International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

Comparison between Zeta Converter and Boost Converter using Sliding Mode Controller

Kambli Omkar Vijay
School of Electrical Engineering
VIT University, Chennai
India

P. Sriramalakshmi
Ap, Select
VIT University, Chennai
India

***Abstract*— This paper presents a dynamic modelling and control of a Zeta converter as well as boost converter evaluated in MATLAB/SIMULINK based simulation. A Zeta converter topology provides a positive output voltage from an input voltage and also provides option for regulating an unregulated power supply. The Zeta converter is configured from buck converter but unlike buck converter, it includes two inductors and two capacitors. A comparison between Zeta converter and Boost converter is done using sliding mode controller under the load voltage variation. The feedback loop provides voltage regulation against any disturbance in load voltage by keeping input side constant. The simulated output voltage, current and graph between voltage gain and duty ratio are shown in the paper.**

Keywords*— Zeta converter, Boost converter, Voltage mode control, Sliding mode controller etc.

I. INTRODUCTION

Switched DC-DC converters aid in increasing the voltage from a low battery voltage thereby facilitating in accomplishing a regulated DC output voltage which would rather require multiple battery sources.

Though zeta converter is similar to that of a buck-boost converter, it has an advantage of non-inverted output. It has a wider range of duty ratio than any other converter. The converter exhibits improved power factor, low input current distortion, low output current ripple and wide output-power range [1]. A boost converter is a DC-DC converter in which output voltage is greater than input voltage, while stepping down a current. As the control input appears in both voltage and current equation, the controlling of boost converter is difficult [7].

In an open loop system output cannot be compensated or controlled if there is an input voltage variation or disturbance. Therefore to regulate the DC-DC converters, different control techniques are applied and a robust output voltage is achieved.

Due to non-linearity of DC-DC converters, linear control techniques are not efficient; therefore to design a linear control system, small signal model is obtained by state space averaged model. The state space model is a time domain model where the system is described by differential equation.

The property of hysteresis control is extended in sliding mode control to multi variable environment, and is able to constrain the system status to follow trajectories which lie on a suitable surface in the state space. The motion of the system as it slides along the boundaries is called a sliding mode and the geometrical locus that contains these boundaries is called the sliding surface [6].

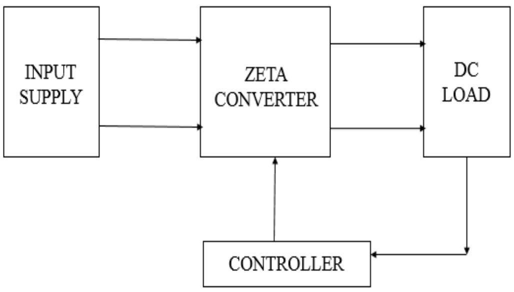

Fig.1. Block diagram for the whole system

The proposed system consists of a DC source, a DC-DC converter, resistive load and a controller for regulating output voltage as shown in Fig 1. This system presents a dynamic modelling and voltage mode control of a Zeta converter and boost converter using a sliding mode controller.

II. OPERATING PRINCIPLE OF ZETA CONVERTER AND DC-DC BOOST CONVERTER

A. *Boost converter*

The conventional boost converter topology is as shown in Fig.2.Also two modes of operation of boost converter are shown in Fig.3 and Fig.4 respectively.

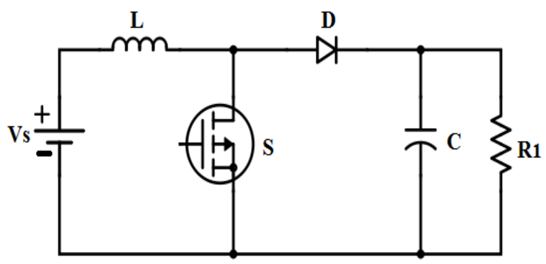

Fig.2 Conventional Boost converter topology

a) Mode 1

In this mode, the switch S is ON, resulting in increasing inductor current. In this mode the equation becomes,

$$\Delta i_{lON} = \frac{DT}{L} V_s \qquad \dots (1)$$

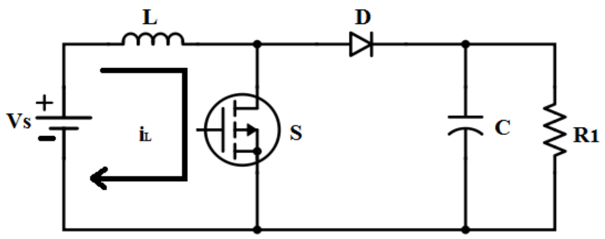

Fig.3 Mode 1 operation of boost converter

b) Mode 2

In this mode, switch S is OFF, the inductor current flows through load and the equation becomes,

$$\Delta i_{lOFF} = \frac{(Vs-Vo)(1-D)T}{L} \quad \text{... (2)}$$

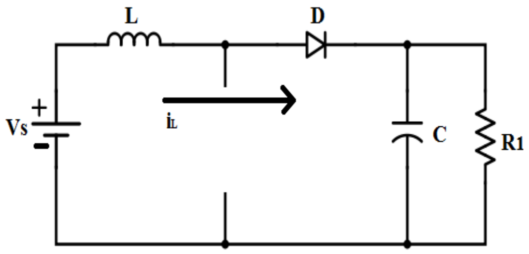

Fig.4 Mode 2 operation of boost converter

B. Zeta converter

The equivalent circuit of Zeta converter is as shown in Fig.5. It comprises of a switch, a diode, two capacitors C_1 and C_2 , two inductors $L_1$and L_2 and a standing resistive load.

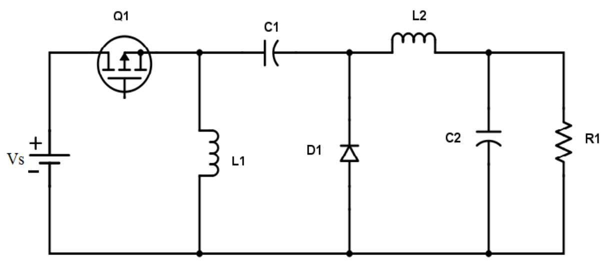

Fig.5 Zeta converter topology

The operation of zeta converter is designed in Continuous Conduction Mode (CCM) and the circuit operation can be defined by two modes of operation are shown in Fig.6 and Fig.7 respectively.

a) Mode 1

In this mode, the switch Q_1 is ON and the diode D_1 is reverse biased. Inductors L_1 and L_2 is charged from the source and the inductor current I_{L1} and I_{L2} increases linearly. Also, discharging of C_1 and charging of C_2 take place.

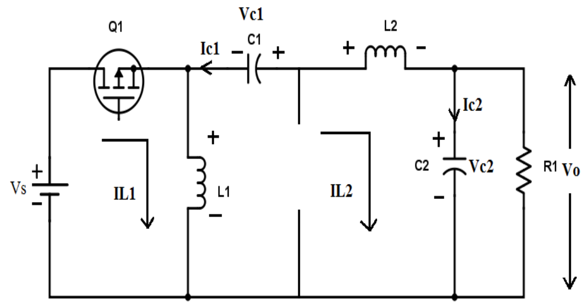

Fig.6 Mode 1 operation of zeta converter

By Kirchhoff's Voltage law,

$$L_1 * \frac{di_{L1}}{dt} = V_s \quad \text{... (3)}$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} + \frac{V_{c1}}{L_2} - \frac{V_{C2}}{L_2} \quad \text{... (4)}$$

By Kirchhoff's current law,

$$C_2 * \frac{dV_{c2}}{dt} = i_{L1} \quad \text{... (5)}$$

b) Mode 2

In this mode, the switch $Q_1$is OFF and the diode D_1 is forward biased. During this interval, previously charged inductor L_1 starts to discharge. So stored energy in L_1 and L_2 are discharged through capacitors C_1 and C_2. Therefore, the inductor currents i_{L1} and i_{L2} decrease gradually.

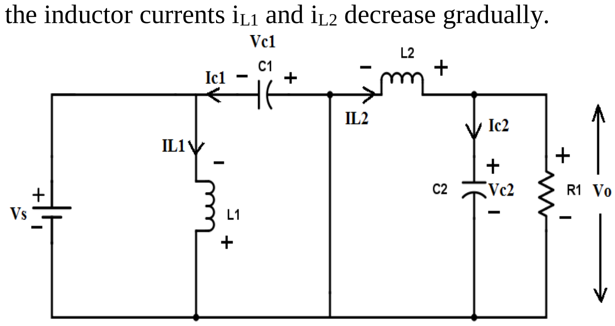

Fig.7 Mode 2 operation of zeta converter

By Kirchhoff's voltage law, voltage across inductor (L_1) is given by,

$$L_1 \frac{di_{L1}}{dt} = -V_1 \quad \text{... (6)}$$

Voltage across inductor (L_2) is given by,

$$L_2 \frac{di_{L2}}{dt} = -V_{L2} \quad \text{... (7)}$$

By applying Kirchhoff's current law, current through the capacitor C_1 is,

$$i_{L1} = C_1 * \frac{dV_{C1}}{dt} \quad \text{... (8)}$$

The relation between input voltage, output voltage and the duty cycle (D) of zeta converter in CCM is given by,

$$D = \frac{v_0}{v_0+v_s}$$

$$\text{Therefore,} \frac{v_0}{v_s} = \frac{I_{in}}{I_o} = \frac{D}{D-1} \quad \text{...(9)}$$

By volt second balance,

$$V_s * t_{ON} + (V_s - V_{c1}) * t_{OFF} = 0$$

Taking average over one cycle,

$$V_o = \frac{D}{D-1} * V_s \quad \text{.... (10)}$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

By applying volt-second balance, the relation between output voltage and input voltage is given by

$$V_o = \frac{1}{D-1} * V_s$$

III. DESIGN OF PROPOSED SLIDING MODE CONTROLLER

To ensure stability in any operating condition, a suitable control technique should be employed for DC-DC boost converter that matches with their non-linearity in input voltage and load variations.

Sliding mode controller is a nonlinear control method that alters the dynamics of the system by applying a discontinuous control signal thereby forcing the system to slide along the cross section of system's normal behavior. The sliding surface is selected in such a way so that the system trajectories near the surface are directed towards the surface itself by the proper controlling of the converter switch irrespective of the circuit parameters. The controller variable provides a fast transient response along with tracking a certain reference path to achieve desired dynamic response. If these conditions are satisfied, the system status moves from its initial value towards the sliding surface thereby maintaining the switching action [6].

IV. CONTROLLER FOR DC-DC CONVERTER

State space averaging is important for mathematical modeling of sliding mode controller. To develop state space model, the equations for the rate of change of inductor current and the equations for the rate of change of capacitor voltage are used [5].

A. *STATE-SPACE MODEL OF ZETA CONVERTER*

State variable description of system is as follows:

$$\dot{x} = \overline{A}x + \overline{B}u$$
$$v_o = \overline{C}x + \overline{D}u$$

$$\overline{\boldsymbol{A}} = \begin{bmatrix} \frac{-r_{C1}(1-d)+r_{C1}}{L_1} & 0 & \frac{-(1-d)}{L_1} & 0 \\ 0 & \frac{-(r_{C2}+R)(r_{L2}+dr_{C1})+r_{C2}R}{L_2(r_{C2}+R)} & \frac{d}{L_2} & \frac{-R}{L_2(r_{C2}+R)} \\ \frac{(1-d)}{C_1} & \frac{-d}{C_1} & 0 & 0 \\ 0 & \frac{R}{C_2(r_{C2}+R)} & 0 & \frac{-1}{C_2(r_{C2}+R)} \end{bmatrix}$$

$$\overline{\boldsymbol{B}} = \begin{bmatrix} \frac{d}{L_1} & 0 \\ \frac{d}{L_2} & \frac{r_{C2}}{L_2(r_{C2}+R)} \\ 0 & 0 \\ 0 & \frac{-R}{C_2(r_{C2}+R)} \end{bmatrix}$$

$$\overline{\boldsymbol{C}} = \begin{bmatrix} 0 & \frac{r_{C2}R}{r_{C2}+R} & 0 & \frac{-R}{r_{C2}+R} \end{bmatrix}$$

$$\overline{\boldsymbol{D}} = \begin{bmatrix} 0 & \frac{-r_{C2}R}{r_{C2}+R} \end{bmatrix}$$

Where r_{C1} and r_{C2} are equivalent series resistors and r_{L1} and r_{L2} are DC resistors.

State-Space Model of Boost converter:

$$\overline{A} = \begin{bmatrix} 0 & \frac{-(1-D)}{L} \\ \frac{(1-D)}{C} & -\frac{1}{RC} \end{bmatrix}$$

$$\overline{B} = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{C} \end{bmatrix}$$

$$\overline{C} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$\overline{D} = 0$$

Instead of state variables, consider new state variable that is the error vector of state space variable X to be considered. So, the sliding surface equation in state space is expressed by,

$$S = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 = J^T x \quad \text{... (11)}$$

Where, $J^T = [\alpha_1 \alpha_2 \alpha_3 \alpha_4]$

$\alpha_1 \alpha_2 \alpha_3 \alpha_4$ are control parameters termed as sliding coefficients.

A sliding surface can be obtained by, S=0.

For this system, it is appropriate to have a general SM control law that adopts a switching function such as,

u=1 when S>0

=0 when S<0

A sliding mode control system is designed for boost converter as shown in Fig.8 [8].

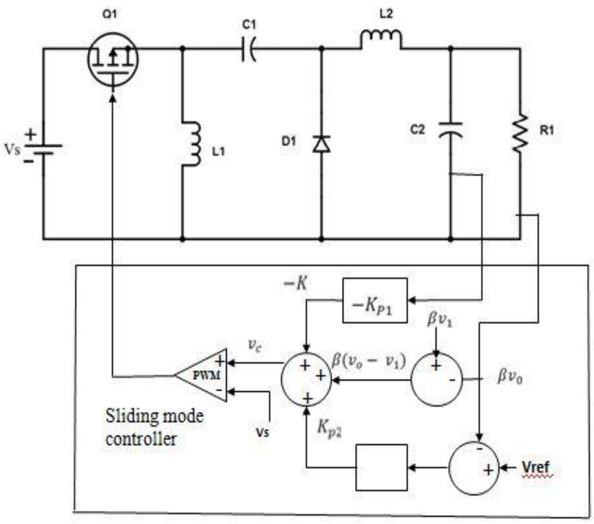

Fig.8 Control scheme of Zeta converter using sliding mode controller

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

The control scheme for boost converter is designed as shown in Fig.9 using sliding mode control technique [8].

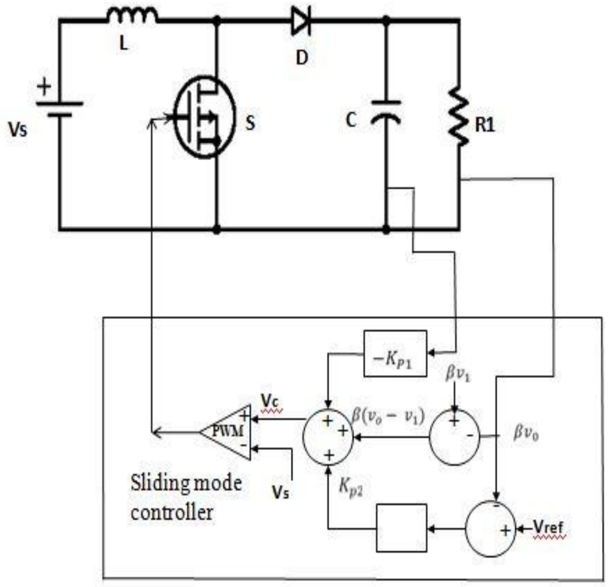

Fig.9 Control scheme of Boost converter using sliding mode controller

IV .DESIGN SPECIFICATIONS

The Zeta converter is designed as follows;

The input inductor L_1 is given as,

$$L_1 = \frac{DV_s}{\Delta i_{L1} f_s} \quad \text{... (12)}$$

Where, Δi_{L1} is the permitted ripple current in inductor L_1 and considered to be 10 % of output current I_0.

The value of input capacitor C_1 is given as,

$$C_1 = \frac{DI_0}{\Delta V_c f_s} \quad \text{... (13)}$$

Where, ΔV_c is the permitted voltage ripple in capacitor C_1 and considered to be 2% of supply voltage V_s.

The output inductor L_2 is given as,

$$L_2 = \frac{DV_s}{\Delta i_{L2} f_s} \quad \text{... (14)}$$

The value of output capacitor C_2 is given by,

$$C_2 = \frac{DV_s}{8 * \Delta V_{c2} f_s^2 L_2} \quad \text{... (15)}$$

Simulink model of proposed converter is implemented with following design parameters;-

Table I. Specifications of DC-DC Converter

Attributes	Zeta Converter	Boost Converter
Supply Voltage (V_s)	48 V	48 V
Output Power (P_0)	100 W	100 W
Switching frequency (f_s)	100 kHz	100 kHz
Duty ratio (D)	69.71%	56.56%
Inductors, L_1=L_2	1.6 mH	1.5 mH
Input capacitor (C_1)	0.1591µF	-
Output capacitor (C_2)	27.34µF	23.3µF
Load resistor (R_L)	121Ω	121Ω
Output Voltage (V_O)	110.5V	109.4V

V. SIMULATION STUDIES AND RESULTS

The performance of controller with reference load voltage variation is analyzed. Under the load voltage variation from 90 V to 120 V, the output voltage and output current can be regulated and controlled by controller.

A). Simulink model of boost converter

The closed loop simulink model of the proposed converter has been designed according to Table 1 parameters.

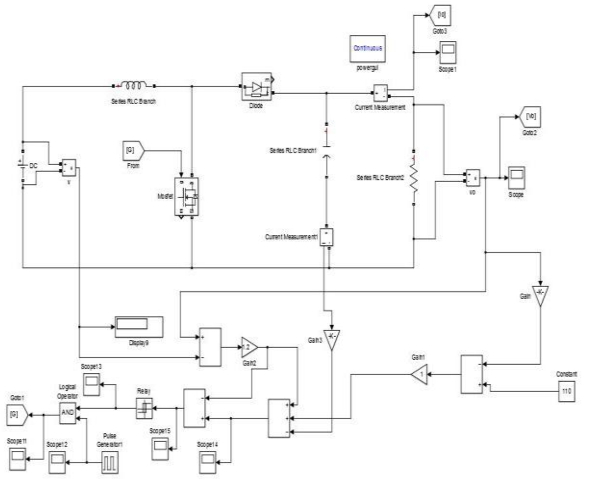

Fig.10 Simulink model of closed loop control of Boost converter

Output voltage of boost converter in closed loop configuration is shown in Fig.11.

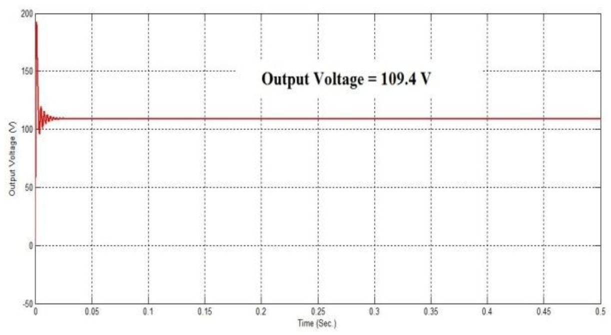

Fig.11 Output voltage of conventional Boost converter

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

Output current of boost converter in closed loop configuration is shown in Fig.12.

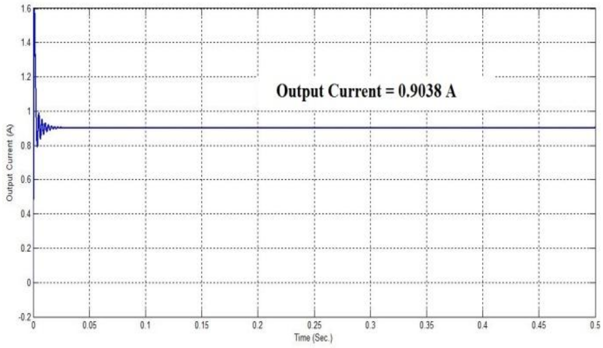

Fig.12 Output current of conventional Boost converter

A. Simulink model of Zeta converter

The closed loop simulink model of the proposed converter using sliding mode controller is shown in Fig.13.

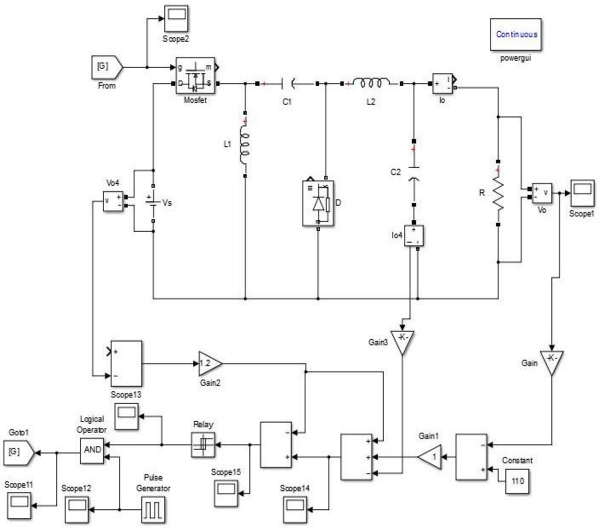

Fig.13 Simulink model of closed loop control of Zeta converter

The output current under dynamic condition is as shown in Fig. 14.

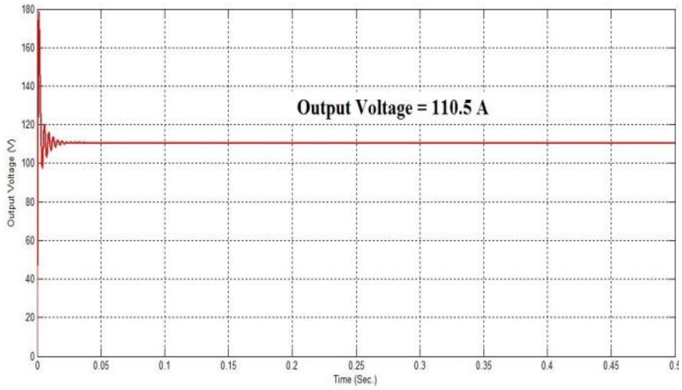

Fig.14. Output voltage waveform of Zeta converter

The output current under dynamic condition is as shown in Fig. 15.

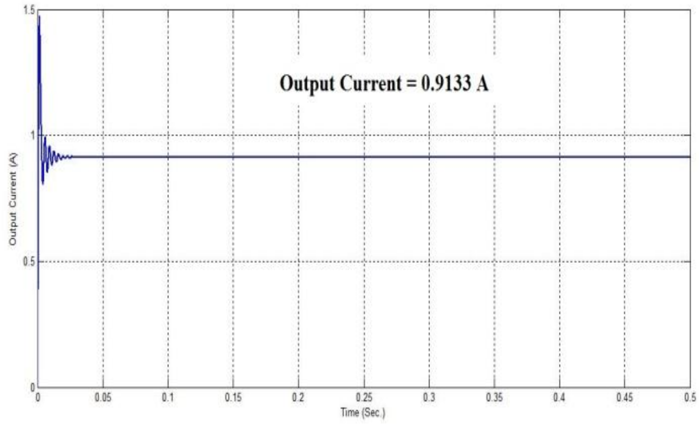

Fig.15. Output current waveform of Zeta converter

From simulation results, the voltage and current stress across the inductor, capacitor and diode are tabulated as below:

Table II. Voltage and current stress across passive components

Attributes	Boost Converter	Zeta Converter
Inductor current (I_L)	2.11 A	$I_{L1} = 2.22\ A$ $I_{L2} = 0.9132\ A$
Capacitor voltage (V_C)	109.4 V	$V_{C1} = -110.5\ V$ $V_{C2} = 110.5\ V$
Diode current (I_D)	2.11 A	0.9134 A

A graph between voltage gain and duty cycle for both boost and Zeta converter is plotted as shown in Fig.16

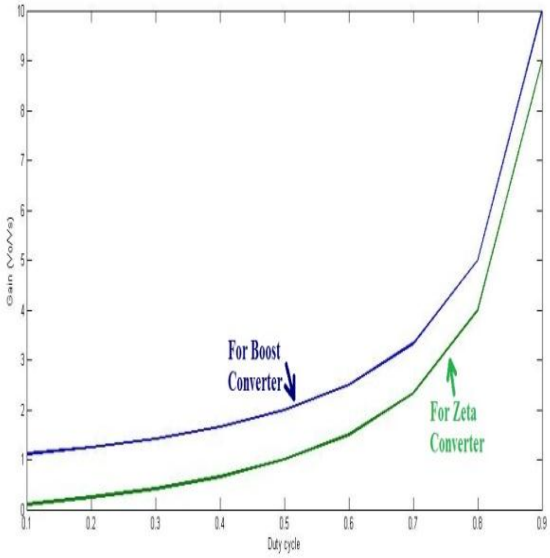

Fig.16. Voltage Gain Vs Duty cycle

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

VI.CONCLUSION

A performance comparison between Zeta converter and Boost converter is done and simulation results using sliding mode controller under the load voltage variation are discussed. Also dynamic modeling of Zeta as well as Boost converter is presented. It is understood that the Zeta converter is suitable for various applications because boost converter has reversed polarity of output voltage and high ripples in output voltage. The output voltage of Zeta converter is boosted more than the voltage obtained with the boost converter. The sliding mode controller is analyzed to regulate output voltage and output current under any disturbance either in supply side or in load side. The simulation results are shown with sliding mode control.

REFERENCES

[1] S.Singh, B. Singh, Bhuvaneswari, V. Bist, " Power Factor Corrected Zeta Converter Based Improved Power Quality Switched Mode Power Supply," IEEE Transaction on Industrial Electronics,TIE-2015, pp. 0278-0046.

[2] Ke-Ming Chen, Tsorng-Juu Liang, Shih Ming Chen, Kai-Hui Chen, " Design and implementation of a interleaved single-phase power factor correction Zeta converter," PEDS,IEEE 10th International Conference, 22-25 April,2013, p.p.171-174.

[3] Pijit Kochcha, Sarawat Sujitjorn," Isolated Zeta converter: principle of operation and design in continuous conduction mode," WEAS transactions on circuits and systems, issue 7, vol.9, July 2010.

[4] S. Singh and B. Singh, "Voltage controlled PFC zeta converter based PMBLDCM drive for an air-conditioner," in IEEE Conf. on Industrial and Information Systems, ICIIS 2010, Jul 29-Aug 01, 2010.

[5] Vulthchhay, Engg and Chanin Bunlaksananusorn, "Dynamic modeling of Zeta converter with state-space averaging technique," ECTI-CON 2008, 5th International conference, vol. 2, IEEE 2008, pp. 961-972.

[6] S.C.Tan, Y.M.Lai, C.K. Tse, "Implementation of Pulse-Width-Modulation based Sliding Mode Controller for Boost converters," IEEE Power Electronics Letters, vol.3, No.4, Dec. 2006, pp.130-135.

[7] S.S.Muley, R.M.Nagarale, "Slidind Mode Control Of Boost converter," IJETAE ISSN:2250-2259, vol.3, Issue 9, Sept.2013

[8] Sumita Dhali, P.Nageshwara Rao, Praveen Mande, K.Venkateswara Rao, "PWM-based Sliding Mode Controller for DC-DC Boost converter," IJERA ISSN:2248-9622, vol.2, Issue 1, Jan.-Feb. 2012, pp.616-623.