MODELING AND SIMULATION OF INTERLEAVED BUCK-BOOST CONVERTER WITH PID CONTROLLER

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Abstract— **In this paper, the analysis and modeling of interleaved Buck- boost converter with PID controller is discussed. Nowadays, Buck-boost power converter is widely used in many applications and power capability demands [1]. The applications of Buck-boost power converter may be seen in electric vehicles [2], photovoltaic (PV) system, uninterruptable power supplies (UPS), and fuel cell power system [4]. Converters are controlled by interleaved switching signals, [5] which have the same switching frequency but shifted in phase. By paralleling the converters, the input current can be shared among the inductors so that high reliability and efficiency in power electronic systems can be obtained and ripples also reduced [2], the converter performance can be improved [3]. The control circuit of this converter is controlled by using the PID controller [3]. The simulation of interleaved buck-boost converter results with PID controller has been presented in detail.**

***Index Terms*—Interleaved Buck-Boost Converter, PID Controller, Buck-Boost Converter, Ziegler Nichol Tuning Method**

1. INTRODUCTION

Interleaving also called as multi phasing is a technique which is useful for reducing the size of filter component [8] . In a interleaved circuit there will more than one power switch. The phase difference for two switches is 180º[2]. Interleaving technique is a strategic interconnection of multiple switching cells that will increase the effective pulse frequency by synchronizing several smaller sources and operating them with relative phase shift [10]. Interleaved method is used in order to improve converter performance in the aspects of efficiency, size, and conducted electromagnetic emission. Interleaved also has benefits such as high power capability, modularity, and improved reliability [3]. But, having interleaved may cost on additional inductors, power switching devices, and output rectifiers. When the size of inductor increases, the power loss in a magnetic component will decrease although both the low power loss and small volume are required.In the power electronic s[4], application of interleaving technique can be found back to early days especially in high power application. The voltage and current stress can easily go beyond the range that power device can handle in high power application.

One solution to this problem is by connecting multiple power devices in parallel or in series. But, instead of paralleling power devices, it is better to parallel the power converters [2]. By paralleling the power converters, the interleaving technique will comes naturally. Interleaving can cancel the harmonics, increase the efficiency, better thermal performance and the high power density can be obtained. Paralleling of converter [1] power stages is a well known technique that is often used in high-power applications to achieve the desired output power with smaller size power transformers and inductor [3]. In addition to physically distributing the magnetic and their power losses and thermal stresses, paralleling also distributes power losses and thermal stresses of the semiconductors due to a smaller power processed through the individual paralleled power stages. As a result, paralleling is a popular approach to eliminating “hotspots” in power supplies [8]. Besides, the switching frequencies of paralleled lower power stages may be higher than the switching frequency of the corresponding single high-power processing stage because lower power faster semiconductor switches can be used in implementing the individual power stages. Consequently, paralleling also offers an opportunity to reduce the size of the magnetic components.

The control objective in the design of PID controller is to drive the Interleaved Buck converter switch with a duty cycle [10] so that the dc component of the output voltage is equal to the reference voltage [6]. The regulation should be maintained constant in spite of variations in the input voltage or in the load [4]. Furthermore, the constraints in the design of controller results due to the duty cycle which is bounded between zero and one. This problem can be solved by modeling the Interleaved Buck-Boost converter using state space averaging technique.

2. BLOCK DIAGRAM OF INTERLEAVED BUCK-BOOST CONVERTER

The Fig.1 shows that the overall block diagram of Interleaved Buck-boost Converter with PID

Controller [8] The DC supply is given to the interleaved buck-boost converter. In Interleaved Buck-boost Converter two switches are connected in parallel. By using paralleling the current can be divided through two switches. So the current stresses can be reduced.

The output of the interleaved buck-boost converter is given as a input to the load [3]. Here PID controller is used. The control circuit of the converter is controlled by the PID. The DC supply is given to the PID controller. In PID Controller the Ziegler-Nichols tuning Method is used. By using this PID controller oscillations and ripples can be reduced. Then the reduced ripple voltage is given to the converter, then it is given to the load.

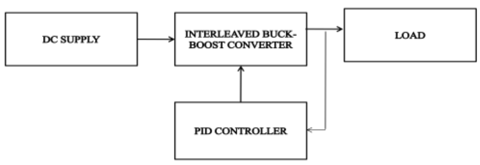


Fig. 1 Block diagram of Interleaved Buck-boost Converter

3. DESIGN OF INTERLEAVED BUCK-BOOST CONVERTER

3.1 Design of Buck-boost Converter

The Buck-boost converter provides an output voltage can be either higher or lower than the input voltage [2]. The output voltage polarity is opposite to that of the supply voltage. It is also called as inverting regulator [4]. The advantage of Buck-boost converter is the increased efficiency. The L and C values can be calculated by

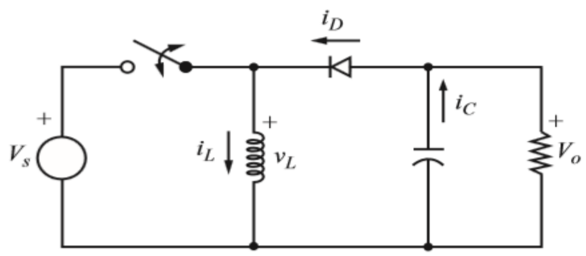


Fig.2 Circuit Diagram of Buck-boost Converter

$$V_0 = -\frac{V_S\alpha}{1-\alpha} \quad (1)$$

$$L = \frac{V_S\alpha}{\Delta I f} \quad (2)$$

$$C = \frac{I_0\alpha}{\Delta V_C f} \quad (3)$$

$$R_O = {}^{V}/_{I} \quad (4)$$

$$\eta = \frac{P_{out}}{P_{in}} \quad (5)$$

Where $V_0$is the output voltage,α is the duty ratio, f is the switching frequency,ΔV_C is the capacitor ripple voltage, ΔI_L the inductor ripple current, L and C are inductor, capacitor respectively,R_O is the load resistance,η is the efficiency,P_{out},P_{in} is the output and input power.

3.2 Interleaved Buck-boost Converter

Interleaved buck-boost converter consists of 'n' single boost converters that are connected in parallel. For the interleaved with two switch, the switching signals operate 180º phase shift between them [8]. The interleaved is formed by two independent buck- boost switching units [4]. For each boost switch unit, there are two switching stages which are switch close and switch open stages [7]. When the switch is closed, the current in the inductor start to rise while the diode is blocking. The inductor starts charging. When the switch is opened, the inductor starts to discharge and transfer the current through diode to the load .

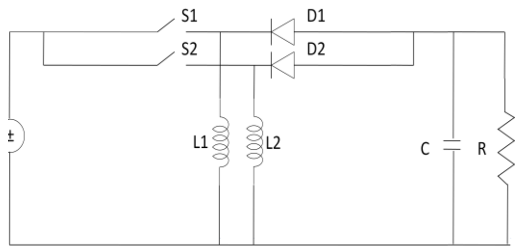


Fig.3 Interleaved Buck-boost Converter

The L and C values of this converter is calculated by

$$L_1 = L_2 = \frac{V_S\alpha}{\Delta I f} \quad (6)$$

$$C_1 = C = \frac{I_0\alpha}{\Delta V_C f} \quad (7)$$

From equation (6),(7) it is observed that L and C values are same as that of the Buck-boost converter.

Table 1. Overall system parameters

S.NO	Prameters	Symbol	Value
1	Input Voltage	$V_{in}(V)$	12
2	Switching frequency	$f_s(H_Z)$	25
3	Inductor	L_1,L_2(□H)	1.4
4	Capacitor	C(□F)	7.2
5	Resistor	$R(\Omega)$	12
6	Capacitor ripple voltage	ΔV_C	0.05
7	Inductor ripple current	ΔI_L	0.2
8	Output Voltage	$V_0(V)$	-18
9	Output Power	$P_0(W)$	27

The calculated design values of Interleaved Buck-boost Converter are shown in Table I.

4. MODELING OF INTERLEAVED BUCK-BOOST CONVERTER

The ZCS interleaved buck converter is modeled using state space averaging technique in which the design is carried out in time domain based on their performance indices [6]. This method is highly significant for this kind of converters since the PWM converters are the special type of non linear systems which is switched in between two or more non linear circuits depending upon the duty ratio .The unique feature of this method is that the design can be carried out for a class of inputs such as impulse [7], step or sinusoidal function in which the initial conditions are also incorporated. As a general case state space averaging method for two switched basic PWM converters is discussed now [4]. The switches S1, S2 is driven by a pulse sequence with a constant switching frequency f. The state vector for an Interleaved Buck-boost Converter is given

$$\boldsymbol{x(t)} = \begin{bmatrix} \boldsymbol{i_{L1}} \\ \boldsymbol{i_{L2}} \\ \boldsymbol{v_c} \end{bmatrix} \quad (8)$$

where$i_{L1}$and i_{L2} are the current through an inductor L1and L2 respectively; V_c is the voltage across the capacitor C. For the given duty cycle d(k) for the k^{th} period, the systems are illustrated by the following set of state space equations in continuous time domain

$$\dot{\boldsymbol{X}} = \boldsymbol{Ax} + \boldsymbol{BV_s} \quad (9)$$

Where x is the state vector matrix, A is the state coefficient matrix and B is the source coefficient matrix, and d is a duty cycle is a function of x and Vs in a feedback system.

State model of an Interleaved Buck-Boost converter is derived and is discussed below. High power densities are possible only for continuous conduction mode (CCM) of operation. Diode Dl and D2 are always in a complementary state with the switches S1and S2 respectively. When S1 - ON, D1 - OFF and vice versa and S2 - ON, D2 - OFF vice versa. For the continuous conduction mode of operation, four modes of operations are possible, and state equations are

Mode 1: S1 is ON and S2 is ON

$$\dot{\boldsymbol{x}} = \boldsymbol{A_1x} + \boldsymbol{B_1V_1} \quad (10)$$

Mode 2: S1 is ON and S2 is OFF

$$\dot{\boldsymbol{x}} = \boldsymbol{A_2x} + \boldsymbol{B_2V_1} \quad (11)$$

Mode 3: S1 is ON and S2 is ON

$$\dot{\boldsymbol{x}} = \boldsymbol{A_3x} + \boldsymbol{B_3V_1} \quad (12)$$

Mode 4: S1 is OFF and S2 is ON

$$\dot{\boldsymbol{x}} = \boldsymbol{A_4x} + \boldsymbol{B_4V_1} \quad (13)$$

$$\mathrm{A}_1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1/\mathrm{RC} \end{bmatrix}; B_1 = \begin{bmatrix} \frac{1}{\mathrm{L1}} \\ \frac{1}{\mathrm{L2}} \\ 0 \end{bmatrix} \quad (14)$$

$$A_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1/L2 \\ -1/C & 0 & -1/RC \end{bmatrix}; B_2 = \begin{bmatrix} \frac{1}{L1} \\ 0 \\ 0 \end{bmatrix} \quad (15)$$

$$\mathrm{A}_3 = \mathrm{A}_1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1/\mathrm{RC} \end{bmatrix}; B_3 = \begin{bmatrix} \frac{1}{\mathrm{L1}} \\ \frac{1}{\mathrm{L2}} \\ 0 \end{bmatrix} \quad (16)$$

$$\mathrm{A}_4 = \begin{bmatrix} 0 & 0 & 1/\mathrm{L1} \\ 0 & 0 & 0 \\ -1/\mathrm{C} & 0 & -1/\mathrm{RC} \end{bmatrix}; \quad \mathrm{B}_{4=} \begin{bmatrix} 0 \\ \frac{1}{\mathrm{L2}} \\ 0 \end{bmatrix} \quad (17)$$

Where

$$[A] = A_1d_1 + A_2d_2 + A_3d_3 + A_4d_4 \quad (18)$$

$$[B] = B_1d_1 + B_2d_2 + B_3d_3 + B_4d_4 \quad (19)$$

$$[u] = V_1 \quad (20)$$

Where d is the duty cycle ratio. d_1, d_2, d_3 & d_4 are the duty cycle of Mode 1, Mode 2, Mode 3 & Mode 4 respectively.

$$\mathrm{d}_1 + \mathrm{d}_2 + \mathrm{d}_3 + \mathrm{d}_4 = 1 ; \quad (21)$$

$$\mathrm{d}_1 + \mathrm{d}_2 + \mathrm{d}_3 = \mathrm{d} ; \quad (22)$$

$$\mathrm{d}_1 = \mathrm{d}_3; \quad (23)$$

$$\mathrm{d}_2 = \mathrm{d}_4; \quad (24)$$

Hence

$$\mathrm{A} = \begin{bmatrix} 0 & 0 & \mathrm{d}_2/\mathrm{L1} \\ 0 & 0 & \mathrm{d}_{2/\mathrm{L2}} \\ -\mathrm{d}_2/\mathrm{C} & -\mathrm{d}_2/\mathrm{C} & -2\mathrm{d}_1/\mathrm{RC} - 2\mathrm{d}_2/\mathrm{RC} \end{bmatrix} \quad (25)$$

$$\mathrm{B} = \begin{bmatrix} \frac{2\mathrm{d}_1 + \mathrm{d}_2}{\mathrm{L}_1} \\ \frac{2\mathrm{d}_1 + \mathrm{d}_2}{\mathrm{L}_2} \\ 0 \end{bmatrix} \quad (26)$$

$$Y = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ V_c \end{bmatrix} \quad (27)$$

Find the transfer function G(s) of the IBC using state space model equation (19) and (27).Finally

$$G(S) = \frac{-6.821\,e^{-13} - 4.762\,e^{005}\,s + 8.223\,e^{-010}}{s^3 + 115.7 s^2 + 3.175\,e^{005}\,s - 3.092\,e^{-009}} \quad (28)$$

5. CLOSED LOOP CONTROL OF INTERLEAVED BUCK-BOOST CONVERTER

The closed loop control system for the Interleaved Buck converter with PID controller feedback is shown in Fig.4

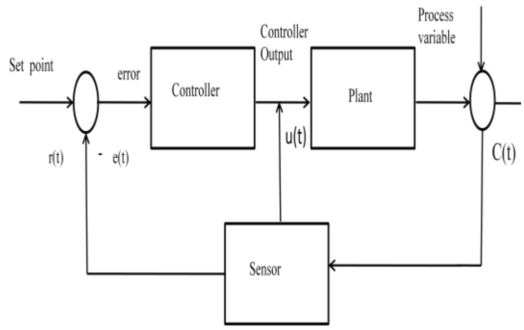


Fig.4 Block diagram of PID Controller

The ultimate aim in designing the controller is to minimize the error between V_0 and V_{ref} from the Figure 3, the important functional blocks that are evident are: PID Controller, PWM(Pulse Width Modulation) and dc-dc converter [3]. The PID Controller acts as a compensator and generates the control signal by compensating the error signal (Ve).PWM block is for the generation of driver signal obtained from the compensator[8]. The error (Ve) between the output voltage (Vo) and reference voltage (Vref) is processed by the compensator block with PID Controller algorithm to generate control signal [7]. The control signal significantly affects the converter characteristics and therefore effective tuning of the controller is one of the desired aspects of the control system [9]. The fine tuned PID controller generates the duty cycle command corresponding to the error signal which is then converted as switching pulses using the PWM functional block.The typical closed loop system using PID controller is shown in the time PID controller can be expressed as,

$$u(t) = K_P e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d \frac{d}{dt} e(t) \quad (29)$$

Where u(t) is the control output, k is the derivative time and e(t) is the error between the Vref and Vo.The transfer function is given as

$$u(s) = [K_P + K_i + K_d s]e(s) \quad (30)$$

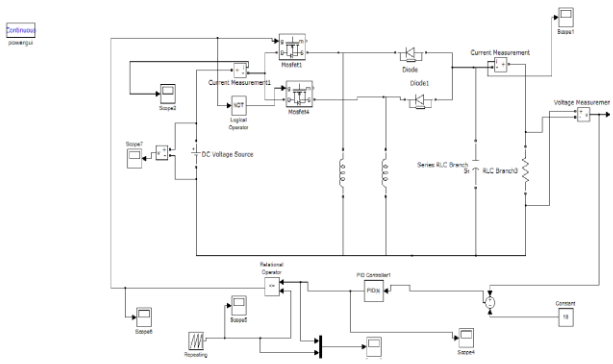
Where $K_p, K_i = \frac{K_p}{T_i}$,$K_d = K_p T_d$ are the proportional, integral and derivative gains of the controller respectively . K_p, T_i and T_d are calculated according to Ziegler – Nichols tuning rules. This method is an accurate heuristic method for determining good settings of PID controllers. This method is based on the empirical knowledge of the ultimate critical gain P_{cr} , which is given by $\frac{2\pi}{\omega}$ where ω is the natural frequency of oscillation of the converter under consideration. The Ziegler – Nichols tuning formulae is illustrated in the Table II.

TABLE II. ZIEGLER-NICHOL TUNING METHOD

Type of Controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45\ K_{cr}$	$\frac{1}{1.2P_{cr}}$	0
PID	$0.6\ K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

6. SIMULATION RESULTS OF INTERLEAVED BUCK-BOOST CONVERTER

The proposed closed loop response of the Interleaved Buck-Boost converter is simulated using MATLAB / SIMULINK. The ultimate aim is to achieve a robust controller in spite of uncertainty and large load disturbances.



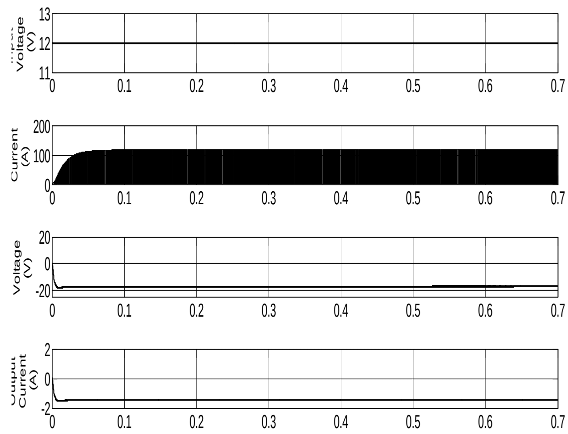


Fig. 6 Output Waveform of the Interleaved Buck- Boost Converter

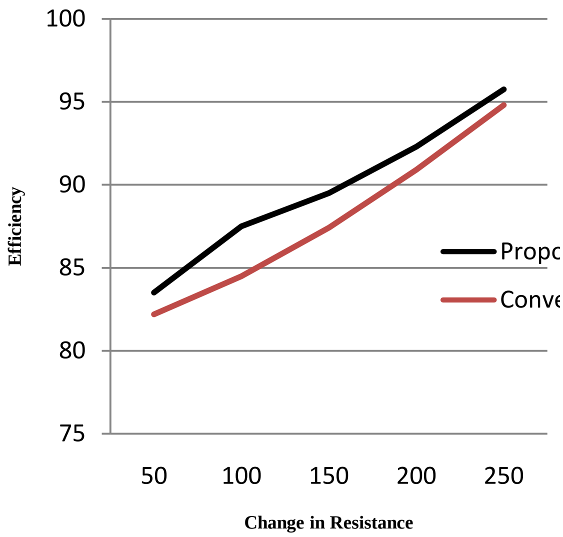


Fig. 7 Comparison of Efficiency

The efficiency of the ordinary Buck-boost Converter, Interleaved Buck-Boost converter are determined [7] and are shown against the load Resistance in Figure 7. The efficiency of the interleaved Buck-boost Converter is high when compared to the Buck-Boost Converter.

7. Conclusion

In this Paper, a new Interleaved Buck-Boost converter has been proposed with PID controller. The simulation results thus obtained using MATLAB Simulink is with the mathematical calculations. The mathematical analysis, simulation study and the experimental study show that the controller thus designed to achieves tight output voltage regulation and good dynamic performances and higher efficiency. It can be conclude that, by using the interleaved Buck-Boost converter, the output voltage ripples can be reduced and efficiency can be improved. Most importantly, the input current has no ripple. By using two switches on the circuit, it can reduce the switching losses because it can alternate the turning on and off between these two switches.

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