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DEPARTMENT OF MECHANICAL AND MECHATRONICS ENGINEERING

DESIGN AND FABRICATION OF SECURE AND SOLAR-POWERED PHONE CHARGING STATION FOR OFF-GRID COMMUNITIES

PROJECT REPORT

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Project report submitted to the Department of Mechanical and Mechatronics Engineering in partial fulfilment for the award of Diploma in Mechatronics Engineering of The Technical University of Kenya

2024

DECLARATION

BY THE STUDENTS

I hereby declare that this project report is our original work and has not been presented for a degree in any University.

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BY THE SUPERVISOR

This project report has been presented for examinations with my approval as the university supervisor.

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ACKNOWLEDGMENT

We express our heartfelt gratitude to the Almighty God for His unwavering guidance and sustenance throughout this project. Special thanks to Mr. Kanyoni for his invaluable advice, encouragement, and belief in our capabilities. We are indebted to our dedicated lecturers for their mentorship and support. Our deepest appreciation goes to our parents for their boundless love, unwavering support, and invaluable contributions to our education. To our friends, we extend sincere thanks for their unwavering encouragement and prayers. Each of these individuals has played a significant role in our journey, and we are grateful for their presence and support.

DEDICATION

We dedicate this project to the almighty God for being a pillar in this research project and granting us the wisdom and understanding for this project. Special dedication goes to our able supervisor, Mr. Makumbi, for guiding me on how to carry out the project. He has been very available and helpful to the end and a great source of knowledge for this project. This project is also dedicated to our friends and families.

Lastly, we dedicate this project to our classmates for their support in any way to see that the project comes to successful completion.

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Acronyms

ABS - *Acrylonitrile Butadiene Styrene*

BMS - *Battery Management System*

DC - *Direct Current*

PV - *Photovoltaic*

LCD - *Liquid Crystal Display*

USB - *Universal Serial Bus*

AC - *Alternating Current*

PCB – *Printed Circuit Board*

CNC - *Computer Numerical Control*

PIN – *Personal Identification Number*

Abstract

The increasing penetration of mobile phones in off-grid communities has highlighted the need for accessible, reliable, and secure charging solutions. Many of these communities lack consistent access to electricity, often relying on costly and inefficient power sources, such as diesel generators or unreliable grid connections. This project presents the design and fabrication of a solar-powered phone charging kiosk aimed at providing a sustainable, secure, and affordable charging solution for off-grid areas.

The proposed kiosk utilizes solar energy to power multiple phone charging ports, with a lead-acid battery storing excess energy for use during low sunlight conditions. The system is equipped with a security feature comprising lockable compartments, each accessible through a PIN-based keypad, ensuring the safety of phones while they charge. The design was tested for solar energy generation, power management, security, and ease of use, with promising results demonstrating its functionality in real-world scenarios.

The charging kiosk was successfully fabricated and tested, showing reliable performance in terms of power efficiency, security, and user interaction. The results indicate that the kiosk offers a practical solution to the challenges faced by off-grid communities in accessing phone charging services, providing a renewable energy alternative while ensuring the safety of devices. Future recommendations include increasing the battery capacity and improving solar panel efficiency to further enhance the system's reliability.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Off-grid communities across the world experience significant challenges in accessing reliable electricity. These communities are often located in remote areas were connecting to the national power grid is either impractical or too expensive. However, mobile phones have become essential tools for communication and access to services such as mobile banking, especially in developing countries. Despite this necessity, off-grid communities face difficulties in regularly charging their phones, as they often rely on costly and unreliable energy sources such as diesel generators, which are environmentally harmful and expensive to maintain.

Current solutions, such as centralized charging stations in off-grid areas, present several issues. These stations are not only expensive but also pose significant security risks, including phone theft, as there are no secure compartments to keep the phones safe during charging. Additionally, centralized systems may not be conveniently located for all members of the community, forcing people to travel long distances for phone charging services.

To address these challenges, a solar-powered phone charging kiosk can offer an accessible, secure, and environmentally sustainable solution. Solar energy is a renewable resource, abundant in many off-grid areas, making it a reliable energy source for mobile phone charging. A secure solar-powered charging kiosk will not only reduce the dependence on traditional power sources but also ensure that individuals can charge their phones safely, protecting them from theft while they are being charged.

1.2 Problem Statement

In off-grid communities, the lack of reliable, affordable electricity makes charging mobile phones a challenge. Centralized charging points often lack security, leading to frequent phone theft and loss of sensitive personal information. Furthermore, these charging points are typically dependent on costly and unreliable energy sources, such as diesel generators, making them unsustainable for long-term use. There is a need for a secure, sustainable, and accessible solution for phone charging in off-grid communities.

1.3 Proposed Solution

This project proposes the design and fabrication of a secure, solar-powered phone charging kiosk for off-grid communities. The kiosk will utilize solar energy to generate electricity, ensuring that it operates independently of the national power grid. It will feature secure compartments for individual phones, accessible only through a unique PIN entered on an electronic keypad. This will minimize the risk of phone theft during charging. Additionally, the kiosk will include multiple charging ports to accommodate several phones simultaneously, ensuring convenience for users.

1.4 Objectives

1.4.1 Main Objective

The main objective of this project is to design and fabricate a solar-powered phone charging kiosk that addresses the power and security challenges faced by off-grid communities.

1.4.2 Specific Objectives

i) To design a modular solar-powered phone charging kiosk that can generate and store enough power to charge multiple phones simultaneously.

ii) To fabricate the phone charging kiosk using durable materials that can withstand environmental exposure.

iii) To test the functionality of the solar charging system and the security mechanism to ensure smooth operation.

1.5 Block Diagram

The system will consist of several components, each playing a critical role in ensuring the kiosk operates effectively. The key components include a solar panel for energy generation, a battery for energy storage, a microcontroller for managing power distribution and security features, and a locking mechanism for the phone compartments. Below is the block diagram representation of the system:

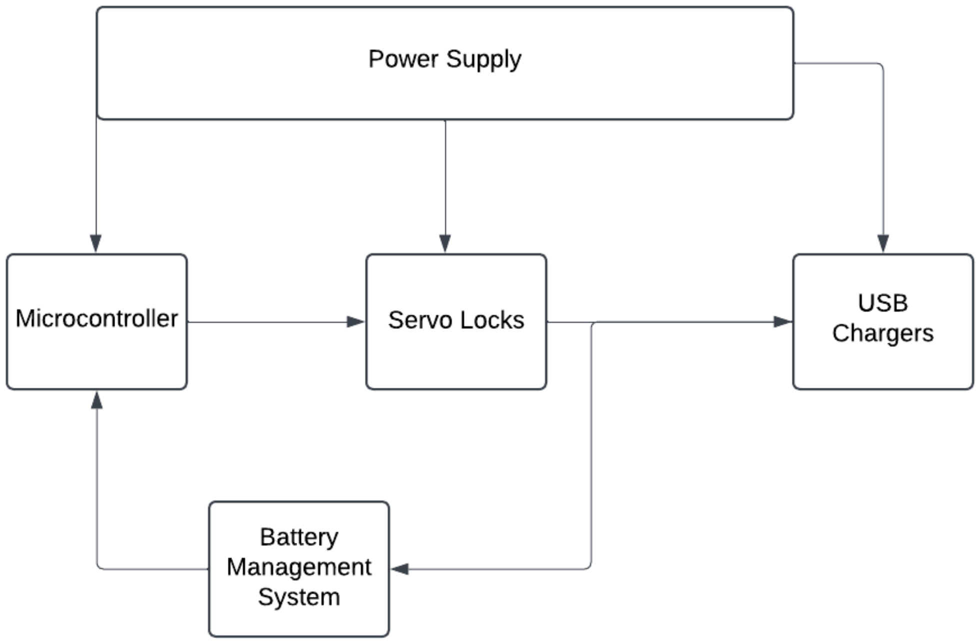

Figure 1.1: Block Diagram

1.6 Specifications

The kiosk will be designed with the following specifications:

Component	Specification
Solar Panel	50W photovoltaic panel
Battery	12V, 100Ah lead-acid battery
Microcontroller	Arduino Uno for system control
Charging Ports	USB ports with 5V output for phone charging
Locking Mechanism	Servo motor controlled by a keypad system
Structure Material	ABS plastic and steel frame for durability

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview

This chapter provides an in-depth review of existing literature related to off-grid phone charging solutions, solar energy systems, security mechanisms for public kiosks, and ongoing research into off-grid mobile charging technologies. The purpose of this review is to analyze the strengths and limitations of current solutions, identify gaps that the proposed solar-powered phone charging kiosk aims to address, and explore relevant technological advances that can be integrated into the project.

Off-grid communities face unique challenges in accessing reliable energy sources. Mobile phone use is prevalent in these areas, yet the lack of electricity infrastructure limits the ability of users to regularly charge their devices. This chapter reviews previous attempts to develop phone charging solutions for off-grid communities and evaluates the potential for solar-powered systems to provide a sustainable and secure alternative.

2.2 Existing Phone Charging Systems

Various phone charging solutions have been developed over the years, ranging from simple hand-crank chargers to more sophisticated solar-powered systems. However, many of these solutions fail to address the core challenges faced by off-grid communities, such as sustainability, security, and affordability. Below is a review of key charging systems relevant to this project.

2.2.1 Phone Charging Services in Off-Grid Areas

In many off-grid areas, centralized phone charging services are common. These services are often located in markets or small shops, where individuals pay a fee to charge their phones. The charging stations are usually powered by diesel generators, solar panels, or car batteries. McTaggart et al. (2012) highlighted the widespread use of such services in rural Africa, where individuals must walk long distances to access charging points and then pay per charge. This model, while effective in providing access to phone charging, has several limitations:

i) **High Costs:** The fees charged for phone charging can be prohibitive, especially for low-income households.

ii) **Unreliability:** Diesel-powered generators are prone to failure due to fuel shortages or mechanical breakdowns, while solar-powered systems often lack sufficient battery storage to meet demand on cloudy days.

iii) **Security Risks:** Phones left at these stations are vulnerable to theft, as there are no secure mechanisms to protect them during charging.

Figure 0-1: The Charging Station

The proposed solar-powered kiosk aims to improve upon these systems by incorporating secure compartments for phones and a reliable energy source powered by renewable solar energy.

2.2.2 Manual Hand Crank Chargers

Manual hand crank chargers are another solution that has been explored for off-grid communities. These devices generate power through mechanical effort, typically by rotating a crank connected to a small dynamo. While hand-crank chargers can provide a portable, off-grid charging solution, they have several significant drawbacks:

i) **Low Power Output:** Hand crank chargers typically generate low levels of electricity (around 5.5V, 600mA), which is insufficient to charge multiple phones at once or charge devices quickly.

ii) **Inefficiency:** The physical effort required to operate the charger makes it impractical for regular use, particularly when multiple devices need to be charged. Additionally, the process of charging a single phone can take significantly longer compared to other methods. Due to these limitations, hand crank chargers have not gained widespread popularity in off-grid communities, except in emergency situations where no other options are available.

Figure 0-2: Manual mobile phone crank charger (jetir.org)

2.2.3 Portable Solar-Powered Phone Chargers

Portable solar-powered phone chargers have emerged as a popular solution for off-grid users. These devices consist of a small photovoltaic (PV) panel connected to a battery that stores energy, allowing users to charge their phones even when sunlight is not available. Golhar et al. (2019) explored the benefits of portable solar chargers in off-grid areas, highlighting their environmental friendliness and relatively low cost. However, these devices are not without challenges:

i) **Limited Capacity:** Most portable solar chargers have small panels and batteries, which means they can only charge one or two phones at a time, and the charging process can be slow, especially on cloudy days.

ii) **Dependence on Sunlight:** The efficiency of these chargers drops significantly during periods of low sunlight or rainy seasons, limiting their reliability as a consistent charging solution. The proposed kiosk improves on this design by incorporating a larger solar panel and a higher-capacity battery, which will allow it to charge multiple phones simultaneously and store enough energy to provide reliable service even on cloudy days.

Figure 0-3: Solar-powered cell phone charger (Solar Electric Blog)

2.2.4 Bicycle Pedal-Powered Phone Chargers

Bicycle pedal-powered phone chargers, as explored by Alwyn and Faizal (2021), use the mechanical energy from pedaling a bicycle to generate electricity through a dynamo. This system has been employed in off-grid areas where bicycles are commonly used for transportation. The main advantages of this system are:

i) **Renewable Energy Source:** Pedaling is a sustainable and renewable way of generating electricity, particularly in areas where bicycles are already widely available.
ii) **Affordability:** Once installed, the system is inexpensive to operate, as it does not rely on external energy sources.

However, the drawbacks include:

i) **Physical Effort Required:** Continuous pedaling is required to generate electricity, which can be exhausting and limits the number of devices that can be charged at once.
ii) **Limited Power Output:** Like hand-crank chargers, bicycle-powered systems produce relatively low amounts of electricity, making them unsuitable for charging multiple devices simultaneously.

Figure 0-4: A pedal-powered phone charger (questoversees.com)

While this solution is innovative, the physical effort required and the limited power output make it less practical for widespread adoption. The solar-powered kiosk, by contrast, provides a passive and scalable charging solution.

2.2.5 Community Power for Mobile Charging Services

Community-based charging stations that utilize excess energy from telecommunication base stations have been implemented in some off-grid areas. According to a report by GSMA (2011), base stations generate more energy than they use, and this excess power can be redirected to charge mobile phones at nearby charging stations. This solution has proven successful in providing reliable charging services to off-grid communities, as telecommunication base stations are typically operational 24/7. However, this system has limitations:

i) **Limited Coverage:** Not all off-grid communities are located near telecommunication base stations, limiting the reach of this solution.

ii) **No Security Features:** Like other centralized charging stations, these facilities often lack secure compartments for storing phones, exposing them to theft and damage.

Figure 0-5: the charging station implemented from a base station (gsma.com)

The proposed kiosk integrates the reliability of renewable energy with a secure storage solution, making it a more versatile and accessible option for off-grid communities.

2.3 Ongoing Research in Off-Grid Phone Charging Solutions

Several ongoing research efforts aim to improve off-grid phone charging solutions, particularly through the use of solar energy and security features. The following are key areas of current research that relate to this project.

2.3.1 Off-Grid Solar-Powered Charging Systems

Recent studies have focused on the use of solar energy to meet the growing demand for phone charging in off-grid areas. According to research by JETIA (2022), solar-powered charging stations have the potential to provide a consistent and reliable source of energy, especially in regions with high sunlight exposure. The main benefits of these systems include:

i) **Sustainability:** Solar energy is a renewable resource that does not produce harmful emissions, making it an environmentally friendly option.

ii) **Cost Efficiency:** Once installed, solar-powered systems have minimal operational costs, as they do not rely on fuel or external energy sources.

However, there are challenges with the security of phones left in public charging stations. Theft and vandalism remain significant concerns, as many stations lack secure compartments for phones. This project addresses this gap by incorporating a secure, PIN-protected storage system.

2.3.2 Security-Based Phone Charging Systems

Research into security-based phone charging systems has focused on integrating advanced locking mechanisms and user authentication technologies to protect devices left at public charging stations. A study by ICIMTech (2022) explored the use of fingerprint-based authentication to secure phones in public kiosks. While biometric security offers a high level of protection, it may not be feasible for off-grid communities due to the high cost of biometric systems and the difficulty in maintaining such technology in remote areas.

In contrast, the proposed kiosk will use an electronic keypad and PIN system, which is more affordable and easier to maintain. This approach provides a balance between security and cost-effectiveness, making it suitable for use in off-grid environments.

2.4 Contribution to Phone Charging Systems

The proposed solar-powered phone charging kiosk builds on the advancements made in previous phone charging systems while addressing key gaps in security, capacity, and sustainability. Its contributions include:

i) **Security:** The kiosk's secure, PIN-protected compartments will prevent theft and unauthorized access to phones during charging, solving one of the major issues faced by current solutions.

ii) **Sustainability:** By harnessing solar energy, the kiosk provides a renewable and environmentally friendly power source, eliminating the need for costly and polluting diesel generators.

iii) **Scalability:** The kiosk's modular design allows for multiple phones to be charged simultaneously, addressing the limitations of smaller, portable solar chargers.

This system represents a comprehensive solution to the challenges of phone charging in off-grid communities, combining renewable energy with secure storage to ensure both accessibility and safety.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Overview

This chapter describes the materials, components, and methods used in the design and fabrication of the solar-powered phone charging kiosk for off-grid communities. The primary goal of this project is to develop a functional, secure, and sustainable phone charging system powered by solar energy. This section outlines the design criteria, the materials chosen, the fabrication processes, and the testing procedures used to ensure the project meets its objectives.

3.2 Materials and Components

The design and fabrication of the solar-powered phone charging kiosk required the careful selection of materials and components to ensure durability, security, and efficiency. The following sections detail the key materials and components used in this project.

3.2.1 Materials

The materials chosen for the construction of the kiosk are intended to be both robust and able to withstand environmental exposure, as the kiosk will be installed in off-grid, outdoor locations. The primary materials used include:

i) **Acrylonitrile Butadiene Styrene (ABS):** ABS is a high-strength plastic material that offers excellent durability, impact resistance, and weatherproofing. It is used to construct the secure compartments of the kiosk, ensuring they can resist forced entry and protect the phones inside.

Figure 0-1: ABS filament spool

ii) **Perspex (Acrylic Glass):** Perspex is used for the transparent windows on the secure compartments, allowing users to view their phones while they charge without compromising security. Perspex is lightweight, shatter-resistant, and UV-resistant, making it suitable for outdoor installations.

Figure 0-2: Perspex

3.2.2 Electronic Components

Several electronic components were selected to provide the energy management, charging, and security functions of the kiosk:

i) **Solar Panel (50W):** The solar panel is responsible for capturing sunlight and converting it into electrical energy. A 50W photovoltaic panel was chosen to provide sufficient power for charging multiple phones simultaneously.

Figure 0-3: Solar Panel

ii) **Battery (12V, 100Ah Lead-Acid):** The battery stores the energy generated by the solar panel, ensuring that the kiosk can continue to operate during periods of low sunlight or at night. A deep-cycle lead-acid battery was chosen for its reliability and ability to handle the charge and discharge cycles required for this application.

Figure 0-4: Lead Acid Battery

iii) **Solar Charge Controller (20A):** The charge controller regulates the flow of electricity from the solar panel to the battery, preventing overcharging and ensuring efficient energy use. A 20A controller was chosen to match the current requirements of the system.

Figure 0-5: Charge Controller

iv) **Microcontroller (Arduino nano):** The Arduino nano microcontroller acts as the central control unit for the kiosk, managing the power distribution, controlling the locking mechanism, and interacting with the keypad system.

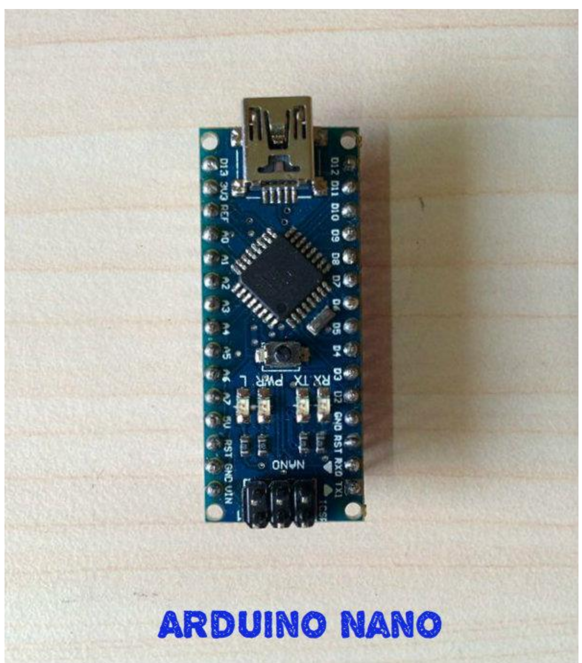

Figure 0-6: Arduino MCU

v) **Keypad and Locking System:** The secure compartments are controlled by an electronic keypad, which allows users to enter a Personal Identification Number (PIN) to lock and unlock their phones. The system uses servo motors to control the locks on each compartment.

Figure 0-7: Servo Lock with Keypad

Figure 0-8: Servo Lock

vi) **USB Charging Ports:** Each secure compartment is equipped with USB charging ports, providing 5V output to charge phones and other devices.

Figure 0-9: USB Cable

3.3 Design and Fabrication Methods

The fabrication of the solar-powered charging kiosk involves several processes, from the design phase using CAD software to the physical assembly of the components. The following sections describe the methods used in the design and fabrication of the system.

3.3.1 Design of the Kiosk

The design process began with the creation of a 3D model of the kiosk using **SolidWorks** software. This allowed for accurate modeling of the mechanical structure, ensuring that all components would fit together seamlessly. The design focused on creating a modular system that could easily be scaled to include more compartments if necessary. Key considerations in the design process included:

i. **Security:** The design incorporates individual lockable compartments for each phone, accessible only via a PIN entered on the keypad.
ii. **Durability:** The materials selected, including ABS and Perspex, were chosen for their ability to withstand harsh environmental conditions, including UV exposure, high temperatures, and humidity.
iii. **Energy Efficiency:** The positioning of the solar panel was optimized to ensure maximum exposure to sunlight, while the battery and charge controller were selected to ensure efficient energy storage and management.

3.3.2 Fabrication of the Kiosk

The fabrication process involved several steps, including cutting, assembling, and wiring the components. The methods used included:

i) **3D Printing:** The storage compartments were fabricated using 3D printing technology, which allowed for precise construction using ABS plastic. This method ensured that the compartments were strong, durable, and weatherproof.
ii) **Laser Cutting:** Laser cutting was used to create the Perspex windows and support panels for the kiosk. This process ensured precise cuts and smooth edges, providing a professional finish to the kiosk.

iii) **Soldering and Wiring:** The electronic components, including the microcontroller, solar panel, battery, and charging ports, were connected through soldering and wiring. This ensured reliable electrical connections and efficient power distribution throughout the system.

iv) **Assembly:** The kiosk was assembled by combining the 3D-printed compartments, the electronic components, and the solar power system. Special care was taken to ensure that the locking mechanism and keypad system were properly integrated into the overall design.

3.4 Design Calculations

To ensure that the kiosk would meet the energy requirements for charging multiple phones, several design calculations were performed.

3.4.1 Solar Panel Sizing

The size of the solar panel was calculated based on the estimated energy requirements for charging multiple phones. Assuming that each phone requires approximately 10W of power to charge, and that the system would need to charge up to 10 phones simultaneously, a 50W solar panel was selected to provide sufficient power for daytime charging, while excess energy would be stored in the battery for later use.

Assumptions:

i) The system is designed to charge 10 mobile phones at once.
ii) Each phone requires 5V and 2A for charging.
iii) The charging time is 4 hours per phone.
iv) Solar panel efficiency is assumed to be 80%.
v) Average sunlight hours per day is assumed to be 5 hours (typical for off-grid areas).

The energy consumption for each phone is calculated as:

$$E = Voltage \times Current \times Time$$

$$E = 5 \times 2 \times 4 = 40Wh$$

Since we are charging 10 phones, the total energy required is:

$$E_{total} = 40 \times 10 = 400Wh$$

The energy output from the solar panel during one hour of full sunlight is:

$$E_{panel} = Paanel\,Power(W) \times Sunlight\,Hours \times Efficiency$$

The solar panel's power output is P=50W:

$$E_{panel} = 50 \times 5 \times 0.8 = 200Wh$$

This means that a 50W solar panel can produce 200 Wh per day under optimal conditions. Since the total energy demand is 400 Wh per day, a 50W solar panel will not be enough to meet the demand for 10 phones.

3.4.2 Battery Sizing

The battery was sized to store enough energy to charge multiple phones during periods of low sunlight or nighttime. A 12V, 100Ah lead-acid battery was chosen, providing a total energy storage capacity of 1,200Wh. This is sufficient to charge up to 10 phones, each requiring approximately 10Wh, ensuring that the system can operate for extended periods without sunlight.

From the earlier calculation, the total energy required for charging 10 phones is 400 Wh per day. The battery should be able to store this amount of energy plus a buffer for cloudy or low sunlight periods.

Assume a 20% safety margin to account for inefficiencies and unexpected power loss:

$$E_{bat} = E_{tottal} \times 1.2 = 400 \times 1.2 = 480Wh$$

The battery capacity is typically given in Ah (ampere-hours) at a specific voltage. For a 12V battery, the required battery capacity in Ah is:

$$bat\,Capacity = \frac{E_{bat}}{voltage} = \frac{480}{12} = 40Wh$$

Therefore, a 12V, 40Ah battery is needed to store sufficient energy for the kiosk.

Lead-acid batteries typically have a recommended DoD of 50% to maximize their lifespan. This means the battery should be sized to account for only half of its total capacity being used regularly. The effective usable capacity is:

$$Usage\ Capacity \ = \ 40Ah \ \times 0.5 \ = \ 20Ah$$

Thus, to ensure proper operation and extend the battery's life, the battery should be rated at least 40 Ah, with only 20 Ah being used regularly.

3.4.3 Charge Controller Sizing

The charge controller was selected to handle the current generated by the solar panel and manage the charging of the battery. A 20A charge controller was chosen to ensure that the system could safely manage the power generated by the solar panel and prevent overcharging of the battery.

The current output of the solar panel can be calculated by dividing its power rating by the voltage of the panel:

$$I_{\max} \ = \frac{P_{solar}}{V_{panel}} = \frac{100}{18} \ = \ 5.56A$$

Thus, the charge controller needs to handle at least 5.56A of current. A 10A charge controller would be suitable, as it provides a margin for safety.

3.5 Operation of the Phone Charging Kiosk

The phone charging kiosk operates by harnessing solar energy to charge a battery, which in turn powers the USB charging ports. The user interface consists of a keypad and LCD display, which allows users to lock their phones securely in individual compartments. The steps involved in the operation of the kiosk are as follows:

i) **User Interaction:** The user places their phone in an available compartment and enters a unique PIN on the keypad to lock the compartment.

ii) **Charging Process:** The phone is connected to the USB charging port inside the compartment, which provides a stable 5V output to charge the phone.

iii) **Power Management:** The solar panel generates electricity during the day, which is stored in the battery. The charge controller regulates the flow of electricity, ensuring efficient charging of both the phones and the battery.

iv) **Security:** Once the phone is locked in the compartment, only the user can unlock it by re-entering their PIN on the keypad. This ensures that the phone remains secure during the charging process.

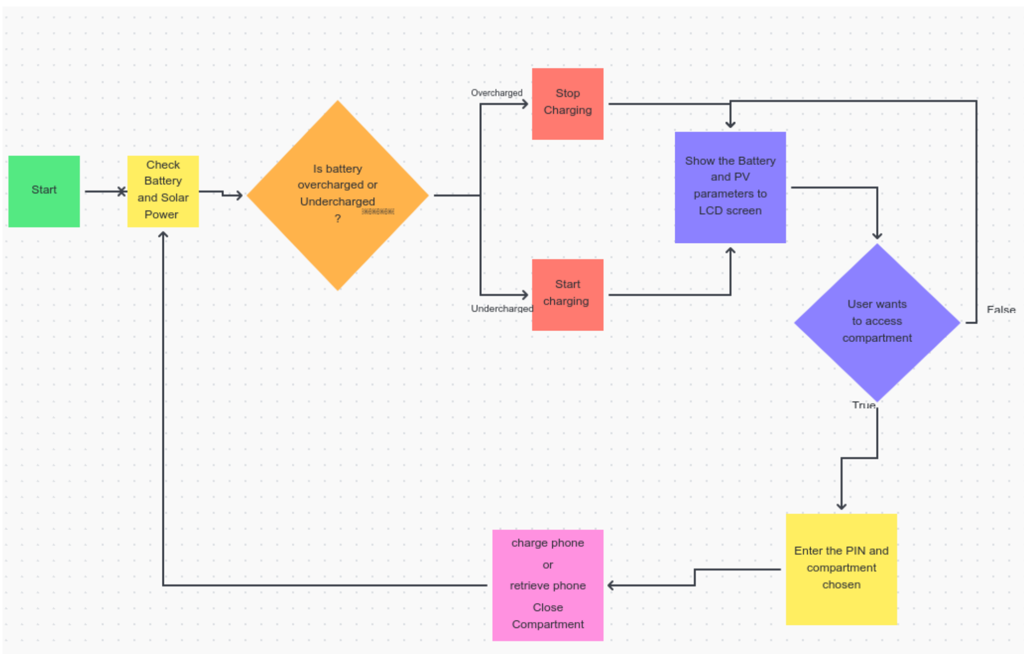

Figure 0-10: A flowchart showing the operation of the phone charging kiosk

CHAPTER FOUR: TESTING, RESULTS, AND DISCUSSION

4.1 Introduction

This chapter discusses the testing process conducted on the solar-powered phone charging kiosk, the results obtained, and an analysis of the system's performance. The goal of the testing phase was to evaluate the functionality of the individual components, assess the overall efficiency of the charging system, and validate the security and user interface features. The tests conducted included the solar energy system test, power management test, security system test, and user interface system test. The results of these tests are analyzed to determine whether the kiosk meets its design specifications and operational requirements.

4.2 Construction Process

The construction of the solar-powered phone charging kiosk involved assembling both mechanical and electronic components. After fabrication, the components were connected according to the design specifications, and the system was prepared for testing.

4.2.1 Tools and Equipment Used

The following tools and equipment were used in the construction and assembly of the kiosk:

i) **3D Printer:** Used to fabricate the secure compartments using ABS plastic.
ii) **Laser Cutter:** Utilized to cut Perspex panels for the transparent windows.
iii) **Soldering Iron:** Used for connecting the electronic components, including the microcontroller, charge controller, and USB charging ports.
iv) **Multimeter:** Used to measure the voltage, current, and resistance during system testing.
v) **Oscilloscope:** Used to test the performance of the microcontroller and other electronic circuits.

4.2.2 Power Supply

The power supply of the kiosk was entirely solar-based, with a 50W solar panel connected to a 12V, 100Ah lead-acid battery. The charge controller regulated the energy flow between the solar panel and the battery, ensuring the battery was charged efficiently without overcharging. The battery provided energy to the USB charging ports, which outputted 5V for charging mobile phones.

4.2.3 Component Connections

The connections between the components followed the block diagram designed in Chapter Three. The solar panel was connected to the charge controller, which then connected to the battery. The battery supplied power to the microcontroller (Arduino Uno), which managed the charging system and security features. The USB ports were connected to the battery via the charge controller, providing stable voltage for phone charging. The keypad was linked to the microcontroller, which controlled the locking mechanism for the phone compartments.

4.3 Fabrication

The fabrication process focused on constructing the physical structure of the kiosk, including the secure compartments, the integration of the solar panel, and the installation of electronic components. The compartments were fabricated using 3D printing, ensuring high strength and durability. The transparent windows for each compartment were cut from Perspex using a laser cutter, providing visibility while ensuring the security of the phones inside.

The electronic components, including the solar panel, charge controller, battery, microcontroller, and locking system, were assembled and connected according to the design specifications. The system was then tested to ensure that all components were functioning properly before proceeding with the formal testing phase.

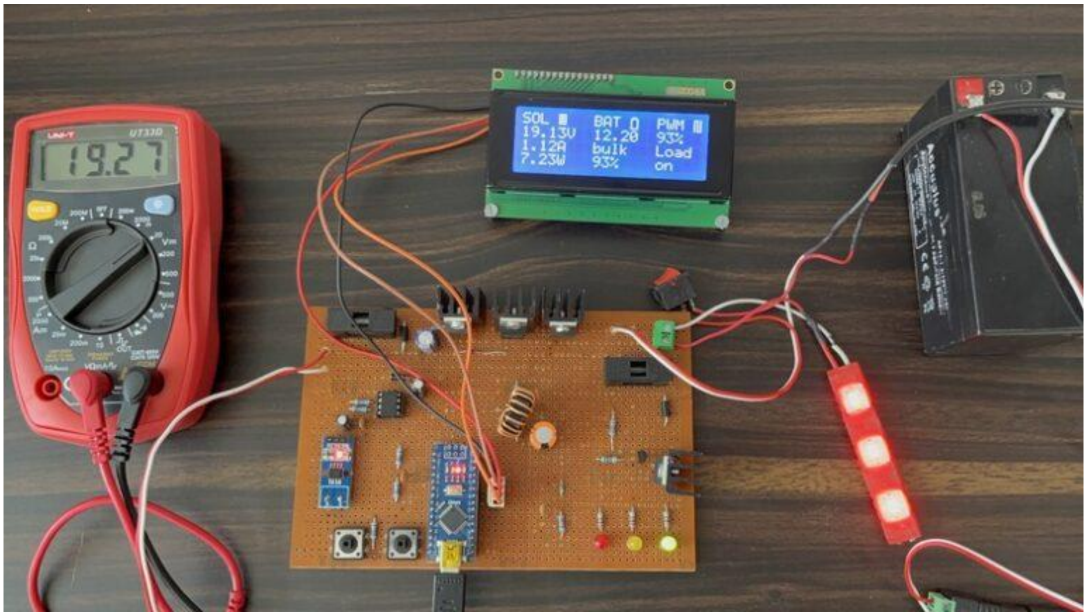

Figure 0-1: Testing Electronic Assembly

4.4 Testing and Results

Several tests were conducted to evaluate the functionality of the solar-powered phone charging kiosk. The testing phase was divided into four main areas: solar energy system testing, power management testing, security system testing, and user interface system testing.

4.4.1 Solar Energy System Testing

The solar energy system was tested under different lighting conditions to evaluate its performance. The test involved measuring the voltage and current output of the 50W solar panel during sunny, cloudy, and low-light conditions. The solar panel was expected to generate a voltage of 18V under optimal sunlight conditions.

Results

Under clear sunlight, the solar panel generated an average of 17.8V, close to the expected output. During cloudy conditions, the voltage dropped to 13V, and in low-light conditions, it dropped to 8V. The results indicated that the solar panel performed well under optimal conditions but showed a significant reduction in performance during cloudy or low-light periods.

Table 0-1: Solar Panel Power Output Test

Test Condition	Power Output (W)	Calculated from (V × A)	Expected Efficiency (%)	Notes
Clear Sunny Day	98.3W	18.2V × 5.4A	98.3%	Near maximum output
Partially Cloudy	60.0W	15.0V × 4.0A	60%	Moderate power due to clouds
Overcast Day	31.25W	12.5V × 2.5A	31.25%	Low power in cloudy conditions
Early Morning	18.0W	10.0V × 1.8A	18%	Reduced output due to low sunlight
Late Afternoon	22.4W	11.2V × 2.0A	22.4%	Lower output, sun fading

4.4.2 Power Management Testing

The power management system, which included the charge controller and the battery, was tested to ensure that energy was being stored and distributed effectively. The system was expected to charge the 12V battery efficiently without overcharging or undercharging.

Results

The charge controller regulated the energy flow properly, maintaining the battery charge between 11.5V and 12.8V. During testing, the system successfully charged multiple phones simultaneously without draining the battery, even during periods of low sunlight. The battery had sufficient capacity to charge up to 10 phones before needing a recharge from the solar panel.

Table 0-2: Voltage and Current Measurements of the Solar Panel

Test Condition	Measured Voltage (V)	Measured Current (A)	Notes
Clear Sunny Day	18.2V	5.4A	Optimal conditions, peak sunlight
Partially Cloudy	15.0V	4.0A	Reduced sunlight, moderate output
Overcast Day	12.5V	2.5A	Low sunlight, minimal output
Early Morning	10.0V	1.8A	Weak sunlight, lower performance
Late Afternoon	11.2V	2.0A	Fading sunlight, moderate output

4.4.3 Security System Testing

The security system was tested to ensure that the compartments could be securely locked and unlocked using the PIN-based keypad system. Each compartment was equipped with a servo motor that controlled the locking mechanism.

Results

The keypad system performed as expected, allowing users to securely lock and unlock compartments with their unique PINs. The locking mechanism responded accurately to the keypad inputs, and no failures were recorded during testing. The servo motors were able to withstand reasonable force, ensuring the compartments remained secure under normal conditions.

4.4.4 User Interface System Testing

The user interface system, which consisted of the keypad and LCD display, was tested for usability and functionality. The system was designed to be intuitive, allowing users to easily lock and unlock their phones in the charging compartments.

Results

The LCD displayed clear instructions, guiding users through the process of entering a PIN and accessing their compartments. The keypad was responsive, and users were able to lock and unlock compartments without difficulty. Feedback from initial users indicated that the system was easy to use and required minimal explanation.

Figure 0-2: Device's UI

4.5 Discussion

The testing results demonstrated that the solar-powered phone charging kiosk met its design objectives. The solar energy system provided sufficient power to charge multiple phones during daylight hours, and the battery allowed for continued operation during periods of low sunlight. The security system functioned effectively, protecting the phones from theft while they were charging. The user interface was simple and intuitive, ensuring that users could easily operate the system.

While the system performed well overall, there were some areas where improvements could be made. The solar panel's performance dropped significantly during cloudy conditions, which may affect the system's reliability in regions with less consistent sunlight. Additionally, while the battery provided enough power for overnight use, extending the battery capacity could increase the system's utility during extended periods of bad weather.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Final Conclusion

This project aimed to design and fabricate a solar-powered phone charging kiosk to serve off-grid communities, providing a secure and sustainable method for charging mobile devices. The system integrated solar energy as the primary power source, a lead-acid battery for energy storage, a charge controller to regulate power flow, and a user-friendly interface with secure compartments for storing phones during charging.

The testing results demonstrated that the kiosk met its design objectives. The solar panel successfully generated enough electricity to charge multiple phones simultaneously, and the battery provided sufficient storage to allow continued operation during periods of low sunlight. The locking mechanism and keypad system effectively ensured that users' phones remained secure while charging, addressing a key concern in existing phone charging solutions for off-grid communities.

In conclusion, the solar-powered phone charging kiosk offers a viable solution to the challenges faced by off-grid communities in accessing reliable and secure phone charging services. By harnessing renewable solar energy and incorporating robust security features, the system provides a sustainable and affordable alternative to traditional power sources, reducing reliance on costly and environmentally harmful diesel generators.

5.2 Recommendations for Future Work

While the system performed well under testing, several areas for future improvement were identified:

i) **Increasing Battery Capacity:** The current battery capacity allows for continued operation during short periods of low sunlight. However, increasing the capacity of the battery would enable the kiosk to operate for longer periods without direct sunlight, improving reliability during extended cloudy weather or nighttime hours.

ii) **Optimizing Solar Panel Efficiency:** Although the solar panel performed well under optimal sunlight conditions, its efficiency decreased significantly during cloudy or low-light periods. Future iterations of the project could explore the use of more efficient solar panels or incorporate a sun-tracking system to maximize solar energy collection throughout the day.

iii) **Improving Security Features:** While the current locking system provides sufficient protection for most use cases, future designs could explore the addition of stronger locks or integrate biometric authentication systems (such as fingerprint scanners) for enhanced security. However, cost and ease of use should be carefully balanced with these upgrades, considering the target communities.

iv) **Modular and Scalable Design:** As the demand for phone charging grows in off-grid communities, the system could be made more modular and scalable. Future designs could include provisions for adding more compartments and charging ports, allowing the kiosk to serve larger groups without requiring significant redesign or expansion.

5.3 Statement of Initial Objectives

The project set out to achieve the following objectives:

i) **Design a solar-powered phone charging kiosk** capable of generating and storing enough power to charge multiple phones simultaneously.

ii) **Fabricate a secure charging station** with lockable compartments, ensuring the security of phones during charging.

iii) **Test the system** to verify its functionality, ensuring that it meets the needs of off-grid communities in terms of power reliability, security, and ease of use.

All the initial objectives were successfully met. The system was designed, fabricated, and tested, demonstrating its ability to provide reliable phone charging in off-grid areas while securing the users' phones.

5.4 Summary of Achievements

The key achievements of the project include:

i) **Successful Design and Fabrication**

The solar-powered kiosk was successfully designed and fabricated using durable materials such as ABS and Perspex. The electronic components, including the solar panel, battery, charge controller, and microcontroller, were integrated seamlessly to create a functional system.

ii) **Effective Energy Management**

The system effectively captured solar energy, stored it in the battery, and distributed it to the charging ports. The battery allowed for continuous operation even during periods of low sunlight.

iii) **Secure Charging Solution**

The integration of secure compartments with a PIN-based keypad locking system ensured that phones were safely stored while charging, addressing a significant concern in off-grid charging solutions.

iv) **User-Friendly Interface**

The system was designed to be intuitive and easy to use, with a responsive keypad and clear LCD display providing instructions to users. The feedback from testing indicated that users found the system accessible and straightforward to operate.

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APPENDICES

Appendix A: Bill of Materials

Table 0-1: BOM

Item	Description	Quantity	Unit Cost (Ksh)	Total Cost (Ksh)
Solar Panel	50W Photovoltaic Panel	1	5,000	5,000
Lead-Acid Battery	12V, 100Ah Deep Cycle Battery	1	10,000	10,000
Charge Controller	20A Solar Charge Controller	1	3,500	3,500
Microcontroller (Arduino Uno)	Microcontroller for System Control	1	2,000	2,000
Keypad	4x4 Matrix Keypad	1	600	600
Servo Motor	12V Servo Motor for Locking Mechanism	2	500	1,000
USB Charging Ports	USB Ports for Charging Phones	4	100	400
ABS Plastic	3D Printed Parts for Compartments	-	1,500	1,500
Perspex (Acrylic Glass)	Transparent Panels for Compartments	-	800	800
Wiring and Connectors	Electrical Wiring and Connectors	-	1,000	1,000
Miscellaneous Tools	Soldering Kit, Multimeter, etc.	-	2,500	2,500
Total Cost				**26,800**

Appendix B: System Schematic Diagram

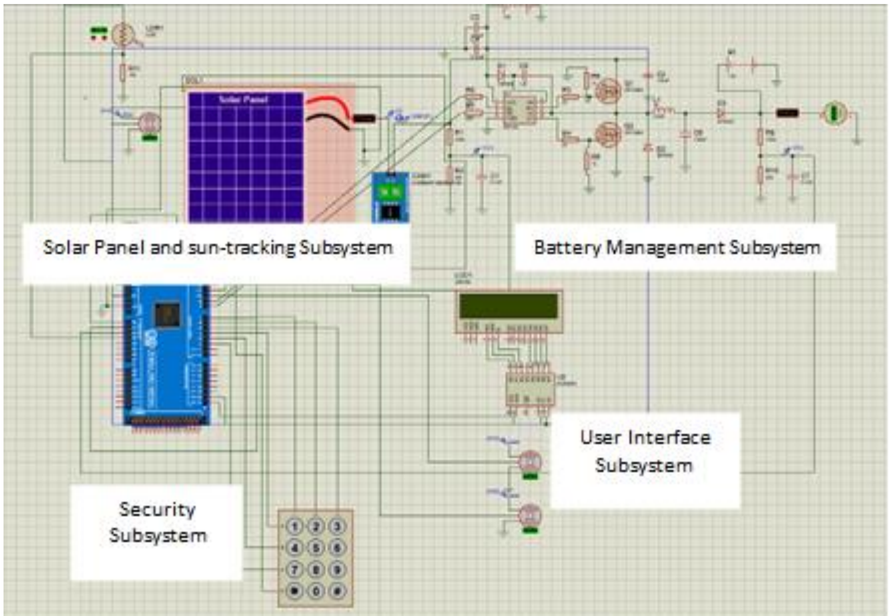

Figure 0-1: The image of the proposed circuit layout

Appendix C: Assembly Drawings

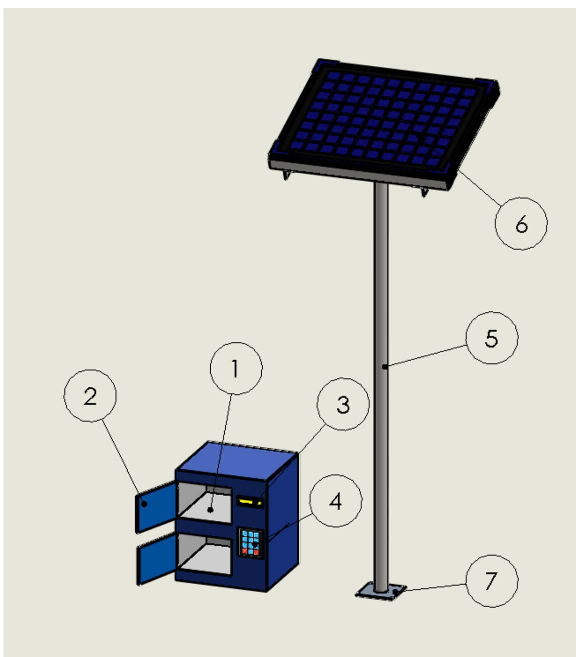

Figure 0-2: The mechanical design of the phone charging station

Appendix D: Testing Data

Table 0-2: Results of parameters

Test Type	Test Description	Result
Solar Panel Output Test	Measured voltage and current under different sunlight conditions	17.8V under sunlight, 13V under cloudy, 8V under low light
Power Distribution Test	Measured power output to USB ports	5V at 2.1A per port with 10 devices connected
Battery Performance Test	Measured battery charge and discharge rates	Battery maintained charge between 11.5V and 12.8V
Security System Test	Functionality of keypad and locking mechanism	All compartments securely locked/unlocked with PIN
User Interface Test	Ease of use of the keypad and LCD display	System was user-friendly and intuitive for all test users

Appendix E: Code Listing

```
#include "TimerOne.h"
#include "LiquidCrystal_I2C.h"
#include "Wire.h"
#include <Servo.h>
#include <Keypad.h>

// Load control algorithm
// 0 - NIGHT LIGHT: Load ON when there is no solar power and battery is above LVD (low voltage
disconnect)
// 1 - POWER DUMP: Load ON when there is solar power and the battery is above BATT_FLOAT
(charged)
#define LOAD_ALGORITHM 0

#define SOL_AMPS_CHAN 1   // Defining the adc channel to read solar amps
#define SOL_VOLTS_CHAN 0  // defining the adc channel to read solar volts
#define BAT_VOLTS_CHAN 2  // defining the adc channel to read battery volts
#define AVG_NUM 8         // number of iterations of the adc routine to average the adc readings

// ACS 712 Current Sensor is used. Current Measured = (5/(1024 *0.185))*ADC - (2.5/0.185)

#define SOL_AMPS_SCALE 0.0263783784   // the scaling value for raw adc reading to get solar amps
// 5/(1024*0.185)
```

```
#define SOL_VOLTS_SCALE 0.02928  // the scaling value for raw adc reading to get solar volts  //
(5/1024)*(R1+R2)/R2 // R1=10k and R2=2.20k
#define BAT_VOLTS_SCALE 0.02928  // the scaling value for raw adc reading to get battery volts

#define PWM_PIN 9        // the output pin for the pwm (only pin 9 avaliable for timer 1 at 50kHz)
#define PWM_ENABLE_PIN 8  // pin used to control shutoff function of the IR2104 MOSFET driver
(hight the mosfet driver is on)
#define PWM_FULL 1023     // the actual value used by the Timer1 routines for 100% pwm duty cycle
#define PWM_MAX 100       // the value for pwm duty cyle 0-100%
#define PWM_MIN 60       // the value for pwm duty cyle 0-100% (below this value the current running
in the system is = 0)
#define PWM_START 90      // the value for pwm duty cyle 0-100%
#define PWM_INC 1        //the value the increment to the pwm value for the ppt algorithm

#define TRUE 1
#define FALSE 0
#define ON TRUE
#define OFF FALSE

#define TURN_ON_MOSFETS digitalWrite(PWM_ENABLE_PIN, HIGH)  // enable MOSFET driver
#define TURN_OFF_MOSFETS digitalWrite(PWM_ENABLE_PIN, LOW)  // disable MOSFET driver

// IDK on the paras to be confirmed (from new)
#define ONE_SECOND 50000
#define LOW_SOL_WATTS 5.00
#define MIN_SOL_WATTS 1.00
#define MIN_BAT_VOLTS 11.00
#define MAX_BAT_VOLTS 14.10
#define BATT_FLOAT 13.60
#define HIGH_BAT_VOLTS 13.00
#define LVD 11.5
#define OFF_NUM 9

// Defining load control pin
#define LOAD_PIN 6  // pin-2 is used to control the load

//-------------------------------------------------------------------------------------------------
// Defining lcd back light pin
#define BACK_LIGHT_PIN 5  // pin-5 is used to control the lcd back light

// --------------------------For charging Station-----------------------------------------------------------
// for the locks for doors 1 and 2
Servo door1;
Servo door2;

// Length of password + 1 for null character
#define Password_Length 5

// Password storage for each door
char Data[Password_Length];
char ConfirmData[Password_Length];
const char MasterDoor1[Password_Length] = "5689"; // Password for door 1
const char MasterDoor2[Password_Length] = "9865"; // Password for door 2
```

```
const int door1Pin = 10;
const int door2Pin = 11;

const byte ROWS = 4;
const byte COLS = 3;
char keys[ROWS][COLS] = {
  { '1', '2', '3' },
  { '4', '5', '6' },
  { '7', '8', '9' },
  { '*', '0', '#' }
};

byte rowPins[ROWS] = { 4, 3, 2, 13 };
byte colPins[COLS] = { 7, 6, 5 };

// Initialize an instance of class
Keypad customKeypad = Keypad(makeKeymap(keys), rowPins, colPins, ROWS, COLS);


//---------------------------------------------------------------------------------------------------
/////////////////////////////////////////BIT MAP ARRAY/////////////////////////////////////////////////
//---------------------------------------------------------------------------------------------------

byte battery_icons[6][8] = { {
                          0b01110,
                          0b11011,
                          0b10001,
                          0b10001,
                          0b10001,
                          0b10001,
                          0b10001,
                          0b11111,
                        },
                        {
                          0b01110,
                          0b11011,
                          0b10001,
                          0b10001,
                          0b10001,
                          0b10001,
                          0b11111,
                          0b11111,
                        },
                        {
                          0b01110,
                          0b11011,
                          0b10001,
                          0b10001,
                          0b10001,
                          0b11111,
                          0b11111,
                          0b11111,
```

```
                        },
                        {
                         0b01110,
                         0b11011,
                         0b10001,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                        },
                        {
                         0b01110,
                         0b11011,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                        },
                        {
                         0b01110,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                         0b11111,
                        } };
#define SOLAR_ICON 6
byte solar_icon[8] =  //icon for termometer
  {
    0b11111,
    0b10101,
    0b11111,
    0b10101,
    0b11111,
    0b10101,
    0b11111,
    0b00000
  };
#define PWM_ICON 7
byte _PWM_icon[8] = {
  0b11101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10101,
  0b10111,
```

```
};
byte backslash_char[8] = {
  0b10000,
  0b10000,
  0b01000,
  0b01000,
  0b00100,
  0b00100,
  0b00010,
  0b00010,
};
//-------------------------------------------------------------------------------------------------------


// global variables

float sol_amps;                    // solar amps
float sol_volts;                   // solar volts
float bat_volts;                   // battery volts
float sol_watts;                   // solar watts
float old_sol_watts = 0;            // solar watts from previous time through ppt routine
unsigned int seconds = 0;           // seconds from timer routine
unsigned int prev_seconds = 0;      // seconds value from previous pass
unsigned int interrupt_counter = 0;  // counter for 20us interrrupt
unsigned long time = 0;             // variable to store time the back light control button was pressed in millis
int delta = PWM_INC;                // variable used to modify pwm duty cycle for the ppt algorithm
int pwm = 0;                       // pwm duty cycle 0-100%
int back_light_pin_State = 0;       // variable for storing the state of the backlight button
boolean load_status = false;        // variable for storing the load output state (for writing to LCD)

enum charger_mode { off,
                    on,
                    bulk,
                    bat_float } charger_state;  // enumerated variable that holds state for charger state machine
// set the LCD address to 0x27 for a 16 chars 2 line display
// Set the pins on the I2C chip used for LCD connections:
LiquidCrystal_I2C lcd(0x27, 16, 2);  // Set the LCD I2C address


void setup() {
  pinMode(PWM_ENABLE_PIN, OUTPUT);  // sets the digital pin as output
  TURN_OFF_MOSFETS;                 // turn off MOSFET driver chip
  charger_state = off;             // start with charger state as off
  lcd.init();                      // initialize the lcd for 16 chars 2 lines, turn on backlight

  // create the LCD special characters. Characters 0-5 are the various battery fullness icons
  // icon 7 is for the PWM icon, and icon 8 is for the solar array
  lcd.backlight();
  for (int batchar = 0; batchar < 6; ++batchar) {
    lcd.createChar(batchar, battery_icons[batchar]);
  }
  lcd.createChar(PWM_ICON, _PWM_icon);
  lcd.createChar(SOLAR_ICON, solar_icon);
```

```
  lcd.createChar('\\', backslash_char);
  Timer1.initialize(20);            // initialize timer1, and set a 20uS period
  Timer1.pwm(PWM_PIN, 0);           // setup pwm on pin 9, 0% duty cycle
  Timer1.attachInterrupt(callback);  // attaches callback() as a timer overflow interrupt
  Serial.begin(9600);               // open the serial port at 9600 bps:
  pwm = PWM_START;                  //starting value for pwm
  pinMode(BACK_LIGHT_PIN, INPUT);
  pinMode(LOAD_PIN, OUTPUT);
  digitalWrite(LOAD_PIN, LOW);       // default load state is OFF
  digitalWrite(BACK_LIGHT_PIN, LOW);  //  default LCd back light is OFF

  door1.attach(door1Pin);   // create an instance for door 1 and attach it to doorpin1
  door2.attach(door2Pin); // create an instance for door 2 and attach it to doorpin2
  // take both to their default location
  door1.write(0);
  door2.write(0);

  // display the constant stuff on the LCD
  lcd.setCursor(3, 0);
  lcd.write(SOLAR_ICON);
  lcd.print(" PHONE ");
  lcd.setCursor(3, 1);
  lcd.print("CHARGER");
  delay(3000);
}

void loop() {
  read_data();
  run_charger();
  // print_data();
  load_control();
  // lcd_display();
  lcd.clear();
  lcd.setCursor(3, 0);
  lcd.write(SOLAR_ICON);
  lcd.print(" ");
  lcd.print(sol_volts);
  lcd.print(" V");
  lcd.print(" ");
  lcd.print(sol_amps);
  lcd.print(" A");
  lcd.setCursor(0, 1);
  lcd.print("* for Door Select:");

  char customKey = customKeypad.getKey();
  if (customKey == '#') {
    selectDoor();
  }
}

//-------------------------------------------------------------------------------------------------
// This routine reads and averages the analog inputs for this system, solar volts, solar amps and
// battery volts.
```

```
//-------------------------------------------------------------------------------------------------------
int read_adc(int channel) {

  int sum = 0;
  int temp;
  int i;

  for (i = 0; i < AVG_NUM; i++) {  // loop through reading raw adc values AVG_NUM number of times
    temp = analogRead(channel);    // read the input pin
    sum += temp;                   // store sum for averaging
    delayMicroseconds(50);         // pauses for 50 microseconds
  }
  return (sum / AVG_NUM);  // divide sum by AVG_NUM to get average and return it
}

//-------------------------------------------------------------------------------------------------------
// This routine reads all the analog input values for the system. Then it multiplies them by the scale
// factor to get actual value in volts or amps.
//-------------------------------------------------------------------------------------------------------
void read_data(void) {

  sol_amps = (read_adc(SOL_AMPS_CHAN) * SOL_AMPS_SCALE - 13.51);  //input of solar amps
  sol_volts = read_adc(SOL_VOLTS_CHAN) * SOL_VOLTS_SCALE;         //input of solar volts
  bat_volts = read_adc(BAT_VOLTS_CHAN) * BAT_VOLTS_SCALE;         //input of battery volts
  sol_watts = sol_amps * sol_volts;                               //calculations of solar watts
}

//-------------------------------------------------------------------------------------------------------
// This is interrupt service routine for Timer1 that occurs every 20uS.
//
//-------------------------------------------------------------------------------------------------------
void callback() {
  if (interrupt_counter++ > ONE_SECOND) {  // increment interrupt_counter until one second has passed
    interrupt_counter = 0;                 // reset the counter
    seconds++;                             // then increment seconds counter
  }
}

//-------------------------------------------------------------------------------------------------------
// This routine uses the Timer1.pwm function to set the pwm duty cycle.
//-------------------------------------------------------------------------------------------------------
void set_pwm_duty(void) {

  if (pwm > PWM_MAX) {  // check limits of PWM duty cyle and set to PWM_MAX
    pwm = PWM_MAX;
  } else if (pwm < PWM_MIN) {  // if pwm is less than PWM_MIN then set it to PWM_MIN
    pwm = PWM_MIN;
  }
  if (pwm < PWM_MAX) {
    Timer1.pwm(PWM_PIN, (PWM_FULL * (long)pwm / 100), 20);  // use Timer1 routine to set pwm
duty cycle at 20uS period
    //Timer1.pwm(PWM_PIN,(PWM_FULL * (long)pwm / 100));
  } else if (pwm == PWM_MAX) {             // if pwm set to 100% it will be on full but we have
```

```
    Timer1.pwm(PWM_PIN, (PWM_FULL - 1), 20);  // keep switching so set duty cycle at 99.9%
    //Timer1.pwm(PWM_PIN,(PWM_FULL - 1));
  }
}

//------------------------------------------------------------------------------------------------------
// This routine is the charger state machine. It has four states on, off, bulk and float.
// It's called once each time through the main loop to see what state the charger should be in.
// The battery charger can be in one of the following four states:
//
//  On State - this is charger state for MIN_SOL_WATTS < solar watts < LOW_SOL_WATTS. In this
state isthe solar

//  Bulk State - this is charger state for solar watts > MIN_SOL_WATTS. This is where we do the bulk of
the battery

//  Float State - As the battery charges it's voltage rises. When it gets to the MAX_BAT_VOLTS we are
done with the

//  Off State - This is state that the charger enters when solar watts < MIN_SOL_WATTS. The charger
goes into this
void run_charger(void) {
  static int off_count = OFF_NUM;
  switch (charger_state) {
    case on:
      if (sol_watts < MIN_SOL_WATTS) {
        charger_state = off;
        off_count = OFF_NUM;
        TURN_OFF_MOSFETS;
      } else if (bat_volts > (BATT_FLOAT - 0.1)) {
        charger_state = bat_float;
      } else if (sol_watts < LOW_SOL_WATTS) {
        pwm = PWM_MAX;
        set_pwm_duty();
      } else {
        pwm = ((bat_volts * 10) / (sol_volts / 10)) + 5;
        charger_state = bulk;
      }
      break;

    case bulk:
      if (sol_watts < MIN_SOL_WATTS) {
        charger_state = off;
        off_count = OFF_NUM;
        TURN_OFF_MOSFETS;
      } else if (bat_volts > BATT_FLOAT) {
        charger_state = bat_float;
      } else if (sol_watts < LOW_SOL_WATTS) {
        charger_state = on;
        TURN_ON_MOSFETS;
      } else {
        if (old_sol_watts >= sol_watts) {
          delta = -delta;
```

```
    }
    pwm += delta;
    old_sol_watts = sol_watts;
    set_pwm_duty();
   }
   break;

  case bat_float:
   if (sol_watts < MIN_SOL_WATTS) {
    charger_state = off;
    off_count = OFF_NUM;
    TURN_OFF_MOSFETS;
    set_pwm_duty();
   } else if (bat_volts > BATT_FLOAT) {
    TURN_OFF_MOSFETS;
    pwm = PWM_MAX;
    set_pwm_duty();
   } else if (bat_volts < BATT_FLOAT) {
    pwm = PWM_MAX;
    set_pwm_duty();
    TURN_ON_MOSFETS;
    if (bat_volts < (BATT_FLOAT - 0.1)) { charger_state = bulk; }
   }
   break;
  case off:
   TURN_OFF_MOSFETS;
   if (off_count > 0) {
    off_count--;
   } else if ((bat_volts > BATT_FLOAT) && (sol_volts > bat_volts)) {
    charger_state = bat_float;
    TURN_ON_MOSFETS;
   } else if ((bat_volts > MIN_BAT_VOLTS) && (bat_volts < BATT_FLOAT) && (sol_volts >
bat_volts)) {
    charger_state = bulk;
    TURN_ON_MOSFETS;
   }
   break;
  default:
   TURN_OFF_MOSFETS;
   break;
 }
}

//------------------------------------------------------------------------------------------------------
/////////////////////////////////////////////LOAD CONTROL/////////////////////////////////////////////////////
//------------------------------------------------------------------------------------------------------

void load_control() {
#if LOAD_ALGORITHM == 0
 // turn on loads at night when the solar panel is not producing power
 // as long as the battery voltage is above LVD
 load_on(sol_watts < MIN_SOL_WATTS && bat_volts > LVD);
#else
```

```
 // dump excess solar energy into the load circuit
 load_on(sol_watts > MIN_SOL_WATTS && bat_volts > BATT_FLOAT);
#endif
}

void load_on(boolean new_status) {
 if (load_status != new_status) {
   load_status = new_status;
   digitalWrite(LOAD_PIN, new_status ? HIGH : LOW);
 }
}

//-----------------------------------------------------------------------------------------------------
// This routine prints all the data out to the serial port.
//-----------------------------------------------------------------------------------------------------
void print_data(void) {

 Serial.print(seconds, DEC);
 Serial.print("      ");

 Serial.print("Charging = ");
 if (charger_state == on) Serial.print("on   ");
 else if (charger_state == off) Serial.print("off  ");
 else if (charger_state == bulk) Serial.print("bulk ");
 else if (charger_state == bat_float) Serial.print("float");
 Serial.print("      ");

 Serial.print("pwm = ");
 if (charger_state == off)
   Serial.print(0, DEC);
 else
   Serial.print(pwm, DEC);
 Serial.print("      ");

 Serial.print("Current (panel) = ");
 Serial.print(sol_amps);
 Serial.print("      ");

 Serial.print("Voltage (panel) = ");
 Serial.print(sol_volts);
 Serial.print("      ");

 Serial.print("Power (panel) = ");
 Serial.print(sol_volts);
 Serial.print("      ");

 Serial.print("Battery Voltage = ");
 Serial.print(bat_volts);
 Serial.print("      ");

 Serial.print("\n\r");
 //delay(1000);
}
```

```
//--------------------------------------------------------------------------------------------------
//------------------------ LCD DISPLAY -----------------------------------------------------------
//--------------------------------------------------------------------------------------------------
void lcd_display() {
  static bool current_backlight_state = -1;
  back_light_pin_State = digitalRead(BACK_LIGHT_PIN);
  if (current_backlight_state != back_light_pin_State) {
    current_backlight_state = back_light_pin_State;
    if (back_light_pin_State == HIGH)
      lcd.backlight();  // finish with backlight on
    else
      lcd.noBacklight();
  }

  if (back_light_pin_State == HIGH) {
    time = millis();  // If any of the buttons are pressed, save the time in millis to "time"
  }

  lcd.setCursor(0, 1);
  lcd.print(sol_volts);
  lcd.print("V ");
  lcd.setCursor(0, 2);
  lcd.print(sol_amps);
  lcd.print("A");
  lcd.setCursor(0, 3);
  lcd.print(sol_watts);
  lcd.print("W ");
  lcd.setCursor(8, 1);
  lcd.print(bat_volts);
  lcd.setCursor(8, 2);

  if (charger_state == on)
    lcd.print("on   ");
  else if (charger_state == off)
    lcd.print("off  ");
  else if (charger_state == bulk)
    lcd.print("bulk ");
  else if (charger_state == bat_float) {
    lcd.print("     ");
    lcd.setCursor(8, 2);
    lcd.print("float");
  }

  //-------------------------------------------------------
  //--------------------Battery State Of Charge ---------------
  //-------------------------------------------------------
  int pct = 100.0 * (bat_volts - 11.3) / (12.7 - 11.3);
  if (pct < 0)
    pct = 0;
  else if (pct > 100)
    pct = 100;
```

```
  lcd.setCursor(12, 0);
  lcd.print((char)(pct * 5 / 100));

  lcd.setCursor(8, 3);
  pct = pct - (pct % 10);
  lcd.print(pct);
  lcd.print("%  ");

  //------------------------------------------------------------------
  //------------------Duty Cycle---------------------------------------
  //------------------------------------------------------------------
  lcd.setCursor(15, 0);
  lcd.print("PWM");
  lcd.setCursor(19, 0);
  lcd.write(PWM_ICON);
  lcd.setCursor(15, 1);
  lcd.print("   ");
  lcd.setCursor(15, 1);
  if (charger_state == off)
    lcd.print(0);
  else
    lcd.print(pwm);
  lcd.print("% ");
  //-------------------------------------------------------------------
  //-----------------------Load Status--------------------------------
  //-------------------------------------------------------------------
  lcd.setCursor(15, 2);
  lcd.print("Load");
  lcd.setCursor(15, 3);
  if (load_status) {
    lcd.print("On  ");
  } else {
    lcd.print("Off ");
  }
  spinner();
  backLight_timer();  // call the backlight timer function in every loop
}

void backLight_timer() {
  if ((millis() - time) <= 15000)  // if it's been less than the 15 secs, turn the backlight on
    lcd.backlight();              // finish with backlight on
  else
    lcd.noBacklight();  // if it's been more than 15 secs, turn the backlight off
}
void spinner(void) {
  static int cspinner;
  static char spinner_chars[] = { '*', '*', '*', ' ', ' ' };
  cspinner++;
  lcd.print(spinner_chars[cspinner % sizeof(spinner_chars)]);
}

//--------------------------------------------------------------------
//-----------------------------------------------------------------------------------------------
```

```
// This routine is the solar charging compartent algorithm
// It  controls the opening closing and other retrivel stuff happening
//----------------------------------------------------------------------------------------------------------------
void selectDoor() {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Select Door (1/2):");

  char doorKey = customKeypad.getKey();
  if (doorKey == '5' || doorKey == '6') {
    lcd.clear();
    getPassword(doorKey);
  } else {
    selectDoor();
  }
}

void getPassword(char doorKey) {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Enter Password:");
  int data_count = 0;

  while (data_count < Password_Length - 1) {
    char customKey = customKeypad.getKey();
    if (customKey) {
      Data[data_count] = customKey;
      lcd.setCursor(data_count, 1);
      lcd.print('*');
      data_count++;
    }
  }
  Data[data_count] = '\0'; // Null terminate the string

  lcd.clear();
  confirmPassword(doorKey);
}

void confirmPassword(char doorKey) {
  lcd.setCursor(0, 0);
  lcd.print("Confirm Password:");
  int confirm_count = 0;

  while (confirm_count < Password_Length - 1) {
    char customKey = customKeypad.getKey();
    if (customKey) {
      ConfirmData[confirm_count] = customKey;
      lcd.setCursor(confirm_count, 1);
      lcd.print('*');
      confirm_count++;
    }
  }
  ConfirmData[confirm_count] = '\0'; // Null terminate the string
```

```
  lcd.clear();

  // Check password for door 1
  if (doorKey == '5' && strcmp(Data, MasterDoor1) == 0 && strcmp(Data, ConfirmData) == 0) {
    openDoor(doorKey);
  }
  // Check password for door 2
  else if (doorKey == '6' && strcmp(Data, MasterDoor2) == 0 && strcmp(Data, ConfirmData) == 0) {
    openDoor(doorKey);
  } else {
    lcd.print("Passwords Mismatch");
    delay(1000);
    selectDoor();
  }
}

void openDoor(char doorKey) {
  lcd.print("Opening Door ");
  lcd.print(doorKey);
  if (doorKey == '1') {
    door1.write(90); // Open door 1
  } else {
    door2.write(90); // Open door 2
  }

  // Wait for user to re-enter password to close the door
  while (true) {
    lcd.setCursor(0, 1);
    lcd.print("Re-enter Password:");

    int data_count = 0;
    while (data_count < Password_Length - 1) {
      char customKey = customKeypad.getKey();
      if (customKey) {
        Data[data_count] = customKey;
        lcd.setCursor(data_count, 2);
        lcd.print('*');
        data_count++;
      }
    }
    Data[data_count] = '\0'; // Null terminate the string

    // Check if the re-entered password matches the original
    if ((doorKey == '5' && strcmp(Data, MasterDoor1) == 0) ||
        (doorKey == '6' && strcmp(Data, MasterDoor2) == 0)) {
      closeDoor(doorKey);
      break; // Exit the loop to allow for another operation
    } else {
      lcd.clear();
      lcd.print("Wrong Password");
      delay(1000);
      lcd.clear();
```

```
    }
  }
}

void closeDoor(char doorKey) {
  lcd.print("Closing Door ");
  lcd.print(doorKey);
  if (doorKey == '5') {
    door1.write(0); // Close door 1
  } else {pp export
    door2.write(0); // Close door 2
  }

  // Notify user to retrieve the phone
  lcd.clear();
  lcd.print("Door Closed");
  lcd.setCursor(0, 1);
  lcd.print("Retrieve Phone");
  delay(10000); // Show message for 3 seconds
  clearData();
}

void clearData() {
  memset(Data, 0, sizeof(Data));
  memset(ConfirmData, 0, sizeof(ConfirmData));
}
```