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Design and Simulation of Pulse-Width Modulated ZETA Converter with Power Factor Correction

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Abstract: **This paper deals with the implementation of pulse width modulated Zeta converter with better efficiency, lower total harmonic distortion factor and power factor correction. It requires simpler control circuitry with fewer external components. Basic operation of Zeta converter is explained. PI filter is used to reduce the harmonics. Performance of Zeta converter in open loop, closed loop is obtained. Zeta converter in closed loop shows better performance compared to open loop. Both circuits are simulated using MATLAB Simu-link. Performance of Zeta converter is compared by giving disturbance in both open loop and closed loop. Zeta converter in closed loop has low THD value and power factor near to unity.**

Key-words: - Zeta converter, THD, Power Factor

1. INTRODUCTION

The conventional technique of AC-DC conversion using a diode rectifier with bulk capacitor is no longer in use due to numerous problems such as low order harmonics injection into AC power supply, low power factor, high peak current, line voltage distortion, increased electromagnetic interference, extra burden on lines, and additional losses.

Solid-state switch mode rectification converters have reached a matured level for improving power quality in terms of power-factor correction (PFC) and reduced total harmonic distortion (THD). The major challenge is to control the output voltage and improve PFC simultaneously.

The basic dc-to-dc converter topologies using Buck-converter, Boost converter and Buck-Boost converter have their intrinsic limitations when used for active power factor correction along with voltage regulation purposes.

In the proposed model a relatively new class of DC-DC converter, Zeta converter is used for active PFC and voltage regulation having advantages of being naturally isolated structure, can operate as both stepup/down voltage converter and having only one stage power processing for both voltage regulation and PFC .

A Zeta converter performs a non-inverting buck-boost function similar to that of a SEPIC. But in application which implies high power, the operation of a converter in discontinuous mode is not attractive because it results in high rms values of the currents causing high levels of stress in the semiconductors. In this paper, an active power factor correction (PFC) is performed by using a Zeta converter operating in continuous conduction mode (CCM), where the inductor current must follow a sinusoidal voltage waveform. This method provides nearly unity power factor with low THD.

2. ZETA CONVERTER

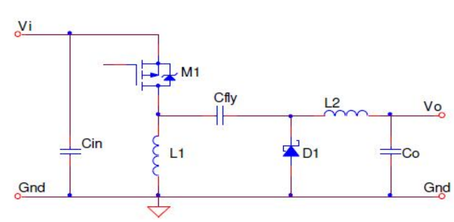

Fig1-Zeta Converter [12]

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Principle of operation

When analyzing Zeta waveforms it shows that at equilibrium, L1 average current equals I_{IN} and L2 average current equals I_{OUT}, since there is no DC current through the flying capacitor C_{FLY}. Also there is no DC voltage across either inductor. Therefore, C_{FLY} sees ground potential at its left side and V_{OUT} at its right side, resulting in DC voltage across C_{FLY} being equal to V_{OUT}.

Stage-1[M_1ON]

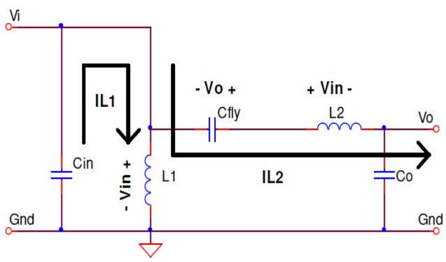

Fig2-Zeta converter during MOSFET ON time

The switch M_1 is in ON state, so voltages V_{L1} and V_{L2} are equal to Vin. In this time interval diode D_1 is OFF with a reverse voltage equal to - (Vin + VO). Inductor L_1 and L_2 get energy from the voltage source, and their respective currents I_{L1} and I_{L2} are increased linearly by ratio Vin/L_1 and Vin/L_2 respectively. Consequently, the switch current $I_{M1}=I_{L1}+I_{L2}$ is increased linearly by a ratio Vin/L, where $L=L_1.L_2/ (L_1+L_2)$. At this moment, discharging of capacitor C_{fly} and charging of capacitor C_0 take place.

Stage-2 [M_1 OFF]

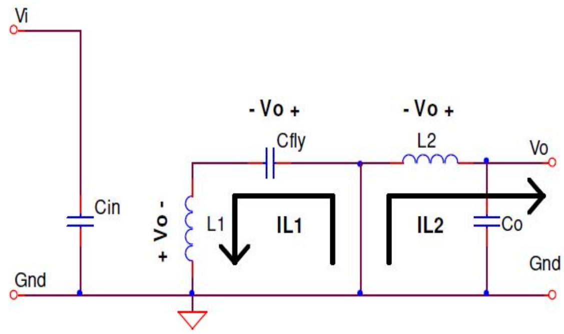

Fig3-Zeta converter during Mosfet OFF time

In this stage, the switch M_1 turns OFF and the diode D_1 is forward biased starting to conduct. The voltage across L_1 and L_2 become equal to -Vo and inductors L_1 and L_2 transfer energy to capacitor C_{fly} and load respectively. The current of L_1 and L_2 decreases linearly now by a ratio $-V_0/L_1$ and $-V_0/L_2$, respectively.The current in the diode $I_{D1}=I_{L1}+I_{L2}$ also decreases linearly by ratio $-V_0/L$. At this moment, the voltage across switch M_1 is $V_M=Vin + V_0$. Figure 4 shows the main waveforms of the ZETA converter, for one cycle of operation in the steady state continues mode.

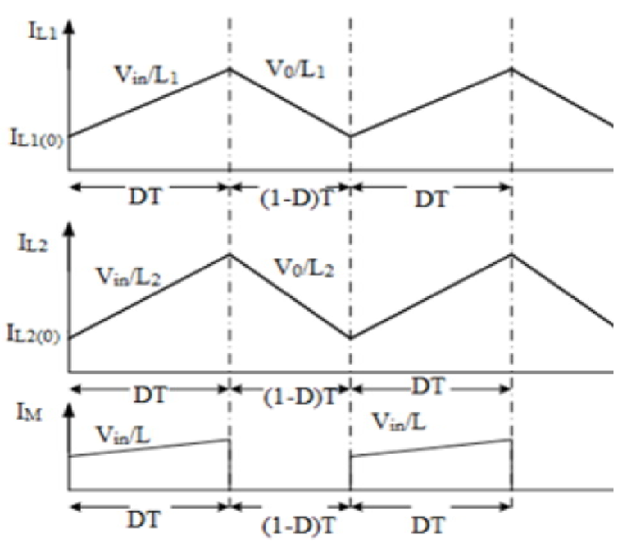

Fig4-Zeta converter waveforms [4]

3.DESIGN OF COMPONENTS OF ZETA CONVERTER [3]

A ZETA converter performs a non-inverting buck-boost function. For a ZETA converter operating in CCM, the duty cycle is defined as

$$D=\frac{V_o}{V_{in}+V_o}$$

To determine the value of inductances $L1$ and L2 the peak-to-peak ripple current is taken approximately 10-20% of the average output current. The value of these inductances may be expressed as,

$$L_1= L_2 = \frac{V_{in}D}{\Delta I_L F_s}$$

The coupling capacitor (C1) is designed on the basis of its ripple voltage. The maximum voltage handled by a coupling capacitor (C1) is equal to input voltage. It can be estimated as

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$$C_{fly} = \frac{I\square D}{\Delta Vc1Fs}$$

The output capacitor (C0) must have enough capacitance to maintain the dc link voltage and must have to provide continuous load current at high switching frequency. It can be calculated as:

$$C_0 \geq \frac{I\square D}{\Delta Vc\square\,(0.5Fs)}$$

where, D is duty cycle, Vo is dc link voltage, Vin is rms value of the input voltage, Io is output rated current, fs is switching frequency, AVc1 is the ripple voltage of the coupling capacitor, AVco is the ripple voltage of the output capacitor.

4.Simulation Results

i. Conventional Open Loop Zeta Converter with RL load

The importance of simulation is apparent for the preliminary design of any system. System behavior and performance can be predicted with the help of the simulation. To verify and investigate the design and performance of the preliminary stage, a simulation study of Zeta converter in open loop is performed for input DC voltage of 15V at 50Hz and output DC voltage of 8.5V and 14W output power rating with a switching frequency of 10KHz,with RL load.

Power circuit of Zeta converter with open loop is shown in figure5.AC input voltage is shown in figure6.Switching pulse and V_{ds} for MOSFET is shown in fig7.Output voltage, output current and output power are shown in fig 8,9&10 respectively Power factor for open loop Zeta converter is shown in fig11.Total Harmonic Distortion is shown in fig12.For conventional circuit THD value is very high.

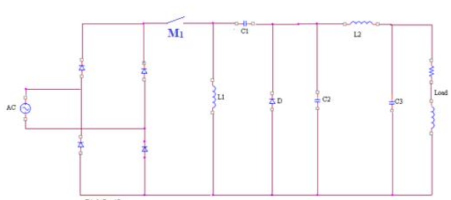

Fig5-Open Loop Zeta Converter

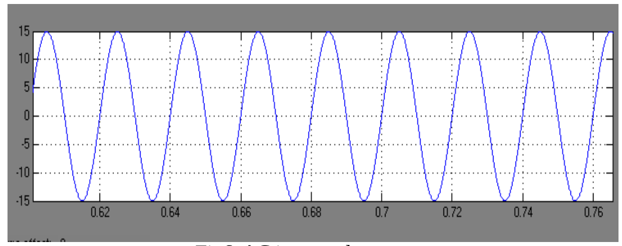

Fig6-AC input voltage

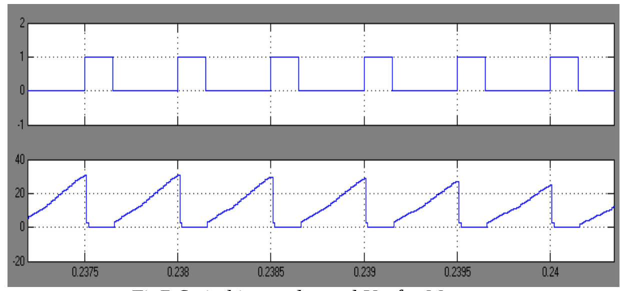

Fig7-Switching pulse and V_{ds} for M_1

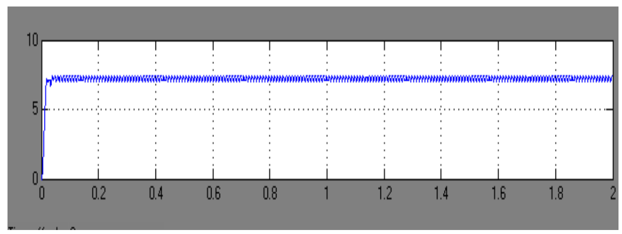

Fig8-Output Voltage

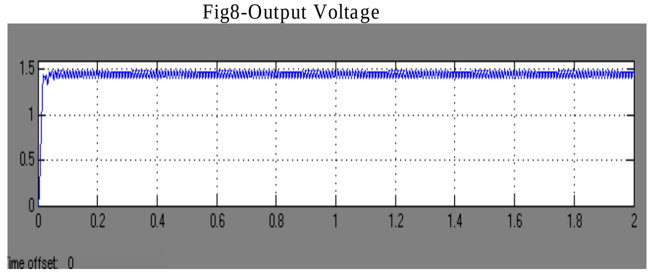

Fig9-Output Current

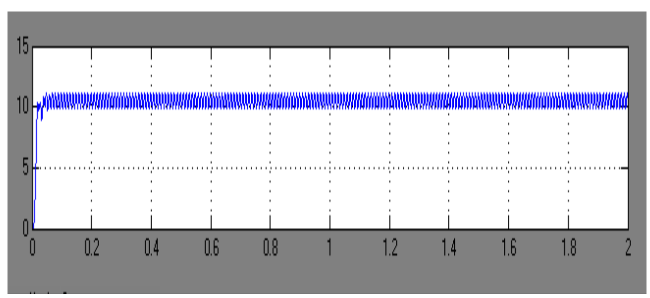

Fig10-Output Power

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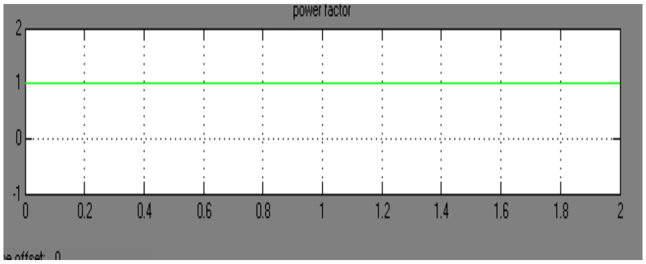

Fig11-Power Factor for conventional circuit

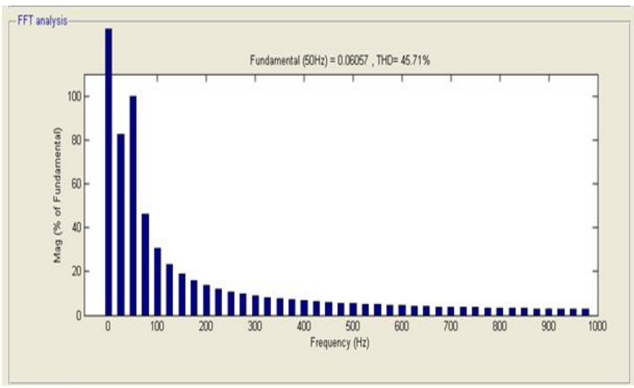

Fig12-FFT Analysis for open loop zeta converter

ii. Conventional Open Loop Zeta Converter with Disturbance in the Input Side

In the circuit of conventional open loop zeta converter, a step disturbance is given in the input side. Input voltage, output voltage, output current and output voltage of the circuit is shown in fig14, 15, 16&17 respectively. Total Harmonic Distortion is shown in fig18.

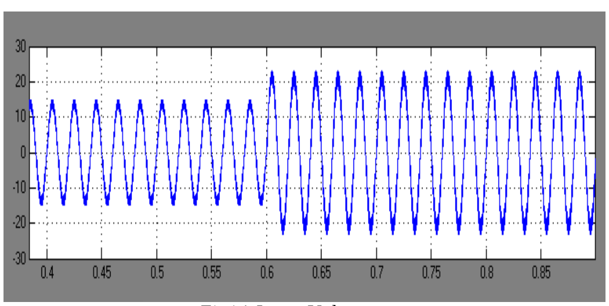

Fig14-Input Voltage

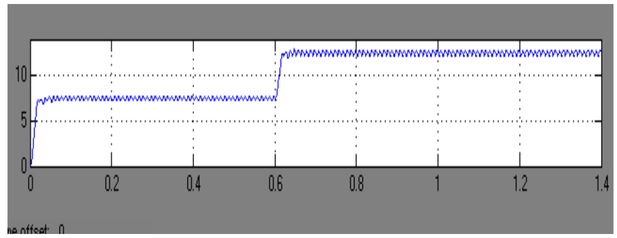

Fig15-Output Voltage

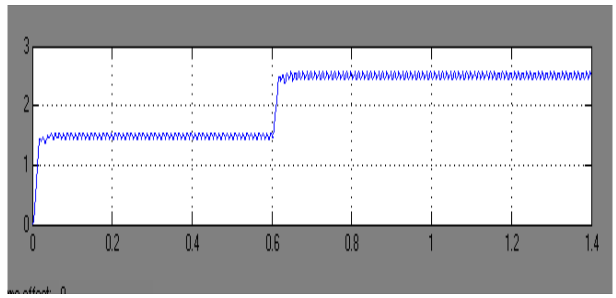

Fig16-Output Current

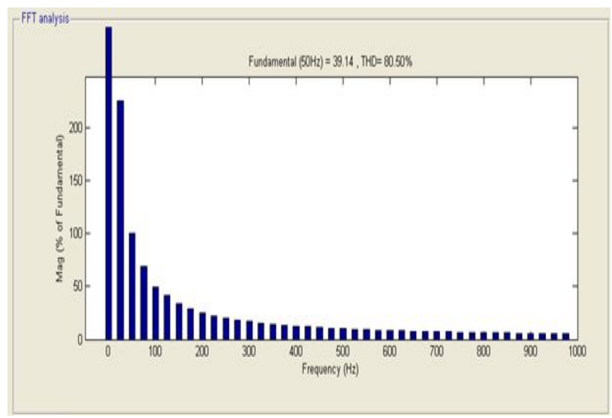

Fig17-FFT Analysis for open loop zeta converter with disturbance

iii. Proposed Closed Loop Zeta Converter with RL Load

Fig 18 shows the closed loop zeta converter for power factor correction with RL load. It uses a very simple control feedback, which only requires output voltage sensing.

A bridge rectifier is used at the input AC side with a power factor corrector using an inductor and capacitor combination. Now, a small value of output voltage, compared to the reference value and resulting value, passes through the proportional

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integral (PI) controller , which generates the PWM output and is used for switching the MOSFET(M_1).

It has inherent power factor correction characteristics with constant duty ratio and switching frequency, offering an attractive solution for lower power applications.

The output voltage regulation is provided by the feedback loop as shown in Fig19, where the output sensed voltage Vo is compared with a reference Vref value and the error is amplified in a proportional integral (PI) controller which is compared with a saw-tooth ramp Vs, thus providing the pulse to power switch. Therefore, this circuit is controlled by the difference in the on- time interval and the constant switching frequency fs.[2]

Input voltage, output voltage, and output current are shown in figure20,21&22 respectively. Power factor for closed loop zeta converter is shown in fig23.Total Harmonic Distortion is shown fig24.

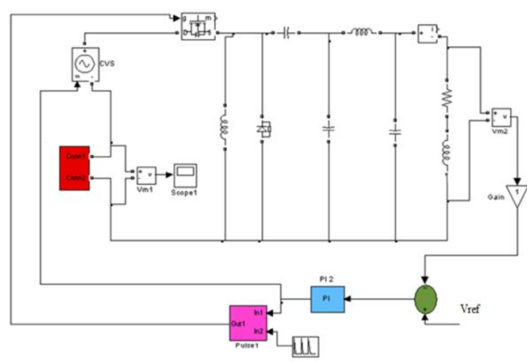

Fig18-Proposed Closed Loop Zeta Converter with RL Load

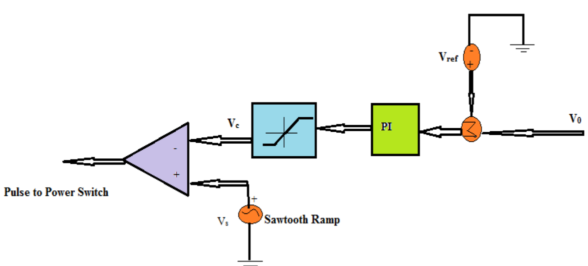

Fig19-Practical voltage follower approach for PWM control

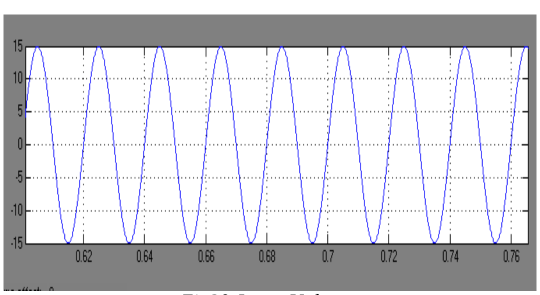

Fig20-Input Voltage

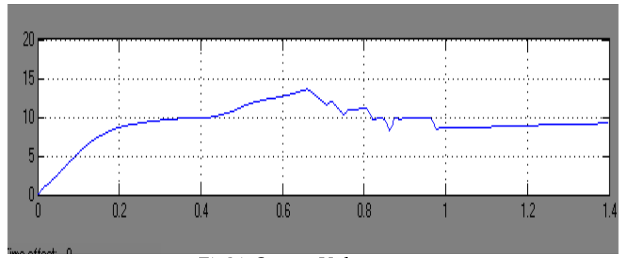

Fig21-Output Voltage

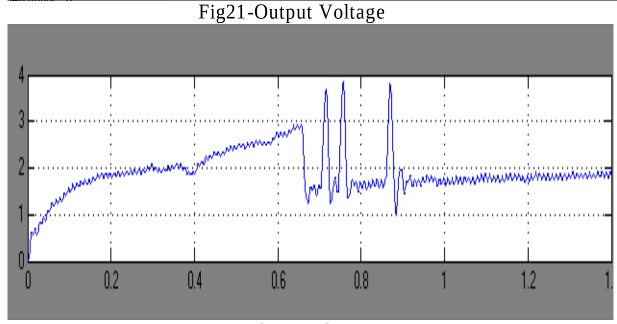

Fig22-Output Current

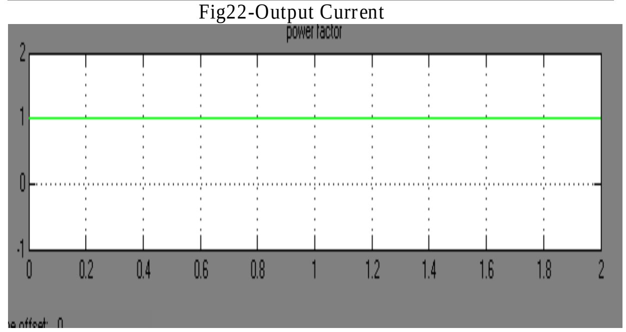

Fig22-Power Factor for proposed circuit

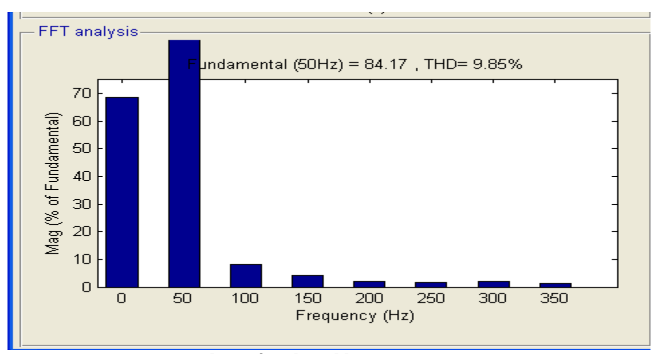

Fig23-FFT Analysis for closed loop zeta converter

iv. *Proposed Closed Loop Zeta Converter with Disturbance in the Input Side*

In the circuit of closed loop zeta converter,a step disturbance is given in the input side. Input voltage,output voltage and output current for the circuit is shown in fig24,25&26.Total Harmonic Distortion is shown in fig27.

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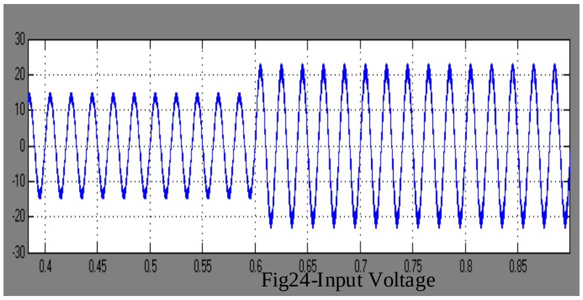
Fig24-Input Voltage

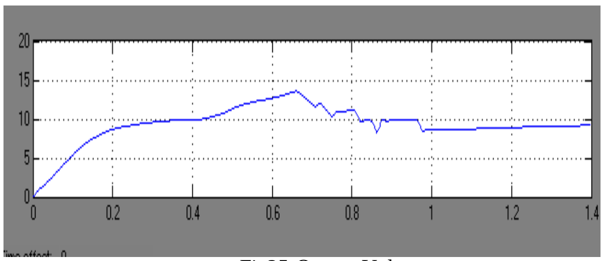
Fig25-Output Voltage

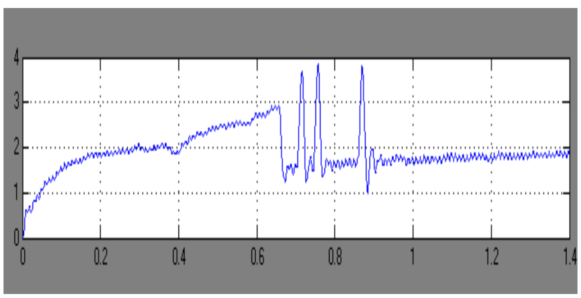
Fig26-Output Power

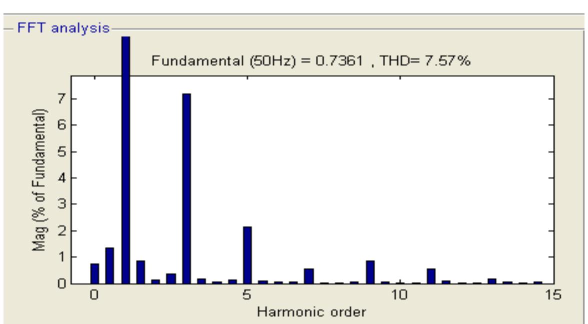

Fig27-FFT Analysis for closed loop zeta converter with disturbance

5.PERFORMANCE

EFFICIENCY- Open loop zeta converter

Input Voltage	Output Voltage	Output Power	Efficiency in %
12	6.5	8.59	91
13	7.1	10.28	92.3
14	7.78	12.1	92.6
15	8.5	14.08	93.1

EFFICIENCY-Closed loop zeta converter

Input Voltage	Output Voltage	Output Power	Efficiency in %
12	4.3	3.8	92
13	7.6	11.4	93.1
14	8.1	13.13	94
15	8.45	14.29	94.5

6.EXPERIMENTAL RESULTS


Fig28-Experimental setup

Experimental results are presented in this section to show the validity of the proposed method, and an experimental prototype of the pulse-width modulated zeta power factor correction converter has been constructed. The experimental setup with detailed specifications are shown in fig28.IR2110 is used as the driver circuit.PIC16F84A is used as the processor. A pi-filter is added to avoid control error caused by the switch noise.

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7.CONCLUSION

This paper explains the pulse width modulated Zeta converter. In this paper design and simulation of Zeta converter in open loop and closed loop are carried out for 8.5V, 14W output .Both the circuits are simulated with RL load. Pi filter is used to reduce the harmonics. The closed loop zeta converter has a good efficiency of 94.5% .The total harmonic distortion of the closed loop zeta converter is good. The power factor correction is very close to unity. The closed loop disturbance circuit has low THD value. It allows correction of power factor operating in continuous mode and therefore more adequate to the application in high power

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