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Hybrid solar-hydro charging system using Arduino Uno R3 and ESP32

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Abstract

This study presents the development and implementation of a Hybrid Solar-Hydro Charging System using Arduino Uno R3 and ESP32, aimed at providing a stable and sustainable power source for small electronic devices. Using a true experimental research design, the system was developed and tested with components such as a solar panel, dynamo, MPPT solar controller, MPPT module, motor battery, voltage sensor, OLED display, jumper wires, and socket outlet. The Arduino Uno R3 controlled voltage regulation via the voltage sensor and the distribution of power between solar and hydro sources. At the same time, the ESP32 enabled wireless monitoring through the Blynk application for real-time data tracking. The researchers participated in the evaluation by testing the charging system with low-power devices and making observations to assess its effectiveness and usability. Results indicate that the hybrid system produced a more stable and efficient voltage output than single-source setups, particularly under varying sunlight and water-flow conditions. The findings demonstrate the system's potential to provide clean and reliable energy in tropical environments with alternating sunny and rainy seasons. Recommendations for future researchers include improving the durability of the dynamo system, conducting long-term testing under varying weather conditions, enhancing battery storage capacity, and expanding the prototype for broader community use. This study advances affordable, localized renewable energy solutions through innovative hybrid technology.

Keywords: Arduino Uno R3, charging system, clean energy, ESP32, hybrid energy, hydro energy, solar energy, voltage output

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1. Introduction

In present-day society, electricity is a crucial component that helps in maintaining a high standard of living. Unlike primary energy sources such as wood or natural gas, electricity serves as an energy carrier with the distinct advantage of supporting a wide range of applications (Löfquist, 2020). According to Khandker et al. (2023), electricity powers essential household appliances, such as cooking, cleaning, heating, and cooling equipment, thereby improving efficiency, convenience, and overall quality of life. Hernández-Callejo et al. (2019) highlight that electricity also sustains modern communication technologies, including mobile devices, computers, and internet-based systems, which are indispensable for global connectivity and information exchange. In the healthcare sector, Lazo et al. (2023) explain that electricity powers advanced diagnostic tools, life-support systems, and hospital facilities, making it crucial for patient care and public health. Similarly, Liu et al. (2023) note that in the transportation sector, electricity powers trains, subways, and electric vehicles, thereby reducing dependence on fossil fuels and contributing to sustainable mobility. Bansal (2020) further notes that in industrial and commercial sectors, electricity supports automation, large-scale production, and technological innovation, all of which are critical for economic development and competitiveness. In addition, Cang (2024) asserts that electricity is essential for the functioning of public infrastructure, such as water distribution, sanitation systems, and security networks, all of which are essential for social stability and well-being. Access to electricity is, therefore, not merely a convenience but a fundamental resource for improving human life and meeting societal needs. Without it, many aspects of daily activity and national development would be severely disrupted, making it difficult for individuals and communities to function effectively (Lusková & Leitner, 2021).

However, as electricity is deeply integrated into nearly every aspect of daily life, demand continues to rise significantly (Zohuri & Rahmani, 2019). At present, a considerable portion of global electricity production still relies heavily on coal, a fossil fuel and a non-renewable resource that requires millions of years to form and thus cannot be replenished within a human timescale. According to Akintunde et al. (2024), excessive dependence on coal not only accelerates the depletion of this finite resource but also has severe environmental consequences. The researchers highlighted that burning coal releases large amounts of harmful gases, including carbon dioxide and sulfur dioxide, which contribute to ozone depletion, intensify global warming, and worsen air quality. These environmental impacts, in turn, disrupt ecosystems, endanger public health, and diminish the overall quality of human life.

To address these challenges, the energy industry continues to explore and develop alternative energy sources that are both sustainable and environmentally friendly. One notable example is hydropower, the most widely used renewable source of electricity in the world, which produces almost 4,500 terawatt-hours per year and supplies about 16% of global electricity (Ritchie et al., 2020). Hydropower uses the movement of water, usually from rivers or dams, to spin turbines that generate electricity. Kabeyi and Olanrewaju (2023) emphasize that hydropower is considered reliable because water flow is naturally replenished through the water cycle, making it a consistent energy source. Following hydropower, wind energy is the next most common, capturing the kinetic energy of moving air to generate electricity. Wind power generates about 2,500 terawatt-hours annually and supplies around 7% of the world's electricity (Ritchie et al., 2020). Wind energy is one of the fastest-growing renewable sources because it is clean, abundant, and can be harnessed both onshore and offshore (Meier, 2020). Another important renewable source is solar energy, which uses photovoltaic panels to convert sunlight into electricity. Solar power produces approximately 2,200 terawatt-hours per year, providing about 5.4% of global electricity (Ritchie et al., 2020). Solar energy is highly sustainable because sunlight is an unlimited resource, with applications ranging from small household systems to large-scale solar farms (Sujatha et al., 2024). The energy industry believes that these alternatives can help reduce the world's dependence on coal and other nonrenewable fuels while also protecting the environment and improving people's way of life.

Be that as it may, alternatives also come with their limitations. According to Kabeyi and Olanrewaju (2023), hydropower requires large water sources and the construction of dams, which entail high costs and can disrupt ecosystems and displace communities. They explain that hydropower is highly dependent on rainfall, making it less reliable in areas prone to drought or with low levels of precipitation. Wind power also faces certain limitations. Dar and Bremen (2019) explain that, since wind is unpredictable and its speed and direction fluctuate, it is difficult to accurately predict how much electricity a wind farm will generate at any given time. Wind energy also poses environmental concerns, as turbines can endanger birds and bats, particularly during migration or when flying nearby (Perold et al., 2020). Moreover, installing wind turbines entails high construction costs and requires extensive land to generate significant amounts of electricity (Juneja, 2024). Solar power also has limitations, primarily due to its intermittent nature: it relies heavily on sunlight, making it an unreliable energy source on cloudy days, at night, or in regions with limited sunlight exposure (Patil et al., 2022). The installation of solar panels also entails high construction costs and requires significant space, as well as a favorable geographic location and climate, to achieve optimal energy generation (Redko & Adamenko, 2024).

Therefore, this study aims to develop an Arduino-based hybrid solar-hydro-powered renewable charging system to generate free, clean energy for various devices. The researchers chose solar and hydropower as energy sources because the machine is designed for tropical weather conditions, specifically the climate of the Philippines, which features distinct sunny and rainy seasons. Given the Philippines' location near the equator and along the Pacific Ocean, where it experiences intense heat and frequent typhoons, the researchers saw potential to maximize both solar and hydro energy as complementary sources. During the hot, dry season, solar panels can generate abundant electricity, while in the rainy season, hydropower can be harnessed from continuous rainfall and water flow. Unlike wind power, which requires vast land areas and is difficult to optimize in the Philippines due to its highly variable topography, the solar-hydro combination provides a more practical and adaptable solution.

To efficiently monitor, control, and optimize power generation from both sources, the system integrates an Arduino Uno microcontroller, widely used in renewable energy prototypes for its reliable sensor interfacing and efficient system control capabilities (Al-Shetwi et al., 2021). Additionally, an ESP32 module is implemented to enable wireless communication, supporting remote monitoring and configuration via Wi-Fi and Bluetooth, thanks to its integrated dual-core processor and low-power design (Ahamed & Rahman, 2022). The combination of the Arduino Uno's dependable hardware control and the ESP32's advanced wireless capabilities enables the system to operate intelligently and responsively, with improved user interaction (Mumtaz et al., 2023). This dual-power configuration ensures a more stable and reliable energy supply year-round, reducing dependence on traditional fossil fuels. Moreover, the proposed charging system uses affordable yet high-quality materials, making the machine accessible not only to urban communities but also to rural and low-income areas.

Statement of the Problem - This research aimed to develop a Hybrid Solar-Hydro Powered Charging System using Arduino Uno R3 and ESP32 to develop free and clean energy for different devices. It sought to respond to the following questions: (1) What is the average voltage output of the Hybrid Solar-Hydro Charging System using Arduino Uno R3 and ESP32 in terms of the solar energy collection, water flow condition, and length of charging time? (2) What is the level of effectiveness of the Hybrid Solar-Hydro Charging System using Arduino Uno R3 and ESP32 in terms of accuracy and voltage output? (3) Is the use of an Organic Light-Emitting Diode (OLED) Display and Blynk Application in the Hybrid Solar-Hydro Charging System using Arduino Uno R3 and ESP32 significantly effective in showing voltage output? (4) Is there a significant difference in charging efficiency between a hybrid solar-hydro charging system, a solar-only charging system, and a hydro-only charging system?

Statement of Hypothesis - This study aims to test the following hypothesis: HO1: The use of an Organic Light-Emitting Diode (OLED) Display and Blynk Application in the Hybrid Solar-Hydro System Using Arduino Uno R3 and ESP32 is not significantly effective in showing battery capacity. H02: There is no significant difference in charging efficiency between a hybrid solar-hydro charging system, a solar-only charging system, and a hydro-only charging system.

Significance of the Study **-** This study is important because it introduces a renewable charging station that uses both solar and hydro power, controlled by Arduino technology using the Arduino Uno R3 and ESP32, to address the growing need for sustainable, renewable energy and environmental concerns. The results and findings of this study will be beneficial to the following: first, students. This study serves as a reference for the application of Arduino technology in renewable energy systems. It encourages further exploration of smart and automated control in hybrid power generation, contributing to academic growth and technological innovation. Second is for Teachers and Faculty Staff. The charging station provides sustainable support for academic electronics that aid tasks. It also promotes the integration of renewable energy practices within educational institutions, aligning with global trends in sustainable development. Third is for employees. The system provides a reliable power source for their electronics, ensuring efficiency and continuity in daily operations. It also introduces them to the practical benefits of renewable energy, which may inspire broader adaptations across the workplace.

Fourth is for the community. This project offers a practical solution for areas with limited or unstable electricity, particularly in rural regions where power access is scarce. It can also reduce dependence on traditional energy sources that are costly and environmentally harmful. Fifth is for the environment. The project demonstrates the feasibility of integrating renewable sources into small-scale charging stations, potentially inspiring larger-scale applications. This study also helps promote clean and green energy. Since it uses renewable sources, it can lessen pollution and contribute to the fight against climate change. Lastly, it is for future researchers. This study emphasizes the importance of developing clean energy solutions and demonstrates how technology and sustainability can work together to address energy challenges. This project can serve as a guide and source of inspiration for developing more innovative ideas focused on renewable energy and Arduino-based technology.

Scope and Delimitation of the Study **-** The general intent of the study was to develop a Hybrid Solar-Hydro Charging System using an Arduino Uno R3 and an ESP32, which utilized a solar panel and a dynamo. There were several specific delimitations in the project. The study was designed for tropical weather conditions, specifically the climate of the Philippines, which is characterized by only two seasons: rainy and sunny. Therefore, it did not include long-term testing across different seasonal variations. The study also did not include a full-scale analysis of the dynamo design's durability during heavy rainfall or flooding. Consequently, only solar energy from sunlight and hydro energy generated from tap water were used in testing. The study was limited to the school premises of Divine Word College of San Jose, Occidental Mindoro; however, it may be possible to expand its application to a larger population. The researchers personally conducted the testing, monitoring, and evaluation of the system, ensuring objectivity and minimizing bias throughout the process. The prototype tested the charging system via the outlet (socket) by charging low-power devices such as mini fans, flashlights, and cellphones. The project was designed solely to provide power through the combined use of a solar panel and a dynamo only. Hydropower provides steady mechanical energy and delivers kinetic energy more effectively than wind, given water's higher density and wind's lower density and fluctuating nature. For this reason, flowing water and sunlight were selected as the system's primary energy sources. The hybrid solar–hydro charging system's output voltage was limited to 14 volts. The research time frame is from August 2025 to February 2026.

2. Methodology

Research Design **-** This study used a True Experimental and Developmental Research Design. The researchers employed this design to develop and test the Hybrid Solar–Hydro Powered Charging Station using Arduino Uno and ESP32. This design was appropriate because it helped determine the cause-and-effect relationship between the independent variables (the Arduino Uno and ESP32) and the dependent variable (the performance and efficiency of the hybrid solar-hydro-powered charging station). In the study by Marcus (2022), a true experimental research design is one in which the researcher manipulates one or more independent variables, randomly assigns participants to experimental and control groups, and analyzes the effect on the dependent variable to identify cause-and-effect relationships. Adding to his study, a developmental research design is a systematic approach that uses iterative design, development, and testing to examine the creation, enhancement, or assessment of products, procedures, or models.

In this study, the researchers developed a prototype of a hybrid charging station controlled by an Arduino Uno and monitored by an ESP32. The Arduino Uno handled voltage, current, and power distribution between the solar and hydro sources, while the ESP32 handled monitoring and data recording. By adjusting and testing these microcontrollers, the researchers observed their effects on the system's overall charging efficiency, voltage output, and stability. The experiment also included comparisons between the hybrid system and single-source setups, such as solar-only and hydro-only charging systems. This helped determine whether using both an Arduino Uno and an ESP32 significantly improved the system's performance. Data was collected from multiple sensors measuring voltage, current, and water flow, with readings automatically logged for analysis. According to Patel et al. (2021), the main advantages of using a true experimental research design were that it allowed the researchers to obtain measurable results, verify the relationship between variables, and determine whether integrating Arduino Uno and ESP32 truly enhanced the efficiency and reliability of the hybrid charging station. Repeated testing was conducted to ensure the findings were consistent and accurate.

Data Gathering Procedure - The researchers conducted a study to assess the accuracy and efficiency of the new device. The experiment involved the researcher testing their prototype device, ensuring objectivity and minimizing bias throughout the process, while they owned electronic devices such as mini fans and flashlights. The prototype device is tested five times to ensure accurate data. The researchers placed their devices in the charging station, observed the charging process, and recorded the time required to fully charge each device. The researchers then collected the data within 2–3 days, calculated the results, and drew conclusions based on it.

Research Process

Stage 1 Preparation and Gathering of Materials

The following supplies are required to create the Hybrid Solar-Hydro Charging System Using Arduino Uno R3 and ESP32. A) For the Machine: Arduino Uno R3, Dynamo, ESP32, Jumper Wires, Motor Battery, MPPT Solar Controller, MPPT Module, Normal Wires, OLED Display, Socket/Outlet, and Solar Panel. B) Casing and Accessories: PVC Panel and Wall Angle Bar. The researchers used the familiar controller kits available at Divine Word College of San Jose, namely the Arduino and ESP32. Major materials were purchased online, including the Arduino Uno R3, solar panel, dynamo, and MPPT Controller. The researchers aimed to find low-cost materials that students could afford. The estimated cost of the materials was ₱5,000, and the total shipping cost was ₱300.

Stage 2 Construction and Development of Product

Figure 1: *Actual Product*

The researchers used an Arduino R3 and an ESP32 to build a Hybrid Solar-Hydro Charging System that combined sunlight and flowing water into a single system, providing a dependable, environmentally friendly way to power small electronic devices. The ESP32 enabled wireless real-time system monitoring, while the Arduino R3 acted as the project's brain, processing sensor data and determining when each power source should turn on. The dynamo converted water flow into electricity during cloudy or rainy conditions. During the day, the solar panel absorbed sunlight and stored the energy produced in a motor battery. The MPPT solar charge controller was used to regulate the energy coming from the solar panel and direct it to the motor battery. Another MPPT module was also used to regulate the energy generated from the dynamo before it was stored in the motor battery. These MPPT controllers helped regulate the voltage output from the two power sources, ensuring stable, efficient charging. A voltage sensor was connected to both power sources to monitor the output voltage of each. The monitored data was displayed through the Blynk application and the OLED display for real-time monitoring. The stored energy from the battery was connected to an inverter, which converted the electrical output into a usable form for charging devices. The inverter was then connected to a three-gang socket for charging electronic devices. The entire setup was encased in a durable PVC panel housing designed to protect the internal components. Wall angle bars were used as the machine's frame, providing structural support. This design resulted in a sturdy and practical prototype that highlighted functionality, sustainability, and the innovative use of accessible materials.

Stage 3 Experimental Stage, Observation, and Data Recording

The researchers evaluated the accuracy and effectiveness of the Hybrid Solar-Hydro Powered Charging System using Arduino Uno R3 and ESP32, focusing on Solar Energy Collection, Hydro Kinetic Energy Collection, Water Flow Condition, and Charging Time. First, the researchers developed and coded the program system using the Arduino IDE for 2 weeks. The "troubleshooting" method was used to adjust the sensors and control system for both the solar and hydro components. The Arduino Uno was programmed to manage power distribution between the solar panels and the micro water turbine. At the same time, the ESP32 was used for wireless data monitoring and transmission, enabling real-time observation of energy readings. Next, the researchers built the prototype by attaching the solar panel, dynamo, and voltage sensors to the Arduino Uno and ESP32 modules. The programmed data was uploaded into the microcontrollers to perform and evaluate the hybrid charging station's functionality. The machine was first tested in direct sunlight to measure its solar energy collection, followed by water-flow trials using pumps to circulate water through the dynamo to determine the hydrokinetic energy output.

The researchers then monitored and recorded the energy generation rate, charging performance, and stability of the hybrid charging station under varying light intensities and water flow rates. The experimental stage lasted 1 day, with testing at different times of day. Multiple troubleshooting procedures were conducted to ensure the reliability of combining solar and hydro energy and to determine the time required to fully charge a standard mini fan or an electric flashlight. Lastly, the experiment focused on comparing results across various conditions to determine the system's overall efficiency, consistency, and effectiveness in solar and hydrokinetic energy collection under different water flow conditions and during charging. The data gathered during troubleshooting served as the basis for evaluating the hybrid solar-hydro charging station's performance and operational feasibility.

The researchers in this study monitored, recorded, and collected data from the hybrid solar-hydro charging station to thoroughly assess its performance and operational response. They monitored the generated voltage, current, and power output from both the solar and hydro components under various environmental conditions. The results were documented photographically and in video recordings to represent the device's production process. The researchers documented all experimental results in detail, recording both consistent performance and irregularities to identify areas for improvement. The collected data served as the basis for a critical review of how the study's objectives were achieved and for an analysis of the system's overall performance. In addition, the system's efficiency and productivity were analyzed under different conditions. Factors such as operational time, power output, and performance consistency were measured and evaluated to determine the system's capability under various test conditions. All variations were systematically recorded to ensure an accurate and valid assessment of performance differences.

Statistical Treatment of the Data - The researchers used a descriptive statistical approach, specifically the weighted mean, to accurately evaluate the efficiency and reliability of the hybrid solar-hydro-powered charging system. This enabled the researchers to assess the system's stability and effectiveness in converting renewable energy into electricity. The researchers also used the Pearson correlation coefficient (Pearson’s r) to determine whether there is a relationship between the use of the Blynk application and the OLED display in displaying the voltage output of the hybrid solar-hydro charging station. To determine significant differences in performance among the hybrid solar-hydro-powered charging station, the solar-only system, and the hydro-only system, the researchers conducted an Analysis of Variance (ANOVA). This statistical tool was used to compare three or more groups and identify significant differences among them. It helped determine variations in charging efficiency, energy output, and charging time for specific devices across different power sources. The researchers used ANOVA to determine whether the hybrid solar-hydro setup is more efficient than its single-source counterparts.

Ethical Considerations - The researchers ensured that ethical guidelines were closely followed throughout the investigation, even without engaging outside respondents. The researchers themselves served as the system's testers, enabling regulated and reliable assessment processes. They ensured that no results were falsified, altered, or selectively published by collecting, evaluating, and presenting the data honestly and openly. Additionally, by using uniform testing protocols and carefully documenting data, the researchers ensured their observations were free of bias. To prevent plagiarism and acknowledge the work of earlier researchers, all relevant literature, technical references, and supporting studies were appropriately referenced. During the system's design, construction, and testing, the researchers also prioritized safety and accountability. To avoid errors, equipment damage, or environmental damage, electrical components, wiring, and energy sources were handled in accordance with appropriate safety protocols. To guarantee adherence to academic standards and institutional rules, permission and direction were sought from the research adviser and school officials. Additionally, the system's hardware and software were lawfully obtained and used appropriately, promoting professionalism and ethical responsibility throughout the study process.

3. Results and Discussion

Table 1

Average Voltage Output of the Hybrid Solar-Hydro Charging System

Indicators	Mean Voltage Output (V)	Interpretation
Solar Energy Collection	8.16 V	High Output
Water Flow Condition	4.97 V	Moderate Output
Length of Charging Time	8.28 V	Very High Output
COMPOSITE MEAN	7.14 V	High Output

Legend: 8.51-9V Very High Output, 7.01-8.50V High Output, 5.51-7V Moderate Output, 4.01-5.5V Low Output, 4V and below Very Low Output

The data from Table 1 show how the Hybrid Solar-rHydro Charging System generates voltage as a function of three variables: the amount of solar energy collected, the water flow conditions, and the charging time. Overall, the results show that solar energy collection produced an average voltage of 8.16 volts, which is classified as High Output. The result suggests that sufficient solar irradiation enables the Photovoltaic portion of the charging system to provide a consistent, reliable voltage source for charging smaller electronics. In contrast, the water flow condition produced a mean voltage of 4.97 volts, classified as Low Output, indicating significant variability in hydroelectric generation based upon changes in water flow rates.

Additionally, the results show that charging time produced an average voltage of 8.28 volts, also classified as High Output. The results indicate that longer charging times enable greater energy accumulation, thereby improving voltage performance. Overall, the weighted mean was 7.14 volts, categorized as High Output, indicating that the hybrid solar-hydro charging system provides a relatively consistent and reliable voltage output when both renewable sources are used together. These findings are supported by Dushimimana and Bikorimana

(2025), who studied a hybrid solar PV-hydropower plant in Rwanda. Their findings indicated that while the combined use of solar irradiation (average daily production of 4.71 kWh) and hydropower provides a stable level of total electricity generation equal to the installed capacity of the hydropower plant, the solar energy helps compensate during periods of hydro generation deficiencies, thus maintaining a consistent overall level of production.

Table 2

Level of Effectiveness of the Hybrid Solar-Hydro System

Indicator	Weighted Mean	Interpretation
Accuracy	13.5	Very Effective
Voltage Output Stability	12.63	Very Effective
COMPOSITE MEAN	13.07	Very Effective

Legend: 12.00-14.00 Very Effective, 10.00-11.99 Effective, 7.00-9.99 Moderately Effective, 5.00-6.99 Slightly Effective, 4.99 and below Not Effective

The results in Table 2 illustrate the effectiveness of the Hybrid Solar-Hydro System in terms of accuracy and voltage output, as determined by a weighted mean analysis. The system documented a weighted mean accuracy of 13.5, interpreted as very effective, indicating that it consistently provided a stable energy supply required for the charging system to operate. In voltage output stability, the system shows a weighted mean of 12.63, interpreted as very effective, indicating that it maintains a steady voltage suitable for charging devices, with only minor changes due to sunlight intensity and water flow. Taken together, the overall weighted mean of 13.07 indicates that the Hybrid Solar-Hydro System is very effective, with stable voltage output and charging accuracy for charging devices. These findings are supported by Dushimimana and Bikorimana (2025), who studied a hybrid solar PV-hydropower plant in Rwanda. Their findings indicated that while the combined use of solar irradiation (average daily production of 4.71 kWh) and hydropower provides a stable level of total electricity generation equal to the installed capacity of the hydropower plant, the solar energy helps compensate during periods of hydro generation deficiencies, thus maintaining a consistent overall level of production.

Table 3

Relationship Between the Use of Organic Light-Emitting Diode (OLED) Display and Blynk Application in Showing the Battery Capacity of Hybrid Solar-Hydro Charging System

Paths	Computed Value (Pearson's rho)	Interpretation
IV1 (Use of OLED Display) => DV (For showing voltage output)	0.46	Moderate
IV2 (Use of BLYNK application) => DV (For showing voltage output)	0.65	Strong
COMPOSITE MEAN	0.56	Moderate

Legends: 0.80-1.000 Very Strong, 0.60-0.799 Strong, 0.40-0.599 Moderate, 0.20-0.399 Weak, 0.00-0.199 Very Weak

Table 3 presents the relationship between the independent variables, which are the use of OLED display and the use of the Blynk Application, and the dependent variable, which is the voltage output of the Hybrid Solar-Hydro Charging System. Using an OLED display yielded a Pearson's rho of 0.46, indicating a moderate relationship. This shows that the OLED display presents voltage readings rather effectively, giving the user a clear, real-time report. Using the Blynk application yields a Pearson's rho of 0.65, indicating a strong association and demonstrating that the mobile-based monitoring system greatly increases accessibility and monitoring effectiveness. The composite mean of the two calculated values is 0.56, indicating a moderate relationship. The Blynk application had the highest rho value of 0.65, suggesting that using a smartphone for remote monitoring provides more accessibility, ease, and real-time tracking. The OLED display had the lowest rho value of 0.46, which is still helpful but only available for on-site viewing. This supports the study by Ali et al. (2025), which states that using an ESP32 microchip to run the Blynk application offers a flexible range of applications, such as wirelessly displaying information through a mobile application.

Table 4

Difference Between Hybrid Solar-Hydro Charging System, Solar-Only Charging System, and Hydro-Only Charging System, in the Charging Efficiency

SUMMARY						
Groups	Count	Sum	Average	Variance		
Column 1	14	118.7	8.478571	0.138736		
Column 2	14	62.2	4.457143	0.128791		
Column 3	14	176.8	12.62857	0.312967		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	467.4443	2	233.7221	1207.878	8.33E-36	3.238096
Within Groups	7.546429	39				
Total	479.9907	41				

Legend: p-value ≤ 0.05 – Significant; p-value < 0.001 Highly Significant

Table 4 presents the results of the ANOVA: Single Factor test, conducted to determine whether a significant difference exists among the three groups (Columns 1, 2, and 3). Based on the Excel results, the computed F-value is 1207.878, which is much higher than the F-critical value of 3.238096. In addition, the computed p-value is 8.33E-36 (p-value < 0.001), which is far below the 0.05 level of significance. Because the computed F-value exceeds the F-critical value and the p-value is less than 0.05, the null hypothesis is rejected. This indicates a statistically significant difference in the mean scores among the three groups. In other words, the differences observed in the data are unlikely to have occurred by chance and instead suggest that the factor being tested had a measurable effect on the outcomes. A closer look at the group means further supports this conclusion. Column 1 has a mean of 8.478571, Column 2 has a mean of 4.457143, and Column 3 has the highest mean of 12.62857, indicating that hybrid energy is more reliable than having a single energy source. This supports the claim of Anandhi et al. (2024) that combining two power sources, such as solar and hydro, can improve a machine's power output compared to a single power source.

4. Conclusions

Based on the gathered data, the researchers concluded that, for the average voltage output of the Hybrid Solar-Hydro Charging System, the solar and hydro components efficiently supply electrical energy. The solar panel produced a high voltage output with the assistance of the Arduino Uno R3 and ESP32, indicating the importance of the system's efficiency; the dynamo produced a moderate output in the hydro component, showing that its effectiveness is also dependent on the strength and consistency of the water flow; and longer charging times produced higher voltage output, indicating that the system's ability to collect and supply enough electrical energy to perform effective device charging. In terms of accuracy and voltage output, the Hybrid Solar-Hydro Charging System demonstrated a very high degree of accuracy and efficacy. Despite changes in solar intensity and water flow conditions, the system consistently delivered reliable, precise monitoring results while maintaining a stable, appropriate voltage level for effective, dependable charging.

Regarding the significant difference between the Organic Light-Emitting Diode (OLED) and the Blynk Application in displaying the voltage output, the investigation reveals the great effectiveness of the Blynk application and OLED display in monitoring the battery capacity of the Arduino Uno R3 and ESP32-based

Hybrid Solar-Hydro Charging System. The Blynk application indicated an important relationship, improving accessibility and real-time remote monitoring, while the OLED display showed a moderate relationship, offering precise and dependable on-site voltage monitoring. Overall, the findings prove that the system's usability and effectiveness in tracking battery capacity and voltage output were improved by both monitoring tools, especially the Blynk application. Lastly, for the significant difference in charging efficiency between the hybrid solar-hydro charging system, solar-only charging system, and hydro-only charging system, the findings show that the Hybrid Solar-Hydro charging system had the highest efficiency, indicating that the combination of solar and hydro energy is more reliable and provides a stable, effective power supply. The solar-only charging system, on the other hand, had moderate efficiency, suggesting that solar energy can provide sufficient power for charging. Still, it has limitations due to sunlight availability and other environmental factors. The hydro-only charging system receives the lowest efficiency, indicating that the flow rate limits the efficacy of hydro energy.

Recommendations - Based on the findings, the researchers recommend the following: programming and wiring are crucial factors in determining the system's performance. Developers can write simpler code and organize wiring with advanced commands, improve the system's capabilities, and reduce errors. The product could see enhancements with the availability of more efficient materials, such as sensors, and higher-voltage yields from the solar and dynamo. Electricians may adapt to hybrid solar-hydro charging systems rather than traditional ones. The researchers found that certain materials are more effective for a charging system than those commonly used. For instance, the ESP32 microchip used to run the Blynk application, which is typically used as a wireless controller for LED lights and other components, is more suitable for beginners to display the output voltage of the hybrid solar-hydro charging system than the Raspberry Pi, which is more complex. The researchers observed that the battery can overheat when it continuously receives energy from solar and hydro. The researchers recommend adding a toggle switch to enable or disable power input from the solar and hydro systems, thereby reducing overheating. This research aims to test how solar and hydropower are used in our charging system. Future researchers should add another power source, such as wind, to produce more energy output.

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