} \qquad (13)$$

$$L_2\frac{diL2}{dt} = V_{in} \qquad (14)$$

$$C_A\frac{dVCA}{dt} = i_{CB} + i_{L1} \qquad (15)$$

$$C_B\frac{dVCB}{dt} = i_{CA} - i_{L1} \qquad (16)$$

$$C_1\frac{dVC1}{dt} = -\frac{(VC1+VC2)}{R} \qquad (17)$$

$$C_2\frac{dVC2}{dt} = -\ i_{CB} - \frac{(VC1+VC2)}{R} \qquad (18)$$

From the above four modes of operations one could infer that working of two phase converter proceeds in a symmetric manner. Each mode of operation shares 90 degrees of entire cycle of operation separately and equally. Charging and discharging of inductors takes place in a manner such that voltage stresses across capacitors are halved compared to existing interleaved converters. The stresses across switches and diodes are also increased considerably. Thereby the voltage transfer gain is improved to a much greater extend.

III.CONTROL SCHEME

The proposed control strategy is developed to tackle variations in the input voltage and load. The control strategy is aimed at implementing a closed loop P-I feedback control in the recommended interleaved converter whose main objective is to achieve load voltage regulation. Load voltage regulation ensures that the HID lamp output remains at a steady value even if there is disturbance in load conditions. Voltage mode of control is implemented here. Voltage mode of operation is preferred here because it is simple to implement and has been useful in industrial applications since decades.

P-I controller is implemented here due to its several advantages. Steady state error resulting from P controller is easily overcome by the use of P-I controller. However, the controller possess negative effect in terms of overall stability of the system, it has a negative impact. This controller is mostly employed in areas where speed of the system is not a matter of significance. It also serves the purpose of the converter by achieving voltage regulation. Fig. 4 shows the block diagram of control strategy implemented.

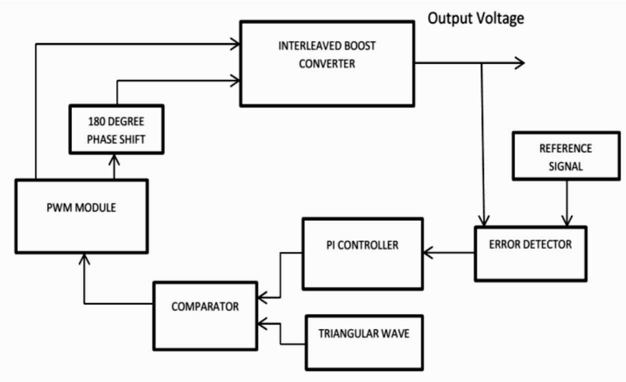

Fig. 4. Block Diagram of control strategy

IV.SIMULATION RESULTS AND DISCUSSION

MATLAB Simulink model is used to simulate the interleaved boost converter to analyze the advantages of this scheme. The simulation results of 25-V input, 400-V output, and 400-W rating converter are studied. The switching frequency is chosen to be 40 kHz. The component parameter specifications are listed in Table I for reference.

The input and output voltage ripples and the size of the energy storage inductors are effectively reduced thereby improving voltage gain making it suitable for star up stage of HID lighting applications. In order to verify the voltage regulation, different load conditions are chosen from full load to light load which imply different disturbances in load conditions.

TABLE I
Component Parameter Specifications

Components	***Specification***
Boost Inductors(L_1,L_2)	CH330060,253µH
Active Switches (S_1, S_2)	IXFH150N15P,150V
Blocking Capacitors($C_{A,}C_B$)	10uF/250V
Output Capacitors(C_1,C_2)	250uF/250V
Power Diode(D_{1a},D_{2a},$D_{1b,}$D2b)	DSEP 60-025A

Fig. 5 shows the two-phase inductor current waveforms of the simulation. Fig. 5 shows that the voltage stress across the switches is only one-fourth of the output voltage. Fig. 7 shows that voltage stress across diodes is half of the output voltage except diode D_{2a} where it only one-fourth the output voltage. Fig. 8 and Fig. 9 show the voltages across output capacitors and blocking capacitors respectively, where the voltage stresses are considerably reduced.

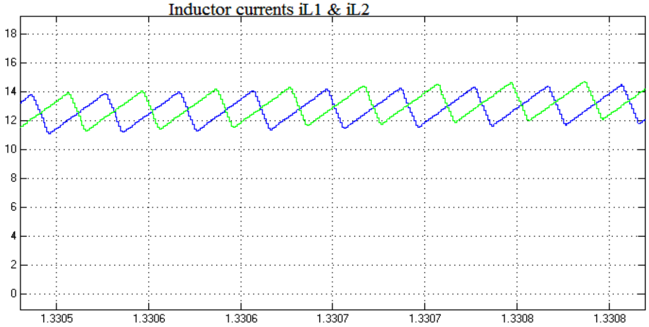

Fig. 5. Waveforms of inductor currents I_{L1}& I_{L2}

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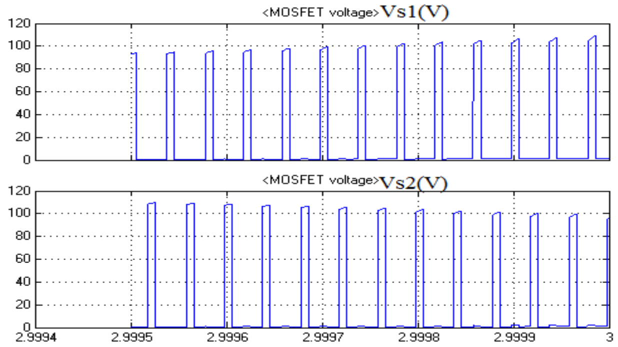

Fig. 6.Waveforms of the voltage stress of V_{S1}& V_{S2}

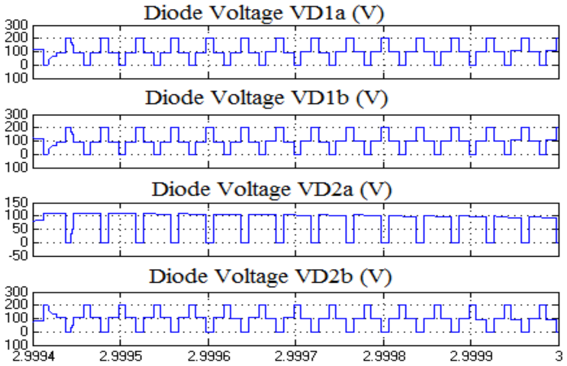

Fig. 7. Waveforms of the voltage stress of V_{D1a},V_{D1b},V_{D2a}, and V_{D2b}

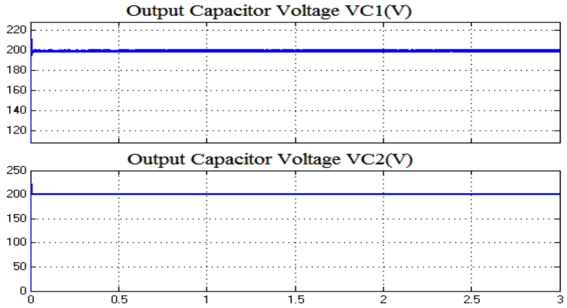

Fig. 8.Waveforms of output capacitors voltages

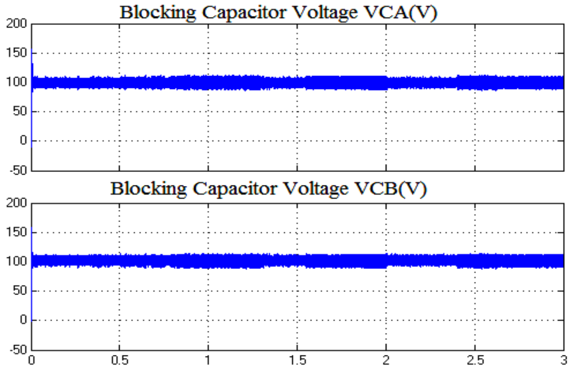

Fig. 9.Waveforms of blocking capacitor voltages

Fig. 11 and Fig. 13 show the load regulation at rated load and no load conditions respectively. At rated load(400ohms),output current which is the ratio of output power to output voltage, is obtained as 1ohms.

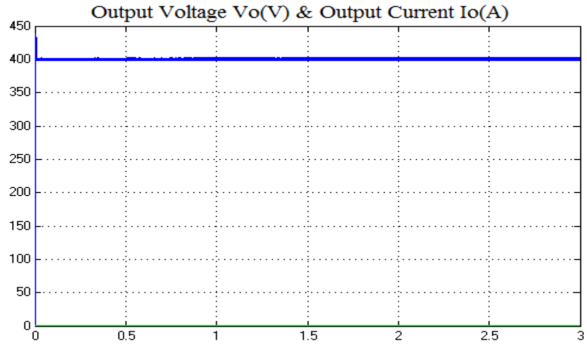

Fig. 10. Output voltage and output current at V_{in}=25V, 400W rating and R=400Ω (Rated load)

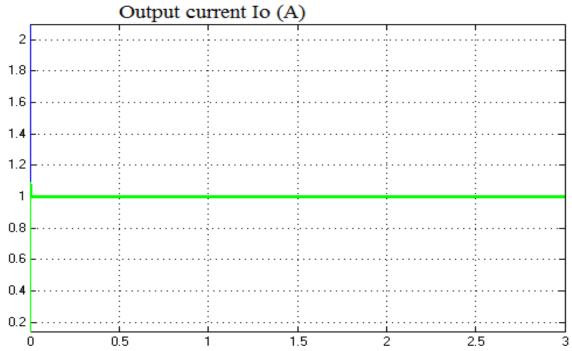

Fig. 11. Output current at V_{in}=25V, 400W and R=400Ω

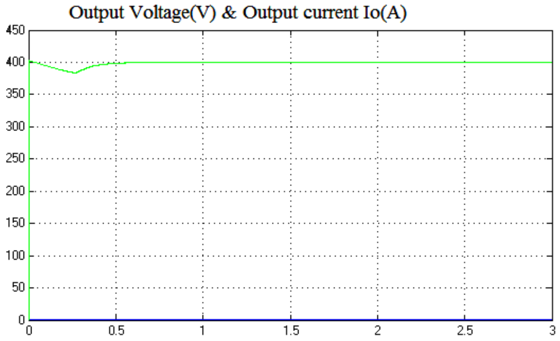

Fig. 12. Output voltage and current at V_{in}=25V, 400W and at no load

V. CONCLUSION

High intensity discharge lamps are gaining much momentum in lighting applications due to the several advantages they posses. Automotive lighting application constitutes a major area of application whereas other applications areas include wide area flood lighting, entertainment lighting systems and areas requiring ambient supply of light energy. But the batteries or fuel cells which are the source of energy supply to the ballast of these HID lamps posses an inherent low voltage property which reduces their capability of working. Hence the ballast circuit of HID lamps is provided with a step up converter which solves this problem to some extent. A new transformer-less voltage boost converter with high voltage gain and reduced semiconductor voltage stress satisfies the purpose of boosting the voltage of these energy sources to a level optimum for operation of HID lamps. Finally, simulation of 40 kHz converter having 25-V input and 400V output is carried out to study the advantages of this scheme. Moreover, load voltage regulation that is achieved with suitable feedback control without involving great complexity, adds to the advantage of this scheme.

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