Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 11, No.1, November : 2024

PERFORMANCE ANALYSIS OF ANN BASED CONVERTER USED FOR ELECTRIC VEHICLE CHARGERS

Kota Sruthi Samhitha, Department of electrical and electronics engineering, JNTUH University college of engineering, Science and Technology, Hyderabad. India. kotasruthi00@gmail.com
Dr. Malaji Sushama, Department of electrical and electronics engineering, JNTUH University college of engineering, Science and Technology, Hyderabad. India.

ABSTRACT
Isolated DC-DC converters are crucial components in EV charging systems, primarily responsible for converting the high-voltage DC input from the grid or energy storage system into a suitable voltage level for the EV battery. A new configuration of converter that can be used for EV charging is Isolated Zeta-Luo converter. Isolated Zeta-Luo is a combination of Zeta and Luo converters. A uniform charging current is obtained for the battery due to the presence of output inductance in both converters. An ANN-based controller is employed to optimize switching patterns and further enhance performance. A comparative analysis of both the ANN based and PI based converters is performed. The simulations of both the converters are performed in MATLAB Simulink. ANN based converter achieve an input power factor of 0.991 while the output voltage gives a minimum settling time of 0.2 sec.
KEY WORDS-
Electric vehicles (EV) charger, Bridgeless Isolated DC-DC converters, power factor regulation, Artificial neural network (ANN) control, constant voltage.

I. INTRODUCTION
The rapid adoption of Plug-in Electric Vehicles (PEVs) has led to an increasing demand for efficient, reliable, and flexible charging solutions. As PEVs become more commonplace, the role of power converters in EV chargers has gained significant importance. These converters are crucial for transforming the alternating current (AC) supplied by the grid into the direct current (DC) required by the vehicle's battery. The performance of these converters directly impacts the overall efficiency, charging speed, and power quality of the EV charging system.
A conventional converter with a power factor corrector uses bulky DC capacitor affects charger efficiency and heating effect [7]. By interleaving two phases, the circuit inductance size is minimized. This, in turn, allows for a reduction in the size of input EMI filters though it leads to poor current ripple characteristics [4].
Among the various converter topologies available, the Isolated Zeta-Luo converters have emerged as promising candidates for EV charging applications. These converters not only offer high efficiency and reliability but also contribute to the improvement of input power factor, which is essential for reducing energy losses and ensuring stable grid operation [1][2]. The Isolated Zeta-Luo converter combines the strengths of Zeta and Luo converters, optimizing performance by operating during individual halves of the supply voltage, which enhances efficiency and provides a uniform charging current [2].
In addition to the inherent advantages of this converter topology, the use of Artificial Neural Network (ANN)-based controllers further improved the converter performance. ANN controllers, with their ability to learn and adapt to varying conditions, optimize the switching pulses of the converter, leading to better efficiency, lower Total Harmonic Distortion (THD) in the input current, and improved input power factor.
The performance of ANN based Isolated Zeta-Luo converter in the context of EV charging applications can be compared with PI based converter to decide a best suitable converter. By evaluating these

converters based on their efficiency, component count, THD, and input power factor, this research seeks to identify the most suitable converter topology for enhancing the efficiency and reliability of EV chargers.

II. METHODOLOGY

Isolated DC-DC converters are crucial components in EV charging systems, primarily responsible for converting the high-voltage DC input from the grid or energy storage system into a suitable voltage level for the EV battery. These converters provide essential galvanic isolation, preventing electrical faults from propagating to the battery and ensuring the safety of both the vehicle and the user. Additionally, they enable efficient power transfer, minimizing energy losses during the charging process.

A. ISOLATED ZETA-LUO CONVERTER

This Zeta-Luo converter is an integration of both Zeta and Luo converter, shown in fig.1, which are made to operate in two individual half cycles. The isolation is provided using a high frequency transformer. The converter operates in six distinct modes, with three modes occurring during the positive half cycle of the supply and three during the negative half cycle.

During the positive half-cycle of the supply voltage, the Zeta converter operates as a buck-boost converter, with switch S1 being activated. In this phase, the magnetizing inductance $Lm1$ charges the intermediate capacitor C1, while the output diode $Do1$ conducts, directing current to the battery. Meanwhile, the Luo converter remains inactive, with switch S2 in the open position [2].

In the negative half-cycle, the Luo converter takes over, functioning as a buck-boost converter with switch S2 being activated. Here, the magnetizing inductance $Lm2$ charges the intermediate capacitor $C2$, and the output diode $Do2$ conducts, allowing current to flow to the battery. During this phase, the Zeta converter is deactivated, and switch S1 remains open [2].

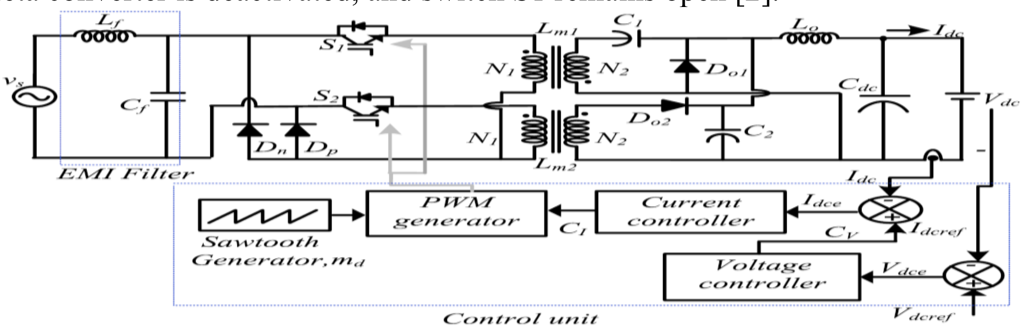

Fig.1 Isolated Zeta-Luo converter

III. CONTROL OF CONVERTERS

Proportional-Integral (PI) controller is commonly used in DC-DC converters to regulate output voltage or current. It adjusts the converter's switching pulses by calculating the error between the desired setpoint (reference) and the actual output. The proportional term responds to the present error by adjusting the duty cycle, while the integral term corrects accumulated errors over time. Together, they ensure stable and precise control of the converter, minimizing output fluctuations caused by changes in input voltage or load conditions. PI controllers are preferred for their simplicity and effective steady-state performance.

PI controllers can be improved by using Artificial Neural Network (ANN) controllers. ANN controllers offer several advantages over traditional PI controllers, especially for complex or nonlinear systems like DC-DC converters used in EV chargers, like adaptive learning, nonlinear control, improved performance, robustness etc.

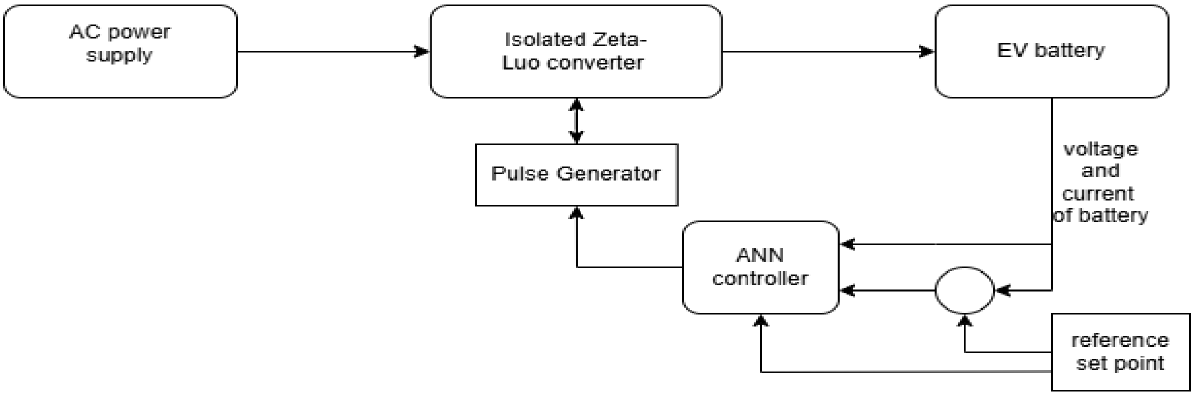

Fig.2 Block diagram of implemented model

A. ANN BASED ISOLATED ZETA-LUO CONVERTER

Artificial neural networks, modelled after the human brain, consist of interconnected nodes that mimic biological neurons. These networks are defined by three key elements: node properties, network architecture, and learning rules.

Based upon data, ANN goes into the training process for its learning and understanding the relationship between the input and output data. Once, the training is successfully completed, the ANN can provide the accurate output for any input variable without knowing the mathematical equation.

Training algorithms for ANNs play a crucial role in optimizing the network's weights and biases to make accurate predictions or classifications. Levenberg-Marquardt algorithm is used for training of ANN.

An ANN-based isolated Zeta-Luo converter integrates the isolated converter topologies with an Artificial Neural Network (ANN) controller to enhance performance. By using an ANN controller, the converter's switching pulses are optimized in real-time, allowing the system to adapt to varying conditions such as input voltage fluctuations or load changes. This leads to improved efficiency, reduced output voltage ripple, faster transient response, and better overall system stability, making it ideal for applications like electric vehicle (EV) chargers where performance and reliability are key.

The implemented model of ANN based converter is shown in fig.2. The ANN-based controller employed, optimizes the performance of the converters. This controller utilizes feedback signals from the battery, such as voltage and current, and a reference signal representing the desired output. By processing the error between the actual and desired output, the ANN generates precise control signals for the pulse generator. This approach offers several benefits, including enhanced dynamic response, adaptability to varying load and input conditions, and improved overall efficiency.

IV. MATHEMATICAL MODELLING

ANN based Isolated Zeta-Luo converter has been modelled using the following equations:

The converter uses magnetizing Inductances for charging and discharging of supply and provide isolation to the output from supply. Mathematically these can be determined using

$L_{m1,2} = (V_s^2/P)(T_s/2)(V_{dc}/(nV_{in}+V_{dc}))$ ....(1)

Where V_s is the rms value of peak magnitude of supply voltage, T_s is the switching time period, V_{dc} is the output dc voltage and P is rated power. The value of intermediate capacitances are determined using

$C_{1,2} = n\,P/(\gamma\,\sqrt{2}V_s f_s\ (n\sqrt{2}V_s + V_{dc}))$ ....(2)

where γ is the max voltage ripple across the capacitor.

To obtain a continuous output current filter inductor is used. By continuous charging and discharging the inductor helps in obtaining continuous output current. It can be obtained using

$Lo = (V_s^2/P)(V_{dc}/(k\,\sqrt{2}V_s f_s))(V_{dc}/(nV_{in}+V_{dc}))$ ....(3)

where k is max allowable current ripple in inductor current.

To mitigate the ripple in output current and voltage the Dc capacitor used which ensures a continuous supply to the battery, can be calculated using

$C_{dc} = P/(2w\Delta V_{dc}^2)$ ……………(4)

where w is supply frequency in radians/sec and ΔV_{dc} ripple in the dc voltage.

Filter capacitor and inductor are

$C_f = (P\sqrt{2}/V_s)/(w\sqrt{2}\ V_s)$, $L_f= 1/(4\pi^2 f_s^2\ C_f)$. ……(5)

respectively.

V. RESULTS OF SIMULATION

This work analyses the performance of isolated Zeta-Luo converter operated using an ANN controller. The converters with PI and ANN have been simulated individually with the same battery load of 10 Ah from an input source of 220volts and 50Hz AC supply with a switching frequency of 25kHz. The outputs have been observed using MATLAB.

The converter when operated using ANN based controller exhibit lesser voltage transients and settling time of peak overshoots as compared to PI controllers.

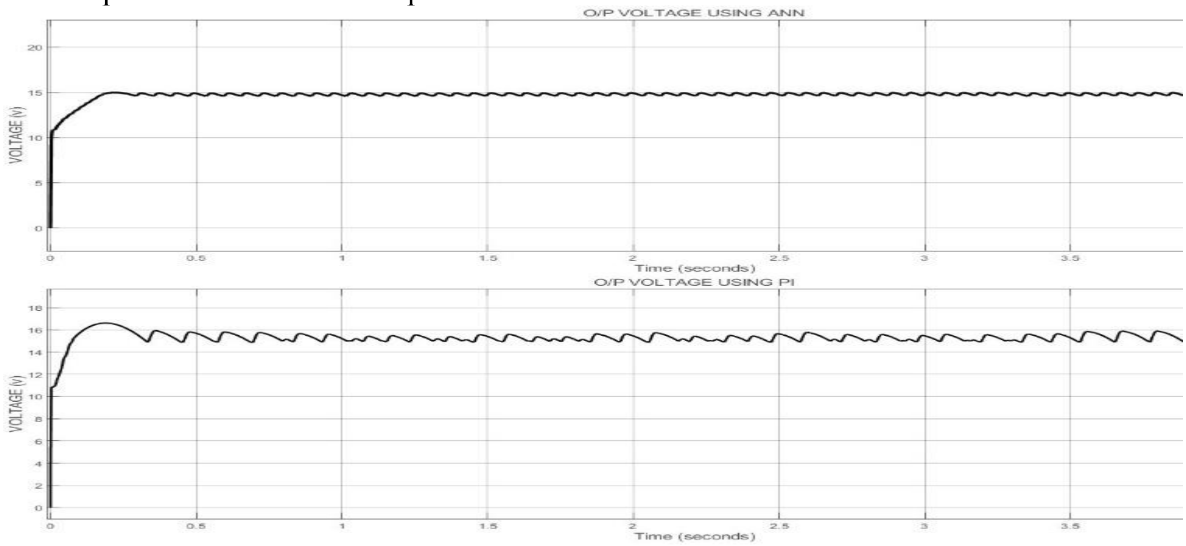

Fig.3 Comparison of output voltages using ANN and PI controllers for Zeta-Luo converter

From the fig.3 it can be seen that the output voltage settling time is around 0.4 for ZETA-LUO converter when operated with a PI controller.

The control of the converter is updated to ANN controllers. A change in the reference voltage is induced at 5 seconds. Both the converters give a settling time around 0.2 seconds which is shown in fig.7, fig.8. The voltage transients of the converter have been reduced with the use of ANN controller compared to PI controller.

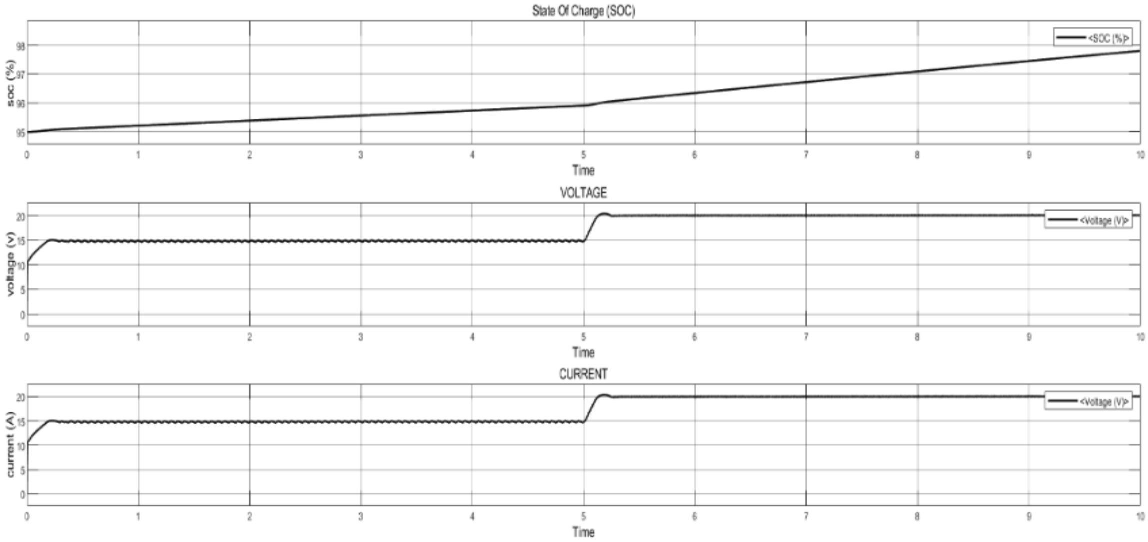

Fig.7 Outputs of ANN based Zeta Luo converter

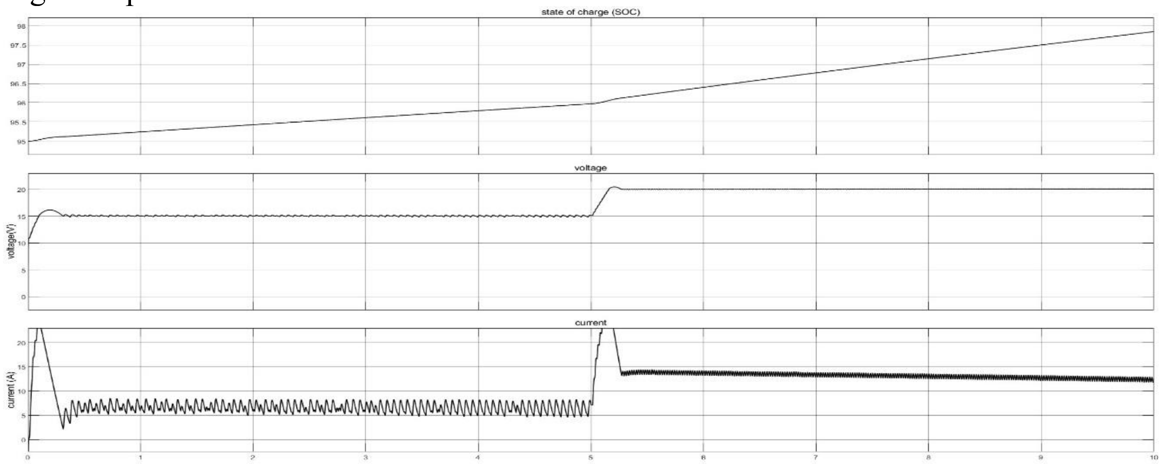

Fig.8 Outputs of PI based Zeta Luo converter

It can be seen that using a PI controller the converter requires almost more than 0.5 sec to reach a steady state also produces more transients in voltage and current.

An improved power factor of the input supply while using an ANN based Zeta -Luo converter can be seen from fig.9 which is almost 0.991.

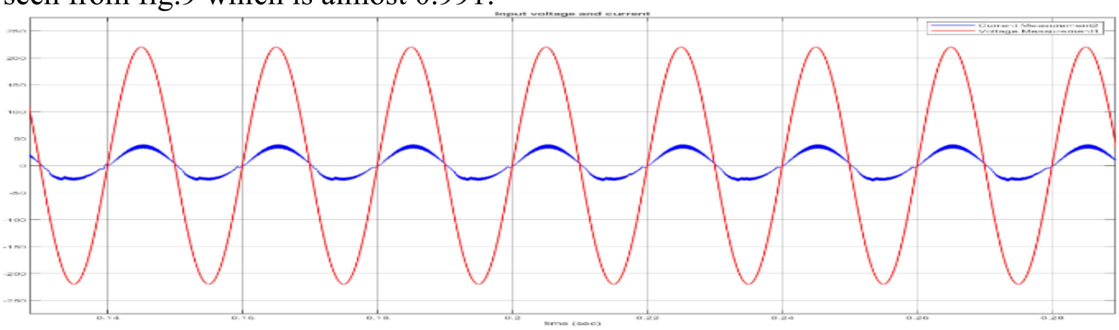

Fig.9 Input voltage and current of ANN based Zeta-Luo converter

The THD value of the input supply current is as low as 4.6% during constant current operation, and as low 9.25% during constant voltage mode shown in fig10.

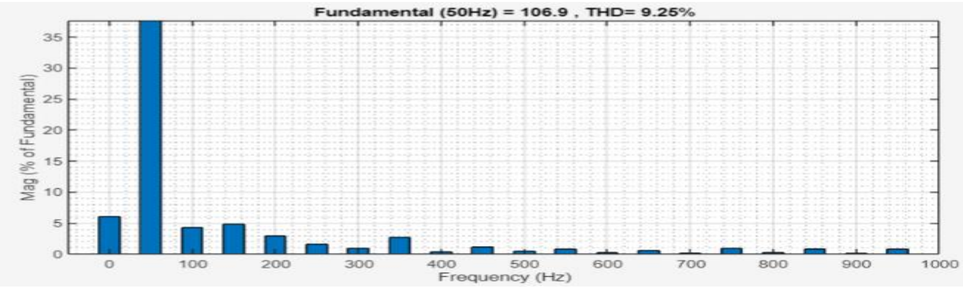

Fig.10 THD for Zeta-Luo converter with ANN controller

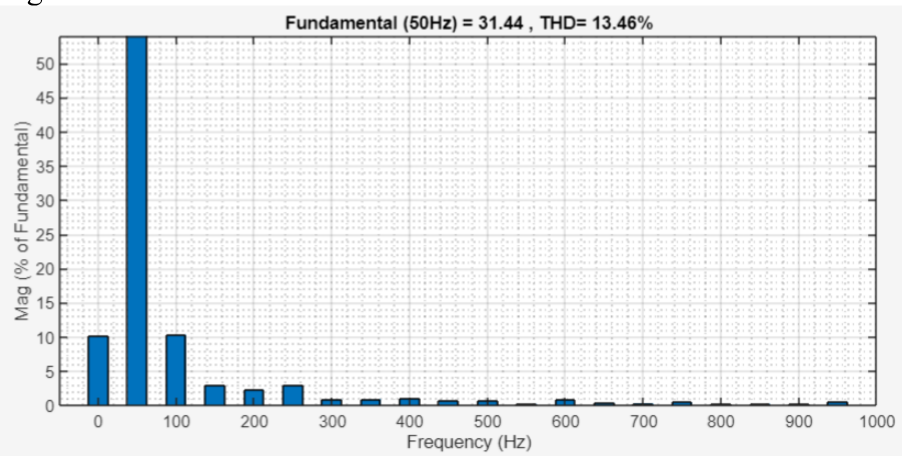

Fig.10 THD for Zeta-Luo converter with PI controller

VI. CONCLUSION

An improved ANN based isolated Zeta-Luo converter has been simulated and the performance of the converter has been analysed. This topology provides the advantage of a reduced component count and enhanced efficiency by integrating different converters within a single-stage converter, each operating during alternate half cycles. Moreover, the integration of ANN control has improved the performance by reducing the output voltage transients and also maintaining a low input power factor. The distortions in grid side current are also reduced.

The ANN-based pulse generation significantly improved the input power factor, achieving values of 0.991 for the Zeta-Luo converter.

ANN based Zeta-Luo converter operates with lower voltage transients as compared to PI based Zeta-Luo converter. The THD of grid current of Zeta-Luo converter is as low as 4.68% during CC.

The grid current distortion during CV is obtained 9.25% with ANN controller for Zeta-Luo converter. In terms of settling time using ANN controller gives better performance than PI controller. But ANN based Zeta-Luo converter gives better performance in terms of THD of input current and PF, than PI based converter. Zeta-Luo converter provides lesser voltage transients, hence can cause lesser heating issues in the components. The Zeta-Luo converter has smaller component sizes resulting in greater efficiency and cost-effectiveness.

VII. REFERENCES

[1] R. Kushwaha, B. Singh, and V. Khadkikar, “An isolated bridgeless Cuk–SEPIC converter-fed electric vehicle charger” IEEE Transactions on Industry Applications, vol. 58, no. 2,pp. 2512–2526, 2022.

[2] R. Kushwaha and B. Singh, "Bridgeless Isolated Zeta–Luo Converter-Based EV Charger With PF Preregulation," in IEEE Transactions on Industry Applications, vol. 57, no. 1, pp. 628-636, Jan.-Feb. 2021, doi: 10.1109/TIA.2020.3036019.

[3] R. Kushwaha and B. Singh, "Interleaved Landsman Converter Fed EV Battery Charger With Power Factor Correction," in IEEE Transactions on Industry Applications, vol. 56, no. 4, pp. 4179-4192, July-Aug. 2020, doi: 10.1109/TIA.2020.2988174.
[4] F. Musavi, M. Edington, W. E erle, and W. G. Dunford, "Evaluation and efficiency comparison of frontend AC–DC plug-in hybrid charger topologies," IEEE Trans. Smart Grid, vol. 3, no. 1, pp. 413–421, Mar. 2012.
[5] F. Lin, M. Huang, P. Yeh, H. Tsai and C. Kuan, "DSP-Based Probabilistic Fuzzy Neural Network Control for Li-Ion Battery Charger," IEEE Transactions Power Electronics, vol. 27, no. 8, pp. 3782-3794, Aug. 2012
[6] "A Single-Phase Integrated Onboard Battery Charger Using Propulsion System for Plug-in Electric Vehicles", IEEE Transactions vehicular technology. Doi:10.1109/TVT.2017.2729345, Aug.2017 Chuan Shi, Yichao Tang, Alireza Khaligh.
[7] L. Petersen and M. Andersen, "Two-stage power factor corrected power supplies: The low component-stress approach," in *Proc. IEEE APEC*, 2002, vol. 2, pp. 1195–1201.
[8] Y. Jang and M. M. Jovanovic, "Bridgeless high-power-factor buck converter," *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 602–611, Feb. 2011.
[9] F. L. Luo, "Negative output Luo converters: Voltage lift technique," *IEE Proc. – Elect. Power Appl.*, vol. 146, no. 2, pp. 208–224, Mar. 1999.
[10] R. Kushwaha and B. Singh, "Bridgeless isolated Zeta-Luo converter based EV charger with PF pre-regulation," in *Proc.GUCON*, 2019, pp. 959–964.
[11] B. Singh and R. Kushwaha, "A PFC based EV battery charger using a bridgeless isolated SEPIC converter," IEEE Trans. Ind. Appl., vol. 56, no. 1, pp. 477–487, Jan./Feb. 2020
[12] K. K. M. Siu and C. N. M. Ho, "Manitoba rectifier—Bridgeless buck–boost PFC," *IEEE Trans. Power Electron.*, vol. 35, no. 1, pp. 403–414, Jan. 2020.
[13] E. H. Ismail, "Bridgeless SEPIC rectifier with unity power factor and reduced conduction losses," *IEEE Trans. Ind. Electron.*, vol. 56, no. 4, pp. 1147–1157, Apr. 2009.
[14] J. Yang and H. Do, "Bridgeless SEPIC converter with a ripple-free input current," *IEEE Trans. Power Electron.*, vol. 28, no. 7, pp. 3388–3394, Jul. 2013.
[15] A. J. Sabzali, E. H. Ismail, M. A. Al-Saffar, and A. A. Fardoun, "New bridgeless DCM SEPIC and Cuk PFC rectifiers with low conduction and switching losses," *IEEE Trans. Ind. Appl.*, vol. 47, no. 2, pp. 873–881, Mar./Apr. 2011.
[16] M. Mahdavi and H. Farzanehfard, "Bridgeless SEPIC PFC rectifier with reduced components and conduction losses," *IEEE Trans. Ind. Electron.*, vol. 58, no. 9, pp. 4153–4160, Sep. 2011.