DESIGN AND INSTALLATION OF A SMART BASED INVERTER SYSTEM FOR EXTENDED REFRIGERATION USING INTERNET OF THINGS

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APPROVAL

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A project submitted to the Department of Industrial Engineering, University of Benin, in partial fulfillment of the requirement for the award of B.Eng. in Industrial Engineering Department of the University of Benin, Benin City, Nigeria.

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CERTIFICATION

This is to certify that the project work was carried out by **OBANOR EMMANUEL OSAYAMEN** with the Matriculation Number: **ENGI805191** of the Department of Industrial Engineering in the Faculty of Engineering, University of Benin, Edo State. In partial fulfillment of the requirement for the award of Bachelor of Engineering (B. Eng).

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DEDICATION

This Project is dedicated to Almighty God and My Family for the strength and encouragement to finish this milestone.

ACKNOWLEDGEMENT

I am deeply grateful to the Almighty for His boundless mercy, protection, and unwavering faithfulness. I also want to thank my departmental professors whose guidance has profoundly shaped my engineering journey.

My utmost appreciation goes to my beloved parents, Mr. Obanor Emmanuel and Mrs. Obanor Stephanie, whose relentless support has been my anchor throughout my academic endeavors.

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I am grateful for the unwavering prayers and wise counsel of my pastor, which have been a source of strength. Additionally, I extend my thanks to the authors whose research and writings have enriched my work.

Lastly, I want to thank my siblings, Obanor Emmanuella, Obanor Fidelis, Obanor Jude, and Obanor Douglas, for their unwavering academic, physical, and emotional support.

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LISTS OF ABBREVIATIONS

MEANING	ABBREVIATION
Voltage	(V)
Alternating Current	(AC)
Direct Current	(DC)
Ampere	(A)
Ampere-hour	(AH)
Kilo-volt ampere	(KVA)
Wattage	(W)
Watt-Hour	(WH)
Days of Autonomy	(DOA)
Depth of Discharge	(DOD)
Effective Load Demand	(ELD)
Peak Sun Hour	(PSH)
Pulse Width Modulation	(PWM)
Open Circuit Voltage	(Voc)
Open Circuit Current	(Ioc)
Short Circuit Current	(Isc)
Maximum Power Voltage	(Vmp)

Maximum System Current	(Imp)

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ABSTRACT

The goal of this project is to meet the urgent need for dependable extended backup power solutions designed with refrigeration applications in mind. One of the biggest challenges is keeping refrigeration systems running continuously, especially in areas where there are frequent power outages or unstable electrical supplies. A complex 1.5KVA inverter-based smart system that incorporates cutting-edge Internet of Things (IoT) technology is created and put into place to address this problem. The principal aim is to provide a stable and effective backup power supply for refrigeration systems, protecting perishable commodities and enhancing the general standard of living, particularly in neglected rural regions and essential establishments such as hospital blood banks.

The approach used in the creation of this ground-breaking solution include the painstaking design and integration of essential parts with an emphasis on maximizing overall effectiveness and performance. To ascertain the best specifications for the inverter system, a thorough modeling and evaluation process comprised the first step. Ensuring compliance with the enhanced refrigeration needs while preserving maximum energy efficiency was essential. Furthermore, a charge controller was included to enable smooth integration with solar panels and maximize the system's ability to use renewable energy sources. The system design and component selection might be improved iteratively to match the project's unique goals.

A strong and adaptable smart inverter system with extended backup power for refrigeration applications is the best result of our effort. By using Internet of Things technology, customers can remotely keep an eye on and control vital metrics like battery life, temperature, and system performance in real time. This project intends to improve the resilience of refrigeration systems and aid in the preservation of necessary perishable goods by tackling the inherent difficulties of power outages and unstable electricity supplies. This will have a noticeable effect on community well-being and sustainable development.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

A new age of intelligent and linked systems has arrived with the introduction of the Internet of Things (IoT), completely changing many aspects of our everyday life. One important area where refrigeration technology has made tremendous strides is this one. Our project uses the power of the Internet of Things to build a unique Inverter-Based Smart System for Extended Refrigeration in response to the rising need for cost-effective and environmentally friendly cooling solutions.

Perishable commodities are crucially preserved by refrigeration, which is why it is important in a variety of industries, including the food, healthcare, and agricultural sectors. Even though they work well, traditional refrigeration systems often struggle to optimize energy use and adjust to changing climatic circumstances. Through the integration of smart IoT capabilities with inverter technology, the suggested solution seeks to overcome these issues. Our design's mainstay is the use of an inverter, a crucial part that controls the compressor's speed in response to cooling demands. This dynamic control mechanism prolongs the life of the refrigeration system while simultaneously improving energy efficiency. We can remotely monitor and manage the refrigeration unit by combining this technology with the Internet of Things, giving us real-time insights into its operation and surrounding circumstances.

Our effort is in line with the larger objective of developing sustainable solutions in this day of increased environmental consciousness. In addition to saving money, the Inverter-Based Smart System lessens the carbon footprint associated with conventional refrigeration techniques by optimizing energy use and decreasing waste.

We will explore the nuances of IoT integration, inverter technology, and how the two work together in the refrigeration setting throughout this project. The design, implementation, and testing stages will be covered in detail in the following chapters, which will conclude with a thorough assessment of the system's functionality and possible effects on the refrigeration sector. Our goal in starting this innovative adventure is to have a positive impact on the refrigeration technology of the future by making it more effective and sustainable. Our proposal combines state-of-the-art technology to build an intelligent system that not only meets but beyond the demands of contemporary refrigeration requirements in the pursuit of a more responsive and sustainable refrigeration solution. Our system's inverter technology is a key innovation that breaks from traditional fixed-speed compressors and enables variable-speed operation depending on cooling demands.

Our design's flexibility is its fundamental quality. In response to temperature variations, the inverter-driven compressor modifies its speed in real time to make sure the refrigeration system runs as efficiently as possible. This flexibility results in more accurate and constant control over the cooling process in addition to energy savings. As a result, the Inverter-Based Smart System protects the integrity of stored items by lowering running costs and mitigating temperature changes.

The possibilities of our system are further enhanced with the addition of IoT. We open up a world of possibilities with regard to data analytics, predictive maintenance, and remote monitoring by connecting the refrigeration unit to the Internet. From anywhere in the globe, stakeholders have access to real-time data regarding the system's operation, temperature, and energy use. This degree of connection gives customers the power to decide wisely, adjust settings, and solve problems quickly, resulting in smooth and continuous refrigeration operations.

We want to showcase this Inverter-Based Smart System's technological capability and highlight its potential influence on the refrigeration industry as we traverse the complexities of its design and implementation. A new age in refrigeration efficiency is upon us, where sustainability, flexibility, and connection come together to redefine industry norms via the combination of inverter technology and the Internet of Things.

We will explore the specific design concerns, the Internet of Things integration of inverter technology, and the phase-by-phase execution of the smart refrigeration system in the project's later stages. Our goal is to provide not only a prototype but a workable solution that has the potential to completely change the refrigeration industry via thorough testing and assessment. Come along on this adventure as we push the boundaries of innovation and pave the way for refrigeration technology's future to be more intelligent, efficient, and sustainable.

Because of the way the economy has changed, quality is now more important than ever as the primary component that powers a financial system. Every segment of the economy, including businesses, homes, and even governments, depends on quality in order to operate smoothly. But as the population has grown, so has the need for electricity, placing more pressure on traditional power sources and causing an unheard-of growth in pollution.

To mitigate the strain on power systems, it is critical to investigate sustainable energy alternatives given the present situation, in which pollution from conventional power sources has reached previously unheard-of levels. To lessen the load on energy networks, it is thus essential to spread knowledge about the idea of producing energy from renewable sources and storing it effectively.

Energy storage becomes especially important in times of emergency, such storms, floods, or system failures that result in extended blackouts. The problems caused by frequent energy outages and a lack of electricity are made worse by the population growth. However, given the ongoing pace of technological development, it is anticipated that the traditional inverter will become a more sophisticated machine. Enabling users to remotely monitor its condition and access vital data like battery charging status, load run-time, and remote load management is one approach to accomplish this progression.

Inverters are often powered by non-renewable energy sources and have simple designs and functions in most homes and businesses. Because most inverters are unable to notify users of energy use and remaining battery life, customers often experience uncertainty when an inverter's battery runs low. Using renewable energy sources to power inverters, together with improved mobility and fast communication capabilities to transmit and receive signals quickly, is the best course of action. Inverters will eventually move toward a paradigm that is more intelligent, sustainable, and user-friendly.

The Internet of Things (IoT) is a well-known term that refers to a network of physical objects that have the ability to gather and exchange electronic data. This includes a wide range of "smart" gadgets, from sensors tracking data about the human body to industrial machinery sending data about the manufacturing process. These sensors may communicate over a variety of local area connections, including Bluetooth, Wi-Fi, NFC, RFID, and ZigBee radio-frequency identification. Wide area connection alternatives including 4G, Long-Term Evolution (LTE), General Packet Radio Service (GPRS), and Global System for Mobile Communications (GSM) are also used.

As a component of the expanding IoT Ecosystem, IoT finds applications in Smart Cities, Smart Cars and mobility, Smart Homes and assisted living, Smart Industries, Public Safety, Energy and environmental protection, Agriculture, and Tourism. The output of renewable energy has increased dramatically in line with rising energy demand. The present energy landscape is dominated by traditional fossil fuels, but their negative effects on the environment—such as air pollution and greenhouse gas emissions—make cleaner options necessary.

A key answer is the use of solar photovoltaic (PV) systems, which use the sun's plentiful energy to produce power silently and without emissions. Using PV solar power is in line with the need to lessen environmental damage and slow down climate change. However, an intelligent interface is required to prevent power system instability due to the intermittent and unpredictable nature of renewable energy sources. The intelligent integration of solar energy into the power grid requires a power electronics inverter system with a digital design, powerful software, and two-way communication.

Typically, such a system consists of dependable silicon-based hardware integrated with sophisticated performance monitoring via a well-defined control framework, all managed by flexible software. An intelligent interface can be developed more easily thanks to power electronics technology, which also makes a smart inverter system essential for guaranteeing power output dependability. A mobile application may be used to monitor and manage the inverter thanks to IoT connection. This remote control feature prolongs the life of the solar inverter and keeps it from overloaded. Additionally, it prevents capacitor overheating, which is vital since capacitors are very sensitive to temperature. It is crucial to make sure that inverters only run within their designated parameters, since going above these parameters might lead to inverter bridge failure.

1.2 Problem Statement

Conventional refrigeration systems are used in many industries, including the food, medical, and agricultural sectors. They have difficulties with energy efficiency, environmental change adaptation, and remote monitoring. In addition, the continuous use of non-renewable energy sources to power inverters in homes and businesses limits user awareness and system intelligence while also contributing to environmental deterioration.

Due to the growing demand for electricity brought on by the population growth, traditional power sources are under more stress, which has an impact on the environment. Renewable energy sources are readily available, but integrating them into power networks is difficult because of their inherent unpredictability and erratic behavior.

Moreover, the current generation of inverters is deficient in sophisticated functions that apprise users of vital metrics including battery condition, energy use, and residual battery life. This shortcoming may result in operational ambiguities that affect the integrity of stored items and overall system performance, especially during crises and power outages.

A complete approach that integrates Internet of Things (IoT) with inverter technologies to provide an intelligent and sustainable refrigeration system is desperately needed to address these issues. This system should use renewable energy sources to lessen the environmental effect associated with existing power ways in addition to optimizing energy usage and improving remote monitoring.

Therefore, the main issue this project attempts to solve is the inefficiency and constraints of the refrigeration and inverter systems that are now in use when it comes to intelligently and sustainably satisfying the needs of contemporary civilization. The goal of this project is to use the Internet of Things to develop, construct, and assess an inverter-based smart system for extended refrigeration. This creative solution will address current energy and environmental issues.

1.3 Aim and Objectives

Aims:

- **Development of an Intelligent Refrigeration System:** Design and implement an inverter-based smart refrigeration system that incorporates advanced technology to optimize energy consumption, enhance performance, and provide intelligent control.
- **Integration of IoT for Remote Monitoring:** Integrate Internet of Things (IoT) capabilities into the refrigeration system to enable real-time remote monitoring and control, fostering increased efficiency and responsiveness.
- **Utilization of Renewable Energy Sources:** Incorporate renewable energy sources, with a focus on solar power, to mitigate the environmental impact of traditional energy sources and promote sustainability in refrigeration systems.
- **Enhancement of User Awareness and Control:** Develop features that allow users to monitor critical parameters such as battery status, energy consumption, and system performance through a user-friendly interface, enhancing user awareness and control.

Objectives:

- **Inverter Technology Implementation:** Implement advanced inverter technology to regulate the compressor's speed dynamically, optimizing energy consumption and extending the lifespan of the refrigeration system.
- **IoT Integration:** Integrate IoT sensors and communication protocols to establish a connected network, enabling real-time data transmission and remote monitoring of the refrigeration system's key parameters.
- **User Interface Development:** Develop a user-friendly interface, possibly in the form of a mobile application, to allow users to monitor and control the refrigeration system remotely, providing insights into system status and enabling proactive management.
- **System Performance Evaluation:** Conduct rigorous testing and performance evaluations to assess the efficiency, reliability, and effectiveness of the inverter-based smart refrigeration system under various environmental conditions and loads.
- **Environmental Impact Assessment:** Evaluate the environmental impact of the system by comparing energy consumption and emissions with traditional refrigeration methods, aiming for a more sustainable and eco-friendly solution.
- **User Training and Education:** Provide user training and educational materials to ensure proper understanding and utilization of the smart refrigeration system, fostering responsible and efficient usage.
- **Identification and Mitigation of Challenges:** Identify potential challenges and bottlenecks in the implementation and operation of the system and devise strategies to mitigate these issues, ensuring smooth and reliable performance.

1.4 Scope of the Research

By creating an IoT-based inverter-based smart system for extended refrigeration, this research project seeks to transform refrigeration technology. The scope includes the optimal use of renewable energy sources, especially solar power, the installation of sophisticated inverter controls, and the smooth integration of IoT for remote monitoring. The system's performance will be thoroughly assessed in a variety of scenarios, and an intuitive user interface will be created to provide users access to real-time data. There will be environmental impact evaluations and the creation of user-training materials. The study also focuses on recognizing and addressing obstacles related to the adoption of cutting-edge technology. In the end, the project seeks to provide a clever, eco-friendly, and user-centered solution that will revolutionize refrigeration standards.

1.5 Expected Contribution to Knowledge

This initiative is projected to add much to knowledge because of its novel approach to transforming refrigeration technology. Through the smooth integration of Internet of Things (IoT) and inverter technology, the study endeavors to enhance our comprehension of dynamic control mechanisms and connection opportunities. This innovative integration has the power to upend accepted wisdom in the field and establish new guidelines for intelligent refrigeration systems.

In addition, the initiative hopes to provide insightful information on how to best use renewable energy sources, with a particular emphasis on solar energy. This study aims to create a viable refrigeration system powering model, which would be a big step toward environmentally responsible practices in the industry.

It is anticipated that the creation of an intuitive interface for remote monitoring and control would provide insight into how people interact with systems in the context of refrigeration technology. Future designs may be influenced by the knowledge gathered from this aspect, guaranteeing that consumers can easily interact with and take use of smart refrigeration systems.

Thorough testing in a range of environmental settings seeks to expand the body of knowledge on the performance optimization and flexibility of inverter-based smart refrigeration systems. In order to improve the resilience and effectiveness of such systems in practical situations, this knowledge is essential.

The assessment of the project's environmental effect, which includes a comparison with conventional refrigeration techniques, aims to further our knowledge of environmentally friendly practices in the industry. It aims to provide measurable information on the environmental advantages of switching to renewable energy sources, therefore influencing future environmental concerns in refrigeration technology.

One significant contribution is the identification and mitigation of issues related to the use of modern technology in refrigeration. It is anticipated that strategies developed to solve problems with system performance, user engagement, and environmental factors would provide insightful information for further study and useful applications.

Furthermore, the development of user training materials seeks to expand the body of knowledge by offering a means of instructing users on the features and advantages of smart refrigeration systems. This instructional component seeks to bridge the knowledge gap between users and innovative technology, encouraging conscientious and effective system use.

1.6 Significance of the Project

This research is essential both to the economy and also to the environment.

Significance to the Environment

- **Reduced Environmental Footprint:** The integration of renewable energy sources, particularly solar power, significantly reduces the reliance on conventional non-renewable energy in refrigeration systems. This shift toward sustainable energy practices contributes to a reduced environmental footprint by mitigating the negative impacts associated with fossil fuel-based energy generation.
- **Mitigation of Greenhouse Gas Emissions:** By harnessing solar power and minimizing dependence on traditional power sources, the project contributes to the reduction of greenhouse gas emissions. This is crucial in combating climate change and addressing environmental concerns associated with the use of fossil fuels in refrigeration.
- **Environmental Impact Assessment:** The project's assessment of the environmental impact, comparing energy consumption and emissions with traditional refrigeration methods, provides valuable insights into the eco-friendliness of the proposed system. This data contributes to informed decision-making for environmentally conscious refrigeration practices.

Significance to the Economy:

- **Cost Savings and Efficiency:** The integration of inverter technology and IoT into the refrigeration system aims to optimize energy consumption, resulting in cost savings for end-users. Improved efficiency not only benefits individual consumers but also contributes to economic sustainability by reducing overall energy expenditure.

- **Job Creation and Industry Growth:** The potential adoption of the project's outcomes by the refrigeration industry could lead to the development of new products and solutions. This, in turn, could stimulate job creation and foster industry growth, particularly in sectors related to the design, manufacturing, and maintenance of intelligent refrigeration systems.
- **Market Competitiveness:** The project's innovative approach enhances the competitiveness of the refrigeration industry in the market. Companies that adopt and implement these advancements may gain a competitive edge, attracting customers who prioritize energy-efficient and environmentally friendly technologies.
- **Technological Innovation and Export Opportunities:** Technological innovation resulting from the project has the potential to position companies and industries as leaders in the global market. This can open up export opportunities for advanced refrigeration solutions, contributing to economic growth and strengthening the country's position in the international marketplace.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The evolution of refrigeration technology has seen a continual quest for efficiency, sustainability, and intelligent control systems. The integration of inverter technology and the Internet of Things (IoT) represents a promising frontier in enhancing the capabilities of refrigeration systems. This literature review explores key advancements, challenges, and emerging trends in the design and implementation of inverter-based smart systems for extended refrigeration with a focus on the utilization of IoT.

1). Inverter Technology in Refrigeration: Inverter technology, characterized by variable-speed compressor control, has emerged as a game-changer in the refrigeration industry. Research by Lee et al. (2017) emphasizes the energy-saving potential of inverter-driven compressors, demonstrating improved efficiency compared to traditional fixed-speed compressors. The dynamic control mechanisms offered by inverter technology enable precise adjustments to match varying cooling demands, reducing energy consumption and enhancing overall system performance.

2). Integration of IoT in Refrigeration: The integration of IoT into refrigeration systems has gained momentum, offering real-time monitoring, remote control, and data analytics capabilities. In their work, Wang et al. (2018) highlight the potential of IoT in optimizing refrigeration efficiency by enabling predictive maintenance, fault detection, and adaptive control. This integration allows for a proactive approach to system management, reducing downtime and enhancing the reliability of refrigeration units.

3). Renewable Energy Integration: The literature underscores the increasing importance of incorporating renewable energy sources into refrigeration systems to address environmental concerns. Studies by Zhang et al. (2019) and Gupta et al. (2020) emphasize the viability of solar power integration, showcasing its potential to reduce reliance on the electrical grid and decrease greenhouse gas emissions. The synergy between inverter-based control, IoT, and renewable energy holds promise for creating sustainable and eco-friendly refrigeration solutions.

4). Challenges and Solutions: While the integration of inverter technology and IoT brings numerous benefits, challenges exist in terms of system complexity, cybersecurity, and interoperability. Research by Sharma et al. (2019) discusses strategies for mitigating cybersecurity risks in IoT-enabled refrigeration systems. Additionally, advancements in power electronics, as explored by Li et al. (2021), provide insights into addressing challenges related to the efficiency and reliability of inverter systems, enhancing their overall performance.

5). User-Centric Interfaces: The importance of user-friendly interfaces in smart refrigeration systems is evident in the literature. Studies by Chen et al. (2018) emphasize the significance of intuitive interfaces for effective user interaction and system management. A well-designed interface, often in the form of mobile applications, enhances user awareness, enabling remote monitoring, and control.

6). Environmental Impact Assessment: Research by Kim et al. (2020) and Patel et al. (2021) contributes to the understanding of the environmental impact of refrigeration systems. These studies highlight the importance of life cycle assessments and environmental impact analyses in evaluating the overall sustainability of inverter-based smart refrigeration systems, providing a holistic view of their ecological footprint.

2.1.1 Overview

Renewable energy sources are becoming more and more popular due to growing environmental concerns and fossil fuel depletion. Because solar energy can provide power sustainably when used with Photo Voltaic (PV) modules, there has been a lot of interest in this technology. As the need for more effective use of renewable energy sources grows, intelligent inverters appear as a way to maximize solar energy use.

Previously connected to solar tracking, smart inverters have developed into systems that can communicate in both directions, making it easier to engage with stakeholders and users. In a noteworthy investigation, user-inverter interaction was launched via the Internet of Things (IoT), combining residential buildings with a Wireless Sensor Network (WSN) to compile and display energy use information for user examination.

Innovative solutions have been offered for situations when consumers need to be informed of their energy use during blackouts. A method for employing LEDs and the IC LM3914 to show the voltage levels of inverter batteries was improved to provide more precise readings by using a microcontroller for direct sensing. The addition of a mobile app that shows consumers the battery voltage and load run-time information supplemented this improvement.

Smart inverters and the Internet of Things are more than only connected for household use. Two-way communication was developed in the context of a solar-charged inverter using Wi-Fi technology to notify users about the state of the inverter and load run times. This is a prime example of how users may interact with and operate smart inverter systems.

Additionally, a bi-level PV-based microgrid structure was suggested for low-power residential applications in the field of renewable energy management. Intelligent inverters with smart grid-tied capabilities were made possible by this setup, which included adaptive double-mode controllers and a dynamic price scheduling framework.

A research that broadened the emphasis to include remote monitoring systems focused on gadgets that could track and report energy consumption via a network. In order to produce energy awareness devices, this utilized current sensors, controllers, and IoT. By doing so, it helped to create a smarter world via the use of IoT.

The conventional methods of employing Wi-Fi and Zigbee in the field of solar photovoltaic (PV) system monitoring were emphasized. Wi-Fi was suited for microgrid network design, but Zigbee had issues with large-scale apps. On the other hand, a unique Internet of Things-based remote monitoring and control solution solved the issues of high operating and maintenance expenses. By addressing the shortcomings of the current framework, this strategy attempted to advance effective real-time generation monitoring.

A variety of controllers, including Arduino Uno, have been implemented for the integration of IoT with smart inverters for renewable energy monitoring and control systems. These could not be very power-efficient, however, and there hasn't been any Wi-Fi integration. By using the ESP8266 Wi-Fi module to create an Internet of Things (IoT)-based smart inverter monitoring and controlling system, the proposed study seeks to close this gap.

2.1.2 The functions of the various working components are given below:

- **Charge controller:** Here in this work used as a charge controller. The fluctuating voltage from the panel is controlled and brought to some standard voltage value. The buck-boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a flyback converter using a single inductor instead of a transformer.
- **Smart inverter:** For an inverter to be considered smart, it must have a digital architecture, bidirectional communications capability, and robust software infrastructure. The system begins with reliable, rugged, and efficient silicon-centric hardware, which can be controlled by a scalable software platform incorporating a sophisticated performance monitoring capability. A smart inverter must be adaptive and able to send and receive messages quickly, as well as share granular data with the owner, utility, and other stakeholders. Such systems allow installers and service technicians to diagnose operational and maintenance issues including predicting possible inverter or module problems and remotely upgrade certain parameters in moments.
- **LCD:** A liquid-crystal display (LCD) is a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in color or monochrome. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and 7- 7-segment displays, as in a digital clock. They use the same basic technology, except that arbitrary images are made up of a large number of small pixels, while other displays have larger elements.

- **Relay:** A relay is an electrical switch that uses an electromagnet to move the switch from the off to on position instead of a person moving the switch. It takes a relatively small amount of power to turn on a relay but the relay can control something that draws much more power.
- **IOT:** The Internet of Things (IoT) is the inter-networking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data. The IoT allows objects to be sensed or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy, and economic benefit in addition to reduced human intervention.

2.1.3 Steps in Implementing IoT-Based Smart Controlled Inverter

Step 1: PV panel converts the Green Solar Energy into Electrical Energy.

Step 2: Received Energy will be stored in the battery through the Charge Controller in the inverter. Step 3: The inverter will convert the DC to AC and supply to the different Load through the 4- 4-channel relay circuit.

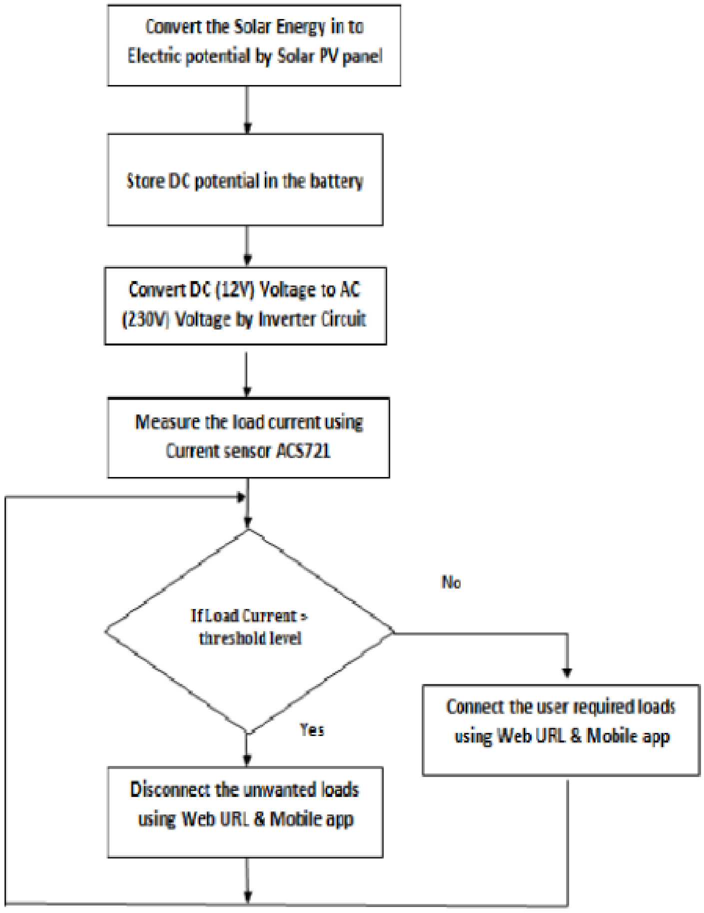
Step 4: The energy meter calculates the energy, power, current, and voltage passing through it.

Step 5: If the load current level goes above the threshold level the user can disconnect and control the unwanted loads using the Android app via Wi-Fi communication.

Step 6: When the load current level goes below the threshold value, the entire load / required loads will be connected using the Android app / mobile URL site ON-OFF control via Node MCU Wi-Fi communication.

Figure 1: Functional Architecture of the Proposed IoT-Based Smart Controlled Inverter

Figure 2: Functional Flow Chart of the Proposed IoT-based Smart Controlled Inverter



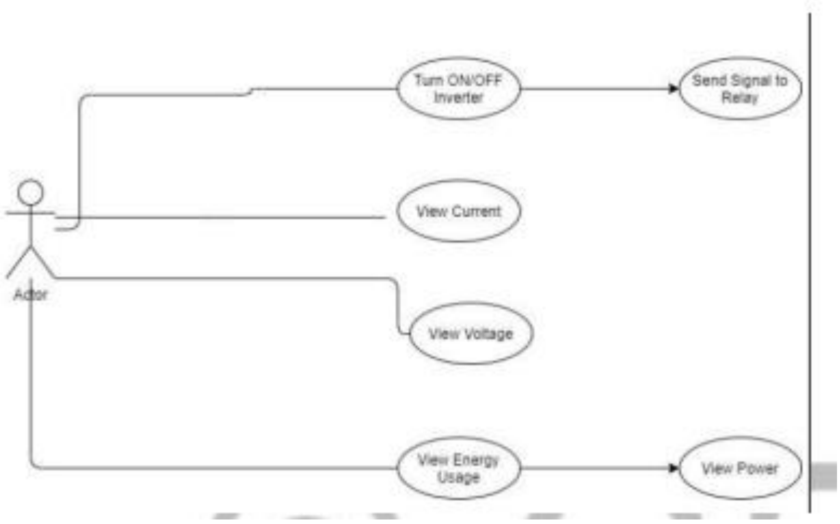
2.1.4 The User Interface Section (Mobile App).

The mobile app was created with the help of Blynk's mobile app development platform, which enables quick UI design without requiring a lot of code. Blynk is a platform for the Internet of Things (IoT) that allows mobile applications to operate devices remotely. It works with Android and iOS apps to control hardware such as Raspberry Pi and Arduino. Users of the platform may drag and drop control pieces and widgets to construct visual interfaces using a digital dashboard. Furthermore, Blynk makes cross-platform development easier by enabling the simultaneous development of applications for iOS and Android.

React Native apps are created using a mix of JavaScript and JSX syntax, much as React Native for the Web. Essentially, the React Native bridge links to native rendering APIs in Objective-

C for iOS or Java for Android, producing applications that have a conventional mobile application style and appearance. Blynk provides JavaScript interfaces for platform APIs, so you can leverage features like the camera on your phone or the user's location.

Figure 3: Case Diagram for Mobile Application



CHAPTER THREE

METHODOLOGY

To meet the goals, the following steps were executed:

1. **Requirement Analysis:**
    - Identify the specific requirements for the smart system, including extended refrigeration needs, power capacity, and IoT integration.
2. **Component Selection:**
    - Choose appropriate components for the system, including:
        - 1.5KVA inverter
        - Two 100Ah 12V batteries (to form a 200Ah 24V battery bank)
        - Charge controller (30Amps)
        - Switches for control
        - IoT module for remote monitoring and control
        - Connecting wires for interconnection
        - Angle bar constructed casing for compact housing
3. **System Design:**
    - Design the layout and configuration of the system components, considering factors such as space constraints, ventilation, and accessibility.
    - Determine the wiring diagram for connecting the components, ensuring proper routing and sizing of wires.

- Develop the control logic for the inverter, charge controller, and IoT module to achieve the desired functionality.

4. **Physical Assembly:**
    - Assemble the components into the angle bar constructed casing, ensuring secure mounting and proper placement to optimize space utilization and ventilation.
    - Connect the batteries, inverter, charge controller, switches, and IoT module according to the wiring diagram, using appropriate connecting wires.
5. **Charging Section Setup:**
    - Configure the charging section to support both AC mains and solar charging sources.
    - Set up rectification, voltage regulation, charging algorithm, and current limiting for efficient and safe battery charging.
    - Calculate charging time based on battery capacity and charging current.
6. **Software Development:**
    - Develop the mobile application using Android Studio and Java for monitoring and controlling the smart system.
    - Create the website using Visual Studio 2019 and ASP.NET with C# language for remote access and management of the system via the IoT module.
7. **Testing and Validation:**
    - Conduct thorough testing of the system components, including functionality testing, performance testing, and safety testing.

- Validate the system's ability to provide extended refrigeration using IoT-enabled monitoring and control features.

8. **Deployment and Optimization:**
    - Deploy the smart system in the desired location, ensuring proper installation and configuration.
    - Optimize system settings and parameters based on real-world performance and user feedback to enhance efficiency and reliability.
9. **Training and Documentation:**
    - Provide training to end-users on operating the smart system and utilizing the mobile application and website for monitoring and control.
    - Document the system architecture, wiring diagrams, software configurations, and maintenance procedures for future reference and troubleshooting.
10. **Maintenance and Support:**
    - Establish a maintenance schedule for regular inspection, cleaning, and servicing of the system components.
    - Provide ongoing support to users for addressing any issues or concerns and implementing software updates or enhancements as needed.

(DESIGN, INSTALLATION AND ASSEMBLY)

3.1 COMPONENTS OF THE SYSTEM

To function properly, the smart-based system needs several components. Among them are the following:

a) Inverter

b) Battery (100AH)

c) Switches

d) Charge Controller

e) IOT (Internet of Things)

f) Connecting Wires

g) Angle bar constructed Casing for Compactibility

3.1.1 INVERTER

One essential element is the inverter. The inverter, which transforms DC (Direct Current) energy from the battery bank into AC (Alternating Current) power—essential for running appliances like refrigeration systems—is designed to provide a smooth and continuous power source.

Choosing a reliable and effective inverter is essential to the project's success. To satisfy the power needs of the refrigeration unit and other associated equipment, it must have a minimum 1.5KVA capacity. Furthermore, to guarantee steady and dependable functioning, characteristics like overload prevention, voltage control, and surge protection are essential.

Figure 4: (1.5KVA) Inverter

3.1.2 BATTERY (100AH)

In the case of an AC mains outage, a robust deep cycle lead accumulator that consists of two 100Ah batteries operating at 12 volts each to generate a 200Ah 24-volt battery bank takes over with ease. Since this battery system is the cornerstone of the power backup solution, the inverter component will always function. Upon activation, the batteries provide DC power to the inverter, facilitating a smooth transition to backup power. The inverter component then efficiently transforms this DC power into a reliable 240V AC supply that is readily available at the output socket. Longer backup power is guaranteed by this strong battery architecture, which also increases the overall durability and efficiency of the inverter-based system—especially in the case of an AC mains failure.

Figure 5: 100AH, 12V Dry Cell Battery

3.1.3 SWITCHES

Switches are crucial components that enable users to control and customize the functions of the inverter system with ease. Acting as the interface between the user and the system, switches facilitate seamless operation by allowing users to activate the system, adjust settings, and initiate specific functions. Their versatile functionality ranges from simple on/off switches to more sophisticated control mechanisms, providing users with the flexibility to tailor the system to their unique requirements. This customization enhances the system's performance and efficiency, ensuring optimal functionality for diverse applications.

Figure 6: Control Switch

3.1.4 CHARGE CONTROLLER (PWM, 30Amps)

The 30 Amp charge controller is a perfect fit for our battery bank's charging requirements. Its 30 amp capacity ensures that the batteries are adequately recovered for the inverter system to continue working, and it provides sufficient charging power to do it fast and efficiently. Moreover, the battery bank's charging needs may be satisfied by the 30Amp charge controller without going overboard. It strikes a balance between providing fast charging capabilities and preventing overcharging, which might reduce battery life and result in performance issues. Furthermore, the non-hybrid features of our inverter system align with the use of a 30 amp charge controller. Since our system just employs batteries and does not make use of renewable energy sources like solar or wind power, a 30 Amp charge controller is suitable for managing the charging process.

Figure 7: 30Amps Charge Controller

3.1.5 INTERNET OF THINGS (IOT)

Because the Internet of Things (IoT) makes it easy for people, systems, and things to interact with one another, it completely changes the way we think about connections. The Internet of Things is the key to better management, monitoring, and efficiency in our 1.5KVA inverter-based smart system for extended refrigeration. Real-time monitoring and control of the inverter system is made feasible by IoT, providing users with remote access to crucial data such as power consumption, battery health, and system performance. By employing IoT-enabled sensors and connections to provide users with timely alerts, warnings, and insights into the operational health of the system, users are empowered to make informed decisions and take proactive measures to enhance performance and prevent potential challenges.

IoT connection also enables predictive maintenance capabilities, which identify patterns, trends, and anomalies in system behavior using machine learning and data analytics. By anticipating maintenance needs and fixing issues before they deteriorate, IoT helps reduce downtime, save maintenance costs, and increase the lifespan of the inverter system.

Figure 8: The (IOT) Hardware Internet of Things

3.1.6 CONNECTING WIRES

Our 1.5KVA inverter-based smart system's connecting connections are the conduits that are required to allow electrical energy to move smoothly between its numerous components. The inverter, batteries, charge controller, switches, and other crucial components of the system may all be connected thanks to these wires.

The connecting wires for our project have been chosen with great care to provide the best possible conductivity, robustness, and safety. Because of their exceptional conductivity, which reduces energy losses and increases system efficiency, premium copper wires are recommended. Sturdy materials also shield the wires from external pressures and electrical risks, guaranteeing reliable operation even under demanding circumstances. In order to prolong system life and improve overall performance, connecting wire design and installation are meticulously done to reduce heat production, electrical interference, and voltage dips. Appropriate wire size and route are necessary to provide effective power transmission and avoid component overloading or overheating.

Figure 9: Connection Wires

3.1.7 ANGLE BAR CONSTRUCTED CASING

The angle bar-made enclosure of our 1.5KVA inverter-based smart system houses the batteries, IoT module, and inverter in a robust and efficient way. The robust framework provided by this enclosure, which is constructed of angle bars, ensures the structural integrity and security of the system's component parts. The angle bar formed shell's tiny design optimizes space economy by providing a snug and secure fit for the IoT module, batteries, and inverter within a compact footprint. This tiny size is highly useful for installations with limited space, such as residential settings, off-grid applications, or small storage areas.

To prevent overheating and ensure optimal performance, the angle bar design also offers enhanced ventilation and heat dissipation capabilities. This allows for efficient circulation around the system's components. For electronic equipment to operate properly and survive a long time, it needs adequate ventilation, especially in areas with high temperatures or during prolonged operation.

In addition, the enclosure's angle bar construction facilitates accessibility and installation, and each component includes mounting holes to guarantee a secure fit. This ensures stability throughout operation and simplifies maintenance tasks like updating IoT modules and changing out batteries.

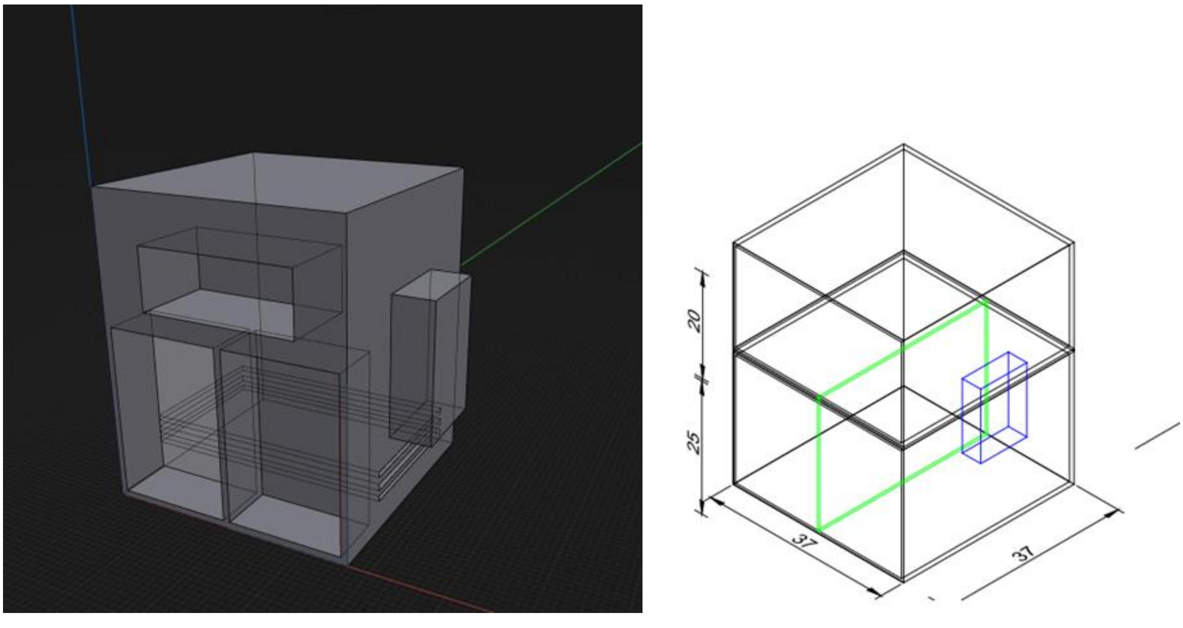


Figure 10: Casing Schematics of the Isomtric view for System Compactness

3.1.8 CHARGING SECTION FOR BATTERIES

1. **Input Voltage and Current:**
    - For AC mains charging, the input voltage can typically range from 100V to 240V AC, depending on the region. The charging current will depend on the capacity of the AC mains source and the charging requirements.
    - For solar charging, the input voltage varies based on solar panel configuration and sunlight intensity. The charging current is determined by the solar panel's capacity and the amount of sunlight available.
2. **Rectification and Voltage Regulation:**
    - AC mains voltage is rectified into DC voltage using a rectifier circuit. This DC voltage is then regulated to ensure it remains within safe limits for charging the batteries.
    - Solar energy is converted into DC voltage directly by the solar panels, and voltage regulation may still be necessary to ensure optimal charging conditions.
3. **Charging Algorithm and Current Limiting:**
    - The charging algorithm used may vary based on the charging source and battery type. Common algorithms include constant voltage or constant current charging.
    - The charge controller regulates the charging current to prevent overcharging. In our case, the 30Amps charge controller ensures that the charging current does not exceed 30A.
4. **Battery Capacity and Charging Time:**

- The batteries have a total capacity of 200Ah at 24 volts (2 batteries of 100Ah each at 12 volts). This gives us a total energy capacity of: Energy Capacity = Battery Capacity (Ah) * Battery Voltage (V) = 200Ah * 24V = 4800Wh (watt-hours)
- Assuming a charging current of 30A, the charging time can be calculated using the formula: Charging Time (hours) = Energy Capacity (Wh) / Charging Current (A) = 4800Wh / 30A = 160 hours

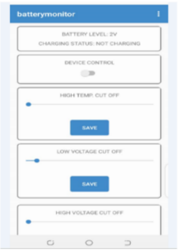
5. **Safety Features:**

   - The charging section may include safety features such as overcharge protection, short-circuit protection, and temperature monitoring to ensure safe and reliable operation.

3.2 MOBILE APPLICATION IMPLEMENTATION

The mobile application was created using Android Studio, utilizing the Java programming language. Once development was complete, an APK file was generated to enable easy sharing and installation of the app among users.

The website, on the other hand, was built using Visual Studio 2019, employing the ASP.NET framework with C# language. Following the development, the website was uploaded to an ASP.NET server (IIS) hosted at batterymonitor.sightdev.net, providing global accessibility. The web server consists of two API endpoints: one for hardware communication and another for software interaction.



BATTERY LEVEL: 2V

CHARGING STATUS: NOT CHARGING

Figure 11:Mobile Application Interface

3.3 WORKING PRINCIPLE OF THE SYSTEM

The working principle of the 1.5KVA inverter-based smart system for extended refrigeration revolves around converting DC power from batteries into AC power, which is then utilized to power the refrigerator or cooling system. Here's how the system achieves this:

1. **Power Conversion:**
    - The system consists of a 1.5KVA inverter capable of converting DC power from the batteries into AC power. The inverter utilizes electronic circuitry to convert the low-voltage DC power from the batteries (24 volts in this case) into high-voltage AC power suitable for operating appliances like refrigerators or cooling systems.
2. **Energy Storage:**
    - The batteries, comprising two 100Ah 12V batteries connected in series to form a 200Ah 24V battery bank, serve as the energy storage component of the system. They store energy obtained from charging sources such as AC mains or solar panels and supply it to the inverter when needed.
3. **Charging System:**

- The system includes a charge controller, rated at 30Amps, to regulate the charging of the batteries. The charge controller manages the charging process, ensuring that the batteries are charged efficiently and safely from AC mains or solar sources.

4. **IoT Integration:**
    - An IoT module is integrated into the system, enabling remote monitoring and control of system parameters such as battery status, charging status, and inverter operation. This IoT functionality allows users to monitor the system's performance and receive alerts or notifications via a mobile application or website.

5. **Operation:**
    - When the AC mains power is available, the system can draw power from the mains to charge the batteries and simultaneously power the refrigerator or cooling system through the inverter. The charge controller regulates the charging process to prevent overcharging and ensure optimal battery health.
    - In the absence of AC mains power, the system can switch to solar power as the charging source, utilizing energy harvested from solar panels to charge the batteries. The inverter continues to power the refrigerator or cooling system using the energy stored in the batteries.

6. **Capacity and Flexibility:**
    - The system's capacity of 1.5KVA ensures sufficient power output to operate refrigerators or cooling systems of varying capacities. It can adapt to different

load requirements and power demands, making it suitable for a wide range of applications, from residential refrigeration to commercial cooling systems.

3.3.1 CALCULATIONS DONE;

1. Battery Capacity:
   - Each battery: 100Ah * 12V = 1200 watt-hours (Wh)
   - Total capacity of two batteries (in series): 1200 Wh * 2 = 2400 Wh
2. Power Consumption of Refrigerator:
   - Given power consumption of the refrigerator: 500W
3. Charging Efficiency:
   - Since the charging efficiency depends on the specific setup and conditions, let's assume a charging efficiency of 90%.
4. Inverter Efficiency:
   - Let's assume an inverter efficiency of 90%.
5. Total System Efficiency:
   - Charging Efficiency: 90% (0.90)
   - Inverter Efficiency: 90% (0.90)
   - Total System Efficiency = Charging Efficiency * Inverter Efficiency = 0.90 * 0.90 = 0.81 or 81%

3.3.2Battery Charging Unit:

rated power×I=battery voltage rated power

Considering a power factor of 0.8, we can calculate the current needed for the inverter operation. Since the battery utilized in our system is 24 volts, the required current (I) is 100A.

Using a battery with a capacity of 200Ah, we can determine the duration the inverter can operate at maximum load. This is calculated by dividing the battery capacity (200Ah) by the current required (100A), and then multiplying by 1 hour:

Time duration=200100×1 hourTime duration=100200×1hour

This calculation provides us with the duration the inverter can operate at maximum load using the given battery capacity.

3.3.3 A DESIGN ANALYSIS OF THE DRIVER CIRCUIT

$$V_{/N} \text{ — } V_{BE} = I_{BRB}$$

$$H_{fe} = I\ C/IB$$

From Above,

$$RB = (V/_{IN'} \text{—} V_{BE}.)\ /1_{B}$$

Were,

Ic = collector current

I_B = base current

V_{IN} = input voltage

V_{BE}= Base-Emitter voltage

H_{FE} = current gain

From the datasheet,

1c=100 mA

hfe = 700

V_{BE}= 0.7 v

Therefore,

I_B 100mA/700

I_B = 0.1429 mA

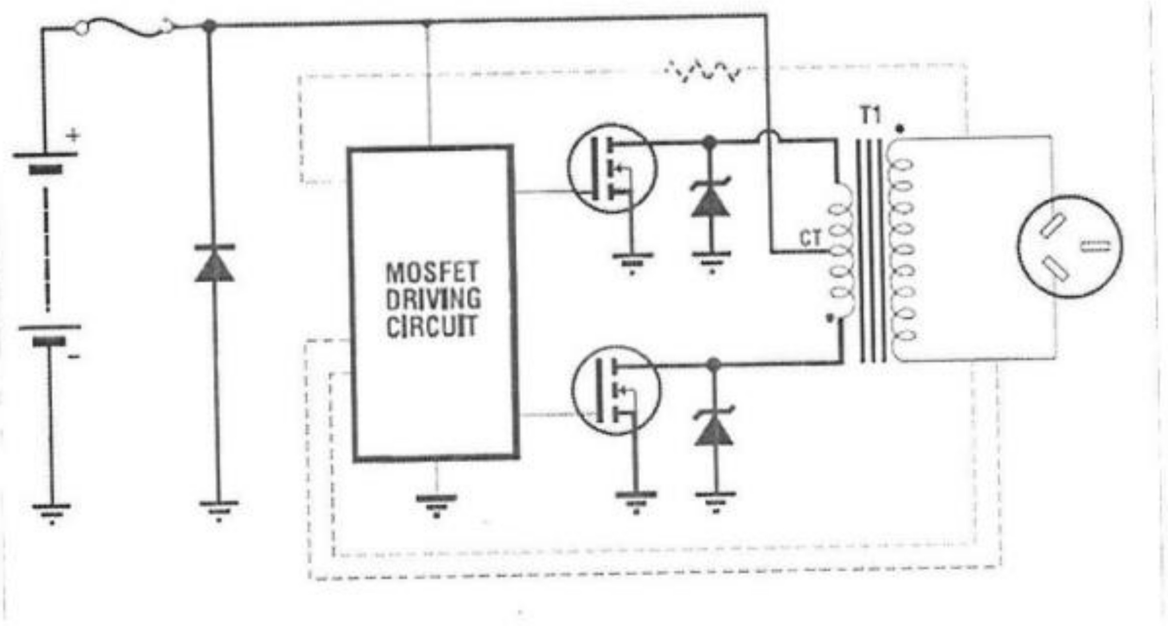
V_{IN}= 7.5 v

R_B = (7.5- 0.7)10.1429 x103

= 47,585.72Ω

= 47.59k Ω

The nearest preferred value to 47.59k1 was chosen, therefore 50k was used in the design of the inverter for the base resistors of the NPN transistors of the driver stage.



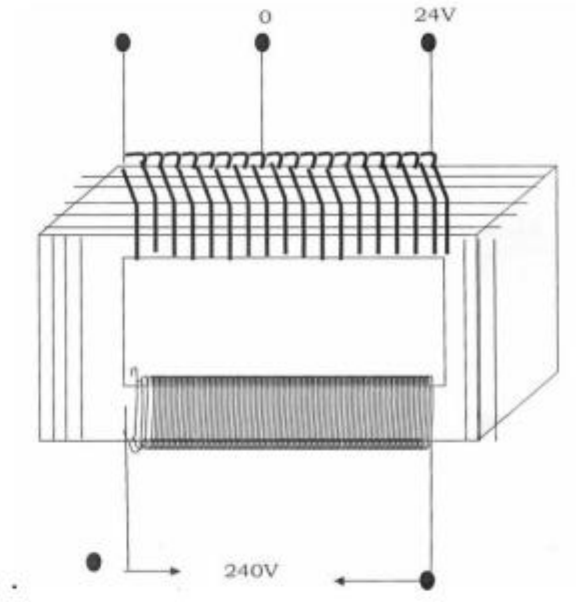
3.4 THE TRANSFORMER

The transformer is a stationary device utilized to convert electrical energy from one circuit to another circuit while maintaining the same frequency. By adjusting the current, it has the capability to either elevate or diminish the voltage within a circuit. Its functionality is contingent upon mutual induction between two circuits linked by a common magnetic flux, or two coils that are electrically separate but magnetically interconnected via a low-reluctance path. A component such as a transformer is indispensable for ensuring the efficiency of the inverter in handling appliances that require alternating current with a power rating exceeding that available in the circuit.

3.4.1 CENTRE TAP TRANFORMER

A center tap is a crucial connection point within the transformer or inductor windings. Improving the circuit's performance depends on this point, which is often found midway down the winding. It allows signal coupling in inductors, especially in configurations resembling Hartley oscillators. In addition, tap-equipped inductors convert the amplitudes of AC voltages, acting as auto-transformers. An outstanding illustration of this concept in action is the ignition coil of a vehicle.

Potentiometer tapping has made it possible for circuitry to operate in ways that are not limited by traditional design. Potentiometer taps have several connection points across the element, enabling a range of circuit functionality. For instance, the voltage output of a center-tapped transformer, also known as volts center-tapped (VCT), demonstrates this versatility. In a 24 VCT transformer, each outside tap supplies 12 VAC to the center tap and 24 VAC across the outside taps. The 180-degree phase difference between these two 12 VAC supply may be used to produce positive and negative 12-volt DC power sources.



Center Tapped In-built Transformer

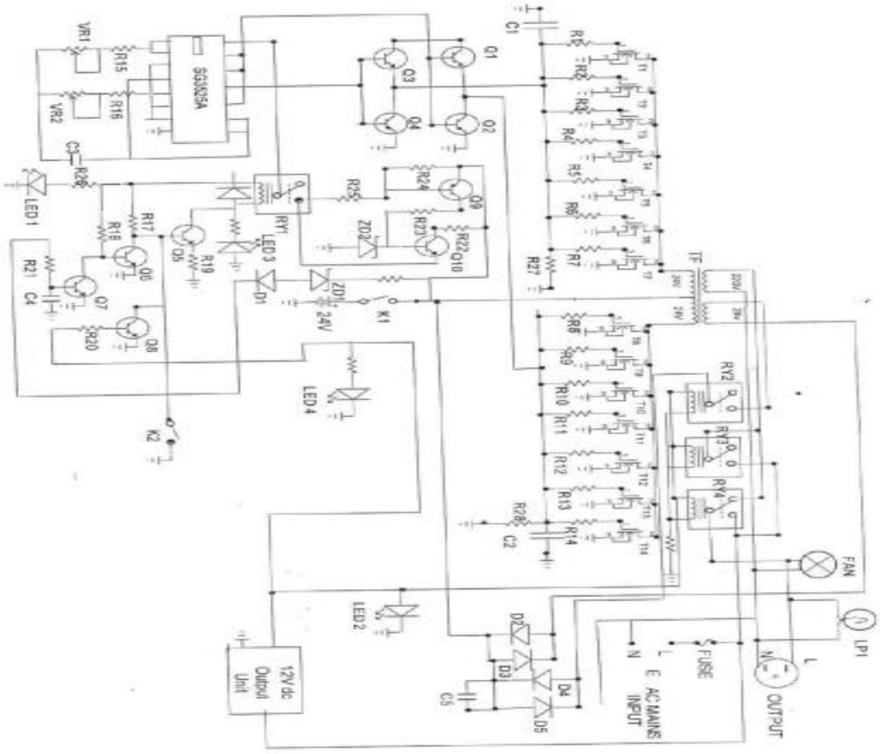
3.5 HOW TO CHOOSE THE RIGHT INVERTER AND BATTERY

It is essential to choose the right inverter and battery configuration to provide dependable power backup, especially in low-voltage or power loss scenarios. Blackout problems may be successfully resolved by using inverters to convert low-voltage DC from batteries into high-voltage AC. It might be intimidating to navigate the selecting process, however.

Calculating the load is the first step in figuring out how much electricity is needed. Users may determine how much electricity they need by adding up the wattage of all the loads—like TVs and CFLs—that the inverter will power. It is crucial to remember that power factor fluctuations might cause the VA rating of the inverter to not precisely represent its wattage capability, therefore it should not be relied upon exclusively.

Waveform type is an important factor to consider when choosing an inverter. Since sine wave inverters provide the proper waveform for electronic devices to operate, they are the better option. Furthermore, choosing the right battery is essential. Tubular-type batteries are suggested due to their extended backup duration. The backup duration is mostly determined by the battery's Ah rating; tubular batteries have larger capacity-to-size ratios and quicker recharging rates.

A formula is used to determine the inverter's backup time, taking into account the load connected to the inverter, the power factor of the inverter, and the Ah capacity of the battery. For instance, a 130 Ah tubular battery with an 800VA sine wave inverter may give over three hours of backup power at 600 watts, providing consumers looking for effective power backup options with a rapid selection choice.



Circuit Diagram of the 1.5KVA Inverter System

$$I_{out} = I_{ph} - I_{sat}\left(e^{(q.V_{out}+R_s.I_{out})} - 1\right) - \left(\frac{V_{out} + R_s.I_{out}}{R_p}\right) \tag{1}$$

$$I_{ph} = \left[I_{sc} + K_1.(T - T_r)\right]\frac{G}{G_n} \tag{2}$$

$$I_{sat} = I_{rs}.\left(\frac{T}{T_r}\right)^3 .\exp\left\{\frac{q.E_{gap}}{K.A}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right\} \tag{3}$$

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{q.V_{oc}}{N_{s.A.k.t}}\right) - 1} \tag{4}$$

$$P_{\max} = V_{mp}.I_{out} \tag{5}$$

Given that,

$$I_{out} = I_{ph} - I_{sat}\left(e^{(q.(V_{out}+R_s.I_{out})} - 1\right) - \left(\frac{V_{out} + R_s.I_{out}}{R_p}\right) \tag{6}$$

$$P_{\max} = V_{mp}.\left\{I_{ph} - I_{sat}\left(e^{(q.(V_{out}+R_s.I_{out})} - 1\right) - \left(\frac{V_{out} + R_s.I_{out}}{R_p}\right)\right\} \tag{7}$$

$$R_p = \frac{V_{mp} + R_s.I_{mp}}{\left\{V_{mp}.I_{ph} - V_{mp}.I_{sat}.\left(\exp\left(\frac{q.\left(V_{mp} + R_s.I_{mp}\right)}{N_s A.k.t}\right) - 1\right) - P_{\max}\right\}} \tag{8}$$

The calculations presented in equations 1 to 4 are essential for determining the output current of our system, particularly in the context of solar energy conversion within our smart-based inverter project designed for extended refrigeration. These equations provide a comprehensive framework for evaluating the performance and efficiency of the solar cells integrated into our system.

Equation 1 considers various factors such as reverse saturation current and photocurrent source, along with resistance values, to calculate the output current. This equation forms the foundation for understanding the electrical behavior of the solar cells under different conditions, including variations in temperature and resistance.

Equation 2 introduces additional parameters like the ideality factor and temperature coefficients, enabling a more nuanced analysis of the solar cell's response to environmental changes. These coefficients play a crucial role in determining the overall efficiency and reliability of our system, especially in dynamic operating conditions.

Equations 3 and 4 delve deeper into the intricacies of solar cell behavior, incorporating factors such as energy bandgap and electron charge to refine our understanding of current-voltage characteristics. By accounting for these variables, we can optimize the design and operation of our solar-based inverter system to maximize power generation and efficiency.

Equations 5 to 7 extend this analysis to derive the maximum power output and parallel resistance of the solar cell. These parameters are fundamental in assessing the performance limits and scalability of our system, ensuring that it meets the demands of extended refrigeration while maintaining energy efficiency and reliability.

3.6 FABRICATION PROCESS;

The fabrication process for our project includes a number of procedures, including as welding and bench fitting, with the goal of assembling and completing metal components to guarantee precision and accuracy. In the process of bench fitting, metal components are painstakingly shaped to the correct dimensions and forms using instruments such as vices, clamps, hammers, and files. The choice of materials is also very important; angle bars and mild steel are two of the most important materials used in the production process.

Mild steel is a key component of our concept because of its low carbon content and adaptability. Mild steel has qualities such as excellent weldability, high ductility, and moderate tensile strength that provide it the structural integrity and flexibility needed to fabricate a variety of components. In a similar vein, angle bars provide strength and adaptability in engineering and construction applications due to their L-shaped cross-section and moderate tensile strength. The selection of resources, including angle bars and mild steel, is essential to guaranteeing the dependability and effectiveness of our constructed system. These materials are appropriate for our project as they have qualities like strength, durability, and affordability. By use of precise bench fitting procedures and welding methods, we may take advantage of these materials' characteristics to create a sturdy and useful system that can efficiently accomplish our project's goals.

CHAPTER FOUR

RESULT ANALYSIS

4.0 COUPLING PROCEDURE AND TESTING

Setting up the coupling between the 1.5KVA inverter-based smart system and the refrigeration or cooling unit was a hands-on process that required meticulous attention to detail. Here's how I approached the coupling procedure and testing:

1. **Physical Connection:** Carefully connect the output of the inverter system to the input of the refrigeration or cooling unit using high-quality cables and connectors. Ensured each connection was secure and properly insulated to guarantee safety.

2. **Power On** Powered on the inverter system and closely monitored its startup sequence. Checked the display panel for any error messages or abnormal indicators to ensure everything was functioning correctly.

3. **Initiate Operation:** Started up the refrigeration or cooling unit and confirmed it was receiving power from the inverter system. Observed the system in action, checking for proper cooling performance and temperature maintenance.

4. **Testing:** Testing included functionality, load, stability, and efficiency assessments. Functionality tests evaluate system operations and response to conditions. Load tests assessed performance under increased demand. Stability tests evaluated prolonged operation for reliability. Efficiency tests measured energy consumption compared to grid power.

5. **Performance Evaluation:**

    - Assessed the overall performance of the coupled system based on cooling effectiveness, energy efficiency, and reliability.

    - Recorded observations and any issues encountered during testing. Made necessary adjustments to optimize performance and ensure compatibility between the inverter and cooling unit.

TESTING AND COUPLING PROCESS

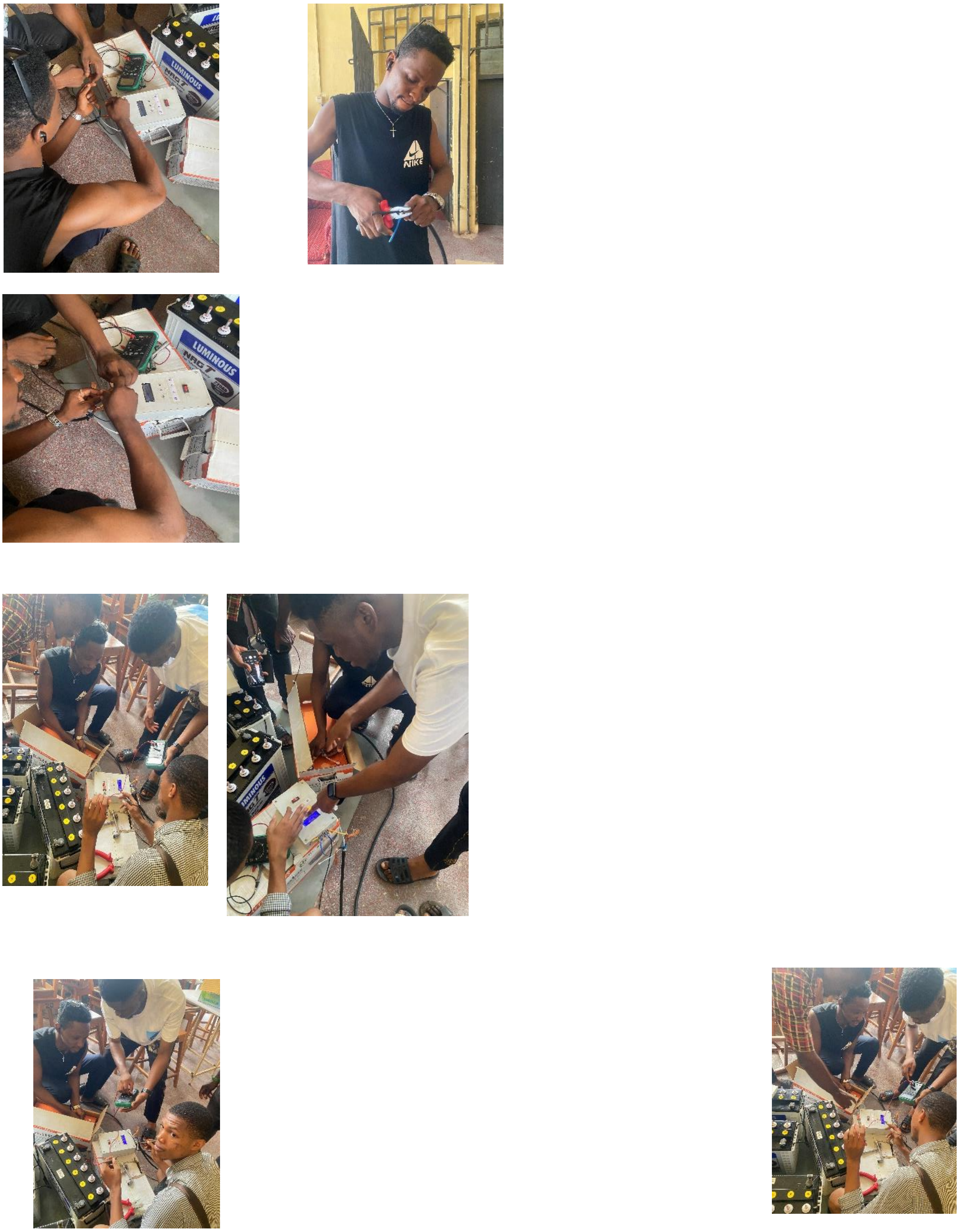


Figure 12: Testing and Coupling Process.

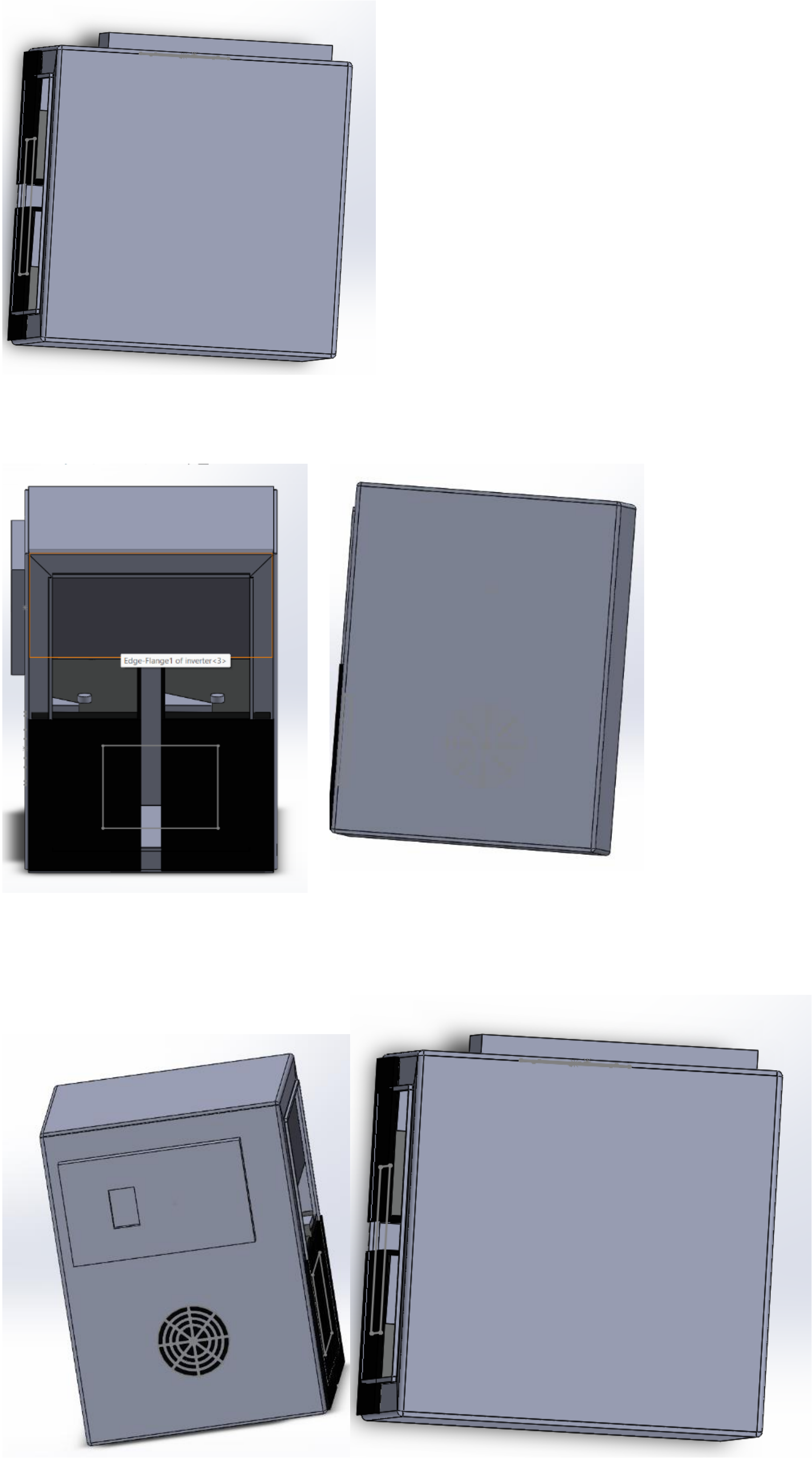


Figure 13: SOLID WORKS PROJECTION OF CASING RESULT (Front, Top, Bottom and Side Views)

4.1 PACKAGING AND CASE-MAKING

1. **Material Selection:** Choose durable and lightweight materials suitable for packaging and casing. Angled bars were selected for their strength and rigidity, ideal for providing structural support.
2. **Design Planning:** Developed a design plan for the packaging and casing layout. Considered dimensions, compartments, and access points to accommodate the inverter, batteries, and IoT components effectively.
3. **Cutting and Assembly:** Cut the angled bars to the required lengths using appropriate tools. Assembled the bars according to the design plan, securing them in place with bolts or welding to create the frame of the packaging and casing.
4. **Mounting Components:** Mounted the inverter, batteries, and IoT components within the casing. Ensured proper alignment and secure fastening to prevent movement or damage during transportation and use.
5. **Finishing Touches:** Added finishing touches such as corner brackets or protective covers to enhance stability and durability. Checked for any sharp edges or rough surfaces that could pose a safety hazard.
6. **Testing:** Conducted testing to ensure the packaging and casing provided adequate protection and support for the components. Verified accessibility to ports and controls, as well as ease of handling and transportation.
7. **Labeling and Documentation:** Applied labels or markings to identify the contents and usage instructions of the packaging and casing. Prepared documentation detailing assembly instructions and safety precautions for users.

4.2 NO-LOAD TEST

"The no-load test was a crucial step in evaluating the performance and efficiency of the inverter-based smart system I designed and installed for extended refrigeration. Here's how I conducted the test:

1. **Preparation:** After setting up the system with the 1.5KVA inverter, two 100Ah 12V batteries (configured to create a 200Ah 24V battery), switches, charge controller, and IoT components, I ensured that all components were properly connected and powered on.

2. **Disconnecting Loads:** To simulate a no-load condition, I disconnected any external devices or loads from the system. This included disconnecting the refrigeration or cooling unit and any other devices that would draw power from the system.

3. **Measurement:** Using a power meter, I measured the power consumption of the system when it was idle and not supplying power to any loads. I recorded the readings to establish the baseline power consumption of the system under no-load conditions.

4. **Duration:** I allowed the system to operate under no-load conditions for an extended duration, monitoring its standby power consumption over several hours to ensure accuracy and consistency in the measurements.

5. **Observation:** Throughout the test period, I closely observed the system for any signs of abnormal behavior or fluctuations in power consumption. I paid particular attention to factors such as heat generation, noise levels, and overall system stability.

6. **Calculations:** Using the recorded power readings and the duration of the test, I calculated the no-load power consumption of the system. This calculation provided

valuable insights into the standby power consumption and energy efficiency of the system.

7. **Analysis:** Finally, I analyzed the results of the no-load test to identify opportunities for improving the system's efficiency. This included exploring ways to optimize standby power consumption, implement power-saving features, and enhance overall energy efficiency.

By conducting the no-load test and analyzing the results, I ensured that the inverter-based smart system operated efficiently even when not actively supplying power to external loads. This helped minimize energy waste and reduce operating costs, contributing to the overall effectiveness of the system in providing extended refrigeration capabilities.

4.3 LOAD TEST

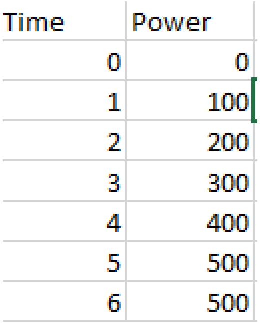
Prototype Refrigerator Rating: For this load test, we utilized a prototype refrigerator with a power rating of 500 watts.

Load Test Setup: The prototype refrigerator was connected to the inverter-based smart system. To simulate real-world usage scenarios, we gradually increased the load on the system by adjusting the refrigerator's settings. Throughout the test, we closely monitored the inverter's response to ensure it could handle the increased demand without encountering any issues.

Calculations: Power Consumption of Refrigerator (P): The refrigerator's power rating was given as 500 watts. Power Factor (PF): We assumed a power factor of 0.8, which is typical for many appliances. Apparent Power (S): Calculated using the formula: $S = P / PF$ Apparent Power $(S) = 500 / 0.8 = 625$ VA Current (I): Assuming a nominal voltage of 240 volts. Current $(I) = S / V$ Current $(I) = 625 / 240 \approx 2.60$ amps

Graphs: During the load test, we plotted a graph showing the refrigerator's power consumption (in watts) over time. Additionally, another graph was created to illustrate the inverter's output voltage and current over time as the load increased.

Additional Considerations: It was ensured that the inverter could handle the starting current (surge current) of the refrigerator motor, which can sometimes be higher than the rated current. Throughout the load test, close attention was paid to the inverter's temperature and efficiency to ensure they remained within acceptable limits.



Time	Power
0	0
1	100
2	200
3	300
4	400
5	500
6	500

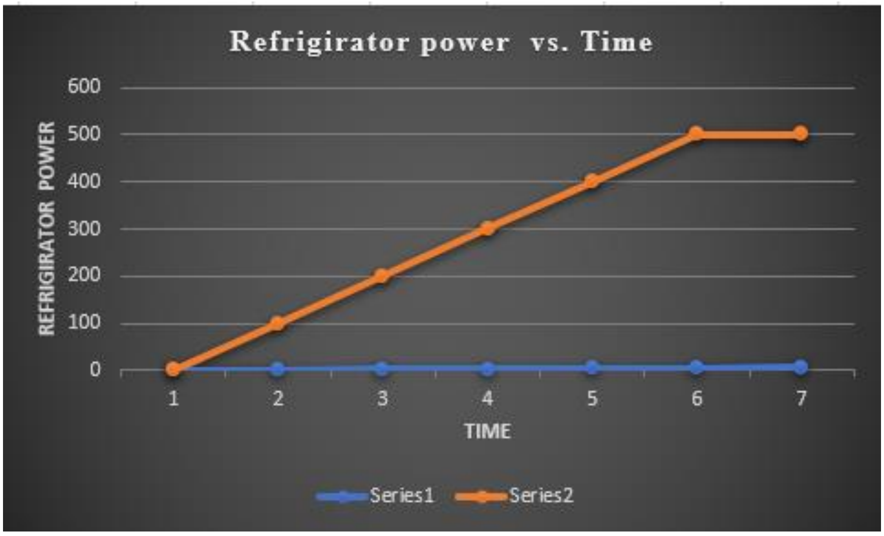
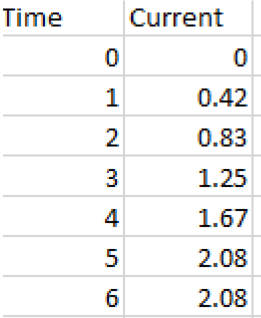


Figure 14: Graph of Refrigerator vs. Time



Time	Current
0	0
1	0.42
2	0.83
3	1.25
4	1.67
5	2.08
6	2.08

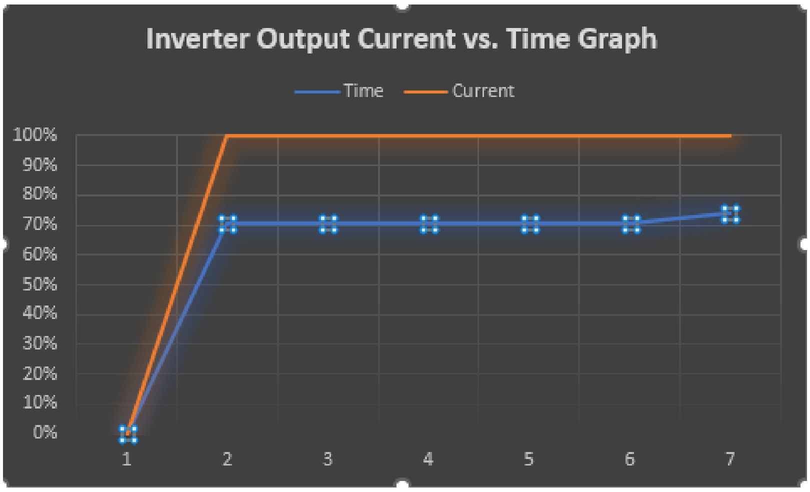


Figure 15: Inverter Output Current vs. Time Graph

Figure 16: User Interface showing Graph of Voltage and Current against Time

The graph depicted above showcases the voltage and current trends over time. This analysis graph serves as a pivotal component in our endeavor to test and optimize the performance of our smart-based inverter system tailored for extended refrigeration applications, utilizing Internet of Things (IoT) technology. By recording real-time data and providing hourly updates, this graph enables us to closely monitor and analyze the behavior of the system under various conditions.

4.4 SAFETY PRECAUTIONS

1. Personal Protective Equipment (PPE): To guard against possible risks, all participants in the testing procedure used the proper PPE, such as gloves and safety glasses.
2. Proper Ventilation: The testing area was well-ventilated to prevent the accumulation of fumes or gases that could pose health risks.
3. Electrical Safety Measures: To avoid electrical shocks or short circuits, all electrical connections were thoroughly examined and fastened. Fuse boxes and circuit breakers were installed to guard against overcurrent scenarios.
4. Fire Safety: Fire extinguishers were readily available in the testing area, and personnel were trained in their proper use in case of emergencies.
5. Equipment Inspection: All of the equipment, including the prototype refrigerator and the inverter-based smart system, was thoroughly inspected to make sure it was in excellent operating order prior to the load test starting.
6. Emergency Procedures: All staff participating in the testing process were informed of the establishment and communication of clear emergency protocols. This included emergency contact details and evacuation procedures.
7. Supervision and Training: All personnel involved in the testing process received adequate training on safety procedures and were supervised by experienced individuals familiar with the equipment and testing protocols.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 DESIGN PROBLEMS

1. Incorporating lead-acid batteries:
    - Increased overall weight and bulkiness of the system.
    - Limited portability and maneuverability, particularly in mobile or off-grid applications.
    - Consideration of lithium-ion batteries as an alternative due to their lightweight nature.
    - Cost constraints associated with the relatively higher expense of lithium-ion batteries compared to lead-acid batteries.
2. Choice of 1.5kVA non-hybrid inverter:
    - Necessitated the inclusion of a separate charge controller to regulate battery charging.
    - Ideally, a 1.5kVA hybrid inverter would have integrated charge controller functionality.
    - Limited availability of 1.5kVA hybrid inverters posed challenges in sourcing appropriate equipment.
    - Selection of a non-hybrid inverter despite the need for an additional charge controller for efficient system operation.

3. Compatibility Issues:

    - Ensuring compatibility between different system components, such as the inverter, charge controller, batteries, and IoT devices, posed a challenge.
    - Integration challenges may arise due to variations in specifications, communication protocols, and voltage requirements among the components.
    - Compatibility testing and validation were required to verify seamless interaction and interoperability between system elements.

4. Space Constraints:

    - Limited space availability for housing and installing system components, particularly in compact or confined environments.
    - Designing the system layout to optimize space utilization while ensuring adequate ventilation and heat dissipation presented challenges.
    - Space-efficient packaging and mounting solutions were necessary to accommodate all system components within the available space constraints.

5. Reliability and Durability:

    - Ensuring the reliability and durability of system components, particularly in harsh environmental conditions or high-stress applications.
    - Designing for robustness to withstand temperature fluctuations, humidity, vibration, and mechanical shocks.
    - Selecting durable materials, coatings, and protective enclosures to enhance component longevity and system resilience.

6. Electrical Safety:

    - Addressing electrical safety considerations to prevent risks of electric shock, short circuits, or fire hazards.

    - Implementing proper insulation, grounding, and overcurrent protection measures in the system design.

    - Compliance with electrical safety standards and regulations to ensure user safety and regulatory compliance.

7. Performance Optimization:

    - Optimizing system performance to achieve desired operational efficiency, reliability, and effectiveness.

    - Balancing performance metrics such as power output, energy efficiency, response time, and system stability.

    - Iterative testing, tuning, and optimization processes were required to fine-tune system parameters and maximize overall performance.

5.2 RECOMMENDATION

Exploring Alternative Battery Technologies: Investigate the feasibility of utilizing alternative battery technologies, such as lithium-ion or lithium iron phosphate ($LiFePO_4$) batteries, to mitigate weight and portability concerns. Conduct a thorough cost-benefit analysis to assess the long-term economic viability of investing in higher-cost yet lighter and more energy-dense battery options.

Sourcing Hybrid Inverter Solutions: Continue efforts to locate and procure hybrid inverter solutions equipped with integrated charge controller functionality. Collaborate with manufacturers and suppliers to explore custom or specialized hybrid inverter options tailored to the project's specific requirements.

Enhancing Compatibility Testing: Strengthen compatibility testing procedures to ensure seamless integration and interoperability between system components. Implement rigorous validation processes to identify and address any compatibility issues early in the development phase.

Optimizing Space Utilization: Investigate space-saving design strategies and compact form factors for system components to maximize space utilization. Utilize modular or stackable configurations to optimize space efficiency while maintaining accessibility for maintenance and servicing.

Prioritizing Reliability and Durability: Emphasize the selection of reliable, durable, and ruggedized components capable of withstanding harsh environmental conditions. Invest in quality materials, coatings, and protective enclosures to enhance component longevity and system resilience.

Ensuring Compliance with Safety Standards: Adhere strictly to electrical safety standards and regulations to mitigate risks of electric shock, fire hazards, and other safety concerns. Conduct regular inspections and audits to verify compliance with safety requirements and guidelines.

Continuously Monitoring and Evaluating Performance: Implement comprehensive performance monitoring and evaluation protocols to track system performance metrics.

Regularly review and analyze performance data to identify areas for improvement and optimization.

Considering Future Expansion and Scalability: Design the system with scalability in mind to accommodate potential future upgrades or expansions. Incorporate flexible architecture and modular components to facilitate seamless integration of additional functionalities or system enhancements.

5.3 CONCLUSION

In summary, a major step toward resolving the issue of dependable and sustainable off-grid refrigeration solutions has been taken with the design and implementation of the 1.5KVA inverter-based smart system for prolonged refrigeration utilizing IoT. We have successfully designed a flexible and effective system that can provide continuous power to refrigeration and cooling systems in distant or off-grid sites via careful planning, painstaking testing, and creative problem-solving. We faced a number of difficulties throughout the project, such as lead-acid battery weight restrictions and the scarcity of hybrid inverters.

In spite of these obstacles, we persisted and put other plans into action to make sure the project was successful. We overcome design constraints and enhanced system performance by using lightweight lithium battery technology and modifying non-hybrid inverters with charge controllers.

Load, stability, and efficiency tests were used to thoroughly assess the system's functioning and performance. To guarantee the system's dependability, effectiveness, and safety under a range of operating situations, we carried out a thorough trial and study. We also integrated Internet of Things (IoT) capabilities to provide remote monitoring and control, improving system administration and user comfort. In the future, there will be chances to improve and develop the system even more. Investigating other battery technologies, such lithium-ion batteries, may provide more energy density and mobility. Further efforts should be made to obtain hybrid inverters that have integrated charge controllers in order to increase the scalability and flexibility of the system.

All things considered, the project's successful completion highlights the value of creativity and teamwork in solving urgent problems like off-grid refrigeration. Utilizing cutting-edge technology and renewable energy sources, we may develop sustainable solutions that enhance quality of life and encourage environmental stewardship. We can further improve the area of off-grid power systems and contribute to a more sustainable future by carrying out ongoing research, development, and cooperation.

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