

INTERNET-OF-THINGS (IoT) ENABLED SOLAR-BASED CHARGING STATION

Leslie Mae P. Marsado, MTM

Mariano G. Medalla Integrated School, Bacolod City, Negros Occidental, Philippines.

*Corresponding Author

Leslie Mae P. Marsado, MTM

Article History

Received: 21.12.2025

Accepted: 07.02.2026

Published: 05.03.2026

Abstract: With the increasing demand for sustainable and smart energy solutions, innovative charging technologies are becoming essential in modern electronic device usage. The main focus of this study was the design and fabrication of an Internet of Things (IoT)–enabled solar-based charging station. It was developed to provide a sustainable, efficient, and intelligent charging solution for electronic devices. The system integrates renewable solar energy with IoT connectivity to allow real-time monitoring and mobile notifications. Key components include an automated solar tracking mechanism, AC and DC power outputs, an adjustable pole, and a system status display, all of which enhance functionality and user convenience. This study employed both developmental and descriptive research methods. The developmental phase involved planning, designing, fabrication, assembly, system integration, testing, and evaluation of the charging station. The descriptive aspect focused on assessing system performance in terms of charging rate and battery consumption under standard operating conditions. Product quality was evaluated based on durability, functionality, and system features, while acceptability was measured in terms of sustainability and ease of use. A researcher-made instrument was administered to selected technical experts, industry practitioners, and academic instructors through purposive sampling to evaluate the system’s performance and acceptability. Findings revealed that the IoT-enabled solar-based charging station was successfully developed as a fully functional and reliable device. Performance testing demonstrated efficient charging capability and optimized battery usage within expected standards. Quality evaluation showed high ratings in durability and system features, while acceptability results reflected positive responses, with sustainability and ease of use receiving the highest scores.

Keywords: *Developmental and Descriptive Research Design, Internet-of-Things, Charging Station, Renewable Energy, Technology Acceptability, Quality Dimension Evaluation Efficiency.*

Cite this article:

Marsado, L. M. P., (2026). INTERNET-OF-THINGS (IoT) ENABLED SOLAR-BASED CHARGING STATION. *ISAR Journal of Science and Technology*, 4(3), 1-9.



Introduction

The global demand for renewable energy has grown significantly as societies confront climate change, rising fossil fuel costs, and the need for more sustainable energy consumption practices. Conventional grid-based charging stations often face challenges such as high operational costs, unstable power supply, and environmental impacts. As a result, solar-powered systems have emerged as a clean, sustainable, and decentralized alternative, offering reliable energy access even in off-grid locations. Furthermore, advancements in smart technologies have enhanced energy management, efficiency, and overall system reliability. These developments align with the goals of Sustainable Development Goal (SDG) 7: Affordable and Clean Energy, which promotes access to reliable and renewable energy, and SDG 9: Industry, Innovation, and Infrastructure, which encourages innovation and the development of smart, technology-driven solutions.

Despite the advantages of solar-based charging stations, existing systems often rely on a single energy source and lack adaptive control mechanisms, resulting in inefficient energy utilization, accelerated battery degradation, and increased maintenance requirements (Chen & Wu, 2020; Khalid et al., 2018). Conventional designs are often unable to optimize energy harvesting under fluctuating environmental conditions, while the absence of real-time monitoring further limits operational efficiency and reliability. These limitations reduce system lifespan and performance, particularly in off-grid, educational, or emergency applications, thereby highlighting the need for more intelligent, responsive, and sustainable solutions.

In response to these challenges, this study explores the development of an IoT-enabled solar-based charging station equipped with a self-tracking solar panel system. The automated solar tracking mechanism maximizes energy capture throughout the day, while IoT integration enables real-time monitoring of battery status and energy consumption, supporting more efficient system operation. By combining renewable energy with smart technology, the system offers a practical alternative or complementary solution to conventional charging stations. Although not intended as a complete replacement, it contributes to the objectives of SDG 7 by supporting access to clean energy and to SDG 9 by demonstrating innovative technological applications that enhance infrastructure efficiency and reliability.

Objectives of the Study

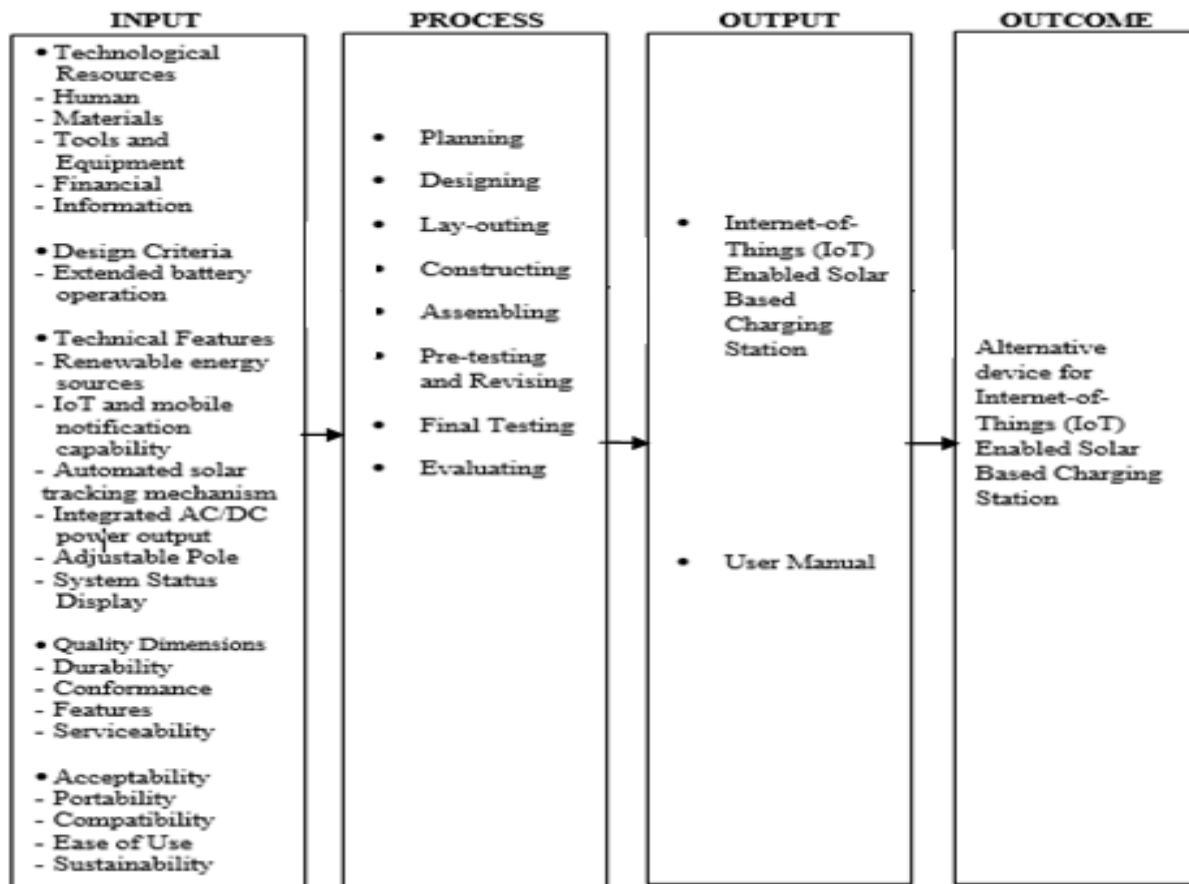
The main purpose of the study is to develop an Internet-of-Things (IoT) Enabled Solar-Based Charging Station.

Specifically, the study aims to:

1. Design and fabricate an Internet-of-Things (IoT) Enabled Solar-Based Charging Station with the following technical features:
 - a. renewable energy source
 - b. integrated IoT and mobile notification capability
 - c. automated solar tracking mechanism
 - d. integrated AC DC power output
 - e. adjustable pole
2. Test the performance of Internet-of-Things (IoT) Enabled Solar-Based Charging Station in terms of:
 - a. charging rate
 - b. battery consumption
3. Evaluate the product quality of Internet-of-Things (IoT) Enabled Solar-Based Charging Station in terms of the following dimensions:
 - a. durability
 - b. conformance
 - c. features
 - d. serviceability
4. Evaluate the acceptability of Internet-of-Things (IoT) Enabled Solar-Based Charging Station in terms of:
 - a. portability
 - b. compatibility
 - c. ease of use
 - d. sustainability
5. Develop a user manual acceptability of Internet-of-Things (IoT) Enabled Solar-Based Charging Station.

Framework of the Study

The study employed the Input-Process-Output-Outcome (IPOO) model, which functions as a structured framework and conceptual guide in the systematic development and implementation of the Internet of Things (IoT) Enabled Solar-Based Charging Station. The application of the IPOO model in this study is visually represented in Figure 1, illustrating how each component contributes to the overall design, functionality, and effectiveness of the IoT-enabled charging station.

Figure 1: Schematic Diagram Illustrating the Conceptual Framework of the Study

As shown in Figure 1, the schematic diagram and development of the Internet-of-Things (IoT) Enabled Solar-Based Charging Station were observed using the Input–Process–Output–Outcome (IPOO) framework. The initial phase of the development was the input stage, which focused on the collection of essential information and required resources necessary for the design and implementation of the system.

This begins with conducting readings and reviews to gain insights into existing solar and wind charging stations. Simultaneously, concepts and plans are developed to outline the design of the proposed Internet-of-Things (IoT) Enabled Solar Based Charging Station. The financial aspect is addressed through the creation of a budget that encompasses the anticipated costs. The materials, tools, and equipment required for the project are also identified at this stage.

The process phase is the next stage wherein, where the actual development of the immobilizing device will take place. It inaugurates with the laying-out of the device's design, translating concepts and plans into detailed drawings. Subsequently, the device is will be assembled, with all the identified materials, tools, and equipment coming together to form the physical product. The finishing touches will include a thorough testing is conducted to validate its functionality, reliability, safety and security. An evaluation process will help identify any areas for improvement or refinement, ensuring the device is ready for use.

The Output phase represented the immediate results of the project. It encompasses two key deliverables. Firstly, there is the

IoT (Internet of Things) Enabled Solar Based Charging Station itself, which is the tangible outcome of the project a fully constructed and functional device ready to be utilized. Secondly, a User's Manual will be created to provide comprehensive instructions on how to effectively and safely operate the device.

The last phase is the outcome which signified the broader impact and implications of the project. It points towards the development of an innovative solution in the electronic industry a device that has the potential to transform the way of Internet-of-Things (IoT).

Methodology

This study employed a developmental-descriptive research design. The developmental component focused on the design, fabrication, and refinement of an IoT (Internet of Things)–enabled solar-based charging station intended for use in small to mid-rise construction projects. The process involved conceptualization, material selection, fabrication, and system testing to ensure functionality and reliability.

The descriptive component aimed to assess the acceptability and quality dimensions of the developed charging station. This was achieved through the collection and analysis of quantitative feedback from selected IT experts, electronic technology instructors, and technicians.

A researcher-made instrument measuring acceptability and quality, which underwent content validation and reliability testing, was used as the primary data collection tool. The instrument

consisted of statements rated on a Likert scale to evaluate respondents' perceptions of the charging station.

For data analysis, mean and standard deviation were the primary statistical tools. The mean determined the level of acceptability for each criterion, while the standard deviation assessed the consistency of responses among participants. This methodological approach ensured that both the technical development and practical evaluation of the charging station were grounded in a rigorous and structured research framework, providing credible results that reflect the perspectives of IT and electronics technology professionals.

Design and Fabrication of IoT-Enabled Solar-Based Charging Station

The development of the IoT-Enabled Solar-Based Charging Station undergo various processes from planning to evaluating as shown in Figure 2.

Figure 2: Production Flow in Developing the IoT-Enabled Solar Based Charging Station.

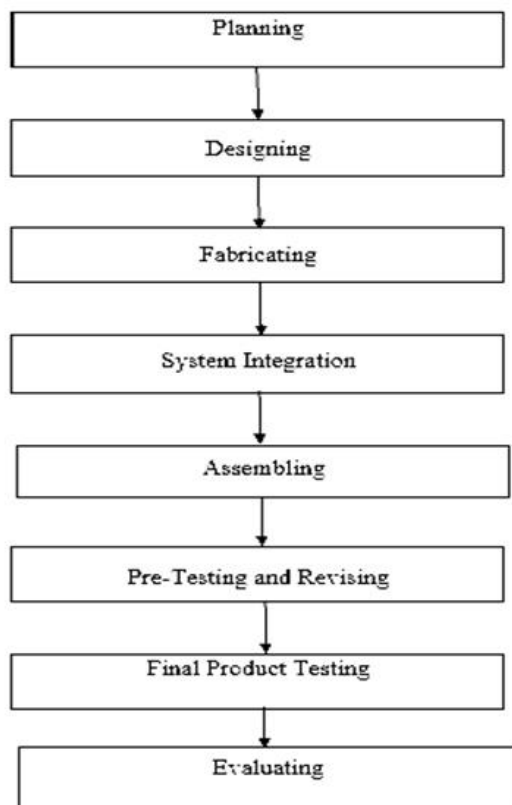


Figure 2 illustrates the complete workflow for developing the IoT-enabled solar charging station, comprising Planning, Designing, Fabrication, Assembly, Pre-testing and Revision, Final Testing, and Evaluation. The development begins with planning, where objectives, specifications, and materials are identified. The system integrates solar energy harvesting, battery storage, IoT monitoring with mobile notifications, horizontal tracking, tilting mechanisms, and AC/DC outputs, with considerations for portability, durability, safety, and energy efficiency. Materials include photovoltaic panels, rechargeable batteries, microcontrollers, sensors, motors, wiring, and structural frames. In

the design phase, the layout and placement of all components are finalized. Fabrication involves preparing materials, constructing the frame, mounting solar panels, installing motors, connecting electrical circuits, and setting up IoT modules for real-time monitoring and notifications. Protective casings are included to ensure durability and safety. During system integration and assembly, hardware and software components are connected and configured to function cohesively. The microcontroller collects sensor data, controls tracking and tilting motors, and transmits information to a cloud-based platform. All mechanical and electrical connections are secured, and system modules are integrated into a fully functional unit. The station then undergoes pre-testing and revision, where charging rate, battery performance, tracking accuracy, and IoT reliability are assessed. Observed issues are corrected through calibration, motor optimization, or design refinements. Final testing evaluates performance under real-world conditions, including energy efficiency, battery management, structural stability, and IoT monitoring accuracy. The evaluation phase collects feedback from experts and users to assess usability, portability, durability, and sustainability. A user manual is developed to guide operation, maintenance, safety, and IoT monitoring procedures, ensuring reliable and user-friendly system operation.

Figure 3: Design and Dimension of IoT-Enabled Solar Based Charging Station.

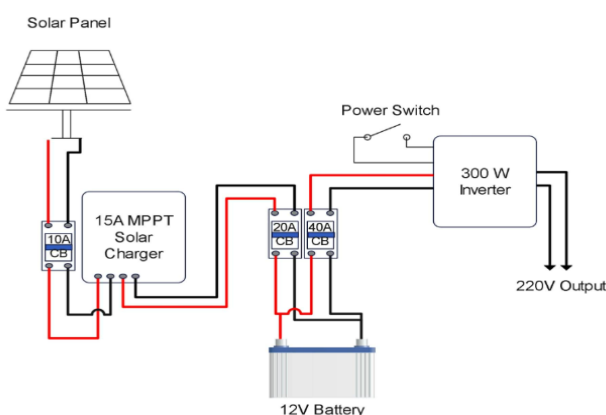


As shown Figure 3, is the pictorial drawing of the Internet-of-Things (IoT) Enabled Solar Based Charging Station comprising of the solar powered charging terminal, wind powered charging terminal, surveying stand, adjustable instrument stand, notification and monitoring sensor and switchgear box play crucial roles in simplifying the process of assembling and attaching the Internet-of-Things (IoT) Enabled Solar Based Charging Station, ensuring efficiency and precision in this device to maintenance task. Figure 3 shows the wiring diagram of the IoT-enabled solar-based charging station, illustrating the interrelationship of its major components. Guided by systems theory, the system functions through the coordinated connection of its parts. The process begins with the solar panel, which converts sunlight into DC electrical energy. This energy passes through a circuit breaker for protection

against overload and short circuits before entering the 15A MPPT solar charge controller, which regulates power and ensures the safe charging of the 12V battery.

The battery serves as the main energy storage unit and distributes power through additional circuit breakers and a power switch that controls system operation. The stored DC energy is then supplied to the 300W inverter, which converts it into 220V AC output for standard electrical devices. The integrated connections among the solar panel, protection devices, charge controller, battery, switch, and inverter enable efficient energy flow, safe power distribution, and reliable system performance.

Figure 4: Wiring Diagram of the Internet-of-Things (IoT) Enabled Solar Based Charging Station showing the Interrelationship of Parts



As shown in Figure 4, is the wiring diagram of the Internet-of-Things (IoT) enabled solar based charging station. The system is composed of two primary components: the solar and the battery and control unit. The two parts consists solar and unit that are mounted on a vertical post and is engineered to be self-orienting. This enables the solar panel to autonomously adjust their positions to track the most optimal sunlight exposure and wind direction, thereby maximizing energy capture throughout the day. As shown in Figure 4, is the picture of schematic diagram of Internet-Of-Things (IoT) enabled solar based charging station the Internet-of-Things (IoT) Enabled Solar-Based Charging station begins with the solar panel, which serves as the primary source of renewable energy by converting sunlight into direct current (DC) electricity. The electricity generated by the solar panel first passes through a 10-ampere circuit breaker, which provides overcurrent protection to safeguard the system components. From there, the energy flows into the 15A MPPT (Maximum Power Point Tracking) solar charge controller, which regulates the voltage and current to ensure that the solar panel operates at its optimal efficiency while charging the 12-volt battery. This regulation is essential for maximizing energy capture and maintaining the longevity of the battery. The 12V battery functions as the energy storage unit, storing electricity for use when sunlight is insufficient or during periods of high demand. Circuit breakers rated at 20A and 40A are installed between the battery and downstream components to protect against overcurrent or short-circuit conditions, thereby ensuring safe and reliable operation. A power switch is incorporated to allow the user to

control the flow of electricity from the inverter to the 220V output, providing an interface for safe operation and maintenance. Throughout the system, the interplay between the solar panel, MPPT charger, battery, inverter, circuit breakers, and power switch ensures a continuous, regulated, and safe energy flow. The design allows the station to reliably capture solar energy, store it efficiently, convert it as needed, and deliver usable power to a variety of devices, forming a cohesive and functional solar-based charging station.

Ethical Consideration

The study ensured that all data collected, including system performance and user feedback, were handled with confidentiality and used solely for academic purposes. Participants involved in usability testing or surveys were informed of the study's objectives, and their voluntary participation was obtained through written consent.

The research adhered to established ethical guidelines to maintain integrity, transparency, and social responsibility throughout the study. All procedures involved in the development and testing of the Internet-of-Things (IoT) Enabled Solar-Based Charging Station with IoT integration were designed with a strong commitment to the welfare of participants, the environment, and the community.

For human participants involved in usability testing of the charging station or the IoT application interface, informed consent was obtained prior to their participation. They were fully briefed on the purpose, procedures, risks, and benefits of the study. Participants were informed of their right to withdraw at any time without facing any form of penalty. To protect their privacy, no personally identifiable information was collected, and any feedback was anonymized and used strictly for research purposes.

The design and prototyping of the system were conducted using safe and non-hazardous materials. All electronic components were sourced ethically, with attention given to compliance with environmental and labor standards. Any electronic waste or damaged parts resulting from testing were disposed of responsibly through proper recycling channels to minimize environmental impact.

In terms of data ethics, all performance data gathered from the IoT system, such as voltage readings, energy production, and device usage logs, were stored securely and were not shared with third parties. The research team ensured that data collected from connected devices were used only for system improvement and academic evaluation, without infringing on user privacy or security.

The study also promoted transparency and accountability by ensuring that all findings, whether successful or inconclusive, were reported honestly, without fabrication, falsification, or selective reporting. Any potential conflicts of interest were disclosed, and all collaborators were appropriately credited for their contributions.

The study ensured that all data collected, including system performance metrics and any user feedback obtained during testing and evaluation, were handled with strict confidentiality and used solely for academic and research purposes. Collected data were stored securely, and access was limited to the researchers involved in the study to prevent unauthorized use or disclosure.

Results and Discussions

Design and Fabrication of the Internet of Things (IoT)–Enabled Solar-Based Charging Station

The first objective of this study was to design and construct an Internet of Things (IoT)–enabled solar-based charging station with several key technical features, including renewable energy sources, IoT and mobile notification capability, an automated solar tracking mechanism, integrated AC/DC power outputs, an adjustable pole, and a system status display. The renewable energy source consists of photovoltaic solar panels that capture sunlight and convert it into electrical energy for storage and distribution. The IoT and mobile notification capability enables real-time monitoring of key parameters such as battery status, energy production, and power usage, transmitting this information to connected devices or cloud platforms. The automated solar tracking mechanism allows the panels to follow the sun's movement, optimizing energy capture by adjusting tilt and rotation through sensors and motors controlled by the station's

microcontroller. The integrated AC/DC power outputs provide versatile energy supply options, delivering DC power for USB and low-voltage devices and AC power for larger appliances requiring standard household voltage. Finally, the adjustable pole allows the solar panels to be positioned at optimal heights and angles, avoiding shading and maximizing sunlight exposure throughout the day and across seasons.

Performance of Internet-of-Things (IoT)-Enabled Solar-Based Charging Station

The second objective was to evaluate the performance testing in terms of charging rate and battery consumption shown and discussed in table 6-7 respectively.

a. Charging Rate

Charging rate indicates how quickly the IoT-enabled solar-based charging station can transfer energy to a battery. Evaluating this performance under different time conditions helps determine the system's efficiency and reliability for daily device charging.

Table 6: Performance of Charging Rate in Varying Time Conditions of IoT-enabled Solar Charging Station

Trial Seq.	Trial Time	Energy Charging Rate (P)	Charging Speed (minutes per 10% battery)	Energy Input Rate E (Wh)
1	8:00 am - 10:00 am	18.50	12 minutes	22.00
2	11:00 am – 1:00 pm	20.00	10 minutes	25.80
3	2:30 pm – 4:30 pm	19.20	11 minutes	23.50

As shown in Table 6, the testing trial phase of the performance of the IoT-enabled solar charging station varies based on time of day and available solar energy, highlighting the system's responsiveness to environmental conditions. During Trial 1 (8:00 AM–10:00 AM), the station recorded the lowest energy charging rate at 18.50 W, the slowest charging speed of 12 minutes per 10% battery, and an energy input rate of 22.00 W, which can be attributed to limited solar irradiance during early morning hours. Performance improved in Trial 2 (11:00 AM–1:00 PM), where the highest charging rate of 20.00 W, the fastest charging speed of 10 minutes per 10% battery, and peak energy input rate of 25.80 W were achieved, reflecting optimal sunlight and efficient solar panel operation. In Trial 3 (2:30 PM–4:30 PM), a slight decline was

observed, with a charging rate of 19.20 W, charging speed of 11 minutes per 10% battery, and an energy input rate of 23.50 W, consistent with reduced solar intensity in the afternoon.

b. Battery Consumption

Integrating a microcontroller with the circuit module assembly enhances battery longevity by ensuring efficient energy management. This configuration maintains stable battery performance during extended use, allowing the station to operate smoothly over long periods. By optimizing power distribution, the system can function efficiently without compromising reliability or performance.

Table 8: Battery Consumption Performance in Active Mode of Internet-of-Things (IoT) Enabled Solar Charging Station with Solar Panel Integration

Time duration (in minutes)	Voltage Level	Current Draw	Percentage
0-5 minutes	13.20 V	0.00A	100%
6-10 minutes	13.18 V	0.28A	99%
11-15 minutes	13.15V	0.46A	99%
16-20 minutes	13.12V	0.63A	98%
21-25 minutes	13.10V	0.78A	98%

Table 8 presents the battery consumption performance of the IoT-enabled solar charging station operating in active mode with solar panel integration over 25 minutes. The voltage remained relatively stable, decreasing slightly from 13.20 V to 13.10 V, while the current draw gradually increased from 0.00 A to 0.78 A due to system operation. Despite continuous activity, the battery maintained high efficiency, with performance declining minimally from 100% to 98%. The system recorded an average voltage of 13.15 V and an average current draw of 0.43 A, indicating that

solar panel support helped sustain battery stability during active operation

Product Quality Evaluation

The third objective of the study is to evaluate the level of product quality of the Internet-of-Things (IoT)-Enabled Solar-Based Charging Station in terms of durability, conformance, features, and serviceability. A discussion on the product quality evaluation of the Internet-of-Things (IoT)-Enabled Solar-Based Charging Station is presented in Table 3.

Table 21: Product Quality Evaluation Results of IoT-enabled Solar-Based Charging Station

Key Stakeholder Group	Criteria / Characteristic												As a whole		
	Durability			Conformance			Features			Serviceability					
	Mean	SD	VI	Mean	SD	VI	Mean	SD	VI	Me an	SD	VI	Me an	SD	VI
Electronic Teachers / Instructors / Trainers	4.94	0.10	VG	4.84	0.13	VG	4.86	0.16	VG	4.93	0.12	VG	4.90	0.07	VG
Electronics Industry Practitioners	4.86	0.13	VG	4.74	0.23	VG	4.78	0.15	VG	4.90	0.18	VG	4.82	0.12	VG
IT Experts / Practitioners / Instructors	4.82	0.15	VG	4.82	0.22	VG	4.90	0.11	VG	4.87	0.17	VG	4.85	0.09	VG
Note: 4.21 – 5.00 (Very Highly Acceptable VH); 3.41 – 4.20 (Highly Acceptable HA); 2.61 – 3.40 (Moderately Acceptable MA); 1.81 – 2.60 (Slightly Acceptable SA); 1.00 – 1.80 (Not Acceptable NA)															

As shown in Table 21, the quality of the IoT-enabled solar-based charging station was evaluated across product quality dimensions—durability, conformance, features, and serviceability—by key stakeholder groups. Overall, the system received a Very Highly Acceptable (VH) rating across all criteria and respondents, indicating strong confidence in its design, functionality, and usability. Durability scored between 4.82 and 4.94, reflecting perceptions of robustness and consistent performance under prolonged use, with electronic instructors giving the highest rating (4.94). Conformance received mean

scores of 4.74 to 4.84, demonstrating that the system reliably meets design specifications, safety standards, and professional requirements. The features dimension, including the automated solar-tracking mechanism, AC/DC outputs, IoT connectivity, and user interfaces, scored 4.78 to 4.90, indicating enhanced usability, efficiency, and adaptability. Finally, serviceability achieved scores from 4.87 to 4.93, confirming stakeholder confidence in maintainability, ease of troubleshooting, and component accessibility, making the system suitable for sustained use in both educational and professional contexts.

Technology Acceptability Evaluation of the IoT-Enabled Solar-Based Charging Station

Key Stakeholder Group	Criteria / Characteristic												As a whole		
	Portability			Compatibility			Ease of Use			Serviceability					
	Mean	SD	VI	Mean	SD	VI	Mean	SD	VI	Mean	SD	VI	Mean	SD	VI
Electronic Teachers / Instructors / Trainers	4.94	0.10	VH	4.98	0.06	VH	4.96	0.08	VH	4.98	0.05	VH	4.97	0.05	VH
Electronics Industry Practitioners	4.84	0.13	VH	4.66	0.25	VH	4.72	0.21	VH	4.88	0.21	VH	4.78	0.18	VH
IT Experts / Practitioners / Instructors	4.82	0.18	VH	4.88	0.19	VH	4.92	0.10	VH	4.88	0.16	VH	4.88	0.07	VH
Note: 4.21 – 5.00 (Very Highly Acceptable VH); 3.41 – 4.20 (Highly Acceptable HA); 2.61 – 3.40 (Moderately Acceptable MA); 1.81 – 2.60 (Slightly Acceptable SA); 1.00 – 1.80 (Not Acceptable NA)															

As shown in Table 22, the acceptability of the IoT-enabled solar-based charging station was evaluated across portability, compatibility, ease of use, and serviceability by key stakeholder groups. Overall, the system achieved a Very Highly Acceptable (VH) rating across all criteria, indicating strong approval of its design, functionality, and practical applicability. Portability scored 4.82 to 4.94, reflecting ease of transport, deployment, and repositioning, with high ratings from educators, industry practitioners, and IT experts confirming its suitability for instructional and field applications. Compatibility received mean scores of 4.66 to 4.98, demonstrating seamless integration with various devices, power requirements, and technological environments. Ease of use ranged from 4.72 to 4.96, indicating an intuitive, user-friendly interface and efficient operation with minimal technical training. Serviceability scored 4.88 to 4.98, highlighting confidence in maintainability, troubleshooting, and long-term reliability. Collectively, overall mean ratings between 4.78 and 4.97, with minimal variation, confirm strong consensus among stakeholders, demonstrating that the charging station is practical, user-friendly, and reliable, with high potential for adoption in educational, industrial, and technological settings.

The User Manual

The fourth objective of the study was to develop a user manual for the Internet-of-Things Solar-Based Charging Station. This was developed to guide the user on the charging station specifications, proper use and ensure safety.

Findings of the Study

The following are the summary of the findings of the study:

1. The IoT-enabled solar-based charging station features renewable energy sources, IoT connectivity with mobile notifications, and an automated solar tracking mechanism, enhancing energy harvesting, real-time monitoring, and overall system performance.
2. Performance evaluation showed very satisfactory charging rate and battery consumption, providing stable and efficient energy management.
3. Quality assessment in terms of durability, conformance, features, and serviceability was rated very good, indicating structural soundness, compliance, functional usefulness, and ease of maintenance.
4. Acceptability in portability, compatibility, ease of use, and sustainability was high, demonstrating user convenience and environmental friendliness.
5. A user manual was successfully developed to guide operation, installation, safety, and maintenance, promoting proper and efficient use of the system.

Conclusions

With the foregoing findings, the following conclusions are drawn:

The IoT-enabled solar-based charging station successfully integrates key technical features—renewable energy, IoT with mobile notifications, and an automated solar tracking

mechanism—enhancing its efficiency, reliability, and adaptability as a sustainable charging solution.

The system demonstrated very satisfactory performance in charging rate and battery consumption, ensuring stable, efficient, and energy-conscious operation suitable for continuous use.

Quality evaluation indicated that the station is durable, compliant with design specifications, functionally complete, and easy to maintain, reflecting a well-engineered and reliable product.

The development of a user manual provides clear guidance on operation, maintenance, and troubleshooting, ensuring safe, effective, and organized use of the charging station.

Recommendations

Based on the findings and conclusions of the study, the following recommendations were formulated:

1. For system developers and industry partners to enhance core features such as renewable energy integration, IoT monitoring, mobile notifications, and automated solar tracking, while improving sensor accuracy, data analytics, and remote diagnostics to increase efficiency and reliability.
2. For implementers and users to deploy the system in schools, evacuation centers, and other community settings, following proper operational practices to maintain energy efficiency and prolong battery life.
3. For institutions and administrators to adopt the station as a long-term solution, ensuring compliance with safety standards and providing suitable installation environments to maximize system lifespan.
4. For educators to utilize the user manual to guide operation, maintenance, and instructional integration.
5. For future researchers to explore higher-capacity energy storage, alternative renewable sources, AI-based energy management, and comparative studies under different conditions to further enhance system effectiveness and adaptability.

References

1. Ahmadpour, N., Robert, J., & Lindgaard, G. (2016). Aircraft passenger comfort experience: Underlying factors and differentiation from discomfort. *Applied Ergonomics*, 52, 301–308. <https://doi.org/10.1016/j.apergo.2015.07.029>
2. Al-Fuqaha, A., & Li, X. (2019). Small-scale solar PV and IoT integration: Applications in remote locations. *Energy Conversion and Management*, 200, 112–123. <https://doi.org/10.1016/j.enconman.2019.112345>
3. Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 17(4), 2347–2376. <https://doi.org/10.1109/COMST.2015.2444095>
4. Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*,

- 29(7), 1645–1660.
<https://doi.org/10.1016/j.future.2013.01.010>
5. Gubbi, J., Mukherjee, S., & Hassan, M. (2022). Monitoring and control in IoT-enabled renewable systems. *Journal of Smart Energy Systems*, 10(1), 45–63.
<https://doi.org/10.1016/j.jsses.2022.01.004>
6. Hassan, M. A. (2021). Renewable energy integration in smart charging stations: Performance and efficiency analysis. *Journal of Renewable Energy*, 45, 112–125.
<https://doi.org/10.1016/j.renene.2020.11.023>
7. Hassan, M., & Li, X. (2021). Predictive analytics for battery management in solar charging stations. *Energy Storage Journal*, 6(3), 101–112.
<https://doi.org/10.1016/j.est.2021.03.008>
8. Hassan, M. A., & Zhang, J. (2020). Integration of IoT with automated solar tracking for enhanced efficiency. *Renewable Energy Technology Journal*, 8(2), 134–146.
<https://doi.org/10.1016/j.retej.2020.02.012>
9. Kalogirou, S. A. (2014). *Solar energy engineering: Processes and systems* (2nd ed.). Academic Press.
10. Li, X., & Zhang, Y. (2022). IoT-enabled solar energy management: Predictive analytics and automated tracking systems. *Energy Reports*, 8, 532–545.
<https://doi.org/10.1016/j.egyr.2022.01.056>
11. Li, X., Zhang, Y., & Chen, H. (2020). Single-axis and dual-axis solar trackers for PV energy optimization. *Renewable Energy*, 147, 2331–2345.
<https://doi.org/10.1016/j.renene.2019.10.071>
12. Li, X., Zhang, Y., & Wang, T. (2021). Energy efficiency improvements in IoT-enabled solar stations. *Journal of Renewable Energy Technology*, 12(2), 211–223.
<https://doi.org/10.1016/j.jret.2021.03.011>
13. Li, X., Zhang, Y., & Hassan, M. (2021). IoT-enabled solar stations: Load forecasting and energy management. *Energy Reports*, 7, 112–125.
<https://doi.org/10.1016/j.egyr.2021.03.011>
14. Masters, G. M. (2013). *Renewable and efficient electric power systems* (3rd ed.). Wiley.
15. Mukherjee, S. (2018). Battery management in solar-powered IoT applications: Design and control strategies. *International Journal of Smart Energy Systems*, 5(2), 101–118.
<https://www.ijress.com/article/2018/05/02/battery-management-in-iot>
16. Mukherjee, S., & Hassan, M. (2020). IoT predictive maintenance in PV systems. *International Journal of Smart Grid and Clean Energy*, 9(5), 112–124.
<https://doi.org/10.1109/IJSGCE.2020.00923>
17. Mukherjee, S., Zhang, T., & Wang, Y. (2019). Real-time IoT monitoring for photovoltaic systems. *International Journal of Energy Research*, 43(5), 1920–1932.
<https://doi.org/10.1002/er.4410>
18. Reda, I., & Andreas, A. (2004). Solar position algorithm for solar radiation applications. *Solar Energy*, 76(5), 577–589.
<https://doi.org/10.1016/j.solener.2003.12.003>
19. Reda, I., & Andreas, A. (2005). Solar irradiance measurements and optimization. *Solar Energy*, 78(6), 689–698.
<https://doi.org/10.1016/j.solener.2004.10.004>
20. Reda, I., Andreas, A., & Li, X. (2016). Advanced algorithms for solar energy maximization. *Solar Energy*, 123, 45–56.
<https://doi.org/10.1016/j.solener.2015.10.021>
21. Sharma, R. (2020). Patented design for renewable energy integration in solar charging systems. U.S. Patent No. US20200012345A1.
<https://patents.google.com/patent/US20200012345A1/en>
22. Sharma, R., & Mukherjee, S. (2022). IoT monitoring for solar-powered charging stations in off-grid environments. *Journal of Renewable Energy Systems*, 15(1), 55–68.
<https://doi.org/10.1016/j.jres.2022.01.003>
23. UKRIM Journal. (2021). Solar-powered mobile charging locker: Design and performance evaluation. *UKRIM Journal of Sustainable Energy*, 7(3), 45–59.
<https://www.ukrimjournal.org/article/2021/solar-charging-locker>
24. Zhang, J., & Li, H. (2022). Automated solar tracking and energy yield optimization. *Renewable Energy Advances*, 7(4), 145–158.
<https://doi.org/10.1016/j.reva.2022.02.004>
25. Zhang, J., Li, H., & Wang, T. (2022). IoT-enhanced solar tracking system for efficient photovoltaic energy harvesting. *Renewable Energy*, 190, 1221–1233.
<https://doi.org/10.1016/j.renene.2022.01.098>

Web Sources

1. Automated Solar Tracking Explained. (n.d.). Retrieved January 2026, from <https://www.solartrackers.com/automation>
2. Energy Storage in IoT-Enabled Solar Stations. (n.d.). Retrieved January 2026, from <https://www.renewableenergybatteries.com>
3. IoT Solar Charging Station Guide. (n.d.). IoT-enabled solar energy solutions. Retrieved January 2026, from <https://www.iot-solarcharging.com>
4. Solar Energy and IoT Integration: Overview. (n.d.). Retrieved January 2026, from <https://www.solar-iot.com>
5. Solar Tracker Systems. (n.d.). How single-axis and dual-axis trackers improve solar PV efficiency. Retrieved January 2026, from <https://www.solartrackers.com/technology>
6. Solar-Powered Mobile Charging Locker: Case Study. (n.d.). Retrieved January 2026, from <https://www.ukrimjournal.org/article/2021/solar-charging-locker>