Engineering and Technology Journal e-ISSN: 2456-3358
Volume 10 Issue 08 August-2025, Page No.- 6586-6592
DOI: 10.47191/etj/v10i08.47, I.F. – 8.482

Design and Implementation of a Solar-Powered RFID-Enabled Charging Booth for Secure and Sustainable Device Charging

V. Agukwendu[1], O. E. Okoye[2], T. E. Amakoromo[3*]
[1,2,3]Department of Physics/Electronics Technology, University of Port Harcourt, River State, Nigeria

ABSTRACT: This study outlines the design and implementation of a solar-powered, RFID-enabled smart charging booth, which aims to deliver secure, efficient, and sustainable mobile device charging solutions in public spaces. The system incorporates solar energy to facilitate off-grid functionality, tackling the issues associated with inconsistent electricity supply in developing areas. The system incorporates RFID authentication to ensure secure access, permitting only authorised individuals to charge their devices, and offers both wired and wireless charging options. The setup incorporates an Arduino Nano microcontroller, ACS712 current sensors, and a wireless charging module to facilitate safe and real-time energy management. The experimental results illustrate the system's adaptability, showcasing its support for a range of mobile devices such as the iPhone 11 Pro (iOS 18), Samsung Z Fold 5 (Android 13), Redmi 9a (Android 10), and Infinix Hot 10 (Android 10). The various devices, spanning multiple operating systems and charging techniques, underscore the extensive applicability of the system in a range of environments. The results indicate that the system improves energy efficiency, enhances user security, and promotes sustainability in public charging infrastructure. Nonetheless, challenges such as the compatibility of wireless charging with Qi-standard devices and the necessity for expedited charging protocols have been recognised. Potential advancements may involve the incorporation of rapid charging technologies and NFC capabilities to expand device compatibility.

KEYWORDS: Solar-powered, RFID authentication, Wireless charging, Energy efficiency, Sustainability

INTRODUCTION

The swift growth of mobile technology has significantly altered modern society, rendering mobile phones essential for communication, commerce, and everyday activities. The evolution of mobile technology has been remarkable since Martin Cooper's demonstration of the first handheld mobile phone in 1973 and the launch of the world's first cellular network in Japan. As of 2014, the number of global mobile phone subscriptions exceeded seven billion, indicating a significant level of adoption (Harris & Cooper, 2019). Nonetheless, in light of their crucial function, mobile phones exhibit a considerable reliance on battery power, necessitating regular recharging (Olabi et al., 2022).

The evolution of smartphone technology has led to a significant rise in power consumption due to resource-intensive applications, including social media platforms like WhatsApp and Facebook, mobile gaming, and streaming services (Paneru & Tarigan, 2023). Consequently, individuals frequently face the challenge of swift battery drain, which requires them to seek dependable charging options (Liu et al., 2019; Gurung & Qiao, 2018). In numerous developing areas, especially in Africa, the electricity infrastructure is marked by instability, frequent outages, and limited coverage, making access to reliable charging facilities challenging (Amani & Jalili, 2021).

In response to these problems, many energy options have been looked into, and solar-powered charging systems have come out as a viable and environmentally acceptable option. Solar power is a plentiful renewable resource that can be used to charge devices in places where the grid is not stable (Yap et al., 2022). Solar charging can help with power supply problems, but there are still security risks at public charging stations. Unauthorised access, energy theft, and misuse can all make the system less efficient and reliable (Jha & Neupane, 2023).

Radio Frequency Identification (RFID) technology is widely utilised across multiple sectors such as access control, inventory management, and security due to its capacity for secure and contactless authentication (Munoz-Ausecha et al., 2021). The incorporation of RFID technology in charging stations establishes an effective access management system, permitting only authorised users to utilise charging services and minimising the potential for unauthorised access (Ayoade & Longe, 2024). Research indicates that RFID-enabled devices effectively reduce unauthorised access and improve operational efficiency (Yadav et al., 2025).

The integration of wireless charging technology into public infrastructure enhances user convenience by removing the necessity for physical connectors, thereby decreasing wear and maintenance expenses (Bassey et al., 2024). Wireless charging methods based on inductive coupling are gaining popularity in smartphones and other portable devices, providing efficient energy transfer over short distances (Nebrida et al., 2025).

Yusoff et al. (2021) investigated the role of RFID in advancing Green IoT technologies, emphasising its effectiveness in minimising energy consumption and carbon emissions in industries such as healthcare and supply chain management. The potential of RFID to facilitate environmentally sustainable and energy-efficient IoT systems is crucial for the development of sustainable public charging stations.

Similarly, MRiduvarshini et al. (2025) created a solar-powered portable charger that uses radio frequency identification (RFID) and is operated by coins. The solution guarantees continuous power storage using solar energy by combining renewable energy with eco-friendly payment mechanisms. Key components of our system's architecture, including safety monitoring and user-friendly interfaces, are highlighted by this advancement.

Ferdous et al. (2016) examined renewable energy solutions for wireless sensor applications in the domain of energy harvesting. Their findings underscored issues such low efficiency and dependence on storage devices, while accentuating solar radiation and RF signals as the most feasible energy sources for sustainable harvesting. Our technology utilises solar energy as the principal power source, reinforcing the assertion that solar power is the most viable choice for off-grid charging stations.

The study by Zhang et al. (2020) came up with WirelessID, a system that uses fingerprints on wireless chargers to find malicious assaults that happen when two devices are close to each other. This study shows how important it is to protect wireless charging networks. We made sure that our design included this functionality so that charging in public places is safe and secure.

Using RFID security and solenoid locks, Alam et al. (2021) showcased a mobile charging station that is both smart and secure. Their research emphasises the need of user authentication and device security, two fundamental features of our technology, and is especially useful in areas where secure charging facilities are lacking.

Furthermore, Fang et al. (2024) used Raspberry Pi to create an RFID-based smart charging system that effectively charges laptops and mobile devices. In line with our system's features that maximise energy efficiency and improve user experience, theirs provides device recognition, real-time battery monitoring, and automatic power-off once devices are fully charged.

Yao et al. (2019) and Althobaiti et al. (2021) talked about ways and techniques for finding energy theft in smart networks. Their work on security standards and anomaly detection fits with our goal of keeping people who shouldn't be able to use the charging system from doing so. This will make sure that energy use is safe and efficient.

This study proposes a solar-powered RFID-enabled wireless charging booth that provides safe, efficient, and environmentally friendly charging for mobile devices. The system addresses the difficulties of inconsistent grid electricity and the requirement for safe, user-friendly charging solutions by combining solar energy, RFID-based access control, and wireless charging technology. This integrated system enables developing countries to benefit from increased energy supply, improved security, and decreased reliance on fossil fuel generators, boosting sustainability and technical growth.

METHOD

The proposed system is a solar-powered, RFID-enabled mobile charging station that incorporates both wired and wireless charging capabilities, offering a sustainable and safe option for public mobile device charging. The system integrates renewable energy harvesting with secure user authentication and efficient energy management, facilitating a dependable off-grid charging solution.

The system's core is managed by an Arduino Nano (ATmega328P) microcontroller, which communicates with an RC522 RFID Reader Module to authenticate users, guaranteeing that only authorised individuals may use the charging service. A 16×2 LCD (LM016L) connected via an I2C interface (PCF8574) shows system status and user information, reducing wiring complexity. Push buttons (B1-B4) allow users to manually select a charging port. Following selection, the system performs RFID authentication before initiating the billing procedure.

The system may charge over USB or WiFi, and relays (RL1–RL4) and NPN transistors (Q1–Q4) control the charging ports. Flyback diodes (D3–D5) are put across the relay coils to protect the transistors from back EMF spikes that happen when the relay switches. The ACS712 30A current sensors keep an eye on the current being pulled by each charging port and the wireless charger all the time. This makes sure that the current is always being monitored and that overcurrent problems don't happen, as seen in figure 1.

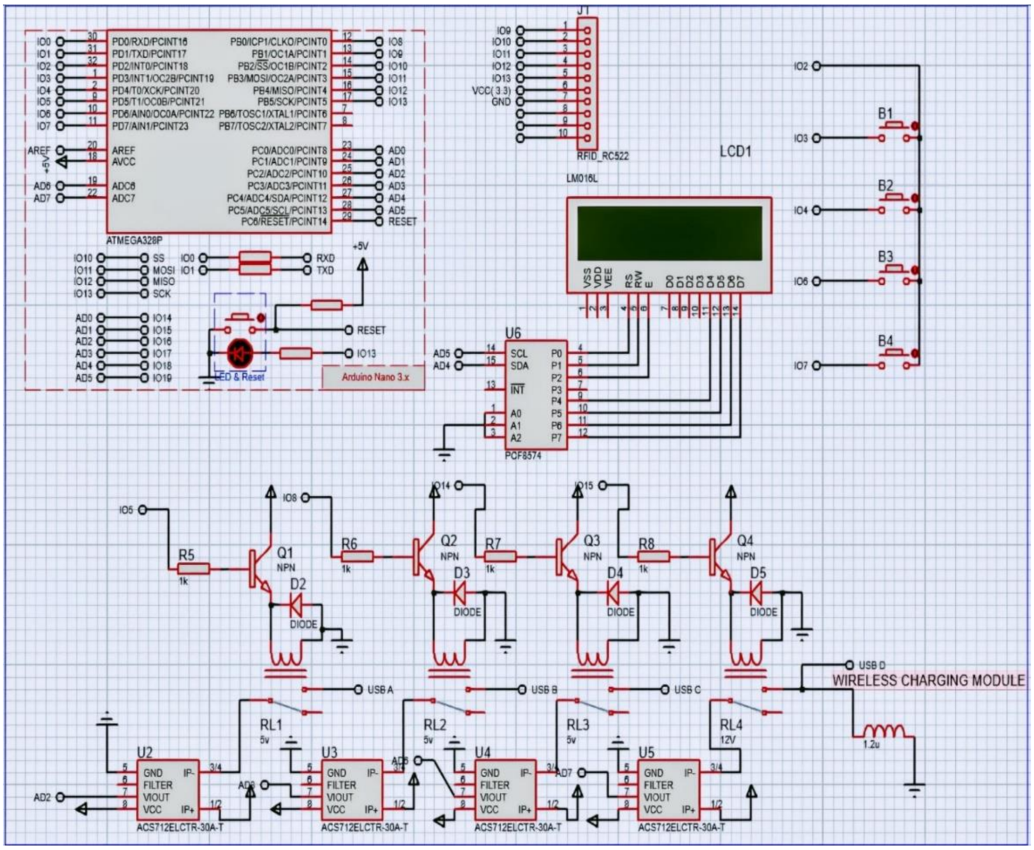

Figure 1. Schematic diagram of the RFID-enabled smart charging system integrating wired and wireless charging ports.

Wireless charging is made possible via the system's integrated inductive charging module, which, in addition to the USB ports, allows compatible devices to charge without cables. The ability to charge numerous devices at once is a major time saver because to this hybrid charging feature.

The charging station may function autonomously from the grid because its electricity is generated by solar panels linked to a battery. It is perfect for public places and places with unpredictable electricity networks since the system architecture encourages sustainability, user security, and energy efficiency.

Figure 2 displays the user input, RFID validation, and charging logic, which are all part of the system's organised process that governs the charging booth's operation. To guarantee safe and efficient operation, the system flow diagram shows how user input, authentication, and charging all work together. The microprocessor, power management units, and user input methods are all clearly illustrated in Figure 3, which is a system block diagram.

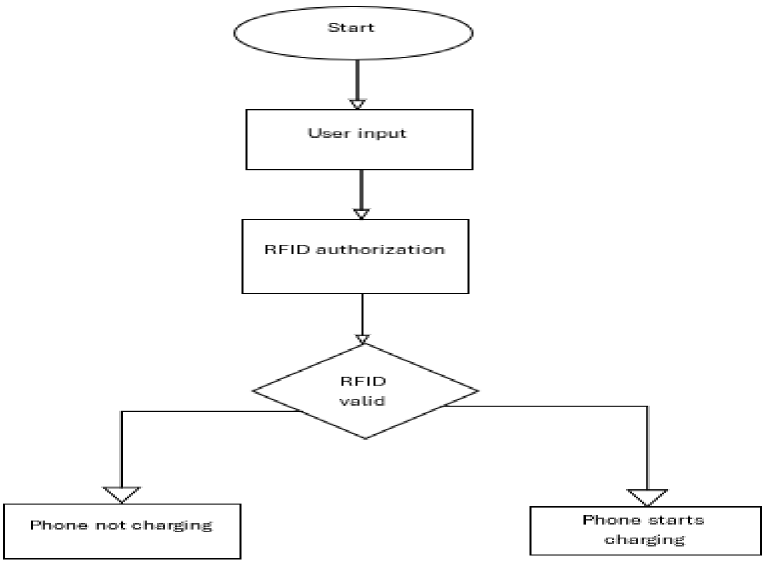

Figure 2. System flowchart illustrating user input, RFID validation, and charging operation logic.

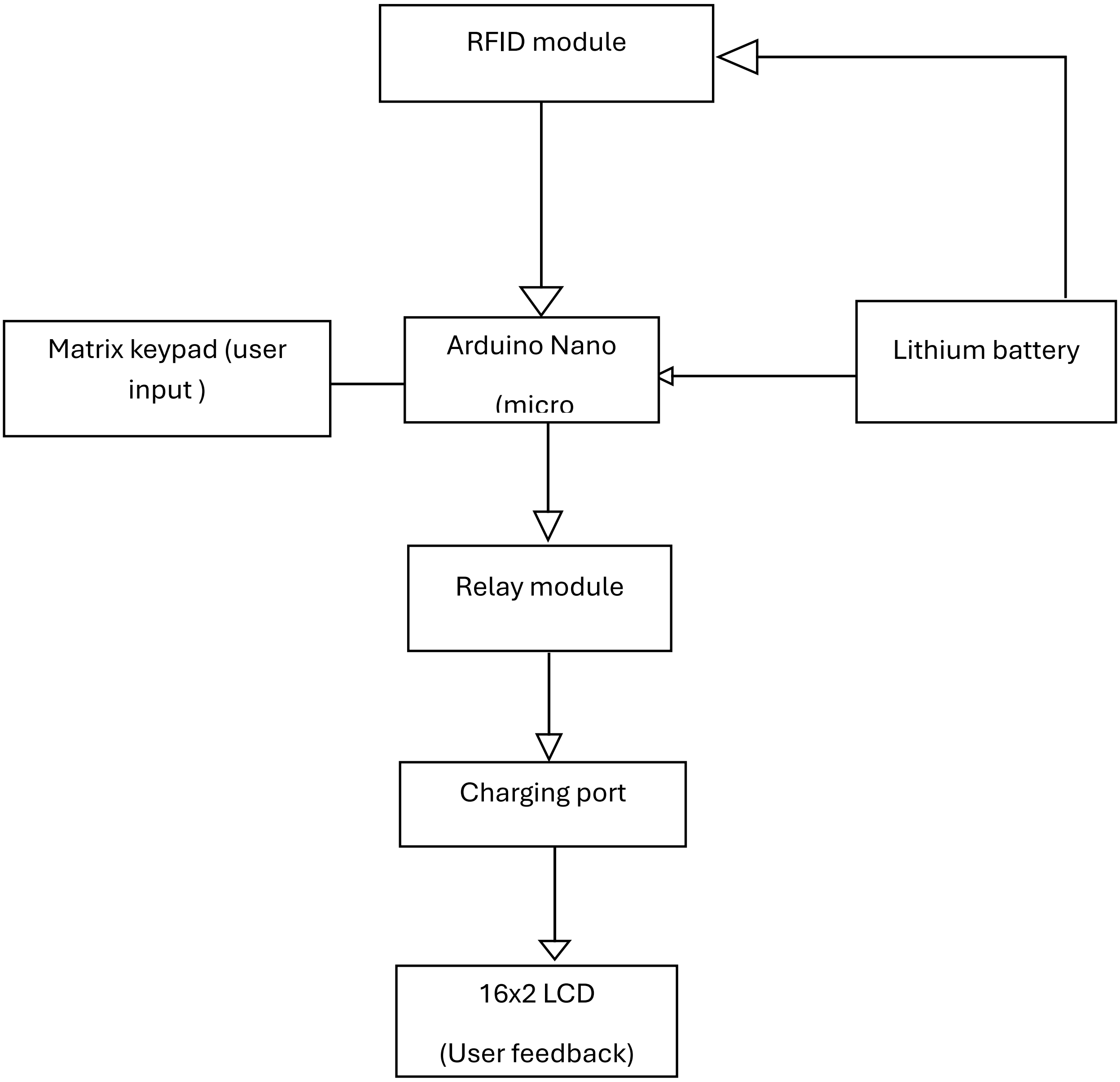

Figure 3. Block diagram of the RFID-enabled smart mobile device charging system.

The software development for the system was carried out using the Arduino IDE, employing a modular programming approach. The software manages the entire process, from initialization (setting up the LCD, RFID reader, and serial communication) to user input handling (scanning RFID tags and button presses). Upon detecting a valid RFID tag, the system checks the stored data against a predefined list of authorized users. Successful authentication triggers the system to activate the appropriate relay and allow current flow to the selected charging port.

Energy monitoring is achieved through the ACS712 sensors, which read real-time current values to detect overcurrent situations and ensure the safety of the devices being charged. The system displays charging status, invalid RFID alerts, and session completion on the LCD display, offering a clear user interface. Additionally, the system includes a cut-off timer, which automatically deactivates the charging relay once the set charging time or full charge is reached, ensuring that devices are not overcharged.

The program flow ensures that charging only occurs after successful user authentication, manages charging session duration, and enforces safety protocols to prevent misuse of the system or damage to devices. The integrated system combines hardware and software components to deliver a reliable, secure, and eco-friendly charging solution for public use.

RESULTS

The system was tested on various mobile devices as shown in figure 4 across different operating systems and charging technologies. Table 1 summarizes the observed charging outcomes.

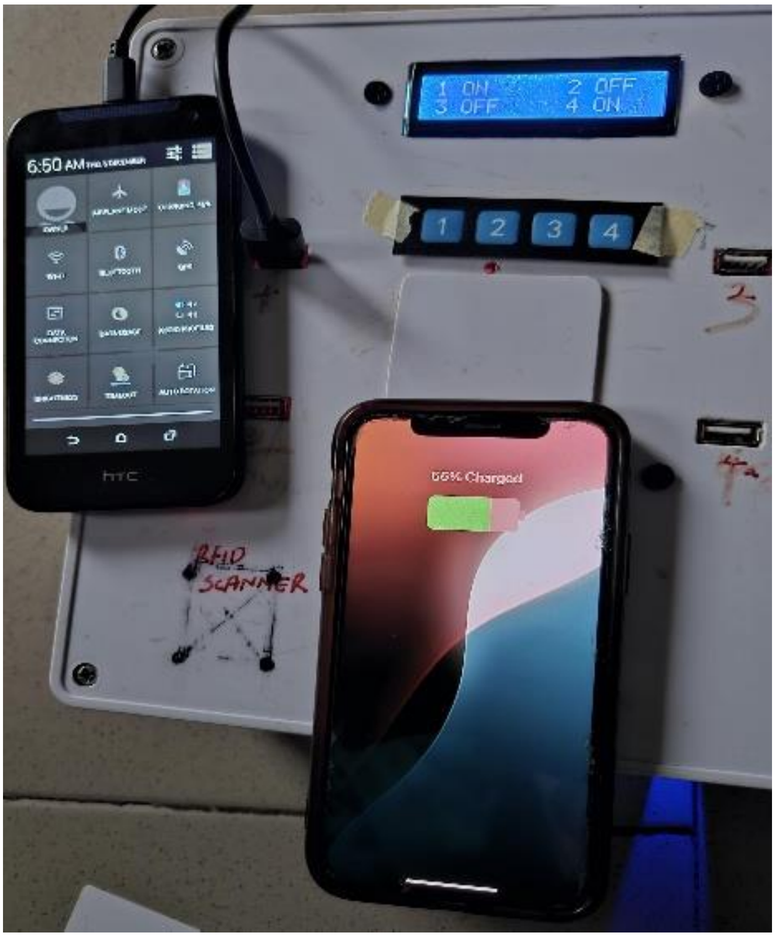

Figure 4: Showing the charging capability as tested with various mobile phones via wireless and USB cord

Table 1: Mobile Device Charging Test Results

S/N	Phone	OS	Charging Status
1	iPhone 11 Pro	iOS 18	Wireless charging
2	Redmi 9a	Android 10	USB cable charging
3	Samsung Z Fold 5	Android 13	USB and wireless charging
4	Infinix Hot 10	Android 10	USB cable charging
5	Infinix Smart 5	Android 10	USB cable charging
6	Tecno Spark 8C	Android 11	USB cable charging
7	iPhone 6s	iOS 9	USB cable charging

DISCUSSION

The solar-powered charging booth equipped with RFID functionality demonstrates versatility and durability by accommodating various device types for charging. The existing literature provides support and contextualises this outcome.

The wireless functionality of the system is evidenced by the capability of devices such as the Samsung Z Fold 5 and iPhone 11 Pro to charge wirelessly. This supports the findings of Zhang et al. (2020), who demonstrated the reliability and security of public wireless charging infrastructure and developed WirelessID for wireless charger fingerprinting. This project assesses the reliability of wireless charging in uncontrolled and open environments.

The choice to operate the booth using solar power aligns with the findings of Ferdous et al. (2016), who identified solar radiation as one of the most viable renewable energy sources for sustainable power generation. A critical aspect for installations in areas with inconsistent electrical supply is the system's reliance on solar energy, ensuring autonomy from grid power.

The implementation of RFID authentication has successfully restricted access to authorised users. This is consistent with the findings of Yusoff et al. (2021), who emphasised the role of RFID in improving security and energy efficiency within the framework of the Green IoT paradigm. RFID's minimal energy consumption and reliable access control effectively prevent unauthorised access and enhance resource efficiency. The incorporation of an LCD display for feedback and RFID validation enhances user experience. This aligns with the research conducted by Fang et al. (2024), which developed a smart charging system utilising RFID and Raspberry Pi, focussing on device identification, real-time feedback, and sustainable energy use. The design ensures efficient, monitored, and user-centred charging sessions. This experiment did not evaluate the coin and RFID-based hybrid payment system; however, MRiduvarshini et al. (2025) demonstrated a public solar charging station effectively utilising both coin and RFID, indicating that the system's architecture is compatible with coin-operated mechanisms. An enhancement for business applications is the scalability of coin or digital payment systems. The implementation of ACS712 sensors for real-time monitoring ensured the system operated safely, preventing overheating and overcurrent incidents. This aligns with the safe and secure design concepts discussed by Alam et al. (2021). Their research demonstrated the significance of implementing intelligent control and access management to ensure the security of devices at public charging stations.

While Data Security and Grid Independence were not directly assessed in this study, Yao et al. (2019) and Althobaiti et al. (2021) emphasise the significance of safeguarding data privacy and ensuring secure power management. Future enhancements may consider this factor. Incorporating encrypted data logging and monitoring system usage may enhance system reliability and increase user trust.

CONCLUSION

The study effectively designed and evaluated a solar-powered, RFID-enabled smart charging booth that accommodates both wired and wireless charging functionalities. The system is designed to create secure, efficient, and sustainable charging solutions for mobile devices, particularly in public spaces and areas with unreliable grid power.

The experimental results indicated the system's adaptability, accommodating diverse device types and operating systems, thereby affirming its extensive applicability. RFID technology for access control offers reliable security, guaranteeing that only authorised users can access the charging service. The system's dependence on solar energy improves environmental sustainability, and real-time current monitoring guarantees safe and efficient charging operations. The system's design is consistent with recent developments in wireless charging security, green IoT technologies, and sustainable public infrastructure, as noted in the literature. The user-centric design, incorporating real-time feedback and efficient energy management, enhances usability and reliability. While the implementation was successful, certain limitations are recognised.

i. The wireless charging capability of the system is restricted to devices that adhere to the Qi standard, thus excluding non-Qi devices from wireless charging.
ii. The charging current of 5V and 1A offered by the system may be inadequate for rapid charging demands, particularly for newer smartphones that necessitate higher power inputs.

Recommendations are proposed to enhance system performance and ensure future-proof design.

i. Integrate USB Power Delivery (USB-PD) and Quick Charge technologies to address the evolving requirements of contemporary mobile devices.
ii. Extend RFID authentication to include NFC-enabled smartphones, thereby enhancing accessibility and user convenience.
iii. Implement encrypted data transmission and remote monitoring to enhance data security, safeguard user information, and prevent unauthorised access.

Subsequent versions of the system may improve through the incorporation of features like smartphone applications for user management, integration with smart grid systems, and enhanced monitoring systems to optimise energy management and strengthen grid resilience. The solar-powered RFID-enabled charging booth offers a scalable, secure, and environmentally sustainable solution to address the increasing demand for convenient mobile device charging. This system presents considerable benefits for both users and service providers, particularly in regions with unstable power grids, thereby promoting sustainability and technological progress.

REFERENCES

1. Alam, M. E., Kader, M. A., Hossain, M., Noushin, F., Alam, M. S., & Farid, S. (2021). IoT Based Smart and Secured Mobile Charging Station in Public Place. IEEE, 1–6. https://doi.org/10.1109/sti53101.2021.9732560
2. Althobaiti, A., Jindal, A., Marnerides, A. K., & Roedig, U. (2021). Energy Theft in Smart Grids: A Survey on Data-Driven Attack Strategies and Detection Methods. IEEE Access, 9, 159291–159312. https://doi.org/10.1109/access.2021.3131220
3. Amani, A. M., & Jalili, M. (2021). Power Grids as Complex Networks: Resilience and Reliability analysis. IEEE Access, 9, 119010–119031. https://doi.org/10.1109/access.2021.3107492

4. Ayoade, I. A., & Longe, O. M. (2024). A comprehensive review on smart Electromobility charging infrastructure. World Electric Vehicle Journal, 15(7), 286. https://doi.org/10.3390/wevj15070286
5. Bassey, N. K. E., Rajput, N. S. A., Oladepo, N. O. O., & Oyewale, N. K. (2024). Optimizing behavioral and economic strategies for the ubiquitous integration of wireless energy transmission in smart cities. World Journal of Advanced Engineering Technology and Sciences, 13(1), 482–497. https://doi.org/10.30574/wjaets.2024.13.1.0447
6. Fang, L. H., Romli, M. I. F., Rahim, R. A., Jobran, J. a. M., Ahmad, N. I., Jabbar, M. A., & Rong, L. J. (2024). Smart charging system for mobile charges and laptops using RFID and Raspberry Pi. In Lecture notes in electrical engineering (pp. 397–409).https://doi.org/10.1007/978-981-97-3847-2_34
7. Ferdous, R. M., Reza, A. W., & Siddiqui, M. F. (2016). Renewable energy harvesting for wireless sensors using passive RFID tag technology: A review. Renewable and Sustainable Energy Reviews, 58, 1114–1128. https://doi.org/10.1016/j.rser.2015.12.332
8. Gurung, A., & Qiao, Q. (2018). Solar charging batteries: advances, challenges, and opportunities. Joule, 2(7), 1217–1230. https://doi.org/10.1016/j.joule.2018.04.006
9. Harris, A., & Cooper, M. (2019). Mobile phones: Impacts, challenges, and predictions. Human Behavior and Emerging Technologies, 1(1), 15–17. https://doi.org/10.1002/hbe2.112
10. Jha, N. R. K., & Neupane, N. S. (2023). Securing the future of mobility: electric vehicle charging infrastructure protection. Journal of Information Technology and Digital World, 5(3), 291–309. https://doi.org/10.36548/jitdw.2023.3.005
11. Liu, Y., Zhu, Y., & Cui, Y. (2019). Challenges and opportunities towards fast-charging battery materials. Nature Energy, 4(7), 540–550. https://doi.org/10.1038/s41560-019-0405-3
12. MRiduvarshini, N., SDharshin, N., BDharani, N., & Senthil, S. R. (2025). Solar powered RFID token operated mobile charging system. 2022 International Conference on Electronics and Renewable Systems (ICEARS), 72–76. https://doi.org/10.1109/icears64219.2025.10941669
13. Munoz-Ausecha, C., Ruiz-Rosero, J., & Ramirez-Gonzalez, G. (2021). RFID Applications and Security review. Computation, 9(6), 69. https://doi.org/10.3390/computation9060069
14. Nebrida, A. P., Ngadanan, N. P., Fernandez, I. O., Natividad, J. P., Marayag, S. V., & Martinez, M. T. (2025). Enhancing security and convenience innovations in Anti-Theft mobile phone charging stations for public venues. In Advances in computational intelligence and robotics book series (pp. 199–228). https://doi.org/10.4018/979-8-3693-9770-1.ch010
15. Olabi, A. G., Abbas, Q., Shinde, P. A., & Abdelkareem, M. A. (2022). Rechargeable batteries: Technological advancement, challenges, current and emerging applications. Energy, 266, 126408. https://doi.org/10.1016/j.energy.2022.126408
16. Paneru, C. P., & Tarigan, A. K. (2023). Reviewing the impacts of smart energy applications on energy behaviours in Norwegian households. Renewable and Sustainable Energy Reviews, 183, 113511. https://doi.org/10.1016/j.rser.2023.113511
17. Yadav, R., Solanki, A. P., Gautam, A. S., Farooqui, D. K., Bhardwaj, A., & Kumar, M. (2025). Operational Efficiency through RFID-Enabled Smart Card Sensor Technology for Identity, Access Control, and Resource Management. Engineering Research Express. https://doi.org/10.1088/2631-8695/adcfef
18. Yao, D., Wen, M., Liang, X., Fu, Z., Zhang, K., & Yang, B. (2019). Energy theft detection with energy privacy preservation in the smart grid. IEEE Internet of Things Journal, 6(5), 7659–7669. https://doi.org/10.1109/jiot.2019.2903312
19. Yap, K. Y., Chin, H. H., & Klemeš, J. J. (2022). Solar Energy-Powered Battery Electric Vehicle charging stations: Current development and future prospect review. Renewable and Sustainable Energy Reviews, 169, 112862. https://doi.org/10.1016/j.rser.2022.112862
20. Yusoff, Z. Y. M., Ishak, M. K., & Alezabi, K. A. (2021). The role of RFID in Green IoT: A survey on technologies, challenges and a way forward. Advances in Science Technology and Engineering Systems Journal, 6(1), 17–35. https://doi.org/10.25046/aj060103
21. Zhang, J., Wang, Z., Ji, X., Xu, W., Qu, G., & Zhao, M. (2020). Who is Charging My Phone? Identifying Wireless Chargers via Fingerprinting. IEEE Internet of Things Journal, 8(4), 2992–2999. https://doi.org/10.1109/jiot.2020.3024572