CHAPTER ONE

INTRODUCTION

1.1 Project Background

In many regions of the world, reliable electricity remains a critical issue, with developing countries facing significant challenges due to inadequate grid infrastructure and frequent power outages. In Nigeria, the dependence on generators as an alternative power source has become a widespread necessity, especially in urban and rural areas where electricity supply is inconsistent and unreliable. This situation has catalyzed the growth of a "generator economy," characterized by the extensive use of gasoline generators to supplement or replace grid electricity. As a result, the need for efficient generator management systems has become increasingly important, not only to ensure continuous power supply but also to optimize the operational efficiency.

The primary focus of this project is the development of a generator monitoring and control system, which integrates fuel monitoring, remote control capabilities, and an automatic transfer switch (ATS) mechanism. This system is designed to address the challenges associated with manual monitoring and operation of generators, which often lead to inefficiencies, high operational costs, and safety risks. The target audience for this project includes residential users, small business owners, and institutions such as hospitals that rely heavily on generators for critical power needs.

The concept of remote monitoring and control of electrical systems has evolved significantly over the past few decades. Early systems were limited to basic telemetry and manual switch operations, which often required significant human intervention. However, advancements in microcontrollers, sensors, and wireless communication technologies have revolutionized this field, therefore, facilitating things like real-time monitoring and automation.

The system's design involves three main components: fuel monitoring, control of generator functions, and ATS functionality. The fuel monitoring component employs ultrasonic sensors to measure the fuel level non-invasively, providing real-time data on fuel consumption and remaining capacity. This information is crucial for preventing fuel shortages, which can cause unexpected generator shutdowns, especially during critical operations. The control component utilizes a solenoid valve and relays to manage the fuel supply and other generator functions, such as the choke and ignition. This allows for automated startup and shutdown procedures, reducing the need for manual intervention and minimizing human error.

The ATS functionality is perhaps the most critical aspect of this project. It enables the seamless switching between grid power and generator power, ensuring uninterrupted electricity supply. This feature is particularly valuable in scenarios where continuous power is essential, such as in healthcare facilities. For example, a small rural hospital in Nigeria may rely on generators to power essential medical equipment during power outages. The ATS system would automatically switch to generator power in the event of a grid failure, thereby preventing disruptions in patient care and potentially saving lives.

Historically, the reliance on generators in Nigeria can be traced back to the country's ongoing struggles with electricity supply. The National Electric Power Authority (NEPA), established in the mid-1970s, was tasked with managing the country's power infrastructure. However, chronic underinvestment, mismanagement, and infrastructural challenges have plagued the sector for decades. This has led to frequent power outages, compelling individuals and businesses to seek alternative power solutions. Today, generators are an integral part of daily life in Nigeria, with a significant portion of the population depending on them as a primary or secondary source of electricity. According to recent data from the National Bureau of Statistics (Odeyale, 2023), a significant portion of households reporting access to electricity still heavily depend on generators for power supply. Among these households, primary reliance on generators stands at 11.3%, with an additional 12.4% relying on them as a secondary source of electricity. Even in urban areas, where grid infrastructure is comparatively better, 6.3% of electricity-accessing households primarily rely on generators.

Regional disparities further highlight the extent of generator dependence, with the south-south and south-east regions showing the highest levels of reliance, where approximately a quarter and a fifth of electricity-accessing households, respectively, rely primarily on generators. Conversely, reliance is lowest in the north-east and north-west regions, indicating variations in electricity access and generator usage across different parts of the country.

These can be seen in table 1.1 (Odeyale, 2023):

Table 1.1: Household Dependence on Generators for Electricity by Region and Area in Nigeria

Region	***Percentage of households reporting generator as their primary source of electricity***	***Percentage of households reporting generator as "other" source of electricity***
North-Central	4.50	11.00

North-East	1.50	4.20
North-West	1.60	5.80
South-East	20.70	20.30
South-South	24.10	14.70
South-West	2.40	10.20
Urban	6.30	16.30
Rural	15.80	9.00

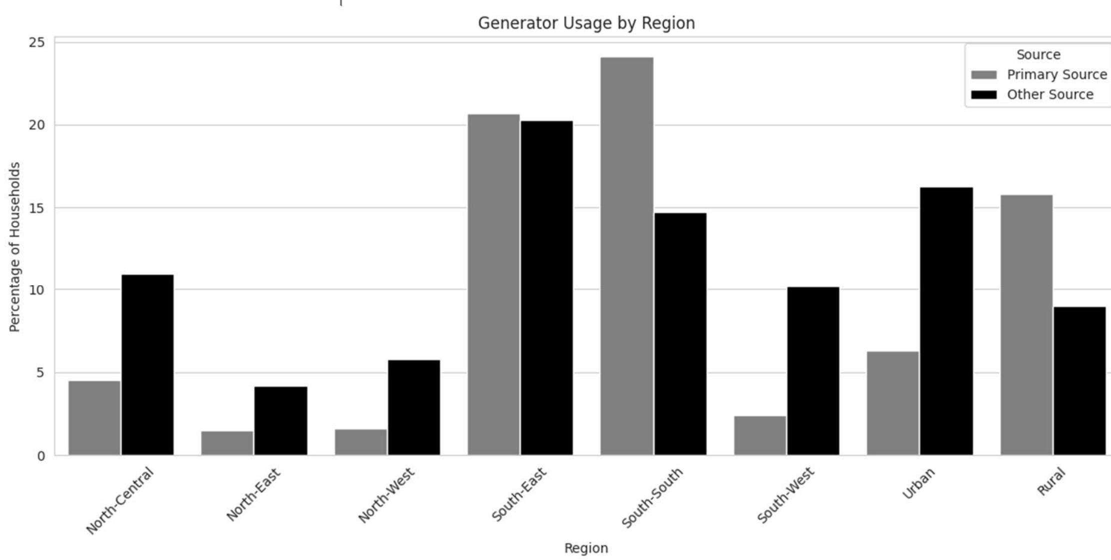

Figure 1.1: Generator Usage by Region in Nigeria

The novelty of this project lies in its holistic approach to generator management. Unlike traditional systems that may only focus on one aspect, such as fuel monitoring or control, this system integrates multiple functionalities into a single, cohesive unit. It not only enhances the efficiency and safety of generator operations but also provides a scalable solution that can be adapted for various use cases. By incorporating real-time monitoring and control capabilities, the system offers a modern solution to a longstanding problem, aligning with global trends towards smart energy management and automation.

In summary, this project represents a significant step forward in the management and operation of gasoline generators in Nigeria. By addressing the key challenges of fuel monitoring, operational control, and automatic transfer switching, it offers a comprehensive solution that can improve energy access and reliability. This development has the potential to impact on a wide range of applications, from residential use to critical infrastructure, making it a valuable contribution to the ongoing efforts to modernize and optimize power systems in the country.

1.2 Problem Statement

In Nigeria, unreliable grid electricity has led to a widespread dependence on gasoline generators for both residential and commercial power needs. This reliance poses several challenges, including inefficient fuel consumption, high operational costs, frequent maintenance issues, and safety hazards due to manual operation and monitoring. Additionally, the absence of a seamless transition between grid and generator power often results in power outages, disrupting daily activities and critical services. This project aims to address these issues by developing a comprehensive generator monitoring and control system that integrates real-time fuel monitoring, remote operation capabilities, and an automatic transfer switch. By optimizing generator efficiency and ensuring uninterrupted power supply, this solution seeks to enhance energy reliability and safety for users, ultimately reducing the operational burden and costs associated with generator use.

1.3 Aims and Objectives

1.3.1 Aim

To develop a generator monitoring and control system using IoT and embedded systems.

1.3.2 Objectives

The objectives of this project are to

i. implement a system that allows for real-time monitoring of generator parameters;

ii. design and implement control mechanisms to remotely start and stop the generator;

iii. integrate a system for automatic transfer switching (ATS) between grid power and generator power to ensure seamless power supply in the event of a grid outage; and

iv. develop a user interface that allows users to interact with the system.

1.4 Significance of the project

The significance of this project lies in its ability to modernize and improve the operation of gasoline generators, especially in regions with frequent power outages. By replacing manual monitoring and control with automated systems, the project reduces human error, minimizes the risk of equipment damage, and enhances overall efficiency. The introduction of remote monitoring and control capabilities allows users to manage generators more effectively, reducing downtime and operational costs. Additionally, the system's automatic transfer switching feature ensures a seamless power supply during grid outages, enhancing the reliability of electricity access.

This project aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 7: Affordable and Clean Energy. By optimizing generator use and improving energy management, the project contributes to more sustainable energy practices and promotes efficient use of resources such as fuel. Moreover, the project's focus on automation and technology integration serves as a model for upgrading energy infrastructure in similar contexts worldwide, supporting the transition towards more sustainable and resilient energy systems.

1.5. Scope of the Project

This project focuses on developing a comprehensive system for monitoring and controlling gasoline generators, specifically targeting issues related to fuel management, operational efficiency, and seamless power transition. The project encompasses the design and implementation of a monitoring system that tracks real-time fuel levels alongside a control mechanism for starting and stopping the generator remotely. It also includes the integration of an automatic transfer switch (ATS) to facilitate the automatic transfer of power between the generator and the grid, ensuring continuous electricity supply during power outages.

The scope is confined to the development of a functional prototype, demonstrating the system's capabilities in a controlled environment. It does not extend to large-scale deployment or commercial production. The focus is on residential and small commercial applications, particularly in regions with inconsistent grid power. The emphasis is on creating a robust, user-friendly solution that can be adapted for similar contexts without delving into broader aspects like energy policy or large-scale energy infrastructure.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

2.2 Review of Related Concept

2.2.1 Sensors for Fuel Level Monitoring

In recent years, various methods have been developed for monitoring fuel levels in generators, each utilizing different types of sensors and technologies to enhance accuracy and reliability.

2.2.1.1 Capacitive Level Sensors

Capacitive liquid level sensors have been explored by researchers such as Kumar *et al*. (2014). These sensors utilized the principle of capacitance variation due to changes in dielectric properties between sensor plates to measure liquid height. They employed a non-contact configuration, where the sensor was placed above the liquid surface, mitigating contamination issues. Various sensor designs were investigated, including single and multiple electrode configurations, with the latter enabling additional measurements like liquid gradient. To enhance accuracy, techniques like air gap compensation and self-inductance reduction were incorporated. While promising results were obtained for measuring levels up to 80 cm, further research is needed to extend the measurement range and address potential limitations like temperature sensitivity.

Hamanaka *et al.* (2017) developed a portable, non-invasive capacitive transducer for fuel level monitoring in a Briggs & Stratton 1450 Series Horizontal OHV engine tank. The sensor consisted of three copper electrodes housed in a printed circuit board in a triangular arrangement. The change in permittivity between air and fuel as the fuel level rose resulted in a change in capacitance, which was converted into an electrical signal using a 555-timer circuit. The authors acknowledge limitations due to temperature variations and inherent disturbances in the laboratory prototype but achieved a successful proof-of-concept with a maximum system error of 1.97%. Their design offers a cost-effective and easy-to-install solution for fuel level monitoring in portable combustion engines; however, further research is needed to mitigate the effects of temperature and improve overall system accuracy.

2.2.1.2 Float (Lever) Sensors

Obikoya, (2014) employed a rotary potentiometer-based level sensor for fuel level measurement. The sensor consisted of a floater connected to a potentiometer arm, with the potentiometer's output voltage directly correlating to the fuel level. This approach, while relatively simple and cost-effective, demands intensive calculations to convert the sensor output voltage into an accurate fuel level reading. The system's accuracy relies on precise potentiometer resolution, mechanical linkage, and the stability of the floater's buoyancy. To enhance the system's performance, future research could explore alternative sensing mechanisms or advanced signal processing techniques to reduce computational load and improve measurement precision.

Shan *et al.* (2020) employed a magneto resistive float level sensor for fuel level monitoring in their remote generator monitoring system. This sensor utilizes a permanent magnet housed within the float, and its movement along a shaft translates to a change in magnetic field position. The authors highlighted the high accuracy (down to 0.02 degrees) of this sensor type. However, they did not discuss any potential limitations, such as susceptibility to external magnetic fields or the complexity of the sensor compared to simpler alternatives (e.g., rotary potentiometer). Further research could explore the trade-offs between sensor accuracy, complexity, and cost for various fuel level monitoring applications.

2.2.1.3 Pressure Sensors

Goundar *et al*. (2014) employed a pressure sensor-based approach for fuel level monitoring, where a pressure sensor was positioned at the top of an air column within the fuel tank. As the fuel level rose, it compressed the air column, increasing pressure on the sensor. This pressure was then converted into an electrical signal, which was subsequently processed by a microcontroller. While this method proved effective in determining fuel levels, it introduced potential limitations. The accuracy of the system could be influenced by factors such as temperature variations, which affect air pressure, and the specific characteristics of the pressure sensor itself. Additionally, the design required careful calibration to ensure accurate fuel level readings. Despite these considerations, the pressure sensor-based approach offers a relatively simple and cost-effective solution for fuel level monitoring applications.

2.2.1.4 Ultrasonic Fuel Level Sensing

Ultrasonic sensors have emerged as a popular choice for non-invasive fuel level measurement. Their ability to accurately determine fuel levels without physical contact with the liquid has made them a preferred option in various industries. For instance, Prayetno *et al*. (2021) investigated a real-time engine oil tank monitoring system using internet-of-things (IoT) technology. Their design employed an HC-SR04 ultrasonic sensor to measure the distance to the oil surface, which was then converted to volume using the known tank dimensions. The authors reported successful testing with a 0% error rate in distance measurement and concluded that the ultrasonic sensor functioned well for this application. This study demonstrates the feasibility of ultrasonic sensors for real-time oil tank monitoring. However, it does not explore potential limitations, such as the impact of temperature variations on sound wave propagation in the oil or the influence of oil fumes on sensor performance.

2.2.2 Remote Control Functionality

Remote control functionality in generator monitoring systems is predominantly facilitated through GSM, Wi-Fi, and Bluetooth technologies

2.2.2.1 Bluetooth Technology

A recent paper by Pinak Sunil Warankar (2023) describes a Bluetooth-based home automation system using Arduino Uno as the central processing unit. Their system utilizes Bluetooth communication between the Arduino and a user's smartphone or tablet for remote control of various household appliances. This offers advantages like user convenience and eliminates the need for physical interaction with switches or controls. However, the authors acknowledge limitations of Bluetooth technology, including limited range and potential interference in the 2.4 GHz frequency band. Future advancements in Bluetooth technology, such as wider range capabilities or mesh networking features, could address these limitations.

2.2.2.2 Global System for Mobile Communication (GSM)

Mfonobong *et al*. (2023) designed a remotely operated electrical energy management system (ROEEMS) for managing power from multiple sources in developing countries with unreliable grids. Their focus was on a cost-effective and user-friendly solution. Notably, ROEEMS employs GSM technology for remote control and monitoring via SMS messaging. This avoids complexities of internet-based systems and leverages the widespread availability of mobile phone networks. Users can send SMS commands to control the power source (solar, utility, or generator) and receive feedback on the system's state. The authors acknowledge that SMS lacks end-to-end encryption but suggest its reliance on A5 cryptographic algorithms offers a degree of security, especially if the SIM access number is kept confidential. This study demonstrates the feasibility of GSM for remote control in resource-constrained environments, but further research could explore enhancing data security for SMS-based communication.

Africa *et al*. (2019) developed a home monitoring and control system using GSM technology for remote operation. Their system utilized a mobile phone application with a graphical user interface (GUI) to send control commands to the system via SMS. A GSM modem received these SMS messages and relayed them to a microcontroller, which in turn controlled the connected appliances through relays. This approach allowed for remote on/off control of multiple appliances, offering convenience and potential safety benefits. The authors identified limitations in the system's portability and scalability, but the core concept of using GSM for remote appliance control demonstrates the potential of this technology for home automation applications.

2.2.2.3 Wireless Fidelity (Wi-Fi)

Atmiasri and Dewi (2023) designed a remote monitoring and recording system for generators using the Arduino Uno microcontroller and Blynk application, a low-code IoT platform. Their system focused on monitoring current, voltage, and RPM (rotational speed per minute) of the generator. Sensors for these parameters transmitted data to the Arduino Uno, which then processed it and displayed it on an LCD screen. The ESP8266 Wi-Fi module then transmitted this data to the Blynk application on a personal computer, enabling remote monitoring. This design highlights the feasibility of using Arduino Uno and Blynk for remote generator monitoring. However, the authors acknowledge limitations in data security as Blynk relies on SMS messaging, which may not be encrypted. Further research could explore secure data transmission protocols for this type of remote monitoring system.

2.2.3 Microcontroller for IoT

Maier *et al*. (2017) conducted a comparative analysis of the ESP32 microcontroller with other options for IoT projects, highlighting its key features and advantages. The ESP32 stands out due to its dual-core processor, offering significantly improved processing power compared to its predecessor, the ESP8266, which is a single-core processor. The ESP32 also boasts a larger memory capacity, enabling it to handle more complex applications and larger amounts of data. Additionally, the ESP32 offers a wider range of GPIO pins, providing greater flexibility for connecting and controlling various devices and sensors. While the ESP32 generally has a higher price point compared to the ESP8266, its enhanced capabilities make it a suitable choice for demanding IoT projects requiring robust performance and expanded functionality.

Kondaveeti *et al*. (2021) conducted a comprehensive review of Arduino in the context of prototyping, contrasting it with platforms such as Raspberry Pi, BeagleBone, Sharks Cove, and Waspmote. Arduino's popularity stems from its accessible nature, low cost, and extensive community support. Its ease of use, with a simplified programming environment and abundant online resources, makes it an ideal choice for beginners and hobbyists. Additionally, Arduino's versatility is enhanced by a wide range of available sensors, shields, and modules, facilitating rapid prototyping and experimentation. However, Arduino's limitations include relatively low processing power, limited memory, and fewer I/O pins compared to more powerful platforms like Raspberry Pi. While Raspberry Pi offers higher processing capabilities and a Linux operating system, it often requires additional hardware components and can be more complex to set up. BeagleBone provides a middle ground with a balance of performance and cost-effectiveness but lacks some features like on-board Wi-Fi. Sharks Cove, primarily focused on Windows development, has limited applicability for general-purpose prototyping. Waspmote, optimized for low-power sensor networks, is not a direct competitor to Arduino in terms of general-purpose prototyping.

In a recent paper by Moharkar (2022), the authors compared four different microcontroller boards commonly used in Internet of Things (IoT) applications: Arduino Uno, Raspberry Pi, BeagleBone Black, and ESP8266. They found that each board has distinct advantages and disadvantages. Arduino Uno, known for its user-friendly interface and vast online community support, is ideal for beginners. However, its limited processing power and memory may restrict its use in complex IoT projects. Raspberry Pi, a credit-card sized computer, offers a powerful processor and runs a full Linux operating system, making it suitable for demanding tasks. Conversely, its higher power consumption and cost might be drawbacks for some applications. BeagleBone Black is another powerful option with a Linux OS, but its complexity makes it less beginner-friendly than Arduino. Finally, ESP8266 is a low-cost Wi-Fi chip that can be integrated with other microcontrollers for wireless connectivity, but its processing power is lower than the other boards. This study highlights the need to consider factors like processing power, memory, cost, and ease of use when selecting a microcontroller board for an IoT project.

2.3 Review of Related Works

2.3.1 Fuel-Level Monitoring

In a paper titled "Design, construction, and implementation of a remote fuel-level monitoring system" by Obikoya (2014), the author describes the development of a system for remotely monitoring fuel level in a tank. The system utilizes a fuel-level sensor constructed with a rotary potentiometer, a floater, and an arm. As the fuel level in the tank changes, the floater moves up or down, causing the potentiometer to rotate and vary the output voltage. This voltage is then transmitted to a remote Aplicom 12

GSM module via a connecting cable. The GSM module is configured using software on a PC to receive control messages from a mobile phone and respond with status messages. The control messages can be sent by an authorized phone number after adding a message identifier. The configuration also includes setting parameters like the SMS center address, disabling acknowledgements to reduce communication costs, defining aliases for commands, and setting input limits for alarms. Once the configuration is complete, the system is ready for operation. By sending a text message containing the identifier, a user can initiate a query to the GSM module, which then transmits the current voltage level from the fuel-level sensor back to the phone. A Visual Basic program running on the PC can then be used to convert the received voltage level into an estimated fuel volume based on a pre-derived equation. The paper also details the experimental setup process, which involves connecting the various components and configuring the software. The results section compares the estimated fuel volumes obtained from the voltage readings with those measured directly using geometric calculations. The comparison shows a good agreement between the two methods, indicating the accuracy of the system. The author concludes that this type of remote fuel-level monitoring system can be a valuable tool for managing fuel consumption, reducing theft and mismanagement, and minimizing operational costs for individuals, businesses, and governments managing large fleets of vehicles or stationary fuel tanks.

In the paper "Smart Generator Monitoring System in Industry Using Microcontroller" by Boopathi (2015), the authors propose a system for remote monitoring of a diesel generator using a microcontroller, GSM modem, and various sensors. The system monitors parameters like fuel level (PH606 sensor), oil level (R series sensor), coolant temperature (LM35D sensor), and circuit breaker status. If any of these parameters exceed a predefined threshold, an SMS alert is sent to a designated user's mobile phone. Additionally, the user can send SMS commands to the system to control the generator on/off based on the availability of the main power supply. The authors achieved communication between the microcontroller and GSM modem using a MAX232 driver circuit. Their experimental results showed successful monitoring of the generator's health and timely notification of abnormal conditions. They concluded that this embedded system offers a powerful and secure tool for remote generator management, improving response times to potential failures and avoiding catastrophic situations. However, the paper does not delve into data security measures or explore the possibility of data logging and trend analysis for predictive maintenance. Furthermore, the authors could explore integration with cloud platforms for centralized monitoring and control across multiple generators.

In their paper "Design of a smart control and protection system for three-phase generator using Arduino," Ali *et al*. (2020) propose a system for monitoring and protecting a three-phase synchronous generator using an Arduino microcontroller. The project aimed to create a low-cost and reliable solution for generator health management. Focusing on monitoring parameters, the authors utilized various sensors to collect data. Current and voltage sensors, an ACS-712 and a ZMPT101B respectively, measured load current, terminal voltage, and frequency. Notably, the frequency was derived from the voltage signal without additional hardware by converting the AC voltage signal to a square wave and measuring the time between rising edges. This eliminates the need for a separate frequency sensor. The collected data was then evaluated against pre-set thresholds within the Arduino code to identify abnormal conditions such as overload current, over/under voltage, and high/low frequency. If these thresholds were exceeded, the system would display an alert message on a serial monitor connected to a PC. Additionally, the authors designed the system for potential Bluetooth communication, allowing for mobile app monitoring of the generator's health. However, the paper does not delve into the specifics of the mobile app development or user interface design. While the authors mention the ability to trigger a circuit breaker to isolate the load in case of abnormal conditions, the paper lacks details on the physical connection for implementing this functionality. Their results demonstrated the successful monitoring of various generator parameters and the ability to detect and report abnormal conditions. However, the research has limitations. The system is designed for single-phase monitoring, and the paper does not explore the feasibility of extending this design for three-phase operation.

2.3.2 Remote Control of Generators

In the paper "Smartphone Remote Control System for Standby Generator Set Based on Android," Chuanhong Zhou and Zhao Xuan developed a remote-control system to address the inefficiencies of manually starting standby generator sets during power outages. They designed the system around an Android-based mobile application, developed using the Android SDK, that includes modules for user login, network communication, and monitoring interfaces. The system operates on a Client/Server (C/S) communication model, where the smartphone acts as the client, connecting to a signal monitoring device via Wi-Fi using the TCP/IP protocol. The communication between the smartphone and the generator controller was managed through the Modbus protocol, a standard for industrial applications, utilizing RS232/RS485 communication interfaces for compatibility with various generator controllers and serial data transmission. The application allowed for real-time control and monitoring of generators, enabling functions like starting, stopping, and querying operational parameters such as frequency, voltage, and running time. The authors found the system to be user-friendly, stable, and effective in improving response times and operational efficiency. However, the methodology was limited by its Android-centric design, necessitating multiple software versions for other operating systems. Additionally, the system's real-time performance and reliability require further refinement to ensure consistent operation under varying network conditions, indicating gaps in its robustness and applicability across different environments.

2.3.3 Automatic Transfer Switch

Barnwal *et al*. (2024), in their paper "Automatic Transfer Switch for Critical Loads Between Renewables, Storage, Mains, or Generator," aim to address the growing demand for reliable power systems by designing an Automatic Transfer Switch (ATS) capable of seamlessly transitioning critical loads between four power sources: renewables, battery storage, mains, and generators. Their methodology involves the use of a microcontroller (Arduino), a voltage regulator circuit for voltage detection, and a relay module for switching between power supplies, with a Liquid Crystal Display (LCD) providing real-time status updates. The ATS prioritizes the use of renewable energy and sequentially switches to other sources as they become available or necessary. The researchers successfully tested the system, noting that the transition from lower-priority to higher-priority sources occurred efficiently, although the switch from high to low priority exhibited a delay in response time. They suggest that future work could improve the system by minimizing switching time, incorporating a Genset start/stop feature, and using data collection for deep learning to optimize energy usage. The paper identifies limitations in the current design, particularly in the switching time, and suggests that more advanced microcontrollers and semiconductor devices could enhance system performance.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The methodology section outlines the systematic approach adopted for this project. It encompasses the procedures, techniques, and tools employed to achieve the project's objectives.

This project utilizes an applied research approach, emphasizing the practical application of theoretical knowledge to address a real-world challenge. The research methodology encompasses the design and construction of both hardware and software components necessary for the system. This process includes the selection of suitable sensors, microcontrollers, and communication modules, and their subsequent integration into a unified system. The system's design and implementation are continuously refined through experimental testing to ensure that the final product meets the desired specifications and functions reliably in practical conditions. The project concludes with the deployment of the system in a real-world setting, which involves the installation of hardware, the establishment of communication infrastructure, and comprehensive functionality testing. The system's effectiveness is assessed based on its accuracy and performance.

3.2 Research Environment

The physical and project environments are carefully considered and designed to ensure the successful implementation and operation of the Generator Monitoring and Control System

3.2.1 Physical Environment

The Generator Monitoring and Control System is tailored for environments where household gasoline generators are commonly used, such as residential buildings and small commercial establishments. The system is designed to withstand the operational conditions of these generators, which can generate significant heat, with ambient temperatures potentially reaching up to 60°C. The hardware also accounts for vibrations caused by the generator's operation, which could impact the system's stability and performance. To address these challenges, all electronic components are securely housed within a robust enclosure. This enclosure protects against environmental factors such as humidity, dust, and potential water exposure, ensuring the system's durability and reliability.

The design includes a dedicated enclosure for the circuit board, which can be mounted at a distance from the generator. This setup facilitates safer operation and easier access for maintenance. The system's connection to the generator is established through wired connections, utilizing shielded cables to prevent electromagnetic interference from the generator's electrical systems. This configuration not only ensures stable data transmission and control but also enhances the system's overall performance in a variety of environmental conditions.

3.2.2 Project Environment

The project environment is a comprehensive environment that includes both hardware and software components. The software development environment comprises integrated development environments (IDEs) such as Arduino IDE for programming the microcontroller units (MCUs) and adafruit.io for developing the software application interface. During the design phase, EasyEDA suite is employed to simulate circuit layouts and validate the functionality of the hardware components before physical implementation.

3.3 Project Approach

3.3.1 Fuel-Level Monitoring with MCU-103 Sensor:

Existing Literature: Capacitive level sensors (e.g., Kumar *et al*., 2014) have been used for fuel level monitoring with some success, but they suffer from issues like temperature sensitivity and a limited measurement range. Ultrasonic sensors, like those discussed by Prayetno *et al*. (2021), offer non-invasive measurement capabilities but may struggle with temperature variations and sound wave propagation issues. Pressure sensors (Goundar *et al*., 2014) and float sensors (Shan *et al*., 2020) provide alternative methods but can be prone to mechanical wear, calibration challenges, and interference from external factors like magnetic fields.

Project Methodology: This project uses a novel approach utilizing an MCU-103 rotation angle sensor in conjunction with a mechanical linkage to a float within the fuel tank. While this method presents challenges in terms of accuracy and potential mechanical issues, it offers a cost-effective alternative to traditional sensors. To address these limitations, rigorous calibration and testing will be conducted to optimize the system's performance. The MCU-103 is not a direct replacement for dedicated fuel level sensors. For accurate and reliable fuel level measurements, ultrasonic, capacitive, or float-based sensors are more suitable options.

3.3.2 Remote Monitoring System with Wi-Fi and Adafruit Interface

Existing Literature: Previous studies have explored various remote-control systems, such as those using GSM (e.g., Mfonobong *et al*., 2023) or Bluetooth (Warankar, 2023), each with specific challenges like data security, reliability, and range limitations.

Project Methodology: This project adopts a Wi-Fi-based communication approach using the ESP8266 microcontroller for real-time fuel level monitoring and generator control. By integrating the Adafruit platform for the user interface, this project offers a reliable and user-friendly solution for remote monitoring. The Wi-Fi communication system ensures a secure and stable connection, suitable for environments where GSM might be unreliable or unnecessary. The Adafruit interface allows for seamless real-time data visualization and control, enhancing user interaction with the system.

3.3.3 Microcontroller and IoT Integration with ESP8266:

Existing Literature: Microcontrollers like Arduino and ESP32 have been widely discussed for IoT applications (Maier *et al*., 2017; Moharkar, 2022), each with strengths and weaknesses in terms of processing power, memory, and ease of integration with other devices and sensors.

Project Approach: By selecting the ESP8266 microcontroller, this project effectively balances processing power, cost, and ease of integration with the MCU-103 sensor and the Adafruit IoT platform. The ESP8266 enables efficient data collection and communication therefore supporting the project's goals of real-time monitoring and remote control. This integration enhances the system's scalability, allowing for future expansions or modifications as new technologies emerge.

3.4 Project Tools

3.4.1 Hardware components

The following table outlines the components used in the development of our generator monitoring and control system.

Table 3.1: List of hardware components

ID	Name	Quantity	Component Type
1	CONN-TH_3P-P5.08	4	Connector
2	ESP 8266	1	Microcontroller
3	CONN-TH_2P-P5.08	7	Connector
4	Trimmer-vert-inline_fer1	1	Variable Resistor
5	LM358	2	Operational Amplifier
6	47R	2	Resistor
7	10kΩ	6	Resistor
8	2.2KΩ	2	Resistor
9	4.7KΩ	3	Resistor
10	470kΩ	14	Resistor
11	1000uF	4	Capacitor
12	Mini360	2	Buck Converter
13	MT3608	2	Boost Converter
14	HDR-F-2.54_1x2	1	Header
15	JQC-3FB-S/005-1Z11	3	Electromechanical Relay
16	AKIB-RELAY-SPDT-JQX-15F	2	Electromechanical Relay (SPDT)
17	ULN2003	1	Darlington Transistor Array
18	1000uF	1	Capacitor

The following subtopics give a comprehensive overview of each component that was used

3.4.1.1 Microcontroller: ESP8266

A. Description: The ESP8266 is a low-cost Wi-Fi microchip with full TCP/IP stack and microcontroller capability.

B. Function: It serves as the central processing unit for the project, managing the sensors and relays, and providing Wi-Fi connectivity for remote monitoring and control.

C. Working Principle: The ESP8266 operates on 3.3V and integrates a Tensilica Xtensa 32-bit LX106 core with a clock speed of up to 160 MHz. It supports IEEE 802.11 b/g/n protocols and includes GPIO, ADC, and PWM capabilities.

D. Configuration: Programmed using the Arduino IDE or other compatible platforms. For this project, it replaces the Arduino Nano and SIM800L module, providing Wi-Fi-based communication instead of GSM/GPRS.

E. Specifications:

a. Flash Memory: 4MB (32Mb)

b. Wi-Fi: 2.4GHz, 802.11 b/g/n

c. Operating Voltage: 3.3V

d. GPIO Pins: Multiple GPIOs, including analog input (ADC)

e. Communication Interfaces: UART, SPI, I2C

f. Power Supply: Can be powered via micro-USB or directly through 5V and GND pins

g. Programming: Compatible with Arduino IDE, Lua, MicroPython, and other environments

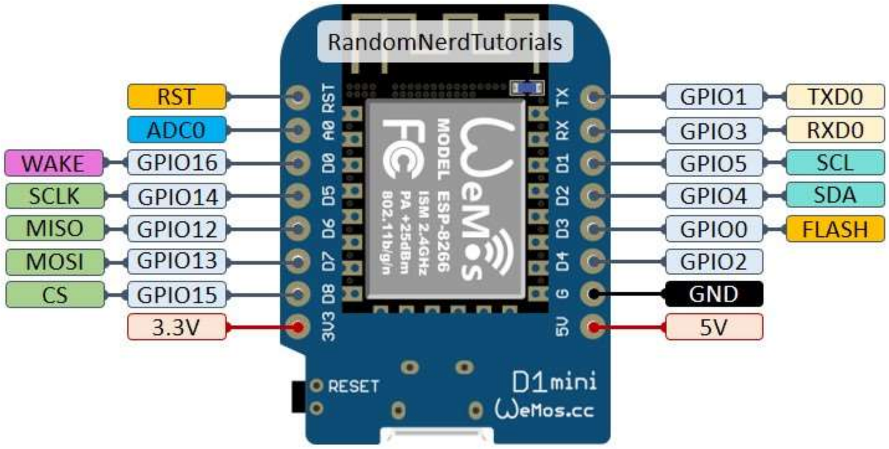

Figure 3.1: ESP8266 Microcontroller

F. Pinout and Labels

Table 3.2: ESP8266 pin description

Pin	Description	Function/Use
3V3	3.3V Power Output	Provides regulated 3.3V output from the onboard regulator, can power external components.
G	Ground (GND)	Common ground for all components and circuitry.
TX	UART Transmit (GPIO1)	Used for serial communication (transmitting data).
RX	UART Receive (GPIO3)	Used for serial communication (receiving data).
D0	GPIO16	General-purpose input/output, often used for wakeup.

D1	GPIO5 / I2C SCL	General-purpose input/output, can be used as I2C SCL (clock line).
D2	GPIO4 / I2C SDA	General-purpose input/output, can be used as I2C SDA (data line).
D3	GPIO0	General-purpose input/output, also used for boot mode selection.
D4	GPIO2	General-purpose input/output, often connected to onboard LED.
D5	GPIO14 / HSCLK	General-purpose input/output, can be used as SPI clock.
D6	GPIO12 / HMISO	General-purpose input/output, can be used as SPI MISO (Master In Slave Out).
D7	GPIO13 / HMOSI	General-purpose input/output, can be used as SPI MOSI (Master Out Slave In).
D8	GPIO15 / HCS	General-purpose input/output, can be used as SPI Chip Select.
A0	Analog Input	Reads analogue input voltage (0-1V).
RST	Reset	Resets the microcontroller when pulled low.
5V	USB 5V Power	Provides 5V input from USB, can power the board and external components.

3.4.1.2 Power Management Components

1. 12 Volt Battery

A. **Function:** Provides the primary power source for the relays, choke actuator, and other components.

B. **Working Principle:** Supplies a stable 12V DC, recharged by the alternator during generator operation.

2. **Buck Converters (Mini360)**

A. **Overview:** The Mini360 Buck Converter is a compact DC-DC step-down (buck) voltage regulator. It is designed to efficiently convert a higher input voltage to a lower output voltage, with a high conversion efficiency of up to 96%. The module can deliver up to 3A of output current, making it suitable for various low-power applications.

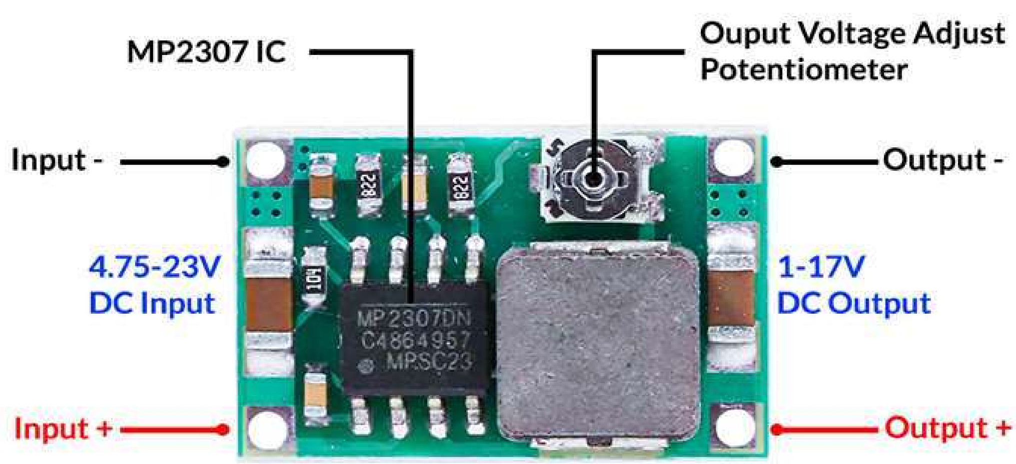

Figure 3.2: Min360 Buck Converter Pinout

B. **Specifications**

a. Features and Specifications

b. MPS MP2307DN buck regulator IC

c. 4.75 – 23VDC input voltage

d. – 17VDC selectable output voltage

e. 3A surge current, 1.8A continuous rated current

f. Maximum conversion efficiency of 95% (5Vin, 3.3Vout ~200mA output)

g. 340kHz switching frequency

h. 30mV no-load output ripple

i. 0.5% load regulation

j. 2.5% voltage regulation

k. -40 to +85°C operational temperature range

l. Built-in 160°C thermal shutdown

m. Dimensions 17x11x3.8mm (0.67×0.43×0.15″)

C. Pinout

Table 3.3: Min360 pin description

Pin	Name	Description
1	VIN+	Positive input voltage terminal. Connect to the positive terminal of the power source (4.75V to 23V).
2	VIN-	Ground terminal for the input voltage. Connect to the ground of the power source.
3	VOUT+	Positive output voltage terminal. Provides the stepped-down voltage (1V to 17V, adjustable).
4	VOUT-	Ground terminal for the output voltage. Connect to the ground of the load circuit.
5	ADJ	Adjustment terminal. Connected to the onboard potentiometer for adjusting the output voltage.

6	EN	Enable pin. Used to turn the module on or off. Connect to high (logic level) to enable and low (ground) to disable.

D. Function: They are used to step down the 12V battery voltage to 5V. This regulated 5V output is essential for powering the various low-voltage components in the circuit, including:

   a. **Microcontroller (ESP8266):** The microcontroller requires a stable 5V supply for reliable operation.

   b. **LM358 Op-Amps:** The op-amps used for voltage sensing and signal conditioning also operate at 5V.

3. Boost Converters (MT3608)

A. Overview: The MT3608 is a high-efficiency, low-quiescence boost (step-up) converter that can output a voltage higher than its input voltage. It is often used in projects requiring a stable higher voltage supply from a lower voltage input, making it ideal for battery-powered applications.

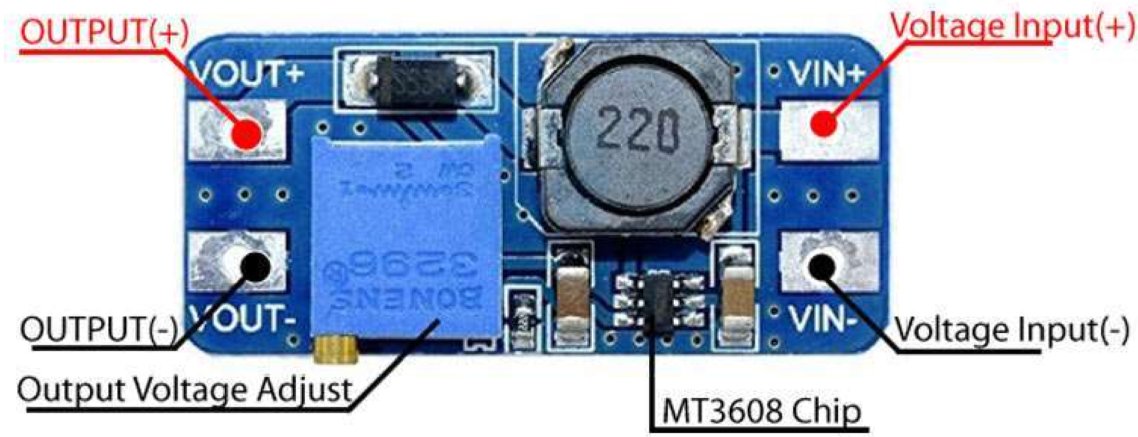

Figure 3.3: MT3608 (Boost Converter) Pinout

B. Specifications

a. Input Voltage Range: 2V to 24V

b. Output Voltage Range: Up to 28V

c. Maximum Output Current: Up to 2A

d. Efficiency: Up to 93%

e. Switching Frequency: 1.2MHz (typical)

f. Module Size: 37.2mm x 17.2mm x 14.0mm

C. Pinout

Table 3.4: MT3608 pin description

Pin	Name	Description

1	SW	Switch Node. Connected to the inductor and diode. The internal MOSFET switch drives this pin.
2	GND	Ground. The reference point for the circuit. Connected to the ground plane of the PCB.
3	FB	Feedback. Connected to a resistor divider to set the output voltage.
4	EN	Enable. A logic high signal enables the converter, while a logic low disables it.
5	VIN	Input Voltage. The power supply input for the IC. Connect to the positive terminal of the power source.
6	VOUT	Output Voltage. The regulated output voltage of the boost converter. Connected to the load.

D. **Function**: The MT3608 boost converters are used to step up the voltage from the 12V battery to a higher voltage, specifically 12.5V. This boosted voltage is used to power components that require a stable 12.5V supply including the relays, choke controller, and fuel lock.

3.4.1.3 Relay Modules

1. JQC-3FB-S/005-1Z11 Relays

A. **Overview**: The JQC-3FB-S/005-1Z11 is an electromechanical relay used in the circuit for switching high-power devices like motors, lights, and other electrical loads. This relay operates with a 5V DC coil and has a single-pole double-throw (SPDT) configuration, meaning it has one common contact that can switch between two other contacts, commonly referred to as Normally Open (NO) and Normally Closed (NC).

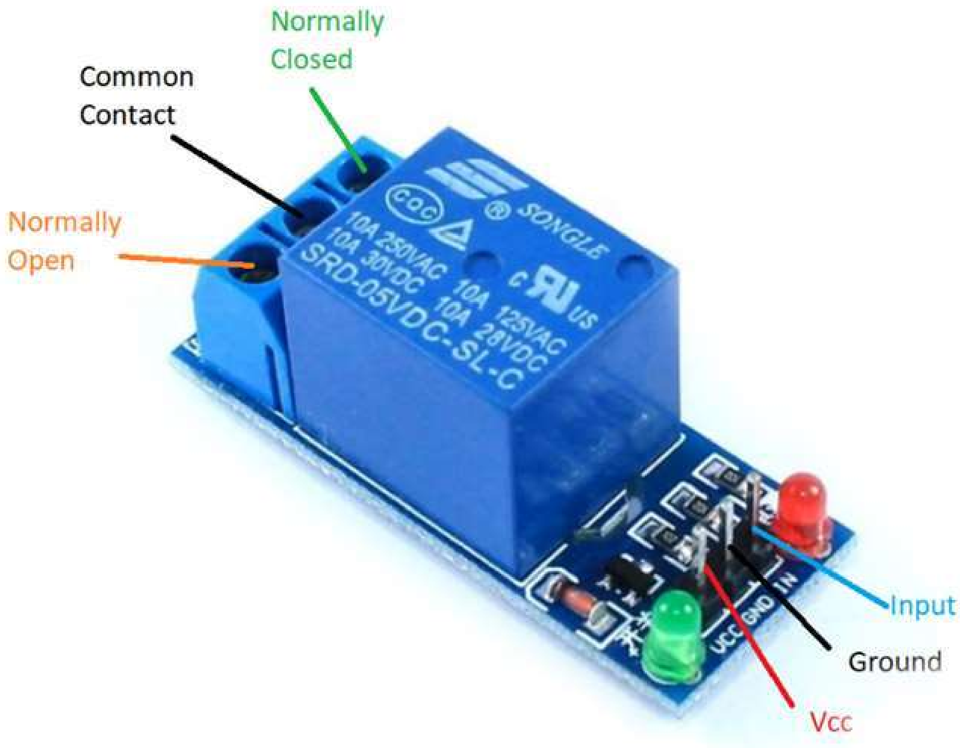

Figure 3.4: JQC-3FB-S/005-1Z11 Relay

B. Specifications

a. Supply voltage – 3.75V to 6V

b. Quiescent current: 2mA

c. Current when the relay is active: ~70mA

d. Relay maximum contact voltage – 250VAC or 30VDC

e. Relay maximum current – 10A

C. Pinout

Table 3.5: JQC-3FB-S/005-1Z11 Relay pin description

Pin Number	**Name**	**Description**

1	Coil (+)	Connected to the positive terminal of the 5V DC supply for the coil.
2	Coil (-)	Connected to the ground (GND) or negative terminal of the 5V DC supply.
3	Common (COM)	The movable contact of the relay. Connects to either NC or NO based on the coil state.
4	Normally Closed (NC)	The contact is connected to COM when the coil is not energized.
5	Normally Open (NO)	The contact is connected to COM when the coil is energized.

D. **Function**: The JQC-3FB-S/005-1Z11 relays are used for various switching tasks in the project, such as controlling the ignition, fuel lock, and choke settings of the generator.

2. **JQX-15F Relay**

1. **Overview: The JQX-15F relay is a miniature power relay with a Single Pole Double Throw (SPDT) configuration. The relay is capable of handling higher power loads, making it suitable for switching between different power sources.**

A. Specifications

a. Temperature Range: -55~+85 °C

b. Max. Switching Power: 4800VA/560W

c. Max. Switching Voltage: 240VAC/28VDC

d. Max. Switching Current: 20A

e. Rating Load: 20A, 240VAC/28VDC

B. Pinout

Table 3.6: JQX-15F Relay pin description

Pin Number	Name	Description
1	Coil (+)	Connected to the positive terminal of the control voltage supply.
2	Coil (-)	Connected to the ground (GND) or negative terminal of the control supply.
3	Common (COM)	The movable contact of the relay. Switches between NC and NO based on the coil state.
4	Normally Closed (NC)	The contact is connected to COM when the coil is not energized.
5	Normally Open (NO)	The contact is connected to COM when the coil is energized.

C. Function: JQX-15F relays in this project are used for Automatic Transfer Switching (ATS) between the grid power and the generator. When the grid input signal is present, the relay remains in the NC position, connecting the grid power to the load. In the event of a power outage, the control system triggers the generator start-up and, once stable, energizes the relay coil. This action switches the relay to the NO position, connecting the generator to the load and disconnecting the grid.

3.4.1.4 Signal Processing

1. **LM358 Dual OP-AMP IC**

A. Overview

The LM358 is a dual operational amplifier (op-amp) integrated circuit. It is widely used in analogue electronics for a variety of applications such as amplification, filtering, and signal conditioning.

B. Specification

a. Integrates two operational amplifiers in one package
b. Supports a wide power supply range:
    i. Single supply: 3V to 32V
    ii. Dual supply: ±1.5V to ±16V
c. Low supply current: 700µA
d. Reliable operation with a single supply for both op-amps
e. Outputs are short-circuit protected
f. Operating ambient temperature: 0°C to 70°C
g. Soldering pin temperature: up to 260°C (maximum 10 seconds)
h. Available in multiple packages: TO-99, CDIP, DSBGA, SOIC, and PDIP

C. Pinout

Table 3.7: LM358 pin description

Pin Number	**Name**	**Description**
1	OUT1	Output of the first op-amp
2	IN1-	Inverting input of the first op-amp

3	IN1+	Non-inverting input of the first op-amp
4	VCC	Positive supply voltage (single supply)
5	IN2+	Non-inverting input of the second op-amp
6	IN2-	Inverting input of the second op-amp
7	OUT2	Output of the second op-amp
8	GND	Ground (single supply)

D. Function: The LM358 is integral to the automatic switching mechanism in this project. It monitors the voltage levels from both the grid and generator inputs. When the grid power is present, the op-amp outputs a signal indicating this condition. In the event of a power failure, the op-amp detects the absence of voltage from the grid input, triggering the control system to start the generator. Once the generator is running, the LM358 detects the stable voltage and signals the microcontroller to switch the load from the grid to the generator.

2. ULN2003A Darlington Transistor Array (Q1)

A. Overview

The ULN2003A is a high-voltage, high-current Darlington transistor array consisting of seven NPN Darlington pairs. Each Darlington pair features high voltage outputs with common-cathode clamp diodes for switching inductive loads. The ULN2003A is commonly used in relay driver applications, lamp drivers, LED displays, and logic buffers.

B. Specifications

a. Input Voltage: Low-level control signals from the microcontroller

b. Output Voltage: Up to 50V

c. Output Current: Up to 500 mA per channel

d. Operating Temperature: 0°C to 70°C

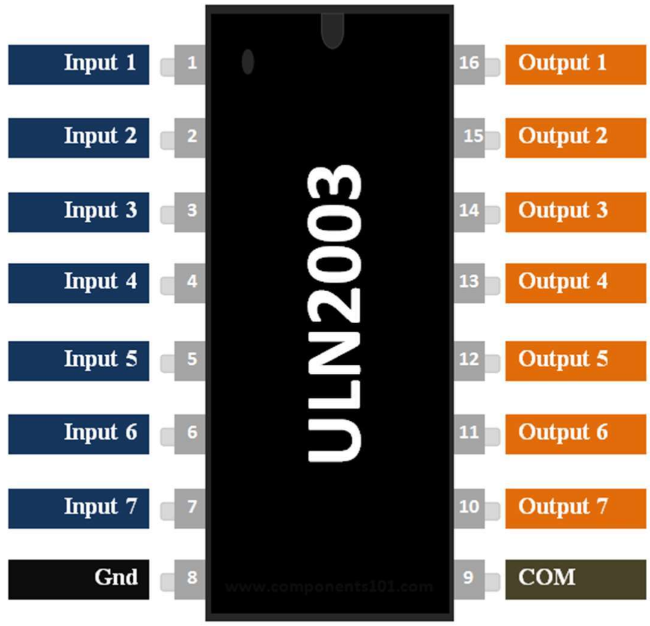

Figure 3.5: ULN2003A Pinout

C. Pin Configuration

Table 3.8: ULN2003A pin configuration

Pin	Description
1-7	Input channels (1-7)
8	Common (GND)
9	Common cathode for clamp diodes (COM)
10-16	Output channels (1-7)

D. Function: In this project, the ULN2003A serves as an interface between the microcontroller and the relays. It is used to drive the relay coils, which require more current than the microcontroller can supply directly. By using the

ULN2003A, the microcontroller can control the high-current relays safely and efficiently.

3. **Capacitors**

   A. **Overview and Function:** Capacitors in the circuit are used to stabilize power supply and filter noise. They store and release electrical energy, smoothing out voltage fluctuations and filtering high-frequency noise.

   B. **Specifications**

      a. Capacitance: 1000µF, 470µF

      b. Voltage Rating: 63V

4. **Resistors**

   A. **Function:** It is used for setting reference voltages, limiting current, and bias op-amps. It provides fixed resistance in the circuit, crucial for signal conditioning and protection.

3.4.1.5 Sensors and Actuators

1. **Rotation Angle Sensor (Fuel Level)**

   A. **Overview**: The MCU-103 is a compact, dustproof rotation angle sensor designed to measure angular displacement. It operates on the principle of a potentiometer, converting rotational motion into a variable resistance. This resistance value is then typically converted into an analog voltage output, which corresponds to the angle of rotation.

Figure 3.6: MCU-103 sensor

B. Specifications:

a. Type: Rotary Potentiometer

b. Output: Analog voltage

c. Resistance: 10k ohms

d. Rotation Angle: 0 to 333 degrees

e. Dustproof Design: Protects internal components from environmental contaminants

f. Operating Temperature: Typically -40°C to +85°C

g. Mounting Type: Surface mount

C. Working Principle: The sensor's shaft is mechanically coupled to the rotating object whose angle is to be measured. As the shaft rotates, the internal potentiometer wiper moves along a resistive track, changing the resistance between the wiper and the fixed terminals. The change in resistance is converted into a corresponding analog voltage output. The analog voltage signal can be further processed by a microcontroller or other electronic circuitry to determine the exact angle of rotation.

D. Pinout:

Table 3.9: MCU-103 pin description

Pin Label	Description
VCC	Requires a 5V positive voltage supply to power the sensor's internal circuitry
GND	Ground reference
Output (Analog)	Provides the analog voltage output that corresponds to the rotational angle of the sensor

E. Function: The sensor is mechanically coupled to the needle of the analog fuel gauge. As the fuel level fluctuates, the float within the fuel tank moves the gauge needle, correspondingly rotating the MCU-103's shaft. The sensor then outputs an analog voltage signal proportional to the needle's position, which is calibrated to represent the fuel level.

2. Choke controller (Actuator)

A. Overview: This is an actuator used in central car locks, commonly known as a door lock actuator, is an electromechanical device that converts electrical signals into mechanical movement.

Figure 3.7: Car lock actuator for choke control

B. **Working Principle**: The actuator works on a simple principle of converting electrical energy into mechanical movement. It consists of a small motor, a set of gears, and a push-pull rod or plunger. When an electrical signal is applied to the motor, it drives the gears, which, in turn, move the rod either inward or outward. This linear movement is used to operate the choke, adjusting the air-fuel mixture by either opening or closing the choke valve.

C. **Specifications**:

Voltage: Operates at 12V DC.

Current: Draws around 0.5 to 1.5 amps, depending on load conditions.

Stroke Length: Provides a linear stroke of around 20 to 40 mm.

Force: Generates a force of approximately 3 to 5 kgf,

Response Time: Actuates fully in under 1 second

3. Fuel Lock (0520D solenoid valve)

A. Overview

The 0520D solenoid valve is an electromechanical device used to control the flow of fluids, such as fuel, by opening or closing an orifice through which the fluid passes.

Figure 3.8: 0520D Solenoid valve

B. Working Principle

The solenoid valve operates using an electromagnetic coil. When an electric current passes through the coil, it generates a magnetic field that attracts a plunger or piston inside the valve. This movement either opens or closes the valve, depending on the valve's design. The valve is in a normally closed configuration which means the valve remains closed when de-energized and opens when the coil is energized.

C. Specifications

Valve Type: Normally closed (NC)

Operating Voltage: Typically operates at 12V or 24V DC

Power Consumption: Varies depending on the valve model, generally low power for efficient operation

Operating Pressure: Suitable for low-pressure fluid control; 0-350mmhg Sealing

Flow Rate: Designed to handle a specified flow rate, ensuring adequate fuel supply without overflow

Material: Stainless steel suitable for handling fuel

Temperature Range: 0 ℃ ~ 55 ℃

3.4.2 Software Components

The key software components used in this project are outlined below:

3.4.2.1 ESP8266 Microcontroller Programming

The ESP8266 microcontroller is programmed using the Arduino Integrated Development Environment (IDE), which allows for easy coding and deployment of firmware. The Arduino IDE provides a user-friendly platform to write, compile, and upload code to the ESP8266. The code includes the following functionalities:

i. **Wi-Fi Connectivity**: The ESP8266 is configured to connect to a local Wi-Fi network, enabling it to communicate with the Adafruit IO platform for data transmission and remote control.

ii. **Sensor Data Acquisition**: The microcontroller is programmed to interface with the MCU-103 sensor, continuously reading fuel level data and processing it for transmission.

iii. **Data Transmission**: The ESP8266 sends the acquired sensor data to Adafruit IO via Wi-Fi. The data is formatted for easy interpretation and visualization on the platform.

iv. **Remote Control Functions**: The ESP8266 receives commands from Adafruit IO to control generator functions, such as starting or stopping the generator, and executes them accordingly.

3.4.2.2 Adafruit IO Platform

Adafruit IO is an IoT platform that provides a seamless interface for data visualization, remote control, and data logging. It serves as the primary user interface for the project. The following features of Adafruit IO are utilized:

i. **Data Feeds**: Sensor data from the ESP8266 is transmitted to Adafruit IO, where it is organized into feeds. These feeds represent various data streams, such as fuel levels, and are displayed in real-time on the platform.

ii. **Dashboards**: Custom dashboards are created within Adafruit IO to visually represent the data feeds. These dashboards include various widgets, such as gauges, graphs, and indicators, that provide an intuitive overview of the system's status.

iii. **Triggers and Alerts**: Adafruit IO allows the configuration of triggers that can send alerts or execute actions based on certain conditions. For instance, if the fuel level drops below a predefined threshold, an alert can be sent to the user, or the generator can be automatically turned off.

iv. **Control Widgets**: Interactive control widgets on the Adafruit dashboard allow users to remotely control the generator. These widgets send commands to the ESP8266, which then acts on them to control the generator's operations.

3.4.2.3 Wi-Fi Communication Protocol

The project leverages the MQTT (Message Queuing Telemetry Transport) protocol for communication between the ESP8266 and Adafruit IO. MQTT is a lightweight messaging protocol well-suited for IoT applications due to its efficiency and low bandwidth requirements. Key aspects include:

i. **Publish/Subscribe Model**: The ESP8266 publishes sensor data to specific topics on the Adafruit IO platform. Users or other devices subscribed to these topics can receive the data in real-time.

ii. **Command Reception**: The ESP8266 subscribes to command topics on Adafruit IO. When a user sends a control command through the Adafruit dashboard, it is received by the ESP8266 and executed promptly.

3.4.2.4 Data Logging and Analysis

Adafruit IO also supports data logging, allowing historical data to be stored and analyzed over time. This feature is useful for trend analysis. Users can review historical data to identify trends, such as fuel consumption patterns or generator usage, which can inform predictive maintenance strategies.

3.5 Procedure for Tools Deployment

3.5.1 System Design and Assembly

This section describes how the components are connected in the system

3.5.1.1 Block Diagram

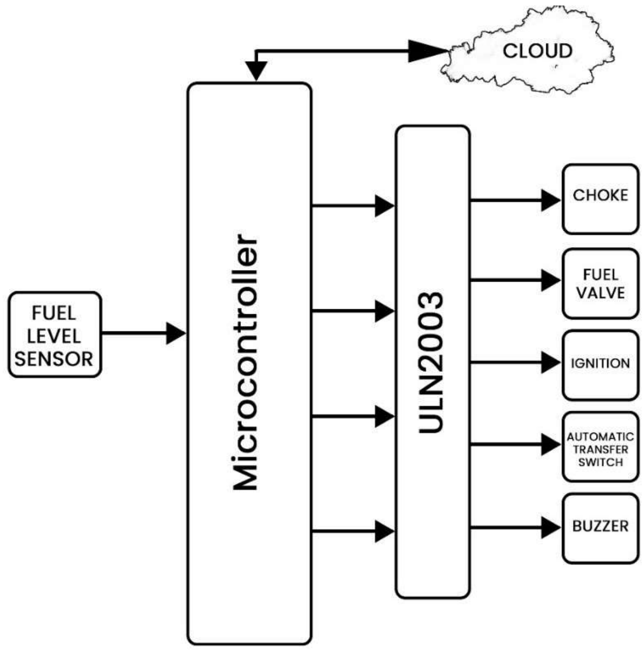

Figure 3.9: System block diagram

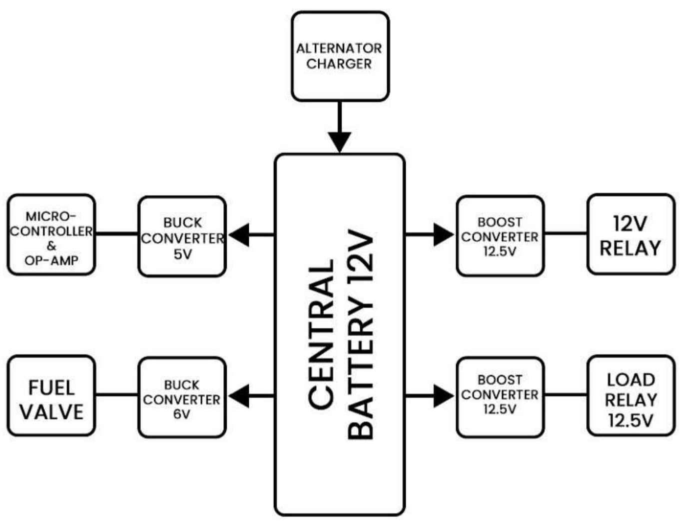

Figure 3.10: Power supply block diagram

3.5.1.2 Flowchart

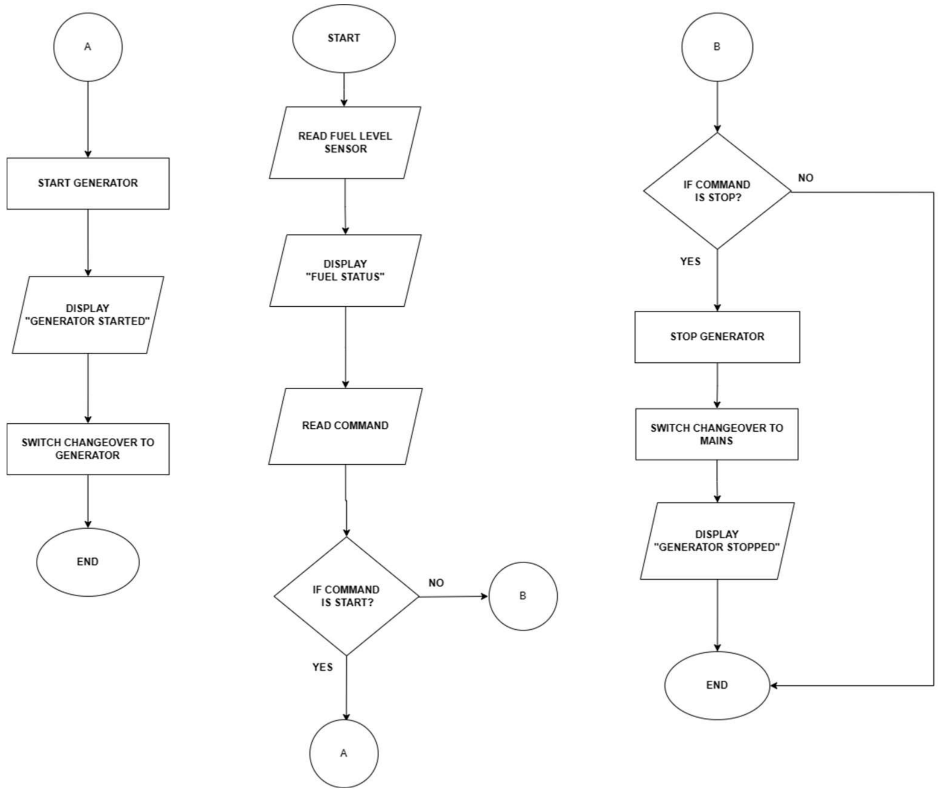

Figure 3.11: System flowchart

CHAPTER FOUR

IMPLEMENTATION & TESTING

4.1 Project Implementation

4.1.1 System Assembly and Setup

4.1.1.1 Hardware Assembly

The hardware assembly process for the Generator Monitoring and Control System involved several critical stages, from initial design to the final setup within the enclosure. The following steps outline this process in detail:

1. Schematic Design

The first step in the hardware assembly was designing the circuit schematic using EasyEDA, a cloud-based EDA tool. This involved selecting the components discussed in the methodology such as sensors, microcontrollers, communication modules, and power management units. Each component's connections were carefully laid out in the schematic, Careful consideration was given to signal integrity, power supply routing, and component placement to minimize interference and ensure stable operation.

2. PCB Layout and Design

After finalizing the schematic, the next phase was translating it into a PCB layout. Using EasyEDA's PCB design tools, the components were placed on the board with attention to minimizing trace lengths and avoiding cross-talk between high-frequency signals. Thermal considerations were also addressed by placing heat-generating components away from sensitive circuits and ensuring adequate thermal relief for heat dissipation.

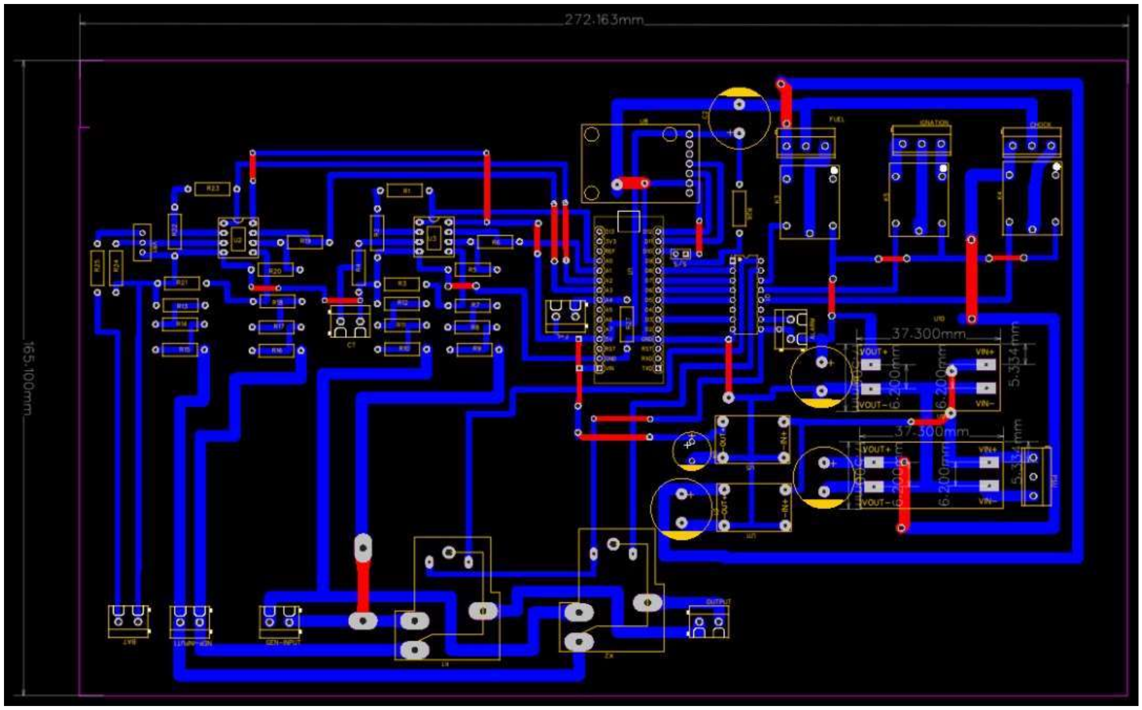

Figure 4.1: PCB Connection Layout

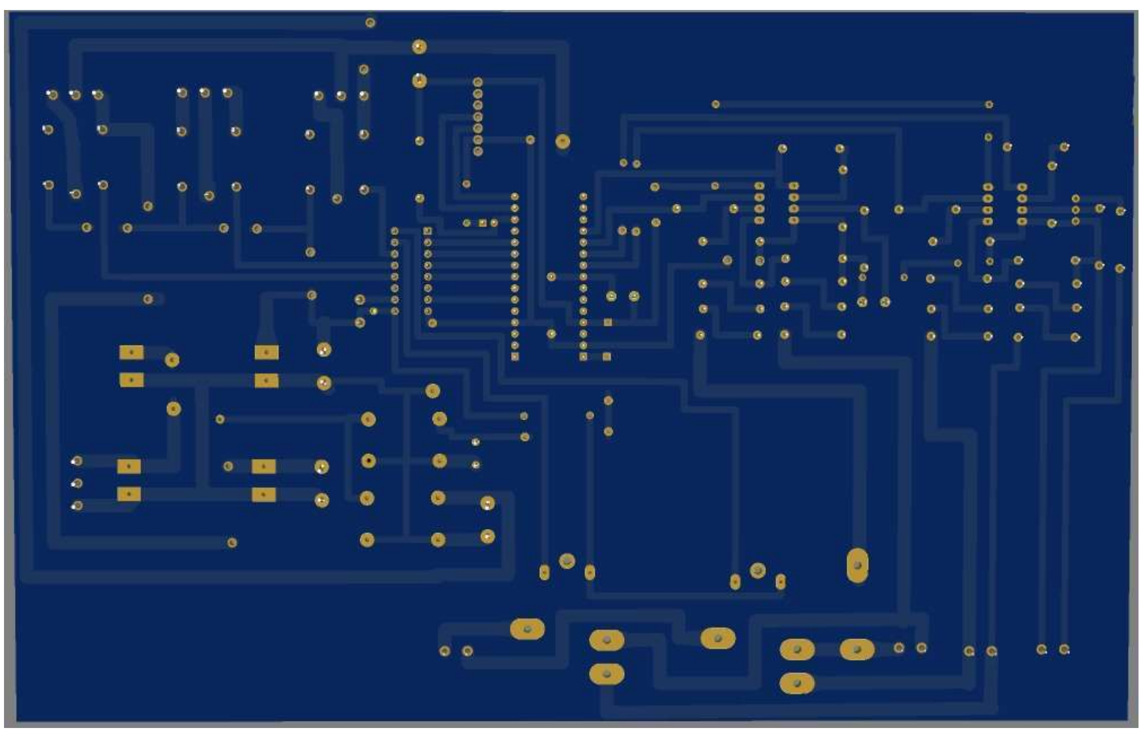

Figure 4.2: PCB Contact Points Layout

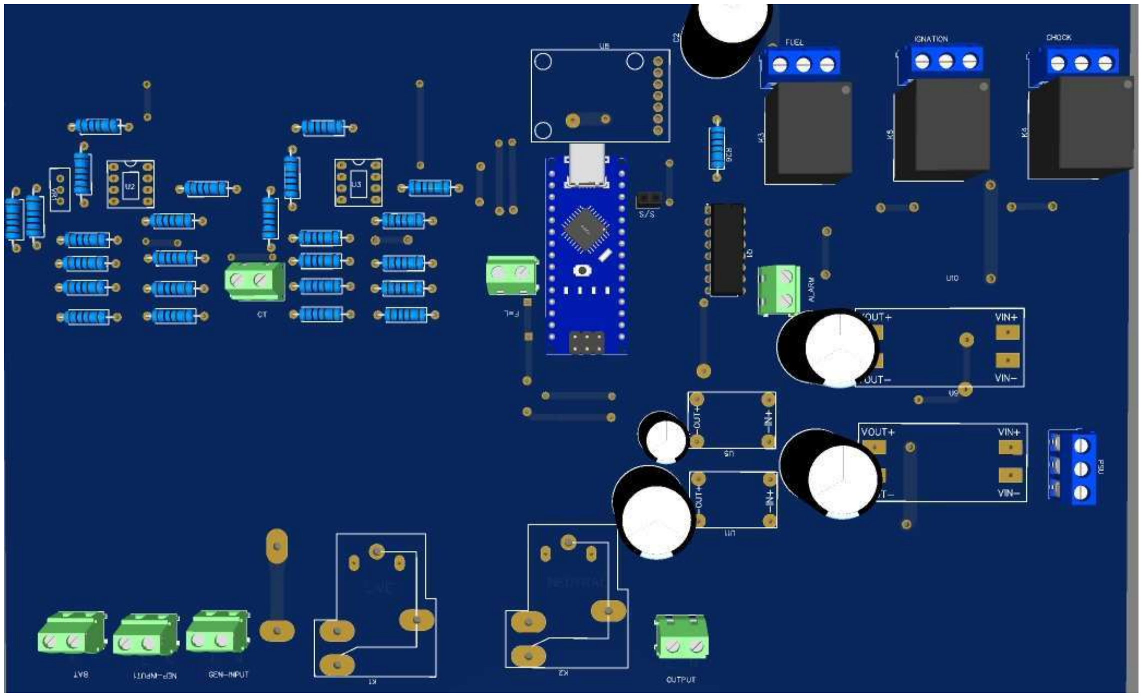

Figure 4.3: PCB Final Design

3. PCB Fabrication

Once the PCB layout was completed and verified, the design files were exported and sent for PCB fabrication. The fabrication process involved creating the board's physical structure, including copper traces, vias, and solder masks. High-quality materials were selected to withstand the operational conditions, including high temperatures and vibrations. The finished PCB underwent a thorough inspection for manufacturing defects, such as shorts, opens, or misaligned layers.

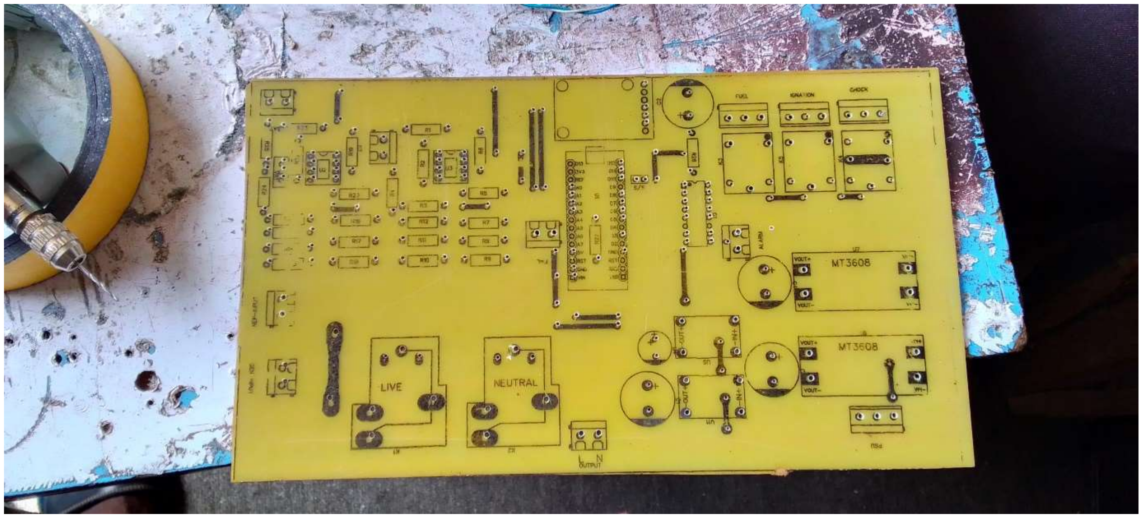

Figure 4.4: PCB Physical Structure

4. Component Soldering

Upon receiving the fabricated PCB, the components were soldered onto the board. This process began with applying solder paste to the PCB's pads using a stencil. Surface-mount components (SMDs) were then placed onto the board. The board was then passed through a reflow oven, where the solder paste melted and formed electrical and mechanical connections between the components and the PCB. Through-hole components were soldered manually, ensuring strong and reliable joints.

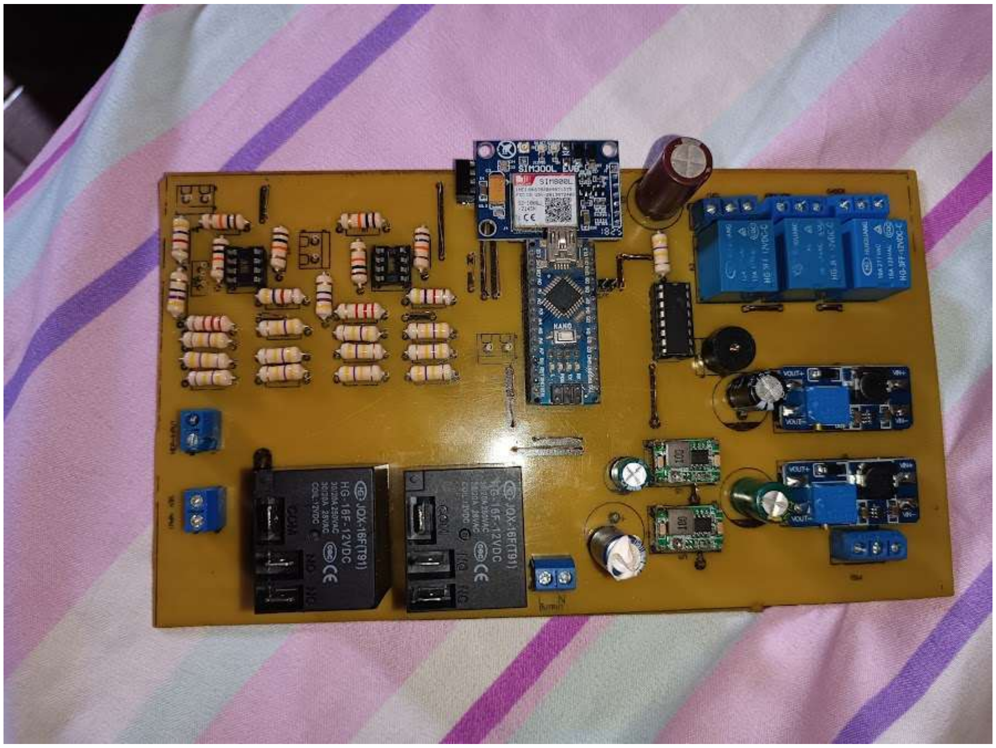

Figure 4.5: PCB Final Structure (Top)

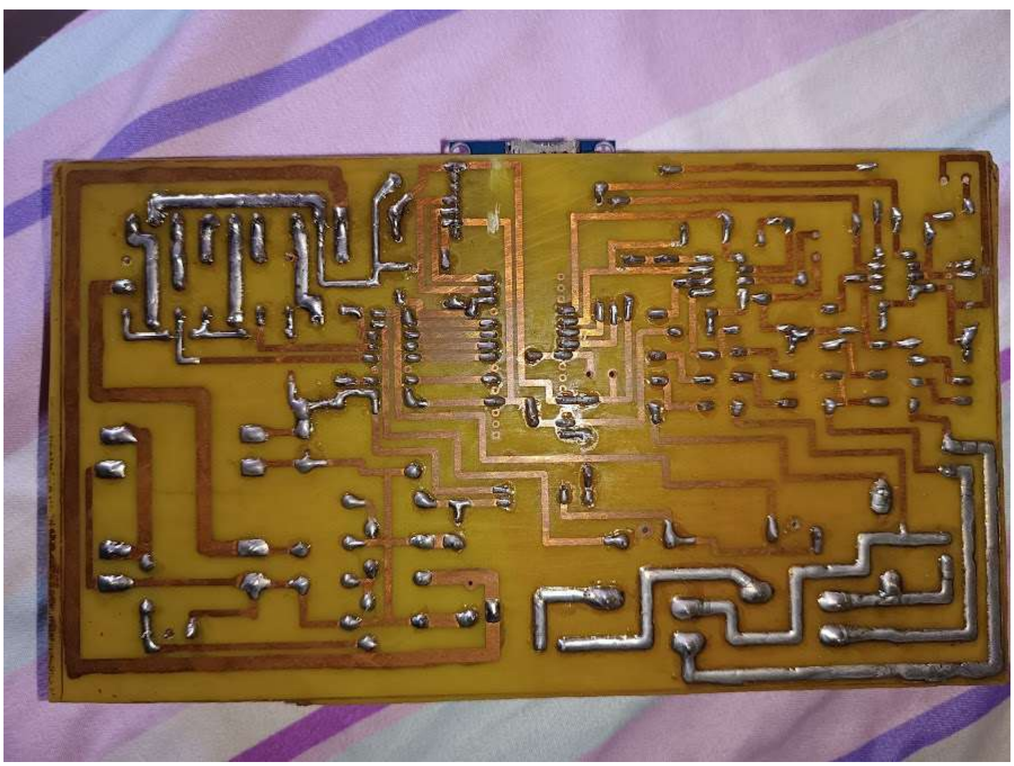

Figure 4.6: PCB Final Structure (Bottom)

5. Stands and Enclosure Integration

To secure the PCB within the enclosure, custom stands were designed and fabricated. These stands provided mechanical support and allowed for proper airflow around the board, aiding in thermal management. The stands were attached to the bottom of the PCB and then attached to the base of the enclosure. This setup ensured that the board was securely positioned and isolated from vibrations that could arise from generator operation.

6. Final Assembly and Wiring

With the PCB securely mounted, the next step was integrating the system with external components. Wires were carefully soldered to the PCB's connectors and routed through designated openings in the enclosure. These wires connected the PCB to external sensors, control interfaces, and power sources. To minimize EMI and ensure reliable signal transmission, shielded cables were used where necessary. The wires were neatly organized and secured within the enclosure to prevent damage and interference.

7. Enclosure Sealing and Protection

The enclosure was designed to protect the internal components from environmental factors such as dust, moisture, and temperature extremes. After completing the internal wiring, the enclosure was sealed with screws. Ventilation slots were strategically placed to allow for passive cooling while maintaining the enclosure's protective properties. The final assembly was then tested for integrity and compliance with safety standards.

8. Quality Assurance and Testing

Before deployment, the assembled hardware underwent a series of quality assurance tests. This included visual inspections for soldering defects, continuity tests to verify electrical connections, and functional tests to ensure all components operated as intended. The system's response to simulated inputs and environmental conditions was also tested to verify its robustness and reliability.

4.1.2 Installation

1. Implementation of Hardware Connections

The hardware implementation of the generator monitoring and control system involves a series of carefully integrated components that work together to manage power distribution, control relays, and ensure reliable operation. The system's core is built around the generator's 12V battery, boost and buck converters, and the ESP8266 microcontroller, which replaced the initially planned Arduino Nano and SIM module. This transition required specific adaptations to the existing circuit board to ensure compatibility with the ESP8266's pin configuration.

2. Power Supply and Distribution

The system's primary power source is a 12V battery, which not only provides energy for the entire system but also plays a key role in maintaining uninterrupted operation. The 12V is fed into both boost and buck converters. The boost converters (U9 and U10) are designed to step up the voltage to 12.5V, providing a slightly higher voltage necessary for operating the relays and actuators, like the choke control and fuel lock. This ensures that these components receive sufficient power, even under varying load conditions. Meanwhile, the buck converters (U5 and U11) step down the voltage to 5V, to supply stable power to low-voltage components such as the ESP8266 microcontroller and signal conditioning circuits, including the LM358 op-amp.

3. Microcontroller and Communication

Initially, the system design featured an Arduino Nano paired with a SIM module for communication purposes. However, the final implementation replaced this setup with an ESP8266 microcontroller. The ESP8266 integrates both the microcontroller and Wi-Fi communication capabilities, streamlining the design and reducing the need for additional components. These changes necessitated modifications to the existing circuit board, originally designed for the Arduino Nano. The adaptation involved rerouting certain connections and using an additional pcb with additional wiring to match the ESP8266's pin configuration with the original board layout. The ESP8266's 3.3V logic level was considered, ensuring that all interfacing components were compatible with 3.3V.

4. Relay Control

The load relays (K1 and K2) are responsible for switching between grid power (NEP) and generator power (GEN), ensuring that the load is powered by the appropriate source. These relays are controlled by the ESP8266 via the ULN2003 Darlington transistor array, which acts as an intermediary thus allowing the low-power signals from the ESP8266 to control the high-power relays. Additionally, peripheral relays (K3, K4, K5) are used to manage the choke, ignition, and fuel lock of the generator, ensuring that the generator starts and operates correctly under different conditions.

5. Signal Conditioning (After Voltage Monitoring Removal)

Initially, the circuit design included voltage monitoring using LM358 op-amps to monitor and condition signals from the NEP and GEN inputs. These signals were then fed into the microcontroller for analysis. However, in the final implementation, the voltage monitoring functionality was removed. The LM358 op-amps, while still present in the design, are now left inactive. The ESP8266 now reads signals directly from only the fuel sensor.

6. Adaptation Process

The transition from the Arduino Nano to the ESP8266 required significant modifications to the existing PCB layout. The Nano's pins were initially configured on the board, and to accommodate the ESP8266, the pin connections had to be remapped. This was achieved by using an additional board with pins to align the ESP8266's GPIO pins with the existing circuit traces designed for the Nano. The 5V power lines were adjusted to cater to the ESP8266's 3.3V logic to ensure that the microcontroller could operate correctly without over-voltage issues. These adaptations allowed the circuit to be reused with minimal redesign while taking advantage of the ESP8266's integrated Wi-Fi capabilities for remote monitoring and control. This is shown in figures 4.7 and 4.8.

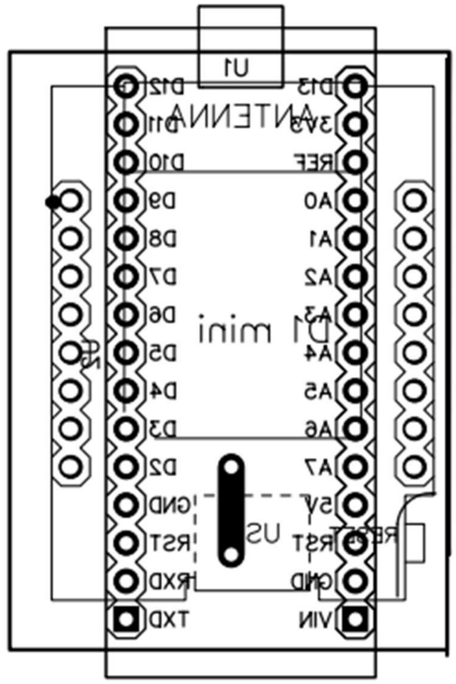

Figure 4.7: Top view of microcontroller pin adaptation

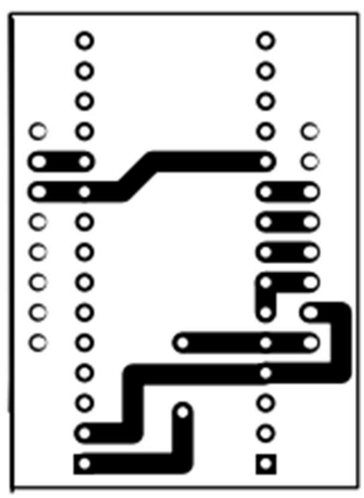

Figure 4.8: Bottom view of pin adaptation

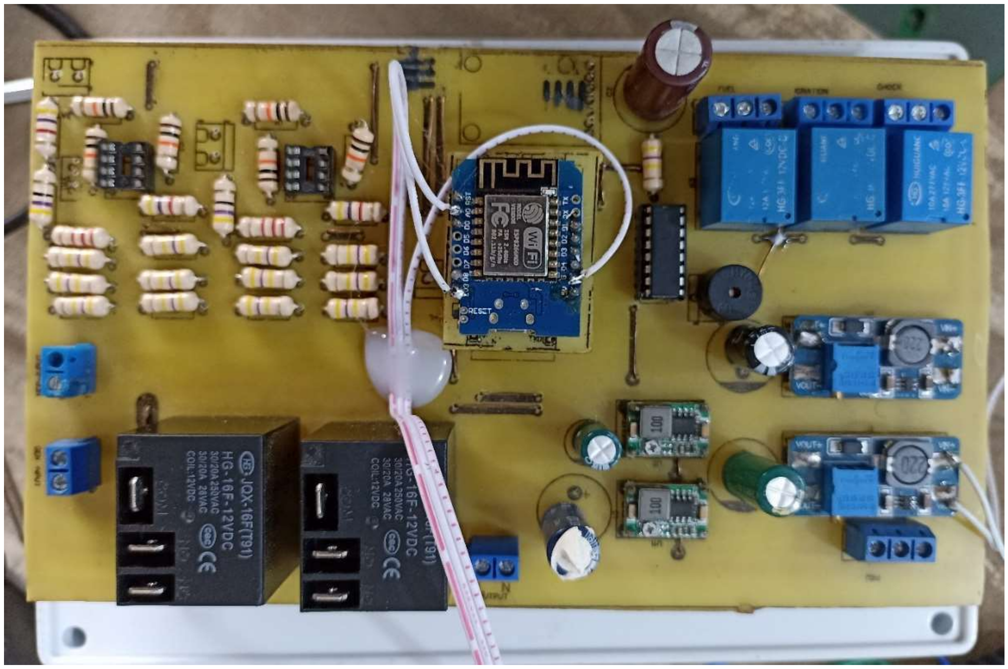

Figure 4.9: Final pcb design

4.2 Project Testing

To ensure the system's functionality, a series of tests were conducted focusing on output voltages from the buck and boost converters, relay responses, system delay times, and sensor calibration.

4.2.1 Microcontroller Testing

Initial testing of the ESP8266 microcontroller was carried out on a breadboard setup. The primary tests involved programming the microcontroller to blink a sequence of LEDs, simulating the startup and shutdown processes of the generator. These basic tests were crucial for verifying that the microcontroller was functioning correctly. Additionally, the microcontroller's ability to upload and run code was tested. The ESP8266 was successfully connected to Wi-Fi, which allowed for integration with an IoT platform. After completing the tests, the system was fully assembled, and more complex code was uploaded to calibrate and test sensor.

4.2.2 Boost and Buck Converters Testing

The boost and buck converters were tested to ensure they provided the correct output voltages necessary for the circuit's operation. A 12V DC supply was connected to the converters, and their output voltages were adjusted using a potentiometer. A multimeter was used to measure the output voltage. A small screwdriver was used to adjust the trimmer (20K Ohms) on the converter until the desired output voltage was achieved. Once the voltage was achieved, the converters were then connected to the circuit.

4.2.3 Relay Testing

Relay operations were tested to validate the system's response during generator startup and shutdown sequences. The tables below illustrate the conditions of the relays at various stages of these sequences.

Table 4.1: Startup sequence relay conditions

Generator Status	Relay 1 Condition	Relay 2 Condition	Relay 3 Condition	Load Relay Condition	Time (seconds)
OFF	ON	OFF	OFF	GRID	0
OFF	OFF	ON	OFF	GRID	2
ON	OFF	OFF	ON	GRID	4
ON	OFF	OFF	OFF	GENERATOR	7

Table 4.2: Shutdown sequence relay conditions

Generator Status	Relay 1 Condition	Relay 2 Condition	Relay 3 Condition	Load Relay Condition	Time (seconds)
ON	OFF	OFF	ON	GENERATOR	0
OFF	OFF	ON	OFF	GENERATOR	2
OFF	ON	OFF	OFF	GENERATOR	3
OFF	OFF	OFF	OFF	GRID	5

These tests confirmed that the relays transitioned correctly between states, ensuring seamless switching between power sources.

4.2.4 Sensor Calibration

The fuel level sensor, MCU-103 with a resistance value of 10K Ohms, was calibrated to align with the fuel meter's gauge. Calibration involved setting the sensor's lowest resistance value (1K Ohms) to correspond with the "Empty" position on the fuel gauge. The calibration process involved comparing readings at various resistance values to determine the appropriate range for the fuel levels. The sensor has an angle of rotation of 333 degrees, while the gauge has a slightly smaller range of 310 degrees.

Table 4.3: Sensor Calibration Results

Sensor Reading	Potentiometer Value	Meter Gauge Position	Attempt Number

1	1K Ohms	Empty	1
40	4.5K Ohms	Middle level	1
82	9K Ohms	Full	1
4	1K Ohms	Empty	2
46	4.5K Ohms	Middle level	2
88	9K Ohms	Full	2

4.3 Circuit Redesign

The initial circuit for the Generator Monitoring and Control System was developed to control the generator's startup, shutdown, fuel monitoring, and communication functions. This circuit featured a combination of relays, power converters, and sensors to manage various processes. The key components included the 12V battery, relays, and an ESP8266 microcontroller, as discussed in the methodology.

However, during the integration of the circuit with the generator, several challenges emerged, particularly with the relay configurations. Repeated trials led to the burnout of the ignition relay due to insufficient protection and overloading. Additionally, the circuit's complexity resulted in issues with maintaining stable connections, which affected the system's overall reliability.

4.3.1 Challenges leading to redesign

After thorough testing of the initial circuit, it became clear that several modifications were necessary to ensure the system's reliability. The key issues that prompted the redesign were:

i. **Relay Burnout**: The relay responsible for ignition control failed under continuous testing, indicating the need for better protection circuits.

ii. **Wiring Complexity**: The original circuit's layout was cumbersome, leading to potential connection issues and difficulty in troubleshooting.

iii. **Component Compatibility**: The original circuit was designed around the Arduino Nano, but transitioning to the ESP8266 required pin remapping, which added complexity to the design.

4.3.2 Redesigned Circuit Layout

To address these issues, a simplified circuit was designed that focused on improving reliability and ease of assembly. The redesigned circuit made the following changes:

i. **Improved Relay Configuration**: The ignition relay was replaced with two JQX-16F(T91) relays that could handle higher current loads between 30A to 40A.

ii. **Simplified Wiring**: The new design streamlined the wiring connections, reducing the overall complexity and improving the system's maintainability.

iii. **Adaptation for ESP8266**: The redesigned circuit board was designed for the ESP8266 microcontroller to ensure proper pin alignment and voltage regulation for compatibility with the 3.3V logic levels.

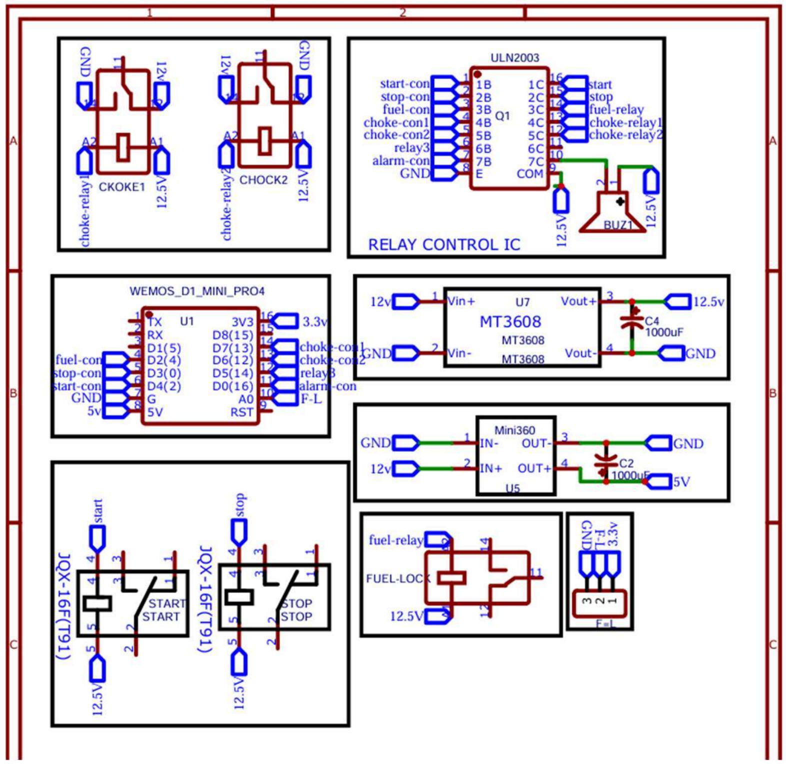

Figure 4.10: Redesigned Circuit Diagram

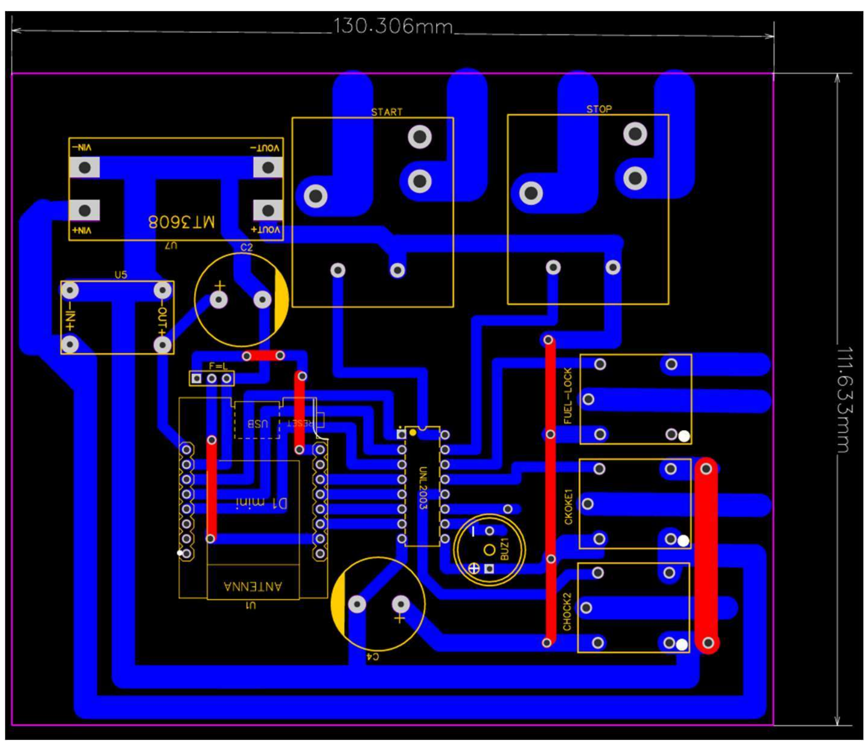

Figure 4.11: Redesigned PCB layout

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The development and testing of the remote generator monitoring and control system encountered several challenges, but despite these setbacks, significant progress was made in achieving the project's primary objectives.

One of the major challenges faced was the delay in receiving components ordered from China, which significantly impacted the project timeline. Additionally, the initial choice of a non-invasive ultrasonic sensor proved to be a setback as it failed to function as expected. This led to the decision to switch to the A5001 invasive resistive sensor, which unfortunately did not produce a linear output, making it unsuitable for accurate fuel level measurement. Eventually, the MCU-103 sensor was adopted, and after careful calibration, it provided a more reliable solution.

Another major challenge was the failure of the SIM module, which was intended to provide cellular connectivity for remote monitoring. This failure limited the system's capability to operate independently of Wi-Fi networks which reduced the overall flexibility of the solution.

Securing a generator for testing also posed significant difficulties. The cost of purchasing a generator was extremely high, and the daily rental costs were similarly expensive. This limitation hindered extensive real-world testing, which would have been essential for validating the system's performance under various operating conditions.

In addition to the challenges, another issue encountered was the expansion of the fuel lock's seal due to prolonged contact with fuel. This expansion compromised the seal's effectiveness and led to leakage concerns. The material of the seal was not resistant to the chemical properties of the fuel, which caused it to deteriorate over time.

Additionally, there was a constant risk of components burning out during testing, especially when dealing with power-sensitive modules like the buck and boost converters. This required careful handling and additional safety measures to avoid damage to the components.

In conclusion, while the project faced numerous challenges, the system was successfully developed and tested with alternative solutions. The iterative process of testing, failure, and adaptation ultimately led to a functional prototype, demonstrating the feasibility of remotely controlling and monitoring a generator. However, the limitations encountered suggest that further refinement and testing are needed to achieve a more robust and reliable system.

7.2 Recommendations

Based on the challenges encountered during the development of this project, the following recommendations are made to improve future iterations and similar projects:

Component Selection and Sourcing: To avoid delays, it's crucial to source critical components from reliable suppliers with faster delivery times, especially for projects with tight deadlines. Having backup suppliers or alternatives can further reduce risks. Extensive research and testing should precede component selection to ensure they meet project specifications, as the incorrect choice of sensors in this project led to wasted time and resources.

Improvement in Sensor Calibration: The issues with the A5001 sensor underscore the need for sensors that provide linear output, essential for accurate measurements. Early testing of sensor output characteristics is recommended to ensure suitability. Developing or integrating calibration tools can enhance accuracy by addressing any non-linearities in sensor readings, improving overall system reliability.

Redundancy in Communication Modules: To prevent failures like that of the SIM module, future designs should include redundant communication methods, such as integrating both Wi-Fi and GSM/4G modules, ensuring the system's functionality even if one method fails. Designing modular communication systems that allow for easy upgrades or replacements without significant redesigns is also recommended.

Access to Testing Resources: The difficulty in securing a generator for testing suggests the need for collaboration with local businesses or institutions that have generators, possibly through partnerships or agreements that allow testing. Alternatively, simulations or smaller-scale prototypes could be developed to evaluate system functionality in a controlled environment before full deployment.

Component Protection During Testing: To minimize the risk of component damage during testing, implementing overvoltage and overcurrent protection circuits is advised. Using fuses, surge protectors, and current-limiting devices can safeguard sensitive components. Additionally, conducting gradual testing with variable power supplies can help identify potential issues at lower power levels before exposing components to full operational conditions.

Further Development and Testing: The system requires extended real-world testing under varying environmental conditions to assess its reliability and performance over time. Such testing could reveal potential issues not identified during initial trials.

Future iterations should focus on enhancing robustness, particularly in managing power fluctuations and ensuring long-term system stability.