Comparative study of Zeta converter based LED Driver

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Abstract*—*The simulation and analysis of Zeta converter based Light Emitting Diode (LED) driver in open loop and closed loop configuration has been considered in this paper. The Zeta converter maintains near unity power factor on LED load of 100 W. The zeta converter with reduced control circuitry is used in this work for obtaining the benefit of less cost and small size. Pulse width modulation technique is used for generating gating pulse for the converter to regulate the output voltage with improved power factor and reduced total harmonic distortion (THD).The open loop and closed loop operation of zeta converter based LED drive are compared based on the input power factor, current THD and efficiency.

Index Terms*—*Power factor, Light Emitting Diode (LED) driver, power quality, Pulse Width Modulation (PWM).

I. Introduction

The applications of LED lamps rapidly increasing in all the sectors, due to the fact that they are having high efficiency with less maintenance [1]-[3]. The LED lamps are vast developing and most efficient lighting technology widely used in automotive lighting, traffic lighting, street lighting, domestic lighting, stage lighting and many other applications [4]-[5]. The LED lamps require DC supply for operation; hence it requires power supply conversion from AC to DC. The power conversion affects the power factor and power quality [6]. The basic power converters such as Buck, Boost, Buck-Boost and CUK converters suffer from low power factor and less efficiency [7]-[9]. In order to improve the power factor and efficiency, several techniques are proposed based on different topologies, which increase the complexity and cost. In this paper, Zeta converter is used for improving the power factor and efficiency.

The Zeta converter is a fourth order DC to DC buck-boost converter [10]-[12]. The simple construction of converter consists of two inductors, two capacitors and a single switch in series with the input power supply [13]-[14]. The two operating modes of Zeta converter are step-up and step-down mode. Because of its simple construction, the converter has more advantages than other similar order converters like Cuk or SEPIC converters [15]. Therefore, this converter has more attention than SEPIC and Cuk converters. This converter has some special characteristics to make its application attractive, as described by Lopez and Peres [16]. The objective of this work includes simulating Light Emitting Diode (LED) driver with Zeta converter in open loop and closed loop configuration and comparing their performance based on power quality standards [18]-[19]. The PI controller and Fuzzy controller based power converters gives better performance without compromising THD and power factor [20]-[26]. The circuit diagram of Zeta converter based LED driver is shown in fig.1.

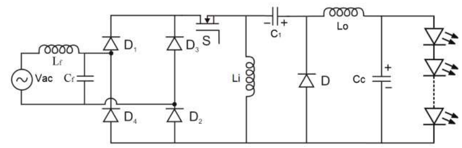

Fig. 1. Circuit diagram of Zeta converter based LED driver

II. PRINCIPLE OF OPERATION

The operating principle of the LED lamp load connected with ZETA converter is analyzed by considering the three stages of operation in Discontinuous conduction mode as shown in Fig.2 [27].

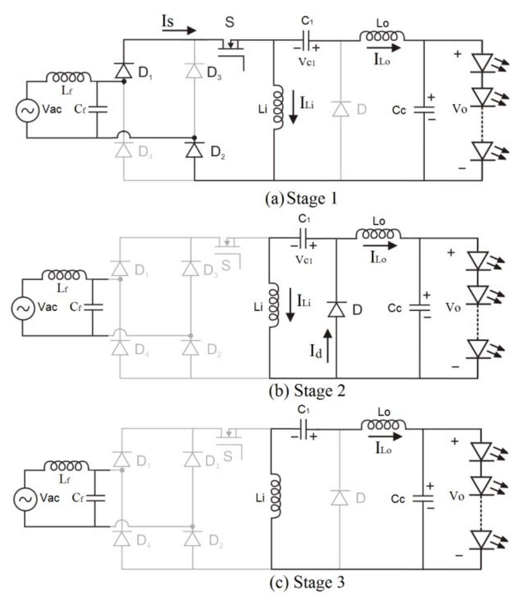

Fig. 2. Three stages of operation of Zeta converter

A. First stage ($t_0 \leq t \leq t_1$): The supply voltage V_{ac} is applied to the rectifier circuit and the DC output voltage from diode bridge rectifier is fed to the inductors L_i and L_o. The switch S is closed at time t_o and the currents I_{Li} and I_{Lo} increases linearly with respect to the supply. If L_{eq} is the equivalent parallel inductance of the inductors L_i and L_o, then the current in the switch S is directly proportional to V_{dc}/L_{eq} [28].

B. Second stage ($t_1 \leq t \leq t_2$): The inductor and capacitors are fully charged and reached the maximum voltage at time t_1. At this time, the switch S is turned off and the diode D starts to conduct. In this mode the energy stored in the inductors and capacitors is transferred to the coupling capacitor C_c. The current through the diode I_d is the sum of the currents I_{Li} and I_{Lo}, and is directly proportional to $-V_o/L_{eq}$ [29]. At the end of this stage the current through the diode until zero. Hence both inductor currents remain zero at the end of this stage and this mode ensures the DCM mode of operation.

C. Third stage ($t_2 \leq t \leq t_3$): The interpretation based on current I_d is that switch S and the diode are in open condition. The coupling capacitor current I_c and the output inductor current I_{Lo} are the same and they are in opposite direction to the magnetizing inductor current I_{Li}, resulting in zero voltage across the inductors [30]. The waveform of the zeta converter during the three modes of operation is shown in fig.3.

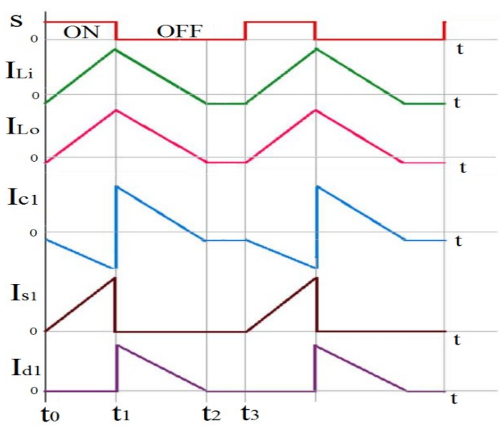

Fig. 3. Waveform of Zeta converter

III. MATLAB SIMULATION OF ZETA CONVERTER

The Matlab simulation has been carried out with open loop and closed loop configuration. The converter is designed for operating in the supply voltage range from 90 to 270 V. The load of the converter is made of series connected LEDs of 100W with the LED output voltage of $V_{dc} = 48V$ [31]. Various analyses have been carried out to ensure the performance analysis of Zeta converter The open loop analysis of the Zeta converter is shown in fig.4.

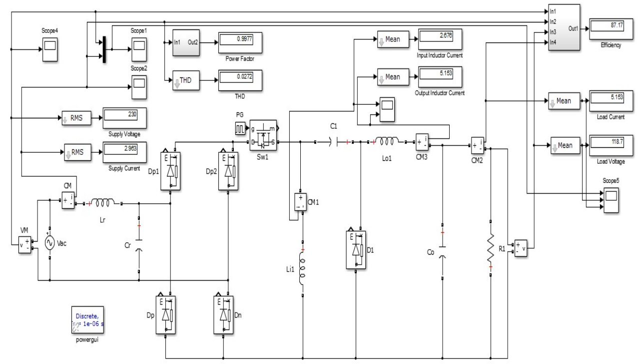
Fig. 4. Open loop configuration of Zeta converter

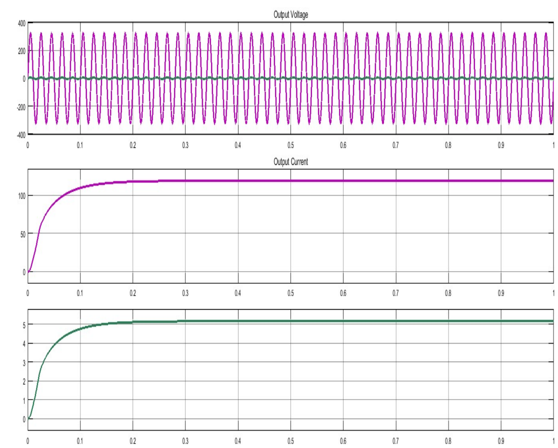

Fig. 5. Supply voltage and output voltage waveform

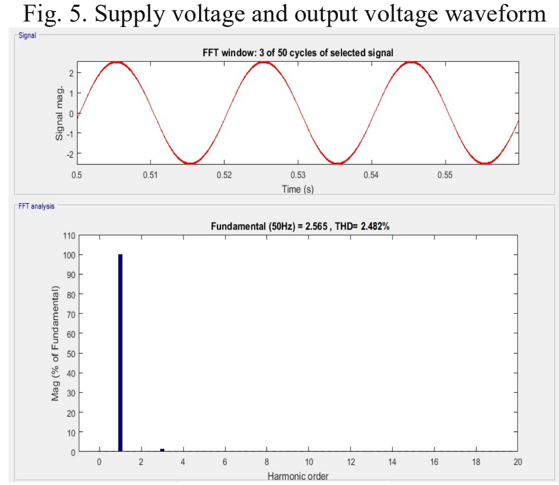

Fig. 6. FFT Analysis

TABLE 1. BASED ON VARIATION IN SUPPLY VOLTAGE

$R_L = 23.04\ \Omega$ $P_{out} = 100w$

S.No	V_{in} (V)	α	I_{in} (A)	V_0 (V)	I_0 (A)	THD %	PF	η (%)
1	90	0.12	1.25	48.1	2.08	2.48	0.9988	89.18
2	150	0.12	1.96	77.4	3.34	2.64	0.9979	88.54

3	230	0.12	3.06	118.7	5.15	2.73	0.9977	87.17
4	270	0.12	3.65	139.5	6.05	2.81	0.9959	86.21

TABLE 2. BASED ON VARIATION IN DUTY CYCLE

R_L = 23.04 Ω P_{out} = 100w

S.No	A	V_{in} (V)	I_{in} (A)	V_0 (V)	I_0 (A)	THD %	PF	η (%)
1	0.2	90	1.65	55.2	2.39	2.57	0.998	88.74
2	0.4	90	3.01	70.24	3.15	3.08	0.975	83.79
3	0.6	90	4.80	86.7	3.76	3.97	0.947	79.78
4	0.8	90	8.95	112.7	4.89	4.88	0.901	75.96

TABLE 3. BASED ON VARIATION IN DUTY CYCLE

R_L = 23.04 Ω P_{out} = 100w

S.No	A	V_{in} (V)	I_{in} (A)	V_0 (V)	I_0 (A)	THD %	PF	η (%)
1	0.2	230	3.92	135.1	5.87	2.77	0.998	88.12
2	0.4	230	6.81	171.9	7.46	2.98	0.989	82.78
3	0.6	230	12.56	223.2	9.69	3.61	0.948	78.93
4	0.8	230	19.39	265.0	11.51	4.36	0.912	75.01

Fig. 5 shows the waveforms of input supply and output voltage of Zeta converter in open loop configuration. The THD analysis has been done for the supply current with the input voltage of 90V AC with 100W LED lamp load. The input filter plays a vital role to eliminate the current THD [32]. The FFT analysis in fig.6 shows the THD values of 2.482% at the supply voltage of 90V with 100W load. Based on the variation in the supply voltage and duty cycle, various analyses has been carried out and tabulated in table 1, 2 &3. The lowest value of THD 2.482% is achieved with the supply voltage of 90V with the maximum efficiency of 89.18%. The performance analysis based on the variation in the duty cycle shows that the THD increases when the duty cycle increases and the efficiency decreases when the duty cycle increases. Hence the zeta converter improves the power quality. Fig 7 & 8 shows the efficiency chart based on duty cycle and supply voltage variation. It shows that there is a decrease in efficiency when the duty cycle increases.

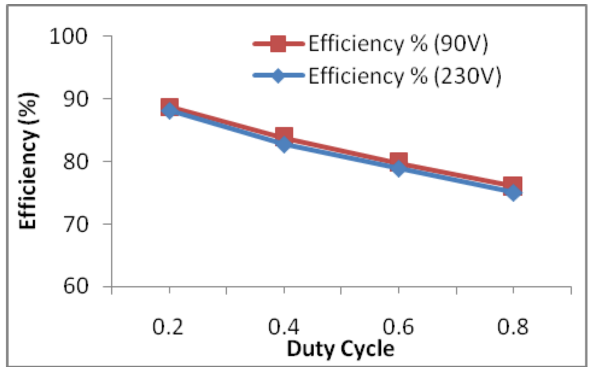

Fig. 7. Efficiency chart based on duty cycle variation

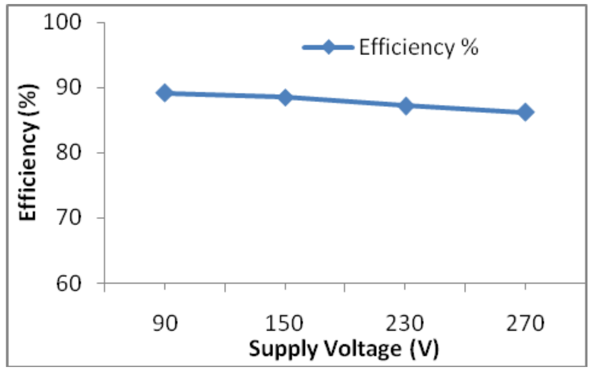

Fig. 8. Efficiency chart based on supply voltage variation

IV. CLOSED LOOP SIMULATION OF ZETA CONVERTER

Fig. 9 shows the simulation of the closed loop operation of Zeta converter. The PI controller is used in the feedback loop to control the gate pulses, which are given to the switches in the converter. The DC output voltage of 48V is maintained constant for the input supply voltage ranging from 90V to 270V AC with the help of the PI controller [32]. In order to get the accurate response, the PI controller is tuned properly with the help of Ziegler Nichols method.

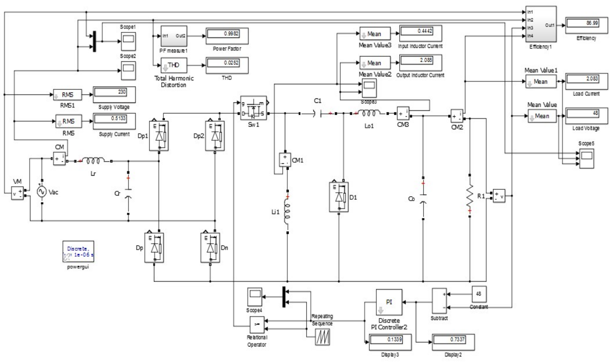

Fig. 9. Closed loop configuration of Zeta converter

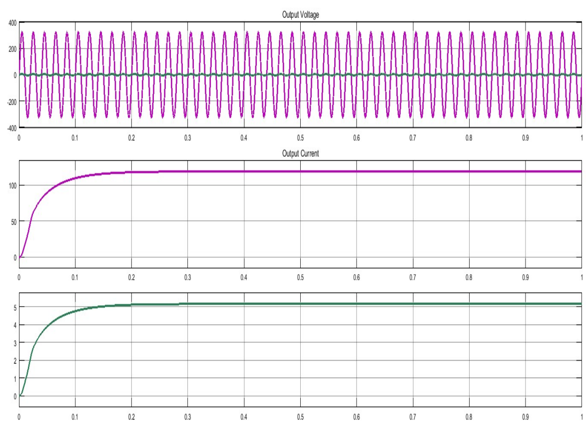

Fig. 10. Supply and output voltage waveform

TABLE 4. BASED ON VARIATION IN SUPPLY VOLTAGE

S.No	V_{in} (V)	I_{in} (A)	V_0 (V)	I_0 (A)	THD %	PF	η (%)
1	90	1.25	48	2.08	2.37	0.998	89.27
2	110	1.02	48	2.08	2.32	0.997	89.13
3	130	0.88	48	2.08	2.31	0.995	88.32
4	150	0.76	48	2.08	2.29	0.994	87.96
5	170	0.68	48	2.08	2.45	0.994	87.32
6	190	0.61	48	2.08	2.34	0.993	87.19
7	210	0.55	48	2.08	2.29	0.995	87.03
8	230	0.50	48	2.08	2.25	0.998	86.99
9	250	0.47	48	2.08	2.33	0.996	85.61
10	270	0.44	48	2.08	2.33	0.994	85.06

TABLE 5. BASED ON VARIATION IN OUTPUT POWER

S.No	Po (W)	V_{in} (V)	I_{in} (A)	V_0 (V)	I_0 (A)	THD %	PF	η (%)
1	100	90	1.25	48	2.08	2.37	0.9984	89.27
2	75	90	0.96	48	1.56	2.85	0.9912	87.65
3	50	90	0.67	48	1.04	3.21	0.9824	84.91
4	25	90	0.36	48	0.52	3.74	0.9729	78.36

Fig.10 shows the waveforms of input supply and output voltage of closed loop configuration of Zeta converter based on PI controller. The performance analysis has been carried out based on the output voltage variation and output power variation with the supply voltage of 90V and 230V. The observed values are tabulated in tables 4, 5 & 6. The maximum efficiency of 89.27% and the current THD of 2.371% have been achieved with the supply voltage of 90V at full load. Fig 11 & 12 shows the efficiency chart based on the output voltage and output power variation. The efficiency curve shows that the efficiency decreases while the output power decreases. The FFT analysis has been carried out for the supply voltage of 230V, the measured current THD is 2.251% as shown in fig.13.

TABLE 6. BASED ON VARIATION IN OUTPUT POWER

S.No	Po (W)	V_{in} (V)	I_{in} (A)	V_0 (V)	I_0 (A)	THD %	PF	η (%)
1	100	230	0.50	48	2.08	2.25	0.9981	86.99
2	75	230	0.39	48	1.56	2.55	0.9922	85.42
3	50	230	0.27	48	1.05	3.19	0.9875	81.64
4	25	230	0.14	48	0.52	3.67	0.9751	77.68

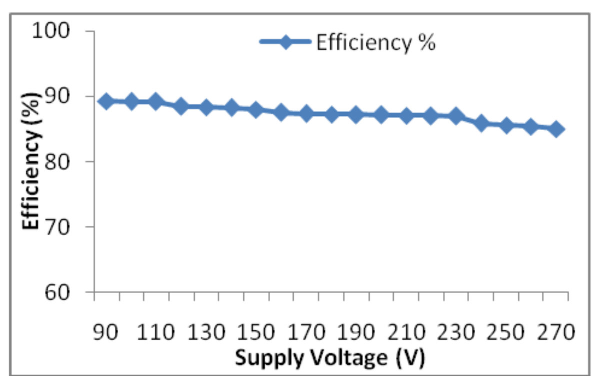

Fig. 11. Efficiency chart based on supply voltage variation

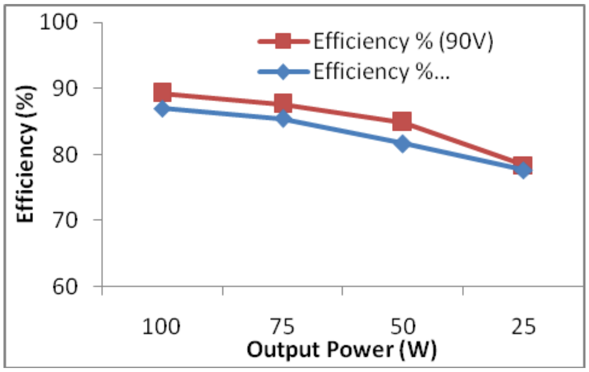

Fig. 12. Efficiency chart based on output power variation

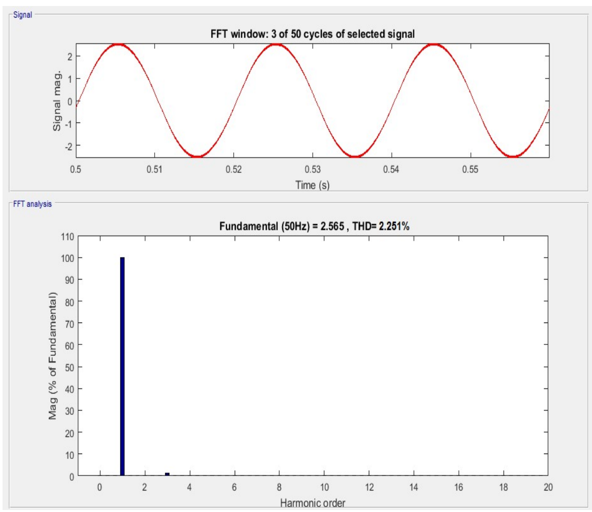

Fig. 13. FFT Analysis

V. IMPLEMENTATION OF FUZZY BASED ZETA CONVERTER

The Fuzzy controller based zeta converter has been designed and implemented to drive the LED lamps. The simulation configuration of Zeta converter is shown in fig.14. Fuzzy controllers are rigid and reliable and used to achieve faster settling time.

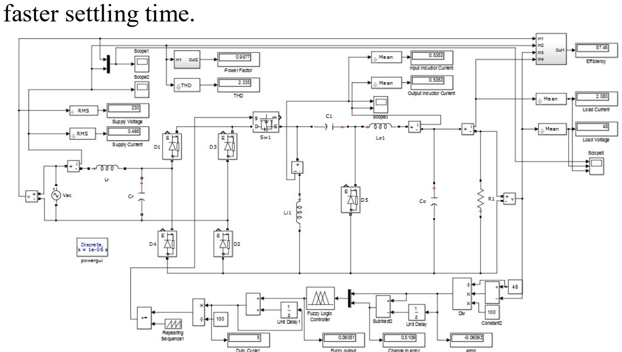

Fig. 14. Closed loop configuration of Zeta converter

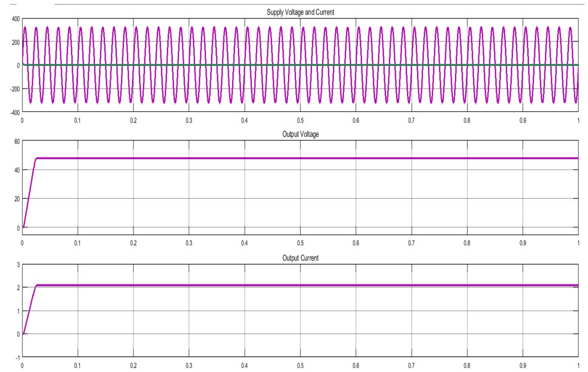

Fig.15. Supply and output voltage waveform

Fig.15 shows the waveforms of input supply and output voltage of closed loop configuration of Zeta converter based on Fuzzy logic controller. The output voltage reached the set point of 48V within 0.04s. Based on the supply voltage variation the analysis has been carried out and the values are tabulated in table 7. The maximum efficiency of 89.87% and the current THD of 2.24% have been achieved with the supply voltage of 90V at full load. Fig. 16 shows the efficiency curve during the supply voltage variation.

TABLE 7. BASED ON VARIATION IN SUPPLY VOLTAGE

S.No	V_{in} (V)	I_{in} (A)	V_0 (V)	I_0 (A)	THD %	PF	η (%)
1	90	1.24	48	2.08	2.24	0.9991	89.87
2	110	1.02	48	2.08	2.26	0.9981	89.62
3	130	0.87	48	2.08	2.28	0.9964	88.35
4	150	0.76	48	2.08	2.29	0.9957	88.09
5	170	0.67	48	2.08	2.29	0.9949	87.92
6	190	0.60	48	2.08	2.30	0.9945	87.63
7	210	0.55	48	2.08	2.36	0.9953	87.54
8	230	0.50	48	2.08	2.34	0.9977	87.46
9	250	0.46	48	2.08	2.30	0.9964	87.11
10	270	0.43	48	2.08	2.26	0.9952	86.95

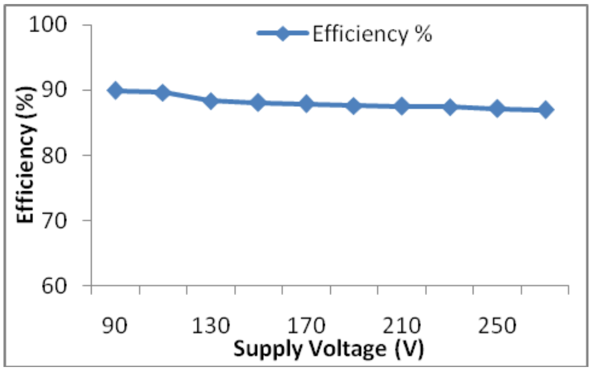

Fig.16. Efficiency curve

VI. CONCLUSION

The Zeta converter based LED driver has been simulated in this paper for LED lighting applications. The LED driver has utilized a Zeta based buck-boost converter for PFC in universal input supply range. This PFC converter has been used for providing the constant DC voltage requirement of LED lamps. PWM control technique has been used to produce the gate pulses for the voltage regulation on LED lamps. The performance characteristics have been evaluated with the LED driver with wide range of power supply. It has been observed that the obtained value of current harmonics in the input side of the converter lie within allowable range for entire universal line voltage as per IEC norms. The closed loop operation of the Zeta converter is analyzed with PI controller and Fuzzy Logic controller. From the analysis, it has been inferred that Zeta converter operated by Fuzzy Logic Controller gives better performance than converter operated by PI controller.

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