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# A Fuzzy Logic Approach for Ripple Minimization and Power Factor Correction in LED Lighting Systems

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***Abstract*—This paper discusses the design and implementation of a fuzzy logic controller (FLC)-based ripple-free LED driver. The suggested LED driver has the ability to provide a constant current to the LED load while ensuring minimum ripple. The FLC is used to control the duty cycle of the switching converter, which regulates the output voltage. The design is optimized for high efficiency and low cost, making it suitable for use in a wide range of applications. The flyback converter in this paper operates in discontinuous conduction mode to achieve a nearly unity power factor, while a parallel-connected boost converter minimizes low-frequency ripple and reduces the need for output filter capacitance. The proposed FLC-based ripple-free LED driver achieved a power factor greater than 0.98 and output current ripple less than 5% with a wide range of input voltages(90V–270V). Validation through the simulation in MATLAB Simulink software confirms the operational effectiveness of the LED driver under a 62W/0.5A LED load.**

***Index Terms*—LED (Light Emitting Diode), FLC (Fuzzy Logic Control), Unity Power Factor(UPF)**

## I. Introduction

Light-emitting diode (LED) technology has become a viable option for effective and eco-friendly lighting systems in recent years. LED drivers play a pivotal role in ensuring the optimal performance of LEDs by regulating the electrical current and voltage supplied to the LED arrays.LED lighting holds numerous advantages, like energy efficiency, a longer life span, being robust and durable, being eco-friendly, and having design flexibility. These advantages collectively make LED lighting a preferred choice across residential, commercial, and industry settings over traditional lighting systems. Generally, LED operates on low-voltage DC power, while most electrical systems supply alternating current. LED drivers convert incoming AC power into the consistent and stable DC voltage and current required by LEDs, ensuring efficient and reliable operation. Reducing flicker is one of the challenges associated with using LED lighting. In an AC input LED the well-known ripple at two times the line frequency occurs because of the energy disparity between the output DC power and the input AC power. This phenomenon can have adverse effects on health, giving rise to a range of health-related concerns [1]. Typically, an excessively large number of output capacitors are required to decrease flicker to a level that is suitable for using Single-stage. This greatly raises the cost of components and negates the original intent of employing a one-stage structure. Two kinds of LED drivers are typically available: single-stage and two-stage. LED drivers with one stage can offer affordable prices along with great efficiency. The notable flicker that the one-stage LED driver generates is a drawback. With appropriate output capacitors, the single-stage LED driver will be able to reduce the flicker, but because of this, the cost increases, and the life of the LED driver is reduced. The two-stage LED driver can greatly lower the flicker intensity, and an LED driver without flickering is naturally achievable. But the additional power stage drives up the price of the individual parts and lowers the system's overall efficiency. Generally, two-stage led drivers can be useful for reducing flicker. First stage results in a high power factor, while dc–dc converters are typically employed in the second stage and it achieves output without flickering. In [2], Boost topology is used to create the first stage, and LLC topology is used to implement the second stage. However, the disadvantage is higher component cost. A traditional offline single-stage LED driver for light emitting diodes is proposed in [3], in which the primary output voltage ripple of the PFC is balanced by producing a ripple voltage with an opposing twice-line frequency using another converter that consumes minority power. In [4], the process of injecting input current with harmonics was described. This method can reduce the low-frequency current ripple in LEDs but the drawback of this approach is that the power factor is reduced. In [5], it suggests using two distinct full-bridge power architectures in a bipolar (ac) ripple cancellation technique to reduce the need for output capacitance but the circuit is complex. In[6], a universal input range led driver is proposed but for every input voltage, we need to change duty manually to get output constant so in this paper an extension work is done to [6] by introducing a closed loop with a fuzzy logic controller so that the duty automatically changes and we can get constant output.

This study uses a discontinuous conduction flyback converter to obtain nearly unity power factor and to reduce low-frequency ripple, a parallel connection with a boost converter is implemented in conjunction with the output voltage so the required output filter is minimized but in Open-loop LED drivers, the absence of real-time feedback mechanisms leads to limited precision and stability, rendering them less capable of dynamically responding to variations in LED characteristics and environmental conditions. closed-loop LED drivers emerge as the best solution, the feedback mechanisms are used to continuously monitor and adjust system parameters. This results in improved stability and accuracy, as well as adaptability to environmental changes, ensuring consistent and efficient LED operation over time. In the past few years, there has been a high interest in improving the dynamic behavior of AC/DC converters through various control techniques. Using a combination of traditional and intelligent control methods has the potential to improve the performance of the driver. [7].Fuzzy logic stands out as the optimal choice for LED drivers by combining traditional and intelligent methods.

Fuzzy Logic Control (FLC) in the closed-loop of an LED driver presents a distinct advantage in its ability to handle imprecise and non-linear characteristics inherent in LED systems Unlike traditional control methods, FLC excels in managing uncertainties related to factors like variations in LED characteristics The inherent flexibility of fuzzy logic in capturing and utilizing linguistic variables makes it well-suited for complex and dynamic LED systems, enabling a more robust closed-loop control mechanism. A ripple-free LED driver based on a fuzzy logic controller (FLC) is proposed.

## II. ANALYSIS OF PROPOSED CONVERTER

As illustrated in the diagram, the converter is divided into two distinct stages. The first stage features the flyback converter designed for operation in discontinuous conduction mode (DCM) to attain Power Factor Correction (PFC). The second stage consists of a boost converter, primarily aimed at removing the low-frequency component in the output and reducing output ripple. The converter consists of two switches $S_1$ and $S_2$ and the operating modes are as follows. In Mode I, both switches $S_1$ and the switch $S_2$ are on, and both the inductance $L_{\text{mag}}$ and boost inductance $L_b$ are energized, and the current increases linearly in both. In Mode II, switch $S_1$ continues to be on and switch $S_2$ of the second stage is turned off, and the current in the inductor increases. In Mode III, the switch $S_1$ is turned off and the current in $L_{\text{mag}}$ will decrease linearly and energy stored in it is transferred to the secondary side, and diode $D_1$ gets forward biased. In Mode IV, Lmag gets completely de-energized and the current value in it reaches zero.

The maximum current in the magnetizing inductance, denoted as $i_{\text{lmag}}$, can be formulated as:

$$i_{\text{lmag}} = \frac{V_{\text{in}}(t) \times D_1 \times T_s}{L_{\text{mag}}} \tag{1}$$

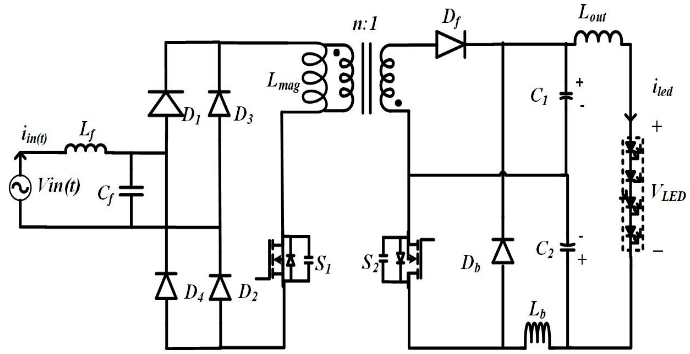



Fig. 1. Flyback-based ripple cancellation LED driver.

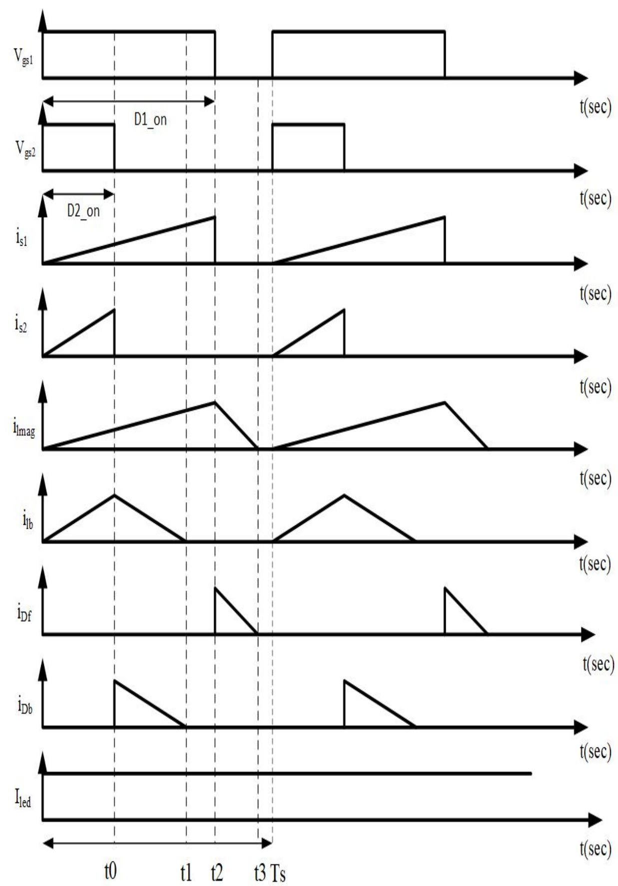



Fig. 2. Key switching cycle waveforms of the ripple cancellation LED driver.

Here, $D_1$ represents the duty cycle of switch $S_1$. Additionally, the peak inductor current in the boost inductance, denoted as $i_{\text{Lb}}$, is determined by the equation:

$$i_{\text{Lb}} = \frac{V_{\text{Lb}} \times D_2 \times T_s}{L_{\text{b}}} \tag{2}$$

where $D_2$ represents the duty cycle of switch $S_2$ and Ts represents the sampling time.

## III. Design of Fuzzy Logic Control

A fuzzy logic controller (FLC) is a powerful tool for closed-loop control of LED driver systems. It is an intelligent control technique that is based on the concept of fuzzy sets and fuzzy logic. Fuzzy logic control varies the duty cycle and maintains constant output automatically based on the input signals from the LED. FLC determines the proper output for the LED driver using fuzzy sets and fuzzy rules. The membership functions and fuzzy rules are adjusted in real-time to adapt to changes in the input signals. This allows the LED driver to maintain a constant output even when the input signals are variable. Fuzzy logic control provides a robust and adaptive control system that can handle uncertainties and changes in the input signals. A fuzzy controller's block diagram is depicted in Fig.3.

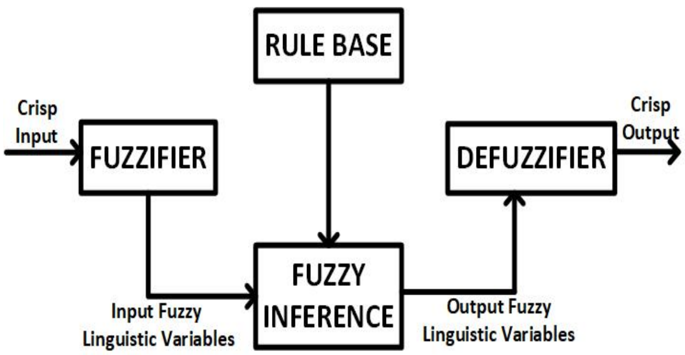



Fig. 3. Schematic Representation of FLC.

As seen in Fig.3, The structure of the FLC system includes the knowledge base, defuzzification interface, inference mechanism, and fuzzification interface. This circuit diagram shown in Fig.4 illustrates a closed-loop control system in which a fuzzy logic controller adjusts the operation of converter to maintain the desired current level at the load despite variations in input voltage or load conditions. At the bottom of the diagram, the fuzzy logic controller receives the error signal ($i_e^*$ - $i_e$), which is the difference between the reference current $i_{\text{ref}}$ and the actual current $i_e$. The controller processes this error using fuzzy logic rules to generate a control signal ($i_{\text{ctrl}}$). This signal is compared against a sawtooth waveform to produce the PWM pulses that drive the switches.This closed-loop approach ensures precise regulation of the LED current, demonstrating the system's adaptability and responsiveness to maintain optimal performance.

The Fig.5 illustrates a flowchart depicting the operational process of a fuzzy logic controller. The controller starts by setting a reference value, which is then compared to the actual value to determine the error (e). This error undergoes fuzzification, converting it into fuzzy values that can be processed using fuzzy logic. Next, "if-then" rules are applied to these fuzzy values to make control decisions. The resulting fuzzy output is then defuzzified into a crisp value, which dictates the change in duty cycle of the controller's output response. The process loops until the output matches the reference value, ensuring the system's desired behaviour is achieved effectively.

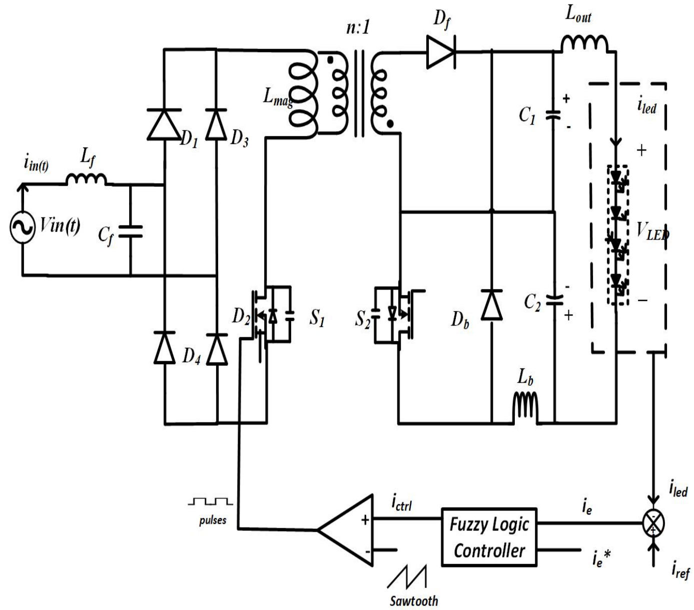



Fig. 4. Control Diagram Of the proposed LED Driver.

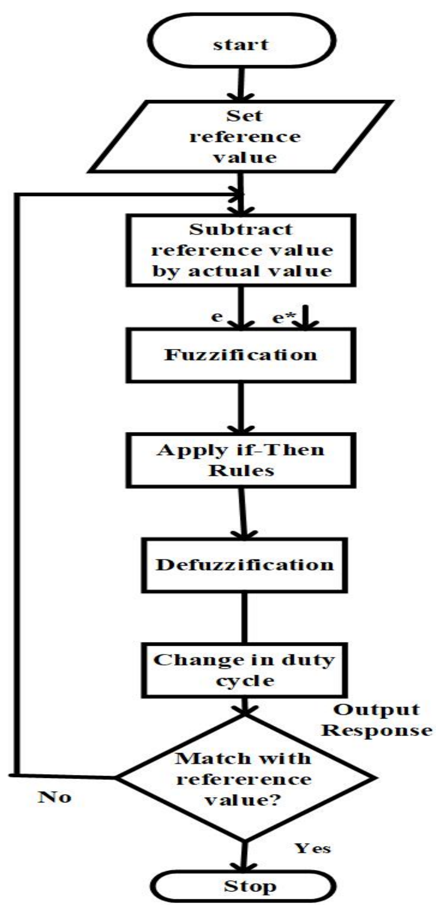



Fig. 5. Process flow chart.

The FLC is fed with inputs, namely the error $i_e$ and its variation $i_e^*$, which are derived from

$$i_e = i_{\text{ref}} - i_{\text{led}} \tag{3}$$

$$i_e^* = i_e(k) - i_e(k-1) \tag{4}$$

where $i_{\text{led}}$ is the output LED current, $i_{\text{ref}}$ is the reference value, and $i_e$ represents the error value. The subscript "$k$" signifies that these values are considered at the opening of the $k$-th switching cycle. The duty cycle is provided as the output by FLC.

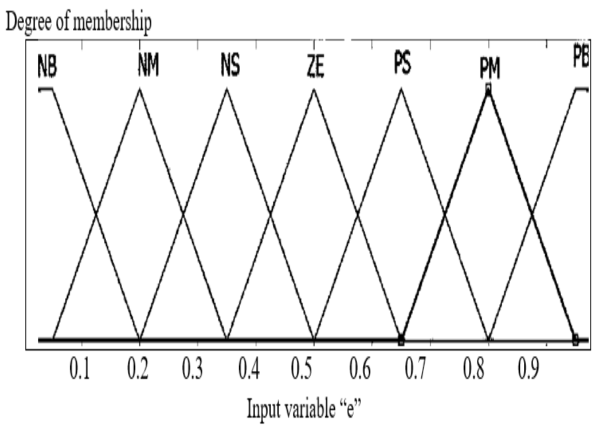



Fig. 6. Input membership Functions .

| e \ e* | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NB | NM | NS | Z |
| NM | NB | NB | NB | NM | NS | Z | PS |
| NS | NB | NB | NM | NS | Z | PS | PM |
| Z | NB | NM | NS | Z | PS | PM | PB |
| PS | NM | NS | Z | PS | PM | PB | PB |
| PM | NS | Z | PS | PM | PB | PB | PB |
| PB | Z | PS | PM | PB | PB | PB | PB |

Fig. 7. Rule Base Table [7].

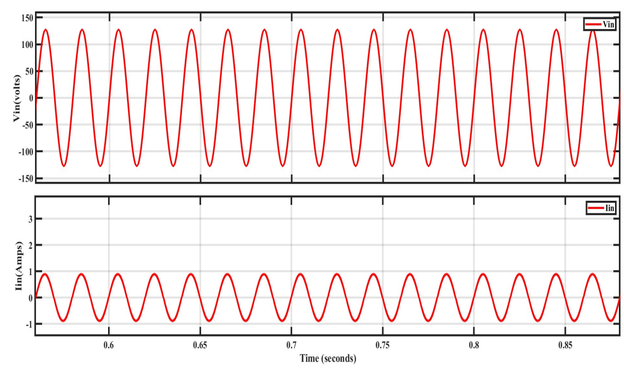
The fuzzy logic system evaluates rules using fuzzy set operations (Max for OR, Min for AND), combines the outcomes, and produces a fuzzy value as the conclusion and it uses rules expressed as IF-THEN statements to decide actions based on fuzzy inputs. Fig.7 displays a tabular representation of rules . The paper introduces a total of seven membership functions for both error and change in error, as depicted in Fig.6, a total of forty-nine rules are generated.

## IV. SIMULATION RESULTS

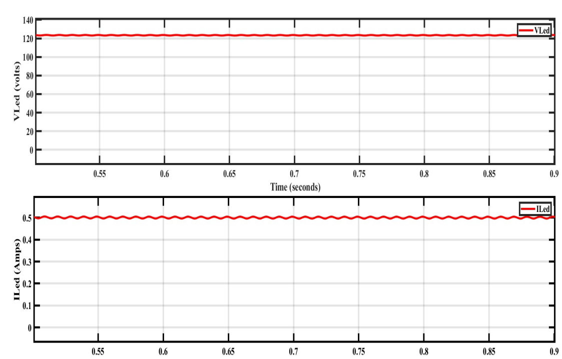
The simulation of the proposed FLC-based LED Driver is done by using both a PI controller and a fuzzy logic controller. TABLE.1 Shows the element parameters of the converter. The suggested converter's simulation results for a 90Vrms input voltage by the fuzzy logic controller are shown in Fig.8 The dynamic response with FLC and with a pi controller is shown in Fig.10

TABLE I
SIMULATION DESIGN SPECIFICATIONS

| Parameter | Value |
|---|---|
| Input Voltage($V_{in}$) | 90-270(rms) |
| Switching Frequency($F_{sw}$) | 40KHz |
| Magnetising Inductance($L_{mag}$) | 0.7mH |
| Turns Ratio(n:1) | 2:1 |
| Boost Inductance($L_b$) | 3mH |
| Output Capacitor($C_1$) | 70µF |
| Boost Capacitor($C_2$) | 10µH |
| Output Power($P_{out}$) | 62W |
| Output Current($I_{out}$) | 0.5A |




**(a)**

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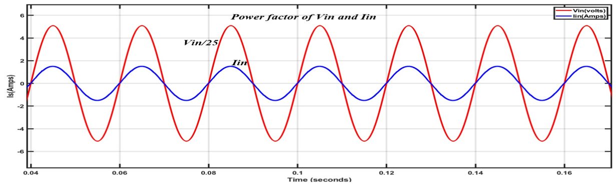
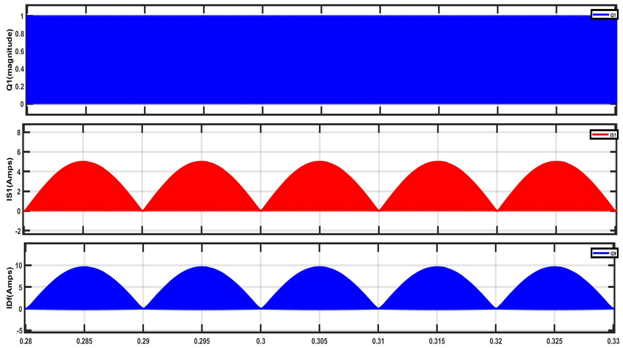



**(c)**

Fig. 8. (a)Input voltage and input current waveforms (b)Output voltage(Vled) and output current(Iled) waveforms (c) Power factor of Vin and Iin.

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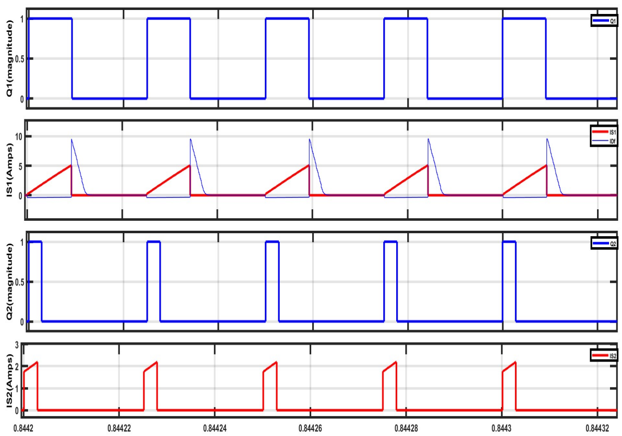
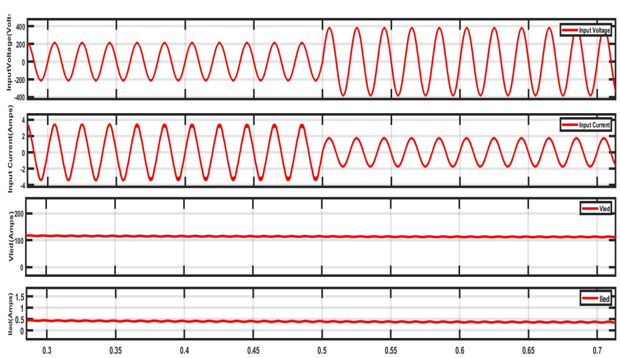



**(b)**

Fig. 9. Key Switching waveforms (a) Overall picture (b)Enlarged picture.

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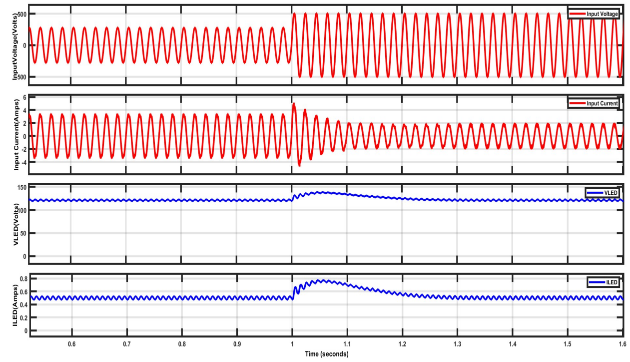


**(b)**

Fig. 10. Dynamic response with(a) Fuzzy logic controller (b)PI controller.

From the above simulation results, we can observe that when input voltage is increasing current decreases so as to maintain the input power constant. When the input voltage is changing fuzzy logic controller adjusts the duty cycle automatically and maintains the constant output. From the above results when input voltage is changing from 150Vrms to 270Vrms duty is automatically changing from 0.643 to 0.363 and maintains the output voltage and current constant at 124V and 0.5Amps.With the fuzzy logic controller, the LED driver demonstrates an output current ripple of 3.9% and a voltage ripple of 0.99%, while the PI controller results in an increased output current ripple of 4.807% and a voltage ripple of 1.2%. With the PI controller when input changes output takes some time to settle down. In simpler terms, the PI controller system exhibits impulsive behavior when the source voltage changes suddenly, whereas the output voltage and current flow smoothly with the fuzzy logic controller under the same input conditions.

## V. Conclusion

In this research, it presents a fuzzy logic controller (FLC) based ripple-free LED driver for power factor correction and ripple minimization. The Fuzzy Logic Controller (FLC) demonstrated its capability to keep the LED driver's output constant, smoothly adjusting to changes in input by automatically modifying the duty cycle making it suitable for a universal input range (90Vrms-270Vrms) and the fuzzy logic controller demonstrated a more effective dynamic performance than the PI controller. The proposed converter ensures a unity powerfactor, minimizes the output current ripple and eliminates the electrolytic capacitance replacing it with a film capacitor, and increases the LED driver's overall lifetime.

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