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Analysis of Parallel Connected Non-Isolated Zeta Converter for Solar Powered Applications

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Abstract— *High efficient parallel connected DC-DC Zeta converter with interleaved control scheme operated under Discontinues conduction mode (DCM) is presented. DCM operation offers ripple free current, compact and cost effective system. Due to these key attributes, parallel connected Zeta converter can be employed in renewable energy application like solar and wind power plants. The converter is designed to deliver 100 W output power with rated output voltage of 48 V. Simulation of the system is carried out in Matlab/Simulink platform. The performance measures of the converter are analyzed during steady state and dynamic operating conditions.*

Keywords—*Primary-side regulation (PSR), Pulse width modulation (PWM), Discontinuous conduction mode (DCM), Continuous conduction mode (CCM).*

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I. INTRODUCTION

Traditionally, Buck, Boost and Buck-Boost converters are used to convert fixed DC to variable DC supply because of its less cost and simple construction. But, these conventionalconverters causehigh ripples, low efficiency, pulsating current in input& output side. In order to resolve these problems, many DC- DC converters with different topology have been proposed to obtain high efficiency and less ripples. Based on the different type of applications, these DC-DC converters can be used as Buck , Boost , and Buck-Boost [1-3] conversions. Since these converters are operated in continuous conduction mode (CCM)[4], it increases the complexity of controlcircuit and also the cost is high. In order to improve the drawback, some converters have been operated in discontinuous conduction mode (DCM) [5]. However, in order to avoid the component stress in the active switches, these converters can be used for low power applications. The Buck converters with DCM mode of operation are normally used for step-down voltage conversion, but results in low efficiencyand high ripples. The conventional buck-boost converter with DCM mode operation is generally employed for step-up or step-down voltage conversion. However, it is not suitable for the low input line voltage (12 V) and wide power ranges in output for renewable applications [6].

This paper presents an interleaved DC-DC step –up or step- down Zeta converter. This converter can be operated in wide range of duty-ratio and output power range than the conventional buck-boost converter. The interleaved Zeta converter features includehigh efficiency, low current ripples in input & output side, and adjustable step-up & step-down output voltage and wide range of output power. Fig. 1 shows the circuit configuration of the conventional Zeta converter [7], from this the Interleaved Zeta converter developed by connecting two identical Zeta converters in parallel.Except the Zeta converter, all other converters are widely used and studied fordifferent types of loads with different modes of operation such as continuous conduction mode (CCM), discontinuous conduction mode (DCM) and boundary conduction mode (BCM).

The buck converter is essentially the cheapest and simple converter among the conventional converters. But the Buck converter is always used when the output dc voltage is much lower than the input voltage [8]. Even during different modes of operation, it creates higher distortions in the mains& output current. Hence, the buck converter is not a very good choice for such kind of applications. On the other hand, the boost converter presents better performance with improvedefficiency and also this has been widely used inindustries [9]. Generally, this converter has been employed where the output voltage requirement is higher than the supply voltage for an efficient operation. Light emitting Diode (LED) lamps are generally low-voltage devices [10]. In order to operate the LEDs for higher-voltage, multiple numbers of LEDs are neededto be connected in series, which leads to be a large load and increased the cost. Hence this converter is not suitable for low power applications.

The limitations of buck and boost converters can be easily overcome by using a buck–boost converter [11]. This converter has a capability to work both in step-up and step-down modes and is able to give high efficiency over the wide input voltage.This is the only converter have the capabilityto satisfy the power supplies which required wide input voltage of specifications. However, this converter is different from the Zeta converter [12]. The buck–boost converter provides the inverting output voltage whereas the Zeta converter provides non-inverting output voltage. The SEPIC [13], Cuk [14]and LUO converters are developed from the boost converter [15] but the Zeta converter is developed from a buck–boost converter.

II. CONVENTIONAL ZETA CONVERTER

Conventionally the single-stage dc–dc power converters have been widely used forvoltage regulation ofLED lamps. Among the different dc–dc converters buck, boost Buck–boost, Cuk, single-ended primary inductor converter (SEPIC), Zeta converter and LUO converter [16-25] are widely used in industries. Except the Zeta converter, all other converters are widely used & studied with different operating modesincluding discontinuous conduction mode (DCM), continuous conduction mode (CCM), and boundary conduction mode (BCM). The research based on Zeta converter for lighting applications has not beenunexplored since long ago. This paper presents an attractive application of the Interleaved Zeta converter compared with conventional zeta converter with high efficiency for the renewable energy applications. Also the Fuzzy [26-28] based Zeta converters are used to achieve the faster settling time than PI controllers [29]. The preference of the Zeta converter has also been emerged to overcome the limitationsfrom other converters.

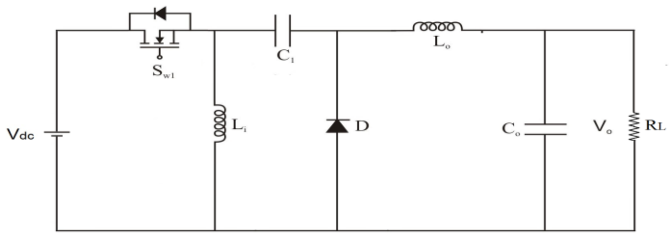

Fig. 1.Circuit diagram of conventinal Zeta converter

Fig.1 shows the circuit diagram of conventional Zeta converter [30]. The Zeta converter has been designed to achieve discontinuous input current compared with SEPIC and Cuk converters. Also it has less ripple contents at the output current compared with SEPIC converter. This reduced ripple in the output current is recommended to power up the sensitive loads such as LED lamps. Some loads are extremely sensitive for the minor variations in voltage. To overcome the discontinuous current at the input and output side, SEPIC converter needs large DC link capacitor at the output. This incurred more cost compared with the Zeta converter in order to achieve less ripple contents to sensitive LED lampsfor the photovoltaic applications. The proposed non-isolated interleaved Zetaconverterefficiently used to drive LED lamps. Although the interleaved Zeta converter has been developed from the conventional Zeta converter, the primary-side regulation (PSR) technique has been employed to improve the performance and efficiency while using for LED lighting applications.

III. INTERLEAVED ZETA CONVERTER

The Buck and Boostconverters with DCM mode of operation were presented inmany papers for step-down or step-up the DC voltage with highefficiency. The conventional buck-boost converter with DCM mode of operation is generally used for step-up or step-down voltage conversion,but the efficiency isless and input current is discontinuous. The DCM mode of operation have a advanatges includes less size of the inductor, and the weight of total circuit. However, it is not suitable for wide range of supply voltage and output power. This paper presents an

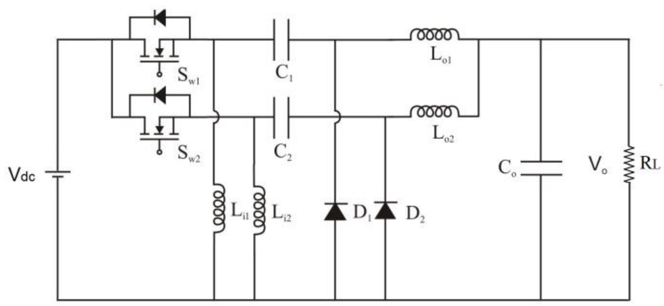

Fig. 2.Circuit diagram of parallel connected Zeta converter

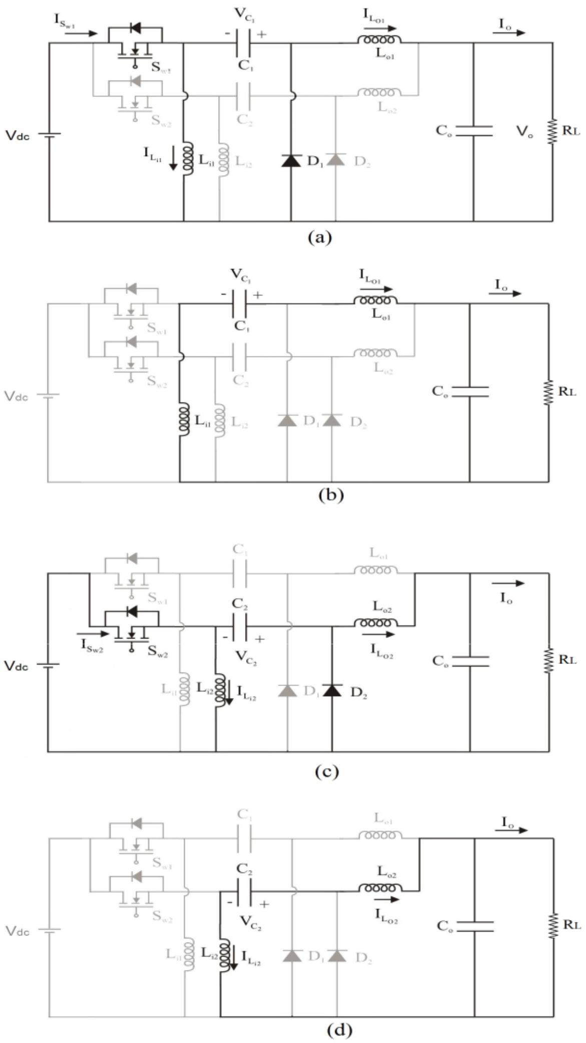

Fig. 3.Different Modes of Operation (a) Mode1 (b) Mode2 (c) Mode3 (d) Mode4

single-phase single stage DC-DC step-up or step-down Interleaved Zeta converter. This converter can be operated in wide range of duty-cycle than the conventional buck-boost converter. The proposed converter features low current ripples, high efficiency, and adjustable step-up/down output voltage for wide range of supply voltage and output-power. The DC link capacitor C_0helps toreduce the current ripple in the Interleaved Zeta converter. The large input inductor provides the continuous input current which helps to reduce electromagnetic interference (EMI) and the filter components design. Fig. 2 shows the circuit configuration of the Interleaved Zeta converter, including two identical Zeta converters in parallel connection.

IV. MODES OF OPERATION

Assumption made to simplify the analysis, the components used in the circuit are ideal. The inductors L_{i1} andL_{o1} are operated in CCM. Theinductors L_{o1} and$L_{o2}$are operated in DCM. Fig. 3 illustrated four modes of operation for different switching period for one complete cycle.

Mode 1 [$t_0 \leq t \leq t_1$]:

During Mode 1, $S_1$is turned on, $S_2$is off. The inductor L_{i1}starts charging from the supply voltage V_{dc}. The inductor L_{o1} is discharging the stored energy to the output capacitorC_o. The inductor L_{o1} and C_o are resonating. The energy stored in the output inductor L_{o1}& the output capacitorC_o is releasing energy to load through capacitor.

Mode 2 [$t_1 \leq t \leq t_2$]:

$S_1$and S_2 both are turned off. The inductor $L_{o1}$is dissipating energy to the output capacitor C_o and the load. End of this mode the inductors $L_{i1,}$ L_{o1} completely discharged and there is minimum current circulating through the output capacitor and the output load.

Mode 3 [$t_2 \leq t \leq t_3$]:

In Mode 3 the switch $S_2$is turned on and switch $S_1$is turned off. The inductor $L_{i2,}$ $L_{o2}$is charging and storing energyfrom V_{in}. Once reached the maximum value, the inductor L_{o2} is releasing energy to $C_{o.}$ The inductor L_{o2} and C_o are resonating and also at the same time the inductor L_{o2} is releasing energy through the output capacitorC_o to the load.

Mode 4 [$t_3 \leq t \leq t_4$]:

Switches $S_1$and S_2 both are turned off. The inductor $L_{o2}$is releasing energy to $C_o$and *the* load. The inductor L_{o1} current circulating though the diode D2.

V. PULSE WIDTH MODULATION SCHEME

Since the DC bus voltage needs to be maintains constant,the MOSFET switches has to be controlled to vary the magnitude DC input voltage. This is normally accomplished by PWM that control the converter. Fig. 4 shows the generation of PWM pulses, among that the square PWM technique is popular in industrial applications. There are two major concerns need to considered while generating square PWM. The first is to minimize generation ofdistortion and ripples in the output voltage and current. The general principle of square PWM is the comparison of two voltage waveforms, one is a high frequency triangular wave, which is also called as the carrier signal and another one is control signal. The triangular carrierwaveform has fixed amplitude. In a square PWM waveform the current distortion is still very significant. If square PWM is implemented in a converter with a large number of pulses per half cycle, such as motor speed control, no separate filter may be needed on the output side.Square PWM offers greater functionality includes minimization of output voltage & current ripples, improve the functional capabilities of the converter, and reductions in size and price. FPGA controller is widely used to generate high frequency pulses for hardware implementation [31-32].

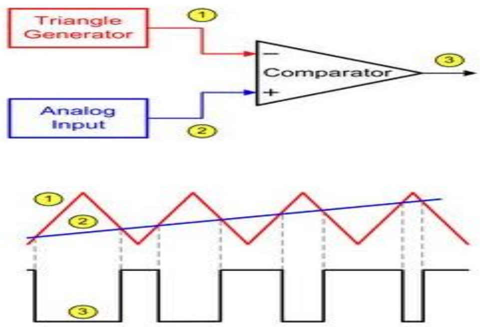

Fig. 4.Generation of PWM pulses

VI. SIMULATION RESULTS

The interleaved Zeta converter helps to improve the efficiency and reduce ripples in the output voltage. In practical conventional Zeta converter circuit, the ripple current is high in the load side. Because of this problem more complicated switching topology ad current controlled configurations are produced. Waveform analysis for Interleaved Zeta converters has been done.In conventional and proposed circuits are simulated and compared.

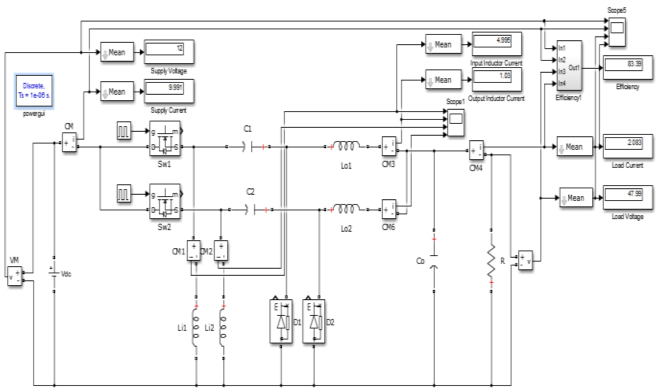

Fig. 5.Open loop simulation of parallel connected Zeta converter

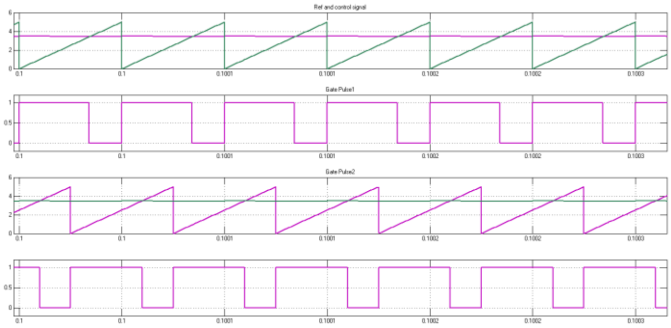

Fig. 6.Switching pulses for S_1& S_2

Fig. 7.

Fig.5 shows the simulation diagram of open loop simulation of Interleaved Zeta converter. Fig.6 shows the switching pulses generated for the switches S_1 and S_2 for open loop simulation with the help of the triangular signal generator.The inductor current wave forms have captured for the further analysis as per the fig. 7. This picture shows that the output inductor currents are in discontinuous current mode and the input inductor is in the continuous current mode. Fig.8 shows the output voltage and current waveforms of interleaved Zeta converter for the desired output voltage of 48V DC. Further analysis have been done to analyse the performance of the parallel connected Zeta converter.

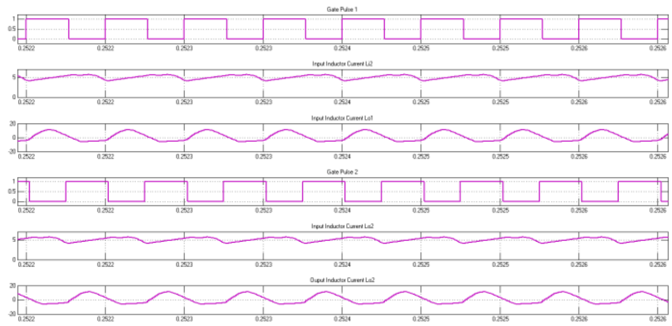

Fig. 8.Input and Output Inductor current waveforms

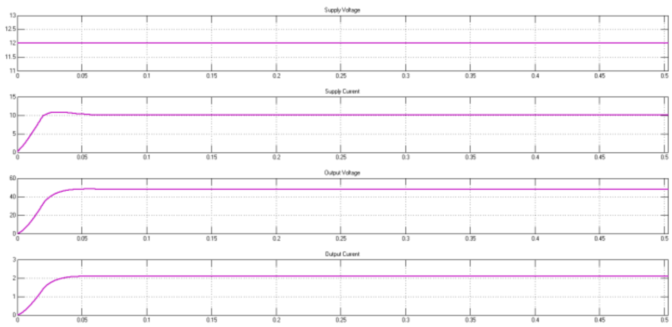

Fig. 9.Output voltage and Current

Further analysis have been done to make sure the better performance of the Interleaved Zeta converter and the values are tabulated. Table 1 shows the open loop readings with the supply voltage variation. It gives the maximum efficiency of 88.35% at the supply voltage of 48V. Table 2 shows the open loop readings with the duty cycle variation. The desired voltage achieved when the duty cycle is 0.81.The output voltage could not be maintain constant in the open loop simulation. Hence the closed loop simulation is very important.

TABLE 1. OPENLOOP READINGS WITH SUPPLY VOLTAGE VARIATION

S.No	Vin (V)	Iin (A)	ILi1 (A)	ILo1 (A)	Vo (V)	Io (A)	η %
1	8	6.87	0.53	0.56	33.0	1.43	86.07
2	12	9.64	0.96	0.99	48.0	2.08	86.43
3	16	13.89	1.07	1.12	66.7	2.90	86.97

4	20	17.40	1.34	1.45	83.6	3.63	87.16
5	24	17.95	1.60	1.71	87.3	4.36	88.35

TABLE 2. OPENLOOP READINGS WITH DUTY CYCLE VARIATION

S.No	D	Vin (V)	Iin (A)	ILi1 (A)	ILo1 (A)	Vo (V)	Io (A)	η %
1	0.1	12	0.03	0.01	0.05	2.1	0.09	56.83
2	0.2	12	0.10	0.05	0.10	4.5	0.20	73.51
3	0.3	12	0.22	0.11	0.15	7.0	0.30	80.14
4	0.4	12	0.39	0.19	0.21	9.5	0.41	83.59
5	0.5	12	0.62	0.31	0.26	12.0	0.52	85.03
6	0.6	12	1.22	0.61	0.98	17.3	0.75	88.70
7	0.7	12	3.00	1.50	1.63	27.5	1.19	91.22
8	0.8	12	7.60	4.30	3.95	48.0	1.73	91.16
9	0.9	12	9.24	9.58	9.64	48.0	2.08	90.17

In order to achive the desired output voltage the closed loop simulation has been done as shown in fig.9 for the Interleaved Zeta converter to ensure to achieve the desired output voltage. PI controller has been used to accomplish the closed loop simulation of the Interleaved Zeta converter. Fig.10 shows the switching waveforms and the inductor waveforms. The input inductor waveform is continuous and the output inductor waveform is discontinuous conduction mode.

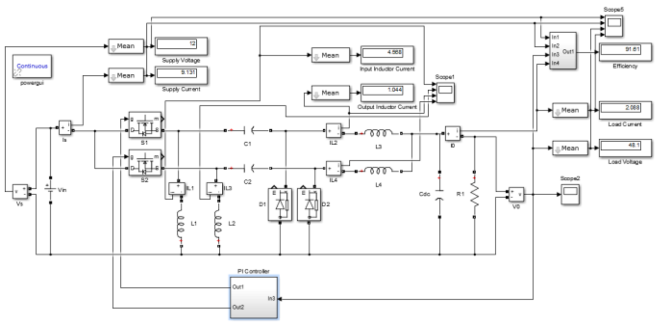

Fig. 10.Closed loop simulation of parallel connected Zeta converter

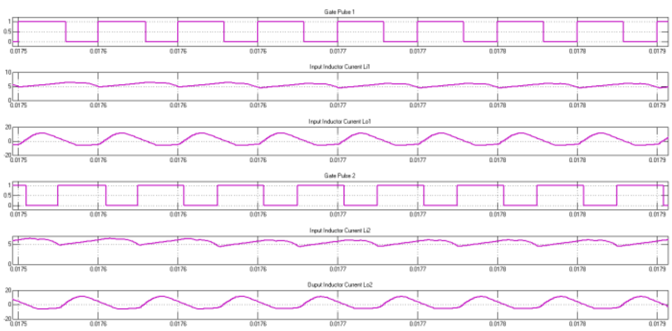

Fig. 11. Switching and Inductor waveforms of Interleaved Zeta converter

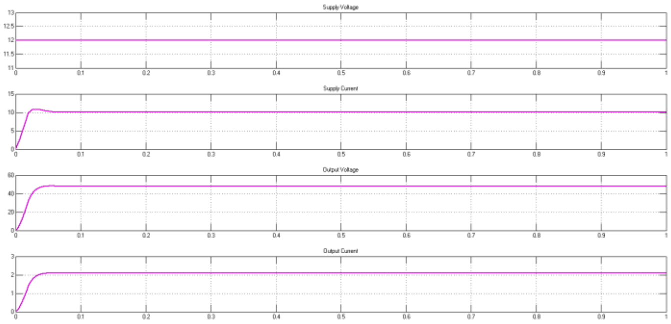

Fig. 12. Supply voltage, output voltage and output current waveforms

Fig.11 shows the supply voltage, output voltage and output current waveforms of the parallel connected Zeta converter.Table 3 shows the closed loop readings with supply voltage variation. The maximum efficiency is 91.41% at the supply voltage of 12V DC. Table 4 shows the closed loop readings with the load variation. The efficiencyc at full load is 91.41%. Table 5 shows the setpoint variation.

TABLE 3. CLOSEDLOOP READINGS WITH SUPPLY VOLTAGE VARIATION

S.No	Vin (V)	Iin (A)	ILi1 (A)	ILo1 (A)	Vo (V)	Io (A)	η %
1	8	13.70	7.25	1.04	48	2.083	91.23
2	12	9.12	4.56	1.04	48	2.083	91.41
3	16	6.90	3.42	1.07	48	2.083	90.57
4	20	5.50	2.60	1.01	48	2.083	90.89
5	24	4.60	1.92	0.88	48	2.083	90.57

TABLE 4. CLOSEDLOOP READINGS WITH LOAD VARIATION

S. No	Load (W)	Vin (V)	Iin (A)	ILi1 (A)	ILo1 (A)	Vo (V)	Io (A)	η %
1	100	12	9.12	4.56	1.04	48	2.083	91.41
2	75	12	6.85	3.388	0.7773	48	1.562	91.21
3	50	12	4.61	2.262	0.5223	48	1.041	90.29
4	25	12	2.29	1.172	0.2597	48	0.521	90.91

TABLE 5. CLOSEDLOOP READINGS WITH SET POINT VARIATION

S. No	Set point	Vin (V)	Iin (A)	ILi1 (A)	ILo1 (A)	Vo (V)	Io (A)	η %
1	30	12	3.515	1.761	0.6494	30	1.299	92.39
2	40	12	6.277	3.141	0.8677	40	1.735	92.14
3	48	12	9.115	4.564	1.043	48	2.083	91.41
4	60	12	14.325	7.319	1.332	60	2.602	90.82

VII. CONCLUSION

The Interleaved dc-dc Zeta converter has been designed and analyzedin order to achieve high efficiency with a low current ripple. This new parallel connected topology concentrates on the improvement from the drawbacks of the conventional Zeta converter. The interleaved zeta converter has beensimulated and analyzed with the wide range of duty cycle, supply voltage and output power variation whichprovides significant performance to drive the LED lamps. The isolated single stage Interleaved Zeta Converter is simulated in a MATLAB and various analyses has been done based on steady state and the dynamic performance, through this the converter performance has been evaluated and the performance indices has been obtained. The advantages of this design achieves the highest efficiency of about 94.98% during the operation across an extensive range of input and output voltages.

REFERENCES

[1]. Mesquine, Fouad, and Hamza Khallouk. "Robust control of a DC-DC buck converter." In Sciences and Techniques of Automatic Control and Computer Engineering (STA), 2017 18th International Conference on, pp. 432-437. IEEE, 2017.

[2]. S. T. Siddharthan, J. Gnanavadivel and S. T. J. Christa, "Design and Analysis of Interleaved buck-boost Converter for household appliances," 2020 4th International Conference on Trends in Electronics and Informatics (ICOEI)(48184), 2020, pp. 181-186

[3]. Shobana, P., N. Geetha, and Gnanavadivel J. "Enhancement of power quality of AC-DC Boost converter with HCC and FLC-A comparative study." In Computing, Electronics and Electrical Technologies (ICCEET), 2012 International Conference on, pp. 254-258. IEEE, 2012.

[4]. Lin, B.R., Hsieh, F.Y.: Soft-switching Zeta-flyback converter with a buck-boost type of active clamp. IEEE Trans. Ind. Electron. 54(5), 2813–2822 (2007)

[5]. Chiang, Chu-Yi, and Chern-Lin Chen. "Zero-voltage-switching control for a PWM buck converter under DCM/CCM boundary." IEEE Transactions on Power Electronics 24, no. 9 (2009): 2120-2126.

[6]. Leung, Kelvin Ka-Sing, and Henry Shu-hung Chung. "A comparative study of boundary control with first-and second-order switching surfaces for buck converters operating in DCM." IEEE Transactions on Power Electronics 22, no. 4 (2007): 1196-1209.

[7]. X. Xie, Z. Zhou, J. M. Zhang, Z. Qian, and F. Z. Peng, "Analysis and design of fully DCM clamped-current boost power-factor corrector with universal-inputvoltage range," in Proc. IEEE PESC, pp. 1115-1119, 2002.

[8]. Ramaprabha N, Gnanavadivel J, Senthil Kumar N, and ST Jaya Christa. "Power quality improvement in single phase AC to DC zeta converter." In Sustainable Energy and Intelligent Systems (SEISCON 2013), IET Chennai Fourth International Conference on, pp. 533-537. IET, 2013.

[9]. M. Shunmathi, J. Gnanavadivel and S. T. Jaya Christa, "Power Factor Correction With Single Stage AC-DC Non-Isolated Zeta Converter Fed SRM Drive," 2021 7th International Conference on Electrical Energy Systems (ICEES), 2021, pp. 95-100

[10]. Bhavsar, Mithun M., and A. P. Paranjape. "Digital synthetic ripple modulation technique for DC-DC converter by using FPGA controller: Modulation technique for synchronus buck converter by using FPGA controller." In Communication and Electronics Systems (ICCES), 2017 2nd International Conference on, pp. 1003-1009. IEEE, 2017.

[11]. Maroti, Pandav Kiran, Sanjeevikumar Padmanaban, Patrick Wheeler, Frede Blaabjerg, and Marco Rivera. "Modified Boost with Switched Inductor Different Configurational Structures for DC-DC Converter for Renewable Application."

[12]. Gnanavadivel J, Senthil Kumar N, and P. Yogalakshmi. "Implementation of FPGA based three-level converter for LIED drive applications." Journal of Optoelectronics and Advanced Materials 18, no. 5-6 (2016): 459-467.

[13]. Hua, Chihchiang, and Chihming Shen. "Control of DC/DC converters for solar energy system with maximum power tracking." In Industrial Electronics, Control and Instrumentation, 1997. IECON 97. 23rd International Conference on, vol. 2, pp. 827-832. IEEE, 1997.

[14]. Axelrod, Boris, Yefim Berkovich, and Adrian Ioinovici. "Hybrid switched-capacitor-Cuk/Zeta/Sepic converters in step-up mode." In Circuits and Systems, 2005. ISCAS 2005. IEEE International Symposium on, pp. 1310-1313. IEEE, 2005.

[15]. M. Perianayagi, N. R. Prabha and J. Gnanavadivel, "Design and analysis of single switch dual output DC-DC SEPIC converter for PV applications," 2019 IEEE International Conference on Innovations in Communication, Computing and Instrumentation (ICCI), 2019, pp. 112-116.

[16]. N Rathina Prabha, J Gnanavadivel, KS .Krishna Veni, ". Performance Investigation of Single Switch Dual Output DC-DC SEPIC Converter for PV Applications," International Journal of Advanced Science and Technology, 29(5),2020, pp. 4676-4683

[17]. Kumar, K., N. Ramesh Babu, and K. R. Prabhu. "Analysis of integrated Boost-Cuk high voltage gain DC-DC converter with RBFN MPPT for solar PV application." In Power and Advanced Computing Technologies (i-PACT), 2017 Innovations in, pp. 1-6. IEEE, 2017.

[18]. Gnanavadivel J, Senthil Kumar N, CN Naga Priya, and KS Krishna Veni. "Investigation of Power Quality Improvement in Super Lift Luo Converter." International Journal of Power Electronics and Drive Systems 8, no. 3 (2017): 1240.

[19]. S. T. Siddharthan, J. Gnanavadivel and S. T. J. Christa, "Enhancement of Power Quality Using Luo AC-DC Non Isolated Converter Fed BLDC Motor Drive for Medical Applications," 2020 7th International Conference on Smart Structures and Systems (ICSSS), 2020, pp. 1-5

[20]. J. Gnanavadivel, P. Yogalakshmi, N. Senthil Kumar, K.S. Krishna Veni, "Design and development of single phase AC–DC discontinuous conduction mode modified bridgeless positive output Luo converter for power quality improvement," IET Power Electronics 2019,12(11) pp. 2722-2730

[21]. Gnanavadivel J, Vidhya Chellappa, and N. Senthil Kumar. "Comparison of power quality improvement techniques in ac-dc Cuk converter." In Computer, Communication and Electrical Technology (ICCCET), 2011 International Conference on, pp. 400-404. IEEE, 2011.

[22]. Ferrera, M.B., Litrán, S.P., Durán, E., Andújar, J.M.: A converter for bipolar DC link based on SEPIC-Cuk combination. IEEE Trans. Power Electron. 30(12), 6483–6487 (2015)

[23]. K Jayanthi, N Senthil Kumar, J Gnanavadivel. "Design and implementation of modified SEPIC high gain DC- DC converter for DC microgrid applications." International Transactions on Electrical Energy Systems, vol. 31(8), pp. 2100-2118. 2020.

[24]. Gnanavadivel J, Senthil Kumar N, C. N. Priya, S. T. Christa, and K. S. Veni. "Single phase positive output super-lift luo converter fed high power LED lamp with unity power factor and reduced source current harmonics." Journal of Optoelectronics And Advanced Materials 18, no. 11-12 (2016): 1007-1017.

[25]. Tekade, Anushka S., Rahul Juneja, Manish Kurwale, and Prashant Debre. "Design of Positive Output Super-Lift Luo Boost Converter for Solar Inverter." In Energy Efficient Technologies for Sustainability (ICEETS), 2016 International Conference on, pp. 153-156. IEEE, 2016.

[26]. Gnanavadivel J, Senthil Kumar N, and Yogalakshmi P. "Fuzzy controller based power quality improvement in three level converter with multiloop interleaved control for marine AC/DC applications." (2017) Indian journal of Geo Marine Sciences, Vol. 46(09), Sep2017, pp. 1908-1919.

[27]. Gnanavadivel J, Senthil Kumar N and Yogalakshmi P. "Comparative Study of PI, Fuzzy and Fuzzy tuned PI Controllers for Single-Phase AC-DC Three-Level Converter." Journal of Electrical Engineering & Technology 12, no. 1 (2017): 78-90.

[28]. J. Gnanavadivel, R. Santhiya and N. S. Kumar, "Comparison of closed loop PF improvement controllers for single phase AC-DC dual output converter," 2011 International Conference on Recent Advancements In Electrical, Electronics and Control Engineering, 2011, pp. 242-247

[29]. Smiline, E. Therese Reena, J. Gnanavadivel, ST Jaya Christa, and N. Senthil Kumar. "Performance evaluation of PI and fuzzy tuned PI controllers for single phase bridgeless modified SEPIC converter." In Circuit, Power and Computing Technologies (ICCPCT), 2016 International Conference on, pp. 1-6. IEEE, 2016.

[30]. Dhote, V. P., and Gaurav P. Modak. "Analysis and study of Zeta converter fed by solar photovoltaic array." In Power and Advanced Computing Technologies (i-PACT), 2017 Innovations in, pp. 1-6. IEEE, 2017.

[31]. Gnanavadivel J, Senthil Kumar N, and S. T. Jaya Christa. "Implementation of FPGA based fuzzy and hysteresis controllers for power quality improvement in single phase three-level rectifier." Optoelectronics and Advanced Materials-Rapid Communications 9, no. 9-10 (2015): 1264-1272.

[32]. K Jayanthi, Senthil Kumar, N, J Gnanavadivel , ". Energy management of distributed renewable energy sources for residential DC microgrid applications," International transactions on electrical energy systems, 30(3),2020, pp. 1-15.