UNIVERSITY OF BENIN

DEVELOPMENT AND ANALYSIS OF A HYBRID ELECTRICITY GENERATION SYSTEM USING SOLAR ENERGY AND WIND ENERGY

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CERTIFICATION

This project was carried out by EKERETE, BERECHIAH LINUS with Matriculation Number ENG1804731, a student of Department of Computer Engineering, Faculty of Engineering, University of Benin, Benin City, and is hereby certified.

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DEDICATION

I simply commit this work to God Almighty, acknowledging His immeasurable blessings and guidance that have sustained me during the process of this research. Firstly, I'm overwhelmingly thankful for the precious gift of life bestowed upon me. It is through His grace and mercy that I have been allowed to embark on this journey and witness its completion.

I spread my gratitude to my wonderful plus loving family for their provision and backing. Also, to my project supervisor, Engr. Dr. Isi Edeoghon whose guidance and directions impacted so much to me in short period of time.

I am grateful to God for blessing me with sound mind, allowing me to think critically, analyze, and comprehend the complexities of this research. His divine wisdom has illuminated my path and provided clarity amidst the challenges encountered along the way.

Moreover, I am grateful for abundance grace bestowed upon team members throughout this research. It is by His unmerited favor that doors have been opened, resources have been made available, and solutions have been revealed. I acknowledge that my achievements are a result of His boundless grace and mercy.

In addition, I thank God for granting me peace amidst the demanding nature of this work. His calming presence has alleviated anxiety and provided me with the strength to persevere during moments of uncertainty. His peace has been my constant anchor, keeping me grounded and focused on the task at hand.

Lastly, I sincerely appreciate His unwavering guidance throughout this research journey. His divine direction has steered me towards the right path, guiding my choices, and enabling me to make meaningful contributions. I recognize that my accomplishment is a testament to His loving guidance and presence in my life.

May this work be a testament to His goodness and a source of inspiration to others?

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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.

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ABSTRACT

Because of the disadvantages linked with the utilization of fossil fuels, eventually a rising interest in increasing the adoption of renewable energy systems. Nonetheless, integrating renewable energy systems into the grid poses numerous challenges concerning constancy, consistency, system operation, and power quality. Lesser hybrid renewable energy systems (HRES) are compact power systems that encompass energy sources and storage units to efficiently manage energy production and consumption. Real-time monitoring of HRES is crucial as it provides precise data for the system operator to assess overall performance and detect any anomalies. In this study, an IoT-based design for HRES is presented, comprising a wind turbine and a photovoltaic system. The suggested design comprises four distinct layers: power, data collection, communication network, and application. Given the wide display of communication technologies available and the lack of a standardized communication framework for HRES (Hybrid Renewable Energy Systems), this study introduces communication models specifically customized for HRES. The monitoring factors are grouped into three categories: electrical, grade, and environmental data. Additionally, the research incorporates network modeling and mockup, with special responsiveness to vital features like network arrangement, link capacity, and latency, all of which are widely analyzed and discussed.

Besides, the collective interest in renewable energy systems is driven by the awareness of the downsides connected with the widespread use of remnant fuels, such as pollution and climate change. Governments, industries, and individuals have recognized the urgency to transition on the way to cleaner and more viable energy sources.

As renewable energy systems become more prevalent, the integration of these systems into the existing power grid becomes a complex and multifaceted challenge. The successful integration requires addressing issues related to structure operation, ensuring steadiness and consistency, and continuing high power value to meet the demands of consumers.

Small hybrid renewable energy systems (HRES) have emerged as a viable solution to harness energy from multiple sources and manage it efficiently. These compact systems

combine various renewable energy sources, such as wind turbines and photovoltaic systems, along using energy storage units. By intelligently optimizing energy production and consumption, HRES can offer a reliable and constant power supply.

Real-time monitoring of HRES is crucial for their effective operation. It enables the system operator to access accurate and up-to-date information about the system's performance. This information is vital for making informed decisions, optimizing energy utilization, and promptly identifying and resolving any abnormal conditions or malfunctions.

To ease real-time monitoring, this work proposes an Internet of Things (IoT) based architecture for HRES. The architecture is designed with four distinct layers to facilitate efficient data flow and communication. The power layer is responsible for energy generation and storage, while the data acquisition layer collects relevant data from various sensors and devices.

The communication network layer ensures seamless connectivity between different components of the HRES architecture, enabling smooth data transfer. To end with, the application layer processes and analyzes the collected data to offer meaningful perceptions to the system operator.

Lastly, one of the significant challenges faced in HRES monitoring is the absence of a standardized communication model. To address this issue, the work defines communication models specifically tailored for HRES. These models aim to establish a common framework for communication, enabling different components to exchange data efficiently.

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CHAPTER ONE

1.1 INTRODUCTION

1.2 BACKGROUND OF THE STUDY

The utilization of energy has transformed over time in response to shifts in human energy consumption patterns. While initially, renewable resources like wind, water, and biomass served as the primary sources of energy for supplying heat, illumination, and practical power, it was the energy contained in fossil fuels and, more recently, nuclear power that drove the substantial growth of the global industrial, residential, and transportation sectors throughout the 20th century. However as the consumption of remnant fuels has increased, motivated by both population growth and an increase in our standard of living, so too have concerns regarding energy security and the adverse environmental effects of greenhouse gases.

Unpredictability in imported energy markets affecting petrol prices and availability have long raised the issue of internal energy security. In addition, recent concerns over the limited supply of fossil fuels and the green-house gases released by fossil-fuel combustion have spurred efforts to utilize renewable resources such as wind, sunlight, biomass, and geothermal heat–to meet energy demands. (Abd Ali et al., 2019)

As a result, Renewable Energy (RE) technologies, including solar, wind, hydro, biomass, geothermal, and hydrogen energy, have been introduced for electricity generation as a response to the ongoing environmental challenges. These technologies are gaining significant traction due to their eco-friendly traits and their capacity to produce electricity with minimal or zero emissions of air pollutants. The growing awareness of environmental cleanliness within society is further driving the interest in RE. Beyond contributing to sustainability, RE also holds economic worth. It benefits the economy by reducing the cost of electricity generation, as it generates energy with natural, renewable resources. (Ang et al., 2022)

Though the acceptance of RE sources for power generation is increasing, majority of power generation is still effected by exploiting remnant fuel due to the intermittency of RE and the high initial cost. Numerous renewable energy sources, such as geothermal, tidal, wind, and solar, offer various benefits and shortcomings. For instance, tidal energy has restrictions, as it can only be effectively connected near coastlines. Geothermal energy, on the other hand, requires extensive infrastructure for heat extraction from the Earth. Meanwhile, solar and wind energy are more versatile as they are readily accessible in a wide range of conditions but wind does not flow constantly and sun particle emission is only present approx. 8 to 10 hours a day.

One way of overcoming this drawback is by utilizing more than one renewable energy resources so that whichever source fails the other source will keep generating the electricity. Hybrid energy system is the combination of two energy sources for giving power to the load. In other words it can define as "Energy system which is fabricated or designed to extract power by using two energy sources is called as the hybrid energy system." Hybrid energy system has good reliability, efficiency, less emission, and lower cost. (Ashish S. Ingole & Prof. Bhushan S. Rakhonde, 2016)

In this proposed system, solar and wind power is used for generating power. Solar and wind has benefits than other non-conventional energy sources. Both the energy sources have greater availability in all areas. The cost of setup is relatively cheap and there is no necessity to find special position to set up this system.

1.3 STATEMENT OF THE PROBLEM

The feasibility of wind and solar energy working together needs to be fully studied especially in our tropical climes as both have the capability to complement themselves depending on weather conditions and time of the day.

1.4 AIM AND OBJECTIVES

The purpose of this project is to design and implement an efficient solar and wind energy system with IoT technology for monitoring and managing the flow graphs, input and output signals.

The **goals** of the project are:

1. To design a solar and wind energy hybrid system

2. To integrate IoT technology for real-time monitoring of the system's performance.
3. To implement the solar and wind energy system in a real-world scenario and evaluate its performance.

1.5 SCOPE OF THE PROJECT STUDY

The researches will emphasis on the technical, economic, and environmental aspects of solar and wind energy generation and their integration into the existing power grid. This project will also focus on the plan and execution of a solar and wind energy scheme with IoT technology for monitoring and handling the flow graphs, input and output signals. The implementation of the system will be carried out in a real-world scenario, and its performance will be evaluated.

The scope of the project study includes:

1. **Overview of Solar and Wind Energy Technologies**: The study will be responsible for a general idea of solar and wind energy technologies, including their working principles, advantages, and limitations.
2. **Technical Analysis**: The study will analyze the technical aspects of solar and wind energy generation, including the plan and construction of solar PV and wind power plants, the performance and good organization of solar PV and wind turbines, and the integration of solar and wind energy into the existing power grid.
3. **Economic Analysis**: The study will analyze the economic aspects of solar and wind energy generation, including the cost of installation and operation, the leveled cost of electricity, and the financial viability of solar and wind power projects.
4. **Environmental Analysis**: The study will analyze the environmental aspects of solar and wind energy generation, including the carbon track, the impact on the local ecosystem, and the potential for reducing greenhouse gas emissions.
5. **Case Studies**: The study will include case studies of solar (PV) and wind power projects from different regions of the world to provide real-world examples of the procedural, economic, and environmentally friendly aspects of renewable energy generation.

1.5 RELEVANCE OF RESEARCH

The use of renewable energy sources such as solar plus wind remains highly relevant in the current global scenario, where there is an crucial need to move from fossil fuel-based energy generation to renewable energy sources to decrease greenhouse gas releases and ease the impact of climate change. The integration of IoT technology with solar as well as wind energy systems can lead to more efficient monitoring and management of these systems, resulting in better performance and increased power production. This project's research is relevant because it will contribute to the development of more efficient and viable energy systems, which will benefit society by reducing carbon emissions and increasing access to clean energy.

The relevance of research on this topic can be summarized as follows:

1) **Climate Change Mitigation:** The use of solar and wind energy for electricity generation can significantly reduce greenhouse gas emissions and mitigate the impact of climate change. According to the International Energy Agency (IEA), renewable energy sources, including solar and wind energy, could provide up to 80% of the world's electricity by 2050, reducing global CO_2 emissions by 60%.
2) **Energy Security:** Solar and wind energy are indigenous energy sources that can enhance energy security by reducing dependence on imported fossil fuels. The use of renewable energy sources can also reduce the vulnerability of the power sector to supply disruptions and price fluctuations.
3) **Economic Benefits:** The setting out of solar and wind power projects can generate employment and stimulate economic growth. Agreeing to a report by the International Renewable Energy Agency (IRENA), the renewable energy subdivision hired 11.5 million people worldwide in 2019, with solar and wind energy accounting for the majority of the jobs.

CHAPTER TWO

2.1 LITERATURE REVIEW

This chapter offers a comprehensive review of past works on the topic of power generation using solar and wind with IoT to monitor the flow graphs, input, and output signals. The literature review will focus on the different approaches used, the results obtained, and the limitations of previous research.

(Ang et al., 2022) made a comprehensive study of renewable energy sources: classifications, challenges and suggestions. The researchers made a comparison among fossil-fuel and renewable energy usage in generating electricity. An evaluation was also made on renewable energy sources as well as the technologies implemented to harness these renewable energy sources in developed and developing countries. Furthermore, a discussion was made on hybrid renewable energy system (HRES), the configuration of a typical HRES in addition to the leveled cost of energy (LCOE) for different HRES. The study also gave some insights into the obstacles, challenges and policies of renewable energy usage in developed and developing countries. However, the research was not able to provide in-depth knowledge and only gave a high-level of HRES.

(Ashish S. Ingole & Prof. Bhushan S. Rakhonde, 2016) made a brief introduction into conventional and non-conventional energy sources. The drawbacks conventional energy sources poses and the need to utilize non-conventional energy sources for power generation. The study also made a brief overview of hybrid energy system and a comparison with independent energy source. For this study, the hybrid energy system designed harnessed solar and wind energy. A review was made on the various components needed in implementing solar-wind hybrid energy system. The research also provided formulas to calculate the power harvested from the wind/solar energy and efficiency of the solar PV panels. However, the study did not show how these components needed for a hybrid energy system were to be integrated.

(Juan Mario Mokoko Ekifang Mangue, 2015) examined the economic feasibility of hybrid renewable energy system as compared to a standalone solar and wind power plants in Malaysia. The HOMER software was used as simulator to compute the best improved model for the system. The study showed data signifying elements, such as solar setting, PV working temperatures, PV good organization, solar irradiance, and functional locations that affect solar power output of PV arrays and complete sizing data for local execution, while at the same time, addressing issues pertaining to reliability and sustainability of existing individual solar power plants. However, some improvements which can be such as: a computer data attainment system can be implemented into the solar-wind hybrid power plant to allow monitoring and recording of performance by both the PV modules and wind turbine.

(M.V.P. Geetha Udayakanthi, 2015) focuses on the design and evaluation of a wind-solar hybrid power generation system in Sri Lanka. The work begins with an introduction emphasizing the significance of renewable energy in the framework of energy security and viable improvement. Sri Lanka's energy resources and the government's renewable energy objectives are discussed. The thesis aims to address the energy challenges in Sri Lanka by exploring the prospective of wind and solar energy sources. Some limitations of this research includes: the use of modeling software like HOMER involves certain assumptions and simplifications. These assumptions might not fully capture the difficulties of real-world energy systems which could lead to deviations between the modeled results and practical implementation. The thesis appears to assume a grid-connected system. While this is common in many regions, it may not address off-grid or remote areas' energy needs, which have different challenges and considerations.

(K. Balaji et al., 2016) this review paper provides an overview of solar-wind hybrid systems and their integration into electricity generation. It discusses the benefits of combining solar and wind energy, technical challenges, and various control strategies for efficient and stable operation. The paper focuses on the plan as well as modeling of a smart standalone crossbreed power generation system called ‘SMART POLES’.

Refer to Appendix for quick review

2.2 COMPONENTS OF A HYBRID POWER ENERGY WITH SOLAR AND WIND

A hybrid solar-wind power generation system with IOT gateway is composed of wind turbine, PV cells, inverter, battery, charge controller, sensors and cables. The PV cells and wind turbine complement each other to satisfy the demand. When energy sources (solar-wind) are abundant, the generated power from the solar, in the day time or during sufficient wind flow will keep on charging the battery until it is completely charged. On contrary, when the energy sources are poor, the battery will take over and release energy to assist the PV array and wind turbine to cover the load necessities until the storage is exhausted.

2.2.1 PV CELLS

PV cell is the part responsible for the conversion light energy to electrical energy. The photovoltaic effect takes place at the surface of the PV cells. They're usually made up of a semiconducting material with silicon as the most common type and other elements such as Phosphorus and Boron.

The solar cells are encapsulated by thin ethylene vinyl acetate (EVA).The EVA is a material with good radiation spread and low degradability to sunbeams, usually secure by a thin glass coating or transparent plastic and the cells are usually like few centimeters in area. A typical solar cell (about 10cm x 10cm) generates about two (2) watts of power which is approximately 15 to 20 percent of light energy that hits the surface. Because of this, cells are usually connected in series to enhance voltage or equivalent to boost current. A photovoltaic component contains of about thirty-six (36) interconnected cells that is glass laminated to an aluminum frame. One or more of these components are connected together to produce a more efficient power supply.

TYPES OF SOLAR PV CELLS

1. **Mono-crystalline**

   The mono-crystalline solar panels are categorized by their structure. As their name implies, they are made of a single silicon crystal. Silicon crystals are grown precisely for use in solar panels. Mono-crystalline solar panels consist of wafers cut from a single silicon crystal.

   Crystalline silicon is the most common material used in solar panels, and the U.S. Department of Energy says it's used in more than 85% of all solar panel installations.

Mono-crystalline solar panels as shown in figure 2.1 are prepared of crystalline silicon. They are made up of wafers that are cut from a single lab-grown crystal. Mono-crystalline is the most efficient solar panel technology on the market. Mono-crystalline solar panels convert more sunlight into electricity than the other types of solar panels. They also accomplish better out of the sun areas. Even when covered by a structure or tree, mono-crystalline solar sheets will still produce electricity.

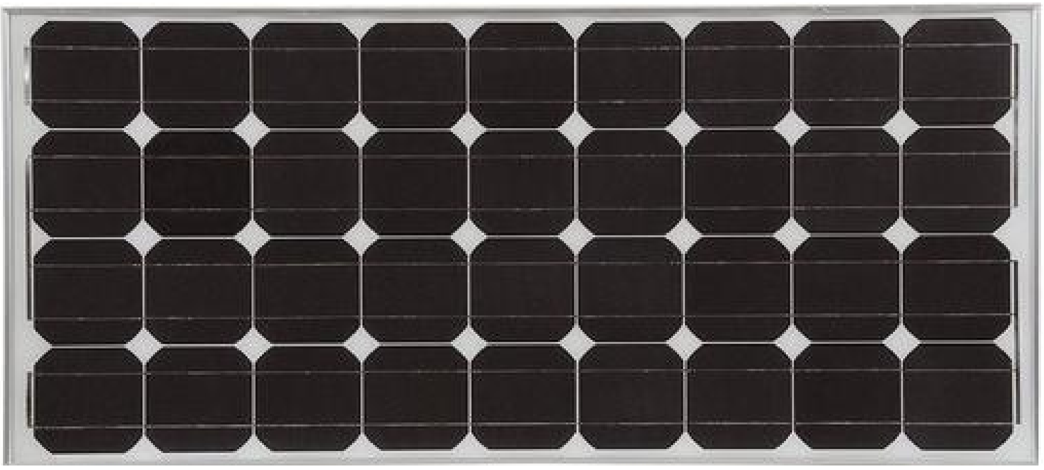


Figure 2.1: Mono-crystalline solar panel

2. Polycrystalline

Polycrystalline solar panels use the same silicon as mono-crystalline ones, but they're made differently. Instead of being a single silicon crystal, they are formed by melting raw silicon and then pouring or injecting it into a mold. As the silicon cools, it takes the shape of the mold, forming new solar panels. Polycrystalline panels are cheaper than mono-crystalline ones, though they are not as efficient. Their lower cost makes them an appealing choice for homeowners and businesses.

Figure 2.2: Polycrystalline solar panel

3. **Thin Film**

In addition to mono-crystalline and polycrystalline panels, there are also thin-film solar panels. These panels are made from a different type of silicon called amorphous silicon. Thin-film panels are very thin, about 10 to 20 times thinner on average compared to mono-crystalline ones. One benefit of thin-film panels is their lower cost, making them more affordable option than mono-crystalline and polycrystalline panels.

Figure 2.3: Thin film solar panel

Table 2.1: Comparison between the three types of solar panel

	Mono-crystalline Photovoltaic System	**Polycrystalline Photovoltaic System**	**Thin Film Photovoltaic System**
Productivity Rate	16-20 %	14-18 %	6-14 %
Low-Light Behavior	Losses under diffuse lighting	Losses under diffuse lighting	Merely low losses
Heat Behavior	Losses at high temperature	Losses at high temperature	Only low losses
Extended Term Test	Very extraordinary performance, stable and high durability	High performance, steady and high strength	Usual performance and smaller strength
Weight-Per Area	Higher	Higher	Lower
Vulnerability To Failure	Very low	Very low	Low
Cost	Most expensive	Intermediate	Least expensive

2.2.2 WORKING PRINCIPLE OF WIND TURBINE

A wind turbine works by changing one kind of energy into another. It's the opposite of an electric fan. When the wind blows, the turbine's blades spin. These blades are shaped to catch the wind. Wind is a mix of air moving in different ways, so the wind hits the blades from various angles. That's why the wind speed is lower near the base of the blades but faster at the tips. A typical wind turbine can handle wind speeds up to around 80 meters per second. The shape of the blades is designed to make sure they catch as much wind energy as possible. To generate electricity, the wind needs to be pretty strong, usually around 40-45 kilometers per hour. The wind speed varies depending on the location, so it's essential to choose the right spot for putting up wind turbines carefully. When the wind makes the fan blades move, they make the rotor spin. The rotor is connected to a generator inside the turbine. The generator's job is to turn the spinning rotor's mechanical energy into electricity, using a principle called electromagnetism.

However, the rotor's speed isn't fast enough to run the generator by itself. That's why there's a gearbox between the slow-turning part and the fast-turning part of the turbine. The slow part connects directly to the rotor and links up with the fast part through the gearbox. The fast part then makes the generator spin. The electricity made by the generator goes through a cable and gets stored by electrical equipment at the bottom of the tower.

To measure how well a wind turbine works, you can check how fast the wind is before it hits the turbine and how fast it is after it passes through. Ideally, the wind speed should be almost zero after passing the turbine, but in reality, it's a bit higher. The slower the wind speed after the turbine, the more energy it captured and can turn into electricity.

There's a law called Betz's law that tells us that no wind turbine can capture more than 59.3% of the wind's energy. It also says that the more energy a wind turbine takes from the wind, the slower the wind speed will be after passing through the turbine.

2.2.3 TYPES OF WIND TURBINE

Majorly two types of wind turbine exist:

2.2.3.1 Horizontal Axis Wind Turbine (HAWT)

Horizontal axis wind turbines are the most common type of wind turbines. They work like a big airplane propeller on a tall tower. When the wind blows, it spins the blades, which are connected to a generator that makes electricity.

These turbines need to face the direction of the wind, so they have a wind sensor to figure out where the wind is coming from. They also have a mechanism to turn the turbine so it faces the wind properly. This is important because it helps the turbine work better and prevents it from getting damaged.

The structure of these turbines needs to be really strong to hold the weight of the blades, gearbox, generator, and other parts. The bottom of the tower also has to be sturdy to handle strong winds in the area.

Horizontal axis wind turbines come in two types: up-wind turbines and down-wind turbines. Let’s discuss more about each of them below.

Up-wind Turbines

These are the most commonly used wind turbines. Up-wind HAWTs face the wind, so the wind hits the rotor blades before the tower. This means the blades don't get blocked by the tower's shadow, making the turbine work better and last longer. However, the need for a mechanism to turn the turbine adds weight to the structure.

Another thing about up-wind turbines is that their rotor blades can't be too flexible, or they might bend and hit the tower when the wind is strong. To prevent this, the rotor is placed a bit away from the tower. This makes it harder to build and requires using stronger materials for the blades.

Down-wind Turbines

Down-wind horizontal axis wind turbines are not as collective as the other types. They look pretty alike to the up-wind ones, except that the rotor is behind the tower, so the wind hits the tower before getting to the blades. This setup allows the rotor blades to be more flexible, meaning they can be made from lighter materials. This design has two benefits: it reduces the weight of the structure and improves the tower's stability by letting some of the force move from the tower to the blades when they bend.

The concept, down-wind turbines don't need a device to turn them as long as they're designed so that the wind makes them turn on their own. However, this passive turning isn't an advantage for large turbines that have grounding cables attached to them.

2.2.3.2 VERTICAL AXIS WIND TURBINES (VAWTS)

Vertical axis wind turbines have their main rotor shaft located up and down. The good thing about this setup is that the turbine doesn't have to always face the wind to work well. This is especially useful in places where the wind direction changes a lot because Vertical axis wind turbines can capture wind from different angles. Also, with the vertical axis, you can put the generator and gearbox close to the ground, so the tower doesn't have to support them, and they're easier to reach for maintenance.

Nevertheless, there are some downsides. Some designs of Vertical axis wind turbines can create a pulsing force, and there may be resistance when the blades turn into the wind. There are also other types of Vertical axis wind turbines to consider:

SAVONIUS TURBINES

Savonius turbines turn because of drag, and they're a type of wind turbine that relies on drag. Their design is quite similar to something called a cup anemometer. In a cup anemometer, like the one you see below, one of the cups always faces the wind and gets the most drag force on its surface. The other cups have different rounded surfaces that reduce the drag. The same idea applies to Savonius wind turbines. In the figure below, you can see that one surface gets the most drag, while the others have less drag force on them.

Figure 2.4: Savonius wind turbine

DARRIEUS TURBINES

Darrieus wind turbines are different from Savonius wind turbines. They are a type of vertical axis wind turbine that uses a lift to generate power. These turbines are the most common among vertical axis wind turbines, and they have curved C-shaped blades that stretch from the top of the tower to the bottom, where they connect to the generator shaft. They work efficiently because they spin faster, which produces more power.


Figure 2.5: Darrieus Turbines

Because Darrieus wind turbines spin faster, they have less twisting power (torque). This means they need help to start spinning, often from another type of turbine like a Savonius. Also, Darrieus turbines can have a problem with a regular up-and-down change in twisting power called "torque ripple," which can stress the tower. But this issue doesn't happen with three-bladed Darrieus wind turbines.

GIROMILL TURBINES

Giromill wind turbines are like Darrieus turbines but with straight up-and-down blades instead of curved ones. They're also lift-type VAWTs, which means they rely on lift. However, they're not self-starting like Darrieus turbines, and they may not spin at a constant speed, so they're not as efficient. But they're cheaper and easier to make, and they can handle windy conditions better. You can see what a Giromill turbine looks like in Figure 2.6 below.

Figure 2.6: Giromill turbine

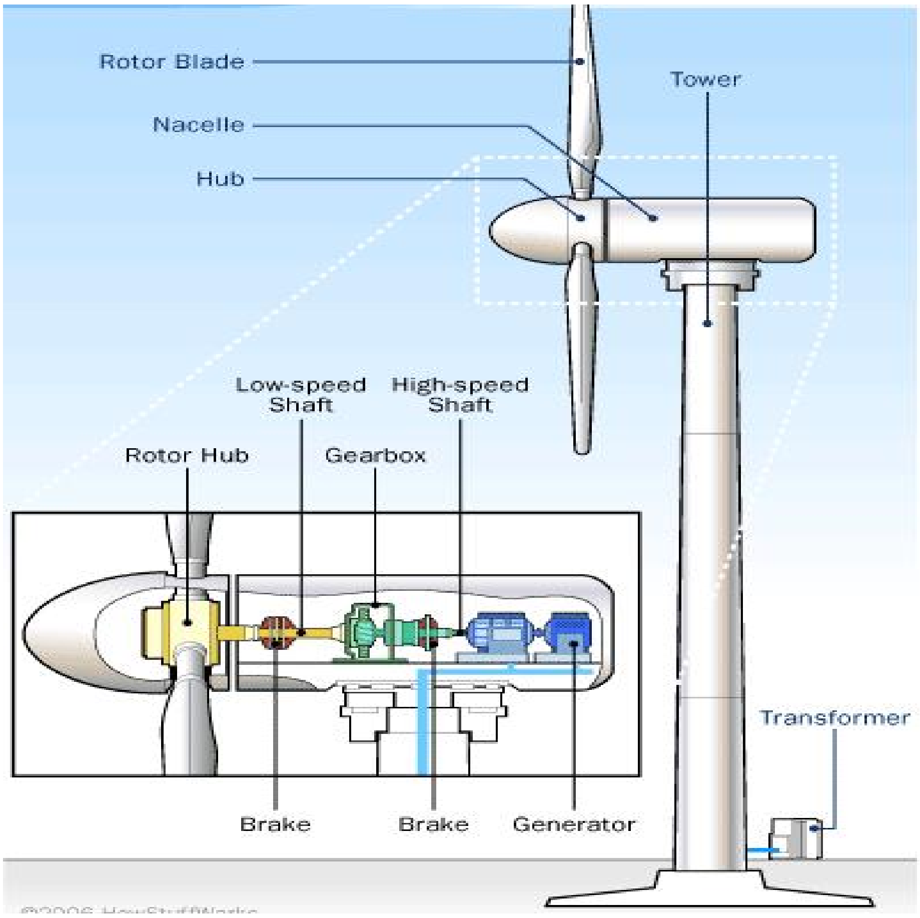


Figure 2.7: Internal components of a wind turbine

2.2.4 COMPONENTS OF WIND TURBINE

The operational of the major wind turbine parts as shown in figure 2.7 are in depth explain below, how wind turbines work to generate electricity:

2.2.5.1 The Nacelle

The most crucial part of a Wind Turbine is the Nacelle. It holds all the important components like the generator, gearbox, and brakes. The Nacelle sits on top of the tower and has the low and high-speed shafts, gearbox, brakes, and generator inside. It also has a controller that gets wind data from an anemometer (to measure wind speed) and a vane (to measure wind direction). There's a pitch control system to adjust the blade angle and a yaw drive to turn the turbine towards the wind.

The wind vane on the Nacelle helps the controller know where the wind is coming from. The direction of the wind affects how the turbines are designed, whether they face into the wind (upwind) or away from it (downwind). Upwind turbines have the rotor in front of the Nacelle, facing the wind, while downwind turbines have the rotor behind the Nacelle, facing away from the wind.

The rotor's direction, whether upwind or downwind, is super important because it affects how the turbine handles changing wind directions. The controller always makes sure the rotor faces the wind to catch it correctly. Most wind turbines are upwind designs.

2.2.4.2 The rotor and turbine blades

The rotor is a vital part of a Wind Turbine, and it's what changes the wind's energy into spinning energy (mechanical energy). It's made up of the turbine blades and the hub that holds them together. Most turbines have two or three blade-like propellers. The hub connects the blades to the main shaft, which connects to the rest of the machine that turns the spinning power into electricity.

The rotor is attached to the turbine's main shaft. When the wind blows, it pushes on the turbine blades, making them spin around the rotor. The spinning rotor turns the power generator, and this generator changes the spinning power into electrical power by using a special field. So, in simple terms, the rotor's job is to show how a Wind Turbine makes electricity.

The turbine blades work like airplane wings. They create two important forces: one called "lift," which goes up and down, and another called "drag," which goes along with the wind. The blades are shaped differently on one side, so when the wind blows over them, it makes a difference in pressure. This difference in pressure makes the low-pressure side pull the blade towards it, and that makes the rotor spin, which is the lift part. The wind's force against the front side of the blade is called drag.
Lift is actually stronger than drag, and this makes a force that goes up and down, making the rotor spin like a propeller.

2.2.4.3 Main shaft

The main shaft of the wind turbine, called the low-speed shaft, does important jobs. It holds up the rotor (the hub and the blades), and it also connects to the high-speed shaft through a gearbox, which is a big part of the turbine. The low-speed shaft takes the spinning motion from the rotor and the twisting power and sends them to the high-speed shaft through the gearbox. This helps turn the generator.

2.2.4.4 Gear Box

The wind turbine's rotor spins slowly, and this power is sent to the generator through a series of parts called the power train. This power train includes the main shaft (low-speed shaft) and a gearbox, which is like a speed changer. The gearbox takes the slowly spinning, strong power from the rotor and turns it into fast-spinning, weaker power, which is what the generator needs. This change in speed helps the generator go from about 15 to 20 spins per minute up to the roughly 1,800 spins per minute needed to make electricity.

2.2.4.5 Controller

A wind turbine needs a controller to work its best. This controller is one of the most important parts of the turbine. It helps make more power and keeps the turbine's parts from getting stressed. The controller has computers that always watch how the turbine is doing and gather information from sensors. It keeps making the energy production better by looking at things like which way the wind is blowing and how fast it's blowing.

The turbine starts spinning when the wind is between 8 to 16 miles per hour and stops when it's about 55 miles per hour. This is because really high winds can harm the turbine, so it's better to turn it off.

2.2.4.6 Braking system

The braking system is a crucial part of a Wind Turbine. It stops the spinning blades automatically if they go too fast to avoid damage. Most modern Wind Turbines use an aerodynamic braking system that can stop the turbine smoothly and quickly, without causing stress or harm to the tower or machinery.

2.2.4.7 Generator

The Wind Turbine generator turns the spinning motion of the rotor blades, caused by the wind, into electricity. The wind directly pushes on the turbine blades, changing the wind's straight-line motion into the circular motion needed to spin the generator rotor and make electricity using magnetism.

Every wind turbine depends on the speed of the wind. The generator won't make electricity until the wind is fast enough to overcome friction and get the blades spinning at the cut-in wind speed. Once it's past this point, the power the generator makes goes up really fast as the wind speed increases. It's like a cube – if the wind speed doubles, the power goes up eight times. But if the wind gets too strong, the generator will stop to avoid any damage.

2.2.4.8 Pitch system

The pitch system in a wind turbine is like a system that adjusts the angle of the blades. It makes the blades turn just enough to capture the most wind energy and make the most power without spinning too fast. This helps keep the turbine safe during strong winds or other problems, making sure it doesn't spin too quickly.

2.2.5 CHARGE CONTROLLER

The charge controller in Figure 2.8 does an important job: it prevents the battery from getting overcharged by controlling the electricity from the solar panel that goes into the battery. This controller is set at a 15-A/200-W unit and uses something called MPPT (maximum power point tracking) to speed up the battery charging by as much as 30% each day. MPPT checks how much power the solar panel is making, compares it to the battery's needs, and adjusts it to the perfect level to get the most power into the battery. To stay safe, the solar charge controller has a 25-A circuit breaker to stop it if there's too much electricity, and it uses a steady 35 mA of power.

Figure 2.8: Charge controller

Two major types of solar control panel are:

Pulse with modulation (PWM) controller: Simple 'pulse width modulation' (PWM) solar charge controllers connect the solar panels directly to the battery. They use a basic on-off switch (transistor) to control battery charging. The switch stays open until the battery reaches a certain charge level, and then it starts rapidly opening and closing (hundreds of times per second) to control the current and keep the battery voltage steady.
This method works alright, but it has a drawback. It pulls down the solar panel voltage to match the battery voltage. As a result, the panel doesn't operate at its best voltage (Vmp), which lowers its power output and efficiency.
PWM solar charge controllers are a good choice for small 12V systems with one or two solar panels, like for simple uses such as solar lights, camping, or basic things like charging USB devices. But if you need more than one panel, you should connect them in parallel, not in series (unless the panels have very low voltage and the battery has a higher voltage).

Maximum power point tracker (MPPT) controller: Maximum power point tracker (MPPT) controllers are much better than PWM charge controllers. They make sure that the solar panel works at its best, with just the right amount of voltage and current to produce the most power. Thanks to this smart tech, MPPT solar charge controllers can be up to 30% more efficient, depending on the battery and solar panel's voltage.

2.2.6 BATTERY

Batteries are how we store renewable energy, but the technology hasn't kept up with advances in wind and solar power. For a while, we used old-fashioned lead-acid batteries. These are a problem because they're heavy, not very efficient, have harmful chemicals, and cost a lot to take care of and replace. The two best choices for storing renewable energy are lead-acid and lithium-ion deep-cycle batteries.

2.2.6.1 LEAD-ACID BATTERIES

Lead-acid batteries are made of heavy lead plates dipped in a sulfuric acid solution, and this mix stores energy through a chemical process. They're the most common and cheapest type of deep-cycle battery. However, these batteries have some issues. They're heavy due to the lead plates, and you need to keep an eye on and regularly refill the sulfuric acid solution. Plus, if you use more than half of their power, it harms them and makes them not last as long.

2.2.6.2 LITHIUM-ION BATTERIES

Lithium-ion batteries are different from traditional batteries that use lead plates and sulfuric acid. Instead, they use lithium salt to store energy through a chemical reaction. These lithium batteries are better because they are lighter, safer, work more efficiently, and are easier to take care of compared to lead-acid batteries. The only drawback is that lithium batteries can be expensive at the beginning. But when you look closely, their benefits save money in the long run over the battery's lifetime.

Gains of Using Lithium-Ion Batteries

- **Extra efficient:** Lithium batteries are better than lead-acid batteries for three main reasons. First, they are lighter. Second, they charge faster. Third, you can use more of their capacity without hurting them.

  Lead-acid batteries can be damaged if you use more than half of their capacity, while lithium batteries can go down to 80% without harm. This means lithium batteries can provide about twice as much usable power per charge compared to lead-acid batteries.

  Besides having greater capacity, lithium batteries are also lighter, about half the weight of lead-acid batteries. They can charge up to five times faster with the right charger.
- **A reduced amount of maintenance:** Lithium batteries come with a built-in system called BMS that keeps an eye on the battery's health and makes sure it stays safe. Because of this BMS, you don't really need to do any maintenance on your lithium batteries.
- **Extended lifespan:** Lead-acid batteries work for a short time and can only be charged a few hundred times during their 2-5 year lifespan. In contrast, lithium

batteries last longer and can be charged 3,000-5,000 times or more, often lasting over 10 years. Some lithium battery makers even give 10-year warranties for their products.

- **Non-toxic / environmentally pleasant:** Extra caution is needed when dealing with lead-acid batteries because they have harmful chemicals that can be bad for people and the environment. Lithium batteries should also be handled with care and recycled correctly, but they don't have the same dangerous chemicals as lead-acid batteries.

2.2.7 INVERTERS

An inverter is an electrical device that changes the power in things like solar panels from one type to another. It turns the kind of power used in small stuff, like solar systems, into the kind used in regular appliances. Things like solar power systems, batteries, and fuel cells make this type of power because it's easier to make.

Figure 2.9: Portable inverter

An inverter's main job is to turn DC power into AC power. We need AC power to run our homes and industries using the public utility grid, but batteries store DC power. Plus, most household appliances and electrical stuff work with AC power.

2.2.7.1 TWO MAIN TYPES OF CLASSIFIED INVERTERS ARE:

2.2.7.1.1 LONE PHASE (SINGLE) INVERTER

Single-phase inverters are divided into two types: half-bridge and full-bridge inverters.

- **Half Bridge Inverter:** This inverter is a crucial part of the full bridge inverter. You can make it using just two switches, and each switch has a capacitor that gives an output voltage equal to Vdc^2. Plus, when one switch turns on, the other one turns off automatically because they balance each other.
- **Full Bridge Inverter:** This inverter circuit changes DC (direct current) into AC (alternate current) by turning certain switches on and off in the right order. This inverter has different modes of operation based on which switches are turned on.

2.2.7.1.2 THREE PHASE INVERTER

A three-phase inverter is a device that changes direct current (DC) input into three-phase alternating current (AC) output. It does this by using three arms that are spaced 120 degrees apart to create a three-phase AC power supply. The inverter's control system can switch at a rate of 50%, meaning it can make adjustments every T/6 of the time T. The switches in the inverter work together in pairs.

Three single-phase inverters are connected to the same DC source, and the voltage in the three-phase inverter is similar to the voltage in a one-phase half-bridge inverter. These inverters operate in two modes: a 120° conduction mode and a 180° conduction mode.

2.2.8 IoT GATEWAY

An Internet of Things (IoT) gateway is like a bridge that links the cloud with controllers, sensors, and smart devices. It's the go-between for data traveling between IoT devices and the cloud. This gateway can be a special piece of hardware or a computer program.

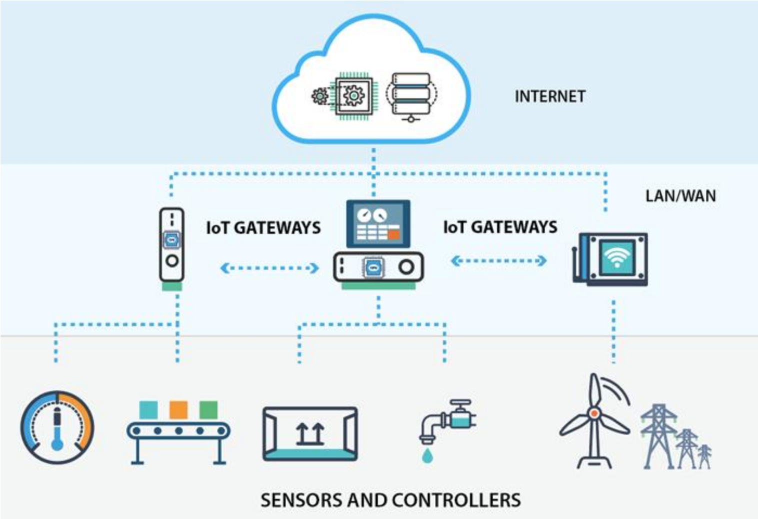


Figure 2.10: Block diagram of an IoT system

IoT gateway block diagram shown in figure 2.10:

2.2.8.1 AMAZON WEB SERVICES (AWS)

Amazon Web Services (AWS) is a all-inclusive and broadly used cloud calculating platform accessible by Amazon.com. It offers a range of cloud-based facilities and solutions that allow persons, organizations, and big business to construct, deploy, and manage various applications and resources without the want for wide-ranging on-premises infrastructure. Here's a brief description of Amazon Web Services and its key components:

- **Compute Services**: AWS provides a selection of computing resources, together with Amazon EC2 (Elastic Compute Cloud), which permits operators to launch virtual-machines (instances) in the cloud. EC2-instances can be customized to meet specific computing requirements.
- **Storage Services**: Amazon Web Services offers storage options that can grow with your needs and last a long time. These include Amazon S3 for keeping objects, Amazon EBS for blocks, and Amazon Glacier for long-term storage.
- **Databases**: Amazon Web Services provides services to manage databases. For example, there's Amazon RDS for regular databases, Amazon DynamoDB for special databases, and Amazon Redshift for data storage.

- **Networking**: Amazon Web Services offers different networking services. These include Amazon VPC, which helps make private networks, AWS Direct Connect for exclusive network links, and Amazon Route 53 for managing domain names.
- **Content Delivery and CDN**: Amazon Web Services has a service called Amazon Cloud-Front that helps spread content all over the world quickly, without delays.

2.2.8.2 ARDUINO NANO

The Arduino Nano is a lesser, versatile, as well as cost-effective micro-controller board designed for various electronic projects and prototyping. It is part of the Arduino family, known for its user-friendly development environment and compatibility using an extensive range of sensors and actuators. Here's a brief description of the Arduino Nano:

- **Compact Size**: The Arduino Nano is one of the smallest boards in the Arduino lineup, making it suitable for projects with space constraints. Its compact dimensions make it easy to integrate into devices or prototypes.
- **Microcontroller**: The board is typically equipped with an ATmega328P microcontroller, which is the same chip used in the Arduino Uno. It takes 32KB of flash memory for program storing and 2KB of SRAM for data storing.
- **Digital and Analog Pins**: The Nano features a fixed arithmetical input/output (I/O) pins, including several PWM (Pulse Width Modulation) pins, which can be used to control motors or dim LEDs. It also has analog input pins for reading analog sensors.
- **USB Connectivity**: The board usually includes a mini USB or micro USB port for programming and power. This allows you to connect it to a computer for uploading sketches (Arduino programs) and powering the board.

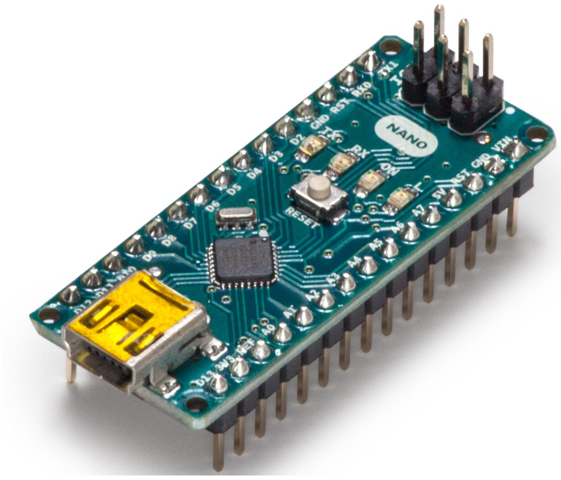


Figure 2.11: Arduino Nano

2.2.8.3 GPRS/GSM module (SIM800L)

The SIM800L is a popular General Packet Radio Service (GPRS) and Global System for Mobile Communications (GSM) module that enables mobile communication in various electronic projects and applications. It's widely used for tasks such as sending and receiving SMS messages, making phone calls, and establishing mobile data connections. Figure 11 below shows the SIM800L module. Here's a description of the SIM800L module:

- **Communication Technology**: The SIM800L module supports 2G communication technologies, specifically GPRS for data transfer and GSM for voice and SMS communication. It functions on the "850/900/1800/1900" MHz frequency bands, creating compatibility using most GSM networks worldwide.
- **Integrated SIM Card Holder**: The module typically includes an integrated SIM card holder, allowing you to insert a standard-sized SIM card. This SIM card is used for network registration and authentication.
- **Serial Communication**: The SIM800L communicates with a microcontroller or computer via UART (Universal Asynchronous Receiver-Transmitter) serial communication. It uses AT commands (Hayes AT command set) for configuration and control.

- **SMS Capabilities**: You can use the SIM800L module to pass on and obtain SMS messages. SIM800L feature is useful for applications like remote monitoring and alert systems.
- **Internet Connectivity**: The module can establish GPRS data connections, enabling devices to send and receive data over the internet. It is commonly used for IoT (Internet of Things) applications that require remote data transmission.

Figure 2.12: SIM800L Module

CHAPTER THREE

METHODOLOGY

3.1 WORKFLOW PROCESS

From the workflow diagram below in figure 3.1 it can be seen that setting up a hybrid power generation begins with gathering the appropriate components similar to solar-panel, wind-turbine, inverter, battery, charge-controller, cables etc. In the case of the project research, the wind turbine was fabricated from a production lab.

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.

The inverter is joined to the battery source where 'AC' is converted to 'DC' energy which is distributed to the load. In setting the IoT monitoring platform, an IoT gateway is established at a point connected to the charge controller in order to read various parameters such as wind power, solar power, battery level, etc.

These parameters are sent from the IoT gateway to AWS servers where they are stored and can be fetched and displayed on real-time monitoring services such as ThingsView which was used in this development research.

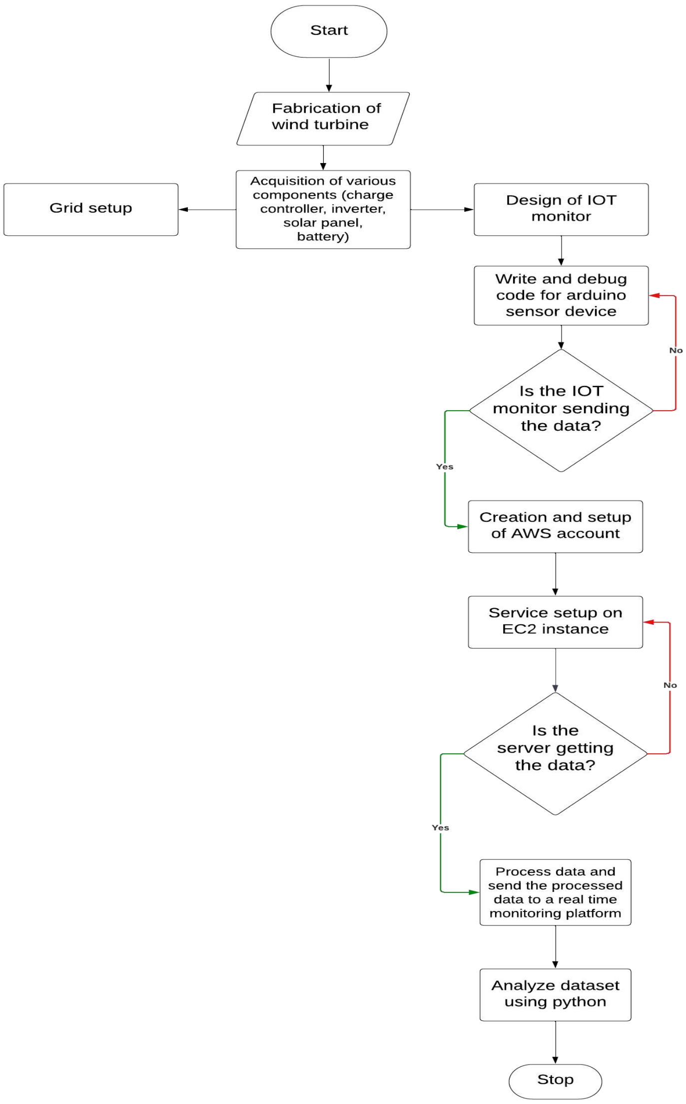


Figure 3.1: Work-flow process chart

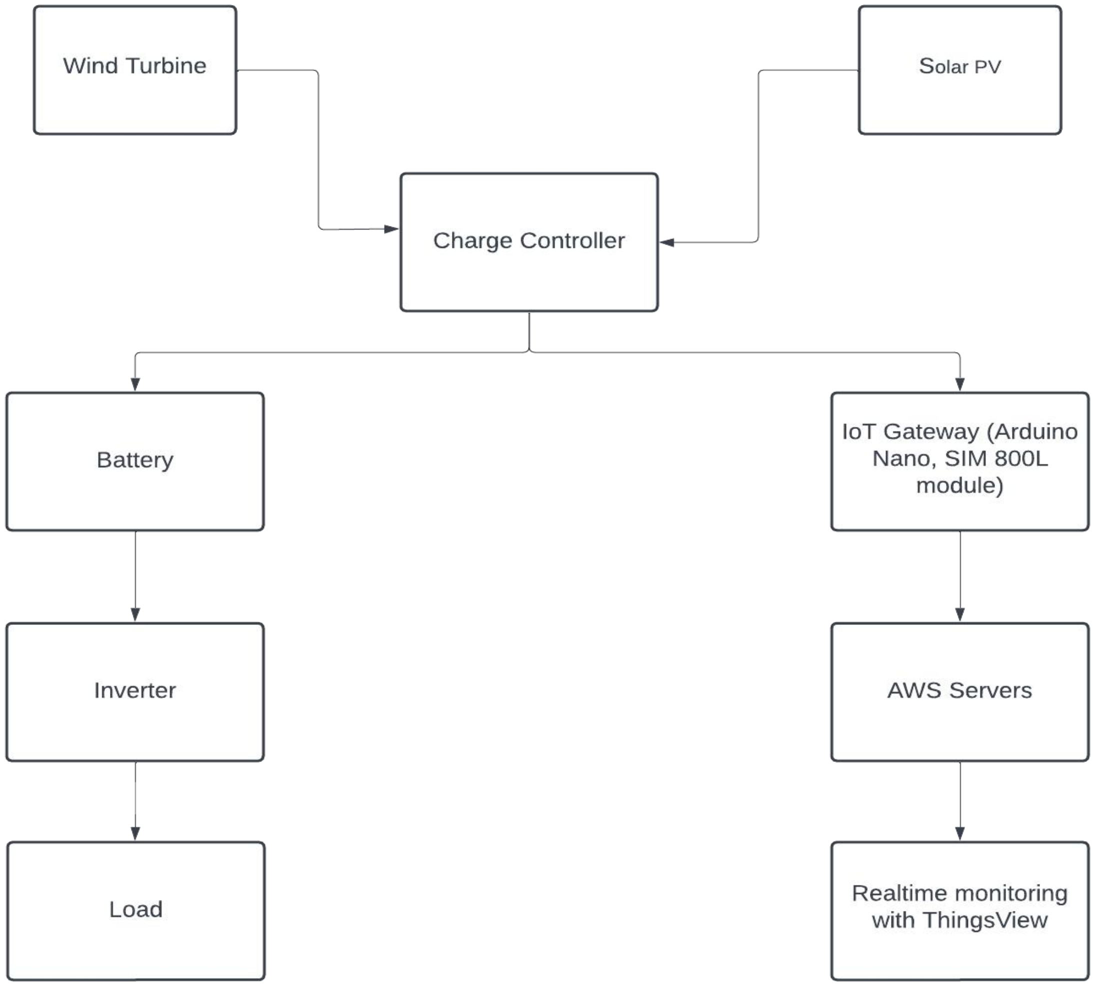


Figure 3.2: Major components of the hybrid renewable energy system

3.2 COMPONENTS OF THE HYBRID SYSTEM

The hybrid electricity generation system will consist of the following components:

- **Solar PV panel:** This is use to convert solar-radiation into electrical energy.
- **Wind turbine:** a device designed to convert kinetic-energy starting from the wind into machine-driven energy, which is then converted into electricity..
- **Charge controller:** is a crucial component in a solar power system. Its primary function is to manage and regulate the charging and discharging of batteries in off-grid and hybrid-solar systems.
- **Energy storage system:** Batteries will be employed to accumulation surplus energy for use through periods of low generation.
- **IoT Gateway:** An intelligent control system will manage the hybrid system, monitors its factors distantly and improving its performance.

3.3 SOLAR PV INSTALLATION

One poly-crystalline solar panel rating of 12v/24v 30A PV is Set-up to harvest maximum solar radiation. The necessary electrical wiring and connectors was installed to connect the solar panels to each other and to the charge controller. Also appropriately rated wiring and connectors is used to handle the system's voltage and current.

3.4 WIND TURBINE (FABRICATION FROM FAN MOTOR)

In fabrication of the wind turbine, the coil of a household standing fan was used.

3.4.1 DISASSEMBLE THE MOTOR

The motor consists of these three major components: the stator, rotor and coils. When this is done, the motor was carefully opened with the right tool such as a screw driver to avoid cuts, or rough handling of internal components such as wires, magnets, coil windings, etc. in it. During the process, the stator and rotor are kept apart. The motor is carefully disassembled as shown in figure 3.3 to separate the coil from the casing surrounding it. After disassembling the casing and identifying the copper coils, and next step is building the wind turbine to locate the highest ohm reading wire out of the four wires that are connected to the coils. This wire will be the most efficient at generating electricity and should have the highest resistance.

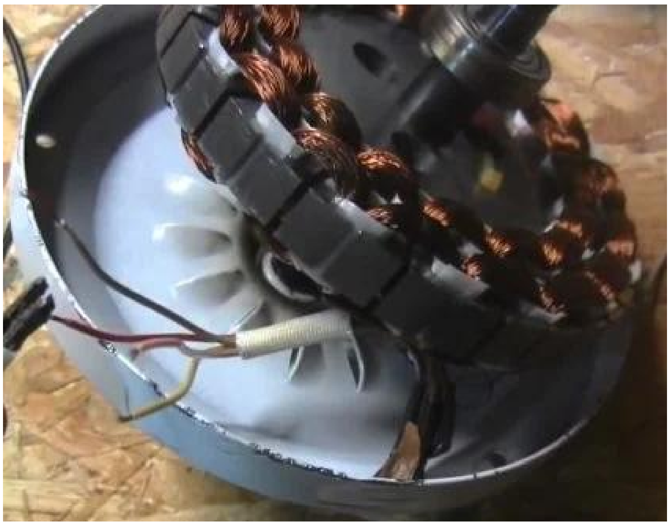


Figure 3.3: Fabrication process using fan rotor

3.4.2 INTRODUCE MAGNETS TO THE ROTOR

The stator as shown in figure 3.4 is the stationary component of the motor is separated from the rotor. The next step is to insert magnets inside the fan housing. The magnets will be attached to the rotor, which will rotate past the copper coils in the stator.

Figure 3.4: The Rotor

Four magnets were placed on four slits of the rotor a magnet. Before magnets were placed, the rotor is cut according to the size of the magnets so as to ensure uniformity. The magnets will be attached to the rotor, which will rotate past the copper coils in the stator. To insert the magnets, you'll need to place them in the fan housing in a way that aligns them with the stator. To ensure that the magnets stay in place and rotate smoothly when this is done, the components are then coupled together and fastened. A drill machine is used to test the swiftness and effectiveness of the implementation to see how much electricity can be generated at different speeds.

Figure 3.5: Attaching magnets to the rotor

3.4.3 ASSEMBLE THE MOTOR

Assemble the motor by placing the rotor in the stator and ensure it aligns with the coils of the stator. Place the stator back into the housing case.

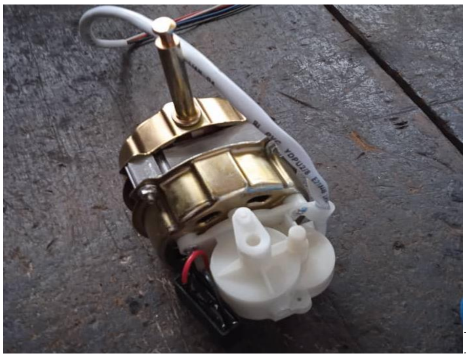


Figure 3.6: Coupled motor

3.4.4 MOUNTING THE BLADES AND BODY OF TURBINE

Mount the blades on the rotor. The blades can be made from 4-inch PVC. To create the blades, you'll need to put the outline of the blades from the paper template onto the PVC and then cut them out using a jigsaw. Once the blades have been cut out, you can smooth the edges using a hand sander. This will ensure that the blades are aerodynamic and efficient at capturing wind energy. Also in constructing the body of turbine, it can be done using a 1-inch galvanized pipe, which will form the main structure of the turbine.

3.4.5 TEST RUNNING THE TURBINE

The turbine can manually be rotated and the voltage and current that it produces can be measured with a multi-meter to determine its output capacity.

3.5 REGULATING VOLTAGE WITH CHARGE CONTROLLER

In setting up the charge-controller, battery is coupled to the controller accordingly to the Positive (+ve) and Negative (-ve) poles. The controller immediately indicates the battery capacity and other useful information on the display monitor and provides menu buttons to set the correct the battery type and parameters. Then the interface of the controller is connected to both solar panel and wind turbine according to positive (+) and negative (-) poles. The controller used is a 30Amp MPPT charge controller.

3.6 SETTING UP THE ENERGY STORAGE SYSTEM

A 200Ah lead-acid battery with six cells is used for storage of excess power generated. The battery is linked to both the charge controller and the inverter. Connect the battery to the inverter, connect the plus (+) side of the battery to the plus (+) side of the inverter and the minus (-) side of the battery to the minus (-) side of the inverter. Make sure the inverter is switched off while doing this. For instructions on connecting the battery to the controller, refer to section **3.5** above.

3.7 SETTING UP THE INVERTER

A 1kva inverter is used which was connected to the battery in the energy storage system. The steps are described above. A solar inverter does the job of turning the special power from solar panels and wind turbines into regular power that you can use for your appliances and stuff in your home or business. This makes it the heart of a hybrid solar-wind power system.

3.8 SETTING UP THE IoT GATEWAY

The IoT Gateway for monitoring the power generation is made of three main components: IoT current monitor which mainly consists of an Arduino nano and GSM/GPRS module (SIM800L module) was used in this project research; a cloud-based platform that receives this data and a real time monitoring platform for displaying of data in real-time with graphical format.

3.8.1 IMPLEMENTING THE IoT MONITOR

In designing the IoT monitor a number of components and sensors was used which are:

- Two sensors (wind and solar)
- One operational amplifier
- Micro controller (Arduino Nano)
- GSM Module

The connection and operation of the different components of the sensor device of wind and solar, operational amplifier, a micro controller (Arduino nano) and the GSM module is shown below:

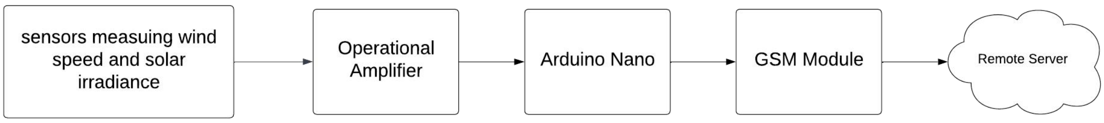


Figure 3.7: IoT monitor block diagram

Wind and solar sensors was used to get the amount of wind speed and solar irradiance, respectively. The output of these sensors will be analog signals. The operational amplifier was used to amplify the analog signals from the sensors. The output of the operational amplifier which is a higher-voltage analog signal is sent to the micro-controller where it is processed, digitized and sent to the remote server through the help of the GSM module.

3.8.1.1 CIRCUIT IMPLEMENTATION

The wind and solar sensors are connected to the Arduino nano using analog input pins. The operational amplifier is also connected to the Arduino nano using a digital input pin. When the wind and solar sensors detect a change in the wind speed or solar irradiance, an analog output is sent. This output is amplified by the amplifier to produce a much higher voltage analog signal which will be digitized by the micro-controller. It was used to measure discharge current of the systems. The gain of the amplifier is about 26, the voltage drop from the Shunt resistor (copper wire-like) was what we measured, the voltage gotten is then multiply by the gain (26). Calculating the current using Ohm's law would have been easier if we knew the resistance value, then dividing by the gain to obtain the actual current/drain current, but the resistance is unknown and the multi-meter precision is not able to measure it, the manual multi-meter was then used to measure the discharged current after it has been calibrated then insert it on code, then test the current.

Initial calculation is done by multiplying it by 0.1, then conversion of the voltage to current. Inside the debug we carried out, we observed the current it measured and convert it to current. We observed the current measured and compared it with the current measured from the Multi-meter. Using those values, we interpolated them to get the actual and correct multiplication factor to give us the correct values, by multiplying the measured values by the actual values to obtain the required values.

The GSM module is connected to the Arduino Nano through the serial communication port. The Arduino Nano which controls and coordinates everything, of which after it have measured all values at specific intervals, which was set at 20 seconds it will just upload using the GSM module by instructing the GSM Module. It instruct the GSM module by using 80 commands which are sent by the serial port, from the post data function it’s clear that its 80 commands that’s used to instruct the model.

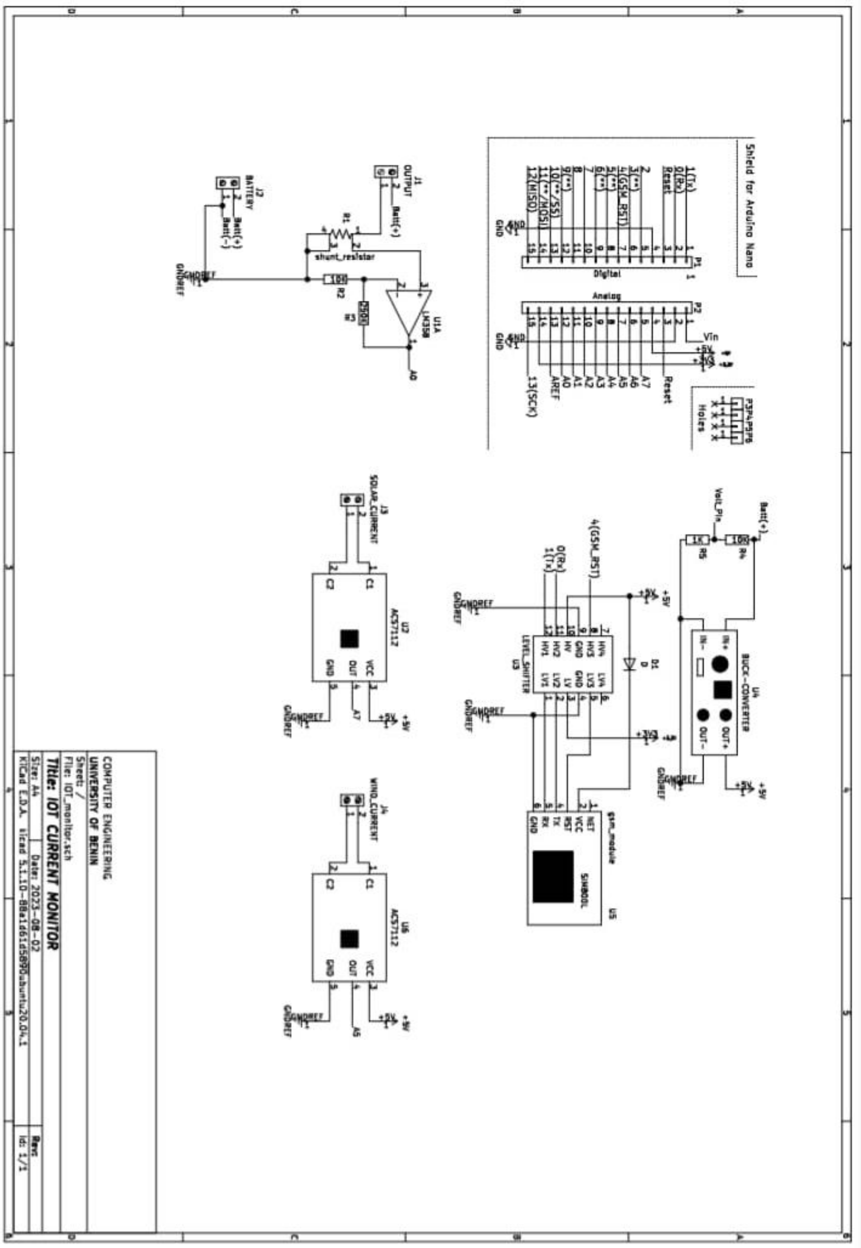


Figure 3.8: IOT monitor circuit diagram

```
#define RESET_PIN 4
#define BATTERY_PIN A0
#define DISCHARGE_PIN A7
#define TURBINE_PIN A6
#define SOLAR_PIN A5
#define GSM_RX_PIN 3
#define GSM_TX_PIN 2

//#define APN "internet.ng.airtel.com"
#define APN "web.gprs.mtnnigeria.net"
```

```
float getDischargeCurrent() {
  float _sampletage = 0;
  int count = 50;
  const float sampletageCalibration = 0.1078;
  for (int i = 0; i < count; i++) {
    _sampletage += analogRead(DISCHARGE_PIN) * sampletageCalibration;
  }
  _sampletage /= count;

  return _sampletage;
}
void Debug() {
  Serial.print("batteryVoltage: ");
  Serial.println(getBatteryVoltage(BATTERY_PIN));
  Serial.print("solarCurrent: ");
  Serial.println(getCurent(SOLAR_PIN));
  Serial.print("wind current: ");
  Serial.println(getCurent(TURBINE_PIN));
  Serial.print("dischargeCurrent: ");
  Serial.println(dischargeCurrent);
  // Serial.print("dischargeCurrent1: ");
  // Serial.println();
}

float getCurent(byte pin) {
  unsigned long timeoutStamp = millis();
  float current{ 0 };
  int analogValue = 0;
  int maxAnalogValue = -1;


  while(1) {
    analogValue = analogRead(pin);
    if (analogValue > maxAnalogValue) {
      maxAnalogValue = analogValue;
    }
delay(10);
if( millis()-timeoutStamp > sampleTime)break;
  }
  Serial.print("max current:: ");
  Serial.println(maxAnalogValue);

      current = ((float)(30 * maxAnalogValue) - 15360) / 511;

  // float voltage = getVoltage(pin, sampleCount);

  return current;
}
float getBatteryVoltage(int pin) {
  float _sampletage = 0;
  float r2 = 1000;
  float r1 = 10000;
  byte sampleCount = 100;

  for (int i = 0; i < sampleCount; i++) {
    _sampletage += analogRead(pin);
    delay(5);
  }
  _sampletage /= sampleCount;
  float voltage = (_sampletage * 5) / 1024;
  float vin = (voltage * (r1 + r2)) / r2;
  return vin;
}
float getVoltage(byte pin, int sampleCount) {
  float _sampletage = 0;
  for (int i = 0; i < sampleCount; i++) {
    _sampletage += analogRead(pin);
    delay(5);
  }
  _sampletage /= sampleCount;
  float voltage = (_sampletage * 5) / 1024;

  return voltage;
}

String jsonify() {

  String temp = "{\"BV\":" + String(batteryVoltage) + ",\"SC\":" + String(solarCurrent) +
",\"WC\":" + String(windCurrent) + ",\"DC\":" + String(dischargeCurrent) + "}";
  return temp;
}
bool sendCommand(String _command, String _response, long timeout) {

  String response = "";
  float t = millis();
  gsm.println(_command);
  Serial.println(_command);
  delay(20);

  while (gsm.available() > 0 && millis() - t < timeout) {
    char c = gsm.read();
    response += c;
    delay(2);
  }
  if (response.indexOf(_response) != -1) {
    Serial.print("Pass: ");
    Serial.println(response);
    return true;
  } else {
    Serial.print("Fail: ");
    Serial.println(response);
  }
  return false;
}
```

Figure 13.9b: Sample of Arduino code transmitting values to the cloud server

```

bool postData(String _data) {
  sendCommand("AT", "OK", 2000);
  sendCommand("ATE0", "OK", 2000);
  sendCommand("AT+SAPBR=3,1,\"Contype\",\"GPRS\"", "OK", 2000);
  delay(1000);
  sendCommand("AT+SAPBR=3,1,\"APN\",\"web.gprs.mtnnigeria.net\"", "OK", 2000);
  delay(1000);
  sendCommand("AT+SAPBR=1,1", "OK", 2000);
  delay(1000);
  sendCommand("AT+SAPBR=2,1", "OK", 2000);
  delay(1000);
  sendCommand("AT+HTTPINIT", "OK", 2000);
  delay(1000);
  sendCommand("AT+HTTPPARA=\"CID\",1", "OK", 2000);
  delay(1000);
  sendCommand("AT+HTTPPARA=\"URL\",\"" + String(url) + "\"", "OK", 2000);
  delay(1000);
  sendCommand("AT+HTTPPARA=\"CONTENT\",\"application/json\"", "OK", 2000);
  delay(1000);
  sendCommand("AT+HTTPDATA=" + String(_data.length()) + ",30000", "DOWNLOAD", 2000);
  delay(1000);
  sendCommand(_data, "OK", 5000);
  delay(10000);
  sendCommand("AT+HTTPACTION=1", "OK", 2000);
  delay(5000);
  sendCommand("AT+HTTPREAD", "OK", 2000);
  delay(5000);
  sendCommand("AT+HTTPTERM", "OK", 2000);
  delay(1000);
  sendCommand("AT+SAPBR=0,1", "OK", 2000);
  delay(1000);
}

```

Figure 3.9c: Sample of Arduino code transmitting values to the cloud server

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULT PRESENTATION OVERVIEW

We present the results and discussions related to the testing of wind turbines and solar panels, equally 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 und-going research.

4.1 WIND TURBINE TESTING

4.1.1 Experimental Setup

The wind turbine model used for testing was fabricated from a fan motor, and located at Faculty of Engineering, UNIBEN. Data were collected using an anemometer to measure wind speed and a multi-meter meter to measure the turbine's output power.

4.1.2 Data Collection

Wind turbine testing was conducted over a period of 7 days, with measurements taken every 10 minutes.

4.1.3 Results

Table 4.1: Wind Turbine Test Results

Time	Speed of Wind (m/s)	Revolution per miles (RPM) of Turbine	Voltage. (V)	Current (mA)	Power
9am	0.5	4.76	2.5	34	0.085
10am	0.6	5.71	2.9	28	0.0812
11am	0.7	6.66	3.3	1.0	0.0033
12pm	1.0	9.52	4.7	1.3	0.00611
1pm	1.1	10.47	4.2	1.2	0.00504
2pm	1.2	11.42	4.7	1.3	0.00611

3pm	0.8	7.61	3.8	1.1	0.00418
4pm	0.9	8.56	4.2	1.2	0.00418
5pm	1.1	10.47	5.0	1.4	0.007
6pm	0.8	7.61	3.8	1.1	0.00418

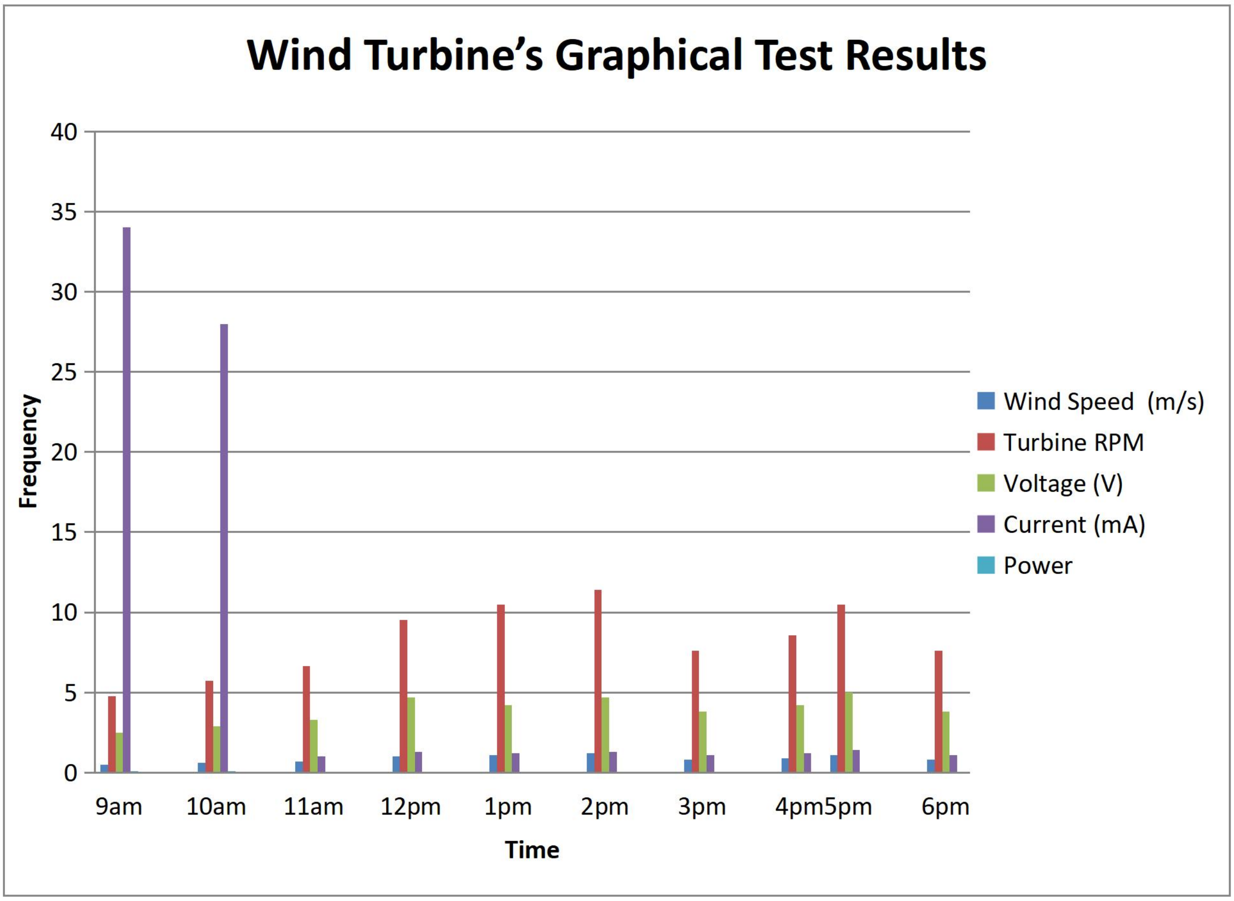


Figure 4.0a Wind Turbine's Graphical Test Results

4.2 ANALYSIS AND DISCUSSION OF WIND TURBINE TEST RESULTS

4.2.1 WIND-TURBINE PERFORMANCE

The wind-turbine demonstrated an increase in output power with higher wind speeds, as shown in Table 4.1. This is consistent with the expected behavior of the turbine.

4.3 SOLAR PANEL TESTING

4.3.1 EXPERIMENTAL SETUP

The solar panel used for testing is an 18V, 4.45A panel, installed at a Faculty of Engineering, UNIBEN. Data were collected using pyranometers to measure solar irradiance and digital multi-meters to measure panel output voltage and current.

4.3.2 DATA COLLECTION

Solar panel testing was conducted over a 9hr period, with measurements taken every hour during daylight.

4.3.3 RESULTS

Table 4.2: Solar Panel Test Results

Time	Output Voltage V	Output-Current A	Power W
9am	5.5	0.11	0.605
10am	9	0.19	1.71
11am	10.5	0.2	2.1
12pm	12.5	0.28	3.5
1pm	14	0.32	4.49
2pm	13.5	0.3	4.05
3pm	11	0.26	2.86
4pm	8	0.16	1.28
5pm	6	0.12	0.72
6pm	2.5	0.05	0.125

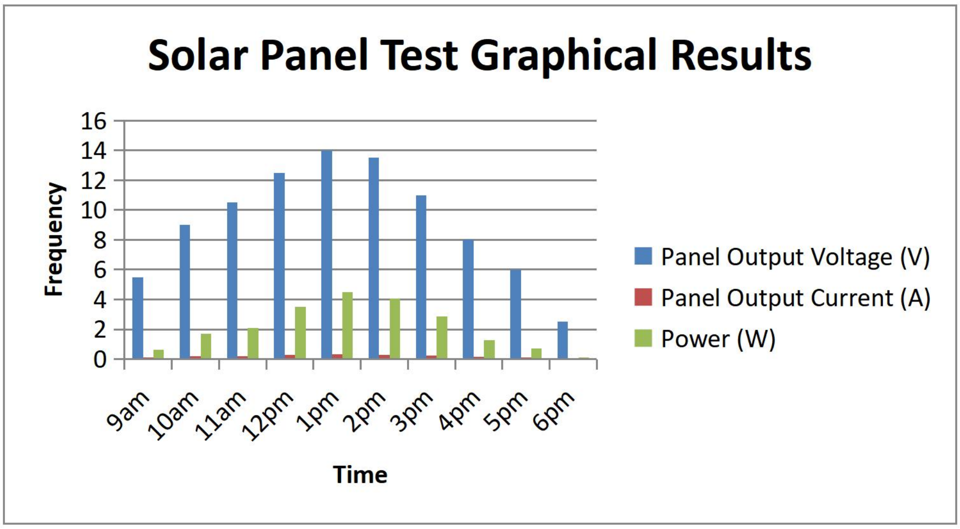


Figure 4.0b: Solar Graphical results

4.5 TOTAL POWER OUTPUT OF THE HYBRID SYSTEM

4.5.1 POWER OUTPUT CALCULATION

The total power harvest of the hybrid structure, considering wind turbine and solar panel contributions togeter, was calculated for various scenarios.

In calculating the total power output at 12:00 PM:

1. Wind Turbine Output Power at 12:00 PM:
    - Wind Speed: 1.0 m/s
    - Turbine Output Power: 0.00611W
2. Solar Panel Output Power at 12:00 PM:
    - Panel Output Voltage: 5.5V
    - Panel Output Current: 0.11A

Now, calculate the power output for each source:

- Wind Turbine Power Output: 0.00611W
- Solar Panel Power Output: (5.5 V) * (0.11 A) = 0.605W

Total Power Output at 12:00 PM:

- Total Power Output = Wind Turbine Power + Solar Panel Power
- Total Power Output = 0.00611 W + 0.605 W = 0.6111W.

As a result, the total power output of the hybrid system at 12:00 PM is 0.6111 W.

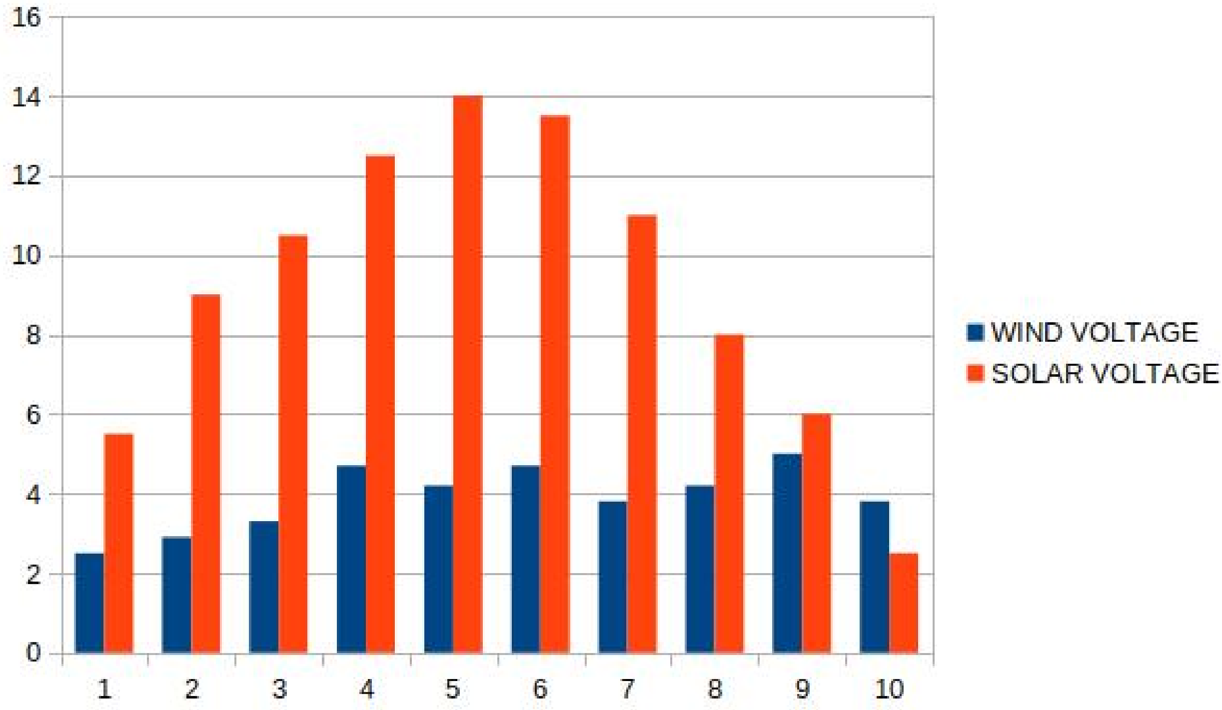


Figure 4.2: Bar chart showing the variation of energy produced by solar and wind

4.6. IMPLEMENTATION OF THE REMOTE SERVER WITH AWS

Implementing the remote server was done with EC2 (Elastic Cloud Compute) on AWS and was done by setting up the security group and creating a virtual machine on which the server lives.

4.6.1 SETTING UP THE SECURITY GROUPS

Two security groups were setup and associated with the EC2 instance which will be created later.

- On the AWS console management, move direct to the "Services" menu then click on "EC2" under "Compute" section. On the EC2 Dashboard, click on "Security Groups" on the navigation pane at the left.

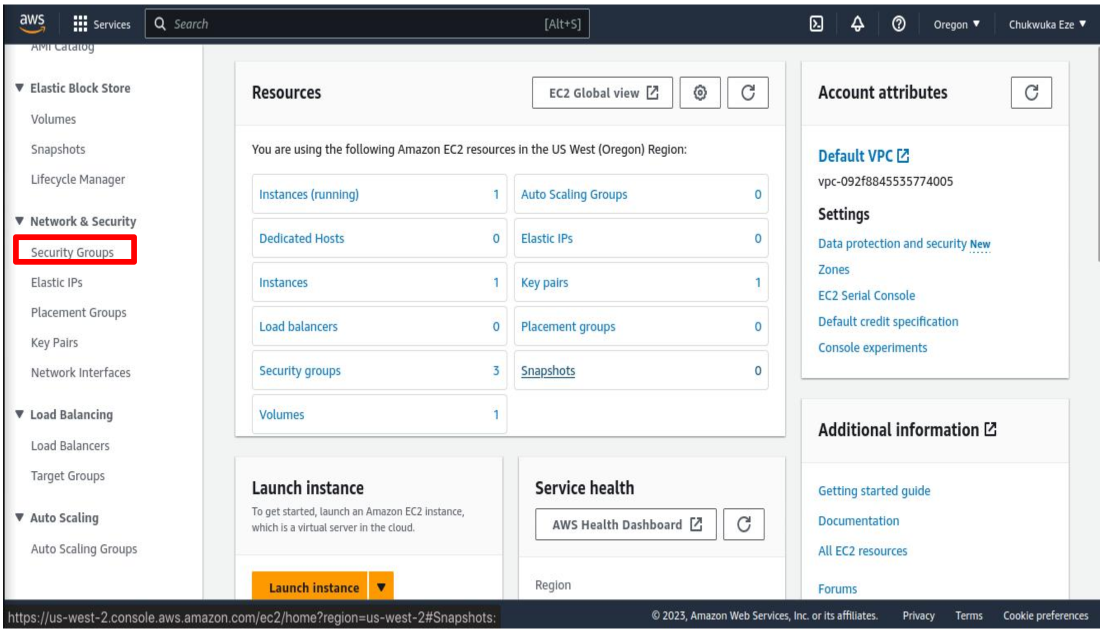


Figure 4.2: AWS Dashboard

- Click "Create Security Group" button, to start creating a new security group.

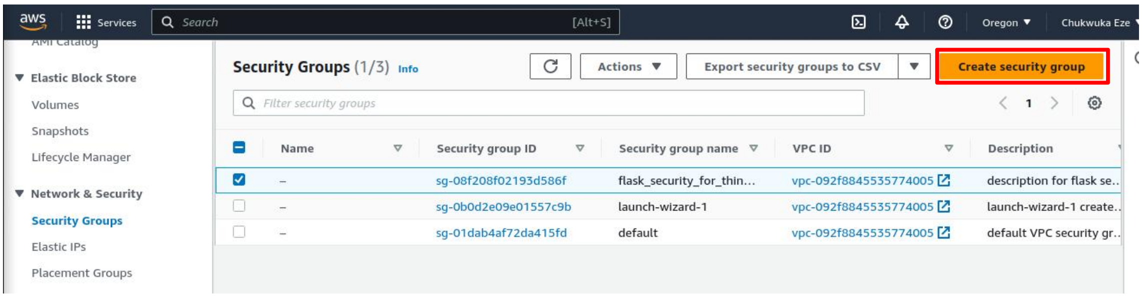


Figure 4.3: List of security groups

- **Configure Security Group Settings**

  Fill in the required information:

➢ **Security group-name:** Provide a vivid name for your security group.

➢ **Description:** This is Optional; add a momentary description of the security group.

➢ **VPC:** Choose 'Virtual Private Cloud' (VPC) where you wish to launch your EC2 instance.

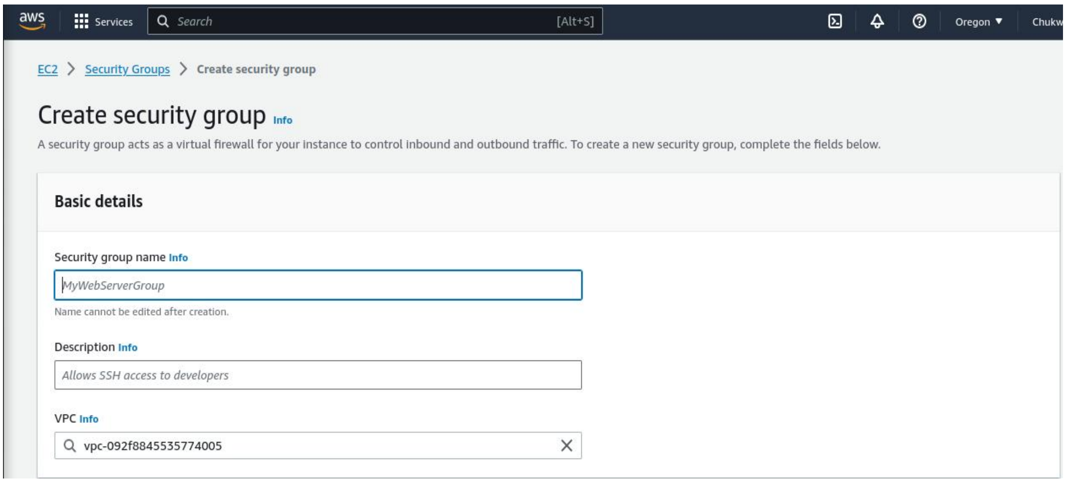


Figure 4.4: Creating a security group

- **Add Inbound Rules**

  In the "Inbound rules" section, specify the rules to allow incoming traffic to your EC2 instances. You can add rules by clicking the "Add rule" button.

  Each rule has four parts:

  - Type: This tells what kind of traffic it allows, like HTTP or SSH. In this project, Custom TCP was used.
  - Protocol: It says which network protocol is used, like TCP, UDP, or ICMP.
  - Port Range: This is the port or a range of ports that are opened. They chose Port 3000.
  - Source: This is where the traffic is allowed to come from. It can be specific IP addresses (like yours), a group of IP addresses (like 0.0.0.0/0 for open access), or the name of another security group.

The Inbound rule configuration used for this project is shown below:

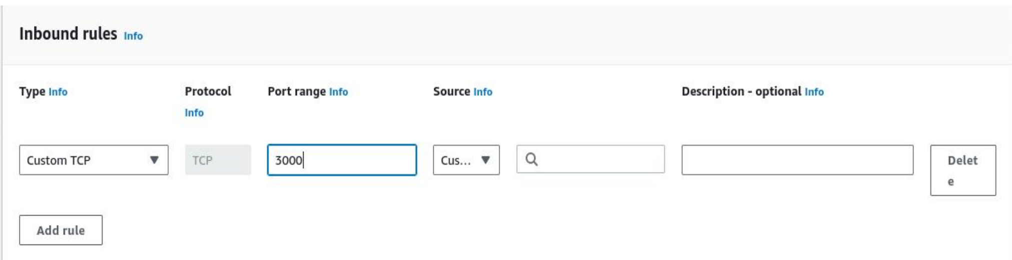


Figure 4.5: Setting Inbound rules

- **Add Outbound Rules**

  In the "Outbound rules" section, specify the rules to allow outgoing traffic from your EC2 instances. By default, everything going out is allowed, but if you want, you can create your own rules. In this project, we used the default setup as shown below.

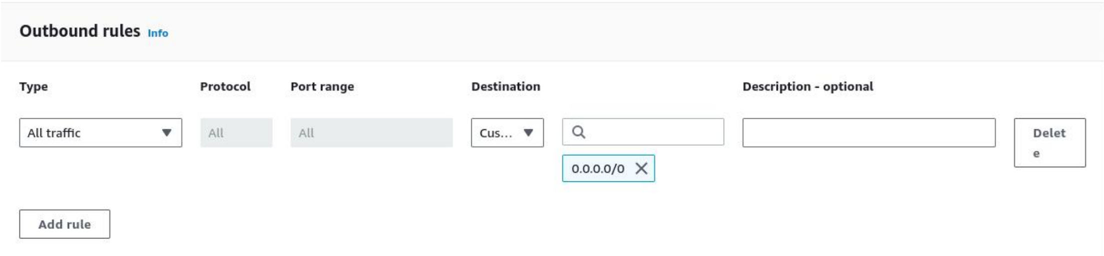


Figure 4.6: Setting Outbound rules

- **Review and Create**

  Review security group settings to make sure they are precise. Next click the "Create security group" button and create the group.

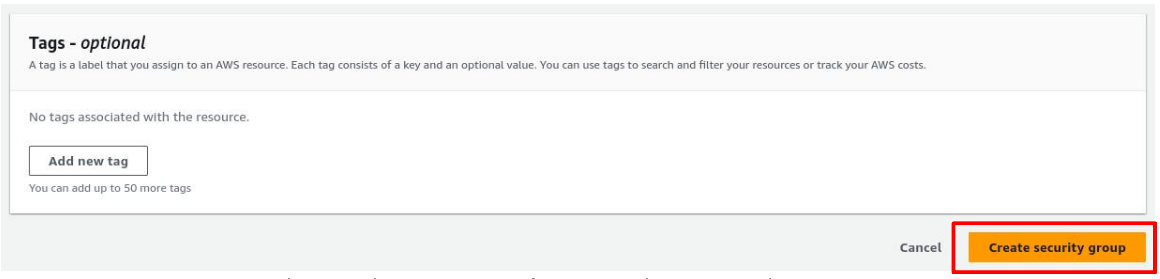


Figure 4.7: Button for creating security group

4.6.2 SETTING UP THE EC2 INSTANCE

- **Access the EC2 Dashboard**

Step 1: To get to the EC2 Dashboard, go to the AWS Management Console. Click on "Services" and then choose "EC2" from the "Compute" section. In the EC2 Dashboard, click on "Instances" on the left side, then, to create a new instance, click the "Launch Instance" button.

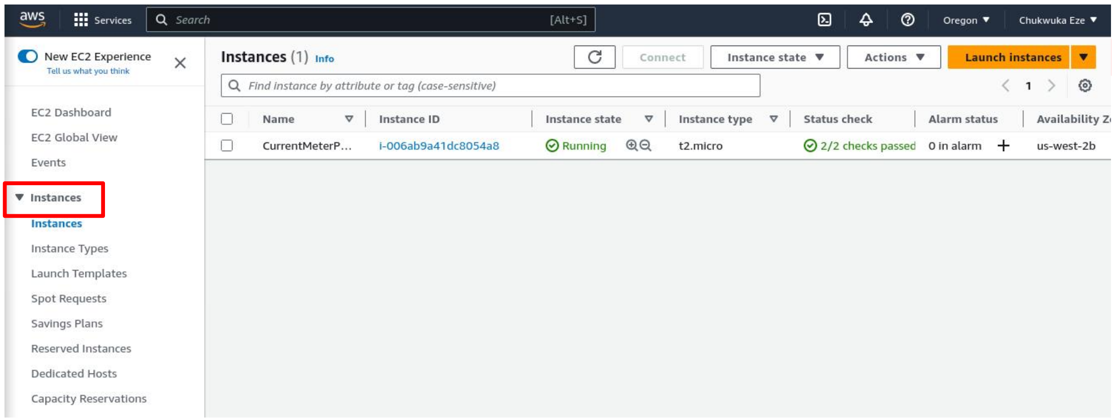


Figure 4.8: EC2 Instances Dashboard

- In the "Machine Image (AMI)" part, pick the image for the computer system and software you want on your EC2 machine.

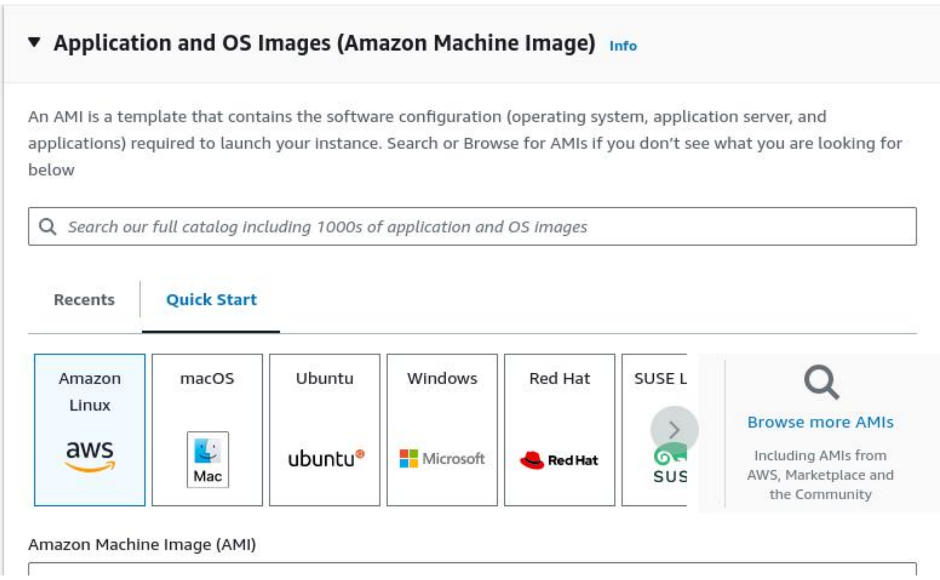


Figure 4.9a: Creating an EC2 instance

- **Instance Type Chooser**

  "Step 2: Choose an Instance Type" is where you pick the type of computer that suits your needs. These computers come in different types with varying amounts of CPU power, memory, and internet speed.

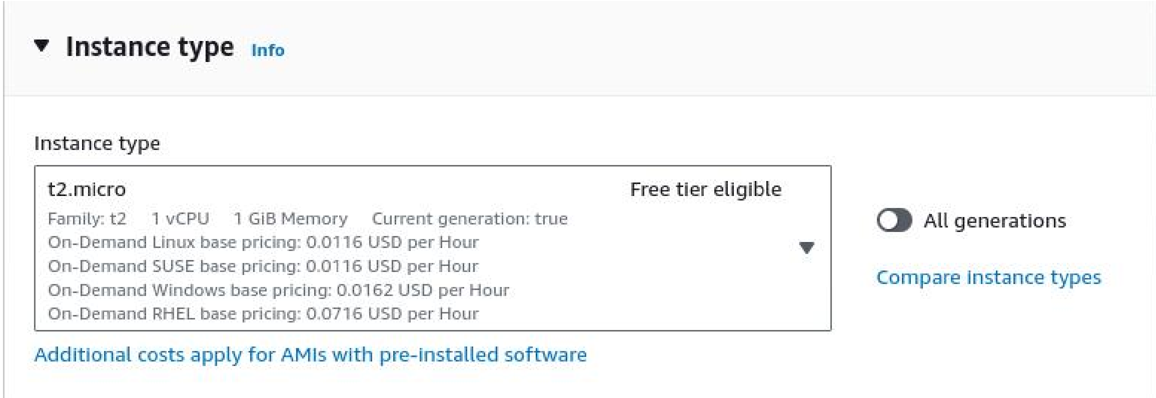


Figure 4.9b: Creating an EC2 instance

- **Instance Details Configuration**

  In "Step 3: Set up Your Instance" part, set different options for a virtual computer, such as:

  - How many computers (EC2 instances) needed to start.
  - Which network and location should be use (Virtual Private Cloud and subnet)
  - Whether they should have a public internet address.
  - If they need special permissions (IAM role).
  - How they should act when you turn them off.

Figure 4.9c: Creating an EC2 instance

- **Add Storage**

  In the "Step 4: Add Storage" section, configure the instance's storage options:

  - **Root volume:** set up the size, type, then encryption for the source size (boot volume).
  - **Volumes added:** Add any additional EBS (Elastic Block Store) volumes as needed.

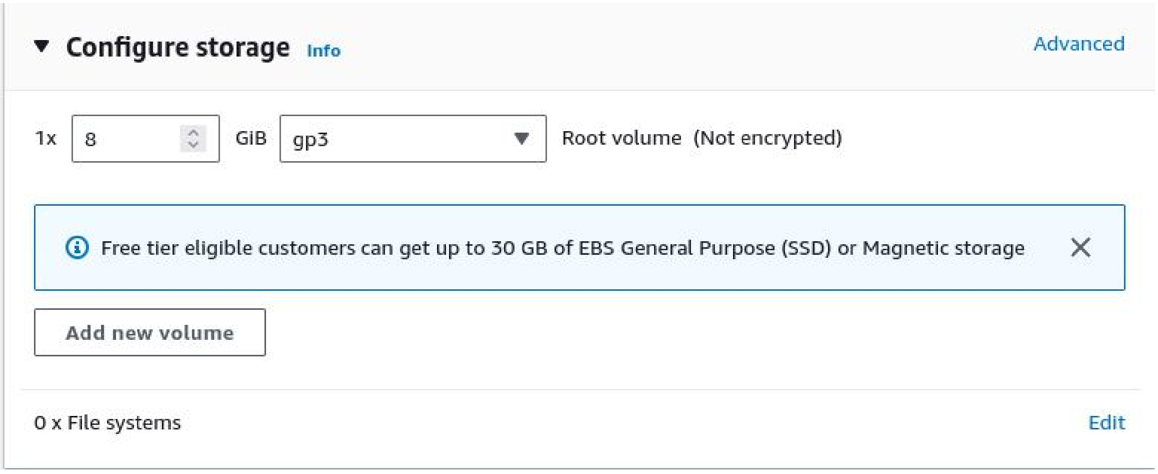


Figure 4.9d: Creating an EC2 instance

- **Configure Security Group**

  In the "Step 6: Configure Security Group" section, Choose a security group that already exists or make a new one.

  Security groups control inward bound and exterior bound traffic to and from your instance. Ensure that you allow necessary ports for your application.

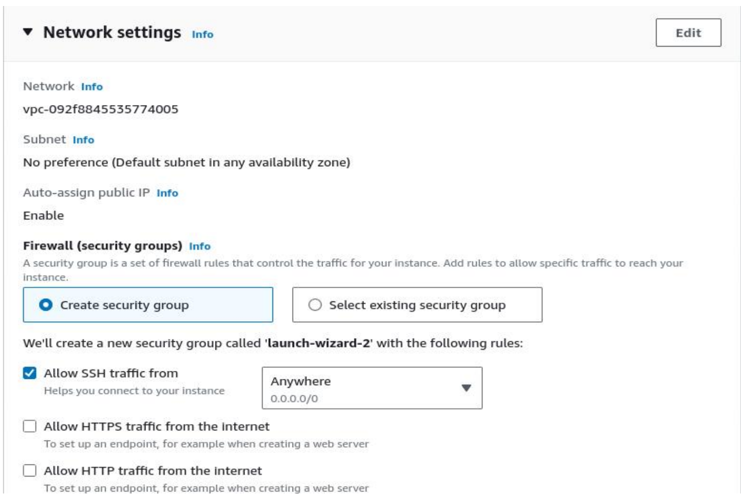


Figure 4.9e: Creating an EC2 instance

- **Instance Launch Review:**
  Review Instance Launch" part, carefully look at all the settings for your EC2 computer. Make sure everything is set up the right way.

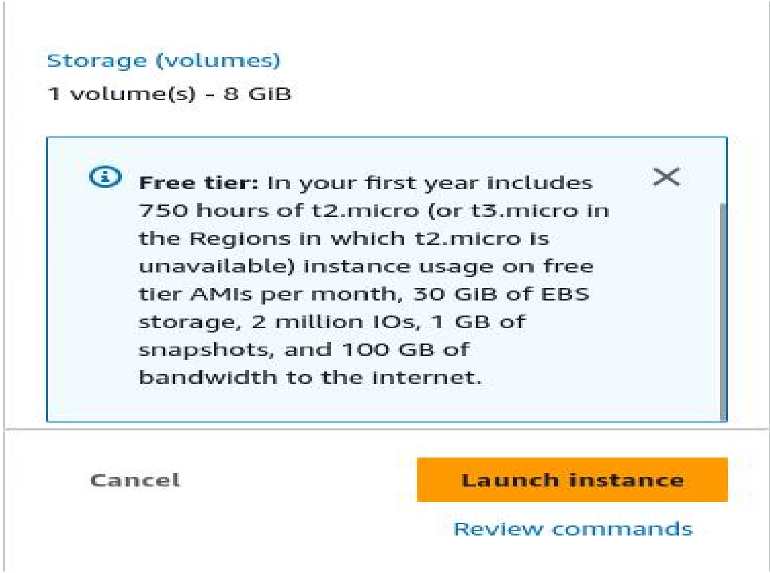


Figure 4.10f: Creating an EC2 instance

The configuration in setting up the EC2 instance for this project is shown below:

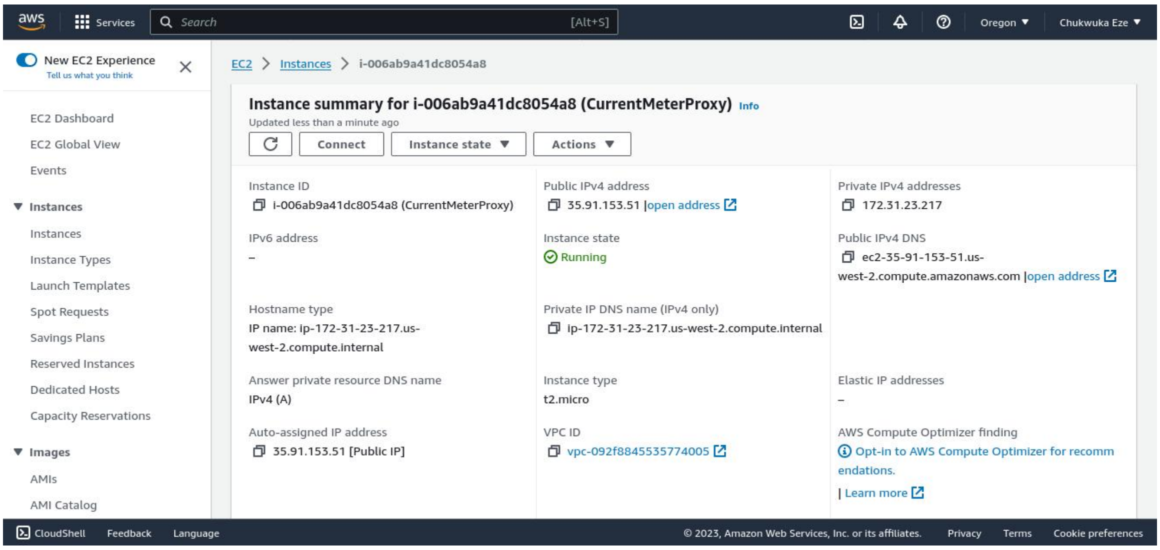


Figure 4.11a: The summary configuration for the EC2 instance setup for this project

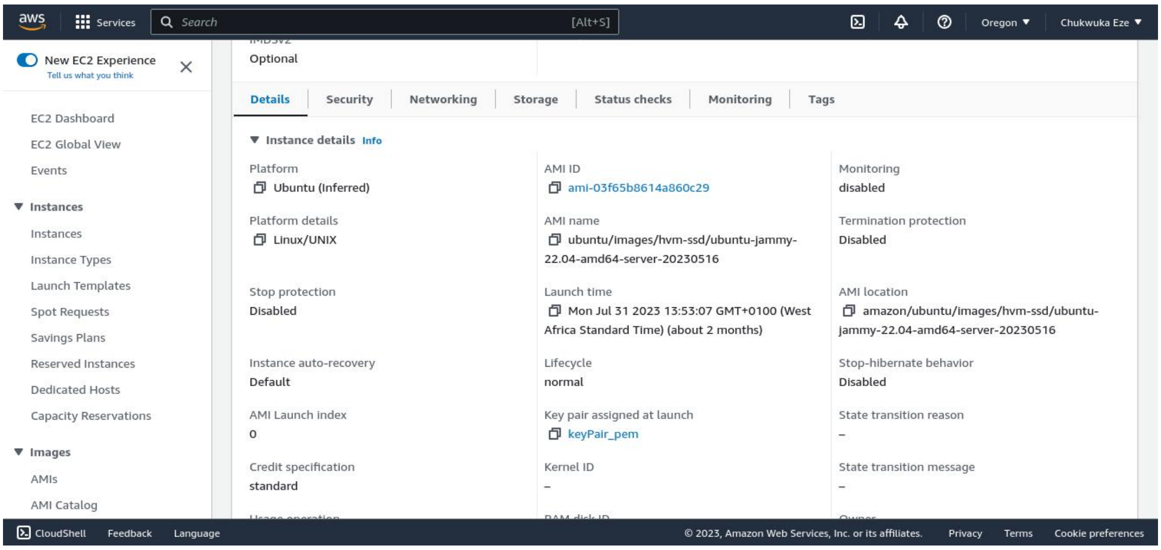


Figure 4.11b: The summary configuration for the EC2 instance setup for this project

4.6.3 CODING THE SERVER ON EC2 INSTANCE

Server runs on EC2 instance which was implemented with Python programming language. The provided Python code represents a Flask-based web application designed to process incoming data, perform calculations, and post the results to the ThingSpeak IoT platform. It utilizes various Python libraries and web frameworks to achieve this functionality.

Code Overview

The code is a Python script that makes a Flask web app. Flask is a small tool for Python that helps make web apps. The app has two main parts: one at "/" and one at "/process," and it uses the ThingSpeak API to send data.

Code Breakdown

1. **Import Libraries**

   The code starts by bringing in important tools like Flask, request, json, and requests. These libraries are used for web application development and data handling.

2. **API Key**

An API key (API_KEY) is defined as a global variable. This key is used to authenticate and authorize access to the ThingSpeak platform when posting data.

3. **Flask Application Setup**

   The Flask application is created using Flask (__name__), where __name__ represents the name of the current Python module.

4. **Routes**

   Two routes are defined within the Flask application

   /: This route responds with "Hello, World!" when accessed.

   /process: This route is designed to handle POST requests for data processing and posting to ThingSpeak.

5. **process Function**

   The `/process` route is handled by the `process` function.

   It extracts incoming data from the POST request and decodes it if necessary.

   The data is then parsed as a JSON object containing various fields such as 'BV', 'SC', 'WC', and 'DC'.

6. **Data Processing**

   The code performs calculations using the extracted data to calculate 'SP' (Product of 'BV' and 'SC'), 'WP' (Product of 'BV' and 'WC'), and 'DP' (Product of 'BV' and 'DC'). The calculated values are formatted as strings with two decimal places.

7. **ThingSpeak Integration**

   A URL('final_url') is constructed to post the calculated values along with the original data to the ThingSpeak platform using the ThingSpeak API. A GET return is made to the constructed URL using the 'request' library. The response from the ThingSpeak API is checked, and success or failure is printed to the console.

8. **Running the Application**

   The flask application is run with 'app.run()' method, enabling debugging, allowing external access and specifying the port 3000.

The complete server code running on the EC2 instance created is shown in Appendix 2.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This project introduces a system using the Internet of Things (IoT) to connect a hybrid renewable energy system in a university campus or private home. The system has four parts: the power, data collection, communication, and application layers. It includes communication models for a hybrid energy setup involving a small wind turbine and solar panel, following certain standards suitable for smaller power systems. The project tested how well it worked using a wireless network called GPRS, which can cover long distances. The results showed that GPRS worked fine, meeting the timing requirements.

This project helps create smarter and more efficient micro grid systems and proves that hybrid renewable energy systems can be integrated. In the future, the plan is to build a working model of this system in a lab and compare it to the simulations. There's also a focus on ensuring the network is secure and data is transmitted safely, addressing issues like cyber-attacks and false data.

The main findings of this project were that:

- Hybrid electricity generation systems can deliver a consistent and workable source of electricity.
- IoT sensors can be used to advance the productivity and reliability of hybrid electricity generation systems.
- The cost of hybrid electricity generation systems is comparable to the cost of traditional electricity generation systems.

5.2 RECOMMENDATIONS

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

- The performance of hybrid electricity generation systems should be further evaluated in different climates and environments.
- Due to the high demand of materials and components to be used, the cost of hybrid electricity generation systems should be reduced.
- The use of IoT sensors in hybrid electricity generation systems should be further explored.

APPENDIX

APPENDIX 1: META-ANALYSIS TABLE

AUTHOR	TITLE	DESCRIPTION OF WORK	REMARKS
(Ang et al., 2022)	A detailed look at renewable energy: Types, problems, and solutions.	The researchers looked at how we make electricity using things like gas and oil, which are bad for the environment, and compared that to how we can make electricity using cleaner, renewable sources. They also checked out how different countries, both rich and not-so-rich, use these cleaner sources to make power. They also talked about something called a hybrid renewable energy system (HRES), what a usual one looks like, and how much it costs to generate energy using different kinds of HRES.	The study also gave some insights into the obstacles, challenges and policies of renewable energy usage in developed and developing countries. However, the research was not able to provide in-depth knowledge and only gave a high-level of HRES.
(Ashish S. Ingole and Prof. Bhushan S. Rakhonde in 2016)	A system that combines both wind energy and solar energy to make power.	The study also made a brief overview of hybrid energy system and a comparison with	The study did not show how these components needed for a hybrid energy system were to be

		independent energy source. For this study, the hybrid energy system designed harnessed solar and wind energy. A review was made on the various components needed in implementing solar-wind hybrid energy system. The study gave us ways to figure out how much power we get from the wind and sun, as well as how well solar panels work.	integrated.
Juan Mario Mokoko Ekifang Mangue in the year 2015.	Examining how to make a solar and wind power system work best at UTP without being connected to the main power grid using the Homer software.	The researcher checked if it makes financial sense to use a mix of solar and wind energy together, rather than just having separate solar and wind power plants in Malaysia. HOMER software was used to simulate and evaluate the top improved model for the system. The research also provided information about things like how the sun is positioned, how hot the solar panels get, how well they work,	Some improvements which can be such as; a computer system to keep track of how well both the solar panels and wind turbine are doing in a solar-wind hybrid power plant. This computer system can monitor and record their performance.

		how much sunlight there is, and where they are placed. This helps figure out how much power solar panels can make locally while making sure existing solar power plants are reliable and sustainable.	
(M.V.P. Geetha Udayakanthi, 2015)	Designing a system that combines wind and solar power in Sri Lanka	The study is about making a system in Sri Lanka that uses both wind and sunlight to make electricity. It starts by talking about why renewable energy is important for making sure there's enough energy and to protect the environment. Sri Lanka's energy resources and the government's renewable energy targets are discussed. The thesis wants to solve Sri Lanka's energy problems by looking at how wind and sunlight can be used for power	the use of modeling software like HOMER involves certain assumptions and simplifications. These assumptions might totally not capture the difficulties of real-world energy systems and could lead to deviations between the modeled results and practical implementation. The thesis appears to assume a grid-connected system. While this is common in many regions, it may not address off-grid or remote areas' energy needs, which have different challenges and considerations.

```
GNU nano 6.2
from flask import Flask, request,jsonify
import json
import requests
API_KEY = "YPJKKBL2HG0ZC08Y&field1"
app = Flask(__name__)

@app.route("/")
def hello():
    return "Hello, World!"

@app.route("/process",methods =['POST'])
def process():
        global base_url
        print("got data")
        request_data = request.get_data()

        # Decode the bytes to a string if it contains text data
        request_text = request_data.decode('utf-8')

^G Help          ^O Write Out     ^W Where Is      ^K Cut
^X Exit          ^R Read File     ^\ Replace       ^U Paste
```

Appendix 2-1: python server-side code running on an EC2 instance

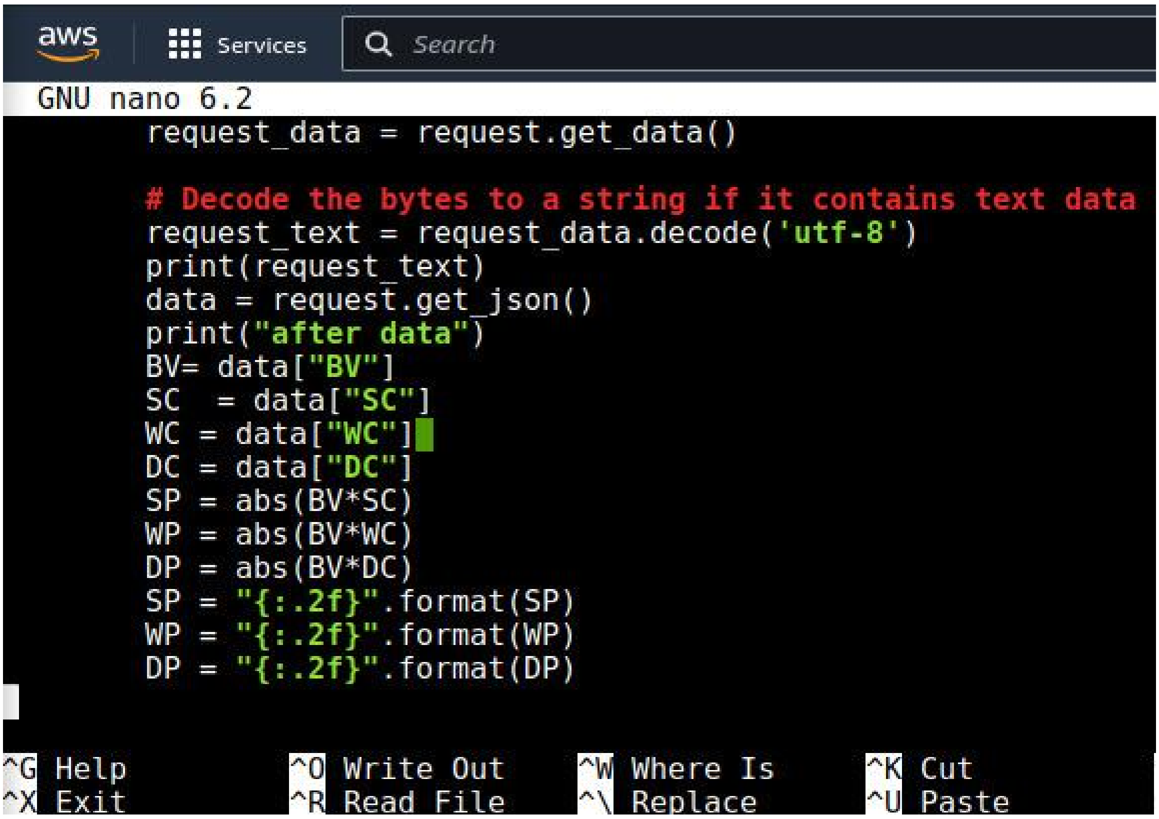
```
aws   Services   Search   [Alt+S]
GNU nano 6.2                                              server.py
        DP = abs(BV*DC)
        SP = "{:.2f}".format(SP)
        WP = "{:.2f}".format(WP)
        DP = "{:.2f}".format(DP)

        final_url = f"https://api.thingspeak.com/update?api_key={API_KEY}&field1={BV}&fi
        print(f"dinal url: {final_url}")
        response = requests.get(final_url)
        if response.status_code == 200:
            print("Success")
            return "success"
        else:
            print("fail")
            return response.status_code

if __name__ == "__main__":
    app.run(debug = True ,host = '0.0.0.0',port = 3000)

^G Help      ^O Write Out   ^W Where Is   ^K Cut      ^T Execute   ^C Locat
^X Exit      ^R Read File   ^\ Replace    ^U Paste    ^J Justify   ^/ Go To
```

Appendix 2-2: python server-side code running on an EC2 instance (contd)



```
GNU nano 6.2
        request_data = request.get_data()

        # Decode the bytes to a string if it contains text data
        request_text = request_data.decode('utf-8')
        print(request_text)
        data = request.get_json()
        print("after data")
        BV= data["BV"]
        SC  = data["SC"]
        WC = data["WC"]
        DC = data["DC"]
        SP = abs(BV*SC)
        WP = abs(BV*WC)
        DP = abs(BV*DC)
        SP = "{:.2f}".format(SP)
        WP = "{:.2f}".format(WP)
        DP = "{:.2f}".format(DP)

^G Help          ^O Write Out    ^W Where Is     ^K Cut
^X Exit          ^R Read File    ^\ Replace      ^U Paste
```


Appendix 2-3: python server-side code running on an EC2 instance (contd)

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M.V.P. Geetha Udayakanthi. (2015). *Design of a Wind-Solar Hybrid Power Generation System in Sri Lanka*.