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Design and Implementation of a High-Efficiency 12V Dual Power Supply System for Electric Vehicle Battery Charging Applications

Stephen Eduku, Joseph Sekyi-Ansah

***Abstract:** The rapid demand for efficient and reliable battery charging solutions for electric vehicles (EVs) has unveiled the limitations of conventional single-source chargers. To address these challenges, this research paper presents the design and implementation of a 12V dual power supply battery charger system capable of operating from both AC mains (grid) and renewable DC sources such as solar photovoltaic (PV) systems. The proposed system (charger) integrates a highly efficient power conversion stage with intelligent charge control to ensure fast, safe, and cost-effective charging. Automated source selection and discontinuous-mode soft switching are employed to improve flexibility, minimize switching losses, and reduce thermal stress. A prototype was designed and simulated using Circuit Wizard software, programmed in C++, and experimentally tested. However, results confirm stable operation with a constant 12V output from both grid and solar inputs, demonstrating enhanced efficiency and reliability. The proposed charger offers a sustainable and versatile solution suitable for domestic, commercial, and industrial energy storage applications.*

***Keywords:** Battery Charger Design, Energy-Efficient Charging Systems, Dual Power Supply, Grid and Solar Photovoltaic Integration, Automated Source Selection Mode, Electric Vehicle.*

Nomenclature:

BESS: Battery energy storage system
ICEs: Internal combustion engines
MPPT: Maximum Power Point Tracking
GSM: Global System for Mobile Communications
LCD: Liquid Crystal Display
AC: Alternating Current
DC: Direct Current
CC: Constant Current
CV: Constant Voltage
PCB: Printed Circuit Board
PV: Photovoltaic
EVs: Electric Vehicles
BMS: Battery Management System
PHM: Prognostics and Health Management
V2G: Vehicle-to-Grid
EVSE: Electric Vehicle Supply Equipment
LIBs: Lithium-Ion Batteries
MSCC: Multi-Stage Constant Current
AI: Artificial Intelligence

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*Correspondence Author(s)

Dr. Stephen Eduku*, Department of Nautical Studies, Faculty of Engineering, Takoradi Technical University, Takoradi, Ghana. Email ID: 5103180335@stmail.ujs.edu.cn, ORCID ID: 0000-0002-9210-8187

Dr. Joseph Sekyi-Ansah, Department of Oil and Natural Gas Engineering, Faculty of Engineering, Takoradi Technical University, Takoradi, Ghana. Email ID: joseph.sekyi-ansah@ttu.edu.gh

I. INTRODUCTION

An effective battery charging system has become essential in today's world due to the rapid emergence of electric vehicles (EVs), which are crucial in reducing greenhouse gas emissions and mitigating global warming caused by internal combustion engines (ICEs). Moreover, advancements in modern technology have increased the demand for portable power supply systems, thereby enhancing mobility and supporting a wide range of domestic, commercial, and industrial devices. Despite this demand, most battery charging solutions remain heavily dependent on conventional grid supply, contributing to energy challenges in many parts of the world. Consequently, the development of dual-source battery charging systems is not only inevitable but also represents a key area of ongoing research in sustainable energy solutions.

Moreover, a review of existing literature reveals that both conventional and emerging battery management system (BMS) technologies play a crucial role in enhancing the efficiency and sustainability of electric vehicles. Previous studies have shown that advancements in BMS architecture significantly improve battery reliability, safety, and lifespan, thereby supporting sustainable transportation initiatives. Research further indicates that effective energy regulation and the integration of renewable energy sources contribute to cleaner and more resilient mobility systems. Collectively, these studies emphasize the ongoing need for innovation in BMS development to achieve long-term global sustainability goals [1].

Nonetheless, recent literature indicates a rapid increase in electric vehicle (EV) adoption, primarily driven by environmental concerns, the depletion of fossil fuels, and the shift toward renewable energy. Studies emphasize that expanding EV charging infrastructure is vital for transitioning from internal combustion engines to electric mobility. Research further compares conventional and advanced charging methods based on operation modes, power topologies, and efficiency. Advanced systems, such as fast, intelligent, and wireless charging, as well as battery swapping, have been explored for their potential to integrate renewable energy and reduce grid load. Overall, prior studies emphasise the need for ongoing innovation in energy management, storage, and power electronics to enhance future EV charging networks [2].

Furthermore, recent literature indicates substantial progress in battery technology, driven by the need to satisfy increasing performance and sustainability requirements in

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both electric mobility and stationary energy systems. In the transportation sector, batteries serve as the primary energy source for electric, plug-in hybrid, and fuel cell vehicles, utilising various charging techniques, including conventional, rapid, and vehicle-to-everything systems.
For stationary applications, batteries are progressively integrated into microgrids and smart grids to enhance energy management and provide temporary storage. Research further reveals advancements in power electronic interfaces, resulting in increased efficiency, enhanced thermal resilience, and improved system durability. Additionally, innovations in electrode and electrolyte materials continue to strengthen energy density, safety, and lifespan, shaping the development of next-generation sustainable battery technologies [3].

Additionally, previous studies have demonstrated that the increasing deployment of lithium-ion batteries in electric vehicles and various industrial applications has heightened the demand for advanced charging strategies designed to enhance charging speed, reliability, and overall battery lifespan. Over the past decade, extensive research has been conducted to identify the optimal charging methods for commercial lithium-ion batteries. However, only a limited number of works have presented a detailed comparative assessment from a control-oriented perspective at the battery pack level. Existing literature broadly classifies charging control techniques into three main categories: non-feedback, feedback, and intelligent control methods. Collectively, these studies highlight the relative strengths and limitations of each approach, providing valuable insights for the development of more efficient and reliable battery charging systems [4].

Meanwhile, recent studies reveal that escalating fossil fuel costs and environmental concerns are driving the global transition toward electric vehicles (EVs) as sustainable alternatives to conventional automobiles. While EV adoption continues to expand rapidly, the large-scale integration of EVs into power grids presents notable operational and technical challenges. Literature highlights that efficient management of charging and discharging activities is crucial to prevent grid instability and performance issues. Moreover, EVs are increasingly viewed as potential distributed energy storage units that can support grid reliability. Research has therefore examined various control structures, optimization strategies, and management objectives for EV charging systems, with a focus on enhancing operational efficiency, economic viability, and environmental sustainability [5].

However, advancements in research demonstrate the development of an improved constant-current and constant-voltage charging strategy aimed at enhancing the efficiency, reliability, and safety of battery charging systems. The approach refines traditional charging frameworks through a cascade control structure that dynamically adjusts the charging current based on real-time estimates of the battery's open-circuit voltage. Two feedback controllers operate concurrently to regulate the charging process and prevent overvoltage conditions. An adaptive reference model ensures stable parameter estimation and overall system performance. Simulation results validated with lithium-iron-phosphate batteries reveal that this method achieves approximately 24% faster charging compared to conventional techniques, representing a practical and cost-effective advancement in modern battery management systems [6].

Recent literature highlights the profound impact of electric vehicles on the automotive industry's evolution. The steady growth of the global EV market is primarily driven by greater model diversity, falling production costs, and advancements in battery innovation. Although substantial progress has been made, ongoing research continues to focus on enhancing the energy density, compactness, and system reliability of battery technologies. Developments in battery materials are also geared toward reducing charging time and extending operational lifespan, reinforcing the viability of EVs as alternatives to conventional combustion vehicles. Global sales data indicate a strong upward trend, with over three million EVs sold in 2020, representing an increase of more than 40 per cent, and projections suggesting their share could approach 30 per cent of total vehicles by 2030 [7].

Contemporary studies suggest that electric vehicles play a crucial role in promoting carbon neutrality and mitigating the impacts of climate change. Progress in this field is closely linked to continual innovation in battery chemistry, management systems, and supportive policy measures. Existing research highlights substantial achievements and ongoing challenges across both hybrid and fully electric vehicle technologies. Emerging directions focus on enhancing lithium-ion, lithium-metal, and post-lithium batteries, complemented by data-driven electrothermal modelling for improved performance and reliability. Moreover, developments in wireless and dynamic charging are reducing dependence on large-capacity batteries. Collectively, the current literature indicates that integrating intelligent energy networks with advanced battery systems is crucial to achieving sustainable electric mobility [8].

Additionally, electric vehicle (EV) technology has emerged as a key driver of sustainable transportation due to its efficiency and potential for reducing emissions. Studies reveal significant progress in battery management, power electronics, and charging systems, yet challenges persist in battery monitoring, thermal control, and fault diagnosis. Integrating lithium-ion batteries with supercapacitors and bidirectional converters offers promising solutions for optimizing EV energy management [9].

Moreover, findings from existing studies indicate that the global transition toward sustainable transportation has positioned electric vehicles (EVs) as strong contenders to replace conventional internal combustion engines. Literature reviews reveal notable progress and ongoing challenges in EV development across both component and system levels, with increasing emphasis on intelligent maintenance supported by Prognostics and Health Management (PHM) frameworks. Research further highlights advancements in battery materials, charging infrastructure, and system optimization, all aimed at improving EV reliability, operational efficiency, and long-term sustainability [10].

Furthermore, recent studies suggest that global efforts to achieve the UN's Sustainable Development Goals, particularly SDG 7 on affordable and clean energy, are accelerating the adoption of electric vehicles (EVs) as a sustainable transportation alternative. Research on EV

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charging technologies has highlighted significant advancements in both front-end and back-end power converter designs, which are crucial to efficient battery charging. Comparative analyses of various EV charging topologies reveal distinct strengths and limitations across systems. Scholars have also proposed numerous optimization strategies to enhance charging performance and efficiency. Furthermore, investigations into vehicle-to-grid (V2G) technologies demonstrate their potential to enhance the integration of renewable energy, strengthen smart grids, and improve grid reliability. However, challenges such as bi-directional power management and infrastructure development remain. Current literature also emphasizes emerging research directions, including wireless charging, seamless grid integration, and battery life optimization, as key areas for future exploration [11].

Moreover, electric vehicles (EVs) are increasingly recognised as a cleaner and more sustainable alternative to traditional internal combustion engine automobiles, with the potential to reduce greenhouse gas emissions and dependence on fossil fuels significantly. Nonetheless, the large-scale transition to EVs relies on the availability of reliable, efficient, and easily accessible charging infrastructure. Recent research has documented notable progress in EV charging technologies, focusing on aspects such as power capacity, voltage and current characteristics, and connector configurations that determine charging efficiency and system compatibility. Despite these advancements, persistent challenges, such as range anxiety, grid integration limitations, and the lack of universal charging standards, continue to hinder widespread adoption [12].

Nonetheless, the rapid expansion of the electric vehicle (EV) industry has heightened the demand for efficient and dependable fast-charging systems. Recent studies have reported significant advances in DC fast charging, including the development of evolving standards and charging modes that reduce charging times and enhance performance. Research emphasises the development of improved DC–DC converter designs, AI-based control, and thermal management using smart sensors to improve efficiency, safety, and battery durability. Nonetheless, challenges in infrastructure, grid integration, and standardisation persist, as projections show that EVs could make up about 35% of global vehicle sales by 2030 [13].

Furthermore, electric vehicles (EVs) are widely regarded as efficient and low-emission alternatives to traditional fuel-powered transportation. As global adoption increases, efficient and accessible charging infrastructure remains vital. Research has advanced various charging methods, conductive, inductive, and battery swapping, each with distinct benefits and limitations. Progress in fast-charging, wireless transfer, and smart grid integration continues to enhance performance, although challenges persist in terms of speed, standardisation, and grid stability. Emerging innovations such as dynamic wireless charging are paving the way for smarter, more sustainable EV charging systems [14].

Additionally, electric vehicles (EVs) have become a significant enabler of the global energy transition; however, their large-scale deployment presents substantial challenges to power grid operation, stability, and planning. Recent research emphasises the development of efficient charging infrastructure and electric vehicle supply equipment (EVSE) to enhance energy utilisation and support the grid. Advancements in on-board and off-board charger topologies, converter designs, and renewable-integrated charging stations are noteworthy, although persistent challenges in grid integration, standardisation, and control optimisation continue to guide future research directions [15].

Nevertheless, lithium-ion batteries (LIBs) are the primary energy storage units in electric vehicles (EVs), where charging rate directly affects system efficiency, thermal behavior, and lifespan. The multi-stage constant current (MSCC) charging technique has emerged as a promising method to minimise charging time while improving energy utilisation and battery durability. However, defining the optimal number of stages, transition conditions, and charging currents remains a significant challenge. Recent studies have evaluated MSCC performance in relation to battery capacity, temperature rise, and cost implications, offering insights for optimising fast-charging systems and power battery design [16].

However, studies reveal that advancements in Battery Management Systems (BMS) are driving the transformation of second-generation hybrid and electric vehicles. Findings indicate notable progress in battery modelling, state estimation, charging control, and cell balancing techniques. Analyses also show improvements in efficiency, safety, and thermal management, although challenges remain in reliability and standardization. Research gaps reported emphasise the need for more intelligent control algorithms and stronger integration with renewable energy systems [17].

Meanwhile, energy storage systems play a crucial role in capturing and utilising energy efficiently, particularly amid the growing global energy crisis. Electric vehicles (EVs) have become central to reducing emissions, with their performance largely dependent on effective Battery Management Systems (BMS). Recent studies emphasise that advanced BMS technologies enhance charging control, thermal regulation, safety, and state-of-charge estimation, which are crucial for reliable EV operation. Despite ongoing progress, challenges persist in optimising the system and integrating it with renewable energy. Current research continues to explore improved materials, control strategies, and intelligent algorithms to strengthen BMS efficiency and support sustainable transportation goals [18].

Additionally, electric vehicles (EVs) are increasingly recognised for their role in reducing emissions and enhancing energy efficiency. Their performance is closely tied to advancements in battery technology and charging systems. Lithium-ion batteries remain the preferred choice for EVs due to their superior energy density, long lifespan, and affordability, though they are sensitive to temperature variations. Other battery types, including nickel-based, lead-acid, and solid-state options, offer trade-offs in terms of cost and performance. Innovations in wireless

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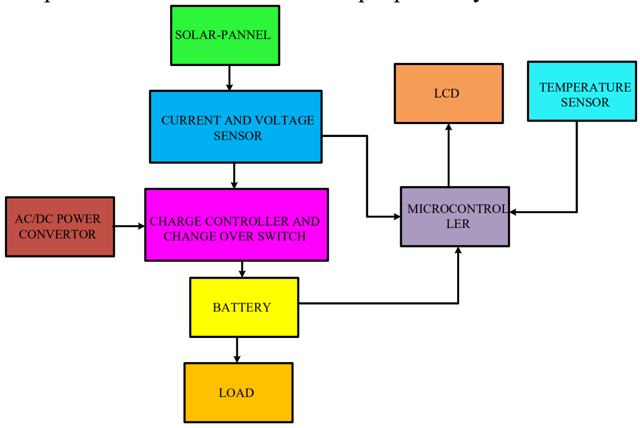
charging and artificial intelligence (AI) are enhancing charging convenience, system control, and energy management. However, sustainable large-scale EV adoption still depends on resolving challenges in recycling, material sourcing, and charging infrastructure [19].

Furthermore, electric vehicles (EVs) continue to face challenges, including high battery costs, limited energy density, and inaccurate state estimation using conventional methods. Recent research trends, based on analyses from the Web of Science database, highlight progress in battery development, safety management, and environmental sustainability. This review covers key energy storage technologies, including lithium-ion, solid-state, and lithium-air batteries, as well as fuel cells and ultracapacitors, emphasising their performance characteristics, benefits, and limitations. It also discusses IoT-enabled techniques for real-time battery monitoring and wireless charging technologies designed to enhance charging efficiency. The study concludes by identifying critical barriers and recommending pathways for advancing future EV battery systems and sustainable electric mobility [20].

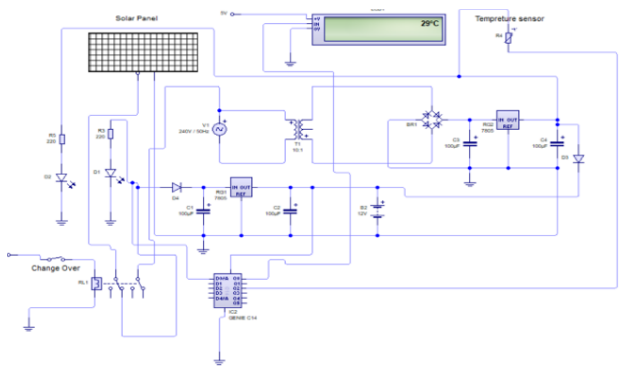
According to the analysis of existing studies, it is evident that most electric vehicle (EV) charging systems heavily rely on the power grid, creating challenges related to sustainability, energy reliability, and grid stress. This overdependence underscores a significant research gap in developing flexible and resilient charging systems. Therefore, it is imperative to design an efficient dual power-source battery charging system that integrates renewable energy with a conventional grid supply. Such a system will promote green energy utilization, reduce greenhouse gas emissions associated with internal combustion engines, and provide an effective backup power solution for emergency systems and facilities. This forms the central motivation and key objective of the proposed research.

II. MATERIALS AND METHODS

This section outlines the systematic approach used in designing and implementing the proposed 12V dual power supply battery charger. It describes the development process, simulation, prototype construction, and experimental validation. The charger was first modelled and simulated using Circuit Wizard software, supported by computer-based programming for control logic development. A physical prototype was subsequently constructed to verify the accuracy of the simulation results. Experimental tests were conducted, and the results were compared with the simulation data. Microsoft Excel was used as a statistical tool for analyzing and validating both sets of results. However, the design approach was guided by key power electronic principles, particularly in regulating current flow to ensure safe and reliable charging. A current sensor was integrated into the circuit to monitor and control charging current, thereby preventing overcurrent and potential system overload. The Arduino Uno microcontroller served as the central control unit, supplied with a regulated 5V power source to drive both the microcontroller and the current sensor. For clarity, Figure 1(a) presents the block diagram of the charger architecture, while Figure 1(b) illustrates the complete circuit schematic of the proposed system.



(a)



(b)

[Fig.1: Proposed Dual Battery Charger Design (a) Block Diagram (b) Circuit Diagram]

A. Construction Procedure

The construction of the 12V dual power supply battery charger involved both circuit integration and physical implementation steps. A temperature sensor was incorporated to monitor system conditions during switching, as illustrated in Figure 2(a). The two input power sources were connected to an automated switching unit, which ensured a continuous and reliable supply of the regulated 5V required for the microcontroller, sensor, and LCD interface. Bides. The microcontroller was configured in conjunction with the LCD, voltage regulator, and supporting components to achieve the intended system functionality. A rectangular Printed Circuit Board (PCB) layout was employed explicitly for the charger to facilitate compact assembly, ensure adequate cooling, and provide protection against thermal stress. The circuit pattern was transferred onto a copper-clad board, which was subsequently etched using a ferric chloride solution. After etching, the board was cleaned, drilled, and prepared for component placement. However, the electronic components were soldered onto the board according to the design layout, and the assembled circuit was enclosed within the PCB casing to ensure mechanical

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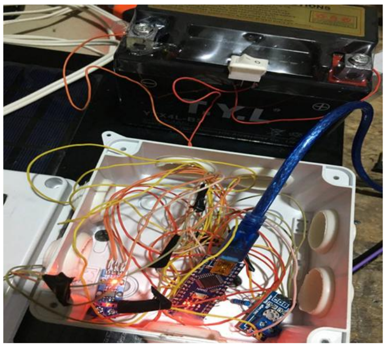
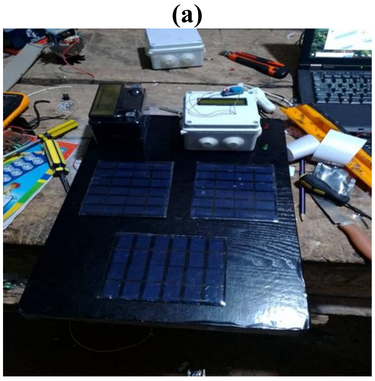
stability and minimize vibration-induced displacements. Figure 2(b) presents the completed hardware packaging of the proposed dual power supply battery charger.



(a)



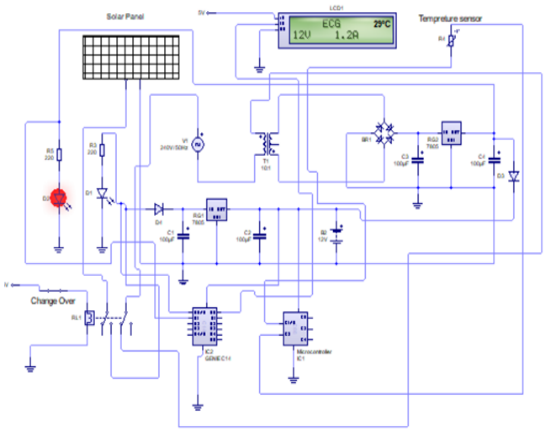
(b)

[Fig.2: Pictorial View of the Proposed Design (a) Construction Procedure (b) Packaging Procedure]

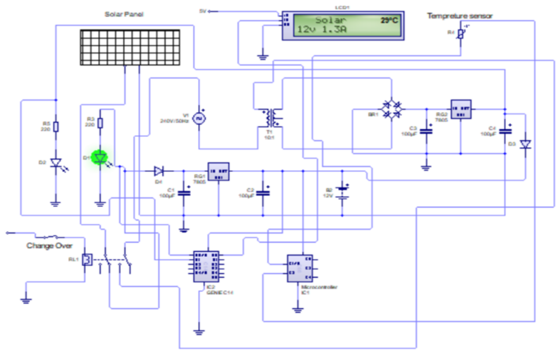
III. RESULT AND DISCUSSION

A. Simulation Results

The performance of the proposed 12V dual power supply battery charger was assessed through simulation using Circuit Wizard software. The system was tested under both grid (ECG) and solar input conditions while connected to the battery. As shown in Figure 3(a), the grid-supplied simulation displayed a stable charging voltage of 12 V with a current of 1.2 A. Likewise, Figure 3(b) demonstrates the solar-powered charging scenario, where the system provided 12 V at 1.3 A. The increased current in the solar mode indicates that the battery directly absorbed 1.3 A from the photovoltaic source, confirming the charger's ability to maintain constant voltage while adapting to different input conditions.



(a)



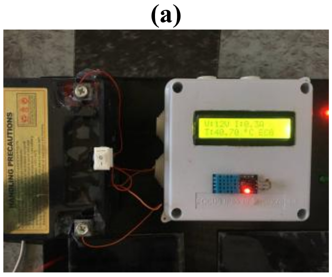
(b)

[Fig.3: Simulation Results (a) Grid Analysis (b) Solar Analysis]

B. Experimental Results

To validate the simulation results, a prototype of the proposed 12V dual power supply battery charger was constructed and tested. Figures 4(a) and 4(b) present the measured outcomes. Upon battery connection, the LCD showed a gradual variation in current until the predefined charging limit was reached. The experimental results closely aligned with the simulation, particularly in maintaining a constant output voltage of 12 V, which confirmed the reliability of the design. As shown in Figure 4(a), under solar input, the LCD recorded a charging voltage of 12 V with a current of 0.05 A. In grid-supply mode, as illustrated in Figure 4(b), the system maintained a 12 V voltage with a charging current of 0.3 A. These findings verify that the charger consistently delivered a regulated 12 V output from both sources, demonstrating its functionality and adaptability to dual-input operation.

(a)



(b)

[Fig.4: Experimental Results (a) Solar Analysis (b) Grid Analysis]

C. Discussion

The results obtained from both simulation and experimental testing provide significant insights into the performance and optimization of the proposed 12V dual-input battery charger. The LCD readings recorded during testing is summarized in the Table 1 highlights the close correspondence between

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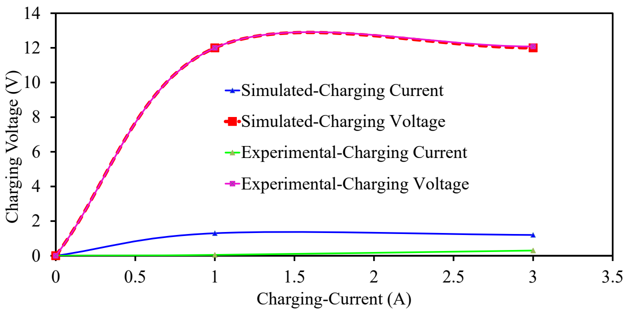
simulated and experimental values. For grid (AC) operation, the simulation yielded an output of 12 V and 1.2 A (Figure 3a), whereas the experimental test under the same conditions produced 12 V and 0.3 A (Figure 4b). Similarly, for solar (DC) operation, the simulation indicated 12 V and 1.3 A, whereas the experimental test measured 12 V and 0.05 A (Figure 4a). These results demonstrate that, despite variations in current values resulting from practical operating conditions and component tolerances, the system consistently maintained a target output voltage of 12 V across both power sources. The strong correlation between simulated and experimental outcomes confirms the accuracy of the system modelling and validates the reliability of the design. Furthermore, the charging characteristics illustrated in Figure 5 reinforce the stability and adaptability of the charger under dual-source operation, thereby supporting the effectiveness of the design for domestic, commercial, and industrial energy storage applications.

Table I: Design Simulation and Experimental Results Analysis

Mode	Simulated current (A)	Experimental charge current	Experimental charging voltage (V)	Simulated charging voltage (V)
off	0.00	0.00	0.00	0.00
Grid	1.2	0.30	12	12
Solar	1.3	0.05	12.08	12



[Fig.5: Proposed Design Charging Characteristics]

IV. CONCLUSION

The design and implementation of a dual 12V battery charger controller were successfully achieved using Circuit Wizard simulation and C++ programming, with experimental results validating the reliability of the proposed system. The charger demonstrated stable operation with both solar and grid power sources, confirming its adaptability and potential as a sustainable charging solution. Although the prototype delivered a consistent 12 V output, the experimental analysis revealed relatively low current levels, indicating the need for further optimization. Future research should therefore focus on enhancing current capacity and exploring the integration of wireless communication technologies, such as Bluetooth, Wi-Fi, or GSM, for remote monitoring and user notifications. Overall, the developed dual-source charger presents a cost-effective and practical solution, particularly suited for rural and off-grid communities with limited access to reliable electricity.

DECLARATION STATEMENT

I, the corresponding author, hereby declare that all listed authors contributed equally to this work. To the best of my knowledge, there are no conflicts of interest associated with this article. This research was conducted independently without any external funding or sponsorship. As the study did not involve human or animal subjects, ethical approval and participant consent were not required. All resources and materials referenced in this study are publicly available.

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/Competing Interests:** Based on my understanding, this article does not have any conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this Research is a crucial factor in affirming its impartiality, as it was conducted without any external influence.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The data and materials supporting the findings of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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AUTHOR'S PROFILE

Dr. Stephen Eduku, (PhD) is a Senior Lecturer in the Department of Electrical and Electronic Engineering at Takoradi Technical University, Ghana, and a member of the IEEE. He obtained his PhD in Power Electronics and Power Drives from Jiangsu University, China, in 2022. He also holds an M.Tech. and a B.Sc. in Electrical and Electronics Engineering from the University of Education, Kumasi Campus, Ghana, as well as an HND in Electrical and Electronic Engineering and a Diploma in Instrumentation from Takoradi Technical University. Dr Eduku's research interests include power electronics applications in power systems, renewable energy integration, smart grids, HVDC and FACTS technologies, electric drives, and the design and performance optimization of fault-tolerant permanent magnet flux-switching machines. He has over a decade of experience in teaching and research, and currently serves as the Head of the Department of Nautical Studies at Takoradi Technical University. His work focuses on bridging the gap between academic research and industrial practice to advance innovations in modern electrical engineering.

ING. Dr. Joseph Sekyi-Ansah, a Senior Professional Engineer. He received a Diploma in Education, a B.Sc., and an M. Tech from the University of Education, Winneba, Kumasi (2008-2015), and a PhD in Mechanical Engineering from Jiangsu University (2016-2020). He has been at Takoradi Technical University (TTU) for the past nine years as a Senior Lecturer and Head of the Department of Oil and Natural Gas Engineering, and a visiting scholar at IITR for the 2023-2024 academic year. He is currently a researcher in computational fluid dynamics, Finite Element Analysis (FEA), Image Processing, Cloud Image Processing, Cavitation, Non-Destructive Testing, and Material Characterization.