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OPTIMIZATION OF AN INTELLIGENT CONTROLLED BRIDGELESS POSITIVE LUO CONVERTER FOR LOW-CAPACITY ELECTRIC VEHICLES

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Abstract. *This paper presents a novel approach to power conversion in electric vehicle (EV) applications. The proposed converter, a Bridgeless Single Stage Positive Luo Converter (BSPLC), is optimized to enhance efficiency and reduce losses in low-capacity EVs. Traditional converters experience higher losses due to their passive components and bridge circuits. By eliminating the bridge components, the converter achieves higher efficiency. An intelligent fuzzy logic controller is employed to provide adaptive control and stabilize output under varying input conditions, improving performance and response time. The converter design is further optimized through parameter tuning and simulation to achieve minimal ripple and maximum power efficiency at 92%. The proposed solution is ideal for low-capacity EVs, as it ensures enhanced power conversion, reduced thermal stress, and improved battery life. The study demonstrates the converter's capability to meet the growing demands for energy-efficient solutions in modern electric mobility.*

Keywords: bridgeless Luo converter, fuzzy logic controller, light electric vehicles, total harmonic distortion

OPTYMALIZACJA INTELIGENTNIE STEROWANEGO BEZMOSTKOWEGO DODATNIEGO PRZEKSZTAŁTNIKA LUO DLA POJAZDÓW ELEKTRYCZNYCH O MAŁEJ POJEMNOŚCI

Streszczenie. *W artykule przedstawiono nowatorskie podejście do konwersji mocy w pojazdach elektrycznych (EV). Proponowany konwerter, bezmostkowy jednostopniowy dodatni konwerter Luo (BSPLC), został zoptymalizowany pod kątem zwiększenia wydajności i zmniejszenia strat w pojazdach elektrycznych o małej pojemności. Tradycyjne przetwornice charakteryzują się większymi stratami ze względu na elementy pasywne i obwody mostkowe. Eliminując elementy mostka, przetwornica osiąga wyższą sprawność. Inteligentny kontroler rozmyty zapewnia sterowanie adaptacyjne i stabilizację sygnału wyjściowego w zmiennych warunkach wejściowych, poprawiając wydajność i czas reakcji. Konstrukcja konwertera jest dodatkowo optymalizowana poprzez dostrajanie parametrów i symulację, aby osiągnąć minimalne tętnienia i maksymalną wydajność energetyczną na poziomie 92%. Proponowane rozwiązanie jest idealne dla pojazdów elektrycznych o małej pojemności, ponieważ zapewnia lepszą konwersję mocy, zmniejszone naprężenia termiczne i dłuższą żywotność baterii. Badanie wykazało zdolność konwertera do sprostania rosnącym wymaganiom w zakresie energooszczędnych rozwiązań w nowoczesnej mobilności elektrycznej.*

Słowa kluczowe: bezmostkowy konwerter Luo, sterownik z logiką rozmytą, lekkie pojazdy elektryczne, całkowite zniekształcenia harmoniczne

Introduction

Light Electric Vehicles (LEVs), including e-bikes, e-scooters, and other small electric vehicles, have gained significant attention as a sustainable alternative to traditional fossil-fuelled vehicles. LEVs offer numerous advantages such as reduced carbon emissions, lower operating costs, and easier navigation in congested urban environments [10]. However, one of the critical challenges in the widespread adoption of LEVs is the efficiency of their power electronics, especially in relation to their charging systems. Efficient power conversion is essential for reliable charging and the overall energy efficiency of LEVs, which directly impacts their range and battery life. The demand for more efficient, compact, and reliable charging systems has led to the exploration of advanced converter technologies to meet the specific requirements of LEVs.

Charging solutions for LEVs primarily focus on ensuring that the power drawn from the grid is efficiently converted to charge the battery while maintaining a high power factor. In LEV applications, Power Factor Correction (PFC) is critical for minimizing losses, improving energy efficiency, and ensuring compliance with grid standards [5]. The most commonly used converters for PFC in LEV chargers include traditional bridge rectifiers followed by a boost converter, Cuk converters, and SEPIC converters. While these converters achieve reasonable performance in terms of power factor correction, they come with inherent limitations, including significant switching losses, larger component sizes, and lower overall efficiency, particularly under low-load conditions.

One of the major challenges with conventional PFC converters is the significant energy loss due to the bridge diode rectifier, which introduces additional conduction losses and heat dissipation. Furthermore, the bulky passive components required for filtering and energy storage increase the size and cost of the charging solution. For LEVs, which are often constrained by space and weight, the limitations of traditional PFC converters hinder their potential to achieve the necessary energy efficiency and compact form factor. Additionally, maintaining high efficiency under varying load conditions, which is typical in LEV charging, poses another technical challenge. To overcome these issues, there is a need for more advanced and optimized converter designs.

The Bridgeless Positive Luo Converter presents a promising alternative to traditional PFC converters for LEVs [3]. By eliminating the need for a bridge rectifier, this converter significantly reduces conduction losses and improves overall efficiency. The Positive Luo Converter topology is known for its ability to step up voltage while ensuring minimal ripple and high power density, making it well-suited for LEV applications [6]. Furthermore, the bridgeless design reduces the number of components, which leads to a more compact and cost-effective solution [4]. In addition, the use of advanced control techniques, such as fuzzy logic control, ensures adaptive and efficient operation under varying input conditions, addressing the issue of efficiency drops in traditional converters.

In this research, the design and optimization of an intelligent fuzzy-controlled Bridgeless Positive Luo Converter for LEVs is proposed. This converter offers several advantages, including reduced component count, higher efficiency, and improved power factor correction. By integrating fuzzy logic control, the converter can adaptively adjust its performance to maintain optimal efficiency across different operating conditions, ensuring stable and reliable charging for LEVs [9]. Through detailed analysis, simulation, and testing, the proposed solution is evaluated against conventional converters to highlight its performance gains and potential for commercialization.

The broader significance of this research lies in its contribution to the development of more energy-efficient charging systems for LEVs, which is critical for advancing electric mobility. As the demand for LEVs continues to grow, there is a pressing need for innovations in power electronics that can support their rapid adoption. The proposed Bridgeless Positive Luo Converter represents a step forward in achieving the dual goals of higher energy efficiency and reduced environmental impact, making it a valuable contribution to the field of electric vehicle technology.

1. Proposed Bridgeless Single Stage Positive Luo Converter

The proposed BSPLC is designed to improve the efficiency of power conversion in low-capacity electric vehicles (EVs) is shown in Fig 1. This converter eliminates the traditional bridge rectifier stage found in conventional converters, which significantly reduces conduction losses and improves overall efficiency [7, 8]. The circuit consists of an input inductor, two MOSFET switches, a Luo inductor, and diodes that facilitate the conversion process. The absence of the diode bridge rectifier ensures that the converter operates in a bridgeless mode, where current directly flows through the MOSFETs during switching, thus lowering conduction losses. Additionally, the Positive Luo Converter topology allows the converter to step up the input voltage to a higher output voltage, making it suitable for charging LEV batteries efficiently.

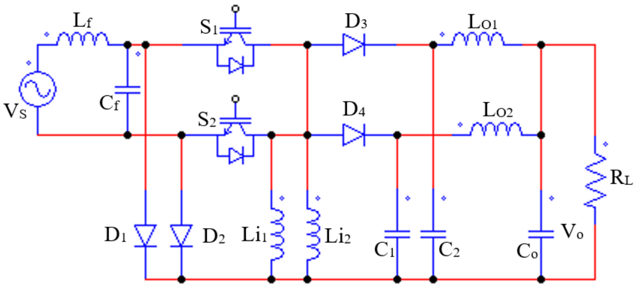


Fig. 1. Positive Output Bridgeless Luo Converter Circuit

During operation, the converter switches between two primary modes – switch ON and switch OFF. When the MOSFETs are turned ON, the input inductor stores energy, and the Luo inductor starts transferring the stored energy to the output. During the OFF state, the stored energy in the input inductor is released, and the diodes allow the energy to flow to the load, ensuring continuous current. The key advantage of this design is its ability to reduce ripples in both input and output, maintain high voltage gain, and achieve a higher power factor. With the integration of intelligent fuzzy logic control, the converter adapts to varying load conditions, ensuring a stable and efficient output, making it highly effective for low-capacity EVs.

2. Control algorithm

The control algorithm for the BSPLC with a Fuzzy Logic Controller (FLC) is designed to provide efficient power regulation, stabilize output voltage, and ensure dynamic response to varying input conditions. Fig. 2 shows the implemented control strategy with feedback of Io and Vo. The Fuzzy Logic Controller is chosen for its ability to handle nonlinear systems and provide robust control without needing an accurate mathematical model of the converter [1, 2]. The algorithm operates by adjusting the duty cycle of the MOSFET switches based on input voltage, load changes, and output voltage deviations.

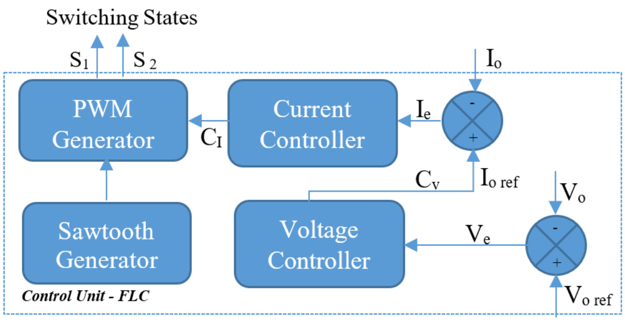


Fig. 2. Control strategy for the proposed BSPLC

Steps of the control algorithm

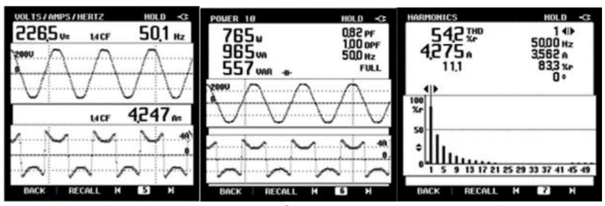
1) Input Measurement: The system continuously measures the output voltage and current of the converter. These values are compared to their reference values (set points) to calculate the error (difference between the desired and actual output) and the change in error (rate of change of the error). These two parameters form the inputs to the FLC. The system uses Mamdani Fuzzy Inference system.
2) Fuzzification: The measured error and change in error are converted into linguistic variables (such as "Positive High", "Negative Low", "Zero") using predefined membership functions. This step transforms precise input data into fuzzy values, which the fuzzy logic system can process.
3) Rule Evaluation: The FLC uses a set of "if-then" rules to determine how to adjust the duty cycle of the converter based on the fuzzy inputs. For example, if the error is "Positive High" and the change in error is "Positive Low", the system might reduce the duty cycle slightly to lower the output voltage. The rules are designed to handle various operating conditions such as overshoot, undershoot, and steady-state errors.
4) Inference Mechanism: Based on the fuzzy rules, the FLC computes a fuzzy output, which represents the appropriate adjustment to the duty cycle of the MOSFET switches. The fuzzy output is a combination of the contributions from all relevant rules, determined by their membership values.
5) Defuzzification: The fuzzy output is converted back into a crisp, actionable value (i.e., the exact duty cycle adjustment for the MOSFETs) using a defuzzification method, typically the centroid method. This provides a precise control signal that adjusts the pulse width of the PWM (Pulse Width Modulation) signal sent to the MOSFET switches.
6) PWM Signal Generation: The duty cycle generated by the FLC is used to modulate the PWM signal controlling the MOSFETs. Adjusting the duty cycle controls the energy transfer from the input to the output, thereby regulating the output voltage to the desired level.

The Fuzzy Logic Controller's ability to adapt dynamically to changing input voltages, load variations, and transient conditions makes it ideal for the bridgeless converter. It ensures efficient operation under different conditions without complex mathematical tuning, providing smooth voltage regulation, minimal ripple, and improved power factor correction.

This intelligent control algorithm enhances the performance and efficiency of the Bridgeless Positive Luo Converter, making it highly effective for low-capacity electric vehicle applications, where varying load conditions are common.

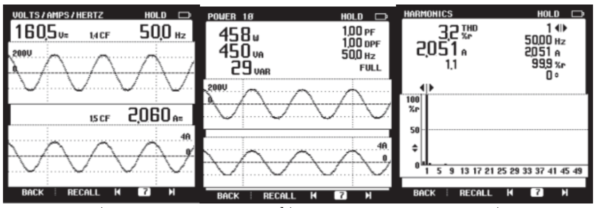
3. Results and discussion

In order to confirm whether the charger is operating as intended, a test bench arrangement is created in the lab. The addition of an input diode bridge rectifier to a traditional EV charger results in utility current distortion of about 54.2%. Bridgeless configuration of this proposed positive output Luo Converter help to reduce the above distortion. In addition to the bridgeless Luo converter, Fuzzy logic controller controls the harmonic content in the input current.



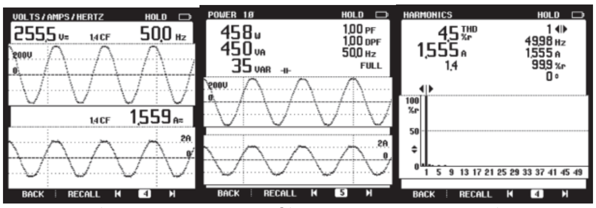
a) b) c)

Fig. 3. Conventional Luo converter with Front end Diode bridge converter: a) voltage and current, b) power, c) input power factor and total current harmonic distortion



a) b) c)

Fig. 4. Power Quality indices: a) voltage and current, b) power, c) utility current THD: for input volatge Vs =160 V



a) b) c)

Fig. 5. Power Quality indices: a) voltage and current, b) power, c) utility current THD: for input voltage Vs = 255 V

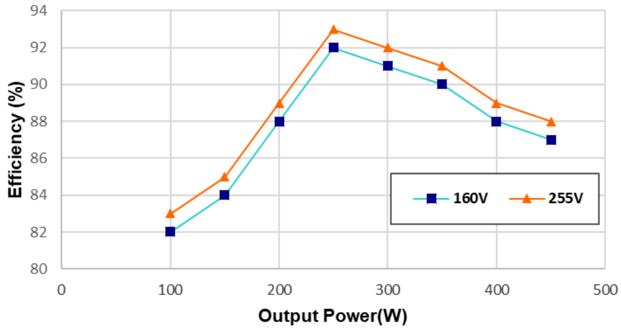


Fig. 6. Efficiency variation with respect to different power levels and input voltage (Vs = 160 V and 255 V)

The results presented in this work demonstrate the charger's performance under nominal operating conditions, with a supply voltage of 220 V at 50 Hz and a rated power of 450 W. As can be observed the charger design that is being shown in this work maintains a power factor of unity while I_{in} keeps a sinusoidal profile with zero phase difference. Total harmonic distortion in I_S is found to be 3.2% (Fig. 4c) and 4.5% (Fig. 5c) for supply voltage RMS values of 160.5 V and 255.5 V, respectively. These values are unquestionably far lower than the benchmark levels and standards established by IEEE-519 and IEC 61000-3-2. Experimental efficiency is calculated for different input voltages and are depicted in Fig. 6. As it is noticed that, the efficiency is found to be satisfactory for different input conditions (Vs = 160 V and 255 V) and it is found to be 92% and 93%, further improvement can be obtained by optimal design of the charger circuit.

4. Conclusion

The proposed Bridgeless Single Stage Positive Luo Converter is a highly efficient and compact solution tailored to meet the demands of low-capacity electric vehicles. Through its innovative design and intelligent control strategy, the converter provides a significant improvement in energy efficiency, power factor correction, and overall system performance. The reduced component count and enhanced operational efficiency make it an ideal choice for LEV charging systems, offering both economic and environmental benefits. The adoption of this converter could lead to more sustainable and reliable LEV charging infrastructure, supporting the broader transition to electric mobility.

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