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Design, Analysis and Controller Design of Zeta Converter

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Abstract

In this paper the design, analysis and controller design of zeta converter is explained. The Dc to Dc Zeta converter is a type of buck-boost converter that provides an dc output voltage with the same polarity of the input dc voltage. Zeta converter is more useful as compared to the other class of converters having the properties of both buck converter and the boost converter i.e. it can be used to provide the step up or step down the applied input voltage. It is usually used in different types of industrial and domestic applications. It provides an non-inverting polarity output dc voltage and it could be designed to obtain the lower ripple output current and as it has smaller settling time which makes the system more faster and increases the adaptability etc. The zeta converter is generally used to get the need of dc appliances by varying the dc output voltage. This paper focusses mainly based how to maintain the constant dc voltage and changing the dc voltage. At first by using MATLAB, ZETA Converter is designed. The dc output voltage of the converter is measured from output of the converter with open circuit. The duty cycle of the switch is varied to vary the output voltage which decides to operate the zeta converter either as a buck converter or as a boost converter. A feedback control design is necessarily required for achieving best voltage regulation, faster dynamic response, and to achieve the stability of the converter. Therefore, in this paper, State space technique is used to attain the small-signal Transfer function duty cycle to the output voltage of dc to dc Zeta converter. Then the Proportional Integral (PI) controller is designed using this transfer function and using the stability equations to attain the specific phase margin of the converter and to reach the required cross over frequency. The result of the simulation shows that the Zeta converter is compensated and also shows the best dynamic response and the steady-state behavior with the presence of load and line variations. The zeta converter is widely used in applications such as e-rickshaw, correction of power factor, for battery charging etc. Here the zeta converter is found to be 90-93% efficient.

Keywords; *Zeta Converter, MOSFET (Metal Oxide Semiconductor Field Effect Transistor), SSA (State Space Averaging Technique), CCM (Continuous Conduction Mode), PI Controller and Simulink Model.*

I. INTRODUCTION

The Zeta converter is a type of DC-DC converter provides a positive (non-inverting) DC output voltage. The level of the voltage can be lesser or higher than the applied dc voltage. The ZETA converter made up of a capacitor (flying capacitor) and two numbers of inductor. The converter uses the gate pulse for MOSFET of the converter which is configured as a converter with higher output than applied input i.e. boost mode. The ZETA converter is also used to regulate the unregulated input dc

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power supply. All types of non-conventional system need a certain power converter. The power electronic DC-DC converter is the essential part of complete system, so there is a requirement of proper design [7]. ZETA Converter is used provide non-inverting (positive) dc output voltage from the input dc voltage. These converters could be used for Step down and step-up from the applied input dc voltage. This type of converter is also can be used for different types of PFC applications and for short circuit protection [10].

Zeta converter can be used to doubled and even tripled of the applied input voltage by varying the duty cycle. Switching techniques can be used to vary the duty cycle. Thus Driver circuit is used to obtain gate pulse which is applied to MOSFET to operate the converter in ON state. The Zeta Converter gives positive (non-inverted) output voltage; it has lower ripple factor, lower diode voltage and can be operated in CCM (Continuous conduction mode). The load is used at the output of the converter. For the variable output voltage we use the large DC power loads. There are different types of converters available which could be used instead of ZETA converter. But there are some certain limitations.

BOOST Converter: This converter is used to step-up the applied input DC voltage. For varying load condition it does not protect and also incapable for over current and short circuit conditions.

BUCK Converter: This converter is used to step-down the applied input DC voltage. This Converter protect against the overload. But these converters have limitations in power factor correction applications.

BUCK-BOOST Converter: This converter is satisfying all the afore mentioned specifications.

CUK Converter and SEPIC Converter: These converters do not protect itself against the varying load condition or overload and to limit the inrush current it requires some additional circuits

Controller of ZETA converter is designed using a PI controller and the corresponding output response is simulated by using the MATLAB/SIMULINK software. The response of ZETA converter recorded when it is subjected to line and load variations is simulated.

II. ZETA CONVERTER

A zeta converter is a 4th order nonlinear system. The non-isolated zeta converter circuit diagram is shown in the fig.1. There are many operating modes are possible for this converter depending on the value of the inductance, the load resistance and the operating frequency. In this paper continuous inductor current iL1 is analyzed by using the state-space method. The analysis of the zeta converter has the following assumptions.

1. Ideal Semiconductors switching devices

2. Converter working in continuous conduction mode (current through inductor)

3. Neglect the Line frequency ripple in the dc voltage.

A. Principle of Operation

ZETA converter is shown in the Fig.1 which comprises of an input capacitor, Cin, an output capacitor, Co, coupling inductor L1 and L2, an coupling capacitor, Cfly, a power PMOSFET, M1 & a diode, D1.

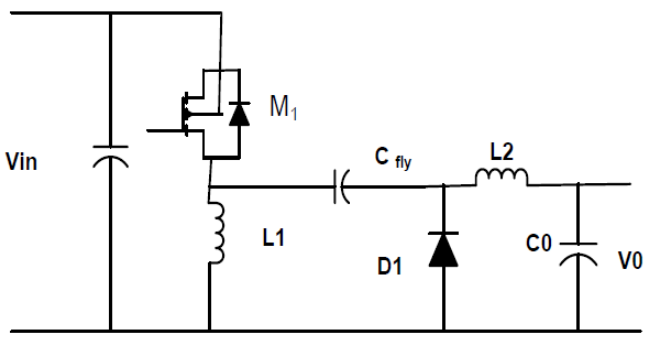

Fig.1. Proposed Structure of Zeta Converter

Fig. 2 shows the ZETA converter working in CCM when switch M1 is on.

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Stage-1[M1ON]

It is very important to analyze the circuit at DC when both switches are off and not switching to understand the voltages at the various circuit nodes, Capacitor Cc will be in parallel with Co. so Cc is charged to the output voltage, Vo, during steady-state CCM. Fig. 2 shows the voltages across L1 and L2 during CCM operation.

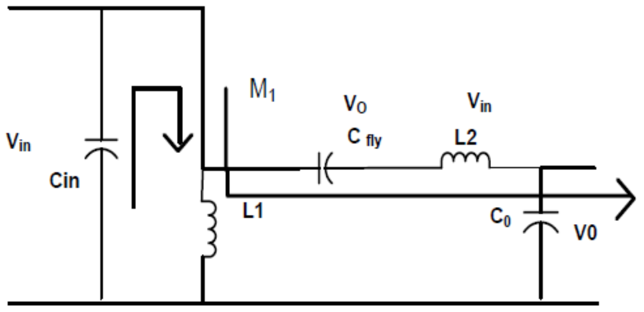

Fig.2. Zeta Converter during ON state

Fig. 3 shows the ZETA converter operating in CCM when M1 is off.

Stage-2 [M1 OFF]

When M1 is off, the voltage across L2 must be Vo since it is in parallel with Co. Since Co is charged to Vo, the voltage across M1 when M1 is off is Vin + Vo; therefore the voltage across L1 is –Vo relative to the drain of M1. When M1 is on, capacitor Cc, charged to Vo, is connected in series with L2; so the voltage across L2 is +Vin, and diode D1 sees Vin + VO.

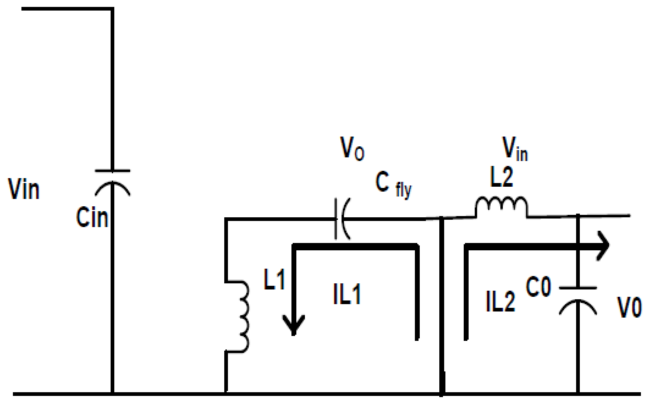

Fig.3. Zeta Converter during OFF State

B. Calculations of Design Parameters of the Zeta Converter

This Paper shows the analysis of all the components of the converter. The output voltage and input voltage can be controlled by controlling the duty cycle.

Let the input voltage Vin be 24 V, the output voltage V0 be 48V, power is of 100 watt.

P=V0I0

100=48*I0

So I0=2.083 Ampere (Output Current)

As per ohm's law we know that

V0=I0R

48=2.083*R

So R=23.043≈25 Ω (Load Resistance)

The Output voltage of the zeta converter with function of Duty c is given by the following equation.

$$V0 = \frac{D}{1-D} Vin$$

Where D is the duty Cycle

$$48 = \frac{D}{1-D} 24$$

So D=67%

The Specifications of the converter is summarized in Table-1

Table-I: Zeta Converter Design Specifications

Sr. No	Components	Values
1	Applied Input Voltage, V_i	24 V
2	Desired Output Voltage, V_o	48 V
3	Power, P	100 Watt
4	Output Current, I_o	2.83 A
5	Switching Frequency, f	50 KHz
6	Resistance, R	25 Ω
7	Pulse Generator duty cycle	67%
8	Capacitor, C	300 uf,
9	Inductor, L	1MH

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C. Converter design using MATLAB/SIMULINK Model

In this paper Simulation has done using MATLAB® version R2014 software package. MATLAB has many applications like it is used for mathematical computational task and can solve very complicated equations within very less time. MATLAB SIMULINK is a model design, which provides an interactive graphical environmental and a set of block libraries that helps us to design, to implement and test. Converters are designed using "SIMPOWER system" blocks.

D. Design Simulation of the Full Bridge Rectifier

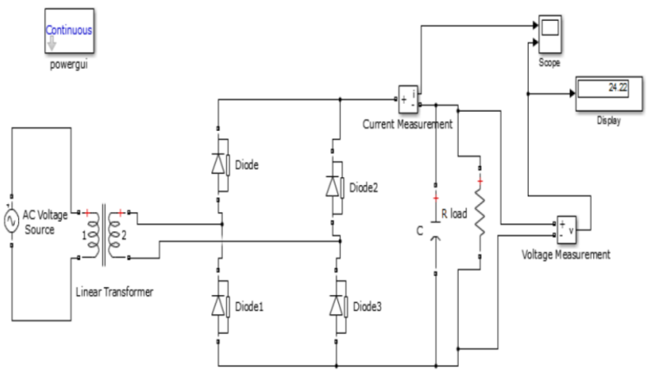

Fig.4. Simulation of Full Bridge Rectifier

Simulation of ZETA Converter is carried out using MATLAB SIMULINK software. So considering this firstly the bridge Rectifier circuit is designed using MATLAB/SIMULINK software. An AC Supply (230 V) is given as input to the rectifier circuit. A linear transformer is used to step down the Applied AC voltage to the rectifier. A capacitor and a resistor are used as a load which is acting as a filter circuit and output of the filter circuit of the rectifier provides 24 V. Hence the output Scope displays bridge rectifier output voltage graph and the output current graph. The graph shows Voltage Verses time and Current verses time graph. Hence this bridge rectifier output voltage is given to the ZETA converter which could be used either to step-up or step-down by varying the duty cycle of the switch.

E. Simulation Output of the Full Bridge Rectifier

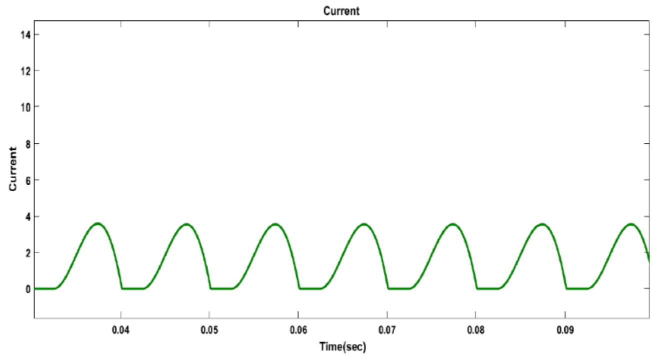

Fig.5 Output Current of the Bridge Rectifier

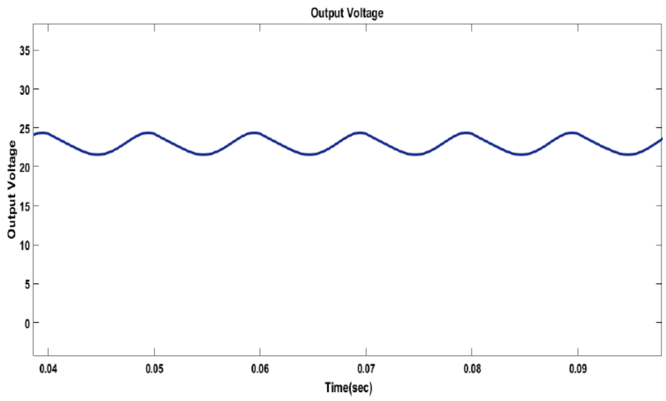

Fig.6. Output Voltage of the Bridge Rectifier

F. Simulation of Zeta Converter

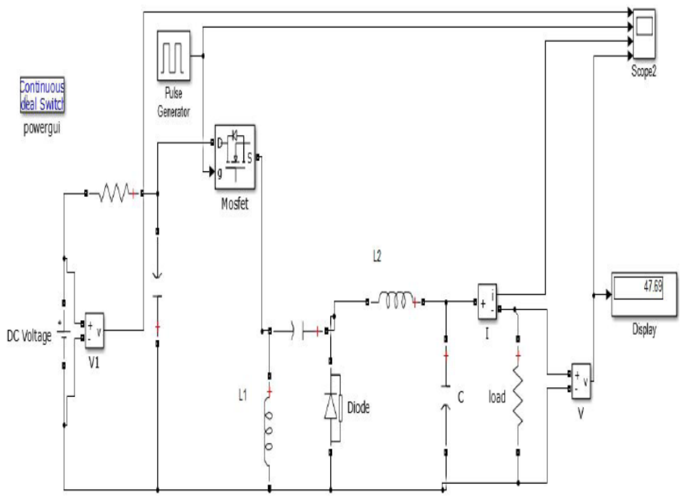

Fig.7. ZETA Converter Circuit Diagram using MATLAB/SIMULINK

In this Simulation the output response of the Zeta converter is analyzed. In this paper the basic zeta converter circuit is designed using MATLAB software where the rectified voltage is applied to the converter. For the fast switching a diode is used for

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the switching operation. So by altering the duty cycle of the pulse generator the output of the converter is doubled of the applied input DC voltage. In this case with 67% of duty cycle the desired output voltage is obtained. Fig.8 shows the rectified voltage which is applied to the converter. Fig. 9 shows the gate pulse applied to the gate of the MOSFET. Fig.10 shows the output current of the converter across the load. Fig. 11 shows the desired d.c. output voltage which is 47.89V. The output waveform shows fewer ripples as compared to the other types of the DC-DC Converters. Thus the efficiency of the converter is nearly in the range of 90-93%.

G. Simulation Output of the Zeta Converter

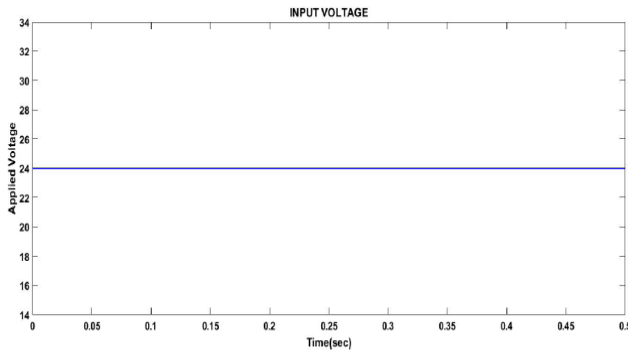

Fig.8. Input Voltage of the Zeta Converter

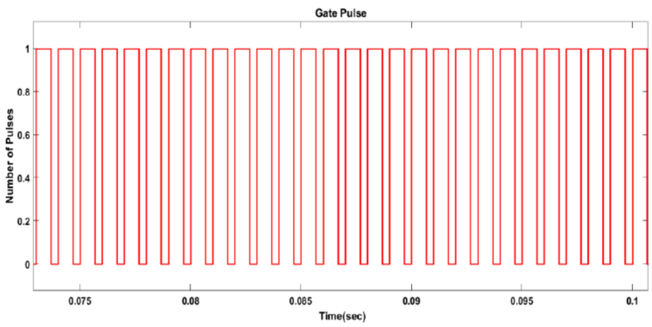

Fig.9. Gate Pulse

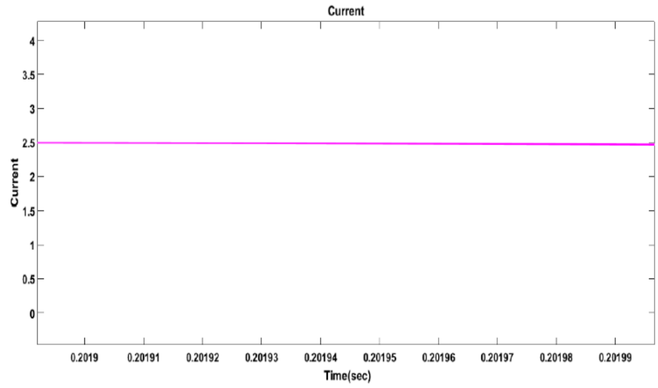

Fig.10. Output Current of Zeta converter

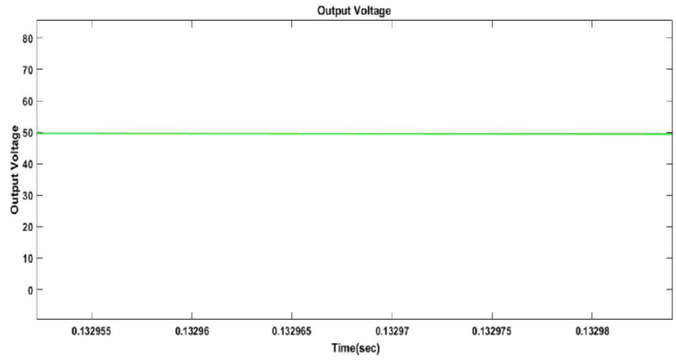

Fig.11 Output Voltage of the zeta converter

III. PROPORTIONAL-INTEGRAL (P-I) CONTROLLER

In some systems, if the gain of the system is too large then the system may be an unstable system. So there is a requirement of the basic controller which can be modified by adding the time integral of the error to control the operation. Thus the output of the system is given by the following equation,

$$\mathrm{OP} = \mathrm{K}(\mathrm{error} + \frac{1}{T_i}\int error\, \mathrm{dt})$$

Where the Ti is a constant called integral time.

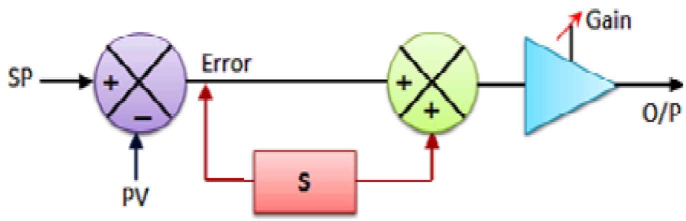

Fig.12. P-I Controller Block Diagram

The output of the controller steps up or down since there is an error and can be determined by Ti. The

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output of the controller remains constant, if there is no error. The offset error is removed by the integral term in the above equation. The block diagram of the closed loop Proportional Integral controller is shown in the Fig.13.

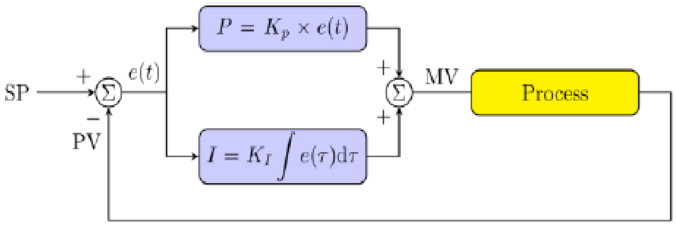

Fig.13. Closed loop PI Controller block diagram

The output of the PI controller is given by the following equation

$$MV(t) = K_P \times e(t) + K_i \int e(t)\,dt$$

Fig. 13 shows the basic structure of a closed loop PI controller. The PI controller calculates an error value e (t) by measuring the difference between the measured Process Variable (PV) and the desired Set Point (SP). The aim of the controller is to minimize the error e(t) by controlling the process by using the Manipulated Variable (MV) of the PI controller. Here the derivative action is not used because it may generate disturbances due to high frequency switching operation.

IV. MATLAB/SIMULINK MODEL OF ZETA CONVERTER WITH OUT AND WITH USING PI CONTROLLER

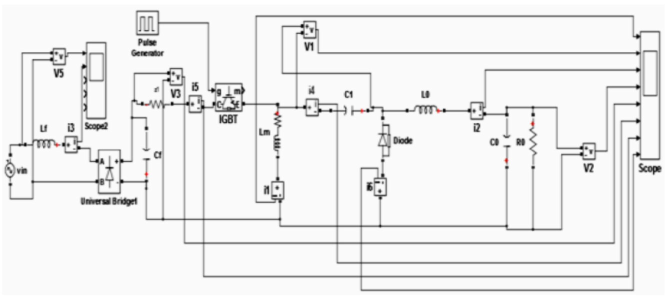

Fig.14. ZETA Converter without PI Controller Model using MATLAB/SIMULINK

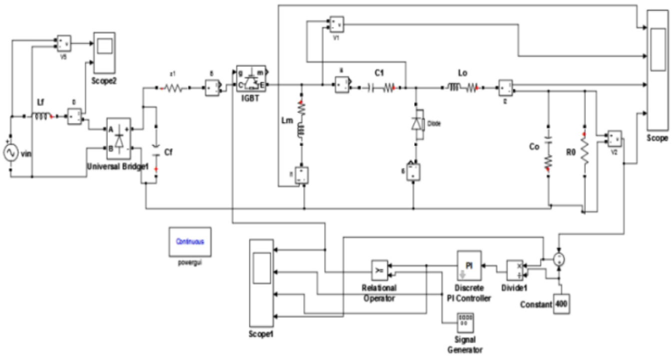

Fig.15. ZETA Converter with PI Controller Model using MATLAB/SIMULINK

V. SIMULATION RESULT OF ZETA CONVERTER

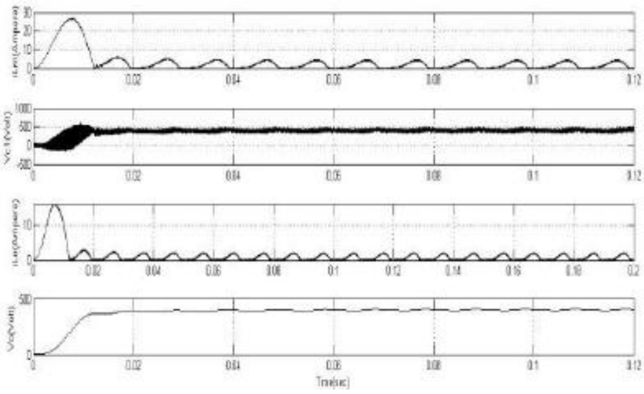

Fig.16. Output waveform of Zeta converter operating in CCM without using PI Controller

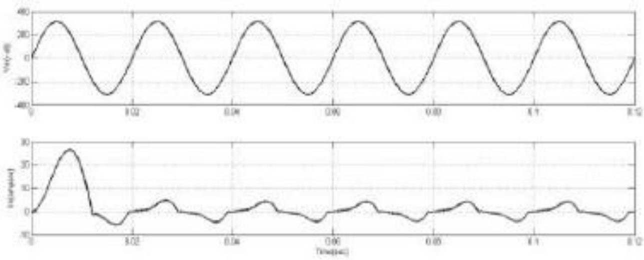

Fig.17. Input waveform of the Zeta converter operating in CCM without using PI Controller

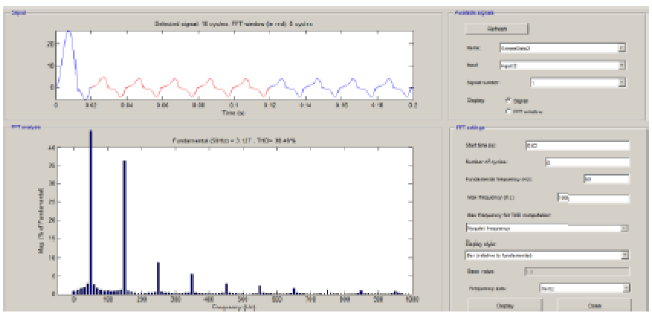

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Fig.18. THD of the input current waveform (Iin) =38.26% of the Zeta converter without using PI Controller

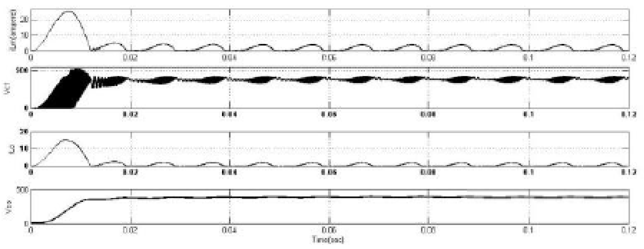

Fig.19. Output waveform of Zeta converter operating in CCM with using PI Controller

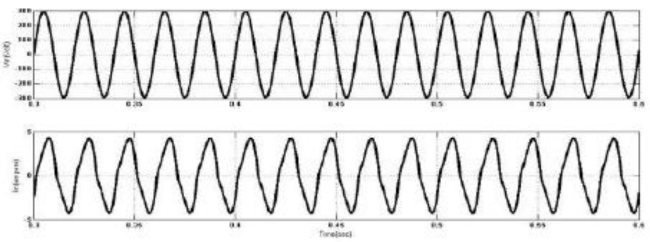

Fig.20 Input waveform of the Zeta converter operating in CCM with using PI Controller

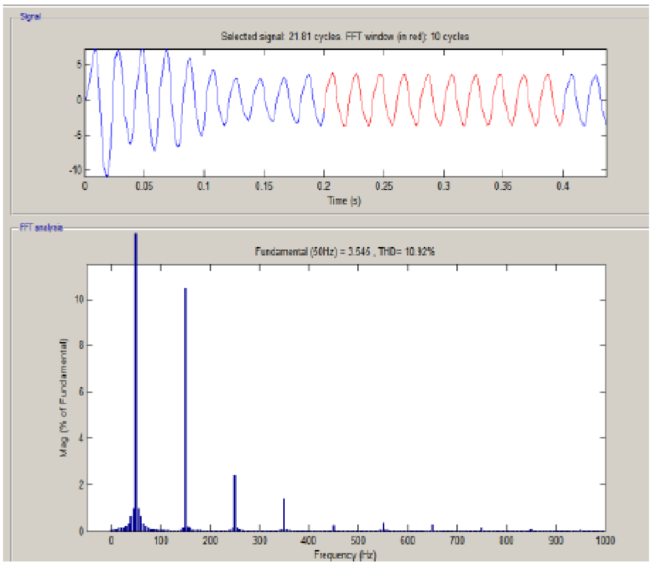

Fig.21. THD of the input current waveform (Iin) =10.92% of the Zeta converter with using PI Controller

VI. ADVANTAGES AND DISADVANTAGES OF ZETA CONVERTER

A. Advantages of Zeta converter

1. It is a type of buck-boost converter. This means that ability to step up and step down the input voltage as well.
2. As compared to regular Buck-Boost converter, it provides better efficiency and better voltage gain.
3. The output voltage of the converter is positive with respect to ground which makes the simple sensing circuit.

B. Disadvantages of Zeta converter

1. As the input current is discontinuous in nature, so it is not desired for some applications.
2. More passive elements are required for the design.
3. As it is a 4th order nonlinear system which makes the control difficult. Some control strategies are very difficult to apply in this converter such as sliding mode control.

VII. CONCLUSION

This paper explains working of ZETA converter which provides regulated d.c. output voltage which can be above and below the applied input voltage. Here the calculations of design parameters of the zeta converter by considering the power of 100 watt and obtained the values of output current, load resistance , and also value of the duty cycle. The advantages of ZETA converter are output voltage of small ripple and ease of compensation. The ZETA converter efficiency is higher as compared to the other DC-DC converter. In this paper the design strategy of zeta converters is also described. The converter parameter designed successfully, and understands the fact of designing AC-DC converters, and evaluates the performance of the designed converters simulation has been done. For comparing the converter performance PI control techniques has implemented.

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