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Modified Interleaved Buck Converter with Closed Loop Control for Higher Step Down Conversion Ratio

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ABSTRACT: This paper deals with Modified Interleaved Buck Converter with closed loop control for higher step down conversion ratio and lower ripple in the output current. With closed loop control it is possible to obtain a constant output for a range of input. This converter is suitable for applications requiring low output voltage. Three MOSFETs are connected in series with two coupling capacitors and closed loop control is provided with PI controller. The modes of operation, simulink model and corresponding simulation results are presented in this paper.

KEYWORDS: Modified interleaved buck converter (MIBC), Step down conversion ratio, Inductor current ripple

I.INTRODUCTION

Modified interleaved buck converter with closed loop control for higher step down conversion ratio is suitable for applications requiring high input voltage and low output voltage. MIBC (Modified Interleaved Buck Converter) is having lot of considerations due to its simple structure and reduced complexity in control. With closed loop control it is possible to obtain a constant output over a range. However in the earlier MIBC the output was not constant, it varies with input.

In this paper, it proposes MIBC with three active switches and two coupling capacitors. The converter acts in continuous conduction mode. If the converter operates in discontinuous conduction mode, all the elements suffer by current stress. Hence conduction loss and core loss of the converter will be increased. During steady state, the voltage stress across all active switches before turn on or after turn off is half of the input voltage. The conversion ratio, output current ripple, ripple in the inductor current are lower. By providing closed loop control the output is constant over a wide range hence it enhances the efficiency.

Modified interleaved buck converter consists of three buck converters connected in parallel. Interleaved stages are for reducing the ripple currents by operating two or more converter circuits (sub-circuits) in parallel and to operate the switches in respective sub-circuit with a phase shift with respect to each other. The phase difference between the operations of the two switches results in the ripple currents of one of the sub-circuits cancelling the ripple currents of the other. This reduces the ripple current in both the input and the output of the converter.

II.LITERATURE SURVEY

The switched mode DC- DC converters are some of the simplest power electronic circuits which convert one level of voltage into another level by switching action. These converters have received an increasing deal of interest in many areas. This is due to their wide range applications such as appliance control, telecommunication equipments, and appliances control, automotive, aircraft etc. Modified interleaved buck converter is an example of such converter. MIBC with closed loop control enable us to obtain constant output for a range of input. Closed loop control is implemented with proportional integral controller. M Jinno and P.Y .Chen discussed on the investigation on the ripple voltage and the stability of SR (synchronous Rectifiers) buck converters with high output current and low output volt (2010). In this paper the synchronous rectifiers composed of MOSFETs are used which enhance the influence of parasitic elements hence output voltage ripple is an important issue and it affects stability. R.L Lin, C.C. Hsu and S.K.

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Changchien proposed interleaved four phase buck – based current source with isolated energy – recovery scheme for electrical discharge machine. (2009).In this paper it provides a major path for the inductor to release its stored energy. Hence it avoids high output voltage. Its limitation is that it has bulky volume. Peng Xu (2001) proposed a family of DC – DC converters which employs an innovative interleaving concept using series primary windings and interleaved parallel secondary sides. The advantages of this converter include reduced filter size, improved transient response and increased efficiency. Wu Chen Xinbo Ruan et al (2009) investigated the DC – DC conversion systems constructed from connecting multiple converter modules in series and parallel at both the input and output sides. They studied the control strategies aiming to achieve proper sharing of the voltage and current at the input and output sides. They also presented the relationship between sharing of input voltages or currents and output voltages or currents. In particular, the inherent stability of control operations applied at the input side and output side is analysed in their work.

III.CIRCUIT OPERATIONS

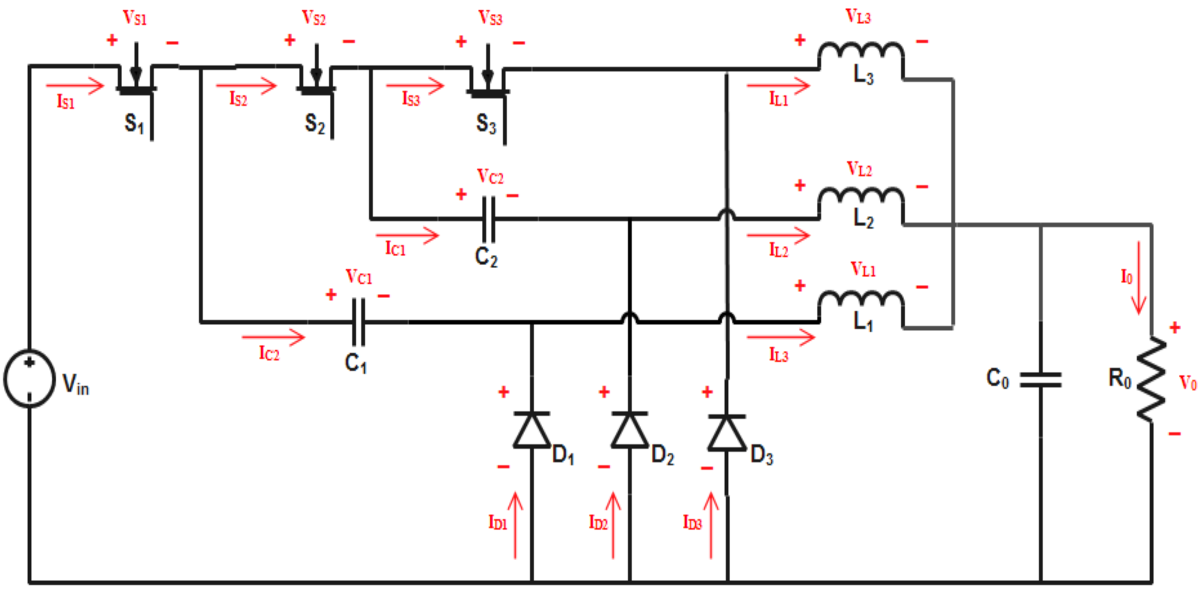

Fig 1: Conventional Modified Interleaved Buck Converter [1]

The fig above shows the Conventional Modified Interleaved Buck Converter. It has three active switches connected in series with two coupling capacitors in the power path. The switches S_1, S_2 and S_3 are driven with phase shift angle of 120^0. Each switching period is divided into three modes. The three inductors L_1, L_2 and L_3 are having the same inductance L. The coupling capacitors C_1 and C_2 are considered as the voltage source. All the power semiconducting devices are ideal. Three buck converters connected in series. Here the switching pulses are provided to three switches at a phase delay of 33.33^0.

Mode 1:

Mode 1 begins when S_1 is turned ON. Then the current I_{L1} flows through S_1, C_1 and L_1 and hence coupling capacitor V_{C1} is charged. The current I_{L2} freewheels through D_2 and current I_{L3} freewheels through D_3. During this mode voltage across L_1 is the difference of the input voltage, voltage of the coupling capacitor V_{C1} and output voltage. Hence I_{L1} increases linearly. I_{L2} and I_{L3} decreases linearly from the initial value.

Mode 2:

Mode 2 begins when S_1 is turned OFF and S_2 is turned ON. When S_1 is turned OFF, currents I_{L1}, I_{L2} and I_{L3} freewheels through D_1, D_2 and D_3 respectively. The voltages become the negative output voltage and the current decreases linearly. When S_2 is turned ON, the energy stored in the coupling capacitor V_{C1} is discharged and coupling

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capacitor V_{C2} is charged. Current Il2 flows through S_2, C_2 and L_2. The current I_{L1} freewheels through D_1 and I_{L3} freewheels through D_3. In this mode voltage V_{L2} is the difference of coupling capacitor voltages and the output voltage.

Mode 3:

Mode 3 begins when S_2 is turned OFF and S_3 is turned ON. The energy stored in the coupling capacitor V_{C2} is discharged. The current I_{L3} flows through C_2, S_3 and L_3. The current Il1 freewheels through D_1 and current I_{L2} freewheels through D_2. During this mode the voltage V_{L3} is the difference between V_{C2} and V_0. The voltage V_{L1} and V_{L2} are the negative output voltages. Hence I_{L1} and I_{L3} decrease linearly from its initial values.

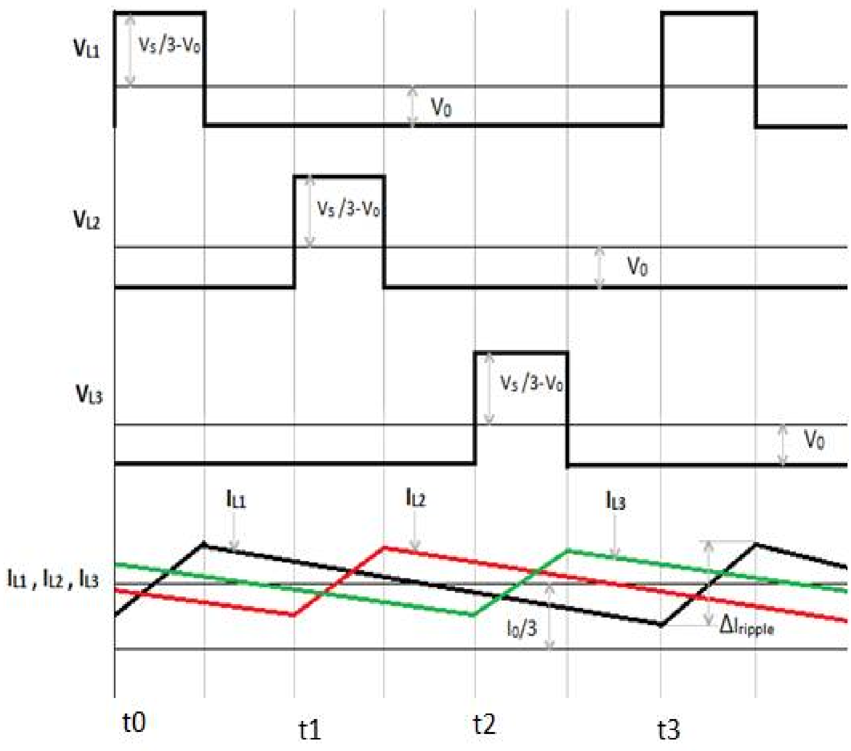

Fig 2 Output waveforms of MIBC [1]

IV. DESIGN EQUATIONS

Input Voltage = 25V
Output Voltage =1.25V
D = Vo/Vin

$\Delta i_L = V_o (1-D) T_s/L$
$L = V_o(1-D) T_s/\Delta i_L$

$C = I_o D T_s / \Delta V$
M: Step down conversion ratio
M = D/3

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V.SIMULINK MODEL

For the MIBC with closed loop, the parameter specifications are as follows

1) Switching Frequency : Fs = 65KHz
2) Input Voltage : Vs = 25V
3) Output Voltage : Vo = 1.25V
4) Output Current : Io = 4A
5) Output ripple Voltage : $V_{o\ ripple}$ = 0.125
6) Inductor ripple current : $I_{L\ ripple}$ = 0.8

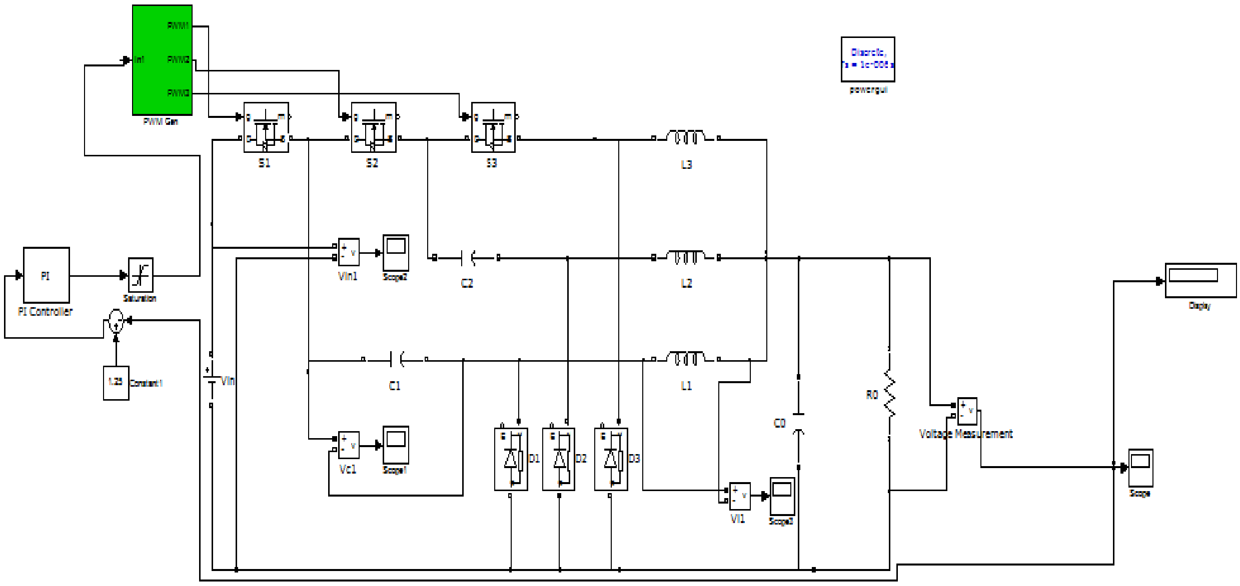

Fig 3 Simulink model of MIBC with closed loop control

VI.SIMULATION RESULT

The simulation waveforms of input voltage and output voltage for the MIBC with closed loop control are shown in **Fig 4** and **Fig 5**. The input given is 25V and the output obtained is 1.25V. The step down conversion ratio (M) is 0.016.

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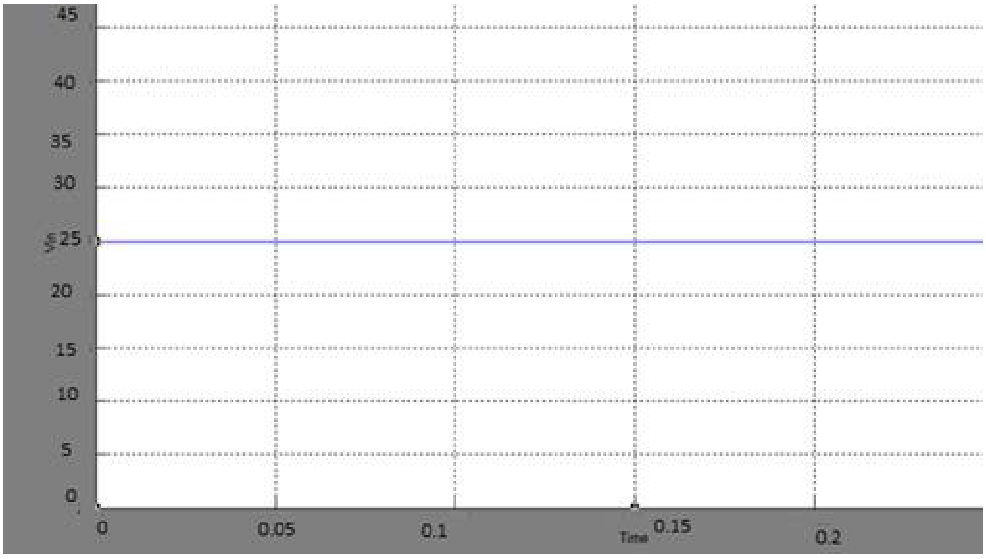

Fig 4 Simulation waveform for input voltage of MIBC with closed loop control

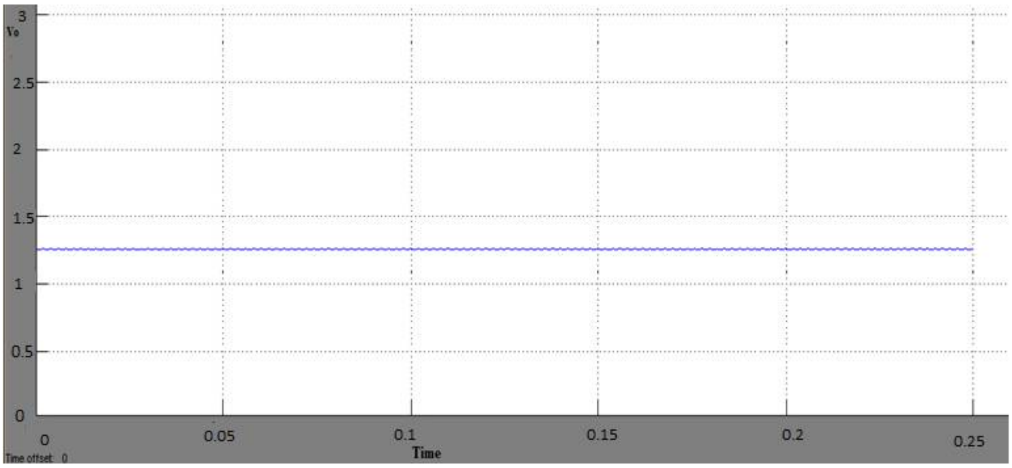

Fig 5 Simulation waveform for output voltage of MIBC with closed loop control

VII.HARDWARE IMPLEMENTATION

The experimental set up of the circuit is shown in the **Fig 6**. The converter circuit, control circuit and phase shift mask are shown.

Specifications:

Switching frequency = 65 kHz
Input voltage = 25V
Output voltage = 1.25V
Output current: Io = 4A

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Output ripple Voltage = 0.125
Inductor ripple current = 0.8

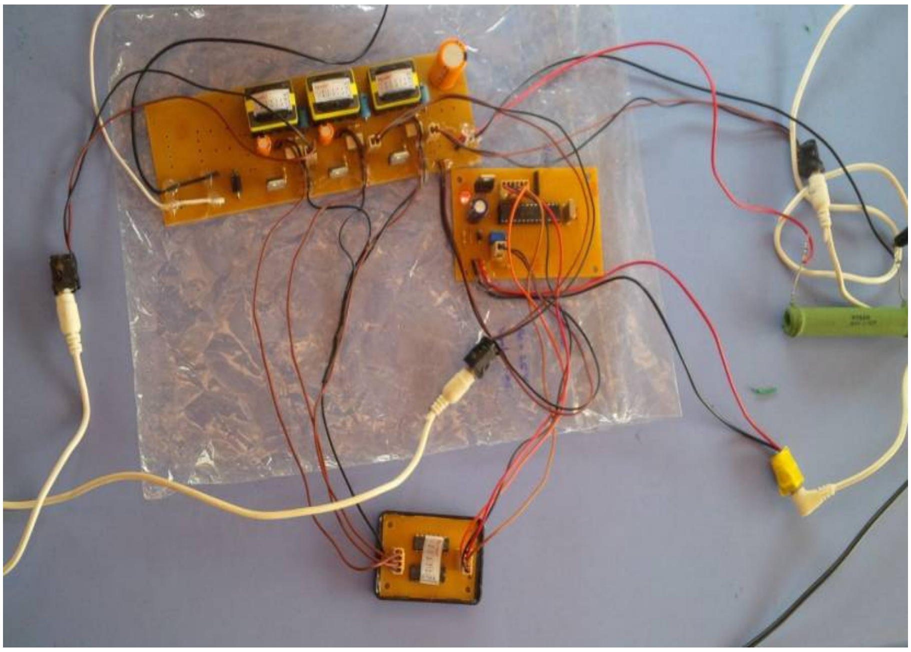

Fig 6 Hardware implementation of MIBC with closed loop control

The waveforms of the output voltage and gate pulses to the switch S_1 of hardware implementation is shown in the **Fig 7** and **Fig 8**

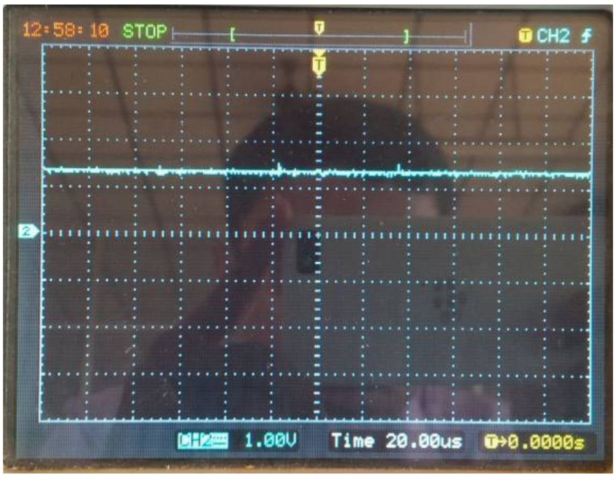

Fig 7 Output voltage waveform

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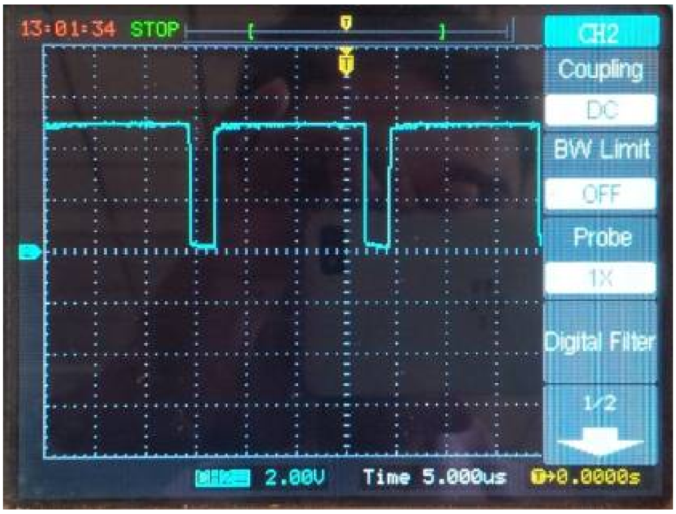

Fig 8 Gate pulses to switch S_1

VIII.CONCLUSION

Modified Interleaved Buck Converter with Closed Loop Control for higher step down conversion ratio is proposed in this paper. With closed loop control a constant output is obtained for a range of input and higher step down conversion ratio. The voltage stress across the switches is reduced considerably when the operating duty ratio is below 50%.The output ripple is also reduced with this interleaved buck converter.

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