Design and implementation of a power supply unit for a smart airport lighting control system

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ABSTRACT

In this paper, a buck-boost converter is used to design and implement a power supply for intelligent airport lighting system applications. Innovative approaches to power supply design are required to meet the increasing demand for fault detection solutions for lighting systems in vital infrastructure such as airports. The buck-boost converter's ability to step up or down input voltage levels makes it particularly well suited to this application, ensuring stable operation over a range of load conditions. With a fast-settling time of 26 ms at 6.1 V input and dropping to 6 ms at 22.4 V input, the power supply offers exceptional output stability. The output stabilizes steadily at 5 V with low ripple over a wide input voltage range (5 V to 23 V). The physical prototype, simulations, component selection and circuit design are all carefully tested and supported by experimental results. According to these results, the proposed converter-based power unit operates with stability and reliability, making it ideal for demanding lighting applications. By improving power stability in dynamic environments, this work improves the reliability of aviation infrastructure power systems and lays the groundwork for future advances in intelligent airport technologies.

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1. INTRODUCTION

The power supply is an essential component that plays a critical role in any electronic system. It provides voltage regulation, power transfer, power conversion, and system protection. In voltage regulation, the power supply maintains a stable output voltage or current despite fluctuations in the input. It also transfers energy efficiently while adjusting voltage and current levels as needed, and provides protection against overcurrent, overvoltage, and short circuit. Power supplies are widely used in various industrial applications, including automotive systems, renewable energy, electronic devices, and aviation. In the latter, power systems have become increasingly critical due to the continuous development of applications such as airport runway lighting control systems. These systems, which consist of integrated lights, power supplies, and control units, are designed to illuminate airport runways, taxiways, and approach zones - providing essential visual guidance for pilots, especially in low visibility conditions. They must comply with stringent International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) guidelines that require consistent lamps brightness levels for safe operation in various environmental conditions [1]-[4].

Recent advances have introduced intelligent lighting systems capable of monitoring the status of individual lamps [5]. As shown in Figure 1, these intelligent modules - typically installed between lamps and isolating transformers - improve fault detection and overall lighting control. However, the major challenge is the voltage fluctuations at the secondary terminals of the transformer caused by changes in runway brightness settings. Without a stable power unit (A), supporting modules such as the measurement (B), processing (C), and communication (D) units can experience a performance degradation and an ultimately affect on the reliability of the entire system. Furthermore, achieving compactness, efficiency, and robustness in the presence of fluctuating input voltages remains an open challenge. This identifies a clear gap in the current literature and design approaches for intelligent airport lighting systems.

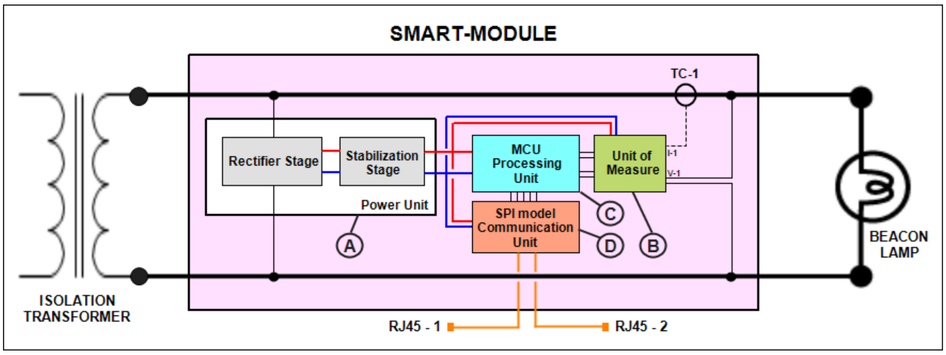

Figure 1. Block diagram of the proposed smart module [5]

To address these limitations, this paper proposes a novel power supply based on a buck-boost converter. Buck-boost converters are static energy converters that regulate the output voltage regardless of whether the input is higher or lower than the target level. Their high efficiency, compact size, and adaptability make the Buck-boost suitable for environments with varying electrical conditions. Over the past decade, significant improvements have been proposed to increase their performance and efficiency [6]-[11]. These converters have found widespread use in battery-powered devices, light emitting diode (LED) drivers, renewable energy systems, and electric vehicle power systems [12]-[18].

This paper presents a custom buck-boost converter designed for intelligent airport lighting systems. It focuses on ensuring stable output under variable input conditions, and improving the overall resilience of the airports lighting infrastructure. The proposed design will be analytically modeled, simulated, and validated through a fabricated prototype. This work contributes to the design of robust and efficient power supply unit used in the aviation lighting systems.

2. THE PROPOSED CIRCUIT DESIGN

2.1. Operating principle of Buck-Boost converter

The buck-boost converter is one of the most frequently used converter topologies in electronics since it allows either increasing or decreasing voltage. Such converter types operate by the output voltage's pulse width modulation (PWM). They are crucial in applications where voltage needs to be maintained constant even when the input voltage fluctuates [19]-[24].

The circuit in question is a combination of a buck converter and a boost converter in the form of step-up/step-down converters as shown in Figure 2. It can be observed that T_{on} is the period of conduction when Q1 and Q2 are turned on. During this period, the inductor stores the energy. During the period when the transistors are turned off, the energy stored is transferred to the load through the output capacitor while the rotation of diodes D1 and D2 remains forward-biased. A feature of the circuit is its ability to ground reference the output voltage during the T_{off} period. This gives more design options for setting the output voltage to be less than, equal to, or greater than the input voltage.

A key advantage of this configuration is its inherent current limiting capability, which reduces the risk of damage to components such as L or D2 during overload or short circuit conditions. This protection is achieved by placing Q1 in series with V_{out}, similar to the topology of a step-down circuit. The principles and design considerations of this circuit are adapted from previously established methods in power electronics [25]-[27].

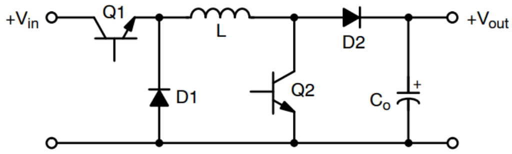

Figure 2. Combined configuration step-up/down regulator

2.2. Field measurements

To develop an intelligent fault detection module (smart module) for airport lighting systems, it is crucial to design a robust power supply stage. This power supply must provide a rectified and stabilized DC output voltage of 5 V to power key components of the smart module, including its processing, measurement, and communication units [5]. The design must also accommodate input voltage variations caused by changes in runway light brightness, a requirement specified by ICAO and FAA standards [1], [3].

Field measurements were conducted at Al Massira Airport in Agadir – Morocco as shown in Figure 3 to evaluate the input voltage ranges at different brightness levels (B1 to B5). These measurements were taken with OSRAM PK30d 6.6 A, 150 W airport beacon lamps as summarized in Table 1.

Figure 3. Field measurements at Al Massira Airport in Agadir - Morocco

Table 1. The measurements of the voltage and current at the terminals of the runway edge lamps

Brightness	Voltage (V)	Current (A)
B1	5.9	2.83
B2	7.7	3.45
B3	9.2	4.16
B4	14.8	5.24
B5	22.3	6.63

The measured voltage and current values illustrate the direct relationship between lamp brightness and terminal voltage. At higher brightness levels (B4, B5), increased filament temperatures result in higher currents and terminal voltages, while lower brightness levels (B1, B2) have the opposite effect. This behavior is consistent with well-established principles of incandescent lamp operation, where filament resistance increases with temperature, affecting brightness and current flow [28]-[30]. These measurements confirm the need for a robust power supply that can stabilize the output voltage despite variations in input conditions. The proposed design achieves this goal through the use of a buck-boost converter, the implementation of this latter is discussed in detail in the following sections. The field data and theoretical underpinnings provide a reproducible basis for the design, ensuring its applicability to similar systems.

2.3. The proposed power supply using a buck-boost converter

2.3.1. Component selection and design justification

The MC34063 integrated circuit (IC) was selected for its suitability in low-power applications, cost-effectiveness, and ease of integration into designs requiring direct current to direct current (DC-DC) conversion. This IC integrates key components such as a temperature-compensated reference, oscillator, comparator, pulse width modulation (PWM) controller, and high-current output switch, which can reduce the need for external parts. Its ability to operate in buck, boost, and buck-boost configurations enables flexible and compact designs, particularly relevant to the variable input voltage conditions of the proposed system [31]. The design advantages of the MC34063 have been extensively demonstrated in previous studies for power supply solutions where stability and efficiency are critical [32], [33]. Its low quiescent current and wide input voltage range make it ideal for handling the input voltage variations (5.9 V to 22.3 V) found in the airport intelligent lighting system's operating environment.

2.3.2. Circuit architecture

The proposed circuit, illustrated in Figure 4, is developed with three main functional units or stages such as rectification and filtering, voltage regulation, and protection with additional filtering, to ensure reliable and stable performance at all times. All three stages are designed developed, and fabricated with strict adherence to design guidance and replication requirements for safety, effectiveness, and availability.

The rectification and filtering stage uses a three-stage capacitor combination to filter out and correct the incoming AC voltage to ensure a stable outflow of DC voltage across the board. A bridge rectifier (BR1) transforms the AC input to DC, and with capacitors (C1, C2, C3), the unbalanced voltage is smoothened, as is the suppression of high-frequency signals, thus ensuring a clean power supply to other stages.

The voltage regulation stage is built with the MC34063 IC operated in a buck-boost mode to receive a variable input voltage and always produce a 5 V output voltage at the end. The output voltage however, is also controlled accurately by connecting the Feedback resistors (R1, R2) to the internal reference of the IC, this stage allows only a properly regulated supply to the circuitry which has a high threshold of sensitivity even if its parameters are inadequately altered at its input. Before the current discharging, diodes D1 and D2 serve as a preventative measure against voltage spikes while an inductor L1 ensures consistency of the current by covering any potential gaps. Lastly, the stage which serves as the filter as well as protection for the board chips against short circuits as well as smoothing out the overall output power.

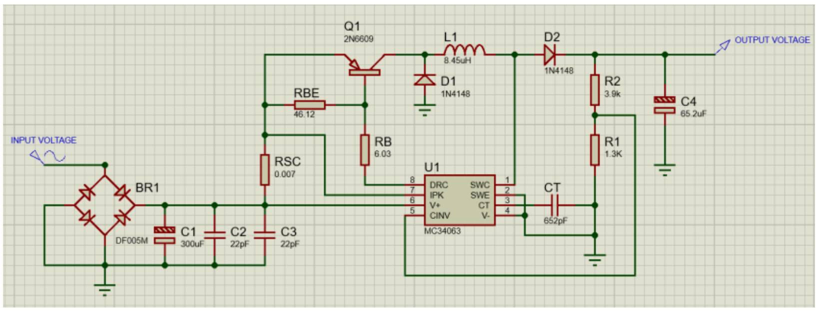

Figure 4. The proposed design of a step-up/step-down switching regulator

2.3.3. Design calculations

The design process followed standard methodologies for buck-boost converters as described in [31], [34], [35]. The design specifications of the proposed circuit are given below:

- Input voltage (V_{in}): 5.9 V to 22.3 V
- Output voltage (V_{out}): 5 V
- Switching frequency (f_{min}): 50 kHz
- ON time of one cycle ($T_{on(max)}$): 16.3 µs
- Output current (I_{out}): 200 mA
- Ripple voltage (V_{ripple}): 1% of V_{out} or 50 mV
- Reference voltage (V_{ref}): 1.25 V

Component values were calculated systematically using established formulas:

- Feedback resistors R_1, R_2

$$R_2 = R_1\left(\frac{V_{out}}{V_{ref}} - 1\right) = 3 \times R_1 \quad (1)$$

1.3 kΩ resistor has been chosen for R_1, for obtained 5V output voltage, then R_2 would be 3.9 kΩ.

- Timing capacitor C_T

$$C_T = 4 \times 10^{-5} \times T_{on(max)} = 652\ pF \quad (2)$$

- Inductor value L_1

$$L_1 = \left(\frac{V_{in(\min)} - V_{satQ1} - V_{satQ2}}{2\, I_{out} \left(\frac{T_{on}}{T_{off}} + 1 \right)} \right) T_{on} = 8.45\ \mu H \tag{3}$$

– The current limiting resistor R_{SC}

$$R_{SC} = \frac{0{,}33}{\left(\frac{V_{in(\max)} - V_{satQ1} - V_{satQ2}}{L_{min}} \right) T_{on(\max)}} = 0.007\ \Omega \tag{4}$$

– Output filter capacitor C_4

$$C_4 = \left(\frac{I_{out}}{V_{ripple}} \right) T_{on} = 65.2\ \mu F \tag{5}$$

– The base-emitter blocking resistor R_{BE}

$$R_{BE} = \frac{10 \times B_f}{I_{pk(switch)}} = 46.12\ \Omega \tag{6}$$

– The base drive resistance R_B for Q1

$$R_B = \frac{V_{in(\min)} - V_{satQ1} - V_{BEQ1}}{I_B + I_{R_{BE}}} = 6.03\ \Omega \tag{7}$$

3. RESULTS AND DISCUSSION

The purpose of this study was to design and evaluate a robust power supply circuit capable of maintaining a stable 5 V output under varying input voltage conditions, specifically for an intelligent airport lighting control system. This section presents the simulation and experimental results, discusses their significance, and relates them to previous research.

3.1. Simulation results

Simulations were conducted using Proteus software to assess the circuit's performance across a range of input voltages (5.9 V to 22.3 V). The results, shown in Table 2 and Figures 5 to 9 demonstrate that the circuit consistently stabilized the output voltage at 5 V, regardless of the input voltage variations.

Table 2. The results of the output voltage and response time simulation

Input voltage (V)	Output voltage (V)	Response time (ms)
5.9	5.0	27
7.7	5.0	25
9.2	5.0	12
14.8	5.0	10
22.3	5.0	8

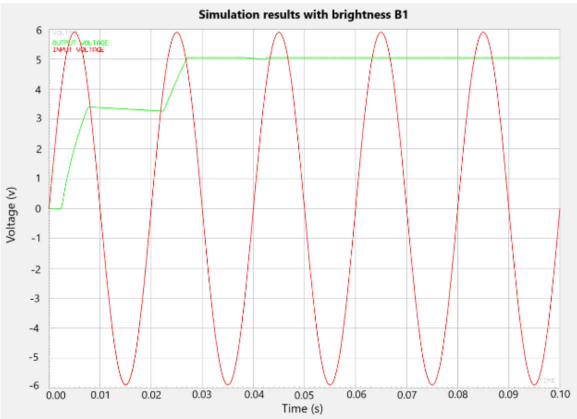

Figure 5. The simulation results with brightness B1

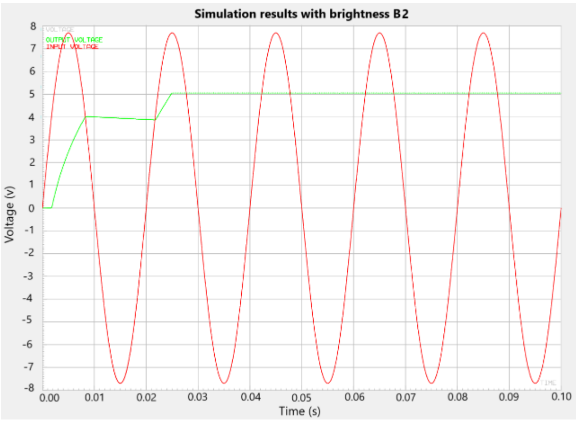

Figure 6. The simulation results with brightness B2

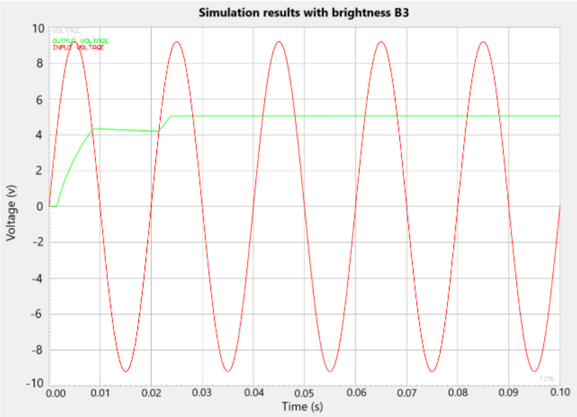

Figure 7. The simulation results with brightness B3

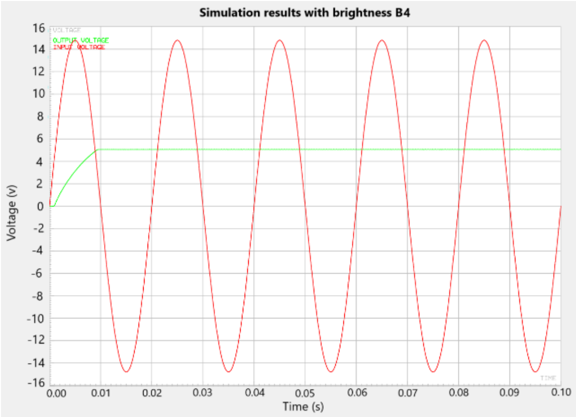

Figure 8. The simulation results with brightness B4

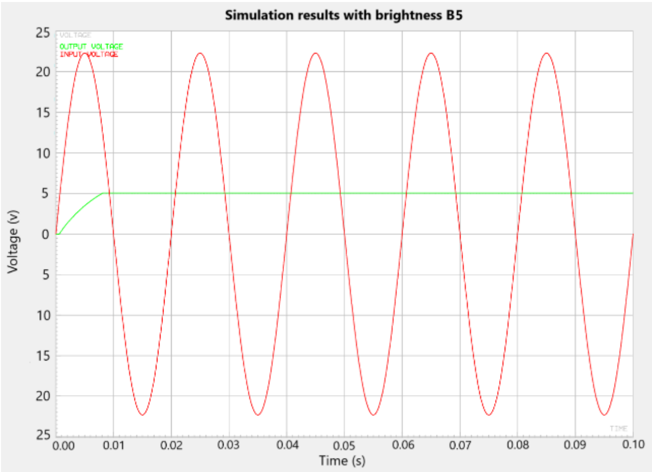

Figure 9. The simulation results with brightness B5

As observed in Figures 5 to 9, the response time decreases with increasing input voltage. This behavior can be attributed to reduced stress on the circuit components at higher voltages, enabling faster output stabilization. These findings align with standard literature [36], which reports similar improvements in response time for buck-boost regulators operating at elevated input voltages.

3.2. Experimental results

A circuit prototype was built to validate the simulation results in Figure 10. Real-time measurements were taken under identical conditions in Figure 11. The measurements confirmed the accuracy of the simulation. The data supports further analysis.

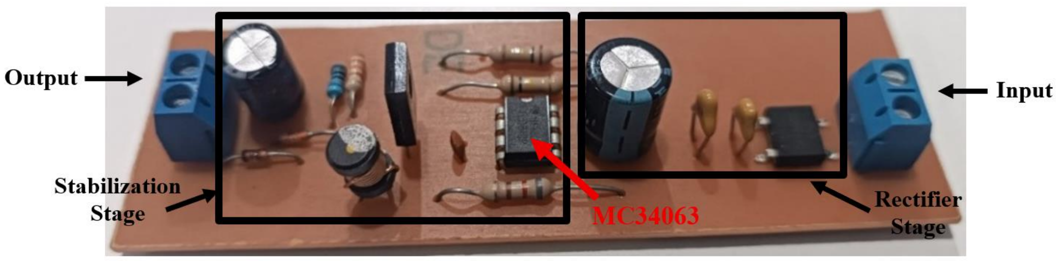

Figure 10. The proposed circuit prototype

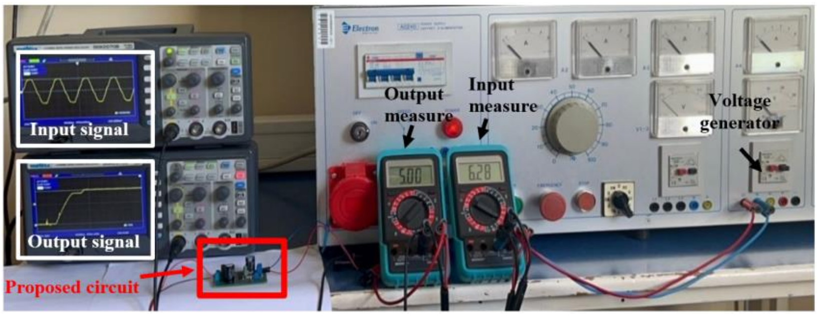

Figure 11. The experimental setup

The experimental results, shown in Table 3 and Figures 12 to 16, closely matched the simulated data, further confirming the circuit's ability to maintain a stable 5 V output. The experimental results reaffirm that the circuit is robust, demonstrating excellent immunity to input voltage variations. This feature is critical for intelligent lighting systems, where stable power supply performance ensures uninterrupted operation of lighting modules.

Table 3. The experimental results of the output voltage and response time

Input voltage (V)	Output voltage (V)	Response time (ms)
6.28	5.0	26
7.4	5.0	22
10.2	5.0	16
15.3	5.0	12
22.4	5.0	6

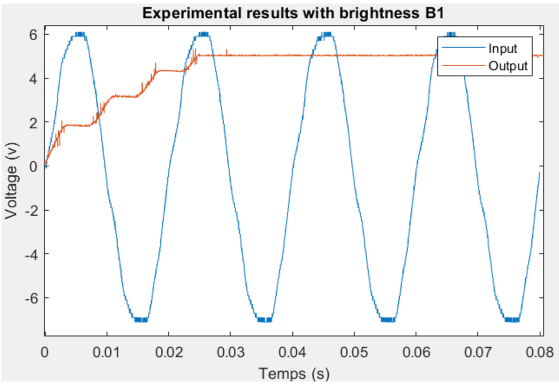

Figure 12. Experimental results with brightness B1

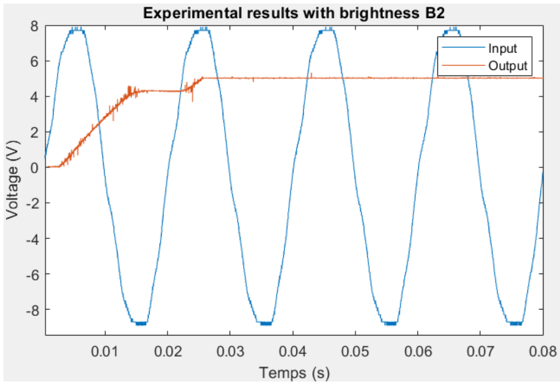

Figure 13. Experimental results with brightness B2

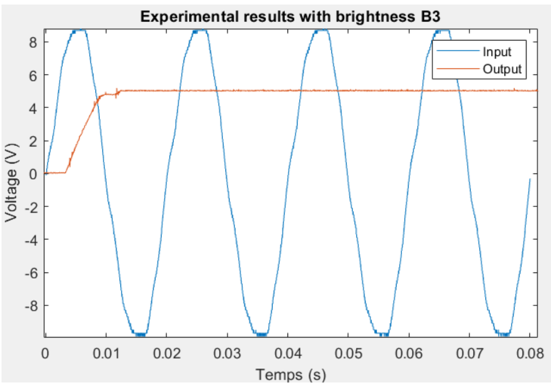

Figure 14. Experimental results with brightness B3

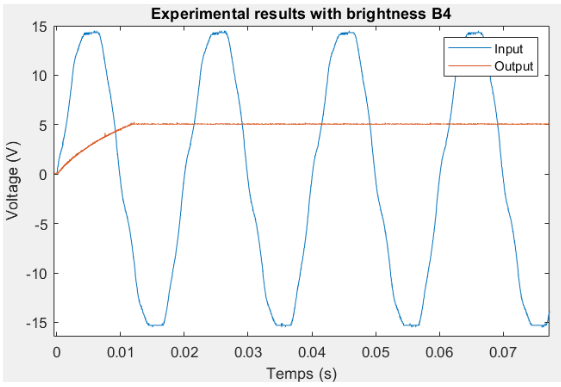

Figure 15. Experimental results with brightness B4

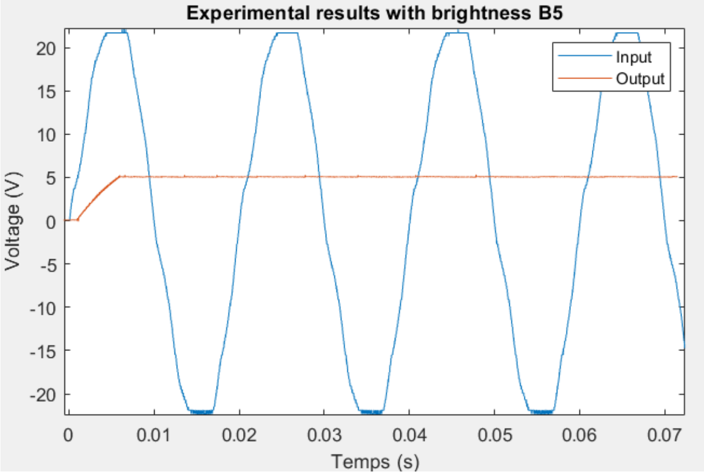

Figure 16. Experimental results with brightness B5

The results shown in Table 4 of this study were compared with similar work in the literature to highlight the advances achieved by the proposed circuit design. In terms of voltage stability, the findings align with previous studies, such as [37], where a buck-boost topology successfully regulated the output voltage despite significant input fluctuations. However, our design demonstrates improved response time due to the careful optimization of key components, such as feedback resistors and the inductor, enabling faster output stabilization. Regarding response time, the proposed circuit significantly outperforms existing designs reported in the literature. For instance, in [23], response times ranged between 12–20 ms depending on the input conditions, whereas our circuit achieved a rapid stabilization time as low as 6 ms at higher input voltages. This enhanced performance can be attributed to the efficient use of the MC34063 IC in buck-boost mode, which minimizes stress on circuit components while ensuring faster voltage correction. These findings demonstrate the proposed circuit's ability to stabilize output voltage quickly and reliably, making it particularly well-suited for critical systems, such as intelligent airport lighting, where rapid adaptation to voltage variations is essential.

Table 4. The comparison of buck-boost converter response times

Study	Input voltage (V)	Output voltage (V)	Switching frequency (kHz)	Response time (ms)
Rana *et al.* [23] in 2021	10 to 75	15	75	12 to 20
Veerachary and Khuntia, [37] in 2021	36	20	50	9
This work	5.9 to 22.3	5	50	6 to 26

4. CONCLUSION

This paper presents the design, simulation, and experimental validation of an intelligent power supply unit tailored for next-generation airfield lighting systems. Using a buck-boost converter, the proposed unit ensures a stable 5 V output over a wide input voltage range (5 V to 22.3 V). Simulations were performed using Proteus software, and the results were verified using a fabricated prototype. The experimental results show strong performance in terms of output stability and response time. Specifically, the device achieves voltage stabilization in 26 ms at 6.28 V input, with the response time decreasing to 6 ms as the input voltage increases to 22.3 V. Once stabilized, the output remains consistently clean and regulated over the entire input range.

This work contributes to the advancement of intelligent power systems by providing a reliable and efficient solution suitable for dynamic and demanding airport environments. It addresses a critical design challenges in smart lighting infrastructure and improves system resilience and operational safety. However, the study has certain limitations, such as the testing under different environmental conditions and the lack of long-term performance evaluation. Future works will focus on optimizing circuit efficiency under variable load conditions, exploring alternative converter topologies for improved performance, and conducting real-world deployment testing in operational airport environments. These efforts aim to further validate and extend the applicability of the proposed design to broader smart infrastructure applications.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

INFORMED CONSENT

Not applicable. This study did not involve human participants who required informed consent.

ETHICAL APPROVAL

This research did not involve any experimentation on human participants or animals.

DATA AVAILABILITY

The authors confirm that the data supporting this study's findings are included in the article.

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