DESIGN OF HYBRID CLEAN AND RENEWABLE ENERGY SYSTEMS FOR TELECOMMUNICATION BASE STATIONS

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A PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF ENGINEERING (B.Eng)

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CERTIFICATION

This is to certify that the project titled "Design of Hybrid Clean and Renewable Energy Systems for Telecommunication Base Stations" for the award of the Bachelor of Engineering (B.Eng.) degree was conducted and duly presented by Idehen Nosa Gabriel (ENG1703949) of the Department of Computer Engineering, Faculty of Engineering, University of Benin, Benin City, Nigeria.

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Engr. Dr. E. O. Olaye

Project Supervisor

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Engr. Dr. A.I . Edeoghon

Head of Department

DECLARATION

This is to declare that this project "DESIGN OF HYBRID CLEAN AND RENEWABLE ENERGY SYSTEMS FOR TELECOMMUNICATION BASE STATIONS" for the award of the Bachelor of Engineering (B.Eng.) degree was conducted and duly presented by Idehen Nosa Gabriel (ENG1703949) under the supervision of Engr Dr. E.O. Olaye and it is a record of the project work in the Department of Computer Engineering, Faculty of Engineering, University of Benin, Benin City, in partial fulfilment of a Bachelor of Engineering in Computer Engineering degree.

______________________ ______________

Idehen Nosa Gabriel Date

(ENG1703949)

DEDICATION

This project is dedicated to God Almighty for the gift of life, love, favour, and kindness over my life. I also give my gratitude to my wonderful and loving family for their provision and backing towards the Successful completion of the project.

ACKNOWLEDGEMENT

I will like to express my gratitude to the almighty God for his mercy and grace over my life and for granting me the power and wisdom to embark on this project. I extend deepest appreciation to my beloved parents, I am thankful for your steadfast love, encouragement, and the sacrifices made. Your backing has been my driving force. I also extend special thanks to my siblings for standing by me, offering their encouragement, and serving as a constant source of inspiration.

I will like to express my heartfelt appreciation to my team members, research colleagues, Ehiorobo David Ogie and Anthony Evans Chukwuemeka, then dear friends for their encouragement, and firm backing have been a constant source of strength and motivation. Finally, I would like to appreciate my dedicated supervisor, Dr. E. Olaye, for his unwavering support, guidance, and invaluable insights throughout this journey.

ABSTRACT

This project aims to design and implement a hybrid clean and renewable energy system for telecommunication base stations, integrating wind and solar energy sources. The primary purpose is to enhance the sustainability, reliability, and efficiency of off-grid power systems, particularly in remote locations where traditional energy sources are costly and environmentally unsustainable. By leveraging the complementary nature of wind and solar resources, the project seeks to reduce dependence on fossil fuels, minimise carbon emissions, and improve the energy autonomy of telecommunication infrastructure. The ultimate goal is to create a resilient, ecofriendly energy framework that contributes to global efforts in combating climate change.

The methodology involved an extensive research and development process. Initially, a detailed literature review was conducted to gather insights from existing studies and identify areas for improvement. The design phase focused on developing a dual-input charge controller system capable of managing power from both solar panels and wind turbines. The system architecture incorporated essential components such as voltage and current sensors, metal-oxidesemiconductor field-effect transistor (MOSFET) drivers, and a battery storage unit. A prototype was simulated using Proteus Computer-Aided Design (CAD) software, followed by the construction of the physical model. The wind turbine was crafted from a modified fan motor, while the battery pack consisted of lithium-ion cells configured for optimal capacity. System testing was conducted under varying environmental conditions to evaluate performance and reliability.

The results demonstrated that, while the solar system consistently generated higher energy outputs, the wind turbine provided supplementary power, particularly during periods of low sunlight. The hybrid system showed potential in maintaining stable power generation throughout different times and seasons. However, challenges in wind turbine fabrication affected overall efficiency. The study concludes that integrating wind and solar technologies enhances the

resilience and sustainability of telecommunication base stations. Recommendations for future work include improving wind turbine fabrication, expanding testing across diverse climates, and exploring additional renewable energy sources to further bolster system autonomy and efficiency.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Telecommunication is a complex field that involves various components and technologies to transmit voice, data, and multimedia information over long distances (Abubakar S. et al, 2023). The facility is supported by structures like utilities and ground networks.

Telecommunication base stations play a pivotal role in facilitating global connectivity, providing essential communication services across vast geographical areas. The energy consumption of these base stations, primarily reliant on conventional sources. However, traditional energy sources, such as fossil fuels and grid electricity, have proven to be costly and environmentally unsustainable (Juraev N., 2023). Recognising the imperative to transition towards sustainable practices, there is a growing need to explore alternative energy solutions that are clean, renewable, and efficient.

The concept of utilising clean and renewable energy sources for telecommunication infrastructure aligns with global initiatives aimed at reducing the carbon footprint and mitigating the impact of climate change. Traditional power sources for base stations, often dependent on fossil fuels, not only pose environmental challenges but also present logistical issues in remote or off-grid locations. Therefore, designing and implementing a system that harnesses clean and renewable energy for telecommunication base stations holds significant promise for achieving a more sustainable and eco-friendly approach.

Renewable energy sources are increasingly being adopted as an alternative to power telecommunication systems, particularly in remote or off-grid locations (Abubakar S. et al, 2023). Studies have reported that renewable energy for telecommunications has several advantages, including reducing operating costs, increasing reliability, and minimizing environmental impact (Deevela et al., 2023). Therefore, the shift towards renewable energy in the telecommunications industry, is not only environmentally responsible but also economically viable in the long run. The integration of solar, rain, wind, and other renewable energy technologies presents an opportunity to decrease reliance on non-renewable resources, lower operational costs, and enhance the resilience of telecommunication networks, particularly in areas prone to power outages or lacking access to conventional energy grids in the long run.

This research project aims to contribute to the ongoing efforts in advancing clean energy solutions for telecommunication base stations. By exploring innovative technologies, assessing the feasibility of renewable energy integration, and addressing potential challenges, the project seeks to lay the foundation for a more sustainable and resilient telecommunication infrastructure. The outcomes of this study have the potential to not only revolutionise the energy landscape of telecommunication systems but also serve as a model for broader applications in the pursuit of a greener and more sustainable future.

1.2 Problem Statement

The current reliance on conventional energy sources to power telecommunication base stations poses significant environmental, economic, and operational challenges. Traditional energy solutions, often fuelled by non-renewable resources, contribute to carbon emissions, increasing the ecological footprint of telecommunication infrastructure. In addition, the dependence on centralized power grids introduces vulnerabilities, especially in remote or off-grid locations where access to reliable electricity is limited, renewable-energy-powered cellular Base Stations offer an ideal long-term solution for the mobile cellular network industry in off-the-grid areas without a mature electric network and in developed countries that suffer from continuous power cuts (Mohammed H. et al, 2017).

Furthermore, in using conventional energy sources, the rising operational costs, susceptibility to power outages, and the environmental impact of fossil fuel consumption underscore the urgent need for a standard shift towards cleaner and renewable energy solutions for telecommunication base stations.

1.3 Aim and Objectives

The aim of this project is to establish a sustainable and clean energy infrastructure for telecommunication base stations. The primary focus is on leveraging renewable energy sources, including solar and wind power, to enhance the overall environmental sustainability of the telecommunication network.

By integrating clean and renewable energy technologies, the project seeks to contribute to the reduction of carbon emissions, operational costs, and dependence on conventional energy sources. The overarching goal is to create a resilient and environmentally responsible energy framework for telecommunication base stations.

The project specifically focuses on the integration of both photovoltaic and wind power technology to enhance power generation efficiency within these critical communication infrastructure systems.

1.4 Objectives of the Study

The primary objective of this research is to enhance the reliability of the clean and renewable energy system designed for telecommunication base stations. Specific goals include:

1. Research and implement wind turbine technology, focusing on enhancing efficiency and reliability in varying wind conditions.
2. Assess the current dependence on conventional energy sources for telecommunication base stations.
3. Develop and test a hybrid system that combines photovoltaic and wind power technologies for enhanced energy generation efficiency.
4. Optimize the coordination and synchronization of photovoltaic and wind power systems to maximize overall power generation efficiency.

1.5 Scope of Work

This research is confined to the enhancement of clean and renewable energy system designed for telecommunication base stations. The primary focus is on optimizing the existing framework rather than introducing entirely novel architectures or exploring alternative energy models beyond the proposed system. Specifically, the study will concentrate on integrating solar and wind within the energy infrastructure.

1.6 Significance of Work

The design improvement of clean and renewable energy system for telecommunication base stations holds utmost importance across various areas with significant implications for environmental sustainability, economic efficiency, and the overall resilience of telecommunication infrastructure.

In environmental conservation, the adoption of clean energy technologies contributes directly to the reduction of carbon emissions, mitigating the adverse impacts of conventional energy sources on the ecosystem. This study aims to contribute in the fight of global warming and help combat climate change and promoting a sustainable future.

From an economic standpoint, the research holds significance in addressing operational costs associated with telecommunication base stations. The integration of renewable energy sources offers the potential for long-term cost savings, providing a more financially sustainable model for maintaining and expanding telecommunication networks.

The resilience and reliability of telecommunication systems are critical, especially during adverse conditions or power outages. The design enhancement of a clean energy framework for base stations ensures continuous and uninterrupted service, minimizing downtime and enhancing the overall robustness of communication networks.

Moreover, the study's implications extend to the broader context of technological innovation and societal progress. As telecommunication networks continue to play a huge role in global connectivity, a cleaner and more sustainable energy infrastructure aligns with the growing emphasis on corporate social responsibility and environmentally conscious practices.

CHAPTER TWO

LITERATURE REVIEW

2.1 Meta-Analysis Table for Design of Clean and Renewable Energy for Telecommunication Base Stations

This section is concerned with giving a critical examination of existing works relevant to the topic in question. A meta-analysis table is used to provide the information got from these works, such as; the different approaches used, the results obtained, and the limitations of previous research, in an organized manner.

Authors	Year	Title	Aim of the Work	Research Method	Result	Research Gap
Michael S. Okundamiya , et al.	2014	Design and control strategy for a hybrid green energy system for mobile telecommunication sites.	The aim of the study was to develop a costeffective and reliable hybrid green energy system for GSM base transceiver station (BTS) sites in isolated regions. The focus was on	The research utilized a genetic algorithm-based technique for optimal technoeconomic sizing of the system's components. The process simulation was conducted using meteorological data from three locations in Nigeria with varying climatic conditions (Abuja, Benin City,	The implementation of the proposed hybrid green energy system (HGES) resulted in an average energy throughput of over 12 kWh US$. The system aimed to satisfy the energy demand of the BTS sites while ensuring safe operation and	The paper identified a research gap in terms of the lack of performance indicators and comprehensive research on the use of green energy solutions, specifically for powering GSM BTS sites in Nigeria. The authors highlighted the need for further

			minimizing the technoeconomic cost of the system for the global expansion of mobile services.	and Sokoto).	minimizing costs.	research on alternative (hybrid) energy systems and enabling technologies for sustainable economic development.

O.E. Olabode, T.O. Ajewole, et al.	2021	Hybrid Power Systems for Off-grid Locations: A Comprehensive Review of Design Technologies, Applications and Future Trends.	The aim of the work is to review technologies, designs, and applications of hybrid power systems in remote locations across the globe. The goal is to identify, understand, and present useful directions for future research in energy systems.	Literature review, analysis, Comparison, and evaluation.	The work identifies the advantages of hybrid power systems over power systems based entirely on diesel resources. It highlights that hybrid power systems are scalable, reliable, cost-competitive, and sustainable. However, it also points out that several pilot projects of hybrid power systems in sub-Saharan Africa countries have failed in a short while after implementation, primarily due to reliability issues	The research identifies the research gap in the reliability of hybrid power systems, especially in pilot projects in subSaharan Africa countries. It suggests that addressing the issue of reliability is crucial to realizing a sustainable offgrid energy system for rural areas in developing countries.

Faran Ahmed et al.	2016	ICT and renewable energy: a way forward to the next generation telecom base stations	The aim of the work is to explore the potential benefits of renewable energy sources in making future systems greener and sustainable, particularly in the field of information and communication technology (ICT)	The method of research used in the work is described as a review of sustainable ICT solutions. The authors examined existing literature and research studies to gather information on the potential of renewable energy in ICT	The result of the work, suggests that renewable energy sources have the potential to make future systems, including telecom base stations, greener and sustainable. The paper outlines the various aspects of renewable energy, including generation, distribution, management, and its application	This research should focus on identifying the technological and infrastructural requirements, as well as the potential barriers, for effectively implementing renewable energy solutions in these smaller-scale applications, in order to achieve greater energy efficiency and sustainability.
Niranjan Rao Deevela et al.	2023	A review of renewable energybased power supply options for	The primary aim of the work is to provide a comprehensive analysis of various	The research method used in this work is a review of the existing literature and field installations. The authors gather	The result of the work is a comprehensive summary of various renewable energy-based	The research gap identified in this work is the need for the evaluation of appropriate low-carbon technologies and

		telecom towers	renewable energy-based systems and their advantages for powering telecom towers. The focus is on minimizing the carbon footprint of telecom towers and promoting the use of low-carbon technologies	information from various sources to analyse and summarize the renewable energybased systems used in powering telecom towers.	hybrid systems that can be used to power telecom towers. The systems discussed include solar photovoltaic panels, wind turbines, fuel cells, microturbines, and hybrid combinations of these technologies. The use of these systems helps reduce the consumption of fossil fuels and mitigate carbon emissions.	the development of policy instruments to promote renewable energy-based power systems for telecom towers. This indicates a potential area for further research and the implementation of sustainable practices in the telecom industry.

Juraev Nurmakhamad	2023	Modern Trends in Increasing the Energy Efficiency of the Base Station Subsystem	The aim of the work is to explore contemporary trends in the realm of telecommunications infrastructur	Literature review, analysis, Comparison, and evaluation.	The document discusses various trends and technologies that can contribute to the increased energy efficiency of the base station	There is need for empirical studies to evaluate the practical implementation and effectiveness of these trends and technologies. Further research

			e to promote a more sustainable and ecofriendly future by increasing the energy efficiency of the base station subsystem. Method of research used in the work: The document does not explicitly state the specific method of research used		subsystem, including the use of advanced hardware, deployment of small cells, implementation of Massive MIMO technology, adoption of Software-Defined Networking (SDN) and Network Function Virtualization (NFV), integration of renewable energy sources, utilization of energy-efficient cooling solutions, and the application of Artificial Intelligence (AI) for predictive maintenance. These advancements	is needed to assess the actual energy savings achieved, scalability, costeffectiveness, and potential challenges during deployment. Additionally, exploring the interoperability and compatibility of these advancements within existing infrastructure would provide valuable insights for optimizing energy efficiency in the base station subsystem. Bridging the gap between theoretical concepts and practical implementation, and assessing the real-world impact and feasibility of these approaches,

					can lead to reduced energy consumption and improved network performance.	would contribute to the effective implementation of energyefficient solutions in telecommunications networks

Dragicevic et al.	2014	Capacity Optimization of Renewable Energy Sources and Battery Storage in an Autonomous Telecommunication Facility	The aim of the work is to minimize the total cost of supplying a remote telecommunication station by utilizing renewable energy sources (RES) and battery storage. The focus is on finding the optimal RES generation and storage mix that ensures reliable and cost-	The research approach used in the work is a robust mixed-integer linear programming (RMILP). This optimization technique considers the intermittent nature of RES and incorporates a central energy storage system (ESS) consisting of a battery and a fuel cell. The optimization is performed under different budgets of uncertainty, resulting in various optimal solutions with different RES and storage	The research yields different optimal solutions based on the budgets of uncertainty considered. These optimal solutions provide insights into the ideal configuration of RES generation and storage capacities for the autonomous telecommunication facility. The results are then tested against a set of possible outcomes to simulate the future operation	-Limited utilization of robust optimization techniques in the context of renewable energy and battery storage optimization. - Lack of consideration for the capacity reduction of batteries over their lifespan due to cycling. - Limited design flexibility in determining the optimal RES mix and storage capacities
			effective power supply to the facility	capacities.	of the system.	

Juraev Nurmakhamad	2023	Use Of Alternative Energy Sources in Telecommunication Stations	The aim of the work is to highlight the bene0fits and potential of using alternative energy sources in telecommunication stations. It emphasizes the importance of sustainable and economically viable solutions to power challenges in the telecommunications industry	The research approach is a literature review or a descriptive analysis of the topic based on existing knowledge and information.	The document discusses the key benefits of utilizing alternative energy sources in telecommunication stations. It mentions that alternative energy sources, such as solar photovoltaic systems, wind turbines, and energy storage technologies, have the potential to reduce operational costs, minimize carbon footprints, enhance energy resilience, and contribute to rural connectivity. It also highlights	The work highlights some potential areas where further research and development may be needed. For example, it briefly mentions challenges such as initial setup costs, integration complexities, and variability in energy production. These challenges suggest that more research could be conducted to address the technical, economic, and operational aspects of implementing alternative energy solutions in

					the availability of government incentives and subsidies to encourage the adoption of alternative energy sources in the telecommunications sector	telecommunication stations. Also, additional research may be required to assess the long-term performance, scalability, and optimization of these solutions in different geographic locations and energy demands

Abubakar S. Sambo, Abdulsalam S. Mustafa, and Nasiru M. Bello	2023	Alternative clean energy for sustainable growth and development of the Nigerian telecommunications sector	The aim of the work is to explore the significance of telecommunications in Nigeria, particularly in the context of the Nigerian telecommunications sector, and to emphasize the need for transitioning to clean energy sources due to	The paper uses a combination of literature review, data analysis, and field observations and/or simulations.	The document presents the optimal power configuration for a BTS, which includes a 16kW PV (photovoltaic) array, 14kW Diesel Generator (DG), 32kWh Battery Energy Storage System (BESS), and Utility. This configuration achieves the lowest Levelised	There is lack of comprehensive solutions and strategies for transitioning the Nigerian telecommunications sector to clean energy sources, considering the challenges such as elevated costs and the industry's familiarity with fossil fuels. The proposed solutions mentioned in the

			the environmental challenges associated with the sector's heavy reliance on fossil fuels.		Cost of Energy (LCOE) at $0.255/kWh. The total estimated production is 32,520 kWh/year, constituting 100% of the energy requirement for the BTS	work, including local clean energy component production, capacity building, and regulatory alignment, may address some of these challenges but would require further investigation and evaluation.

Win Zaw Myo Htet et al.	2019	Construction of WindSolar Hybrid Charge Controller	The aim of the work is to construct a wind-solar hybrid charge controller using an Arduino Uno and high ampere dc relays. The controller is designed to manage the energy flow between the wind and solar power sources, the battery, and	The researchers used an Arduino Uno microcontroller board as the main control unit for the system. They employed LM358 dual operational amplifier IC for voltage and current sensing, and optocoupler and MOSFET for charging rate control. The research involved circuit design,	The constructed wind-solar hybrid charge controller successfully regulated the charging process of the battery based on the battery voltage. When the battery voltage reached a certain threshold, the controller switched the power source to a dump load to prevent	The authors highlight the importance and advantages of using charge controllers, suggesting that there might be a lack of awareness or understanding among users regarding the benefits and proper utilization of charge controllers in renewable energy systems.

			the load in a hybrid renewable energy system.	programming, and testing of the hybrid charge controller.	overcharging. Conversely, when the battery voltage dropped below a certain level, the system started charging the battery. The controller also provided various protection functions such as over-charge protection, shortcircuit protection, pole confusion protection, and automatic dump load function.	

2.2 Components of a Hybrid Power Energy with Solar and Wind

Hybrid power systems combining solar and wind energy sources harness the opposite but matching nature of solar and wind energy, ensuring a more stable and reliable power supply. An understanding the components of such a hybrid power system and their roles is crucial for maximizing efficiency and optimizing energy production.

The integration of solar and wind energy sources in a hybrid system enables more consistent and reliable power generation compared to standalone systems. Solar energy production peaks during the day, coinciding with lower wind speeds, while wind energy production tends to increase during the night and in periods of low solar radiation or cloudy weather. By combining these resources, hybrid systems can maintain a more stable power output throughout the day and across different seasons.

Each component in a hybrid solar-wind system plays a specific role in optimizing power generation and system performance. Solar panels and wind turbines capture renewable energy from the sun and wind, respectively, while the charge controller, battery bank, ensure efficient energy storage, management, and conversion. Together, these components form a versatile and sustainable power solution capable of meeting the energy needs of various applications.2. This project will focus more on the implementing the harnessing of wind energy to achieve optimum power supply and complementing it with solar.

2.2.1 Wind Turbine

A wind turbine is a device that converts the kinetic energy of wind into mechanical energy, which can then be converted into electricity. Wind turbines are a key component of wind power generation systems, harnessing the natural power of wind to produce renewable energy.

Wind turbines work on a simple principle of using wind to make electricity instead of using electricity to make wind, like a fan. Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

2.2.1.1 Types of Wind Turbines

The orientation of the rotation axis is a defining feature of wind turbines, determining whether they rotate horizontally or vertically. This characteristic serves as a key parameter for classifying and differentiating various types of wind turbine designs and configurations.

2.2.1.1.1 Horizontal Axis Wind Turbines (HAWT)

The most commonly used wind turbine is the Horizontal Axis Wind Turbine. These turbines use airfoils (aerodynamic blades) which are connected to a rotor by positioning in upwind or downwind. These are available either in two-bladed or three-bladed and operate at high speed. Machines with upwind rotors require a yaw, or tail vane, to help them orient into the wind while downwind rotors have blades that are coned allowing the turbine to orient on its own. One drawback identified with downwind rotors, however, is that they have been known to ‘walk’ around when trying to line up with winds during low-speed conditions, diminishing low wind speed energy production.

Current horizontal axis wind turbines utilize the aerodynamic lift force to rotate every rotor blade similar to when an airplane flies. Generally, the aerodynamic lift force works once they exposed to winds around both the higher and lower segments of a blade. The pressure difference which is formed between the top & bottom faces of the blade generates a force in the top direction of the blade. These turbines can be used in any direction of wind through the furling system. This system rotates the face of the rotor to come perpendicular to the wind’s direction. Therefore, the face of the rotor can be moved to that direction where it can face wind at the highest speed.

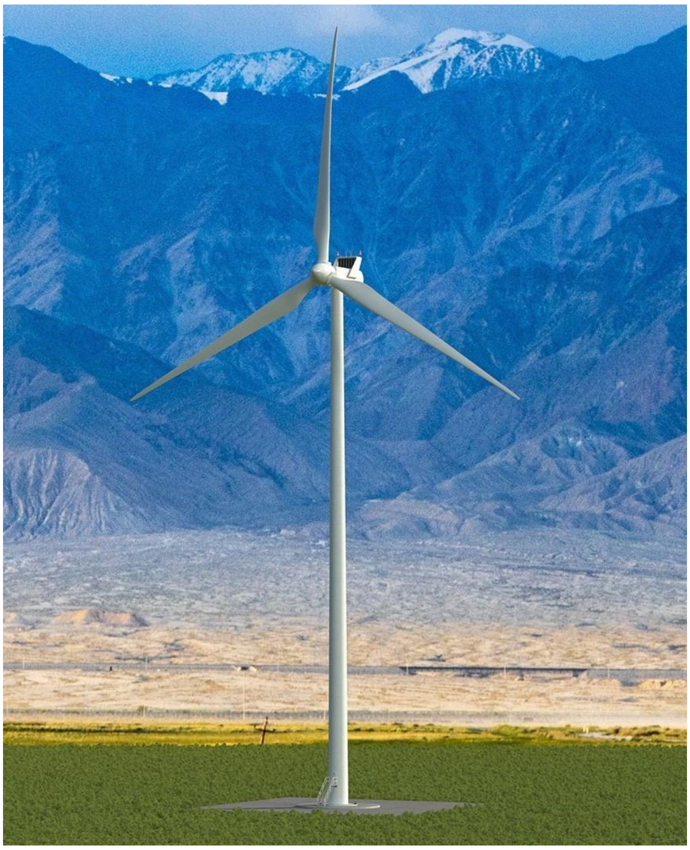

FIG 2.1: Horizontal Axis Wind Turbine (HAWT)

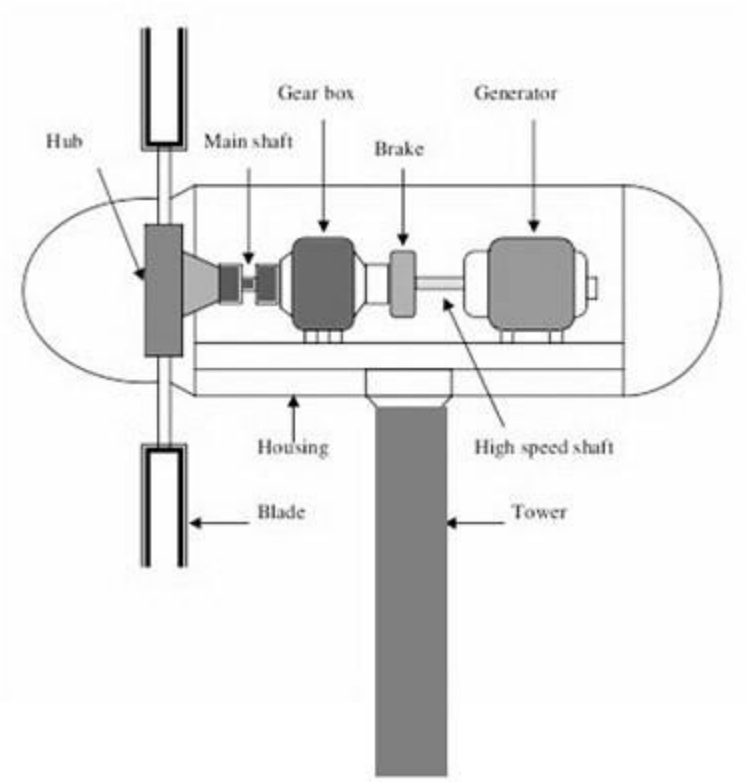

FIG 2.2: Components of a HAWT

2.2.1.1.2 Vertical Axis Wind Turbines (VAWT)

A vertical axis wind turbine (VAWT) is a type of wind turbine in which the axis of rotation of the rotor is perpendicular to the wind direction. The VAWT is designed in such a way that it does not need to be pointed into the direction of the wind; as a result of this, it does not require the wind-sensing and orientation mechanisms, this is an advantage on sites where the wind direction is highly variable. The gearbox and generator are positioned at the base of the turbine, which makes maintenance easy. Since the rotor is perpendicular to the wind speed, no specific aerodynamics are required for the design. The size of the VAWT is smaller than the HAWT which gives them various advantages. There are two types of VAWT: Savonius and Darrieus. Savonius wind turbines have blades built around the vertical shaft in a helix form, which looks like DNA. Darrieus turbines are like eggbeater shapes whose wings are longer and wider and attached to the upper and lower ends of the rotor shaft, giving a maximum swept area.

The drawbacks for the VAWT are that some designs produce pulsating torque. Drag may be created when the blade rotates into the wind.

Also, it is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten the service life.

However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50 per cent of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

FIG 2.3: Helical Savonius Vertical Axis Wind Turbine.

FIG 2.4: Darrieus Vertical Axis Wind Turbine

2.2.2 Charge Controller

A charge controller is a crucial component in renewable energy systems its primary function is to regulate the voltage and current generated from the renewable energy source, flowing to the battery bank or other energy storage systems. This regulation is essential to prevent overcharging and damage to the batteries, as well as to optimize charging efficiency. A hybrid charge controller designed for wind turbines and solar panels is a device that integrates the functionalities of charge controllers for both types of renewable energy sources into a single unit. This controller is intended to manage the charging process from both wind turbines and solar panels simultaneously, allowing for seamless integration of these renewable energy inputs into a single energy storage system, typically batteries.

The charge controller circuit does an important job; it prevents the battery from getting overcharged by controlling the electricity from the energy sources that goes into the battery.

2.2.3 Lithium-Ion Battery Pack

A lithium-ion or Li-ion battery is a type of rechargeable battery that uses the reversible intercalation of Li+ ions into electronically conducting solids to store energy. In comparison with other commercial rechargeable batteries, Li-ion batteries are characterized by higher specific energy, higher energy density, higher energy efficiency, a longer cycle life, and a longer calendar life. The battery pack is a collection of individual Li-ion batteries or cells connected together to provide a specific voltage and capacity. The electrical energy got from the renewable energy source is stored in this battery pack to be used to power other devices.

FIG 2.5: Lithium-Ion Battery

CHAPTER THREE

METHODOLOGY

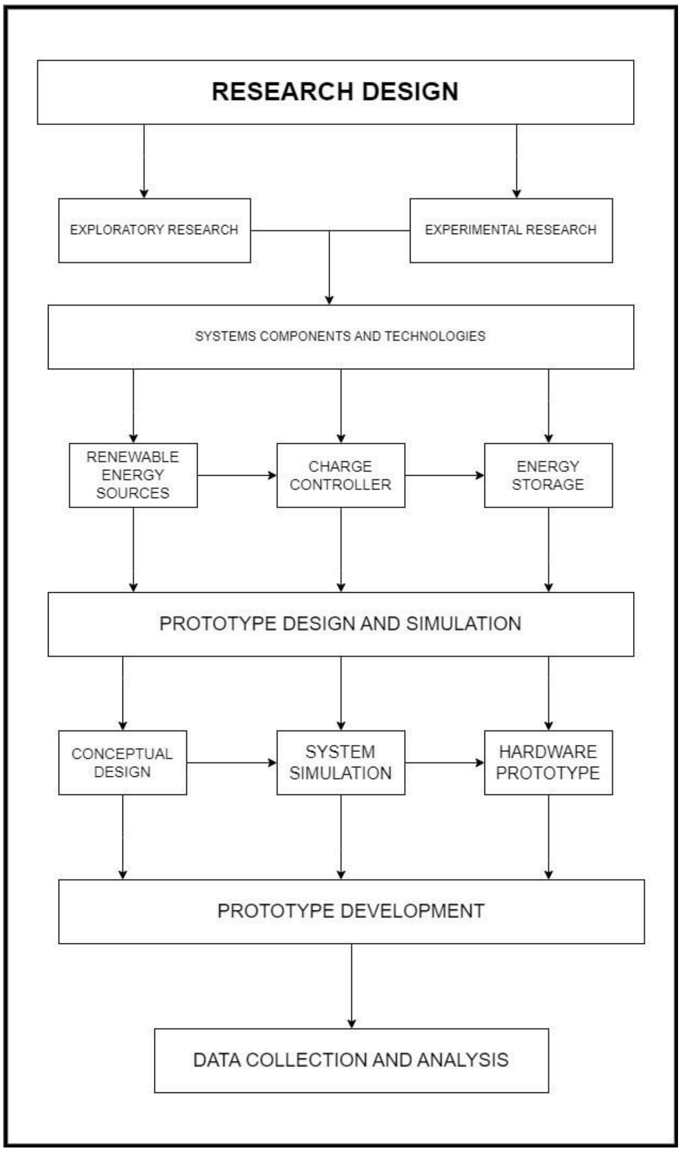

FIG 3.1: System Architecture

3.1 Workflow Process

From the workflow diagram above in figure 3.1, it can be seen that the project begins with intensive research design which consists of exploratory research and experimental research; this is basically literature review of similar works done in the past to gather data and information and improve on past works. After this stage comes the system components and technology which involved looking into various renewable energy sources, their implementation, via charge controller and storage of energy harvested from these sources. Furthermore, a prototype design was done to simulate the design of the system, after which the prototype was developed. The energy sources that were looked into are solar and wind energy sources, it was important to gather the appropriate components similar to solar-panel, windturbine, battery, charge-controller, cables etc. A solar panel was used to harvest solar energy and a wind turbine was used to harvest wind energy.

Both the wind turbine and the solar-panel are coupled to the charge-controller in demand to adjust the power generated from both energy sources. The charge-controller is coupled to the battery for power storage.

3.2 SYSTEM DESIGN

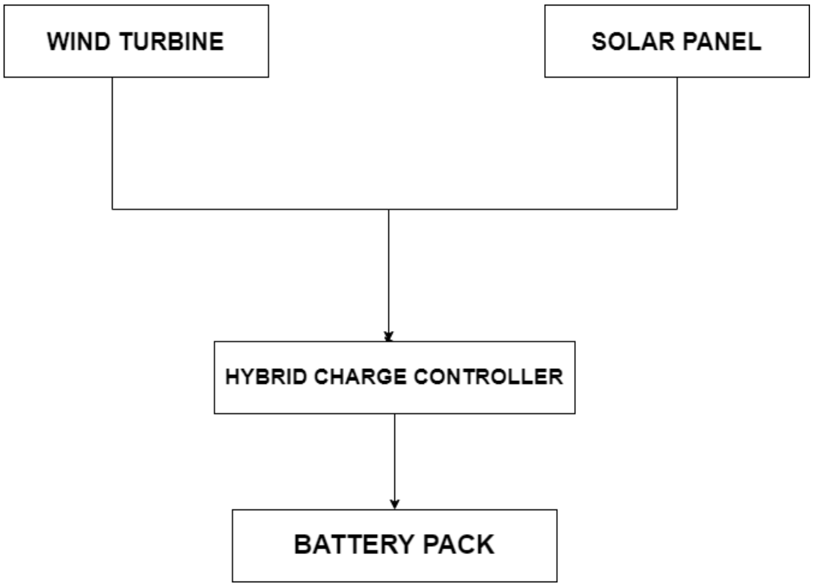

FIG 3.2: Component Flow Diagram

This work focused more on integrating wind turbine technology with solar technology for more power yield, in the UNIBEN terrain which was used for the testing, solar is more suitable for sunny periods of the day and wind turbines work their best during windy periods of the day like cloudy periods, evenings and nights during rain falls.

3.2.1 Simulation of the System

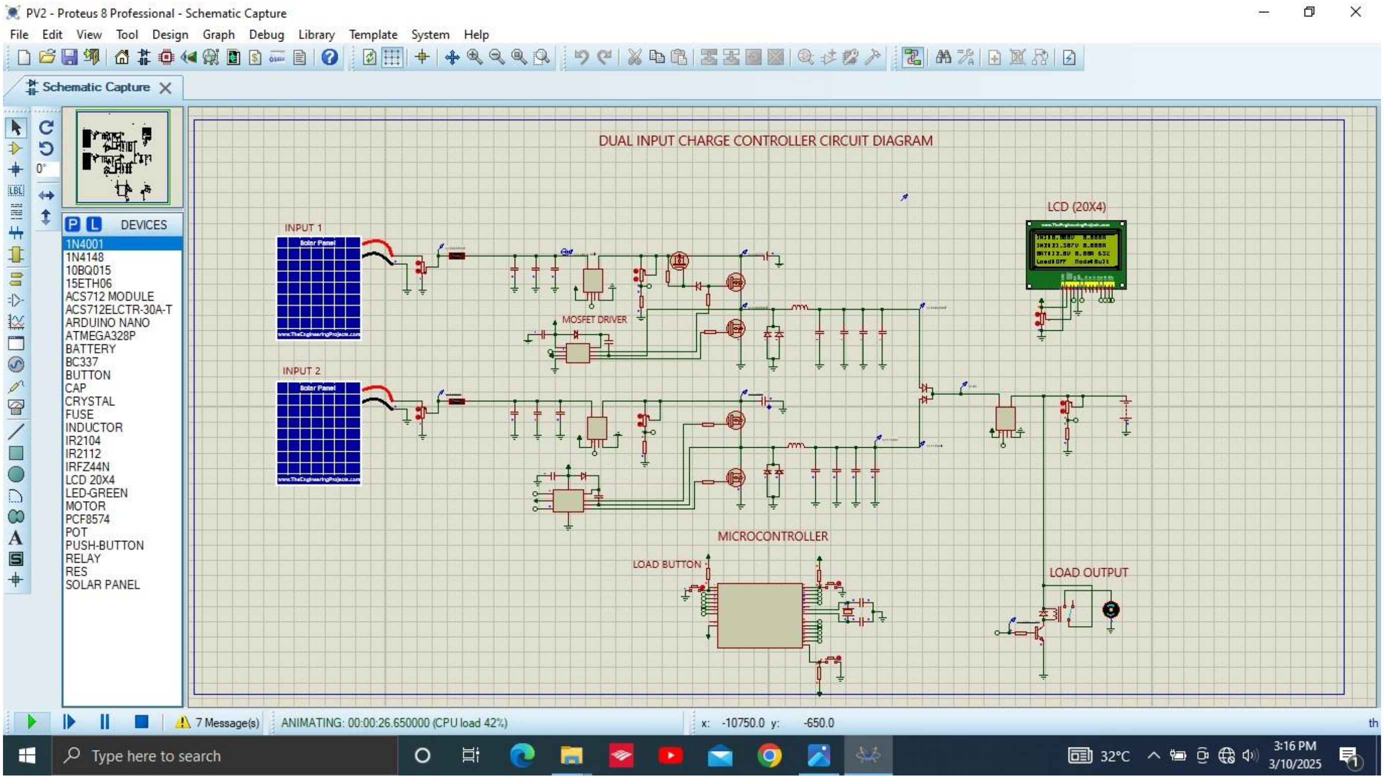

FIG 3.3: Project Simulation

Figure 3.3 shows the simulation of the system carried out using Proteus CAD software. It involves a dual input charge controller system employing an ATmega328P microcontroller chip. The system is designed to manage and regulate the charging of a battery using two distinct power inputs. The schematic above clearly shows the integration of various components necessary for the operation, including voltage and current sensors, relay modules, MOSFET drivers, and an LCD for system feedback.

The microcontroller is programmed to interface with multiple sensors. Voltage sensors connected through analogue pins A3, A4, and A5 are responsible for monitoring the voltages from Input 1, Input 2, and the battery, respectively. Current sensors connected to analogue pins A0, A1, and A2 provide real-time measurements of current from the same three sources. The relay, connected to digital pin 12, controls the load status, while MOSFET drivers (IR2104 and IR2110) are connected via pins 11, 9, and 10 to control PWM signals that regulate charging processes.

The simulation anticipates that the two input sources, possibly which are DC sources, will provide voltage levels adequate for charging the battery. The battery voltage is monitored continuously to ensure it remains within safe operational thresholds. The system dynamically adjusts the PWM duty cycles to control the current flow from the inputs, optimizing the charging process according to the battery's state. The battery charging process transitions through bulk, absorption, and float stages, determined by real-time voltage levels.

Expected outputs include the precise regulation of current and voltage to prevent overcharging or deep discharging of the battery. The relay manages the load connection, toggling it based on battery conditions and user input through a control button. The LCD screen displays live feedback of voltage, current levels, load status, and charging modes, ensuring the operator is continuously informed of the system's performance. Safety mechanisms are embedded in the system code, ensuring that any condition breaching predefined safety thresholds, such as overcurrent or overvoltage scenarios, results in an automatic shutdown to protect the battery and connected components.

This simulation clearly shows a sophisticated integration of both hardware and software to achieve an efficient, automated charge control system. The setup reflects real-world scenarios where dual power inputs need to be managed to ensure consistent and safe battery charging. The careful design and coding contribute to a stable and responsive system, ideal for this intended application and this power management system, to ensure battery longevity and efficiency.

3.2.2 Setting up the Wind Turbine

The wind turbine was assembled using the motor, the blades and the turbine stand of a Standing fan. The motor of a fan was converted into a turbine generator by magnetizing the rotor. The fan motor consists of the stator, rotor and coils. The motor is disassembled to separate the stator, rotor and coil.

FIG 3.4: Disassembled Fan Motor

FIG 3.5: Fan Rotor

The rotor is cut by shaving of small portions of its circumference's width to create four slits on it. Four paramagnets were attached to these slits in order to induce a current in the coil from the rotation of the rotor. The motor is coupled together and thus from magnetization, the assembly was transformed into a generator. The generator was attached to the blades and encased before the turbine stand was attached.

FIG 3.6: Paramagnets used for Magnetisation of the Rotor

FIG 3.7: Magnetised Rotor

FIG 3.8: Coupled Motor

3.2.3 Setting up the Charge Controller Circuit

The charge controller is a very important aspect of the design, as it controls and regulates the voltage and current from the renewable energy resources to ensure safe charging of batteries or the other devices connected to it.

3.2.3.1 Design Analysis of the Charge Controller

This section provides a comprehensive overview of the design process of the charge controller, breaking down each major component and explaining the rationale and methodology behind their selection and optimization.
The charge controller is designed to manage and regulate power from two independent sources to charge a battery efficiently and safely, making it a dual input charge controller. This process consists of several major blocks.

A visual representation of the block diagram of the entire dual input charge controller circuit as shown in Figure 3.7 illustrates the sequential flow of energy from the charge controller sources i.e. Solar panel or wind turbine.

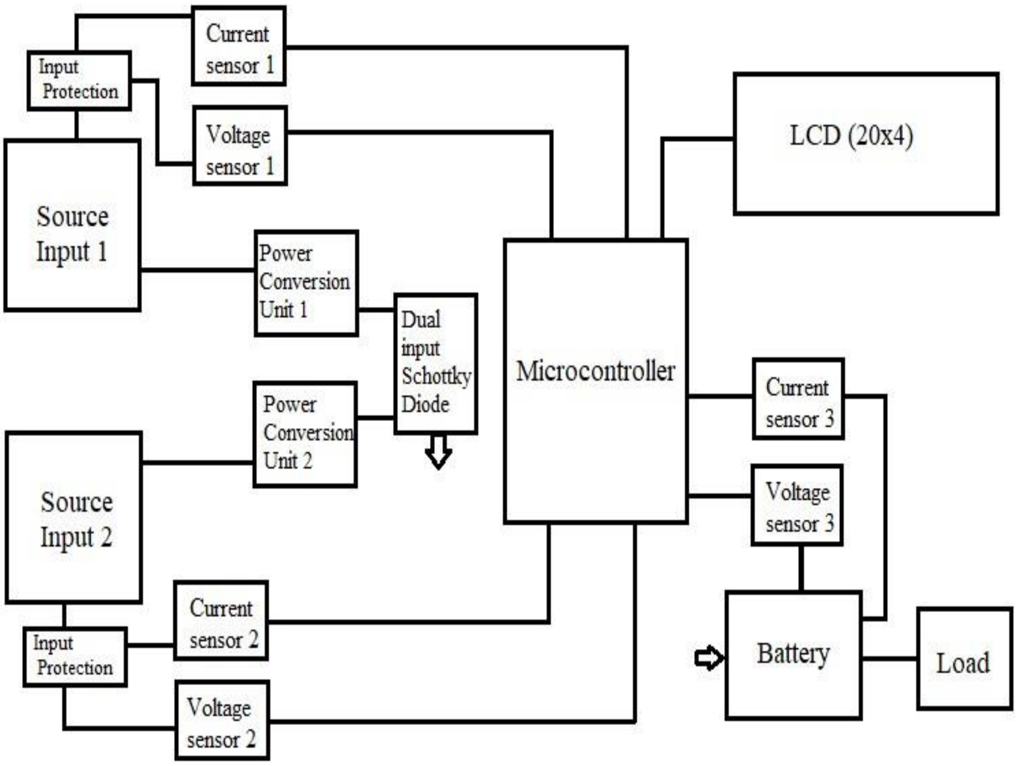

FIG 3.9: Charge Controller Block Diagram

3.2.3.2 Design Specifications of the Charge Controller

Inputs

1. Input Sources: Solar panel and auxiliary input (e.g., wind turbine or grid power).
2. Input Voltage (V_{in}): 12V (Nominal, assume range of 12V to 20V)
3. Current Handling Capacity: Up to 10A per source.

Outputs

1. Output Voltage: Adjustable, range of 12V to 24V
2. Output Current: 10A max
3. Switching frequency: 100kHz
4. Ripple current (ΔI_L): 20% of max current i.e. 2A

Microcontroller

1. Model: ATmega328P.

Display

1. LCD Type: 20x4 character LCD.
2. User Interface: Two toggle screens for displaying input/output voltages, currents, and status messages, navigated using a push button.

Sensors And Protection

1. Current Sensors: ACS712, for real-time current measurement.
2. MOSFET Drivers: IR2104 and IR2110 for efficient control of high-current MOSFETs.
3. MOSFETs Used: IRFZ44N (3 in parallel for enhanced current handling).
4. Protection:
5. Over-voltage and over-current protection.
6. TVS diodes rated for 450–500W to safeguard against voltage spikes.

Circuit Design

1. PCB Layers: 2-layer PCB design.
2. Power Management: Efficient handling of high currents with low power dissipation.

Efficiency and Performance

1. Boost Features: Circuit optimized for minimal losses.
2. Power Delivery: Reliable up to 10A output.

3.2.3.3 Building Blocks

a. The Input Source

The input source for your dual-input charge controller consists of two power inputs i.e. Solar panel input and an auxiliary input source (wind turbine or alternate DC source). The solar panel or auxiliary source supplies electrical energy to charge the battery. Input sources typically deliver power at varying voltages, like in the case of solar panels which delivers power in varying degree with the intensity of the sun.

b. Input Protection

The input protection of a charge controller is designed to safeguard both the controller and the input sources (such as solar panels or auxiliary power supplies) from potential damage due to electrical faults or adverse conditions. The input protection circuitry usually comprises a fuse which helps to prevent over-current spikes, and a transient voltage suppressor (TVS) diode which is a device used to protect unexpected over-voltages and surges caused by static electricity and power supply fluctuations.

c. Current Sensor

The current sensor is used to measure the amount of current that is generated by the input source. The current sensor detects the incoming current from both the input sources and also the battery, and sends detected values to the micro-controller which further processes the current signal and then performs other operations.

d. Voltage Sensor

The voltage sensor is used to detect and measure the voltage generated by the input sources and battery. It records the voltage values of the input sources and also the battery and sends these readings to the micro-controller for further processing.

e. Power Conversion Unit

The power conversion unit is the block that comprises the circuitry that manages the entire power within the charge controller, it consists of a DC-DC converter circuit that includes components such as power switches (I.e. MOSFETs, IGBTs), diodes, inductors, capacitors. Figure 3.8 shows the block diagram for the power conversion unit and their inter-related connections.

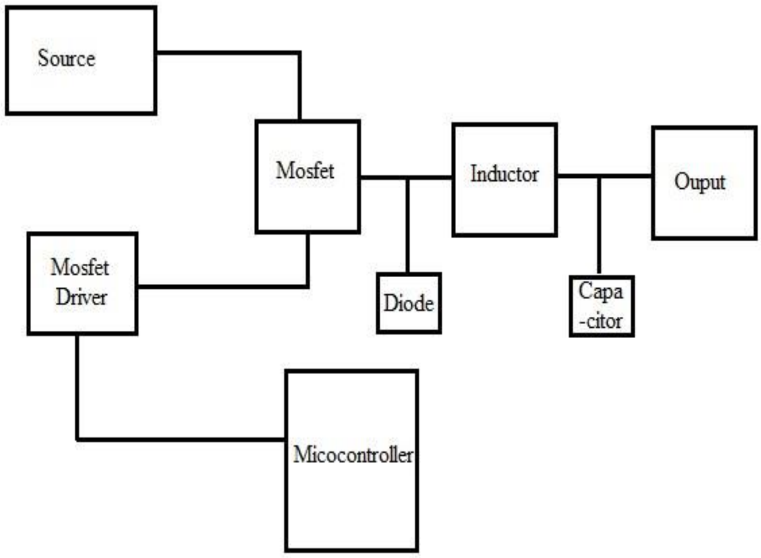

FIG 3.10: Power Conversion Unit

Mosfet Selection

The charge controller utilizes IRFZ44N N channel mosfet with a high current (I_d = 49A) handling capability and a maximum drain to source voltage (V_{ds} = 55V) within the operation of the charge controller.

Inductor Selection

The value of the inductor L is critical for maintaining continuous current flow and minimizing ripple.

For a buck converter: $L = \frac{V_{in}(1 - D)}{\Delta I_L . f_s}$

Where:

V_{out}: Output voltage

D: Duty cycle $D = \frac{V_{out}}{V_{in} + V_{out}}$

ΔI_L : Inductor current ripple (usually 20-40% of the maximum output current) f_s

: Switching frequency of the MOSFET

For $V_{out} = 36V$, $V_{in} = 24V$, $\Delta I_L = 4A$, $f_s = 100kHz$

D = 0.6

Hence, $L = \frac{24x(1-0.6)}{100x10^3x4} \approx 24uH$

Capacitor Selection

The capacitor is given by the relationship; $C = \frac{\Delta I_L}{8.f_s.\Delta V_{out}}$

Where:

ΔV_{out} is the allowable ripple voltage (Usually 1% of the V_{out}, I.e 0.36V)

Hence, $C = \frac{4}{8x100x10^3x0.36} = 138.9uF$

The closest capacitor that can cover for the 138.9uF is the 220uF(50V) electrolytic capacitor.

Diode Selection

The voltage rating for the power converter circuit is given as: 1.2 x $V_{out.}$

For V_{in} = 36V, the voltage rating is given as: 1.2 x 36V = 43.2V.

Also, the current rating for the diode is given as $I_{out} + \Delta I_L/2$

Hence, it has been calculated to be 22A.

In order for better efficiency and power management, we will select a diode of slightly higher value (I.e 30A, 50-60V)

f. Dual Input Schottky Diode

The dual input Schottky diode manages the power coming from both input sources and transfers the higher generated power to the output of the charge controller needed to charge the battery as well as power any external load device or circuit. The MBR4045PT dual input Schottky diode has been employed in this project because of its ability to meet the requirements of the power generated from the input sources.

g. Microcontroller

The microcontroller used in this project is the ATmega329P microcontroller chip. It is basically the brain of the charge controller and it plays many crucial roles in this circuit.

The **ATmega328P** primarily serves as the control unit, orchestrating how power from the two input sources is managed and directed to charge the battery safely and efficiently. It reads voltage and current data from sensors connected to each input and the battery. Using its **analogue-to-digital converter (ADC)**, it processes the analogue signals from these sensors, converting them into digital values for analysis. The microcontroller continuously monitors these parameters to determine the state of the battery and inputs.

```
// Enhanced Current Sensor Reading
float readACS712(int pin) {
  float Samples = 0.0;
  const int numSamples = 64;  // Increased samples for more stability

  for (int x = 0; x < numSamples; x++) {
    Samples += analogRead(pin);
    delayMicroseconds(10);
  }

  float AvgAcs = Samples / numSamples;
  float AcsValueF = (2.5 - (AvgAcs * (VREF / ADC_RESOLUTION))) / 0.185;

  return abs(AcsValueF);
}

// Improved Voltage Sensor Reading
float readVoltage(int pin) {
    float rawVoltage = 0.0;
    const int numSamples = 64;  // Increased samples for more stability

    for (int i = 0; i < numSamples; i++) {
        rawVoltage += analogRead(pin);
        delayMicroseconds(10);
    }

    rawVoltage /= numSamples;
    return (rawVoltage / ADC_RESOLUTION) * VREF * VOLTAGE_DIVIDER_RATIO;
}
```

FIG 3.11: Code snippet for current and voltage readings.

The microcontroller handles the **battery charging logic**, determining whether the battery is in the **bulk, absorption, or float charging stage**. Based on the battery voltage, it dynamically adjusts the charging mode to ensure optimal battery health. It also calculates the **battery's charge percentage** using the measured voltage, providing real-time information about the battery's status.

```
#define IR2104_INPUT_PIN 11 // Input pin for IR2104
#define IR2110_HIN_PIN 9   // HIN pin for IR2110
#define IR2110_LIN_PIN 10   // LIN pin for IR2110

// PWM Settings
#define PWM_FREQUENCY 50 // 50 Hz typical for most MOSFET drivers
#define INITIAL_DUTY_CYCLE 50 // 50% initial duty cycle

// Battery Charging Parameters
#define BATTERY_BULK_VOLTAGE 14.4  // Bulk charge voltage
#define BATTERY_ABSORPTION_VOLTAGE 14.7  // Absorption charge voltage
#define BATTERY_FLOAT_VOLTAGE 13.6  // Float charge voltage

// Battery Voltage Parameters
#define BATTERY_MIN_VOLTAGE 11.0  // Minimum voltage (empty)
#define BATTERY_MAX_VOLTAGE 12.6  // Maximum voltage (full)

#define ADC_RESOLUTION 1024.0
#define VREF 5.0
#define VOLTAGE_DIVIDER_RATIO 10.0 // Adjusted voltage divider ratio

LiquidCrystal lcd(RS, EN, D4, D5, D6, D7);

// Global variables
float dutyCycle1 = 50.0;  // Initial duty cycle for Input 1
float dutyCycle2 = 50.0;  // Initial duty cycle for Input 2
bool loadStatus = false;
String batteryMode = "Float";
```

FIG 3.12: Code snippet for Battery charging Logic

A key control role involves managing the **pulse-width modulation (PWM) signals** sent to the MOSFET drivers (**IR2104 and IR2110**). These signals adjust the duty cycle to control the power flow from the inputs to the battery, ensuring efficient energy transfer. The microcontroller also handles **relay switching** to control the load. It monitors a **button input** that allows manual toggling of the load status. The load is only powered when conditions are safe, and the user activates it.

To ensure system safety, the microcontroller executes a **safety check routine** that continuously evaluates voltage and current readings against defined thresholds. If parameters exceed safe limits—like battery overvoltage, excessive current, or dangerous input fluctuations—the controller disables charging and load output, safeguarding the system from damage.

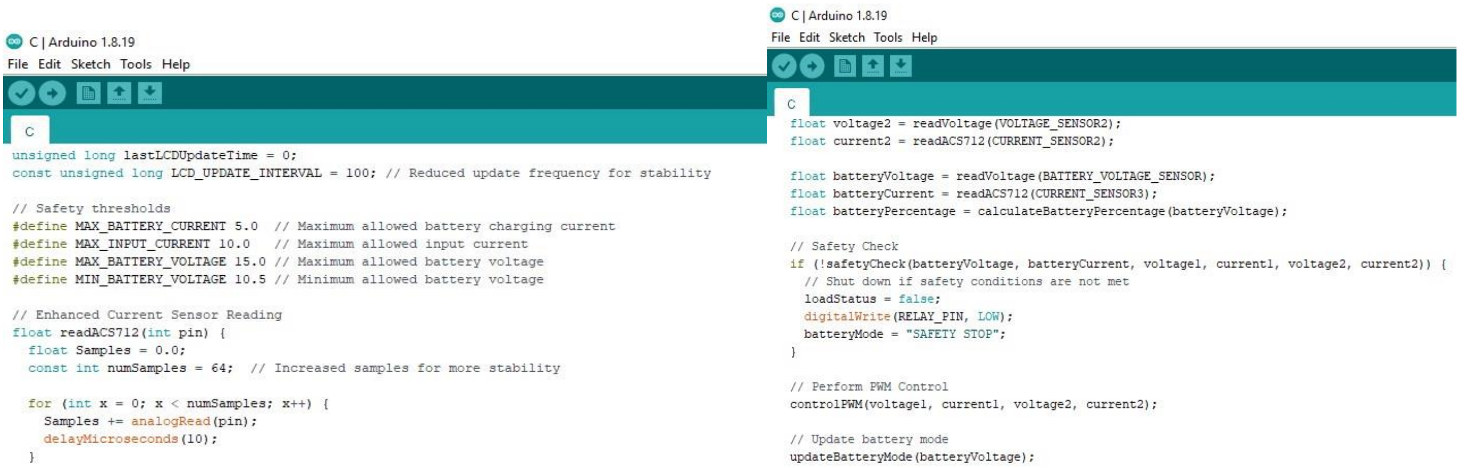

FIG 3.13: Code snippet for Safety check

The **ATmega328P** also manages **user interface feedback** by updating the **20x4 LCD display** with real-time information on input voltages, currents, battery status, load status, and charging mode. It ensures the display is refreshed at controlled intervals for clarity and readability. Additionally, it logs detailed system status information to the **serial monitor** for debugging and performance analysis.

Overall, the **ATmega328P** functions as the central intelligence of the charge controller system, ensuring precise measurement, control, safety enforcement, and user feedback for reliable and efficient battery charging.

h. LCD

The liquid crystal display (LCD) is an essential component in the charge controller that provides a visual interface for users to monitor and interact with the system. It shows the current state of the charge controller, displays charging parameters such as voltage, current, and power. It also allows users to navigate to menus to view more system parameters.

i. Battery

The battery is another crucial component in the charge controller, as it stores the energy generated by the sources, powers the entire circuit, including the ATMEGA328P microcontroller. It also provides power to the load when the primary power source is not available. The system is designed such that the battery powers the system before it can perform its charging functions.

3.2.3.4 Charge Controller Components

This section of the chapter discusses the various components that have been used in this project, highlighting their basic functions and some of their images.

They include the following;

1. Current Sensor (ACS712): ACS712 is a Hall-effect-based linear current sensor that measures current in a circuit. It outputs an analogue voltage proportional to the current flowing through a charge controller, it monitors the current flowing into or out of the battery to ensure it stays within safe limits.

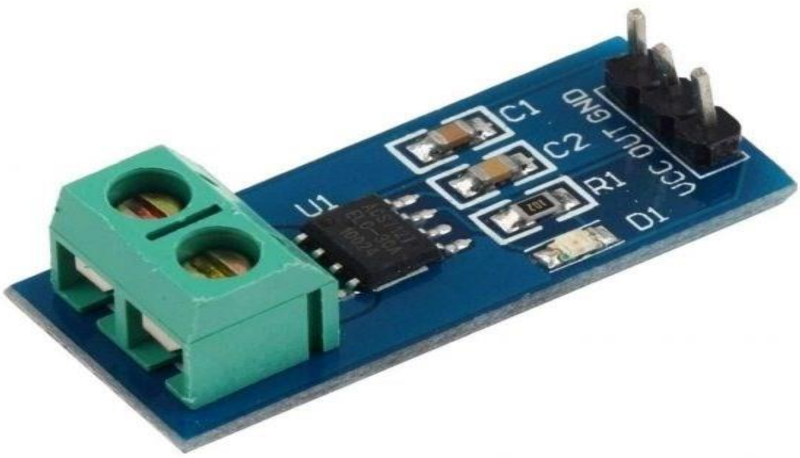

FIG 3.14: ACS712 Current Sensor

2. Voltage Sensor: A voltage sensor detects and measures the voltage level of a system and provides a corresponding output signal. It basically consists of a pair of voltage divider which is used to measure the voltage and scale its value to that readable by the micro-controller.

3. MOSFET Driver: A MOSFET driver is a circuit that provides the appropriate gate drive voltage and current to control MOSFETs efficiently, enabling high-speed switching with minimal power loss. The IR2104 and IR2110 MOSFET drivers have been utilized in this project. Now, let’s take a brief overview into both MOSFETs drivers;

a. IR2104: The IR2104 is a versatile and widely used half-bridge gate driver designed to control N-channel MOSFETs in high-side and low-side configurations. It is a dip 8 IC socket, and particularly well-suited for DC-DC conversion.

FIG 3.15: IR2104 MOSFET Driver

b. IR2110: The IR2110 which is a dip 14 IC socket is a high-performance dualchannel gate driver designed to control high-side and low-side N-channel MOSFETs or IGBTs in half-bridge or full-bridge configurations. It is widely used in motor drives, inverters, DC-DC converters, and advanced charge controllers due to its flexibility and robust features.

FIG 3.16: IR2110 MOSFET Driver

4. Atmega328p: The ATmega328P is an 8-bit micro-controller based on the AVR architecture developed by Atmel (now part of Microchip Technology). It is widely used in embedded systems, including applications like charge controllers, IoT devices, and Arduino boards. It is the brains of the charge controller as it performs various functions within the charge controller.

FIG 3.17: Atmega328P Micro-controller

5. MOSFETS: MOSFETs are essential components in power electronics due to their fastswitching speed, low conduction losses, and ability to handle high currents and voltages. The IRFZ44N MOSFET has been utilized for this project, it is an N-channel MOSFET commonly used in power applications due to its affordability, robust performance, and availability.

FIG 3.18: IRFZ44N MOSFET

6. LCD: The LCD is the unit of the charge controller that provides a visual platform for displaying system information parameters. it serves as a user interface, providing realtime information about the system's operational status, performance, and settings. The 20x4 LCD display has been integrated in this project.

FIG 3.19: LCD (20x4)

7. Relay: A relay is an electrically operated switch that uses an electromagnetic coil to control the opening and closing of electrical contacts. In charge controllers, relays play a vital role in managing power flow and ensuring system protection. A 5V relay has been used for the project for the load control.

FIG 3.20: 5V Relay

8. Fuse: A fuse is a passive safety device designed to protect electrical circuits by interrupting the flow of current when it exceeds a specified limit. In charge controllers, fuses play a critical role in safeguarding components, batteries, solar panels, and loads from damage due to over-current or short-circuit conditions.

9. TVS diode: A TVS (Transient Voltage Suppression) diode, such as the P6KE30A, is a specialized diode designed to protect electronic circuits from transient voltage spikes caused by events like lightning, power surges, or inductive load switching. The P6KE30A is commonly used in charge controllers to safeguard sensitive components from over-voltage conditions.

FIG 3.21: P6KE30A TVS Diode

10. Diode: The diode plays several functions in the charge controller which includes the blocking of reverse currents, protection against reverse polarity, surge protection, overvoltage protection etc. In this project, several power diodes including dual input diode like the MBR4045pt Schottky diode have been utilized to provide better system protection and power channelling in the charge controller.

FIG 3.22: MBR4045PT Dual Input Diode

11. Capacitor: Capacitors are essential components when it comes to electronic circuit and particularly in the case of charge controllers where they perform various functions like filtering, smoothing, voltage regulation and energy buffering. In this project, the electrolytic and the ceramic capacitors have been used due to their respective applications. The values of the capacitors include 100uF, 470uF, 22uF, 0.1uF etc.

12. Resistor: Resistors play a very crucial role in charge controller design, they are used in voltage divider pairs to measure the voltage, they also serve the purpose of limiting current flow in certain parts of the charge controller circuit.

13. LED: The light emitting diodes (LEDs) serve the function of power indication in the charge controller, they also help to display the charging status of the battery.

14. Buttons: Buttons are integral components of the charge controller as they perform a few functions which ranges from mode selection to system configuration.

15. Crystal Oscillator: The crystal oscillator is component of the charge controller that helps to provide a stable clock signal for the micro-controller. The crystal oscillator that has been integrated with the micro-controller operates at a frequency of 16MHz.

FIG 3.23: 16MHz Crystal Oscillator

16. Potentiometer: The potentiometer is a variable resistor that provides a way to adjust and fine-tune various parameters like voltage and current flow within the charge controller circuit.

17. Voltage Regulator: The voltage regulator is used to regulate the amount of voltage flowing within the charge controller, and providing a stable voltage for the charge controller of 5V, and also other circuit components that utilize a voltage up to about 15V. The 7805 and 7815 voltage regulators have been for this project.

18. Transistor: The transistor acts as a switch to control the relay, which in turn connects or disconnects the load from the output voltage. It is used to amplify the control signal from the microcontroller to drive the relay. The BC337(NPN) transistor has been used as the transistor for the relay control.

19. Inductor: The inductor is a passive electronic device that plays a key role in the charge controller, it serves various functions like filtering, energy storage, and voltage regulation. It is incorporated in the buck converter circuit to provide a stable and efficient power to the battery.

20. Heat sinks: The heat sink is also an important component of the charge controller that helps to dissipate heat generated by the power electronic components, such as MOSFETs and diodes.

FIG 3.24: Heat Sink for Thermal Management

3.2.3.5 Charge Controller Circuit Design

This section discusses the connection of the various circuit components of the charge controller and includes the overall circuit diagram that incorporates all the components working together. In this project, the circuit diagram and the PCB circuit has been designed using Proteus CAD software.

A. Circuit Diagram

The dual-in charge controller circuit diagram as shown in Figure shows the specific circuit components as utilized for this project and how each of these components are connected to one another to perform efficiently in the charge controller.

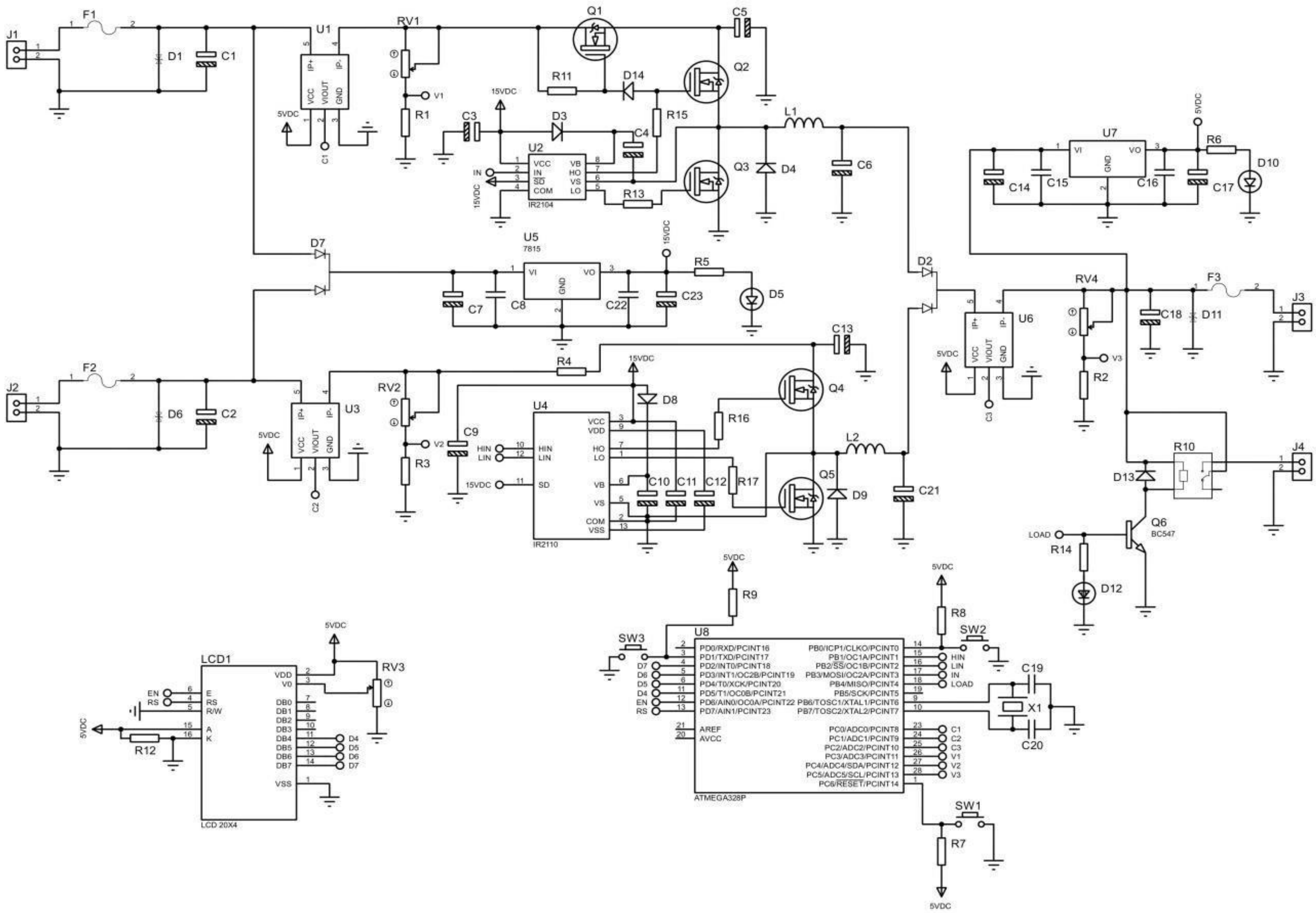

FIG 3.25: Dual Input Charge Controller Circuit Diagram

B. PCB Design

The dual input charge controller circuit has been designed on a printed circuit board as shown in Figure using Proteus CAD software. Here, proper design management has been employed to ensure that the circuit works efficiently in accordance with the circuit simulation. The PCB design has been implemented on a two-layer board and proper heat management has been incorporated into the designed board.

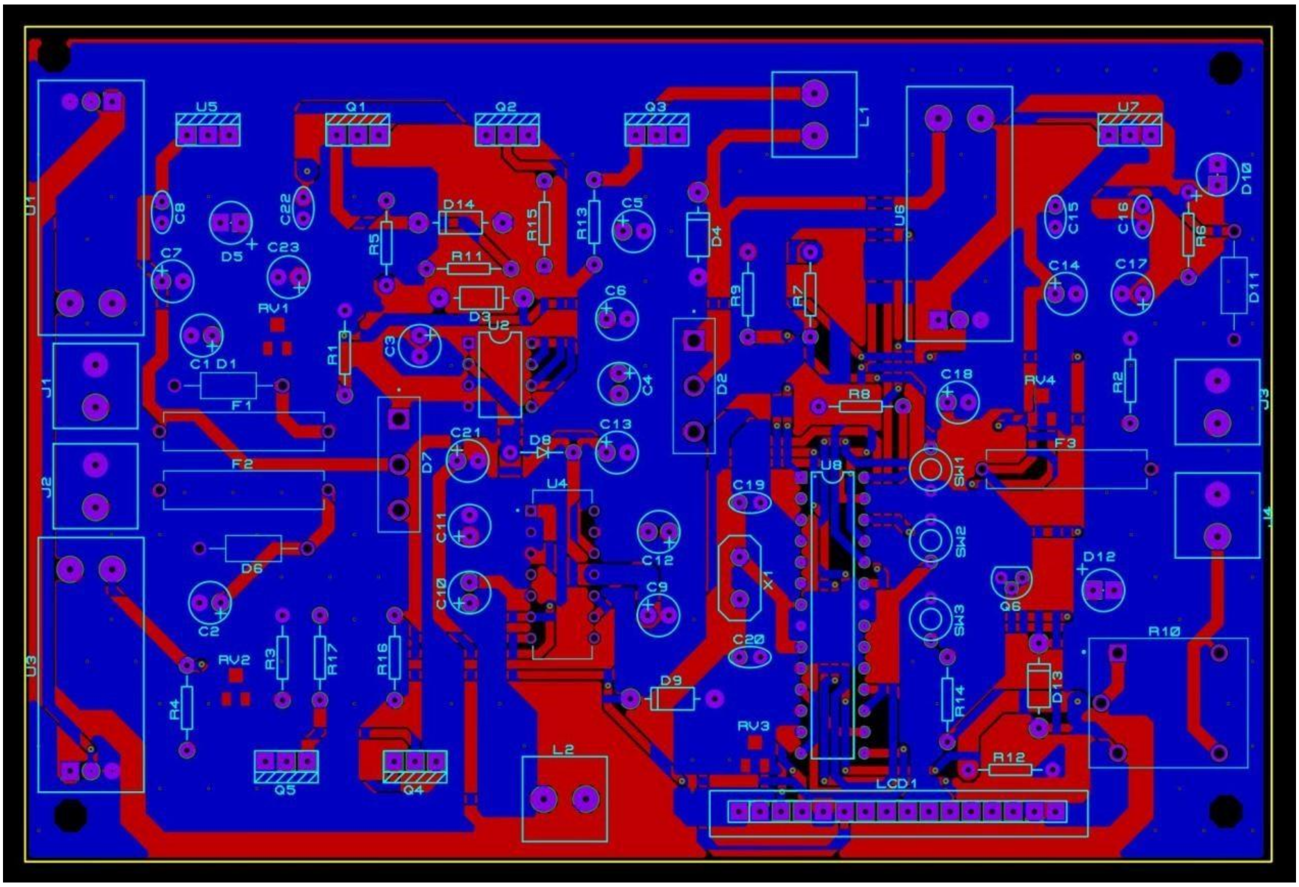

FIG 3.26: Dual Input Charge Controller PCB Design

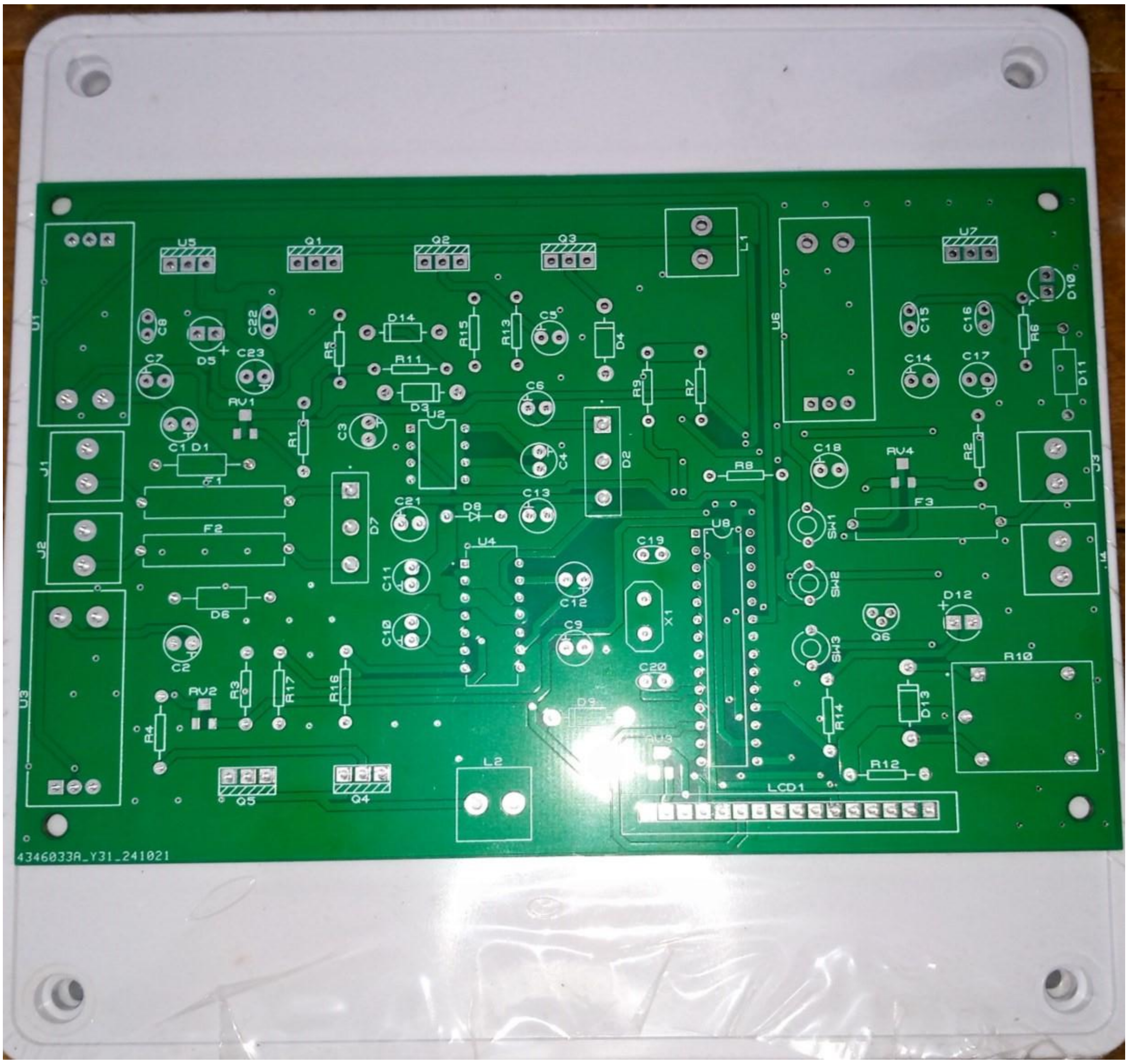

FIG 3.27: Dual Input Charge Controller PCB

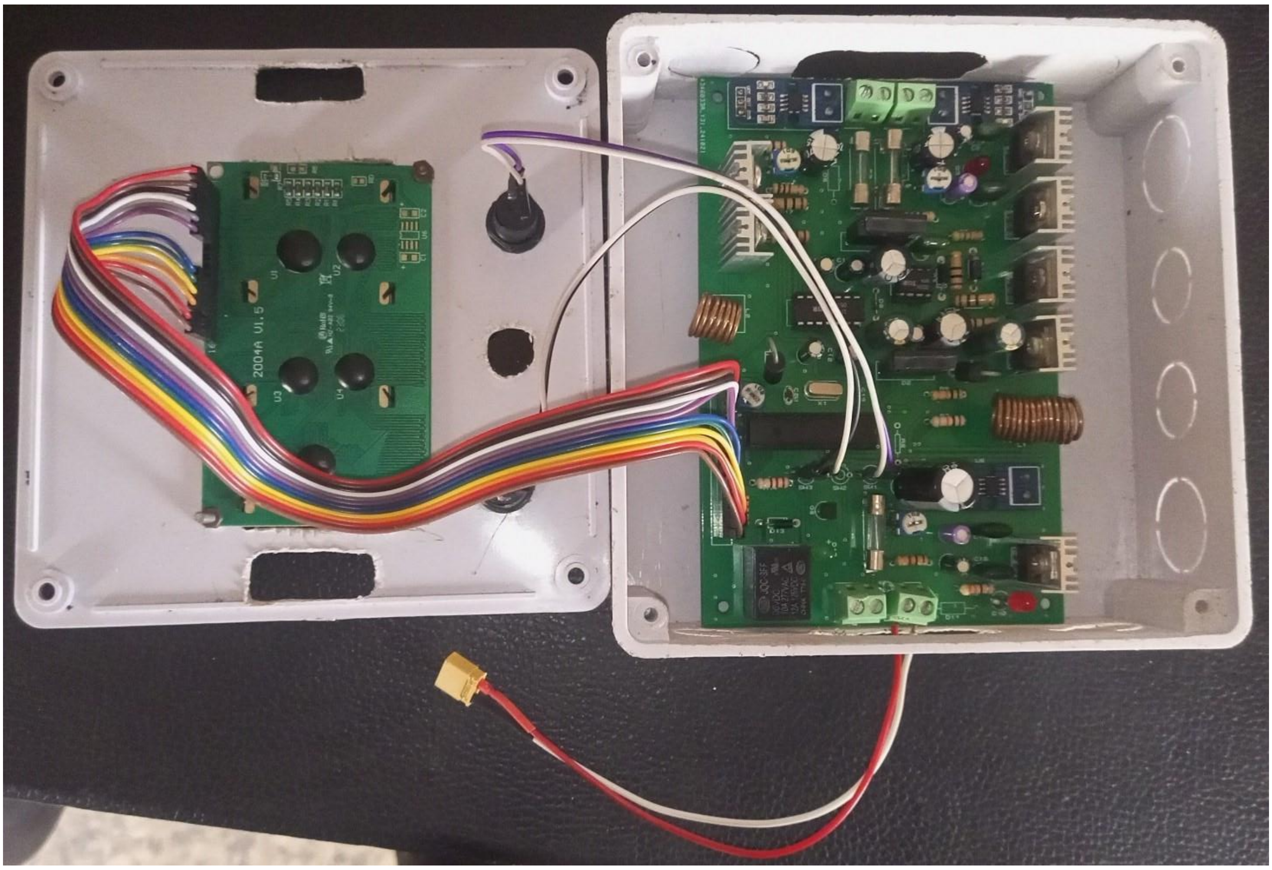

FIG 3.28: Internal View of the Dual Charge Controller

3.2.4 Setting up the Battery Pack

The battery pack is the storage device for storing the energy that is harvested from the renewable energy sources. It is made up of 12 lithium-ion batteries, each rated at 3.7V and 2000mAh. Four of these batteries are connected in parallel (that is the all the positive terminals connected together and negative terminals together) to increase the capacity of the battery to 8000mAh. This parallel connection is replicated to get 3 sets of parallel battery connections. These 3 sets are then connected together in series (that is positive terminals to the negative and vice versa), giving as a battery pack with a nominal capacity of 11.1V and 8000mAh. The battery pack will take up to 12.6V when fully charged. The battery pack is connected to the charge controller circuit to regulate the current and voltage flowing to it.


FIG 3.29: The Battery Pack

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Result Presentation Overview

The results and discussions related to the testing of the wind turbine, various solar panels and the charge controller, the output of the system as well as the overall power output of the hybrid system. The data obtained from these tests are essential for assessing the performance and viability of the hybrid renewable energy system.

4.2 Hybrid Power Generation System Testing

Due to the complimentary nature of wind and solar system, the system was tested at different times of the day to get the optimal energy generation capacity of both systems. The wind turbines capacity was tested at evenings and night time at the Akalu Ibiam Hostel (Hall 4) of the university of Benin. The solar system was tested at daytime and also at evenings. The speed of the fan blades generates different voltage and current and at different days, time and season and are greatly affected by weather conditions. The solar panel also generate different currents and voltage with different intensity of sun beams, with high intensity generating higher voltages and currents, and lower intensity generating lower voltages and current. The battery percentage before and after charge was also taken account of as well as the time of charge. This testing was done over a period of 10 days. It should be noted that the volage reading recorded below represent the mean voltage values of the highest and lowest observed values during each test.

Table 4.1 Hybrid Power Generation testing table

S/N	Date	Wind Turbine Voltage Generated (V)	Solar Panel Voltage Generated (V)	Battery Voltage before charge (V)	Battery \Charge After (V)	Voltage Difference
1	11/02/24 11:30–12:45	2.30	15.80	9.08	10.49	1.41
2	13/02/24 19:05–19:25	6.18	1.43	10.23	10.25	0.02
3	15/02/24 09:45–10:05	1.54	8.13	10.27	10.96	0.69
4	18/02/24 18:30–18:55	4.11	3.63	10.89	10.91	0.02
5	19/02/24 11:29–12:02	0.94	9.11	10.90	11.92	1.02
6	22/02/24 21:00–21:35	6.37	0.0	11.86	11.88	0.02
7	25/02/24 13:30–13:45	0.45	13.45	11.63	11.96	0.33

8	01/03/24 11:10–11:55	3.13	10.13	11.47	11.98	0.51
9	03/03/24 17:30–18:05	0.00	3.12	11.78	11.79	0.01
10	05/03/24 20:30–21:15	4.52	0.00	11.77	11.77	0.00

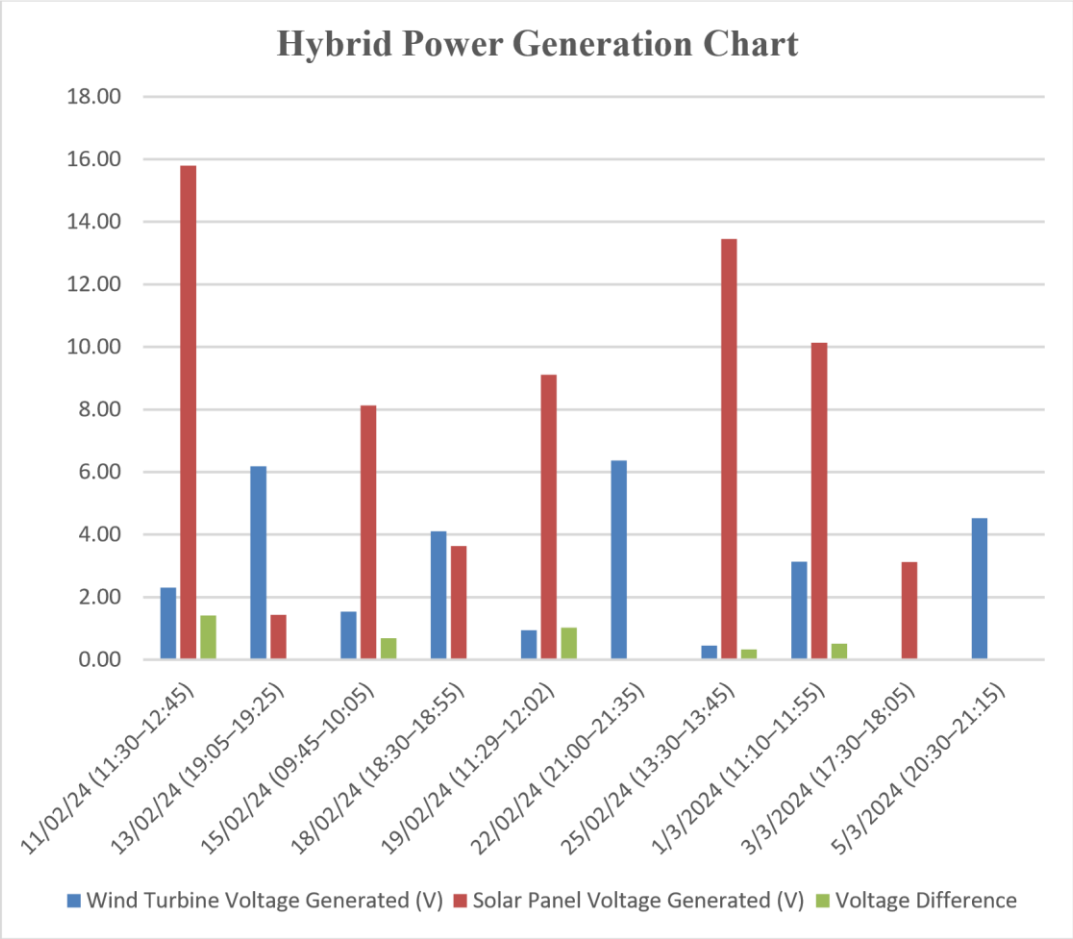

FIG 4.1: Hybrid Power Generation Chart

4.21 Analysis of System Result

From Table 4.1 it is evident that the solar system generated more energy that the fabricated wind turbine system. The wind turbine system added little to no voltage and energy to the set up due to some complications in the fabrication system.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project focuses on the integration of wind turbine technology into the existing solar configuration for telecommunication base stations which presents a promising avenue for enhancing the sustainability and reliability of off-grid power systems. When combining wind and solar resources, the hybrid system can capitalize on the complementary nature of these renewable energy sources, where the combination helps reduce the inconsistent power supply that standalone systems often face. This approach ensures more consistent power generation throughout the day and year.

Moreover, the incorporation of a wind turbine into the energy mix offers additional benefits beyond those provided by solar energy alone. Wind turbines can generate power even during periods of low sunlight, such as at night, thereby extending the operational hours and reliability of the base station. This diversification of energy sources enhances the system's overall energy yield and reduces dependence on fossil fuels or grid-supplied electricity, contributing to environmental sustainability and cost savings in the long term.

The integration of wind turbine technology with the existing solar configuration for telecommunication base stations represents a significant step towards achieving clean, reliable, and sustainable energy solutions in remote and off-grid environments.

5.2 Recommendation

For future research and development, the following recommendations are made:

1 To advance the development of such hybrid systems, additional research is required to enhance the DIY or personal fabrication of wind Turbines. Meanwhile, commercially available turbines that adhere to established design specifications offer a viable solution for immediate implementation.

2 The performance of hybrid electricity generation systems should be further evaluated in different climates and environments.

3 Due to the high demand of materials and components to be used, the cost of hybrid electricity generation systems should be reduced

4 A monitoring system should be implemented to ensure real time tracking of battery performance, for fault detection and analysis, to collect data analyse and plan based on this data.

5 Exploring other alternative clean and renewable energy methods like piezoelectricity and biogas power generation, is crucial for achieving autonomy from fossil fuels and gridsupplied electricity.

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