CLOSED LOOP CONTROL OF INTERLEAVED BOOST CONVERTER WITH PISO CONFIGURATION AND VOLTAGE MULTIPLIER MODULE

Swapna S Gowda, Sharath Kumar Y N

PG Student, Asst. Professor
Dept. of Electrical and Electronics Engg.
Dayananda Sagar College of Engineering, Bangalore, India

Abstract : This paper presents closed loop control of interleaved boost converter with voltage multiplier cell. An interleaved boost converter with parallel input series output coupled to a voltage multiplier circuit on the output side which provides a higher voltage gain than that of a conventional boost converter. Parallel input connection is used to share the input current and to reduce the conduction losses, while the series output connection along with the voltage multiplier cell is to employ the high voltage gain. Additionally, in order to obtain the controlled output voltage from the DC-DC converter under varying input conditions, it is required to regulate the output voltage which can be obtained using closed loop control. A PI controller is implemented to improve the performance of the proposed IBC during the disturbances due to renewable energy sources. The closed loop control of the proposed IBC with voltage multiplier module is analyzed and simulated for R load using MATLAB Simulink.

***IndexTerms* - Interleaved Boost Converter, Voltage multiplier module, High Voltage Gain, PI controller**.

I. INTRODUCTION

The usage of Batteries and PV module as the primary source as more become more obvious as it provides clean electrical energy. Thus, to transfer the energy from conventional batteries (40Vdc) to conventional110/220Vrms ac systems, it is necessary to step up the battery voltage using a dc–dc converter.

The conventional boost converters can theoretically serve the purpose, but in order to achieve high voltage gain, the converter has to be operated with very high duty ratio approx. greater than 0.9 which results in variations in the output voltage with the small variations in duty cycle leading to instable operation of the converter. Also, the parasitic elements does not allow larger voltage step up due to the losses in the circuit components [1-4].

In order to achieve required high voltage, the boost converters are to be cascaded or high frequency isolation DC-DC converters with high turns ratio of transformer can be employed. The use of an interleaved-boost converter associated with an isolated transformer was introduced, using the high frequency ac link. Despite the good performance, the topology uses three magnetic cores, which prejudice the weight, the volume, and the efficiency of the structure [5-6].

An interleaved-boost converter employing multiplier capacitors connected in series with high gain has been proposed in [7]. This converter presents low-input current ripple and low-voltage stress across the switches. However, peak current flows through the series capacitors at high power levels.

In [8-10], an interleaved high step-up boost converters with winding-cross-coupled inductors is presented, where a coupled inductor with three windings is used achieving good performance. Paper [11] discusses the closed-loop control of interleaved high step up converter to obtain high reliability. The switch voltage stress and the diode peak current are minimized due to the multiplier cells. Also, there is no reverse-recovery problem for the clamp diodes. Paper [12] introduces interleaved boost converter with PISO configuration with high voltage gain and voltage multiplier module than the conventional boost converter using magnetic coupling.

In the proposed paper, the closed loop control for high voltage gain interleaved boost converter with voltage multiplier module is implemented. In order to obtain the controlled output voltage from the DC-DC converter under varying input conditions, it is required to regulate the output voltage which can be obtained using closed loop control. The closed loop control of the proposed IBC with voltage multiplier module is analyzed and simulated for R load using MATLAB Simulink and the results are compared with open loop control system.

II. INTERLEAVED BOOST CONVERTER WITH VOLTAGE MULTIPLIER MODULE

2.1. *Converter Configuration*

This section presents the operational principle and equations of the IBC with Voltage multiplier module operating in continuous conduction mode. The circuit is composed of two phase interleaved boost converter with parallel input series output connection and to achieve high voltage gain, voltage multiplier module is magnetically coupled to the conventional interleaved boost converter as seen in the fig 1.

The two coupled inductor are modeled as a combination of an ideal transformer with a turn's ratio n, a magnetizing inductance and leakage inductance in this paper. The voltage multiplier module is comprised of secondary windings (N_{S1} and N_{S2}) of two coupled inductors, two output diodes D_3 and D_4 and the two capacitors C_3 and C_4.

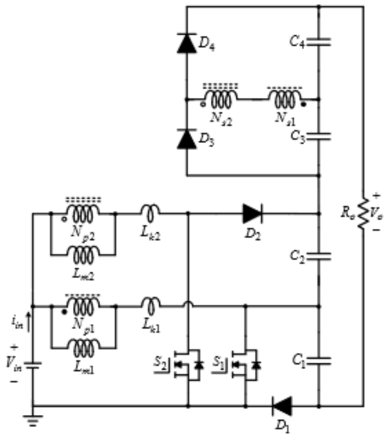

Fig 1: Interleaved Boost Converter with Voltage Multiplier Module

The circuit is realized by magnetizing inductances L_{m1} and L_{m2}, the leakage inductances L_{k1} and L_{k2}, S_1 and S_2 are the power switches. C_1 and C_2 are the output capacitors. D_1 and D_2 are the output diodes. The gating pulses to the two power switches S_1 and S_2 work in the interleaved fashion with a 180° phase shift. It is to be noted that the duty cycle should never be lesser than 50%, as there would be no energy transfer from the coupled inductors primary side to the secondary one. The proposed switching cycle is composed of four stages which is explained in detail below.

2.2. Operation principle

For the theoretical analysis, it is assumed that input and output voltages are ripple free and all devices are ideal. At the initial stage (i.e, before the start of first stage) both the switches are turned on and so both the inductors (N_{P1} and N_{P2}) are energized. There are four modes of operation under steady state operation of the IBC converter with voltage multiplier cell.

Stage 1[t_0, t_1]: In this interval, at $t = t_0$, S_1 begins to turn on with ZCS condition, while S_2 continues to be in the on state. The diodes D_1, D_2 and D_3 are reverse-biased, as shown in Fig No 2.

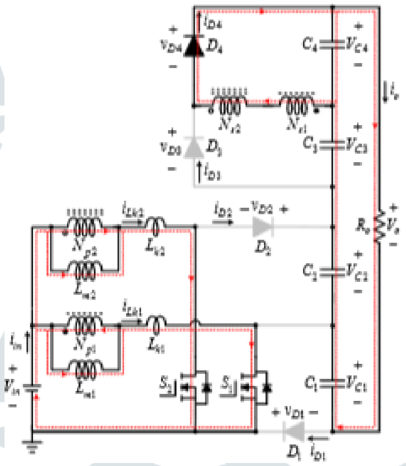

Fig 2: Stage 1[t_0, t_1]

Inductor leakage current iL_{k1} increases quickly. The capacitor C_4 is charged via D_4 by transferring the energy stored in the inductor L_{m1} through the secondary side of the coupled inductor. Also, the reverse recovery problem of diode D_4 can be overcome as the current through the diode D_4 reduces and the stage 1 ends when the current i_{D4} decreases to zero and D_4 turns off.

The equations that represent this stage are

$$L_1\frac{diL1}{dt} - Vi = 0 \qquad (1)$$

$$L_2\frac{diL2}{dt} - Vi = 0 \qquad (2)$$

$$V_{C4} = (-nL_2\frac{dis}{dt} + M\frac{diL2}{dt}) - (nL_1\frac{dis}{dt} + M\frac{diL1}{dt}) \qquad (3)$$

where M is the mutual inductance and k is the magnetic coupling coefficient given by,

$$M = nkL_{B1}$$

$$k = \frac{VL1}{nVLB1}$$

Stage 2[t_1, t_2]: In this interval, at t = t_1, diodes D_2 and D_3 becomes forward biased as power switch S_2 is turned off as shown in fig 3.

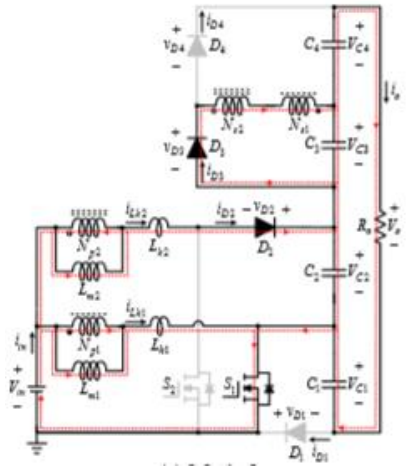

Fig 3: Stage 2[t_1, t_2]

The capacitor C_3 is charged via D_3 by transferring the energy stored in the inductor L_{m2} through the secondary side of the coupled inductor. The capacitor C_2 gets charged as the inductor current ilk2 flows through D_2, C_2 and power switch S_1. The reverse recovery problem of diode D_2 will be alleviated as the current through the diode D_2 reduces and at t = t_2, this mode ends when the current i_{lk2} decreases to zero and D_2 turns off.

The equations that represent this stage are

$$L_1\frac{diL1}{dt} - Vi = 0 \qquad (4)$$

$$V_{C2} + L_2\frac{diL2}{dt} - Vi = 0 \qquad (5)$$

$$V_{C3} = (-nL_2\frac{dis}{dt} + M\,\frac{diL2}{dt}) - (nL_1\frac{dis}{dt} + M\,\frac{diL1}{dt}) \qquad (6)$$

Stage 3[t_2, t_3]: In this interval, at t = t_2, due to leakage inductor L_{K2}, the power switch S_2 turns on while the switch S_1 continues to be in the on state and hence the diodes D_1, D_2 and D_4 becomes reversed biased as shown in fig 4

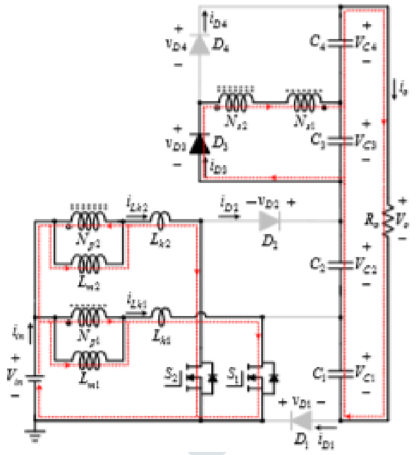

Fig 4 : Stage 3[t_2, t_3]

Inductor leakage current iL_{k1} increases quickly with high rate. The energy stored in the inductor L_{m2} continues to transfer to the secondary side of the coupled inductor thereby charging the capacitor C_3 via D_3 whereas the current through the diode D_3 decreases which overcomes the reverse recovery problem of diode D_3. At t = t_3, this mode ends when the current i_{D3} decreases to zero and D_3 turns off.

The equations for this stage are as follows

$$L_1\frac{diL1}{dt} - Vi = 0 \qquad (7)$$

$$L_2\frac{diL2}{dt} - Vi = 0 \qquad (8)$$

$$V_{C3} = (-nL_2\frac{dis}{dt} + M\,\frac{diL2}{dt}) - (nL_1\frac{dis}{dt} + M\,\frac{diL1}{dt}) \qquad (9)$$

Stage 4[t_3, t_4]: In this interval, at t = t_3, diodes D_1 and D_4 becomes forward biased as power switch S_1 is turned off as shown in fig 5.

The capacitor C4 is charged via D4 by transferring the energy stored in the inductor Lm1 through the secondary side of the coupled inductor. Meanwhile i_{Lk1} reduces and flows through C_1 and D_1. At t = t_4 the stage 4 ends when the current i_{Lk1} decreases to zero and D_1 turns off.

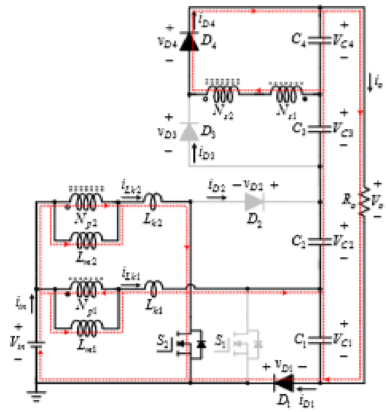

Fig 5: Stage 4[t_3, t_4]

The equations are as follows

$$L_2\frac{diL2}{dt} - Vi = 0 \tag{10}$$

$$V_{C1} + L_1\frac{diL1}{dt} - Vi = 0 \tag{11}$$

$$V_{C4} = (-nL_2\frac{dis}{dt} + M\frac{diL2}{dt}) - (nL_1\frac{dis}{dt} + M\frac{diL1}{dt}) \tag{12}$$

III. CLOSED LOOP CONTROL OF IBC WITH VOLTAGE MULTIPLIER MODULE

In order to obtain the controlled output voltage from the DC-DC converter under varying input conditions, it is required to regulate the output voltage which can be obtained using closed loop control. This can be achieved with the assistance of negative feedback which is called as closed loop method. For PWM dc-dc converters, the control of the output voltage can be carried out in a closed-loop fashion using two common closed-loop control methods namely,

- The voltage-mode control.
- The current-mode control.

3.1. Voltage-Mode Control

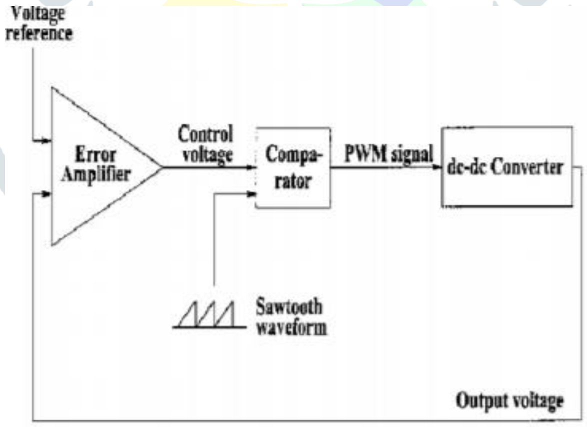

Fig 6: Voltage Loop Control

The block diagram of Voltage mode control is illustrated in Fig 6. This technique helps in sampling the converter output voltage and compared with the reference voltage which results in error voltage. The error voltage is then fed to the error amplifier which produces a controlled voltage which is then compared with a constant-amplitude saw tooth waveform. The main switches of the converter are provided with the PWM signals produced by the comparator, with adjusted duty cycle for stabling the output voltage to the desired level.

The Error amplifier shown in Fig 6 reacts fast to changes in the converter output voltage. Thus, the voltage control loop provides good load regulation. To alleviate this line regulation problem, the voltage control loop scheme is sometimes augmented by a so called voltage-feed forward path. The feed forward path affects directly the PWM duty ratio according to variations in the input voltage.

3.2. PI Controller

The block diagram of proportional and integral controller is as shown in the Fig 7. The main disadvantage of the P controller is it does not eliminate the steady state error. So this can be eliminated by PI controller. This controller is used in such areas where the speed of the system does not come into picture. By using PI controller rise time and settling time of the system reduces.

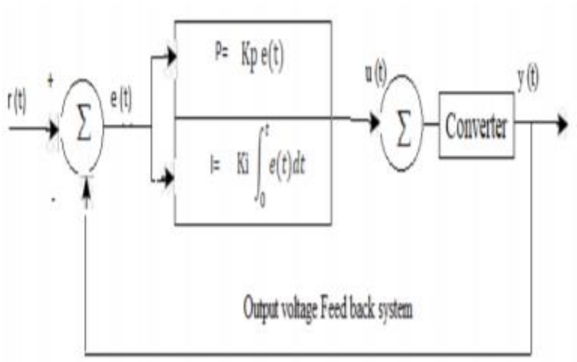

Fig 7 : Block Diagram of PI Controller

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + u(0)$$

u(0) = initial value of the output at t = 0

A PI controller gives the control signal based on the error value as the difference between a desired set point and a measured process variable. It is very advantageous as it is very feasible and can be easily implemented.

3.3. Compensator Design

The use of compensator aims to guarantee the system stability. The transfer function that relates output voltage with duty cycle is the first step to be determined. For the proposed converter, the same function used for the conventional boost converter has been employed.

$$G(s)= \frac{(Vin/(1-D)2)(1-(s/(R0(1-D)2))LB1)}{s2(LB1CBoosteq/(1-D)2)+s(LB1/(R0(1-D)2))+1} \quad (13)$$

The equivalent capacitance of the proposed topology Ceq is the value seen by the source, and it is calculated as follows:

$$\frac{1}{\mathrm{Ceq}} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} + \frac{1}{C4}$$

$$C_{eq} = 2.5*10^{-5}\ \mathrm{F} \quad (14)$$

Using the energy-conservation principle, it is possible to convert Ceq into C_{BOOST}eq, which is the capacitance of the equivalent conventional boost

$$\frac{1}{2}\, C_{Boost\_eq} V^2{}_{Boost\_eq} = \frac{1}{2}\, C_{eq} V^2{}_{Proposed\_Boost}$$

$$C_{Boost\_eq} = 0.1\mathrm{mF} \quad (15)$$

On substituting the values of L, R, C, Vin and D, we get the transfer function of the interleaved boost converter with voltage multiplier module. The control to output transfer function is given as

$$\frac{V0(s)}{d(s)} = \frac{-0.02589s+1108.033}{3.7396e-7s^2+2.3372e-5s+1} \quad (16)$$

Using the above transfer function, the Kp and ki values can be calculated using which the stable output voltage of the IBC with voltage multiplier cell can be obtained.

IV. SIMULATION RESULTS

The analysis of the closed loop control of high voltage gain IBC with the Voltage multiplier module is presented in this paper through simulation. The circuit components are connected in the Simulink model of the high step up IBC with the parameters mentioned in table I.

Table I: Parameters used for simulation

Parameters	**Values**
Input Voltage	40V
Output Voltage	400V
Switching Frequency	40kHz
Capacitors	100µF
Magnetising inductance	135µH
Leakage inductance	1µH

4.1. Open loop System

The simulation circuit of the Interleaved High Step-Up DC-DC Converter With Parallel-Input Series-Output Configuration and Voltage Multiplier Module is as shown in Fig 8. The design parameters are used as specified in the table 1.

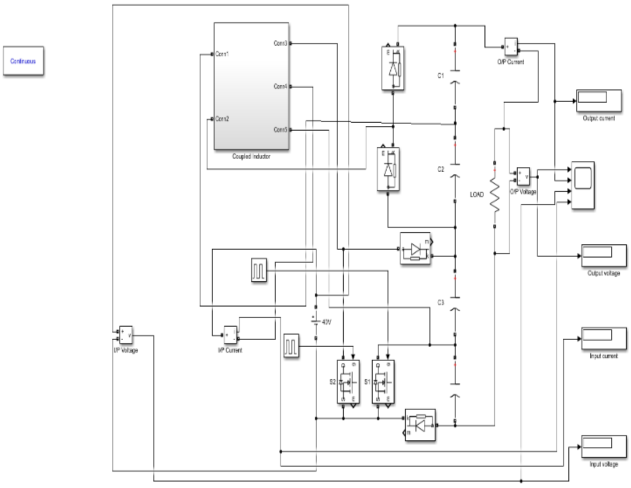

Fig 8: The simulation circuit of open loop system.

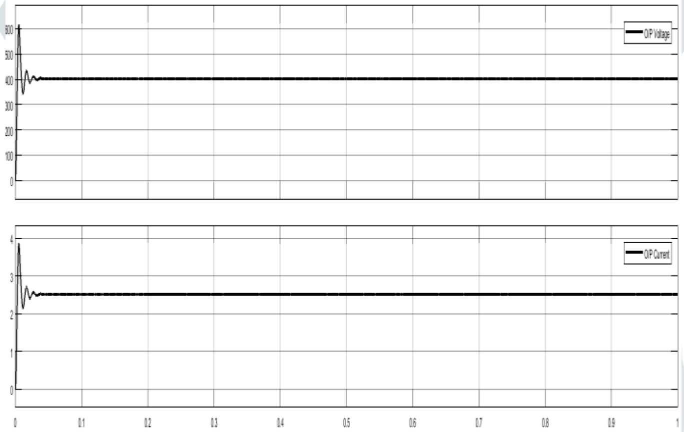

Fig 9: Output voltage and Output current waveform of the proposed IBC with open loop system

The Fig 9 shows the output voltage and output current simulated waveform which attains steady state at 400V and the load current attaining steady state at 2.5A. It can be seen from the simulation results that the output voltage and output current reaches a stable value below 0.05µs.

4.2. Closed loop System

The Simulink model of the closed loop control of the Interleaved High Step-Up DC-DC Converter With Parallel-Input Series-Output Configuration and Voltage Multiplier Module using PI controller is as shown in Fig 10.

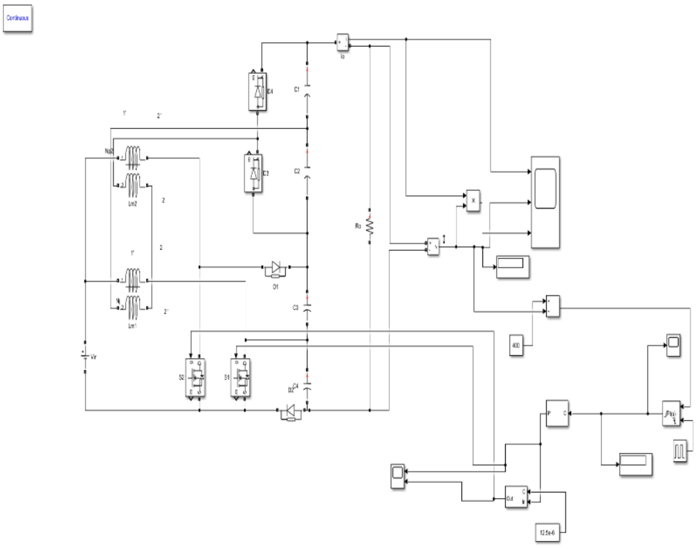

Fig 10: The simulation circuit of Closed loop system.

The Fig 11 depicts output voltage and output current waveform with a steady state and without overshoot as compared to the converter without controller. The output voltage of the converter with controller is almost 400V , its settling time is around 0.02 second and rise time is around 0.014 second . Thus the converter with the controller has reduced settling time, reduced rise time and provides the steady state output.

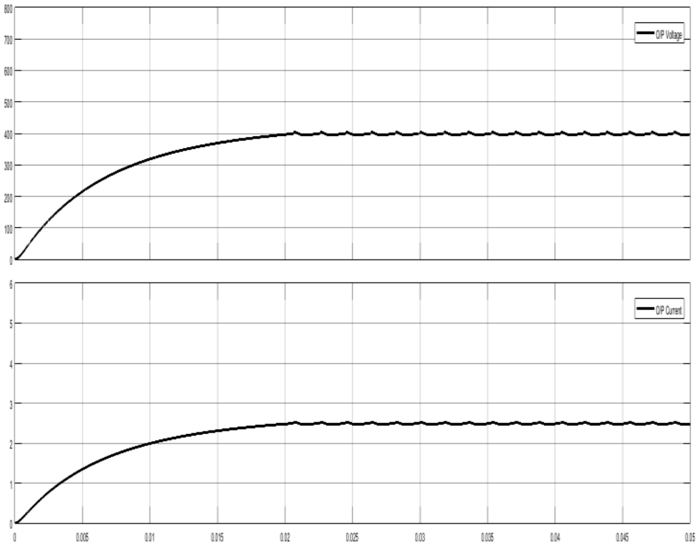

Fig 11: Output voltage and output current waveform of the proposed IBC with Closed loop system

V. CONCLUSION

The closed loop control system for an interleaved boost converter with PISO configuration and voltage multiplier module has been proposed for high voltage conversion. The closed loop system of IBC with voltage multiplier cell is implemented and simulated using MATLAB Simulink. The closed control system provides a stable output voltage for any variations in the input voltage. Thus the simulation results shows that the converter with controller reduces the settling time, rise time and provides the steady state output and hence improves the converter performance

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