

**SOLAR-POWERED RENTAL STATION FOR DETACHABLE
POWER SOURCES**

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Electricity is essential to everyday living, powering different activities and circumstances, especially in households, from lights and appliances to connectivity. Electricity powers nearly every aspect of home living, being the most used energy source and notable expense among Filipino households, with a 94.8% usage rate based on the Philippines Statistics Authority (2023). During frequent power interruptions, Filipino households face severe impacts from frequent power interruptions including comfort issues and disruption of work and livelihoods. Many households rely on diesel generators as a temporary measure, but these are costly to run and contribute to noise and air pollution, indicating the need for other alternative measures for power sources.

According to Villamil et. al (2020), “The internet of things is an emerging technology that is currently present in most processes and devices, allowing to improve the quality of life of people.” As IoT continues to revolutionize daily living, solar energy, powered by innovations such as photovoltaic (PV) panels, plays a crucial role in shaping the future of global energy. Photovoltaic solar

energy is rapidly becoming a key player in the global energy transition. This surge in demand and innovation paves the way for a more sustainable future, making solar energy a central focus in the race for renewable solutions. As highlighted by Sampaio and González (2017), "The capture of solar energy through photovoltaic (PV) panels to generate electricity has emerged as one of the most promising markets in renewable energy." In response to this, many systems utilize off-grid renewable energy; systems such as solar power systems are designed to provide electricity. This aligns with the study of Ramly, Jamal, Abd Ghafar, and Babu (2019), who highlighted that the "Emergency Portable Solar Power Supply is a product that uses a renewable energy source (sunlight) as the main source of electricity."

Today's solar power systems offer many benefits. The technologies mentioned above can contribute to addressing key issues in the Philippines. They aim to reduce the impact of frequent power interruptions and emergencies, while promoting scalable renewable energy innovations for affected communities. Additionally, it contributes to sustainable energy systems by addressing the unique reliability challenges of off-grid and disaster-prone areas in the region.

According to an article by Albay (2025), In the Philippines, the average Filipino household experiences 28 electricity supply interruptions in a year,

due to frequent outages caused by plant breakdowns based on a report. The sudden or frequent power interruptions force households and businesses alike to rely on costly diesel generators as a backup power source. In August 2025, the National Grid Corporation of the Philippines (NGCP) reported an unscheduled power interruption affecting Camiguin and Misamis Oriental, which are home to 92,808 and 956,900 households based on the Philippine Statistics Authority (2020). The outage left thousands of households and businesses without power, mostly relying on diesel generators and various power sources. Addressing this gap in reliable energy access is crucial to providing communities with an affordable, sustainable power alternative and reducing the impacts of sudden interruptions.

Recent efforts to adapt solar-powered power supply systems show potential but face limitations. For instance, Gozano et al. (2023) designed a solar-based portable power supply with a modular battery pack. However, the portable power supply was shown capable of only supplying a lower energy load, such as charging mobile phones, mobile lighting and small auxiliary loads such as a small AM/FM radio. There were also shortcomings, such as the short lifespan of AC power whenever the battery pack reaches a certain voltage drop.

Innovations in solar-powered power supply systems offer a promising

solution to these challenges. Bhatti et al. (2024) developed a portable solar station with integrated battery management and load monitoring system, having a power output of 200 W, and a 2x2 array of 50 W solar panels to provide electricity for basic necessities, in times of power interruptions due to natural disasters. Similarly, the study by Ramly et al (2019) designed a portable solar power supply for emergency situations, supplying electricity up to 100W at one time, and utilizing Arduino Uno with Bluetooth module and voltage sensor to get the voltage readings integrated into a mobile application. The said system lasted for two days without the need for charging. Despite these innovations, current solar-powered power supply systems still face limitations, such as low energy capacity, short battery lifespan, and restricted support for higher power loads.

To bridge these gaps, this study proposes a solar-powered rental station for detachable power sources with a 2x2 solar panel array for energy harvesting, a LiFePO₄ battery for reliable storage, and an inverter for AC power conversion. The system integrates an ESP32 microcontroller, integrating IoT mechanisms to manage operations, with GPS for location tracking and GSM for communication. A coin-slot mechanism with a solenoid lock ensures secure access, while a mobile app provides real-time monitoring of battery charge levels and system status. The compact and user-friendly design offers a sus-

tainable solution for communities affected by frequent power interruptions.

1.2 Statement of the Problem

Air pollution is among the Philippines' most critical environmental issues, primarily caused by the use of fossil fuels. The Philippines' reliance on fossil fuels for electricity generation, particularly coal, contributes to elevated levels of air pollution. In 2025, coal accounted for approximately 52.7% of the country's electricity generation, while natural gas contributed 20.1%. This dependence on fossil fuels leads to the emission of pollutants that adversely affect air quality and public health. (LowCarbonPower, 2025).

Electricity is a necessity for modern life. In Camiguin (served by CAMELCO) and certain parts of Misamis Oriental (served by MORESCO 2), the local community frequently experiences unscheduled power interruptions, occurring multiple times a week. This issue is consistent with research indicating that power interruptions are common in developing countries (Ibañez, 2024; Taniguchi, 2019), such as the Philippines, particularly in rural areas (Ibañez, 2024; Ali, 2016). These interruptions not only hinder productivity but also affect daily comfort in many households, making them very inconvenient and a source of frustration.

Despite the availability of off-grid setups, power banks, and small gaso-

line generators, these options are often limited by cost, power capacity, or environmental sustainability. Furthermore, the reliance on fossil-fueled alternatives poses safety risks and contributes to pollution. In response, the government encourages a shift away from fossil fuel energy sources (Koons, 2024) and promotes the use of renewables, as outlined in the policy framework provided for in Republic Act (RA) No. 9513 or the “Renewable Energy Act of 2008”. Hence, there is a growing need for technological systems, such as solar-powered systems, to align with sustainability mandates. Studies show that the transition to greater use of renewables has wide-ranging implications (Villanueva, 2021), underscoring the importance of integrating supportive technologies into local environmental strategies.

Solar-powered systems have been introduced either as portable power supplies or as charging stations, yet existing systems face multiple limitations. Many of these are only capable of supplying low-energy loads, such as charging mobile phones, providing mobile lighting, or powering small auxiliary devices like AM/FM radios (Gozana et al., 2023). Additionally, the average cost of an off-grid setup is high (Boodoo, 2024), making it unaffordable for many households. Research also shows that solar-powered systems are commonly installed within the premises of the college campus (Catalan et al., 2019), but have not been widely initiated for communal purposes (Catalan et al., 2023).

Furthermore, a notable gap exists in security, as many systems lack sufficient measures to prevent delinquent users from tampering with or vandalizing the system. These gaps, along with the promotion of solar-powered coin-operated charging stations in remote and island barangays, are highlighted by Catalan et al. (2023), as these areas often face significant challenges in power accessibility.

Given these limitations, there is a clear need for an innovative solar-powered rental system that is both affordable and scalable, while providing reliable energy access for households and public areas affected by frequent and unscheduled power interruptions. This study aims to design and develop a solar-powered rental station with detachable power sources, offering a sustainable and user-friendly alternative to conventional backup solutions, while also addressing the need for improved security features.

1.3 Objectives of the Study

In view of the above stated problem, the following objectives are:

1.3.1 General Objectives

- To design and develop a solar-powered rental station with detachable power sources that serves as a sustainable and user-friendly solution for supplying electricity, specifically intended for communities experiencing frequent power interruptions.

1.3.2 Specific Objectives

- To design the system architecture that integrates photovoltaic panels, energy storage, and a power inverter, ensuring sufficient capacity for powering small to medium-scale appliances.
- To develop a functional prototype of the rentable station with a detachable power source, with a secure coin-operated or app-based access mechanism for rental use.
- To integrate GPS and GSM modules to support real-time location tracking, communication, and monitoring of rented units.
- To evaluate the system's performance in terms of efficiency, portability, security, and user satisfaction in a rental-based context.
- To provide sustainable energy access through affordable and shared power sources powered by solar energy.

1.4 Significance of the Study

This project benefits a diverse range of stakeholders including:

Community Residents - Community residents will benefit from continuous access to electricity through the solar-powered portable power source. This system ensures the community residents can use essential household ap-

pliances and stay connected during power interruptions, improving their daily lives and overall comfort.

Environment - This study contributes to environmental sustainability by promoting the use of solar energy, a renewable resource, instead of relying on fossil-fueled generators. The system reduces carbon emissions and pollution, aligning with global sustainability goals.

Future Researchers - Future researchers will find this study helpful because it gives important information on how to create solar-powered portable charging systems with features like GPS tracking, coin/app payment, and real-time monitoring.

SDG 7: Affordable and Clean Energy - This system provides support in giving people access to energy that is affordable, reliable, and environmentally friendly by offering a solar-powered rental station that provides communities, especially those often experiencing blackouts, with a clean and low-cost source of electricity.

Industry, Innovation, and Infrastructure - This helps achieve the goal of improving systems, creating new technologies, and building stronger infrastructure by using modern technologies, as well as solar energy, which helps in creating innovative solutions that give communities a reliable energy option during power interruptions.

1.5 Scope and Limitations

This research focuses on designing a solar-powered rental station with detachable power sources to provide reliable and sustainable electricity for communities in Camiguin and selected areas in Misamis Oriental, which face frequent power interruptions. The system integrates photovoltaic panels, energy storage, and a power inverter to power small to medium-scale appliances. The design will include a coin-operated or app-based access mechanism for renting the power sources.

The study will incorporate GPS and GSM modules for real-time location tracking and communication, ensuring efficient monitoring of rented units. The system will be evaluated for efficiency, portability, security, and user satisfaction, focusing on its performance in a rental context. By offering a solar-powered alternative, this targeted solution addresses a critical gap in providing reliable energy access for communities affected by frequent power interruptions.

However, the proposed system also has several limitations. The detachable power source is not capable of operating high-demand power appliances such as air conditioners and large electrical equipment due to its limited power capacity. It cannot be used to charge electric vehicles, including electric cars like Tesla, as these require significantly higher power input. The deployment of

the system is limited only to selected areas that frequently experience power interruptions and have sufficient exposure to sunlight, as it cannot operate efficiently in locations without proper solar access. Additionally, the coin-operated mechanism cannot accept paper money bills, and the system does not dispense physical change; instead, any remaining balance or excess payment will be credited to the user's mobile application account. Furthermore, the system is unable to operate during extreme weather conditions, such as typhoons, to ensure user safety and protect the equipment from potential damage.

1.6 Conceptual Framework

Figure 1.1
Process flow on how the system operates

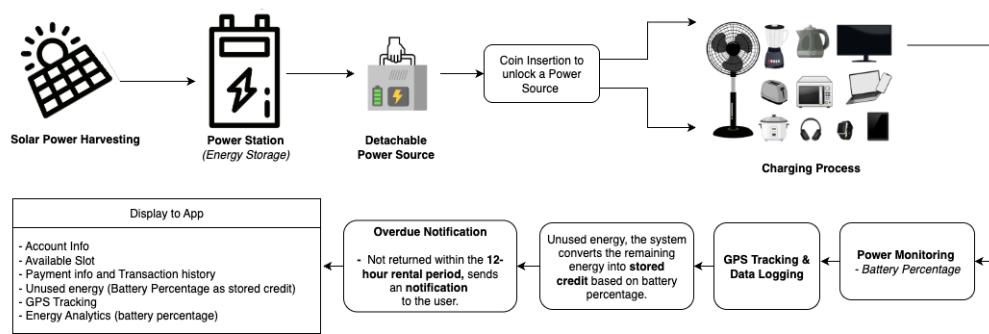


Figure 1.1 illustrates the step-by-step process of how the proposed system functions, beginning with energy harvesting and ending with user access to the detachable power source. The process starts when photovoltaic (PV)

panels capture solar energy and convert it into electricity. This electricity is then stored in the LiFePO₄ battery, ensuring a reliable and long-lasting power supply. To make the stored energy usable for different devices, the system employs an inverter, which converts the direct current (DC) from the battery into alternating current (AC). Next, the ESP32 microcontroller, integrated with IoT mechanisms, monitors and manages the flow of energy. Through this control unit, real-time data such as battery charge level and system status can be tracked. Supporting modules such as GPS (for location tracking) and GSM (for wireless communication) enhance the monitoring and management of the system, particularly for rented power sources. For the rental mechanism, the system is equipped with a coin slot or app-based access system that unlocks the detachable power source through a solenoid lock. Once accessed, the user can rent and carry the power source for portable use, such as charging appliances or gadgets during power interruptions. The accompanying mobile application provides the renter with real-time updates on the battery level, usage duration, and system availability. Lastly, once the power source is returned, the system resets and recharges through solar harvesting, making it ready for the next user. This cyclical process ensures that the system remains sustainable, user-friendly, and reliable for communities experiencing frequent and unscheduled power interruptions.

1.7 Definition of Terms

Internet of Things (IoT) A network of physical devices, such as sensors, appliances, and power sources, connected to the internet, enabling them to collect, send, and receive data for remote monitoring, control, and management.

Solar Energy Energy that is harnessed from sunlight using technologies such as photovoltaic (PV) panels, which convert sunlight into electricity, which is used to power the portable power sources.

Fossil Fuel Natural energy sources such as coal, oil, and natural gas, derived from the remains of ancient plants and animals, that are burned to produce energy but contribute to environmental pollution and climate change due to the emission of greenhouse gases.

Photovoltaic (PV) Panels Solar panels that convert sunlight into electricity, serving as the primary source of power generation for solar-powered systems.

Portable Power Station Compact, mobile units that provide electrical power for charging devices or operating appliances, often powered by renewable sources like solar energy and designed to be easily transported or moved.

Renewable Energy Energy derived from natural resources that are replenished on a human timescale, such as sunlight, wind, and geothermal heat, which are harnessed to produce electricity in an environmentally sustainable manner.

Off-grid power system A power system that operates independently from the main electricity grid, using renewable energy sources like solar or wind to provide electricity in areas without access to centralized power.

Solar harvesting The process of capturing sunlight using solar panels or other solar technologies and converting it into usable electrical energy, typically for storage in batteries or direct use.

Power Interruption A temporary loss or disruption of electrical power, often due to faults, maintenance, or other technical issues in the power grid, affecting the availability of electricity to households or businesses.

CHAPTER 2

REVIEW OF RELATED LITERATURE

This chapter highlights related projects or studies that offer valuable insights to the researchers, serving as a foundation for the development of the study.

2.1 Design of a Solar-Based Portable Power Supply with Modular Battery System for the Dumagat Tribe in Norzagaray, Bulacan

Access to reliable and sustainable energy is a critical issue in many rural and indigenous communities. One such community is the Dumagat tribe in Norzagaray, Bulacan, where there is a notable lack of access to electricity despite the usage of electronic devices like phones. Addressing this issue requires innovative solutions that not only meet their energy demands but also ensure sustainability and accessibility.

In this context, Gozano et al. (2023) conducted a study on a solar-powered portable power supply designed to provide the Dumagat Tribe with basic energy needs. This system incorporated a solar panel, a modular battery pack, and an inverter, aimed at powering low-energy devices and addressing the tribe's electricity needs. Using an Arduino data logger, the study measured the

charging and discharging rates of the system, showing promising results while also identifying areas for improvement, such as the need for higher-capacity batteries and more efficient solar panels.

2.2 Construction of a Portable Solar Power Supply for Household Appliances

Oluwasegun et al. (2018) developed a portable solar power supply system designed to power household appliances, offering a sustainable, eco-friendly alternative to traditional non-renewable energy sources. The system consists of a solar panel, a charge controller, a 12V lead-acid battery, a pure sine wave inverter, and an Arduino phase for voltage monitoring. The system was tested with household appliances such as a 300W electric blender and a 300W electric kettle, demonstrating its ability to provide reliable power. The solar panel efficiently converts sunlight into electricity, which is stored in the battery for use when solar energy is unavailable, providing a continuous energy supply.

The portable solar power system was able to power household appliances effectively, with minimal voltage drop during use, ensuring its practicality and dependability. By using solar energy, the system reduces electricity costs and promotes environmental sustainability by lowering greenhouse gas

emissions. The use of a pure sine wave inverter ensures stable and high-quality power for sensitive appliances. Oluwasegun et al. (2018) concluded that this system offers a cost-effective, clean energy solution for households, though further enhancements are needed to support higher electrical loads for more extensive applications.

2.3 Emergency Solar Portable Power Supply

The "Emergency Portable Solar Power Supply" study by Ramly et al. (2019) explored the development of a portable solar power system designed to provide electricity in areas without reliable grid access, particularly during power outages. The system utilizes solar photovoltaic (PV) technology to convert sunlight into electricity, which is stored in a battery for later use. Key components of the system include solar panels, batteries, charge controllers, inverters, and a microcontroller with Bluetooth functionality for remote monitoring. The study emphasizes the importance of sizing the solar panels and batteries properly to ensure a consistent energy supply, particularly in off-grid or emergency situations. By harnessing renewable solar energy, the system reduces reliance on fossil fuels and contributes to environmental sustainability. The solar panels used in the system have an efficiency rating of around 15-18

2.4 Portable Solar-Station with Integrated Battery Management and Load Monitoring System

Abdur et al. (2024) describe the development of a portable solar-powered station designed for disaster response, offering a 200W output using a 2x2 array of 50W solar panels. The system integrates a battery management system (BMS) and load monitoring mechanism (LMM), providing power for essential needs such as lighting, mobile device charging, and medical equipment in emergency situations. Replacing diesel generators reduces environmental pollution and noise, offering a sustainable, clean energy solution in areas with limited infrastructure. Its compact design allows easy transportation to disaster zones, making it an effective tool for providing reliable power where it's needed most.

The system also features an MPPT solar charge controller, optimizing energy efficiency and extending battery life by preventing overcharging and undercharging. The design incorporates Nantong YIDA YD-W50 Monocrystalline solar panels and a 12V 80Ah lead-acid battery, ensuring reliable energy storage. Abdur et al. (2024) conclude that this portable solar station provides a cost-effective, low-maintenance, and environmentally sustainable alternative to traditional diesel generators, making it a practical solution for disaster-prone regions.

2.5 Solar Powered Mobile Power Bank Systems

Solar-powered mobile charging systems offer a sustainable solution for powering devices during power interruptions and disasters. The research by Abdur et al. (2024) focuses on a Solar-Powered Portable Power Bank designed for mobile phones, using solar energy to charge a battery, which in turn provides power through a USB port. This system is particularly useful in disaster events and remote areas with limited electricity. The system utilizes two 6V solar panels to charge a 12V battery, with a microcontroller monitoring the battery's charge level and controlling relay circuits to ensure safe charging. LEDs display the battery charge level, offering a user-friendly interface for monitoring.

The proposed system has multiple advantages, including reducing reliance on traditional power sources and providing a reliable charging solution in emergencies. It addresses environmental concerns by utilizing renewable energy, minimizing pollution compared to conventional power generation methods. The microcontroller ensures efficient charge flow and protects the system from damage caused by overcharging or voltage fluctuations. Abdur et al. (2024) conclude that for optimal performance, the system requires direct sunlight and proper placement of the solar panels. The design can be improved by enhancing its portability and ensuring better protection for the mobile devices

and battery, making it a practical and eco-friendly alternative to traditional charging methods.

2.6 Multiport Universal Solar Power Bank

Altelmessani et al. (2024) introduce the concept of a Multiport Universal Solar Power Bank, designed to harness solar energy for a portable power supply. This device aims to address critical needs in emergency situations and recreational activities like camping, especially in remote areas where access to electricity is limited. Equipped with solar panels for efficient energy absorption, the power bank offers both DC and AC outputs, making it versatile enough to charge a wide range of electronic devices. The project emphasizes the importance of sustainability, using renewable resources to reduce reliance on non-renewable energy sources and provide a reliable, eco-friendly power source.

The system is capable of powering various appliances, including small household electronics, portable fans, lights, and mobile devices, with an AC output of up to 400W and a battery capacity of 20,000mAh. It also incorporates safety features to protect against overcharging, overheating, and other risks, ensuring both user safety and device longevity. The study highlights the project's compact and lightweight design, making it ideal for on-the-go use,

such as in emergencies or outdoor activities. By focusing on energy independence and environmental sustainability, the project contributes to reducing environmental impact while offering a reliable and versatile energy solution.

2.7 Portable Power Supply Design with 100 Watt Capacity

Zakri et al. (2021) developed a portable solar power supply design with a 100W capacity, aimed at providing sustainable energy in areas with limited electricity access. The system utilizes solar cells and a transformer to store energy in batteries with capacities of 20Ah, 60Ah, and 100Ah. The solar-powered generator can charge devices like lamps, laptops, LED televisions, and fans, supporting electrical loads under 100 watts for up to 12 hours. The system includes a Solar Charge Controller (SCC) to prevent overcharging, ensuring battery safety and longevity. The design is portable, easy to operate, and suitable for off-grid locations such as plantations or rural areas.

The tool's efficiency depends on the battery capacity and weather conditions. For example, charging the 20Ah battery takes about 5 hours under optimal sunlight, while larger batteries (60Ah and 100Ah) require more than one day to fully charge. This design is versatile, offering both AC and DC outputs, and is equipped with an LCD for voltage display, as well as safety features such as overcharge protection. Zakri et al. (2021) conclude that this

portable power supply offers a practical, environmentally friendly solution for off-grid applications, with the flexibility to charge batteries via solar energy or electrical sources.

2.8 Design and Development of Portable StandAlone Solar Power Generator

Prathiba et al. (2020) developed a portable, standalone solar power generator designed to replace diesel generators with a sustainable, eco-friendly solution. The system integrates a solar panel, a battery, a bidirectional buck-boost converter, and an inverter, all supported by a Maximum Power Point Tracking (MPPT) algorithm for optimal efficiency. The generator provides a green energy source to meet load requirements and stores excess energy in a battery for use when solar energy is unavailable. The bidirectional converter enhances battery charging efficiency and ensures regulated DC voltage output, while the MPPT algorithm maximizes power extraction from the solar panel to improve overall system performance.

The portable solar generator utilizes a bi-directional converter and MPPT to achieve high efficiency, allowing it to charge and discharge a 12V lead-acid battery. The system is capable of powering both DC and AC loads, using a push-pull full-bridge inverter to drive AC devices. The system is de-

signed for off-grid applications, including emergency situations and areas without access to electricity. The study emphasizes the system's compact design, cost-effectiveness, and potential for use in relief camps and remote locations. The project demonstrates a practical and portable renewable energy solution for sustainable power generation in diverse applications, especially in areas with limited access to the grid.

2.9 A solar-powered multi-functional portable charging device (SPMF-PCD) with internet-of-things (IoT)-based real-time monitoring- An innovative scheme towards energy access and management

Rehman et al. (2024) propose a solar-powered multi-functional portable charging device (SPMFPCD) with IoT-based real-time monitoring, designed to address the growing need for reliable and versatile energy solutions across various sectors, including transportation, communication, and emergency services. The device integrates a highly efficient solar panel, a charge controller, sensors, and an IoT module for real-time monitoring of power parameters. This innovative system supports diverse applications, such as emergency medical device charging, outdoor adventures, disaster management, and public spaces. The IoT capabilities provide continuous monitoring, ensuring efficient operation and proactive maintenance, enhancing the reliability and scalability

of the system.

The study emphasizes the significance of integrating advanced technologies, such as IoT-driven battery energy storage system (BESS) health monitoring, to optimize the performance and lifespan of the system. The study also conducted an economic and environmental impact assessment, showing the feasibility and sustainability of widespread SPMFPCD deployment. The proposed system demonstrated competitive cost-effectiveness, with a low cost of electricity and minimal annual operating costs. The integration of renewable energy sources like solar power and the IoT-based health monitoring system positions the SPMFPCD as a promising solution for providing accessible, environmentally friendly energy in various settings, highlighting its potential to contribute to sustainable energy management and community empowerment.

2.10 Development of a Low Cost Portable Hydro and Wind Power as Emergency Power Source

The study of low-cost portable hydro and wind power system as an emergency power source by Supardi et al. (2020) explored the development of a low-cost portable hydro and wind power system as an emergency power source. The system is designed to provide power for recharging essential equipment such as mobile phones, radios, and emergency lights, which are essential

during prolonged outdoor activities or power outages. This system can be implemented in remote areas with fluctuating water flows, making it an ideal solution for communities with limited access to electricity. The study found that the portable hydropower system, when coupled with wind power, could generate reliable electricity. These findings support the integration of renewable energy sources in off-grid locations, where accessibility to traditional power infrastructure is limited, and emphasize the importance of efficient turbine and generator design for portable power generation.

2.11 Development of Portable Solar Storage Device

Roslan et al. (2019) developed a portable solar storage (PSS) device designed to address the increasing demand for sustainable and portable power sources. The PSS is tailored for outdoor activities, such as hiking, camping, and climbing, providing a portable solution for charging electronic devices. The system uses a 12V or 18V solar panel to charge a battery with 98W of energy storage. During testing, the system showed charging rates of 16.086 W/h for the 12V solar panel and 13.35 W/h for the 18V panel, demonstrating the effectiveness of solar energy harvesting. The PSS was capable of recharging devices with capacities up to 10,000mAh, offering a reliable power supply for small electronic gadgets.

The study highlights the advantages of using solar panels for off-grid applications, noting that the PSS is ideal for areas with ample sunlight, such as Malaysia. The device's efficiency was calculated at 12.75%, with the system capable of charging devices like phones, smartphones, and power banks. However, the study also found limitations in charging larger devices with the 12V solar panel. Roslan et al. (2019) concluded that while the PSS provides an environmentally friendly and practical solution for outdoor power needs, further improvements in solar panel capacity and battery efficiency are needed to enhance its performance for higher power demands.

2.12 Renewable Energy from Solar Panels: A Study of Photo voltaic Physics and Environmental Benefits

Jaiswal (2023) provides an in-depth analysis of solar energy's growing role in the global energy transition, focusing on its environmental, economic, and technological advantages. The study highlights that global solar photovoltaic (PV) capacity reached about 1,059 gigawatts by 2021, reflecting rapid adoption and its significant contribution to reducing greenhouse gas emissions. Technological advancements, such as bifacial and perovskite solar cells, have increased the efficiency and affordability of solar power, making it more accessible. The research also stresses the importance of supportive policies and

regulatory frameworks in promoting solar energy deployment.

The environmental benefits of solar power are significant, with Jaiswal (2023) noting that solar energy could reduce up to 80% of greenhouse gas emissions by 2050. Additionally, the integration of solar energy with energy storage systems is essential for improving reliability and addressing challenges related to intermittency. The study concludes that solar energy plays a crucial role in achieving sustainable development, reducing climate change impacts, and driving economic growth. With ongoing technological advancements and effective policies, solar power is set to be a key component of the future energy system.

2.13 Power Consumption of Household Appliances

Power consumption patterns in households are significantly influenced by the frequency and duration of appliance usage. Pulvera (2021) found that household appliances such as televisions, electric fans, and refrigerators are among the most frequently used devices, contributing considerably to total electricity consumption. The results revealed that the television set operates for an average of forty-four (44) hours per week, followed by the electric fan with fifty-one (51) hours, and the refrigerator with one hundred five (105) hours of usage weekly. These appliances are commonly prioritized for their essential

roles in providing comfort, entertainment, and food preservation within the household.

Pulvera (2021) further emphasized that electricity usage is affected by several factors, including low voltage supply, appliance wattage, power interruptions, standby power, and user behavior. Among these, user awareness and proper energy management play a crucial role in reducing unnecessary power consumption. The continuous use of high-demand appliances such as electric fans and refrigerators, especially in tropical climates like the Philippines, highlights the dependence of households on these devices for maintaining comfort during hot weather and ensuring food preservation. Consequently, understanding the frequency of appliance use helps identify energy-saving opportunities and promote consumer awareness.

2.14 Electricity Distribution and Supply Authority

Battery selection plays a critical role in optimizing the performance and sustainability of photovoltaic (PV) systems. According to the Electricity Distribution and Supply Authority (EDSA, 2024) under the Government of Sierra Leone, three major battery options are typically considered in solar power applications—Flooded Lead Acid, Sealed Lead Acid (SLA), and Lithium Iron Phosphate (LiFePO_4). The study highlighted that LiFePO_4 batteries are

preferred for the Regional Emergency Solar Power Intervention (RESPITE) Project due to their superior efficiency, longevity, and environmental advantages.

LiFePO₄ batteries are generally more energy-efficient, allowing for greater energy utilization and reduced losses during charging and discharging. In contrast, SLA batteries exhibit lower efficiency, which can result in higher energy wastage. Additionally, LiFePO₄ batteries support a higher depth of discharge (DoD), enabling deeper energy use without significantly affecting their lifespan. This characteristic makes them more suitable for daily solar energy cycling compared to SLA batteries, which tend to degrade faster under similar conditions.

Another major advantage of LiFePO₄ technology is its longer cycle life. The EDSA (2024) report notes that LiFePO₄ batteries can endure more charge-discharge cycles before their performance diminishes, offering better long-term reliability. They also possess higher energy density, meaning they can store more energy in a smaller physical footprint—an important factor when space constraints exist in solar installations.

In terms of maintenance, LiFePO₄ batteries are maintenance-free, unlike SLA batteries which often require periodic electrolyte checks and refilling. While LiFePO₄ batteries have a higher upfront cost, they compensate with

lower operational and maintenance expenses throughout their lifespan. From an environmental perspective, LiFePO₄ batteries are also less harmful and easier to dispose of or recycle compared to lead-acid types, which generate toxic emissions during recycling.

2.15 Assessing the Impact of Power Outages on Appliances of Farmers and Fisherfolks in Selected Barangays of Cawayan, Masbate, Philippines: Basis for a Proposed Extension Program

Frequent power interruptions have long been a challenge in rural communities, particularly among farmers and fisherfolk who depend on electricity for household and livelihood activities. The study aimed to determine the impact of frequent power interruptions on the appliances and economic well-being of residents in selected barangays of Cawayan, Masbate. Employing a descriptive research design, the researchers gathered data from 266 respondents through paper surveys and face-to-face interviews to assess the frequency, duration, and effects of power interruptions. Findings revealed that almost all respondents experienced power interruptions lasting three to four hours, leading to increased electricity consumption and higher bills. Refrigerators and televisions were the most power-consuming appliances, and there was significant damage to appliances, especially bulbs, as well as disruptions to income-

generating activities. The study results showed that many respondents had an annual income of less than P18,200, which was considered low and may have resulted in difficulty in paying high bills brought by power outages. All respondents relied on the power grid as their source of electricity, and power interruptions were a common occurrence. The data revealed that 97.7% of respondents experienced power interruptions, with 51.1% experiencing 3-4 hours of interruption. Almost all respondents claimed that power interruption increased their electric consumption and bill, and 56% were not satisfied with their electric bill when there was a power interruption. It was concluded that unreliable electricity supply and lack of maintenance significantly affect low-income households that rely solely on the power grid as their source of electricity. The study recommended strengthening local power infrastructure and promoting renewable energy education through a proposed extension project that trains communities in the use of solar energy as a sustainable and reliable alternative to the current power grid system. This helps reduce air pollution and climate change while building the capacity of farmers and fishers to adapt to these changes.

2.16 Solar-Powered Coin-Operated Mobile Charging Station for Sustainable Energy Access and Resilience

The increasing demand for sustainable and accessible energy has driven innovations that utilize renewable sources to meet electricity needs in both urban and rural areas. The study by Catalan, Occeña, Gabion, Occeña, and Ejar (2023) aimed to develop a solar-powered, coin-operated mobile charging station designed to provide continuous off-grid power using photovoltaic (PV) technology. Employing a developmental research approach, the researchers designed, fabricated, and tested a prototype equipped with solar panels and an integrated storage battery system capable of charging multiple mobile devices for both commercial and emergency purposes. The results demonstrated that the charging station effectively powered various mobile gadget models with no compatibility issues, maintained stable operation even under limited sunlight, and offered cost efficiency through its low maintenance and sustainable design. Furthermore, the system contributed to reducing carbon emissions and supported the green technology initiatives of Guimaras State University. It was concluded that the solar-powered charging station is a practical and eco-friendly innovation that promotes energy resilience in communities affected by power outages. The study recommended installing such systems in strategic locations for communal purposes and remote areas, integrating security features

to prevent misuse, and conducting further research to enhance its technological design and promote the widespread adoption of renewable energy solutions.

2.17 Synthesis

The reviewed literature collectively highlighted the potential of solar-powered systems such as several power sources, mostly portable power stations as sustainable energy solutions, especially in off-grid and rural areas where power interruptions are common. Studies by Gozano et al. (2023), Oluwasegun et al. (2018), and Ramly et al. (2019) developed solar-based portable power supplies that integrated photovoltaic panels, charge controllers, batteries, and inverters. While Rehman et al. (2024) integrated IoT for real-time monitoring and efficiency optimization, later research by Abdur et al. (2024) and Altelmessani et al. (2024) enhanced system functioning through battery management and load monitoring systems. The suggested system's use of an ESP32 microcontroller, GPS and GSM modules, and LCD-based monitoring for energy tracking and operational management directly demonstrates these works' focus on the importance of effective energy harvesting, battery management, inverter stability, and smart control for system reliability.

The importance of choosing appropriate energy storage methods is also emphasized by a number of studies. Lithium Iron Phosphate (LiFePO₄) bat-

teries are preferred to conventional lead-acid batteries because of their longer cycle life, higher efficiency, and maintenance-free operation, which makes them suitable for solar-powered systems with frequent charge-discharge cycles in accordance to EDSA (2024), and Zakri et. al (2021). Moreover, the Masbate (2024) study and Pulvera (2021) illustrate how heavily Filipino households depend on devices like fans, televisions, and refrigerators which are often affected by power interruptions.

This insight emphasizes the necessity of accessible and reasonably priced renewable energy sources that can sustain necessary home loads. Moreover, Catalan et al. (2023) demonstrated that coin-operated solar-powered charging stations effectively promote energy access and sustainability, supporting the integration of a coin-slot mechanism and solenoid lock for secure, pay-per-use operations in community-based systems.

A significant study gap still exists in the integration of several key elements into a single deployable system, even if these studies collectively validate the effectiveness and feasibility of portable solar systems. An IoT-enabled monitoring and tracking system, a rental-based model with detachable power sources, and secure access mechanisms intended for community users are not offered in the literature currently in publication. A 2x2 solar panel array, an MPPT charge controller, a LiFePO₄ battery for effective energy

storage, and an inverter for AC conversion are all integrated into the proposed Solar-Powered Rental Station with Detachable Power Sources to address the problem at hand.

The system integrates ESP32-based monitoring, GSM and GPS connectivity, and a coin-slot mechanism for secure and traceable rentals, with a mobile application for real-time battery monitoring. By combining sustainable energy harvesting and smart control, it offers a practical and eco-friendly solution to power interruptions in communities. In summary, the synthesis of current literature highlights the importance of integrating efficient solar energy systems, smart monitoring, reliable storage, and accessible user feature concepts that form the foundation of the proposed Solar-Powered Rental Station with Detachable Power Sources.

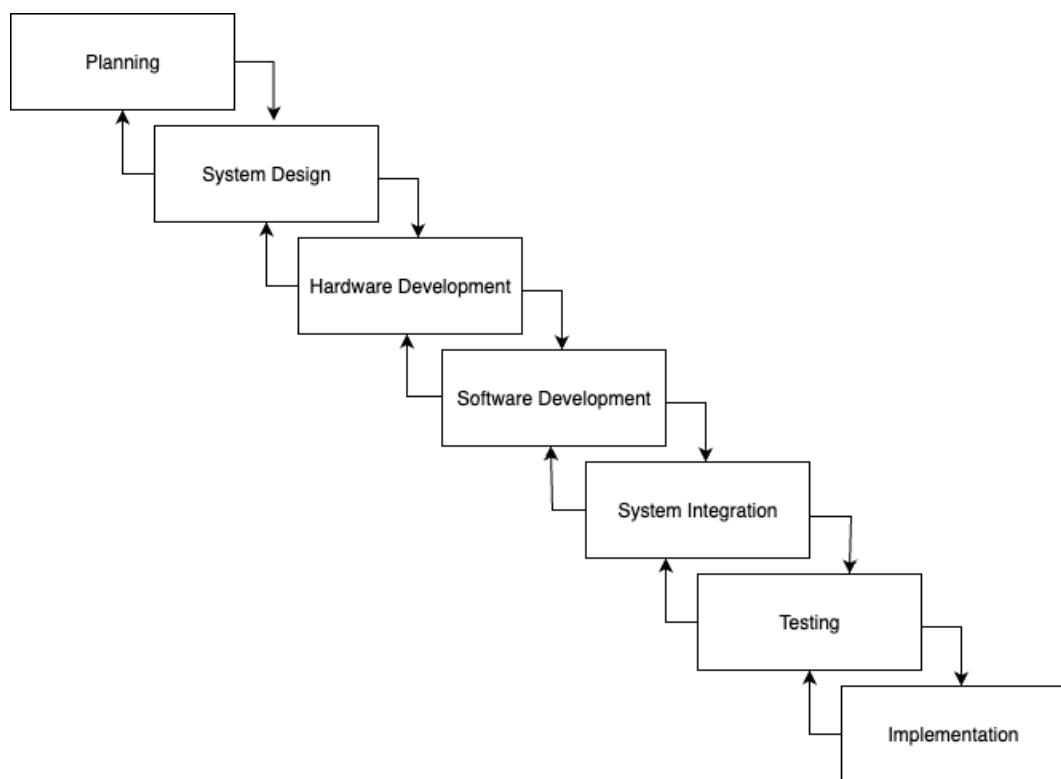
CHAPTER 3

METHODOLOGY

In this chapter, the researchers detail the methodology employed to conduct the study, providing a comprehensive overview of the research design, data collection, and analytical procedures.

3.1 Research Design

Figure 3.1
The Waterfall Model



In Figure 3.1, the system creation process is illustrated, utilizing a modified waterfall model. This systematic approach consists of several key stages, commencing with requirements gathering and followed by requirements analysis, hardware development, software development, system design, integration, and testing & evaluation. This procedural framework acts as a guiding path for researchers to achieve the study's intended objectives.

3.2 Planning

3.2.1 Data Collection

The research team will gather data from both primary and secondary sources. For the primary data, first-hand interactions will be conducted with community residents, power supply providers, and solar energy experts. Community residents, as the primary users of the solar-powered rental station, will provide information on the demand for portable power sources, willingness to adopt a solar-powered system, and feedback on system usability and effectiveness in addressing power interruptions. Power supply providers, such as local electric cooperatives like CAMELCO and MORESCO 2, will provide data on the frequency of power interruptions, challenges in accessing reliable energy, and the overall energy demand in the community. Insights from solar energy experts will focus on technical aspects of solar power systems, including op-

timal photovoltaic panel configurations, energy storage solutions, and power inverter specifications.

Secondary sources will include academic papers, case studies, industry reports, and other literature related to solar energy, portable power stations, and renewable energy systems. These sources will provide a theoretical foundation and context for the study, ensuring that both practical relevance and technical feasibility are considered in developing the solar-powered rental station system.

3.2.2 Data Gathering Procedure

To obtain relevant qualitative data for the study, a series of in-depth interviews will be conducted with selected community residents using purposive sampling. The interviews will focus on understanding residents' experiences with frequent power interruptions, the challenges they encounter during interruptions, and their perceptions of a solar-powered rental station as an alternative energy source. These discussions will also explore their reliance on backup power systems and their willingness to adopt renewable energy solutions. Participants will be purposively selected, particularly those who frequently experience power interruptions, depend on electricity for livelihood activities, and have expressed interest in solar technology. Combined with

qualitative tools, this approach will ensure a comprehensive understanding of the community's energy needs, user expectations, and potential areas for improving the design and implementation of the solar-powered rental station system.

3.2.3 Data Finding Analysis

The analysis of the collected data will lead to several important findings. The first will reveal that community residents frequently experience power interruptions that disrupt both household and livelihood activities. These interruptions will highlight common challenges related to the reliability, cost, and accessibility of backup power solutions. Residents will express concerns about their dependence on the unstable power grid and the lack of affordable alternatives during interruptions. The analysis will also uncover the community's openness to adopting a solar-powered rental solution, recognizing its potential to provide a more sustainable and reliable energy source. Feedback from interviews and discussions will emphasize the need for practical improvements to the proposed system, such as flexible payment options (coin- or app-based), increased power capacity, and user-friendly accessibility. These insights will be vital in assessing the system's feasibility and refining its design to ensure it effectively addresses the residents' energy needs.

3.3 Design

3.3.1 User Definition

After the planning phase, the system's users were identified. For this study, the Community Resident is defined as follows:

Community Resident - A person residing in a local community who is actively involved or has access to portable power sources during power interruptions or emergencies.

3.3.2 System Requirements

Table 1: System Requirements

Category	System Requirement
Input Requirements	<ul style="list-style-type: none"> - The system shall collect user information during account registration through designated input fields in the mobile application. - The system shall accept user login credentials such as username and password for authentication. - The system shall accept rental requests, including power source selection, rental duration, and payment method (coin-based or app-based). - The system shall receive telemetry data from each power source, including battery percentage, GPS location, and rental status through the GSM module.
Process Requirements	<ul style="list-style-type: none"> - The system shall process rental transactions by verifying payment completion before authorizing power source access. - The system shall generate and transmit an access token or unlock code to the power source upon successful rental approval.

Category	System Requirement
	<ul style="list-style-type: none"> - The system shall continuously monitor and record the battery level, location, and usage duration of active rentals. - The system shall process the return of rented power sources by validating device ID, updating the database, and releasing the final transaction summary.
Output Requirements	<ul style="list-style-type: none"> - The system shall display rental confirmation details such as power source ID, rental duration, and current charge level. - The system shall provide real-time status updates on the mobile app, including remaining battery percentage, and device location. - The system shall generate notifications for payment confirmation, overdue alerts, and successful returns.
Control Requirements	<ul style="list-style-type: none"> - The system shall implement user authentication and authorization mechanisms to restrict access to registered users only. - The system shall validate all rental and payment data to ensure that only completed and legitimate transactions are processed.
Performance Requirements	<ul style="list-style-type: none"> - The system shall maintain fast response time during login, payment processing, and rental activation to ensure a smooth user experience. - The system shall provide real-time monitoring and synchronization of power source data through reliable GSM and IoT communication. - The system shall ensure continuous operation and high availability to prevent service interruptions during rentals.

3.3.3 System Design and Architecture

Figure 3.2
System Architecture

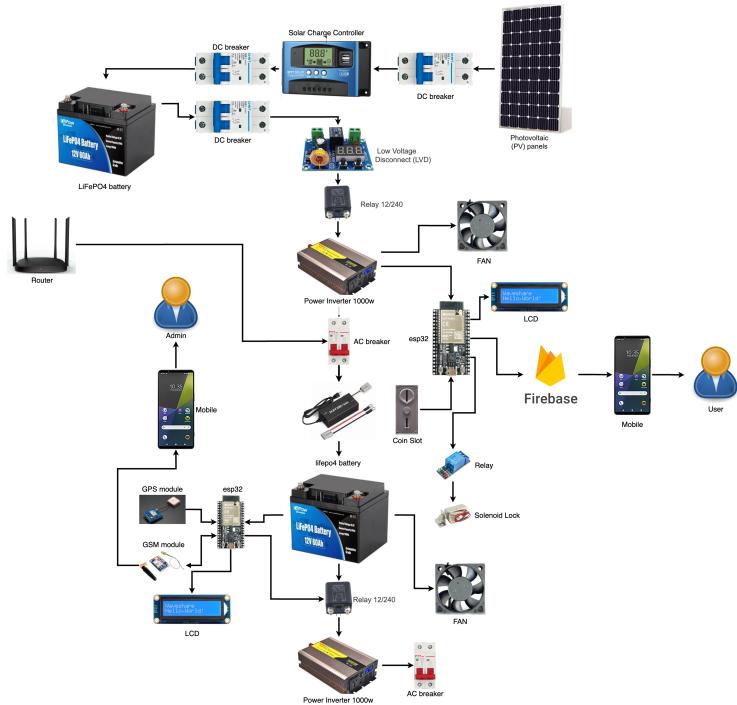


Figure 3.2 illustrates the architecture of the KuRyenta system, a solar-powered, coin-operated, GPS-enabled portable power source. The diagram shows how solar energy is captured by the photovoltaic panels and stored in a LiFePO₄ battery through the solar charge controller. The stored energy is then converted into usable AC power by the power inverter, which is accessible to the user via a coin-operated access system.

The ESP32 microcontroller manages the system's operations, integrat-

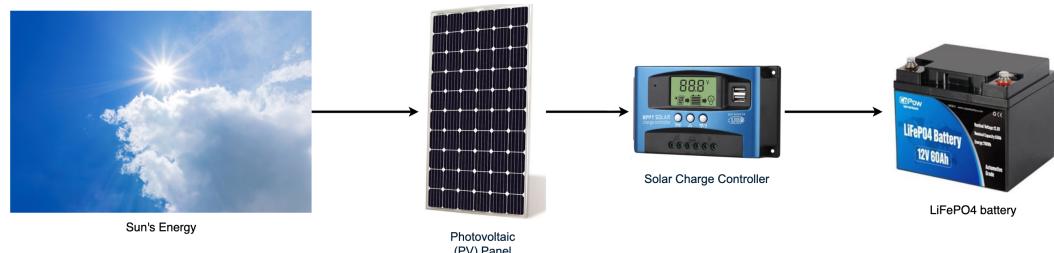
ing key components such as the GPS module for location tracking and the GSM module for communication with the admin. A coin slot and solenoid lock control the unlocking of the portable power sources, ensuring that users can access the power only after payment is made. The user can interact with the system through a mobile app that displays the battery's charge level and other important information. In essence, the KuRyenta system is designed to provide a sustainable and secure solution for portable power, incorporating solar energy, and coin-based access for a user-friendly and efficient experience.

3.3.4 System Flowchart

3.3.5 Solar Energy Harvesting

Figure 3.3

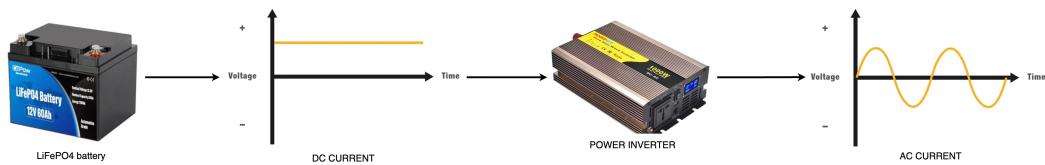
Conversion of sunlight into electrical energy using PV panels and a charge controller



3.3.6 Energy Conversion DC to AC

Figure 3.4

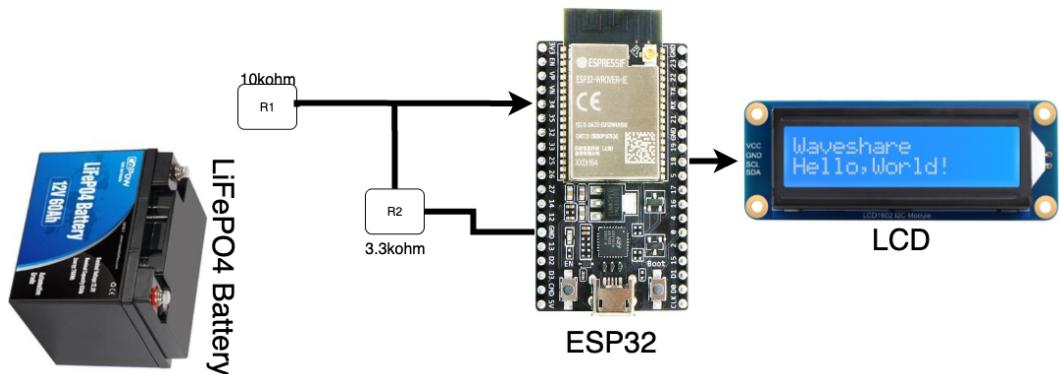
Battery DC power converted to AC output via inverter.



3.3.7 Power Monitoring

Figure 3.5

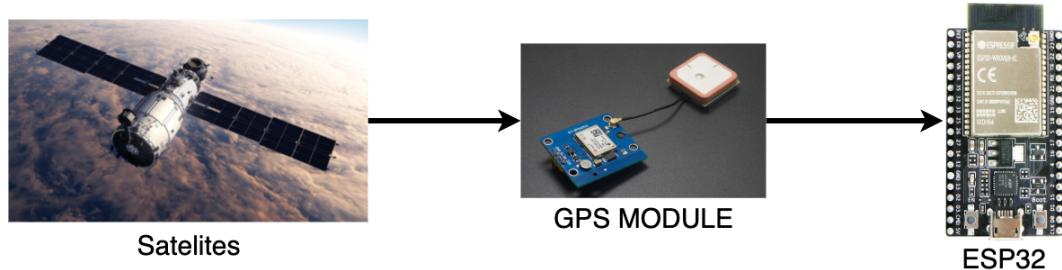
ESP32 measures battery voltage and displays data on LCD.



3.3.8 GPS Tracking

Figure 3.6

ESP32 receives real-time location data from GPS satellites using GSM Module

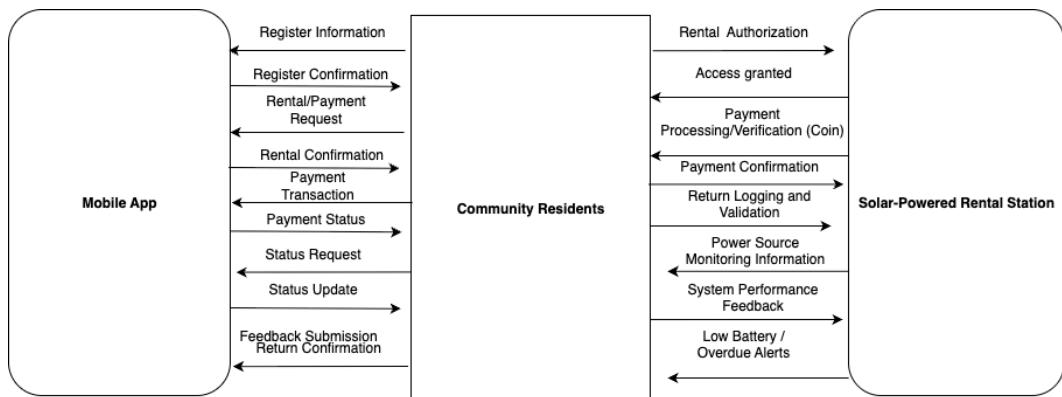


3.4 Develop

3.4.1 Context Level Diagram

Figure 3.7

The Context Level Diagram



This Figure 3.7 illustrates the Context Level Diagram of the system.

The Mobile App serves as the primary interface through which Community

Residents interact with the Solar-Powered Rental Station. The Community Resident starts by providing their registration information via the Mobile App, which sends this data to the system. Once registered, the system sends back a registration confirmation and the Mobile App allows users to proceed with rental/payment requests. The Mobile App then facilitates payment transactions where the Community Resident can complete the payment either through a coin-based mechanism or an app-based method. Once the payment transaction is successfully completed, the Mobile App receives a payment confirmation from the System, ensuring the rental is validated. The Community Resident can then use the Mobile App to check the system status, such as battery levels, power source availability, or the remaining rental time. After use, the Community Resident sends a return request via the Mobile App, which then communicates with the System to confirm the power source return. The System logs the return and ensures the process is validated, signaling the completion of the rental session. Additionally, the Mobile App allows the Community Resident to submit feedback on their experience with the service.

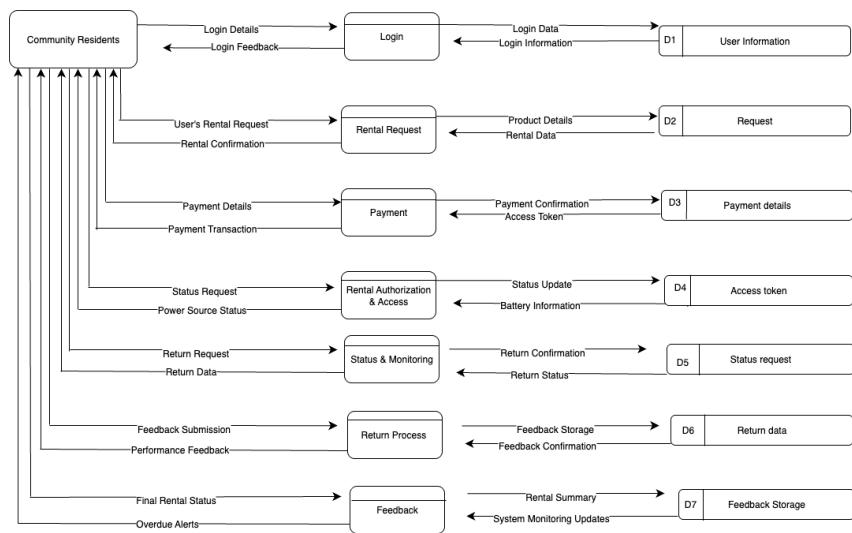
On the other side, the System (the Solar-Powered Rental Station) manages the backend of the rental process. It verifies rental requests from Community Residents and authorizes them to rent a power source. It also handles payment processing, ensuring that the payment is verified before the rental is

completed. Once payment is confirmed, the System updates the Mobile App with the confirmation. The System also monitors the rented power source, providing live monitoring information, such as the power source's battery level and available runtime. If the Community Resident fails to return the power source on time or if the power source is running low on battery, the System sends low battery or overdue alerts to both the Mobile App and the Community Resident, prompting them to take action.

3.4.2 Data Flow Diagram

Figure 3.8

Data Flow Representation of the Solar-Powered Rental Station System



The Figure 3.8 shows the complete process flow of the solar-powered rental station system, illustrating how community residents interact with the

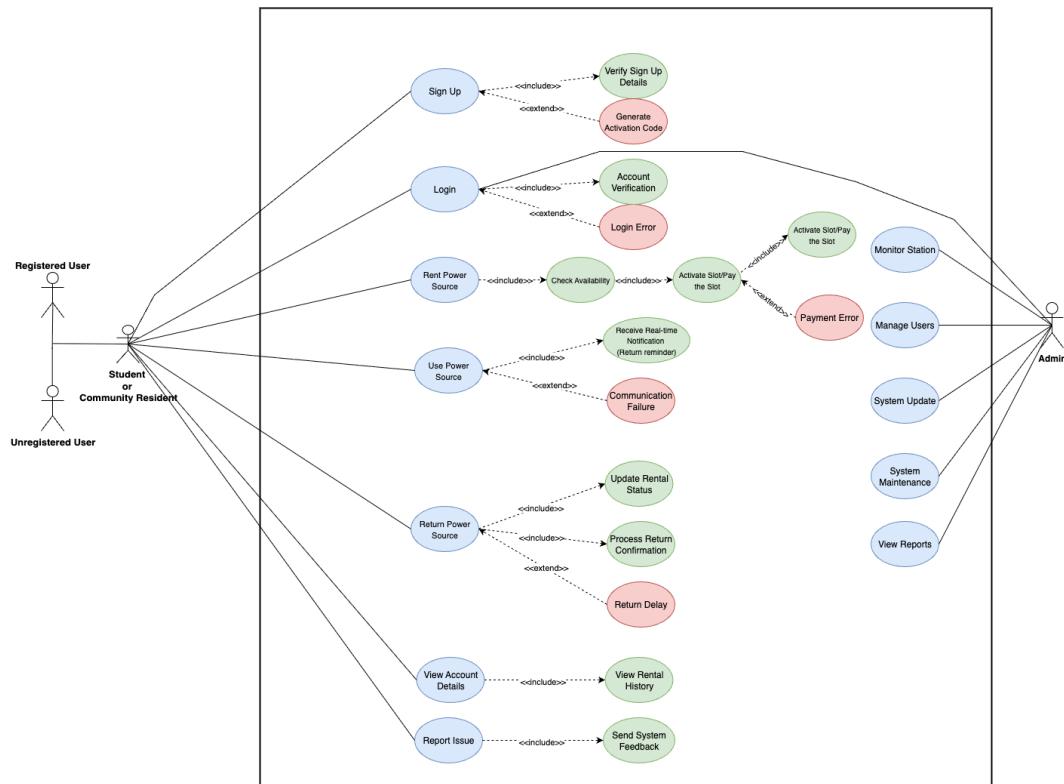
mobile application and system database. It begins with the login process, where residents input their login details, which are verified by the system. Once authenticated, the system provides feedback confirming successful login. After logging in, the user proceeds to make a rental request by selecting a power source and specifying the rental duration. The system responds with rental confirmation and product details. The user then moves to the payment process, where payment details are submitted through the app. The system validates the payment, sends a confirmation, and generates an access token that authorizes the user to unlock and use the detachable power source.

Once access is granted, the rental authorization and monitoring phase begins. The system continuously provides updates on the power source's status, such as battery level and remaining usage time, ensuring that the user can track energy consumption. When the rental period ends, the user then sends a return request, and the system verifies and confirms the return while updating the rental status. After returning the power source, the user proceeds to the feedback process, submitting performance feedback through the app. The system stores the feedback and confirms successful submission. After that, the system records the final rental summary and sends any overdue alerts if the power source is not returned on time. Overall, the diagram presents a clear and structured view of how the user's actions and system responses are linked

throughout the entire rental transaction cycle, which is from login to feedback completion.

3.4.3 Use Case Diagram

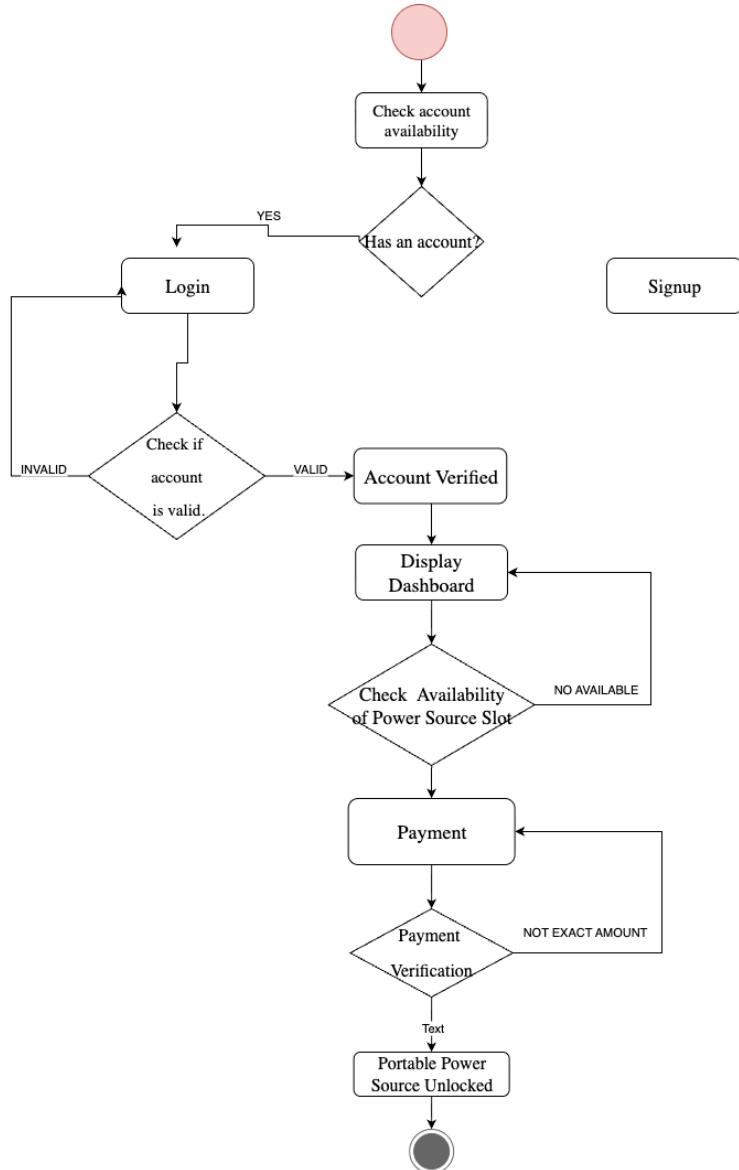
Figure 3.9
Use Case Diagram



3.4.4 Activity Diagram

Figure 3.10

Activity Diagram of the Community Resident



This Activity Diagram shows the step-by-step activity flow of the system from user login to unlocking the portable power source. The process begins with checking account availability. If the user already has an account, they proceed to the login step; otherwise, they must sign up first. After logging in, the system checks if the account is valid. If the account is invalid, the process returns to the login step. If valid, the system verifies the account and displays the dashboard. Next, the system checks if a power source slot is available. If no slot is available, the user remains on the dashboard until one becomes free. If a slot is available, the process continues to the payment step. The system then verifies the payment amount. If the amount entered is not exact, the process returns to the payment step. If the payment is correct, the portable power source is successfully unlocked, completing the process.

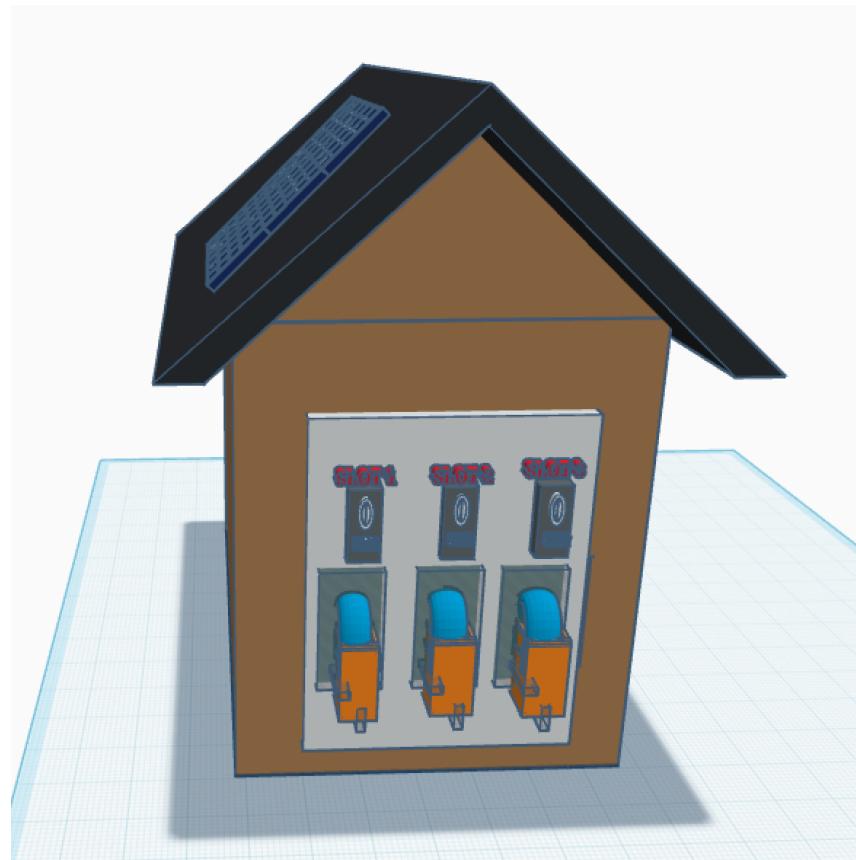
Overall, the diagram clearly shows how the user interacts with the system , which starts from account access, validation, and payment, up to unlocking the rented portable power source.

3.4.5 Hardware Design Flowchart

3.4.6 3D Design

Figure 3.11

Three Dimensional Representation of the System



3.4.7 System Design

3.4.8 Materials and Cost

Table 2: Hardware Components and Cost

Component	Price
Battery x 2	₱12,000.00
Solar Charge Controller	₱1,000.00
Solar Panel	₱2,500.00
Pure Sine Wave Inverter x 2	₱6,000.00
Lithium Battery Charger	₱500.00
Low Voltage Disconnect module	₱100.00
Coin Slot Facade	₱150.00
ESP32 x 2	₱400.00
DC breaker x 3 (Cable, Mounts)	₱100.00
Relay Module 12/ 240v x 2	₱240.00
Liquid Crystal Display (LCD) x 2	₱400.00
Relay	₱50.00
GPS module	₱200.00
GSM module	₱600.00
AC breaker	₱1,200.00
Solenoid lock	₱200
Router	₱1,500.00
Total	₱27,140.00

Table 2 shows the following materials that will be used in the study.

APPENDICES

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