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Conception and Exertion of Discrete PID Controller for Zeta Converter

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Abstract: herein, a venture is contrived and executed with discrete PID controller for Zeta converter. This expedient comprises of zeta converter and a discrete PID controller. The zeta converter is a proselytizer topology to harvest a controlled voltage from an undulated input voltage. The intent of this task is to outline and execute the discrete operation of PID controller for zeta converter. This Paper manages the machination and persistent state investigation of Closed Loop zeta converter profited by discrete PID control method and the mimeograph have been performed exploiting MATLAB/Simulink.

Keywords: Zeta converter, PID controller, Discrete

I. INTRODUCTION

Down to earth electronic converters utilize exchanging strategies. Changed mode DC-to-DC converters change over one DC voltage level to another, which might be higher or lower, by putting away the information Energy incidentally and after that discharging that Energy to the yield at an alternate voltage. The capacity might be in either attractive field stockpiling segments (inductors, transformers) or electric field stockpiling segments (capacitors). There are numerous kinds of DC-DC converters which incorporates Buck (Step down) converter, Boost (Step up) converter, Buck-Boost (Step up-Step down) converter [2] [5][6].

Zeta, or 'opposite sepic', is another of those dc-dc converters, as Cuk and Sepic, which have a capacitor in arrangement with the power way. It is a fourth request non-altering DC-DC converter fit for opening up or lessening the information voltage to the coveted directed yield by basically differing the obligation cycle. The Zeta converter comprises of inductorsL1, L2 and capacitorsC1, C2 [7]. The advantages of the zeta converter over the sepic converter incorporate lower yield voltage swell and less demanding pay. It is the perfect power supply for applications requiring a steady info current like battery charges and LED lights.

The state space analysis of this converter involves a mathematical relation between inputs, state variables and output which are referred to as the modeling of the system. The state model of the system consists of the state equation and the output equation [3].

A proportional integral derivative common controller (PID controller) is a controlled feedback mechanism widely used in control systems. A PID controller continuously calculates an error value as the difference between a desired set point and a measured value. On proffering the three constant values namely P, I and D in the PID controller algorithm the PID can provide controlled hopper for specific process set back. The PID controller is more efficacious in maintaining the constant output voltage and in reducing the amount of ripple in the output voltage [1].

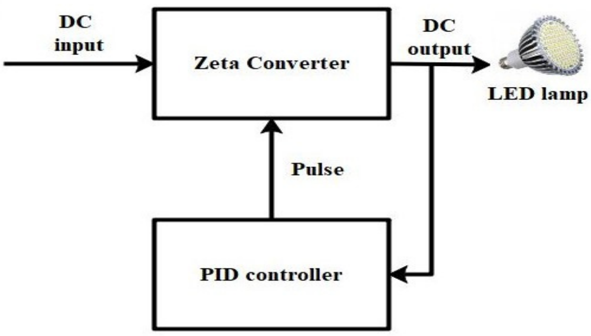

Fig. 1.Block diagram of Zetaconverter using discrete PID controller.

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II. Zeta Converter

Zeta converter is a DC-DC converter which maintains the output voltage polarity identical as that of the input. The circuit consists of MOSFET as switch, two capacitors, two inductors and a load resistance.

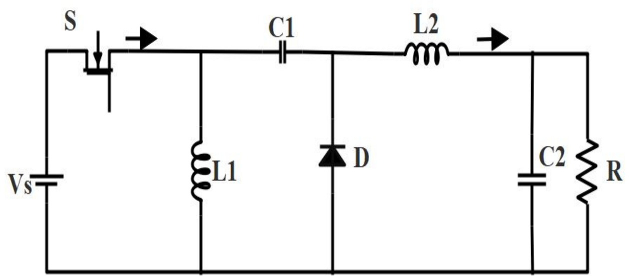

Fig. 2.Schematic diagram of Zeta converter

The Inductor L_1 and L_2 were designed in order to reduce production cost and output ripple current. Zeta converter is similar to a Buck-Boost converter without having the property of Capsized output. The Zeta converter is pretend to operate in continuous conduction mode. There exists of two modes of operation.

III. Operation Principle and its Out-turn Designs

A. MODE 1

As in fig.3 mode 1 the switch will be closed. When Switch is turned ON (ON-state), the diode is turned off. This is expressed as an open circuit for diode and short circuit for Switch. At this time, diode D is OFF with a reverse voltage equal to - ($V_S + V_0$). During this state, inductor L_1 and L_2 will be in charged phase. This means that the inductor current i_{L_1} and i_{L_2} increases linearly.

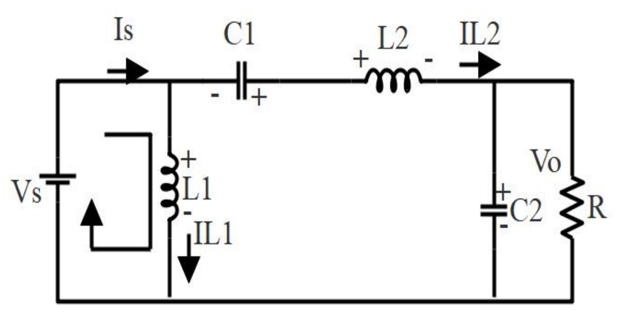

Fig. 3.Zeta converter under ON state

The capacitor C_1 is discharged at this stage and the energy is charged to V_0 which is connected in series with L_2. The sum of the charging inductor current flows through S.

On applying Kirchhoff's voltage law to fig.3 and the voltage equations be,

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1} \quad (1)$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} + \frac{V_{C1}}{L_2} - \frac{V_{C2}}{L_2} \quad (2)$$

On applying Kirchhoff's current law the voltage rate flowing through the capacitors will be,

$$\frac{dV_{C1}}{dt} = -\frac{i_{L2}}{LC_1} \quad (3)$$

$$\frac{dV_{C2}}{dt} = \frac{i_{L2}}{C_2} - \frac{V_{C2}}{RC_2} \quad (4)$$

B. MODE 2

In Fig.4 mode 2 the switch is open. When S is turned OFF (OFF- state), the diode is on. The equivalent circuit of this mode shows that the diode is short circuited and Switch is open circuited. Inductor L_1, which was previously charged have to be discharged now. At this state, inductor L_1 and L_2 are in discharge phase. The diode will get forward biased depending on the voltage polarity of the inductor and the further conduction takes place.

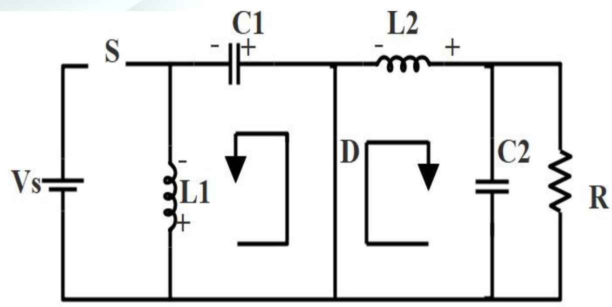

Fig. 4. Zeta converter under OFF state

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Energy in L_1 and L_2 are discharged to C_1 and the output sector, respectively. As a result, inductor current i_{L1} and i_{L2} decreases linearly.

On applying Kirchhoff's voltage law, voltage across inductor L_1 is obtained as,

$$\frac{di_{L1}}{dt} = -\frac{V_{C1}}{L_1} \quad (5)$$

$$\frac{di_{L2}}{dt} = -\frac{V_{C2}}{L_2} \quad (6)$$

On applying Kirchhoff's current law, the amount of current flowing through the capacitor C_1 is obtained as,

$$\frac{dV_{C1}}{dt} = \frac{i_{L1}}{C_1} \quad (7)$$

$$\frac{dV_{C2}}{dt} = \frac{i_{L2}}{C_2} - \frac{V_{C1}}{RC_2} \quad (8)$$

The relation between the input and the output voltage of the Zeta converter are given by the expression,

$$V_o = V_s \frac{D}{1-D} \quad (9)$$

The duty cycle D for Zeta converter in CCM is given by,

$$D = \frac{V_o}{V_o + V_s} \quad (10)$$

$$\frac{D}{(1-D)} = \frac{V_o}{V_s} = \frac{I_{in}}{I_o} \quad (11)$$

IV. DESIGN EQUATION OF ZETA CONVERTER

On Applying Kirchhoff's voltage law on Zeta converter circuit for the first and second mode the derived equations are as below. The output ripple current through the inductor is expressed as,

$$\Delta I_{L1} = \frac{DV_s}{FL_1} \quad (12)$$

$$L_1 = \frac{DV_s}{F\Delta L_1} \quad (13)$$

The output ripple current through the inductor is expressed as,

$$\Delta I_{L2} = \frac{DV_s}{FL_2} \quad (14)$$

$$L_2 = \frac{DV_s}{F\Delta I_{L2}} \quad (15)$$

The capacitor ripple voltage ΔV_{C1}&ΔV_{C2} is derived from the Kirchhoff's current law for the first and second mode as

$$\Delta V_{C1} = \frac{1}{C_1}\int_0^{T_{ON}} i_{C1}\, dt \quad (16)$$

$$C_1 = \frac{DV_o}{FR\Delta V_{C1}} \quad (17)$$

$$\Delta V_{C2} = \frac{1}{C_2}\int_0^{T/2} \frac{\Delta I_{L2}}{4}\, dt \quad (18)$$

$$C_2 = \frac{DV_s}{8F^2 L_2 \Delta V_{C2}} \quad (19)$$

Where, F= switching frequency

From the power loss equation,

$$V_s I_{in} = V_o I_o \quad (20)$$

The calculation for the input current

$$I_{in} = \frac{V_o I_o}{V_s} \quad (21)$$

V. STATE SPACE MODEL

State space averaging (SSA) is a renowned method used in modeling of switching converters. In order to develop the state space averaged model, the equation for the rate of inductor current change along with the rate of capacitor voltage change are used.

A state variable description of a system is as follows,

$$X = Ax + Bu \quad (22)$$

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$$V_o = Cx + Du$$

Where A is n$\times$ n matrix and B is n$\times$ n matrix, C is m $\times$ n matrix and D is to represent duty cycle ratio.

For a system that has a two switch topologies, the state space equations can be described as

Case1: When switch is closed

$$X = A_1 x + B_1 u$$
$$V_o = C_1 x + D_1 u$$

Case2: When switch is open

$$X = A_2 x + B_2 u$$
$$V_o = C_2 x + D_2 u$$

For switch closed time DT and open time (1-D) T, the average weighted equations are,

$$X = [A_1 d + A_2(1-d)]x + [B_1 d + B_2(1-d)]u$$
$$V_o = [C_1 d + C_2(1-d)]x + [D_1 d + D_2(1-d)]u$$

Let us assume the variables,

$$x_1 = i_{L1}$$
$$x_2 = i_{L2}$$
$$x_3 = V_{C1}$$
$$x_4 = V_{C2}$$
$$u = V_s$$

State space equation for ON state is derived from the equation (1), (2), (3), (4) as

$$\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L_2} & \frac{-1}{L_2} \\ 0 & \frac{-1}{C_1} & 0 & 0 \\ 0 & \frac{-1}{C_2} & 0 & \frac{-1}{C_2 R} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \\ 0 \end{bmatrix} [u]$$

State space equations for OFF state is derived from equation (5), (6), (7), (8) as

$$\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-1}{L_1} & 0 \\ 0 & 0 & 0 & \frac{-1}{L_2} \\ \frac{1}{C_1} & 0 & 0 & 0 \\ 0 & \frac{1}{C_2} & 0 & \frac{-1}{C_2 R} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \quad (23)\ (24)\ (25)$$

From ON state and OFF state equation, the state space equivalent equation obtained as,

$$\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-(1-d)}{L_1} & 0 \\ 0 & 0 & \frac{d}{L_2} & \frac{-1}{L_2} \\ \frac{(1-d)}{C_1} & \frac{-d}{C_1} & 0 & 0 \\ 0 & \frac{1}{C_2} & 0 & \frac{-1}{C_2 R} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} \frac{d}{L_1} \\ \frac{d}{L_2} \\ 0 \\ 0 \end{bmatrix} [u] \quad (26)\ (27)\ (28)\ (29)$$

$$C = [0 \quad 0 \quad 0 \quad 1] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

$$D = [0]$$

The values of A, B, C, D was found and after that the transfer function can be calculated by using the MATLAB coding.

The transfer function is

$$\frac{V_o(s)}{V_{in}(s)} = \frac{3.75e^{07}s^2 - 1.041e^{-09}s + 1.953e^{13}}{s^4 + 1e^{04}s^3 + 6.318e^{07}s^2 + 6.771e^{09}s + 1.302e^{13}}$$

VI. PID CONTROLLER

PID Controller is a most normal control calculation utilized as a part of modern computerization and applications and over 95% of the mechanical controllers are of PID write. PID controllers are utilized for more exact and

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precise control of different parameters. A PID controller is an input circle controlling instrument. It rectifies the blunder between a deliberate esteem and coveted set point esteem. The PID controller figuring includes three distinct parameters, the corresponding worth (P) respond to the present mistake, the vital (I) the respond to the total of late blunder and the subsidiary (D) respond to the rate at which the mistake has been evolving. The total of these three activities is utilized to alter the procedure by means of control component. By "tuning" the qualities in the PID controller, it can give a control activity according to the particular prerequisites.

Utilizing the state space investigation, DC converters are displayed which decides the state factors which incorporates the inductor current and the capacitor voltage. The central Requirement is to acquire a consistent yield voltage for input unsettling influence and this can be accomplished by straightforwardly tuning I esteem [10].

The Ziegler-Nichols method was introduced by John Ziegler and Nathaniel Nichols. As in the method I and D gains are first set to zero. The P gain is increased until it reaches the critical gain K_{cr} at which the output of the loop starts to oscillate. K_{cr} And the oscillation period P_c are used to set the gains as shown in table1.

The transfer function model of the converter can be represented as

$$G(s) = \frac{3.75e^{07}s^2 - 1.041e^{-09}s + 1.953e^{13}}{s^4 + 1e^{04}s^3 + 6.318e^{07}s^2 + 6.771e^{09}s + 1.302e^{13}}$$

By using transfer function derive for the quadratic equation by,

$$1 + G(s)H(s) = 0$$

Where,

H(s) =1 (unity feedback gain)

TABLE I
GAIN PARAMETER CALCULATION

CONTROL TYPE	K_p	T_i	T_d
P	$0.5*K_{cr}$	-	-
PI	$0.54*K_{cr}$	$P_{cr}/1.2$	-
PID	$0.6*K_{cr}$	$0.5*P_{cr}$	$0.125*P_{cr}$

Then,

$$1+\frac{3.75e^{07}s^2-1.041e^{-09}s+1.953e^{13}}{s^4+1e^{04}s^3+6.318e^{07}s^2+6.771e^{09}s+1.302e^{13}} = 0$$

By solving the above equation, the characteristics equation if derived
Substitute s=j□, and equating real terms in the characteristics equation to find the value of □

$$P_{cr} = \frac{2\pi}{\omega}$$

Reset time,

$$T_i = 0.5 \times P_{cr}$$

Derivative time,

$$T_d = 0.125 \times P_{cr}$$

Integral gain,

$$K_i = \frac{K_p}{T_i}$$

Derivative gain,

$$K_d = K_p T_d$$

VII. Discretizing a PID Controller

The continuous-time domain controller is transformed into the discrete-time domain using Trapezoidal method is called as Tustin method or Bilinear – Transformation

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method. This Tustin method tracks the analog controller output more accurately at the sample times and approximate to the analog integration are better than other methods.
On transforming the continuous PID into Discrete PID controller we have simulated using discrete powergui, we have successfully obtained the required output voltage. [8]

VIII. Simulation Circuits and its Waveforms

The simulation is carried out for different input (from 8V to 15V) while the output voltage (Vo) was maintained at a constant level (12 V). To maintain a constant output voltage even in the presence of variation in input voltage from 8V to 15V, the duty cycle of gate pulse of the MOSFET is changed. And the dynamic response of the converter will get improved by the closed loop simulation.

There is an error in the output voltage of the open loop system which in turn makes the system unstable. To make the system stable a feedback path is given. The error in the output voltage is compared and is given to the controller.

TABLE II
DESIGN SPECIFICATIONS

PARAMETERS	VALUES
V_s	8V
V_o	12V
D	0.6
F	25KHz
ΔI_{L1}	0.12A
ΔI_{L2}	0.12A
ΔV_{C1}	0.06V
ΔV_{c2}	0.06V
L_1	1.6mH
L_2	1.6mH
C_1	480μH
C_2	10μH
R	10Ω
K_p	0.001
K_i	12.224
K_d	8.545e-7

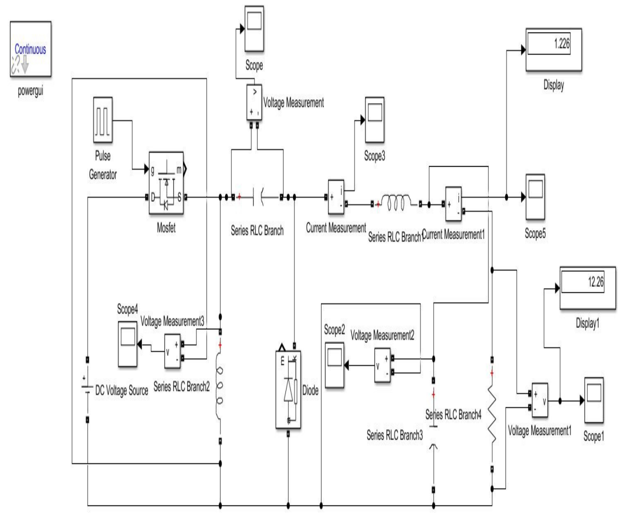

Fig.5.Simulink model of open loop control

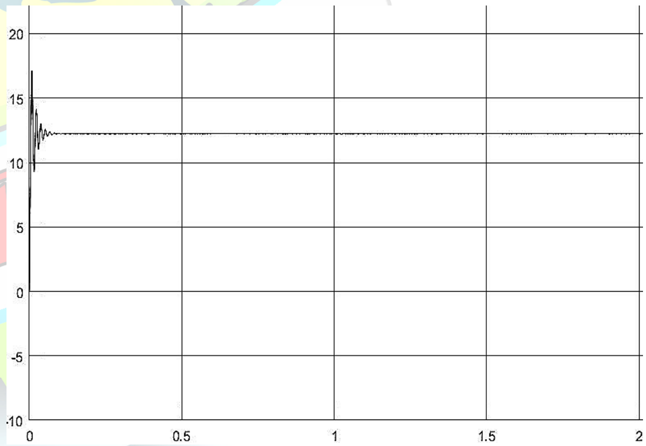

Fig.6.Output voltage waveform boost mode

The output voltage waveform has been plotted by keeping time(s) in X-axis and output voltage (V) in Y-axis. The output voltage is depicted as 12.26V

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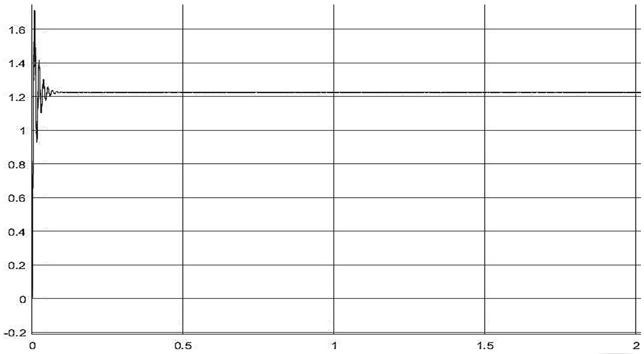

Fig.7.Output current waveform boost mode

The output current waveform has been plotted by keeping time(s) in X-axis and current (A) in Y-axis. The output current obtained was 1.226A.

Fig.8.Output current waveform buck mode

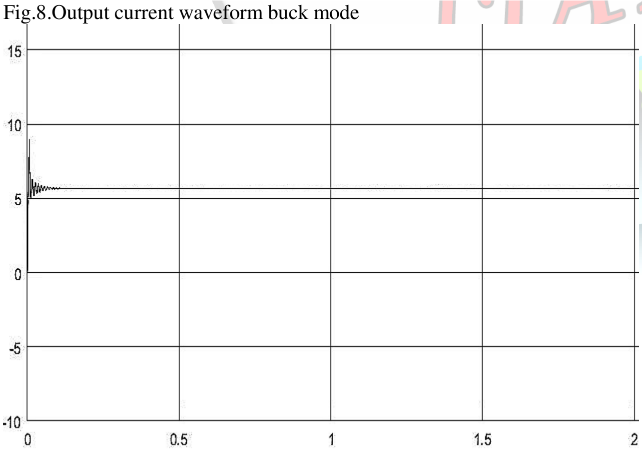

Fig.9.Output voltage waveform buck mode

The output voltage waveform has been plotted by keeping time(s) in X-axis and output voltage (V) in Y-axis. The output voltage is depicted as 5.65V.

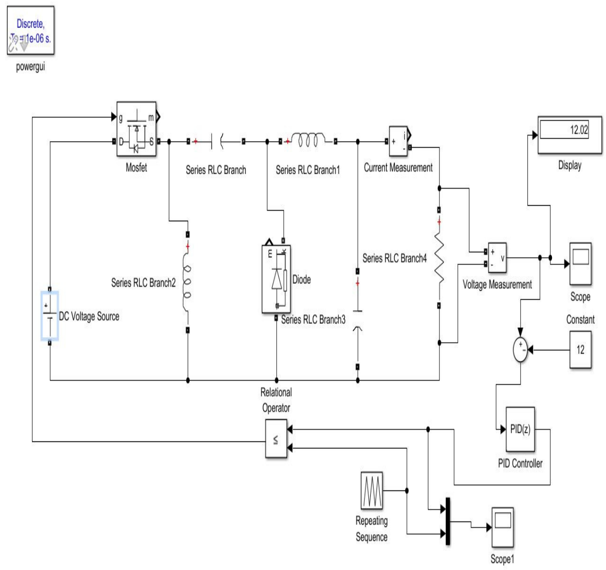

Fig.10.Simulink model of closed loop control

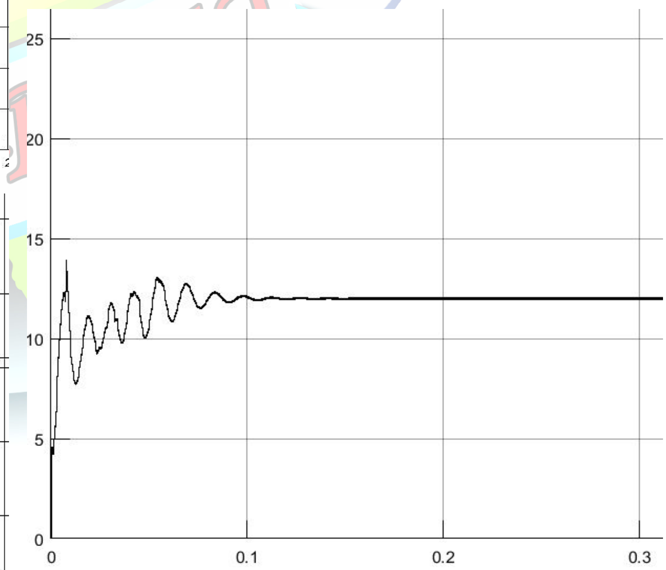

Fig.11.Output voltage waveform (closed loop)

The output voltage waveform has been plotted by keeping time(s) in X-axis and output voltage (V) in Y-axis. The output voltage is depicted as 12.01V.

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IX. CONCLUSION

Thus in this paper the dynamic modelling of the Zeta converter has been designed. The open loop and the closed loop design were simulated using Matlab. And it is found that the output voltage remains constant under various load conditions. The proposed system will be implemented in driving LED lamp with constant input to avoid flicker.

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