Feasibility Study of a Fuzzy Logic-Based Energy Management System for Solar, Wind, and Battery Hybrid Energy

(A Case Study on Ziway/Dembel Lake Island)

Gosa Girma Hurisa

A Thesis Submitted to

The Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Power)

Office of Graduate Studies

Adama Science and Technology University

September, 2024

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "Feasibility Study of a Fuzzy Logic-Based Energy Management System for Solar, Wind, and Battery Hybrid Energy (A Case Study on Ziway /Dembel Lake Islands)" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Gosa Girma	____________	____________
Name of the Student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, I hereby certify that we have reviewed the revised version of the thesis titled "Feasibility Study of a Fuzzy Logic-Based Energy Management System for Solar, Wind, and Battery Hybrid Energy (A Case Study on Ziway/Dembel Lake Island)" prepared under my supervision by Gosa Girma Hurisa. This thesis has been submitted in partial fulfillment of the requirements for the Master of Science degree in Power Engineering. Therefore, I recommend the submission of the revised thesis to the department in accordance with the applicable procedures.

Dr.Shimelis Demissie	_______________	_______________
Major Advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

I, the advisor of the thesis entitled, **"**Feasibility Study of a Fuzzy Logic-Based Energy Management System for Solar, Wind,and Battery Hybrid Energy(A Case Study on Ziway/Dembel Lake Islands)**"** and developed by Gosa Girma Hurisa, here by certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr.Shimelis Demissie	______________	______________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Gosa Girma Hurisa have read and evaluated the thesis entitled"Feasibility Study of a Fuzzy Logic-Based Energy Management System for Solar, Wind, and Battery Hybrid Energy(A Case Study on Dembel Lake Islands)" and examinedthe candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Power Engineering.

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ACKNOWLEDGMENT

To begin, I would want to express my sincere gratitude and appreciation to God, the Almighty, for His unwavering support and immeasurable grace during my research trip.

I would want to thank Dr. Shimelis, my advisor, from the bottom of my heart for all of his support and assistance during my research. This thesis has been greatly influenced by his wise counsel, creative ideas, and unwavering drive. I am incredibly grateful for all of the time and work he has put into helping me grow and succeed, and I am delighted to express my gratitude for his incredible mentoring.

Apart from my adviser, I would want to extend my sincere appreciation to my family and friends, whose unselfish support has been crucial to my path. Who I am today has been greatly influenced by your constant support and encouragement. Your presence has been a continuous source of motivation, and you have made the classroom a really happy and encouraging place that has tremendously benefited my academic endeavors. This project has been enjoyable and successful because of your sacrifices and belief in me.

ABSTRACT

Lake Ziway, also called Dembel, is a large freshwater lake in Ethiopia's Oromia Region, located approximately 168 kilometers south of Addis Ababa. The islands within the lake are vital to the local inhabitants, presenting energy challenges distinct from those of mainland regions. Island areas often benefit from the enhanced utilization of renewable energy generation and storage technologies. This thesis investigates the feasibility of establishing an electricity supply system for the islands in Lake Ziway/Dembel using renewable energy resources, focusing on the integration of solar photovoltaic (PV) and wind energy in a stand-alone hybrid system. Power management is implemented through fuzzy logic control and the study also highlights the importance of sustainable energy sources and storage methods. Simulation results show that the FLC-based power management approach effectively meets the projected energy demands of Tulu Gudo Island under various scenarios. Optimization, conducted using HOMER software with inputs including resource availability, load, system size, and component costs, indicates that the total investment for the optimal hybrid system, including PV, wind turbines, battery storage, and converters, amounts to $472,720. The levelized cost of electricity (COE) is calculated to be $0.277 per kWh, demonstrating the economic viability of renewable energy solutions for Tulu Gudo Island.

Keywords: Fuzzy Logic Controller, HOMER, Hybrid system, Island electrification, MATLAB, Solar, Wind, Ziway/Dembel.

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LIST OF ABBREVIATIONS

BESS	Battery Energy Storage System
BMS	Battery Management System
CCECE	Canadian Conference on Electrical and Computer Engineering
DC	Direct Current
ERG	Energy Resource Group
FL	Fuzzy Logic
FLC	Fuzzy Logic Controller
HAWT	Horizontal Axis Wind Turbine
HBF	Heinrich Boll Foundation
HC	Hill Climbing
HES	Hybrid Energy System
HOMER	Hybrid Optimization Model for Electric Renewable
HS	Hybrid System
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
INC	Incremental and Conductance
MATLAB	Matrix Laboratory
MPPT	Maximum Power Point Tracking
MSE	Micro and small enterprises
NASA	National Aeronautics and Space Administration
PMS	Power management system
PV	Photovoltaic
RES	Renewable energy source
UAE	United Arab Emirate
UEAP	Universal Electricity Access Program
VAWT	Vertical Axis Wind Turbines
WECS	Wind Energy Conversion System
WT	Wind turbine

CHAPTER ONE

1. INTRODUCTION

1.1 Back Ground

Lake Ziway, also called Dembel, is a large freshwater lake in Ethiopia's Oromia Region that is situated roughly 168 kilometers south of Addis Ababa. This vast lake, which is 440 square kilometers in size and is a part of the Rift Valley. It is located at an elevation of 1,636 meters and measures 31 kilometers in length and 20 kilometers in width. The lake is relatively shallow, with a maximum depth of about 9 meters, despite its vastness.

Debre Sina, Galila, Bird Island, and Tulu Gudo are the five islands that dot Lake Ziway. Particularly Tulu Gudo is revered in local legend since it is thought to have served as the Ark of the Covenant's hiding location during the ninth century. Lake Ziway is a significant landmark in Ethiopia because of its natural beauty and historical and cultural significance.

The islands in the lake are extremely important to the local inhabitants, even outside of their historical connections. Tulugudo is home to about 2000 people, Tedecha can handle more than 3,000 people, and Funduro supports less than 100 people. For the people living around Lake Ziway, fishing is a major source of income. Unfortunately, the lack of refrigeration and other preservation infrastructure puts the sustainability of this fishing operation at risk. Notwithstanding these difficulties, Lake Ziway continues to be a breathtaking natural wonder rich in cultural significance and history (Gizaw and Bekele G, 2023).

In any place, energy is a necessary commodity for raising incomes and enhancing living standards. For people as well as nations, it is a vital force behind social advancement and economic prosperity. Still, most people on the planet reside in rural areas, where the dispersed nature of these communities makes it difficult for governments to offer even the most basic energy services. A major obstacle to the development and standard of living in these areas is the disparity in energy access.

Global energy consumption is rising and is predicted to do so in the ensuing decades due to population growth, which is predicted to increase by roughly two billion people during the same period. Since 2000, there appears to have been a noticeable increase in the world's energy consumption of roughly one third. This expansion of energy-dissipative economic activity is expected to drive up electricity consumption by 50% between 2021 and 2040 (IEA 2022).

Nonetheless, the structure of energy consumption may be suitably formed, and the correlation between energy consumption and economic development could be synchronized and quantified while taking into account energy-associated environmental issues, such as CO2 emissions (Karakurt and Aydin, 2023).

The energy industry in Ethiopia has two challenges. The first problem is limited access to modern energy sources, and the second is a strong reliance on traditional biomass energy sources to meet the growing energy demand (Mondal and Ringler, 2020). This double difficulty highlights the intricate relationships at work in the country's efforts to secure a robust and sustainable energy future. Investigating the complex story of Ethiopia's energy sector is crucial to understanding these nuances.

Ethiopia currently depends primarily on hydropower, which accounts for almost 90% of its total energy consumption. Nonetheless, the energy paradigm in rural homes follows a different path, with fuel wood accounting for a significant portion of their energy needs more than 80%. This country's widespread reliance on fuel wood not only exacerbates deforestation but also plays a major role in seriously degrading the soil (Hailu and Kumsa, 2021). This complex relationship between energy sources and environmental effects highlights the need for a thorough analysis of Ethiopia's existing energy situation as well as the necessity of sustainable alternatives.

The Universal energy Access Program (UEAP) aims to increase national per capita energy usage from the current 28 kWh to 128 kWh by 2015. It also aims to improve overall access to electricity. Reaching this lofty objective will need a significant increase in power plant capacity, from the existing 2GW to 10GW. The Ethiopian government recognizes that expanding the grid will not be the only way to quickly improve rural areas' access to power.

Ethiopia has a wealth of renewable energy resources that can be used to generate electricity on its own in isolated areas. These resources can be used singly or in combination, and they include small-scale hydropower, biomass, wind, and solar energy. Remarkably, traditional biomass continues to be the major source of energy for 83% of Ethiopians living in rural regions.

The government has redesigned its Off-Grid Rural Electrification Acceleration Plan in response to this difficulty. Encouraging private sector participation in providing access to rural areas without electricity is the goal of the Rural Electrification Strategy. In order to remove barriers and encourage private sector participation throughout the whole off-grid power provision spectrum generation, transmission, distribution, and marketing this entails creating institutional and financial frameworks.

For many rural villages, the lack of readily available power has been a major barrier to growth. Due in large part to the isolated locations and sparse populations of these rural areas, the traditional methods of power delivery have proven to be uneconomically viable, unreasonably expensive, unreliable, and difficult to maintain. Many of these towns so still lack access to electricity, and it's possible that they won't get it from utility services in the future.

The growing expenses associated with fossil fuels and the need to extend power lines, in addition to the need to reduce carbon dioxide emissions, have prompted the creation of hybrid power systems designed for remote areas. These systems function independently without depending on a sizable, centralized electrical grid because they are specifically made for the production and use of electricity. Interestingly, hybrid power systems combine many power sources and can in different sizes: from large island networks to single household energy supplies.

Decentralized generation especially based on renewable energy technologies emerges as the most effective way to supply electricity in places that are yet unreached by traditional means. The difficulties in extending conventional grid including obtaining replacement parts for conventional sources like diesel generators and delivering fuel to far locations highlight the practicality of decentralized generation. Conventional power sources' operating durations can be effectively reduced by using renewable energy sources (RES), which provide a local and sustainable option. This decreases fuel usage while simultaneously lowering maintenance requirements, which improves power generation's sustainability.

The hybrid renewable energy source minimizes the time difference between peak load and maximum power production by including storage technologies to meet demand during times when renewable sources are unavailable. It also has controllers and power conditioning devices for converting and controlling energy in various forms.

A hybrid solar power system is a more dependable and efficient energy production configuration that combines solar energy with another power source, such as a wind turbine. This hybrid system makes use of the summertime high efficiency of solar panels and the wintertime peak performance of wind turbines. Hybrid Power Systems frequently provide more economic and environmental benefits as compared to the use of solar, wind, or geothermal systems alone.

The hybrid solar wind power system described in this work makes use of a voltage-regulated inverter that is controlled by a fuzzy logic controller. An electric renewables hybrid optimization model is used to optimize the system's parameters. Through modeling and simulation in the MATLAB environment, we are able to observe and assess the optimal configuration for the fuzzy hybrid logic controller-controlled hybrid photovoltaic/wind/battery system.

It is difficult to determine the ideal capacity for Battery Energy Storage Systems (BESS) because solar and wind power sources are erratic. Under sizing the storage system can cause power outages and jeopardize system reliability, while oversizing it results in needless installation and operating costs. It is crucial to strike a balance between cost and dependability, which calls for the creation of effective capacity estimation methods for BESS.

The goal of several studies has been to maximize storage system sizing when combined with solar and wind PV plants (Giulietti, M., & Chen, B. 2016). These studies use these resources' synergies to calculate the optimal BESS capacity. Notwithstanding these developments, there is still a great deal of room for creative inquiry in this area, which might save expenses and boost revenue. This thesis emphasizes prospects for private investment and the development of tourism in the nation, in addition to giving islanders access to power.

A crucial step in enhancing rural areas' socioeconomic circumstances and promoting the nation's overall development is electrifying villages. Having more access to electricity has many advantages, including lowering poverty rates through raising living standards, generating employment, and promoting economic expansion. Furthermore, the availability of electricity has a major role in providing basic necessities like healthcare, education, and water for irrigation and drinking, hence meeting the demands of people living in rural and island areas (Kumaravel, S& Ashok, S. 2012).

1.2 Statement of the Problem

Ethiopia's many islands lack consistent access to electricity, which causes differences in development between them and the mainland. This uneven distribution of power hinders island populations' socioeconomic development. Islands' isolated locations make it difficult to expand the electrical system because of poor infrastructure and technological impediments. Due to its challenging connectivity to the main power system, Ziway Islands primarily depends on traditional biomass fuel for lighting and cooking. This long-term financially unsustainable use of non-renewable energy sources is risky for the environment.

There are several urgent problems with using conventional biomass fuels. It causes the forest's firewood resources to be continuously depleted, which has negative effects on the ecology. Furthermore, women and children, who are usually in charge of gathering wood and fuel, are disproportionately affected by the rising cost and unavailability of household fuels, especially firewood. The trade balance and availability of foreign exchange in Ethiopia are further aggravated by the high cost of fuel imports.

Additionally, the majority of the lighting systems on these islands run on kerosene, which emits pollutants and smoke in addition to being unhealthy. Furthermore, the shortage of electricity in these places affects vital institutions like schools and health centers, highlighting the pressing need for dependable and sustainable energy solutions.

A number of drawbacks emerge when contrasting alternative controllers with a fuzzy logic controller (FLC) for effectively controlling and optimizing energy generation and storage in solar, wind, and battery hybrid systems: PID controls are dependent on exact mathematical models. These models can be challenging to derive and may not adequately describe system behavior in systems with highly variable inputs, such as wind and solar electricity, which could result in inefficiencies. Conventional logic controllers don't react to changes in real time; instead, they operate according to preset rules. Poor performance results from this in variable situations, including solar and wind power generation. A significant amount of historical data must be used for comprehensive training of ANN-based controllers. This could be a drawback if there is insufficient data or if the data is not accurate in representing all potential operational scenarios.

1.3 Motivation of the study on Dembel Small Island

Small islands' isolated locations and scarce resources provide particular difficulties in supplying their energy needs. Their reliance on imported fossil fuels to generate power exacerbates these problems by creating environmental problems and economic weaknesses. Small islands are increasingly relying on alternative energy sources like solar, wind, and battery storage to address these issues. These islands hope to lessen their need on fossil fuels and transition to a cleaner, more sustainable future by switching to renewable energy. However, there are major barriers to the implementation of large-scale renewable energy projects due to limited land and geographic limits. Notwithstanding these difficulties, creative fixes and technical developments are being sought to get beyond these obstacles and encourage the use of renewable energy in tiny island communities. Moreover, the absence of electricity.

1.4 Objectives of the study

The general and specific goals listed below will be developed in order to finish this thesis assignment.

1.4.1 Main objective

To evaluate the feasibility of implementing a solar, wind, and battery hybrid energy system with fuzzy logic-based energy management to provide reliable, cost-effective, and sustainable electricity for Ziway/Dembel Lake Island.

1.4.2 Specific Objectives

- To assess the renewable energy potential (solar and wind) on Ziway/Dembel Lake Island through resource evaluation and data analysis
- To analyze the environmental impact.
- Creating component models to replicate solar panels, wind turbines, batteries, and converters.
- To design and develop a fuzzy logic-based energy management system.

1.5 Scope of the Study and Limitation

In order to meet the energy demands of the Ziway islands, the goal of this thesis was to develop and simulate a hybrid solar-wind renewable energy system using a fuzzy logic controller and the relevant software. An in-depth examination of the site's energy load requirements served as the foundation for the study. The primary goal was to ascertain whether integrating solar, wind, and battery technologies for the islands was both technically and financially feasible. Important information was gathered and analyzed to determine the ideal setup for the system.

The feasibility of a wind, solar, and battery hybrid energy system was the exclusive subject of this study; other renewable energy sources such as micro hydro, biogas, biodiesel, and comparable alternatives were not included. Although a thorough examination of various sources could have been necessary to determine appropriate pairings for particular energy requirements, it was outside the purview of this thesis. The research was intentionally restricted to developing a stand-alone hybrid solar-wind system.

1.6. Significance of the Study

This study offers the government and investors important information about the viability, quality of the power supply, initial investment costs, and ongoing operating costs of hybrid renewable power projects in the nation. Having this knowledge will make creating investing plans more successful. This study offers a workable approach for comparable projects and rural electrification initiatives, which policymakers and pertinent stakeholders might employ. This study solves issues related to electrification by utilizing available renewable energy sources such as solar and wind power. The nation's efforts to reduce poverty are directly aided by the reasonably priced electricity produced by renewable resources. Hybrid energy systems, which comply with global regulations and emission reduction targets, thus appear to be the best option for remote locations.

1.7. Outline of the Study

In this thesis, there are five chapters. The introductory chapter offers a broad summary of the subject. The proposed components for producing green energy, especially solar and wind power, are explained in detail in the second chapter, which also provides a comprehensive literature analysis. Evaluation of the potential of these energy resources at the selected site is the main topic of the third chapter, which also covers capacity design for each component, system modeling, and the collection and analysis of primary and secondary data. In Chapter 4, the MATLAB function program and fuzzy logic controller implementation are shown, together with the HOMER feasibility of the hybrid and the simulation outcomes of the hybrid components in MATLAB/Simulink 2019a. The last one, contains the conclusions and suggestions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Literature Overview

Ethiopia and other countries have hosted a large number of hybrid power production research studies. Using a range of technological options and investigative techniques, numerous research assessed the different arrangements of renewable energy resources, including solar, wind, and battery energy, as well as their hybrid arrangements. Numerous studies have been published for various forms of applications, as evidenced by their results; a review of some of these publications can be found in the paragraphs that follow.

In Terefe J. (2013)'s study, three micro and small enterprises (MSEs) at the Welenchity site that manufacture metal and wood products were to be supplied by a hybrid electric power generation system. The first step of the investigation was to assess the location's potential for solar and wind energy. The HOMER program was used to evaluate the data that was gathered from different sources. The results of the investigation indicate that the site has significant potential for both solar and wind energy, providing ideal circumstances for the installation of a hybrid renewable energy system.

Scholars like Zhang et al. (2020) and Khan and Mathew (2019) have come to an agreement regarding the appropriateness of fuzzy logic techniques for integrated power system management. The application of fuzzy control techniques offers an organized way to monitor load and energy source variations, which improves integrated power systems' dependability. The Homer software is frequently utilized while figuring out the best configuration for hybrid systems.

Zhang et al. (2020) looked into the viability of using a hybrid solar-wind-battery system to electrify a remote Pacific island. To maximize system sizing and evaluate economic viability, the study used a techno-economic analysis. The study emphasized the need of taking into account regional environmental conditions and fluctuations in energy use, and it highlighted the necessity of having a thorough grasp of these elements. A gap was found in the evaluation of the planned hybrid system's social acceptability and long-term environmental implications, despite the economic study being comprehensive. The study came to the conclusion that even though the suggested hybrid system showed economic viability, more research was necessary to address social and environmental issues.

The study by Althubaiti et al. (2017) concentrated on a hybrid power system that used fuzzy logic. Their study includes using MATLAB to construct fuzzy logic control with the goal of efficiently managing the load and available energy sources according to predetermined rules. It is significant to note that the focus of this study is focused on energy management; the ideal configuration of the hybrid power system employing Homer is not taken into consideration.

Kim et al.'s (2022) research concentrated on whether a Caribbean island could adopt a hybrid solar-wind-battery system. To evaluate the hybrid system's resilience and dependability across a range of weather scenarios, their study used a probabilistic modeling approach. To assess system reliability in the face of changing weather, use probabilistic modeling. An area of unmet research need was found in the study's analysis of the socioeconomic variables affecting the local community's hybrid energy system adoption. Although the research showed that additional study of socio-economic factors is necessary for successful deployment, the hybrid system showed good reliability.

Smith and colleagues (2021) investigated the viability of establishing a hybrid system comprising solar, wind, and battery power for a distant community situated in the Himalayas. To maximize the system configuration while accounting for local weather patterns and energy consumption, the research used a thorough techno-economic analysis. Concerning the evaluation of seasonal changes' effects on the performance and long-term economic sustainability of the hybrid system, the study found a research gap. The study stressed the need for more research on seasonal fluctuations even if it concluded that the hybrid system was economically feasible.

In their study from 2022, Patel and Nguyen focused on using a solar-wind-battery hybrid system to electrify a secluded island in Southeast Asia. To maximize the system's efficiency, the researchers used a scenario-based modeling technique that included several system configurations and energy storage capacities. The study highlighted a research need in the area of knowing the best mix of solar and wind components for various geographic regions. Although the hybrid system demonstrated adaptability, the study highlighted the need for location-specific optimization methodologies.

Aziz (2017) created a model of an off-grid hybrid energy system (HES) to power an electrified desert safari camp in the United Arab Emirates. Researchers are looking on Off-Grid Hybrid Energy Systems (HES) as potential solutions to the electrification of rural areas, particularly desert safari camps in the United Arab Emirates (UAE). By modeling an off-grid hybrid energy system (HES) for the purpose of electrifying a desert safari camp in the United Arab Emirates, he made a valuable contribution to the field. The study highlighted the utilization of batteries, wind turbines (WT), and photovoltaic (PV) panels together, demonstrating the configuration's economic potential. To optimize system components and determine economic feasibility, the process probably included techno-economic analysis with simulation tools. Information on the precise instruments and settings utilized throughout the modeling procedure would offer

2.2. Basic Understanding of Renewable Energy

Photovoltaic (PV) and wind power technologies are the most commonly used methods for producing electricity in rural and island locations. The focus of this thesis is limited to solar and wind energy, with brief summaries of these two energy sources given in the following sections.

2.2.1. Solar System

Solar energy is the result of harnessing solar radiation to create usable chemical, electrical, or calorific energy. This energy has grown throughout time to rank among the primary renewable energy sources, along with wind, biomass, and hydraulic energy.

When considering alternative energy sources, solar energy consumption is still quite modest. The energy corresponding to solar radiation received at the earth's surface is by far the most abundant resource of all those available to humanity, yet even among renewable energies, it is still in the minority.

To comprehend the many conversion processes of our star's radiation, a few theoretical foundations are necessary. They can be obtained by first addressing the resource, which is the solar energy that reaches the surface of the earth, and then elucidating the physical laws that control how radiation interacts with matter to transform into heat or electricity in various materials.

The amount of solar energy that is usable by humans is different from the total solar energy in the vicinity of the Earth's surface because of a number of variables, including geography, seasonal fluctuations, cloud cover, and the amount of land that is inhabited by humans. These factors all place restrictions on our capacity to use solar energy (Bekele, G. 2009). The sun produces solar radiation, which is a sort of solar energy. It is the primary source of energy for the production of biomass, water, and wind. As a result, it is appropriate to acknowledge that the sun is the source of all renewable energy.

2.2.1.1. PV Cells, Modules and Arrays

The photovoltaic (PV) cell is an essential part of a solar electric system. Numerous functional components make up solar systems, including as modules, or panels, which are arranged in arrays, and cells. Solar cells are individual photovoltaic devices. Even though a single photovoltaic cell only produces one or two watts of power, its potential is increased when many cells are connected to form larger units called modules. These modules can be joined together to create larger structures known as arrays, which will further increase power output. PV systems may thus supply nearly any amount of electricity, no matter how big or tiny (Bekele, G. 2009).

According to Markvart and Castaner (2012), a photovoltaic module is made up of several PV cells that are carefully coupled in series to raise voltage and in parallel to enhance current. Because individual cells only provide a small amount of electrical power, it is necessary to connect numerous cells using series, parallel, or series-parallel arrangements.

a) Series Wiring: By connecting the positive terminal of one solar module to the negative terminal of another, series wiring raises the voltage of a solar module. The configuration of the batteries in a flashlight is similar to this (Markvart, T., & Castaner, L. 2012).

b) Parallel wiring, on the other hand, seeks to raise a solar array's output current (amps) while preserving a steady voltage. All of the negative terminals and the positive terminals of several modules are connected in parallel wiring (Bekele, G. 2009).

c) Series-Parallel Combination: By connecting solar panels in a series-parallel configuration, a greater wattage array can be produced by amplifying both the voltage and current output. PV cells must be connected in parallel or series depending on the exact voltage and current requirements in order to withstand high loads.

PV systems may adapt to a range of power needs, meeting the demands of various applications, thanks to this clever blend of series and parallel wiring arrangements. Electronic calculators and other small devices require more power than a photovoltaic cell can provide. The average silicon solar cell generates 0.5 volts. Figure 2.1 below illustrates how the PV cells must be linked in series or parallel, depending on the required voltage and current, to handle higher loads.

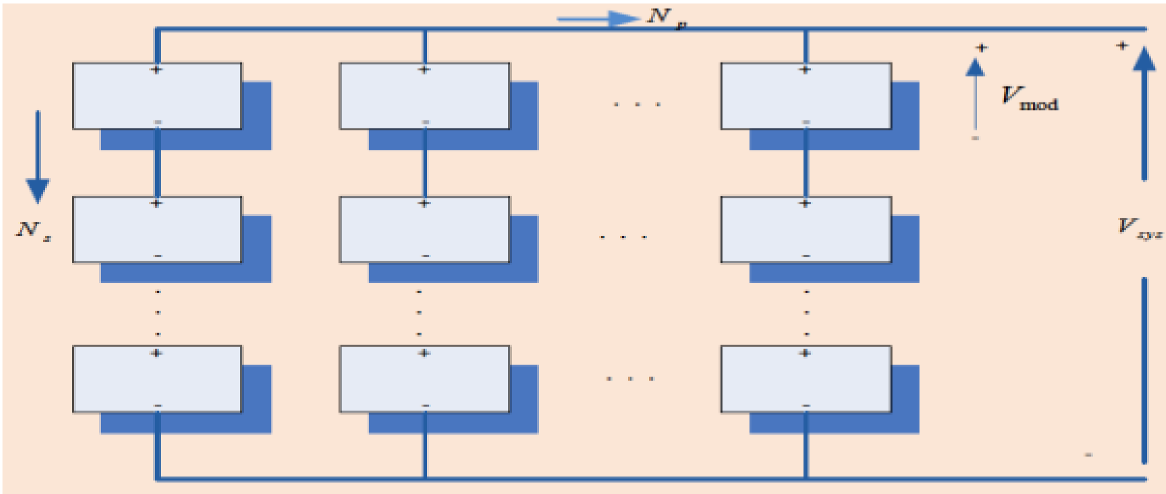


Figure 2.1 Series and parallel connection of the PV-modules (Deb, S. G. 2012).

The term "direct radiation" describes solar energy that travels directly to the Earth's surface, whereas "diffuse radiation" is the consequence of sunlight being dispersed by different atmospheric components like dust, humidity, pollution, and clouds. Broadly speaking, global-horizontal radiation is the sum of direct and dispersed sunshine. Photographic (PV) cells and other solar technologies can function well with diffused radiation, but concentrating solar methods use mirrors and lenses to focus on direct radiation. Significantly, photovoltaic cells are able to produce power even in cloudy conditions in addition to utilizing the direct portion of sunlight. Its capacity to absorb and transform solar energy in a variety of air circumstances is highlighted by this. For photovoltaic cells, the average annual solar energy collected is taken into account rather than the immediate irradiance.

There are three different sorts of modules, depending on the manufacturing process (H Shezan, A. S. K., et al. 2016).

a) Mono-crystalline Silicon:- single-crystalline Silicon Single-crystal solar cells make up the majority of the market. Silicon is refined, heated, and crystallized into ingots in order to make the cell. The most efficient kind of solar cells are mono-crystalline silicon ones, but because of the technology required to create big, very uniform silicon crystals, they are also the most expensive. Sunlight is converted by the solar cell into electrical energy that can be stored or used to run appliances.

b) Polycrystalline Silicon:- The processes used in the production and operation of polycrystalline cells are comparable. The difference is the usage of less expensive silicon. The particular cell is really large and readily forms into a square shape, thereby eliminating any empty space between cells. In comparison to single crystalline, it has a marginally lower conversion efficiency, but its manufacturing costs are also cheaper. The efficiency of cells varies from 10% to 13%. (Luque, A., & Hegedus, 2013).

c) Amorphous Silicon:- The crystal structures of the two silicon varieties previously utilized in solar cells are different. Silicon that is amorphous lacks this structure. Vaporized silicon is deposited in extremely thin layers over a glass, plastic, or metal support to create amorphous silicon units. They are assembled into long, rectangular "strip cells" since they may be created in sizes up to many square yards. "Modules" are created by connecting these in series. The low efficiency of approximately 6% is their drawback. These days, amorphous silicon solar cell panels are available in many forms, including roof tiles that can take the place of traditional brick tiles in solar roofs. PV cells are currently made using a variety of other promising materials in addition to the ones mentioned above, like copper indium selenide ($CuInSe_2$) and cadmium telluride (CdTe). (Luque, A., & Hegedus,2013).

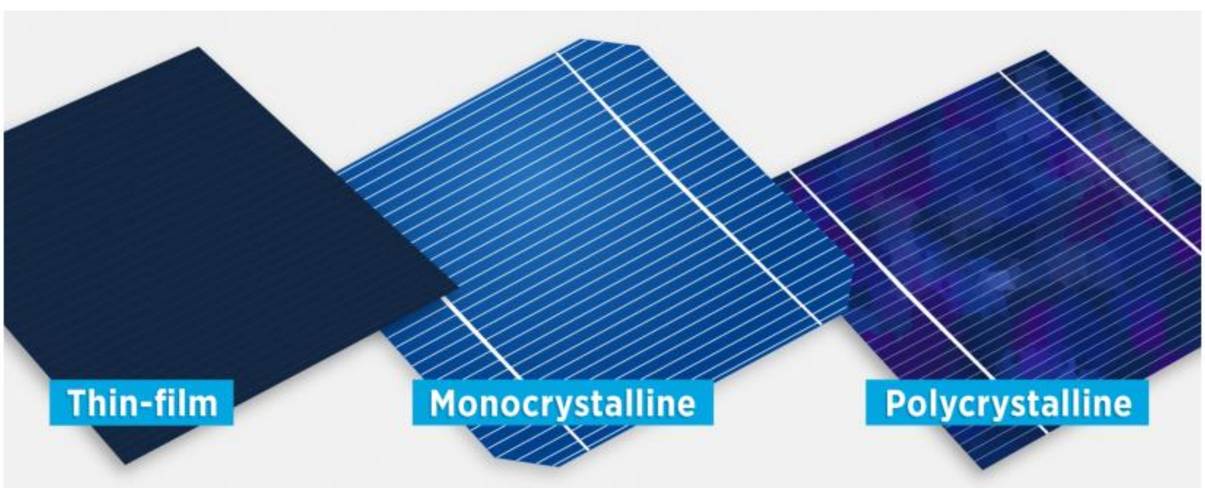


Figure 2.2 Type of photovoltaic cell (Luque, A. and Hegedus, S,2013)

2.2.1.2 Fundamental Operating Guidelines Solar-Powered Photovoltaic Systems

PV cells use the photoelectric effect to convert sunlight directly into energy. Semiconductor materials covered with compounds that absorb light are used to produce cells. The separation of electrical charges on the top and bottom of the solar cell occurs when electrons pass through the semiconductor to the bottom layer. An electrical circuit is completed and electrons are allowed to return to the top by connecting the bottom layer to the top using a conductor. This produces an electric current, which allows the process to repeat itself when more sunlight is available (Clean Energy Associates). Direct conversion of mild energy into electrical power at the atomic level is known as photovoltaic. Certain materials have a characteristic known as the image electric impact, which causes them to absorb light photons and emit electrons.

Photovoltaic (PV) cells use the photoelectric effect to directly harvest sunlight. These cells are made of semiconductor materials that have been covered in compounds that absorb light. The semiconductor's electrons become activated when sunlight strikes the cells, dividing the electrical charges in the top and bottom layers of the cell. An electrical circuit is completed by joining a conductor between the bottom and top layers, which permits electrons to travel back to the top and produces an electric current. More sunlight can be used to repeat this process, allowing for the continuous production of power (Clean Energy Associates).

Fundamentally, photovoltaic technology involves directly converting light at the atomic level into electrical power. Some materials have the ability to absorb light photons and then release electrons, a phenomenon known as the photoelectric effect. Useful electricity is produced when these free electrons are drawn in and used as electric current. Essentially, sunlight dislodges electrons from semiconductor material when it interacts with a solar cell. The trapped electrons can flow as electric current by creating an electrical circuit by attaching electrical conductors to the positive and negative sides of the cell. This current thus functions as a useful source of electricity, able to power a variety of loads.

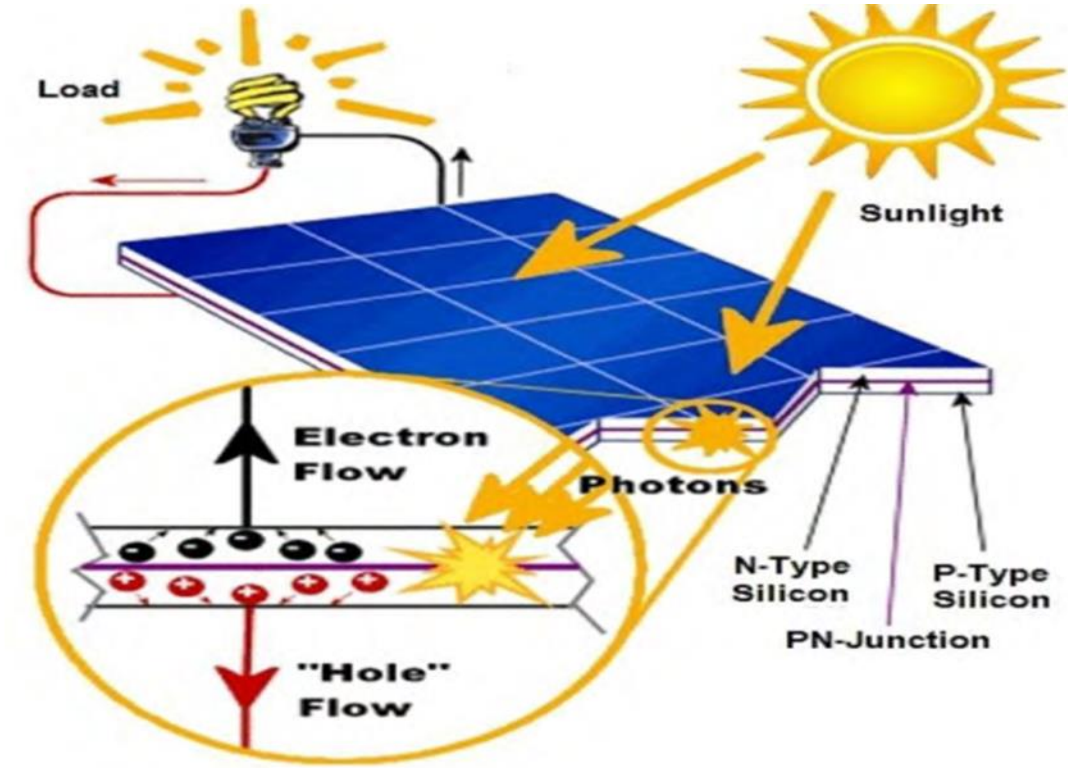


Figure 2.3 Basic operation of photovoltaic system (Bizuayehu, T,2011).

2.2.1.3 Equivalent Electrical Circuit of PV Cell

To describe the operating properties of the circuit, the equivalent circuit model employs a circuit component to create a particular circuit network.

A current source connected in series with a diode can simulate the characteristics of an ideal solar cell; hence, the model receives a shunt resistance and a series resistance component. The light-generated current (IL) and the current (I) at the output terminals are equal to less than the diode current ID and the shunt leakage current Ish. The collection resistance Rs, a measurement of the internal resistance to current flow, is influenced by the depth of the p-n junction, contaminants, and contact resistance. There exists an inverse correlation between the shunt resistance Rsh and the leakage current to ground. In the case of an ideal PV cell, $R_s = 0$ and $R_{sh} = \infty$ The conversion of solar energy

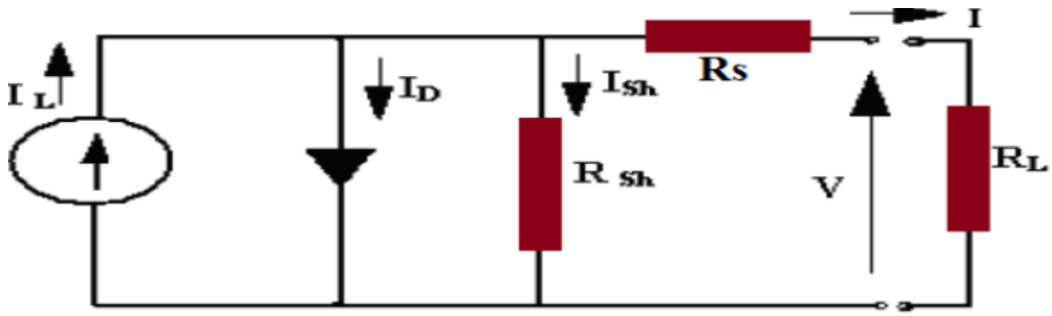


Figure 2.4 A PV cell equivalent electrical circuit (Duffie, J.A. and Beckman, W.A., 2016)

The open-circuit voltage of the cell is obtained when the load current (I) is zero and is given by the following:

$$Voc= (IL – ID) Rsh \qquad 2.1$$

The diode current is given by the standard diode current expression:

$$I_D = I_O[\exp(\frac{qVoc}{AKT})-1] \qquad 2.2$$

Where is the saturation current of the diode (A), q is electron charge (1.6×10^{-9} C), A is curve-fitting constant, K is Boltzmann constant (1.38×10^{-9} J/°K), and T is temperature on absolute scale ° K.

Thus, the load current is given by the expression:

$$I = I_L – I_D – I_{sh} \qquad 2.3$$

$$I = I_L - I_O[\exp(\frac{qVoc}{AKT}) - \frac{Voc}{Rsh}] \qquad 2.4$$

Leakage current to earth is the most recent phrase. It pales in comparison to and is typically disregarded in practical cells.

Under complete illumination, the open-circuit voltage and the short-circuit current are the two most important figures of merit that are frequently employed to describe the electrical performance of PV cells.

By briefly cutting the output terminals, the terminal current can be used to calculate the short-circuit current. Under this scenario, the photocurrent is the short circuit current, disregarding the smaller diode and ground leakage currents at zero voltage.

The open-circuit voltage is as follows when the highest photovoltaic voltage is given by I:

$$V_{oc} = \frac{AKT}{q} \ln(\frac{IL}{Io} +1) \qquad 2.5$$

2.2.2 Solar Radiation

It is stated that solar radiation is the primary source of renewable energy and that thermal and photovoltaic conversion are two potential uses for this energy. It is the energy or radiation that the sun emits. It is sometimes referred to as solar radiation in short wave form and can take many different forms, including ultraviolet, x-ray, radio waves, heat (infrared), and visible light. Solar radiation measurements are often lower on gloomy days and greater on clear, sunny days. The amount of solar radiation that reaches the earth's surface depends on a number of factors, including location, activity, the earth's rotation, cloud cover, ozone layer health, and the time of day. Standard spectra have been created to serve as a foundation for both simulator construction and the theoretical evaluation of the impacts of sun radiation. For daily solar radiation (irradiation) in the Northern Hemisphere, seasonal fluctuation is highly reliant on latitude when it occurs on a horizontal surface outside of Earth's atmosphere.

2.2.3 Factors influencing the module's performance

The following variables have an impact on the solar module's performance:

- Load resistance
- Sunlight intensity
- Cell temperature
- Shading

Load resistance: a module will function at its greatest point, resulting in the highest efficiency, when the loads suitably align with a module V-I curve. Sunlight radiation is directly correlated with the power that the module produces. Temperature of the cells: Module efficiency decreases and voltage is reduced as the temperature rises above the standard operating temperature of 25^{0}C. Shade: A solar module's characteristics curve is influenced by shading, even in a partial way, which drastically reduces production. The total open circuit voltage of all the completely irradiated cells multiplied by the shaded cell, which is regarded as a load, is a negative voltage. As a result, the hot spot effect is created by the shadowed cell producing heat, permanently damaging the cell. Wiring a bypass diode in anti-parallel to bypass the cell in the event of shading can help avoid this impact. The wiring of the modules (series or parallel) determines the output reduction in the case of shade. Dust or any other shadowing effect has the potential to generate shading.

2.2.4 Photovoltaic Energy Conversion

The unique selling point of photovoltaic energy is its direct conversion of solar radiation into electrical energy through an electronic solid-state process, setting it apart from conventional power generation systems. As a result, photovoltaic systems are silent when operating and have a long service life, excellent dependability, and minimal maintenance needs. Moderate climates with higher fractions of diffuse radiation can also benefit from the utilization of both direct and diffuse radiation due to the nature of the conversion process. The ability of PV to be modularly integrated into buildings and used for dispersed applications with extremely low load requirements is another significant benefit (Leong Kit Gan & et al, 2015).

Solar energy conversion mechanisms come in two varieties.

- Direct and indirect solar energy conversion

  Direct solar energy conversion for different application: -

  - ✓ For heating commercial and residential
  - ✓ For electricity production
- An indirect solar energy source

Benefits of Photovoltaic Systems

- Wherever it counterbalances emissions of greenhouse gases and other pollutants, the energy supply is limitless, renewable, and free.
- It generates energy during the day, when demand is at its highest and production costs are usually at their highest.
- The facilities can run with very little maintenance after the first setup.
- When compared to other power systems, operating expenses are incredibly inexpensive.
- It produces electricity at the actual site of usage and is incredibly reliable.
- PV systems are readily extendable, making it possible to set them up initially on a cheap budget and add more modules later on, if needed.

Drawbacks of Photovoltaic Systems

- For the majority of PV power generation systems to operate at average efficiency, substantial tracts of land are needed. Additionally, the silicon utilized is highly costly.

- Present estimates have the cost of solar energy roughly double that of conventional sources (coal, oil, etc.).
- The issue of nocturnal downtime implies that photovoltaic systems can only produce electricity during the day because of the irregular and inconsistent way that solar radiation reaches the surface of the earth.

2.3 Wind Turbines

2.3.1History of wind power

Wind power has a long and illustrious history, having been used for a variety of reasons by ancient civilizations. About 5000 years ago, wind power was first utilized to move ships down the Nile River. Over time, it was developed to meet the needs of various cultures for industrial and transportation purposes. During the 1700s and 1800s, wind energy was particularly useful to European society for pumping water and grinding cereals.

When electricity became available in the late 19th century, interest in using wind power to generate electricity increased. In the United States' rural areas, the first windmill built especially for producing power was erected in 1890. But wind energy remained a niche application, mostly for distant battery charging, for the most of the twentieth century.

Rising oil prices during the 1970s energy crisis led to a resurgence of interest in wind power and other alternative energy sources. Research, development, and demonstration initiatives pertaining to wind turbines and other renewable technologies have been heavily funded by governments across the globe. This resulted in the development of prototype wind turbines in the US, including the Mod-0 in 1975 and the Mod-5B in 1987, which demonstrated improvements in wind turbine efficiency and design.

Since then, the wind energy sector has grown and innovated remarkably. The efficiency and output of energy have been greatly enhanced by technological developments, such as taller turbines with greater rotor diameters. Global wind power adoption has been further boosted by government policies that support renewable energy, falling costs, and environmental concerns.

2.3.2 Wind Turbines Components

Wind turbines with a horizontal axis are the most prevalent form.

Drive : High-Speed Shaft (HSS), Brakes, Gear Box, Couplings, Bearings, and Low-Speed Shaft (LSS)

Electrical: Power Electronics, Generator,

Control mechanisms include the pitch and yaw motors, brakes, gearboxes, and direction and wind sensors.

Supporting Structures: Tower, It is necessary for the reader to become acquainted with the parts of a wind turbine.

Rotor : The hub and blades collectively are referred to as the rotor.

The hub serves as the low speed shaft's and rotor blades' connecting point.

Anemometer: Measures the wind speed and transmits wind speed data to the controller.

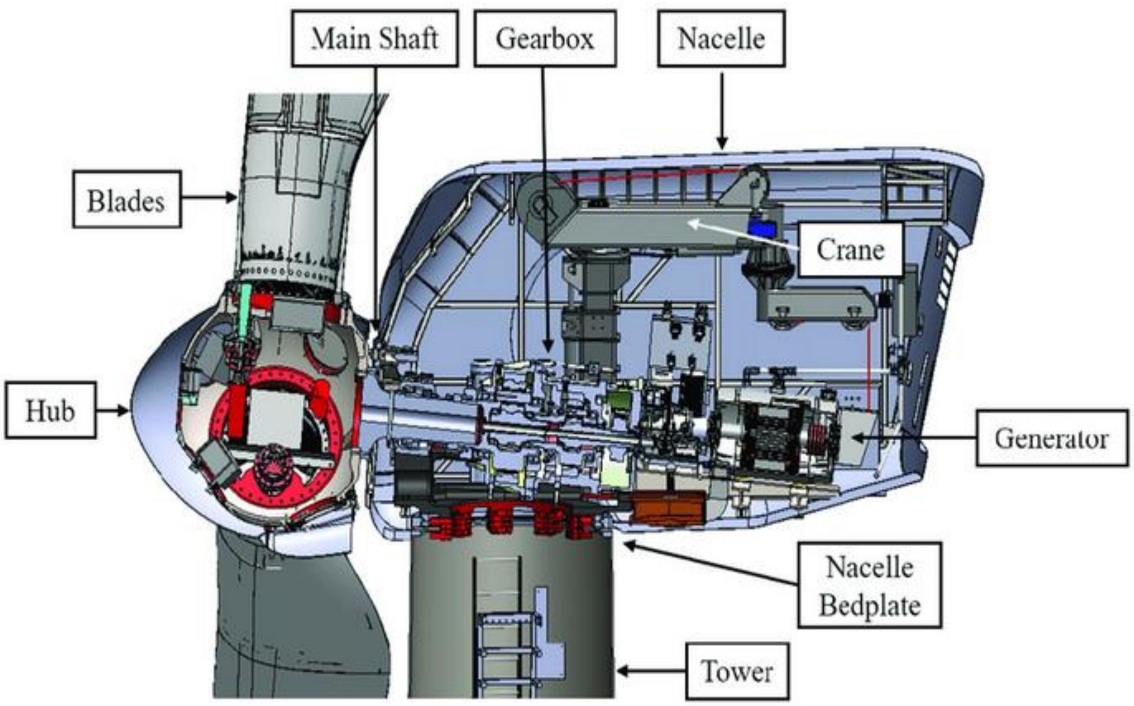


Figure 2.5 Component of wind turbine (Burton et.al 2011)

Gear box: The high-speed shaft and low-speed shaft are connected by gears, which raise the rotational speeds from roughly 30 to 60 revolutions per minute (rpm) to roughly 1000 to 1800 rpm, which is the rotational speed needed by the majority of generators to generate energy. Since the gear box is an expensive and heavy component of wind turbines, researchers are looking on "direct-drive" generators, which spin at lower speeds and do not require gear boxes.

Controller: The machine is started by the controller at wind speeds between 3.5 and 7.2 meters per second (m/s), and it is shut off at roughly 30 m/s.

Generator: The generator is the part of the system that turns the shaft's rotational energy into an electrical output, and it is attached to the high-speed shaft.

Shaft with high speed: it powers the generator.

Low-speed shaft: Approximately 30 to 60 rotations per minute are made by the rotor on the low-speed shaft.

Nacelle: High- and low-speed gearboxes are located in the nacelle, which is situated atop the tower.

Pitch: To regulate the rotor speed and prevent it from turning in winds that are too high or too low to generate electricity, blades are pitched or turned away from the wind.

Rotor: The hub and blades collectively are referred to as the rotor.

Tower: Steel lattice, concrete, or tubular steel are used to build towers. Towers that are higher allow turbines to absorb more wind energy and produce more electricity since wind speed rises with height.

Wind direction: Because it faces the wind, this turbine is known as a "upwind" turbine. Other turbines have an orientation that is "downwind," meaning they face the wind.

Wind vane:In order to appropriately orient the turbine with respect to the wind, the wind vane measures the direction of the wind and communicates with the yaw drive..

Yaw drive: Since upwind turbines face the wind, the rotor is kept facing the wind even when the wind direction shifts. The rotor of a downwind turbine is blown downwind by the wind, hence no yaw drive is needed.

Yaw drive: Powered by the yaw motor.

Electronic equipment: includes ground support equipment, electrical lines, controllers, and equipment for connections.

Wind energy is one of the electricity sources that is expanding the quickest in the world today, and it is essential to the shift to more renewable and sustainable energy sources in the future. Improvements in wind turbine technology are being driven by ongoing research and development, which is why wind power is becoming a more significant part of the world's energy mix.

The unequal heating of the land and sea surfaces of the earth by the sun produces winds. They therefore represent a type of solar energy. Generally speaking, the ratio of incident solar power to total wind power is on the direction of two currents, indicating a balance between input and dissipation due to surface drag and turbulence.

The majority of wind turbines (WT) are devices designed to produce electricity from the stored energy in the wind. These devices are primarily categorized according on how their blades interact with the wind through aerodynamic forces, which can be drag, lift, or a combination of both; also, the direction of the rotor axis with respect to the tower and the ground is classified as either downwind or upwind (Ahmed, 2011). There are two types of wind turbines based on axis orientation: HAWTS (horizontal axis wind turbine) and VAWTS (vertical axis wind turbine) (Figure 2.6a).

The VAWTs that are primarily utilized for water pumping are the Savonius (Figure 2.6 b) and the Darrieus (Figure 2.6 a) WT. Smaller towers are less expensive since they can receive wind from any direction and don't require wind direction tracking equipment. Additionally, because the rotor and generator can be coupled at ground level, maintenance is made easier and maintenance costs are lowered. Its lack of self-starting, significant torque variations, and restricted regulating options at high wind speeds are its key drawbacks.

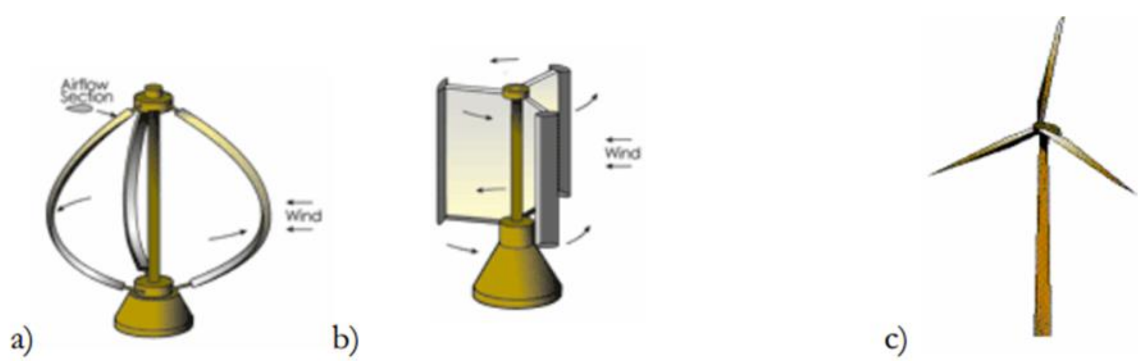


Figure 2.6Types of wind turbine (Burton et.al 2011)

The other kind are called HAWTs, and they have rotors that are maintained perpendicular to the wind. Lift is the rotating driving force, and the blades can be located either upwind or downwind of the tower. Because the rotors of the HAWTs are positioned at the summit of a tower, they are able to extract larger wind speeds farther from the ground.

2.3.3 Wind Turbine Type and Blade Aerodynamics

Wind kinetic energy is transformed into mechanical energy by a wind turbine, with modifications made for different uses. Wind generators transform mechanical energy into electrical power, whereas windmills directly power machines.

Wind turbines having two configurations upwind, where the wind confronts the rotor, and downwind, where the wind faces the tower dominate the market. HAWTs have difficulties that are lessened by design modifications and control systems, such as flow disturbance from the tower and fatigue stress from passing blades. Although they are not obstructed by towers, downwind turbines have power losses as a result of blade shading. Although they have self-adjusting nacelles, they have problems with untwisting cables.

In contrast to HAWTs, vertical axis turbines (VAWTs) use lift and drag differently, however they are less efficient and commercially viable. Certain VAWT types experience low efficiency.

With an aerodynamically constructed rotor and effective power generating, transmission, and regulating components, the contemporary wind turbine is a complex piece of equipment. These wind turbines vary in size from several million to a few thousand watts (small wind turbines). (Large Wind Turbines). In locations where the wind is favorable, the current tendency in the wind business is to aim for larger units with multiple MW capacity since system scaling can lower the unit cost of wind-generated electricity. The majority of modern commercial devices are three-bladed rotor horizontal axis wind turbines (HAWT).

2.3.4 General Workings Principles of Wind Turbines

The rotor blades begin spinning when wind blows against them. High-speed gearboxes are coupled with turbine rotors. Rotors rotate at low speeds and high speeds thanks to a gearbox. The generator's rotor is connected to the gearbox's high-speed shaft, which causes the electrical generator to run faster. To provide the magnetic coil of the generator field system the necessary stimulation so that it can produce the necessary amount of power, an exciter is required. Both the alternator's field flux and speed determine the voltage that is produced at the output terminals. Uncontrollably strong wind is regulating the speed.

In order to ensure consistency in the alternator's output power, excitation needs to be adjusted based on the availability of wind power. A turbine controller measures the speed of the wind and regulates the exciter current. After that, a rectifier receives the electrical generator's (alternator's) output voltage and converts it to DC.

Typically, a wind turbine has two or three blades. The cost of two blade machines is slightly lower. Machines with three blades experience less mechanical stress and are less prone to fatigue issues. A wind turbine's yaw bearing enables it to rotate such that it faces any direction of wind. Wind turbines are supported by towers, which elevate them over any obstacles.

2.3.5 Wind Energy Harvesting with HAWT

The right wind turbine is used to harvest wind energy. The wind turbine captures the kinetic energy of the wind and transforms it into mechanical shaft energy. The transmission system transforms the rotational energy into electrical energy. The transmission system is made up of the generator, optional gearbox, brake(s), rotor shaft with bearings, and optional clutches. Equation (2.6) can be used to express the amount of energy present in the wind.

$$P_w = \frac{1}{2}\rho A V^3 \qquad 2.6$$

Where, ρ =Density of air (kg/m)

A = the swept area (m^2)

Pw = power in the wind (W)

v =instantaneous wind velocity (m/s)

The amount of energy that can be extracted from freely flowing fluid streams is restricted since doing so would require a reduction in the fluid's velocity, or its kinetic energy, to zero, which is not conceivable. Certain fluids might just flow around (bypass) the turbine rather than through it. Equation (2.7) provides the expression for this constraint in terms of the Betz limit, which is specified by the power coefficient Cp.

$$Cp = \frac{\text{Rotor}-\text{power}}{\text{Power in the wind}} \qquad 2.7$$

The power coefficient, CP, is a function of the axial induction factor. The optimum of this function (which is a maximum value for CP) is 0.5926 (=16/27) (Twidell, J., & Weir, T,2016)

Thus the electrical power output from the wind turbine can be expressed by equation (2.8).

$$Pw\ out = \frac{1}{2}\eta_t C_p PAV^3 \qquad 2.8$$

Where, Pw out = output power of wind turbine

ηt= Overall efficiency of the transmission system/power train

C_p= the power coefficient

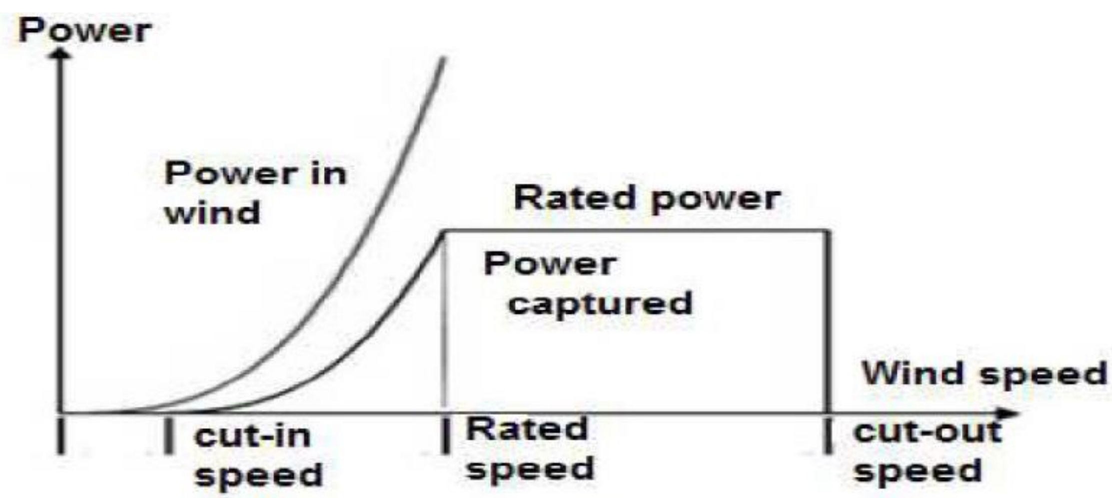


Figure 2.7 General power curve of wind turbine (Patil, M. R,2019)

The wind speed at which a wind turbine starts to generate power is known as the cut-in speed. The wind speed at which the turbine performs at its highest level of energy conversion efficiency is known as the rated wind speed. The power production at a wind speed that is equal to or greater than the specified speed is known as the rated power. The wind speed at which the turbine may shut down to prevent damage to the rotor and drive train components, or high wind stalling characteristics, is known as the cut-out speed.

2.3.5 Wind Turbines Power Control Mechanism

Every wind turbine has some kind of power control built in. Diverse techniques exist for managing the aerodynamic forces acting on the turbine rotor, which in turn limits the power at extremely high wind speeds to prevent damage to the turbine. In the business, power control is typically applied in three ways (Getachew, B.,2009).

- Still control
- Pitch control
- Active still regulation

Still control, also known as passive control, is the most straightforward, reliable, and affordable control mechanism. In this system, the blades are fixedly affixed to the hub at a fixed angle. The fixed-blade pitch is chosen so that the turbine can generate its rated power or maximum at the desired wind speed. When wind speed above a specific threshold, the rotor's aerodynamic design causes it to stall, or lose power, limiting the aerodynamic power applied to the blades.

Pitch control is an additional control mechanism that allows the blades to be oriented towards the wind or away from it depending on whether the power output is too high or too low. The benefits of this kind of control often include enhanced energy capture, effective power regulation, aided starter, and emergency stop. Pitch changing system response time must be quick. From an electrical perspective, effective power regulation is maintained at high wind speeds such that the generator's mean power output remains relatively near to its rated power. One may list the additional complexity brought about by the pitch mechanism and the greater power variations at high wind speeds as drawbacks of this control technique.

The third potential control method is active stall control, which involves pitching the blades to actively regulate the stall. To maximize efficiency, the blades are pitched like a pitch-controlled wind turbine at low wind speeds. Pitching the blades slightly in the opposite direction of a pitch-controlled turbine causes them to enter a deeper stall at high wind speeds. In addition to inheriting the benefits of both pitch and stall control techniques, the active stall wind turbine produces a smoother limited pow type and has the ability to compensate for variations in air density., as opposed to pitch-controlled wind turbines, which experience significant power swings. This control type inherits the benefits of both pitch and stall control systems and has the ability to correct for variations in air density.

2.3.6 Turbine Siting

One of the most difficult parts of using wind energy is locating a location for a wind turbine. In addition to making the local households uncomfortable with its loudness, a turbine placed too close to a residence may experience interference from nearby buildings. The expense of the cables shouldn't be disregarded if it is too far away (Gipe, P., 2014). When it comes to wind, the natural world is typically a great resource for determining the best location for wind turbines. Information regarding the predominant wind in the area can be found by observing the inclination of trees and plants. The most accurate source of information, nevertheless, is meteorological data gathered over a thirty-year period and organized into wind rise diagrams. However, such information is scarce, particularly in a nation like Ethiopia. In these kinds of situations, looking around you can provide important hints regarding the local wind pattern. (Association for Danish Wind Industry, 2008)

Additionally, there shouldn't be any adjacent obstructions (such trees, little homes, or other structures) at the chosen location. Transportation infrastructure, including roads, should be taken into account while choosing locations for wind turbines.

2.4 Energy Storage (Battery types and operation)

The renewable energy sector faces the challenge of maintaining a steady electricity output due to the natural fluctuations in production and demand throughout the day. To address this, energy storage systems are essential. When there is less demand, they gather excess energy, store it, and release it to fulfill the demand. For wind and solar power, rechargeable batteries, or accumulators, are used. These batteries store electric energy as electrical charges in the form of ions. In remote areas relying on solar or wind energy, an optimal battery solution is crucial to meet electricity needs at night, on cloudy and rainy days, or when wind speeds are low. Batteries also help stabilize the voltage fluctuations produced by solar panels and wind turbines (Hankins, 2010). The Battery Management System (BMS) includes protective features against overcharging and deep discharging, providing a reliable control system during both surplus and deficit power conditions. This ensures efficient use of available energy and protects the battery from potential damage due to extreme charge or discharge situations. As a key part of the energy management system, the BMS helps maintain a consistent power supply, especially during low power generation periods. Its functions include not only optimizing energy use but also implementing protective measures to extend the battery's lifespan and reliability, contributing to the overall stability and resilience of the system.

In a photovoltaic system, a storage battery's primary duties include:

- ❖ Hold onto the electrical energy produced by the photovoltaic panels and release it to the electrical loads when required.
- ❖ Provide stable power to electrical loads at safe voltages and currents, smoothing out any fluctuations that might occur in PV systems.
- ❖ Deliver surge or high peak currents to electrical loads or appliances when necessary.

2.4.1 Types of Batteries

The most common battery kinds are:

✓ Lead acid (Pb-acid)

✓ Nickel Cadmium (NiCd)

✓ Nickel- metal hydride (NiMH)

✓ Lithium ion (Li-ion)

The choice of battery for a particular application may depend on execution and take cost efficiency into consideration.

- ➢ Nickel-Metal Hydride.

The NiMH offers an enhancement in energy density compared to NiCd and is a development of NiCd technology. The main structural distinction is that the anode is composed of metal hydride, which removes the cadmium environmental concern. Its minimal memory impact is another improvement in performance. On the other hand, the NiMH has a high self-discharge rate, is less able to produce high peak power, and is more likely to suffer damage from overcharging. Even while NiMH is now more expensive than NiCd, prices are predicted to decline sharply in the future. This assumption is mostly predicated on contemporary enhancement initiatives aimed at utilizing this technology on a broad scale in electric automobiles. (Association of American Manufacturers, 2017).

- ➢ Lead acid

This is the most widely used kind of rechargeable battery on the market today, even if its energy density is the lowest when compared to weight and volume, due to its development and execution surpassing cost ratio proportion. Sulfate is created when lead acidic battery water and lead are discharged; this water dilutes the sulfuric acid electrolyte, and the electrolyte's specific gravity lowers as the battery's charge drops. Furthermore, the lead oxide layer forms at both the positive and negative plating during the charging process. (Association of American Manufacturers, 2017).

- Nickel Cadmium Batteries

Secondary or rechargeable batteries are made of nickel-cadmium (Ni-cad) materials. Both standalone and grid-connected solar systems can benefit from its attractive performance when compared to lead-acid systems. These advantages include a long battery life, low maintenance costs, relative protection against excessive battery discharges, low temperature capacity retention, and non-critical voltage regulation requirements. When compared to lead-acid systems, nickel-cadmium batteries' primary drawbacks are their high cost and restricted availability. (Association of American Manufacturers, 2017)..

- Lithium ion Battery

a specific sort of battery made of lithium, the lightest metal with ideal electrochemical potential. Lithium-Ion batteries, on the other hand, are made of chemically derived lithium ions because lithium is an unstable metal. Lithium-Ion batteries have an exceptional energy density and are lightweight, making them ideal for portable electronics like laptop computers. Furthermore, toxic metals like lead, mercury, or cadmium are no longer used in lithium-ion batteries, which have no memory effect. Lithium-Ion batteries have only one drawback: at the moment, they are more expensive than NiCad and NiMH batteries.

Lead-acid batteries have been chosen for this thesis based on performance over cost ratio.

2.5 Solar PV and wind energy hybrid system

Even though the renewable energy sources are more applicable in different parts of the world, they cannot deliver a continuous power when they are used separately. To overcome such problem, hybrid technologies are used now days. In hybrid technologies, more than one energy resources are utilized and converted them into a single energy form. In order to say a given system is a hybrid system, the following things must be included.

• The system must contain a primary source of energy, mainly renewable energy source.

• The system should also compose a secondary source of energy for providing power in case of shortage such as fuel cell or battery and diesel generators.

• It also requires a storage system for a stable output power.

• To regulate the current flow through the battery, it needs a charge controller.

A PV array, wind turbine, battery, IGBT inverter, controller, and connectors make up a hybrid PV and wind system. Together, the wind turbine and PV array meet the need for power. When these energy sources are in plentiful supply, the generated power will be used to feed the battery until it is fully charged after satisfying the load demand. The battery, on the other hand, will release energy when sources are low, enabling the solar panel and wind turbine to keep supplying power until the store is used up.

2.6 System for Energy Management

The power output of renewable energy generation is inherently contingent upon climatic conditions. Achieving a consistent power supply to the load becomes a significant challenge, primarily hinging on the state of the battery system. The incorporation of an energy management system becomes pivotal in substantiating the efficacy of the proposed system. By addressing the dynamic interplay between renewable energy availability, battery conditions, and load requirements, the energy management system serves as a crucial component in ensuring the system's resilience and optimizing overall performance.

MPPT (Maximum Power Point Tracking) control algorithms are commonly integrated into systems to optimize power capture from varying wind speeds and solar irradiations. These algorithms adjust the firing angle of the converter to achieve the maximum available power. Several MPPT techniques have been explored in the literature for Wind Energy Conversion Systems (WECS) and Solar PV systems, including Hill Climbing (HC), Incremental and Conductance (INC), Perturb and Observe (P&O), Fuzzy Logic (FL), and various Evolutionary Algorithms(Sudha, R., et al. 2018).

While Perturb and Observe is a widely used MPPT technique due to its simplicity and effectiveness, its performance is compromised by the rapid fluctuations in wind speed and solar irradiation. This leads to challenges in accurately tracking the optimal point of the system, resulting in the failure of the primary objective of MPPT.

Generally to address these above issues, a Fuzzy Logic Controller (FLC) is employed in this system. FLC is chosen for its ability to track maximum power efficiently, especially in the face of rapid variations. The advantage lies in the FLC's use of pre-defined data for the system, allowing it to adapt and respond effectively to dynamic changes in wind speed and solar irradiation

Power management is necessary to prevent a blackout, safeguard the battery from deep draining or overcharging, and ensure that power sources interact effectively to provide an efficient power balance load. The PMS defines the system's working mode and responds to the values supplied to the various regulator's converters to control the powers of each source based on the real-time conditions of the monitored parameters (sunshine, battery voltage, and load demand).

In summary, while the technical and economic feasibility of hybrid systems has been well-explored, research gaps remain in areas such as social and environmental impacts, socio-economic factors influencing adoption, and the need for region-specific and seasonal optimization strategies. A number of research gaps are highlighted by the evaluated literature. Although conventional control approaches have been used to regulate the supply and demand of power in a variety of hybrid systems, they continue to face problems with power stability and quality. According to the examined studies, power fluctuations resulting from renewable energy sources' variability can be lessened through the application of artificial intelligence control approaches. These methods do have certain drawbacks, too, like long execution durations. Furthermore, the performance indicators that were employed in the papers' evaluations are not sufficiently covered in the articles.

In general the objective of this thesis is to close these gaps by creating an intelligent controller that can maximize the electricity produced by wind and photovoltaic (PV) energy sources. In particular, it emphasizes the integration of Maximum Power Point Tracking (MPPT) with a fuzzy logic controller to optimize power extraction from PV and wind sources. Furthermore, there is a dearth of thorough coverage in the literature about intelligent control techniques for managing load demand and hybrid solar and wind systems. In order to overcome the shortcomings in the existing approaches, this research aims to improve MPPT efficiency and guarantee a more stable and reliable power supply by utilizing the superior capabilities of fuzzy logic.

CHAPTER THREE

3. METHODOLOGY

3.1. Methodology of the System

The methodology for this thesis involves the modeling and optimization of various components within a hybrid renewable energy generation system. This system encompasses wind, solar, and battery-based renewable energy sources.

3.2. Data Collection and Feasibility Study

The highest work is field data collection, which comprises data of the number of households and site observation to evaluate their living style. The data used in the design of the hybrid components are collected directly from the site and the NASA data obtained using the latitude and longitude of the site.

- The wind speed and solar radiation of the selected sites were gathered from Space Administration (NASA),
- Internet (websites): All component costs associated with PV modules, wind turbines, converter and storage batteries were collected by consulting several websites. Scientific research and related literatures are reviewed on rural electrification related to Ethiopia as well as other countries.

3.2.1 Solar Data for Research Site

Dembel islands a special zone of Oromia and is surrounded by East Shewa Zone and East Arsi Zone. It is located at 7.933′N 38.7166′E at an elevation of 1712 meters, 168 km southeast of Addis Ababa. The following Table 3.2 shows Dembel island daily averaged solar radiation in (kWh/m2) in 2022.

Table 3. 1 Monthly averaged radiation (kWh/m2/day) (NASA, 2022)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sl radiation	6.33	6.75	6.7	6.13	6.05	5.54	4.76	4.98	5.44	6.08	6.18	6.23

According to Table 3.1 above, the average daily radiation is 4.76 kWh/m2 in July and 6.75 kWh/m2 in November. The lowest radiation occurs in July. The Dembel Island regions receive sufficient sunlight, making them appropriate for photovoltaic (PV) installations. The Dembel Islands site, as provided by NASA.

3.2.2 Wind Data for Research Site

Like the variation of temperature Dembel Island have different values of wind speed in different months with the same geographical condition. The following Table 3.2 shows Dembel island daily average wind speed in (Km/h) in 2022.

Table 3.2 .Monthly averaged wind speed (Km/h) (NASA, 2022)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W- 10m	3.94	4.1	3.61	3.41	2.83	2.85	3.39	3.21	2.23	3.68	4.17	4.16

Ethiopia, a country with over 100 million people, has made significant progress in harnessing wind energy. According to the Ethiopian Electric Power Corporation (EEPCo), the nation has the potential to generate over 1.3 million megawatts (MW) of wind power, positioning it as one of the most promising wind energy markets in Africa. Major projects include the Adama Wind Farm, where the first phase, Adama I, was completed in 2012 with a capacity of 51 MW, followed by Adama II in 2015 with a capacity of 153 MW. Additionally, the Ashegoda Wind Farm, completed in 2013, has a capacity of 120 MW. Ethiopia's energy consumption is projected to increase by 5% annually until 2040, according to the International Energy Agency (IEA) (EEPCo, 2021).

3.3 PV Potential Assessment

Temperature and sun irradiation determine a PV array's power output. In this model, the power output is computed as

$$P_{pv} = \eta pvgApvgGt \qquad 3.1$$

Where Gt is the solar irradiation in the tilted module plane (W/m2), Apvg is the PV generator area (m2), and ηpvg is the PV generation efficiency. ηpvg can also be defined as

$$\eta_{pvg} = \eta_r \eta_{pc}[1-\beta(Tc-Tcref)] \qquad 3.2$$

Where ηpc is power conditioning efficiency which is equal to one when MPPT is used, and β is temperature coefficient ((0.004-0.006) per 0C), and ηr is the reference module efficiency, and

Tcref is reference cell temperature in oC. Reference temperature (Tcref) can be obtained by relation

$$T_c = T_a + (\frac{NOCT - 20}{800})G_t \quad 3.3$$

Where Gt is the solar irradiance in the slanted module plane (W/m2), Ta is the ambient temperature in 0C, and NOCT is the nominal operating cell temperature in 0C.

When normal and diffuse solar radiation are taken into account, the total radiation in the solar cell can be approximated as

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad 3.4$$

3.4 Modeling PV Panel

The fundamental component of a solar array, the solar cell is essentially a P-N junction semiconductor with photovoltaic effect power generation capabilities. A PV array is made up of series-parallel connections between PV cells. For an array with Ns series connected cells and Np parallel connected cells, using the ideal single diode as depicted in Figure, the array current and array voltage may be related as

$$I = N_p[I_{ph} - Irs[\exp(\frac{q(V+IRs)}{AKTNs} - 1)]] \quad 3.5$$

$$I_{rs} = I_{rr}(\frac{T}{Tr})^3 \exp[\frac{EG}{AK}(\frac{1}{Tr} - \frac{1}{T})] \quad 3.6$$

Where T is the cell temperature (K), A is the diode ideality factor, K is Boltzmann's constant, and q is the electron charge (1.6 × 10-9C). The band gap energy of the semiconductor used in the cell is represented by EG. Irs is the cell reverse saturation current at T. Tr is the cell referred temperature. Irr is the reverse saturation current at Tr. The photo current Iph fluctuates with the cell’s temperature and radiation as follows

$$I_{ph} = [Iscr + Ki(T - T_r)\frac{S}{100}] \quad 3.7$$

An extra shunt resistance is used in parallel with the ideal shunt diode model in the single diode model. With the single diode model, the I-V characteristics of a PV cell can be obtained as follows:

$$I = I_{ph} - I_D \quad 3.8$$

$$I = I_{ph} - I_o[\exp(\frac{q(V+RsI)}{AKT} - 1) - \frac{V+RsI}{Rsh}] \quad 3.9$$

Where A represents the diode constant, q is the electron charge (1.6 × 10-9 C), K is Boltzmann's constant, T is the cell temperature (^{0}C), Rs is the series resistance (ohm), Rsh is the shunt resistance (ohm), I is the cell current (A), and V is the cell voltage (V).

Table 3.3 Electrical characteristics for photovoltaic array specifications

Description	Vaule
Peak power (Pmax)	325W
Voltage at Pmax (Vmp)	35.99V
Current at Pmax(Imp)	9.03A
Oen circuit voltage(Voc)	45.48V
Short circuit current (Isc)	19.39A
Power tolerance	±3%
Series fuse rating (A)	15
Parallel resistance of PV model (ohms)	1096.45
Series resistance of PV model (ohms)	0.4584
Cell efficiency	17.45%
Current temperature coefficient α (Isc)	0.032%/ 0C
Voltage temperature coefficient β (Voc)	-0.343%/ 0C
Power temperature coefficient γ (Pmax)	-0.42%/ 0C

The link between the PV module's current and power can be discovered under a range of temperatures and irradiances. G = 600W/m2, 800W/m2, and 1000W/m2 are the respective values of the I-V and P-V characteristic curves, which are depicted with the temperature fixed at 25°C and the irradiance varied. The curve is nonlinear and is dependent on both sun radiation and temperature. As the irradiation rises, the current increases more than the voltage and the maximum power point increases as shown in figure 3.1.

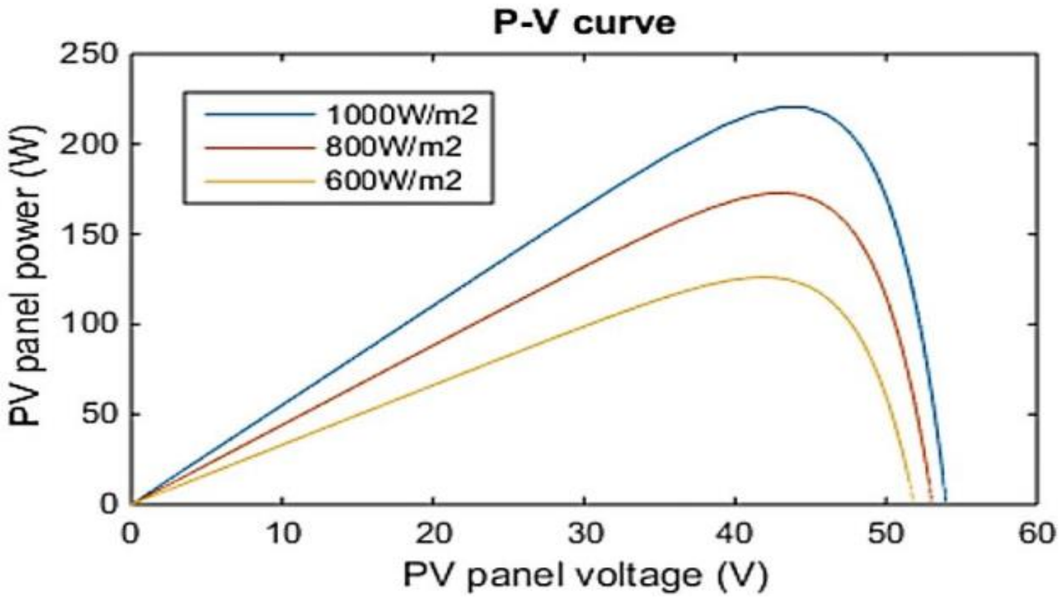


Figure 3.1 Power versus voltage P-V curve at different irradiance

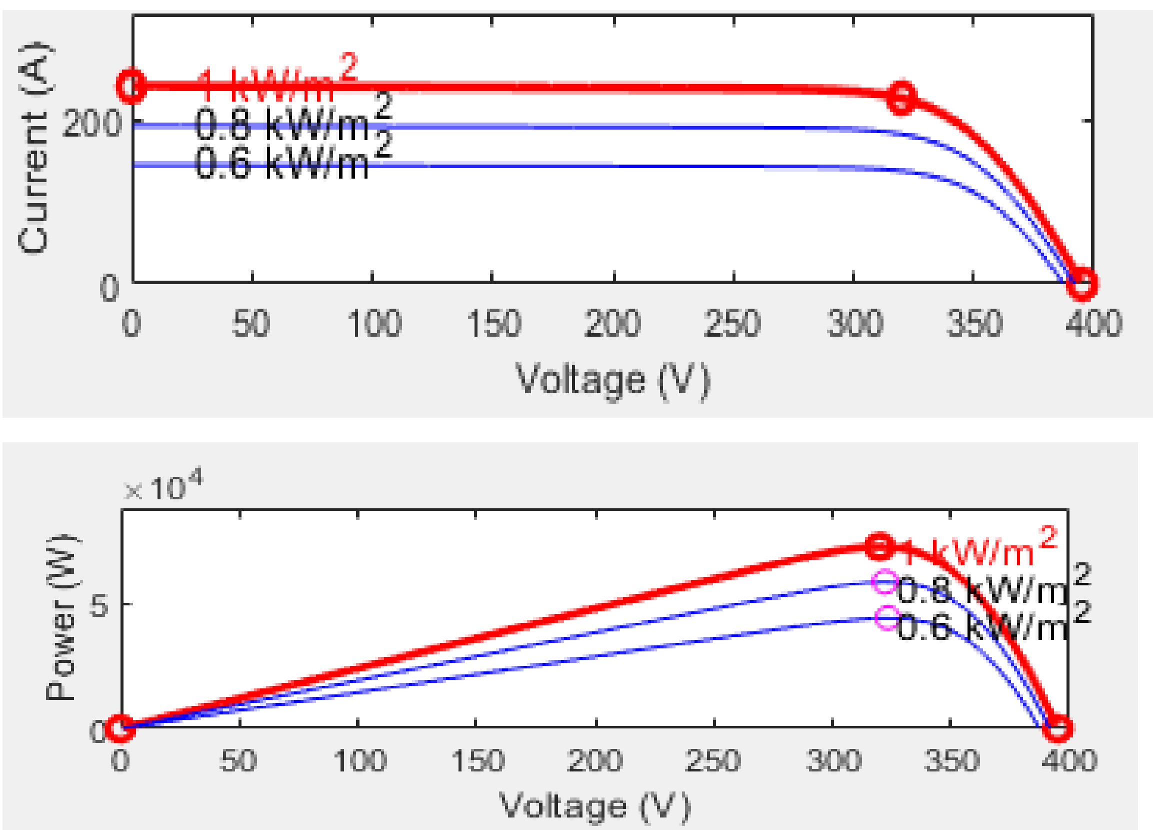


Figure 3.2 P-V and I-V characteristics with fluctuating temperatures and constant solar radiation

3.5. Evaluation of Wind Potential

The basic formula that determines the wind turbine's mechanical power is

$$P_w = \frac{1}{2} C_p(\lambda,\beta) PAV^3 \qquad 3.10$$

Where A is the rotor blade intercepting area (m2), V is the average wind speed (m/s), ρ is the tip speed ratio, and Cp is the power coefficient. Betz's coefficient, or the power coefficient Cp, has a theoretical maximum value of 0.593.

The definition of the Tip Speed Ratio (TSR) for wind turbines is the ratio of the blade tip's rotational speed to the wind velocity.

Mathematically,

$$\lambda = \frac{R\omega}{V} \qquad 3.11$$

Where V is the average wind speed (m/s), ω is the angular speed (rad/s), and R is the turbine's radius (m).

One way to collect wind energy is by

$$Q_W = P*t \text{ [kwh]} \qquad 3.12$$

Sometimes it is impossible to estimate the wind velocity directly at any given height due to a variety of reasons. The wind speed at any given height can therefore be found by interpolating or extrapolating the data at any reference height. Since the wind speed is measured at a lower altitude, nearby vegetation, shadows, and obstructions may cause errors.

The very low wind speed at which a turbine initially rotates and begins to produce power is known as the "cut-in speed." Cut-out speed is the high wind speed at which there is a risk of rotor damage due to the high forces acting on the turbine structure. The braking system is used to stop the rotor in order to avoid damage. The wind speed that falls between the cut-in and cut-out speeds, at which point the electrical generator's maximum power output is reached, is known as the rated power output. For a fixed rotor blade size, the power production in terms of wind speed can be predicted, and the power generation varies with changes in wind velocity. Therefore, the best generator speed for the changing velocity should be established in accordance with the change in wind velocity and maximum power. To extract the maximum power, the generator's angular speed must be adjusted; this procedure is called maximum power point tracking (MPPT). The MPPT is the focus of the following section. For the best TSR, the power coefficient is maximum when the blade pitch angle is zero.

The formula provides the optimum rotor speed.:ω

$$\omega_{opt} = \frac{\lambda opt}{R} V_{wn} \quad 3.13$$

$$V_{wn} = \frac{R\omega opt}{\lambda opt} \quad 3.14$$

Where R is the turbine's radius in meters, Vwn is the wind speed in meters per second, ωopt is the optimal rotor angular speed in rad/s, and λopt is the optimal tip speed ratio.

In terms of rotational speed, the turbine's output power and torque (Tt) may be determined by

$$P_w = \frac{1}{2}\rho A C_p(\lambda,\beta)\left(\frac{R\omega opt}{\lambda opt}\right)^3 \quad 3.15$$

$$T_t = \frac{1}{2}\rho A C_p(\lambda,\beta)\left(\frac{R}{\lambda opt}\right)^3 \omega_{opt} \quad 3.16$$

The fitting equation in form represents the nonlinear function known as the power coefficient (Cp).

$$C_p(\lambda,\beta) = c_1\left(c_2\frac{1}{\lambda i} - c_2\beta - c_4\right) e^{-c5\frac{1}{\lambda i}} + c_6\lambda \quad 3.17$$

$$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad 3.18$$

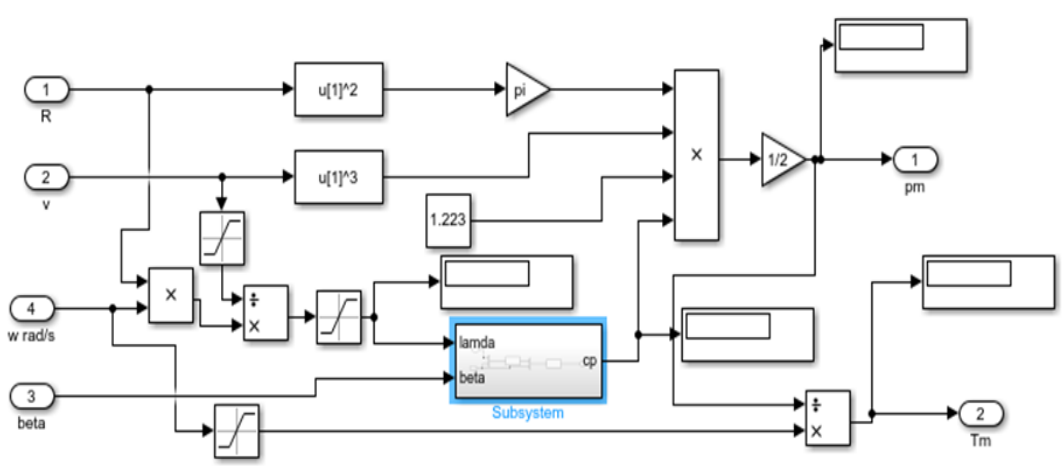


Figure 3.3 Modeling of the wind turbine

3.6 PMSG Modeling

The following equations represent the PMSG model in the d-q synchronously rotating reference system:

$$\frac{d}{dt}i_d = \frac{1}{Ld}v_d - \frac{Rs}{Ld}i_d + \frac{Lq}{Ld}p_{wm}i_q \quad 3.19$$

$$\frac{d}{dt}i_q = \frac{1}{Lq}v_q - \frac{Rs}{Lq}i_q + \frac{d}{dt}p_{wm}i_q - \frac{\lambda pwm}{Lq} \quad 3.20$$

$$T_e = \frac{3}{2}p[\lambda i_q + (L_d - L_d)\, i_d\, i_d] \quad 3.21$$

The generator inductance on the d-q axis is represented by Ld, Lq; the stator resistance is Rs; the dq-axis voltages are vq, vd; the dq-axis currents are id, iq; the rotor angular speed is wm; the amplitude of the induced flux is λ; the number of pole pairs is p; and the electromagnetic torque is Te.

Table 3. 4 PGE25 wind turbine technical specifications.

Parameter	Vaules
Rated Power	25KW AC
Available Tower Height	20/30/36 meter
Selected Tower Height	36 meter
Rotor Diameter	20 meter
Swept Area	305 m^2
Rotational Speed	32rpm
Cut in Wind speed	3.5m/s
High Wind Speed Cut out	25m/s
Low Wind Speed Cut out	1.7m/s

3.7 Electrical Model of Battery

The projected amount of energy to be stored is established initially when sizing the battery storage system. As was indicated in the part before this one, wind and photovoltaic energy sources complement each other. Therefore, it's critical to understand how much excess and deficient energy is produced by the combination of PV and WECS in relation to the available load demands in order to calculate the ESS size. Over the course of a day, the total quantity of excess and deficient energy that was available for PV and WECS was computed. The system power output curve demonstrates that there are instances in which the system's power output exceeds the demand from the load. The excess electricity produced by the RES is either used to recharge the batteries or stored there.

The battery bank is made up of a number of separate batteries connected in series to create bus voltage strings, and in parallel to boost the battery bank's capacity. Lead–acid batteries are frequently utilized in standalone wind-solar hybrid power systems. These batteries are defined by two key indices: the State of Charge (SOC) and the floating voltage (also known as the terminal voltage).

A DC source is stored in a battery, which is a type of storage device. Lead acid batteries are chosen taking into account the temperature variation of the surrounding location and the autonomy day. Trojan SSIG 12V, 230Ah lead-acid battery types with a 0.7 depth of discharge are compatible with this battery size.

$$C_{Ah} = \frac{EL * AD}{\eta inv * \eta bat * Vn * DOD} \qquad 3.22$$

$$AD = 2days$$

$$EL = 631.787kwh$$

$$Vn = 12v$$

$$\eta = 95\% = 0.95\ inv$$

$$\eta = 85\% = 0.85\ bat$$

$$DOD = 70\% = 0.7$$

$$CAh = \frac{461.203*2}{0.95*0.85*12*0.7}$$

$$C_{Ah} = = 67.944KAh$$

Total number of batteries required is

$$B_t = \frac{CAh}{Bc} \quad 3.23$$

$$B_t = \frac{67994Ah}{230Ah} = 296$$

Number of batteries connected in series

$$B_s = \frac{Vdc}{Vn} \quad 3.24$$

$$B_s = \frac{500}{12} = 42$$

Number of batteries connected in parallel

$$B_p = \frac{Bt}{Bs} \quad 3.25$$

$$B_p = \frac{296}{42} = 8$$

3.8 Converter

There are four main types of converters: DC/DC, DC/AC, AC/DC, and AC/AC. To produce the desired conversion output, power electronics devices (such as IGBT, power MOSFET, and power transistor) are arranged differently and employed as switching gates. They transfer the desired voltage level from a given DC voltage level. The triggering signal for DC/AC converters, also known as inverters, might be square, sine, or modified sine waves. The square wave type is the most straightforward and affordable of the three, but it produces an output signal that is of the lowest quality. The most often used low-cost inverter is the modified sine wave type, which can handle a variety of load types. The best-quality signal is produced by pure sine wave inverters, which are utilized for delicate electronics like stereos, laser printers, medical equipment, etc.

Depending on how they are used, inverters can be classified as stand-alone, grid-tied with battery backup, or grid-tied without a battery. These days, the most widely used inverters are grid-tied, battery-less models. By connecting directly to the public utility, these inverters use the power from the utility as a storage battery. Because they must sell electricity to the grid, give power to backed-up loads during outages, and recharge batteries from the grid, photovoltaic system, or wind turbine after an outage, grid-tied inverters with battery backup are more sophisticated than grid-tied inverters without battery backup. The standalone inverters are suited for remote hybrid system installation and are developed for independent utility-free power systems.

3.9 Modeling of Boost Converter

A simple DC-DC boost converter shifts the power consumption away from the PV generator and toward the load as the adaption condition occurs. The adaption has a duty signal of (0<D<1), which is considered satisfactory. The boost converter's IGBT valve gate is controlled by the PWM signal. The DC-DC boost wiring Simulink diagram is shown in Figure 3.4.

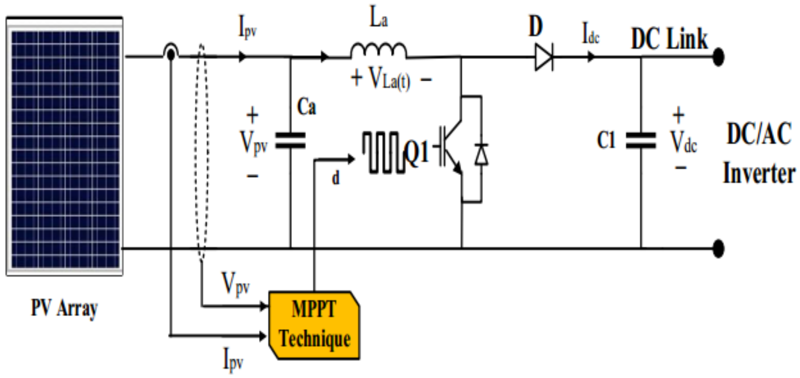


Figure 3.4 DC-DC boost converter

The basic configuration of the DC-DC boost converter

$$V_O = \frac{Vin}{1-D} \qquad 3.26$$

$$I_{out} = (1\text{-}D)I_{in} \qquad 3.27$$

$$R_{eq} = R_{in}\,(1-D)^2 \qquad 3.28$$

$$R_{in} = \frac{Vin}{Iin} = R_o(1\text{-}D)^2 \qquad D=1\sqrt{\frac{Rin}{Ro}} \qquad 3.29$$

$$L = \frac{(Vo-Vin)Vin}{f(\triangle I)Vo} \qquad 3.30$$

$$C = \frac{(Vo - Vin)\,Iout}{f(\triangle I)Vo} \qquad 3.31$$

The variables Vo and Vin are the output and input voltage and duty cycle, respectively, and Iout and Iin are the output and input current, respectively. The DC-DC boost converter's equivalent resistance is denoted by Req, while its input and output resistances are represented by Rin and Ro, respectively. The frequency is indicated by f, the DC-DC boost converter's inductor is L, its capacitor is C, and the ripples in current and voltage are ΔI and ΔV.

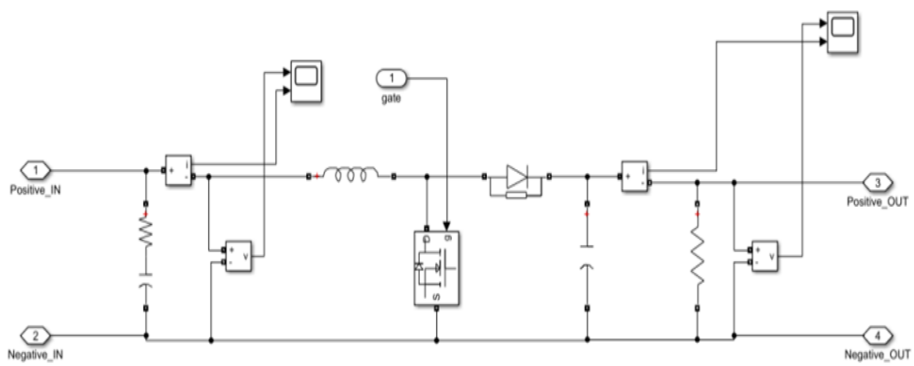


Figure 3.5 Simulink diagram of DC-DC boost converter

3.10 Hybrid System of PV and Wind Energy

A hybrid energy system combines two energy sources to provide the load with power. Stated differently, a hybrid energy system is one that is created or intended to generate electricity through the utilization of two or more energy sources. A hybrid energy system is less expensive, more dependable, efficient, and produces fewer emissions. Power is generated in this suggested system using both solar and wind power. More benefits than any other non-conventional energy source come from solar and wind power. In every location, both energy sources are more readily available. It requires less money. No specific site is required for the installation of this system.

Environmentally beneficial and widely available are wind and solar power systems. Because wind energy is more unpredictable than solar energy and has a higher flow wind speed, wind energy systems might not be technically practicable everywhere. Even though the renewable energy sources are more applicable in different parts of the world, they cannot deliver a continuous power when they are used separately. To overcome such problem, hybrid technologies are used now days. In hybrid technologies, more than one energy resources are utilized and converted them into a single energy form. In order to say a given system is a hybrid system, the following things must be included.

• The system must contain a primary source of energy, mainly renewable energy source.

• The system should also compose a secondary source of energy for providing power in case of shortage such as fuel cell or battery and diesel generators.

• It also requires a storage system for a stable output power.

• To regulate the current flow through the battery, it needs a charge controller.

A PV array, wind turbine, fuel cell, IGBT inverter, controller, and connectors make up a hybrid PV and wind system. Together, the wind turbine and PV array meet the need for power. When these energy sources are in plentiful supply, the generated power will be used to feed the fuel cell until it is fully charged after satisfying the load demand. The fuel cell, on the other hand, will release energy when sources are low, enabling the solar panel and wind turbine to keep supplying power until the store is used up.

3.11 Controller Design

This section offers a thorough explanation of the overall system's controller design, including the fuzzy logic controller. The FLC is specifically designed for Maximum Power Point Tracking (MPPT) of both the PV and wind components. Additionally, the battery is utilized as a energy storage system in this study. The general control architecture is illustrated in the block diagram shown in figure 3.6.

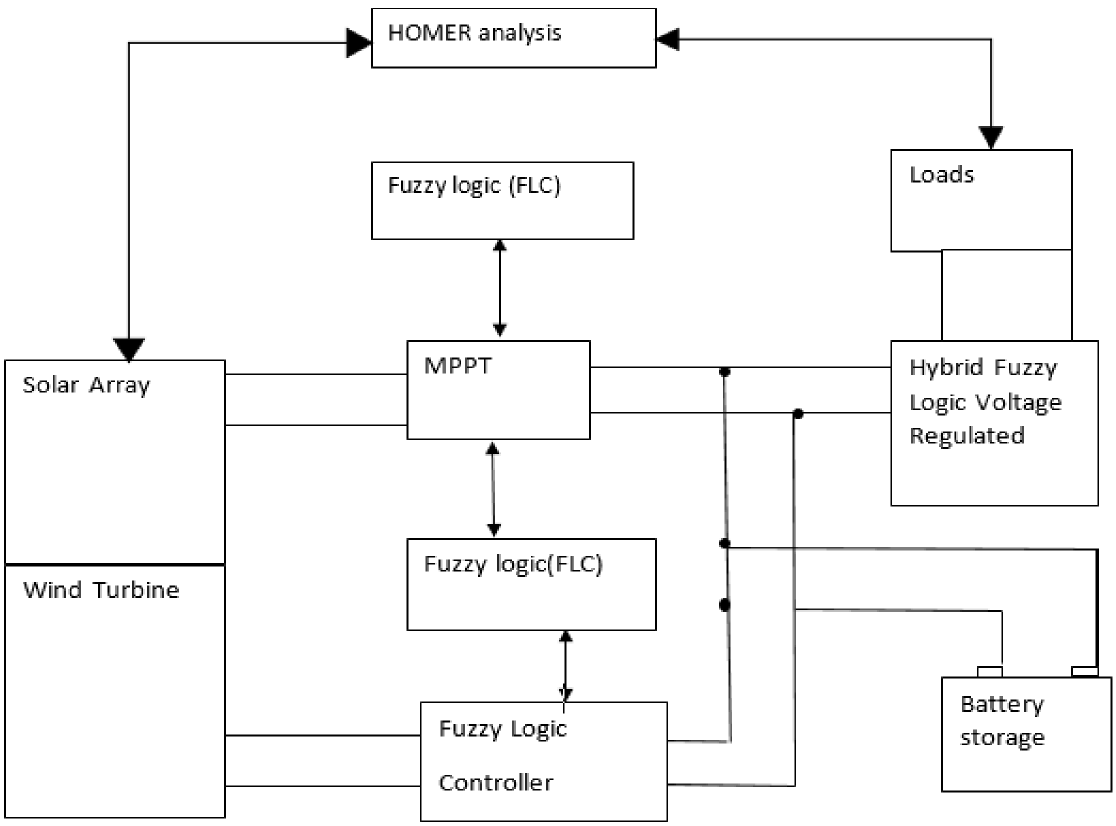


Figure 3.6 Block diagram of proposed solar wind hybrid power system

3.12 Estimation of Load

Predicting a power system's electrical demand for a given amount of time is known as load estimating. The electrical demand that the power system must supply at a given moment is known as load. Primary load is the term used to describe the electrical demand that is connected to lights, radios, TVs, computers, domestic appliances, and industrial activities. Unmet load refers to the shortfall that results from an electrical demand that is higher than the supply.

3.13 Load profile of the Tulu Gudo Islands

Residential load of Tulu Gudo refers to the demand that must be immediately met by the energy supply system. This includes necessities such as lighting, refrigeration, TV, radio, and other household appliances. It is assumed for load estimate purposes that each household's annual electricity use is constant and continuous. In determining the load for the village, the total population and number of households were considered, which 2000 are and 250, respectively.

Table 3.5 Home appliances of the Tulu Gudo Island

Load Type	Rating (watt)	Number of Equipment per house	Time (Hrs/day)	Wh/day	KW
Lamp CFL	15	4	4	240	0.06
TV	60	1	4	240	0.06
Stove	2000	1	0.5	1000	2
Refrigerator	80	1	7	560	0.08
Radio	20	1	4	80	0.02
Mobile Charger	10	2	2	20	0.02
Others	50	2	1	100	0.01
Total Energy				2240wh	2.27kw

Table 3.6 Loads in religious institutions of the Tulu Gudo Island Appliance

Type of Load	Equipment Rating(W)	Number of Equipment	Running Time(Hrs/day)	Energy consumption (Wh/day)	Power (KW)
CFL lamp	15	4	6	360	0.06
Fluorescent	50	2	6	600	0.1
Amplifier	415	1	3	1245	0.415
Others	50	2	1	100	0.1
Total Energy				2305wh	0.675kw

Table 3.7 Loads in health center of the Tulu Gudo Island

Appliance Load Type	Equipment Rating (watt)	Number of Equipment	Running Time (Hrs/day)	Energy Consumption (Wh/day)	Power (KW)
Store and Refrigerator Room lighting	15	1	2	30	0.015
Examination room Lighting	15	3	2	90	0.045
Delivery &Injection room Lighting	15	2	2	60	0.03
Waiting Room/ Verandah ligthing	8	1	2	16	0.008
Toilet lighting	8	2	1	16	0.016
Guard house lighting	8	1		32	0.008
Salon lighting	11	2	4	88	0.022
Bed room lighting	8	2	4	64	0.016
TV	50	1	6	300	0.05
Computer	250	1	5	1250	0.25
Vaccine refrigerator	60	1	24	1440	0.06
Charger	20	2	2	80	0.04
Others	50	2	1	100	0.1
Total Energy				3551Wh	0.66

Table 3.8 Loads in primary school of the Tulu Gudo Island

Appliance Load Type	Equipment Rating(W)	Number of Equipment	Running Time (Hrs/day)	Energy consumption (Wh/day)	Power (KW)
Lamp CFL	15	10	4	600	0.15
Computer	250	2	5	1250	0.5
Mobiles	10	10	2	200	0.1
Printer	600	1	1	600	0.6
School TVs	60	1	6	360	0.06
Tape /Radio	50	1	6	300	0.02
Others	50	2	1	100	0.1
Total Energy				3410Wh	1.53

Table 3. 4 Flour-making Mill

Equipment	Quantity	Capacity (KW)	Running time (hour/day)	KWh/day	Power (KW)
Flour Milling	1	12.5	5	62.5	12.5

Table 3.10 Total Loads of the Tulu Gudo Island

Load Type	Quantity	Amount of energy required (KWh/day)	Total amount of energy required(KWh/day)	Power KW
Home Appliances	250	2.24	560	56
Religious institutions	1	2.305	2.305	0.675
Health Center	1	3.551	3.551	0.66
Primary school	1	3.431	3.431	1.53
Flour Milling	1	62.5	62.5	12.5
Total Energy			631.787kwh	72kw

The subsequent stage involves estimating the overall daily energy consumption for all consumptions, as the energy requirements for the loads have been estimated. Thus, the sum of the power usage by Tulu Gudo Island households, schools, health facilities, religious institutions, and flour milling equals the total daily energy consumption. E=631.787kwh

Total Energy = 72kw

Solar power cover 70% of the total load, which is 0.7 *72KW = 50.988KW

The system loss 10%

Total Ppv power = 50.988+0.1*50.988

Total Ppv power = 56.08 KW

3.14. Designing PV Systems

Many components make up a solar PV system, and the components used should depend on the applications, site location, and system type. Inverter, PV module, and off-grid loads (appliances) are the main parts of a solar PV system. The initial phase of solar PV system design involves determining the overall power or energy consumption of all loads that the system must supply.

The entire amount of electricity required for Island 72.84Kw, Solar PV covers 50.98kw.

Considering a 10% reduction in system power, system loss = 50.98*0.1=5.09 KW. The solar PV system can generate 56.08 KW of power in total. The second phase involves measuring the solar PV system's component parts, counting the PV modules, totaling the panel area, and figuring out the power converter or inverter's capability. Assuming a system voltage of 12V (Vm) and 4 modules (Ns), a string with 325W (Pm) of rated solar power is needed to compute the number of parallel threads. You can apply the empirical formula that follows.

The minimum solar daily radiation= 4.76 KW/m2/day.

Step 1: Radiation calculation

Peak solar hour (hours @1KW/m^2 = 1kW/m2/day)

Worst month PSH = 4.76h/day

Step 2: Calculation of power installed

E=power *time = 56.08kW* 4.76kW / M / Day = 266.94kwh

Pv= load/efficiency = 266.94/0.69= 386.87kw/day

Ppeak=325.10kWh / day/4 .76kW/m2/day =81.27kwp

Step 3:Calculation of string length, from the module voltage, Vm (assume 12V: string with 4 modules) used higher standard voltage for reducing losses.

Ns =Vdc/Vm=48v/12v= 4

Step 4: Calculation number of strings (assume 325Wp module)

$$Np = Ppeak/Ns*Pm$$

$$Np = 81.27kw/4.76*325 = 63$$

Step 5: Calculation total number of modules,

Total Module =Ns*Np =63*4 =252

Assume a single solar module having 0.4m2 cross sectional area, the total area required for Solar panel is can be calculated as follows.

Ap=N*Am =252*0.4m2=100.8m2

Inverter sizing

The AC load and surge power considerations dictate the inverter's size.

The inverter size ought to be 25–30% larger than the sum of the loads' wattages. 72.84 kW is the maximum AC load, and the inverter constant is 1.25. As a result, the inverter's rating is 72.84kW * 1.25 = 91.05kW (AC x 1.25). Sizes of inverters ranging from 100 to 250 kW were available. For this thesis, a converter with a 100kW capacity and a full load efficiency of more than 90% was selected.

3.15. Wind Turbine Designing

The daily peak power for wind generation system is obtained by dividing daily energy contributed by wind turbine to the average hour of wind turbine running per day. The hourly wind speed of the located area was calculated by using average wind speed of 2.83 m/s for the worst day. To determine the hourly power output of WT, equation (3.18) is used with average WT parameters cp,ρ and rotor diameter of the wind turbines are 0.48, 1.22 kg/m2 and 7m respectively.

$$P_{PW} = \frac{\text{Daily Energy Required}}{\text{Wind running Hour per day}} \quad 3.32$$

Now, the total power generated from a single WGS is calculated as follows

Ew = (0.5)(0.48)(1.2)(A)Vw^3(8760) = 2199.488KWh/year

The total energy demand that was expected to be contributed by the wind energy conversion system is found to be 62262kWh/year. The daily peak power for WGS is calculated using equation (3.10) as follows:

$$P_{PW}=\frac{62.262MWh/yr}{24h*365days/yr}=7.107KW/day$$

The total number of wind turbine required is given by:

$$\text{Number of wind generator required (NWG needed)} = \frac{\text{Total Load Demand}}{\text{Energy from WG}} \qquad 3.33$$

$$\text{No of required } =\frac{62262}{2199.488} = 28W$$

3.16 Fuzzy logic concept

L.A. Zadeh first proposed the fuzzy theory in 1965. He believed that the traditional paradigm placed more emphasis on accuracy than on simple and effective control mechanisms. The Fuzzy sets, in contrast to classical sets, have a degree of membership for every element.

Fuzzy logic is a form of many-valued logic in which the truth value of a variable might be any real number between 0 and 1. It addresses the concept of partial truth, where the truth value may range from 100% true to 100% false. In Boolean logic, on the other hand, variables' truth values can only be the integer numbers 0 or 1.

Fuzzy logic is based on the observation that people frequently draw inferences from vague and non-numerical data. Fuzzy sets and models are examples of mathematical representations of imprecise and ambiguous data that are referred to as "fuzzy". These models have the ability to recognize, convey, alter, interpret, and apply vague and ambiguous facts and data.

If-Then Rules:

A few rules apply to fuzzy sets. Furnishing fuzzy logic requires a rule basis above all others. Numerous instances of If-Then rules often make up the rule foundation. Declaring the membership functions and fuzzy sets comes first. Subsequently, the If-Then rules pertaining to the membership functions for that specific control are determined. It is these input rules that govern the output.

3.16.1 Fuzzy Logic Controller Algorithm

A clever technique for managing integrated energy sources so that it satisfies load requirements under a range of load scenarios is the fuzzy logic controller. Establishing the constraints, allocating the language variables, and establishing the controller's rules are the steps involved in creating controller designs.

Usually, an If-Then rule has two components. 1) Antecedent and 2) Consequence or Conclusion are the two. Then statement is the consequence, and the "If" statement is the antecedent.

If- (Antecedent) and Then -(Consequence).

Classical Set: The components that make up a classical set for a discourse universe must adhere to the set's principles. It is embodied by

$A=\{x \varepsilon U | \text{ x meet meets some condition}\}$

It is also indicated by

$\mu A(x) = \{1 \text{ if } x \varepsilon A$

$\mu A(x) =\{0 \text{ if not } \varepsilon A\}$

Fuzzy set: In contrast to a classical set, a fuzzy set has a degree of membership for each element that makes it a part of that specific set.

$$A = \{(\chi, \mu_A(\chi)) | \ \chi \ \varepsilon \ U\} \qquad 3.34$$

Take two sets of fuzzy variables, A and B, such that A, B ∈ U. The Universe of Discourse is represented by U.

The primary set operations are:

- Complement
- Intersection
- Union

Complement:A fuzzy set with the membership function displayed below is said to be the complement of the fuzzy set:

$$\mu_{A^-}(x) = 1- \mu A(\chi)) \qquad 3.35$$

Intersection: It is the largest fuzzy set in both A and B that includes every element in both A and B. 'A ∩ B' is another way to write it. Intersection's membership function is described as follows:

$$\mu_{AnB}(x) = \mu A(x) v \mu_B(x) \ \max(\mu_A(x), \ \mu_B(x) \ ) \qquad 3.36$$

Union: The smallest set that includes every element in either "A" or "B" is referred to as such. Both "A + B" and "A U B" can be used to write it. According to Union, the membership function is as follows:

$\mu_{AUB}(x) = \mu_A(x) v \mu B(x) \ = \max(\mu A(x), \ \mu B(x))$

Advantages of Fuzzy Control:

It is superior than the other controllers because of a few advantages. They are:

- Firstly, very simple to understand as the control operates on a very basic notion.

- It has human-like intuition, which enables it to adjust to control challenges with strength..
- Even with loud inputs, it can function effectively.
- Because it only operates based on rules, it can function with various inputs and produce multiple outputs. It is simpler to create the fuzzy control rule base than it is to optimize the PID control settings.
- When any sensor stops working it can be programmed to turn off safely, instead of keep on working which could be dangerous to the plant.

Fuzzy logic's available tools aid in drawing conclusions about various courses of action based on the necessity or likelihood of particular plant circumstances.

Put Fuzzy Logic into Practice:

It efficiently translates an input to an output, and control over the mapping is simple and requires little in the way of intricate process knowledge. Actions to Take for Fuzzy Control:

- Initially, examine the ways in which the operator and the rule base system can be utilized for this control.
- Comprehend the notion of membership functions and language variables..
- Examine the power system that needs to be managed and determine which state variables should be regarded as system inputs.
- Gain knowledge on how to regulate the state variables in order to achieve the necessary control in the plant.
- Currently, create the rule foundation for the language variables in inputs and outputs..

3.16.2 Fuzzy Control Approach:

The linguistic variables' formation of rules is the primary source of dependence for control using fuzzy logic. Fuzzy logic control does not necessitate complex numerical calculations, in contrast to other methods. The model is controlled by means of elementary mathematical computations only. Even though it depends on basic mathematical analysis, and it functions effectively in a control system. Consequently, this approach to plant control is among the greatest and most straightforward ones currently in use.

Furnished set theory forms the basis of fuzzy logic control. Every element in fuzzy set theory has a degree of membership that identifies its affiliation with a specific set. Fuzzy sets can be thought of as classical sets with somewhat softer edges. When a plant needs to operate with a moderate level of precision and doesn't require intricate mathematical analysis, fuzzy logic controllers, or FLCs, are more frequently utilized. Additional benefits are:

- ❖ It doesn't need incredibly accurate inputs.
- ❖ Fast microprocessors are not necessary to provide an effective reaction.
- ❖ In comparison, it requires relatively little data, mostly for membership functions and rules.
- ❖ It is more effective and capable of outperforming non-linear models.

The three main components of a Fuzzy Logic controller are

a. Fuzzification

b. fuzzy rule base and interfacing engine

c. Defuzzification

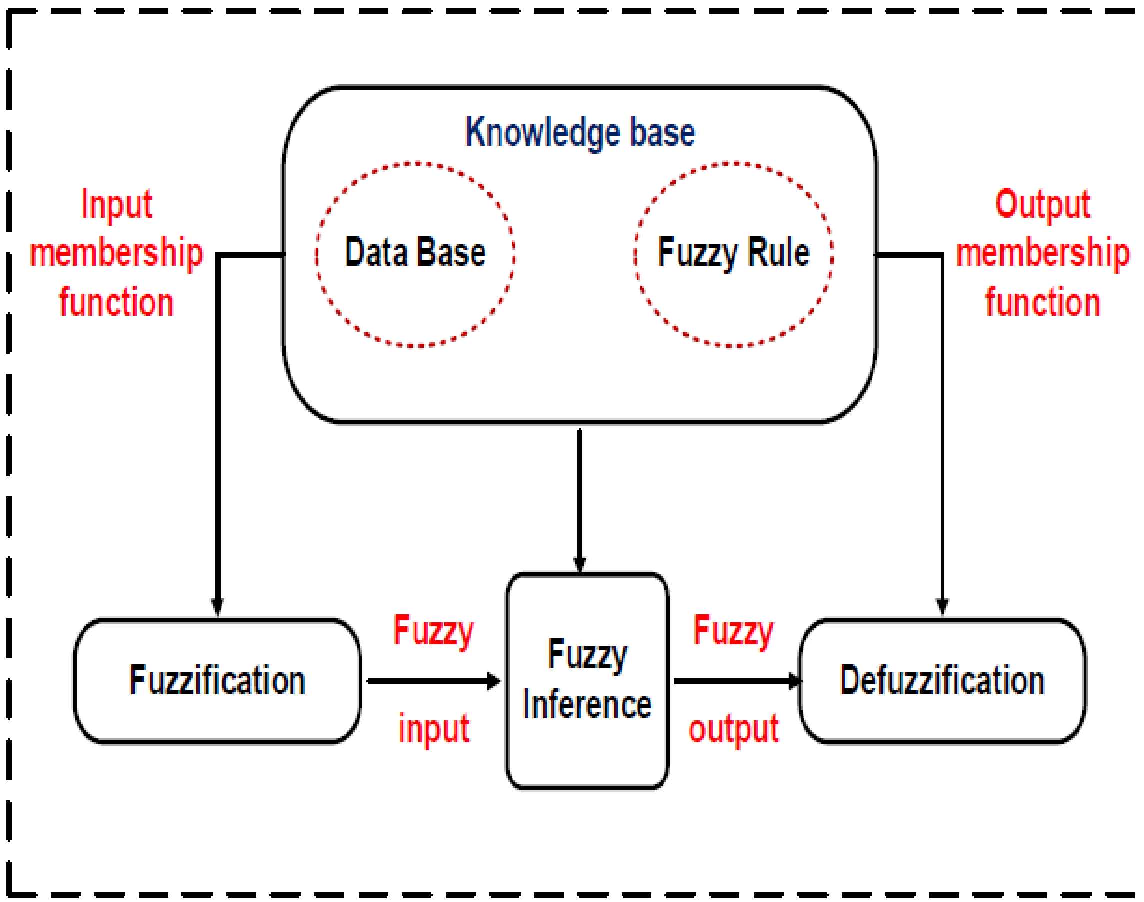


Figure 3.7. Fuzzy Logic Controller Structure for Power Management

Fuzzification module:

Finding the state variables that effectively regulate the plant is the most crucial phase in creating a fuzzy controller design. The state variables must be determined before being sent via the fuzzification block in order to fuzzify the inputs, since the FLC can only process fuzzy inputs. The numerical inputs must first be transformed into fuzzy language variables because the Fuzzy Rule base solely applies linguistic variable rules. The procedure for translating a fuzzy input language from a numerical state variable is referred to as the "fuzzification process". The variables that are usually employed are state error, the area of a state error (integral of state error), and the rate of change of state error (derivative of state error). The visual depiction of an element's level of affiliation with the fuzzy set is known as the membership function. Various membership functions can be employed for both input and output, contingent on the level of precision required. Triangular and trapezoidal membership functions are frequently utilized. Other membership functions that are accessible are Bell-shaped and Gaussian. The precision and efficacy of control improve with the number of membership functions.

The more membership functions that are taken into account for a linguistic variable, the more complex and time-consuming the calculations become. As a result, the decision of how many membership functions to use must be made with the speed and effectiveness of the control in mind.

3.16.3 Fuzzy Rule Inference:

Two techniques exist for fuzzy inference. They are Sugeno and Mamdani. Below is an explanation of them:

Mamdani Approach: The most often used approach for the fuzzy interface is Mamdani's method. It was one of the first fuzzy set theory-based control systems ever constructed. Ebrahim Mamdani first proposed it as an attempt to operate a boiler and steam engine combination by combining a collection of linguistic control principles that he had learned from seasoned human operators. Fuzzy sets are anticipated as the output variable by this inference approach. Using a single output spike as the membership function instead of a distributed fuzzy set is both feasible and efficient. The term "singleton output membership function" refers to this. Because it significantly reduces the computation needed by the more widely used Mamdani approach to calculate the two-dimensional function's centroid, it improves the Defuzzification procedure.

However, any inference system where the output membership function is either linear or constant can be modeled using the Sugeno type of inference.

Defuzzification:

The common techniques used for defuzzification are:

- Center of gravity method
- Bisector of area method
- Mean of minimum method.

Defuzzification is the opposite of Fuzzification. The FLC is a fuzzy number, which is a language variable. True prerequisites show that the linguistic variables need to be adjusted to provide crisp output. The most well-understood Defuzzification system, the center of gravity strategy, is applied in this research effort. It obtains the center of gravity of a fuzzy set-affected region.

The process of providing a quantitative result in a fuzzy form is called defuzzification. Certain rules in a fuzzy control system transform different variables into a "fuzzy" form; the result is displayed as membership functions and the degree to which they belong in fuzzy sets. In this case, choosing the fuzzy set with the highest membership belonging is the simplest but least effective method. This methodology's drawback is that some data is lost during the procedure. With this method, the rules that carried out "Reduce Pressure" might as well not have existed.

The results of the results should first be included in some way as part of a useful defuzzification process. The shape of a triangle represents the most typical fuzzy set enrollment capacity. Assume that the remaining figure would take the shape of a trapezoid if this triangle were to be cut in a straight, level line at some point between the top and the base.

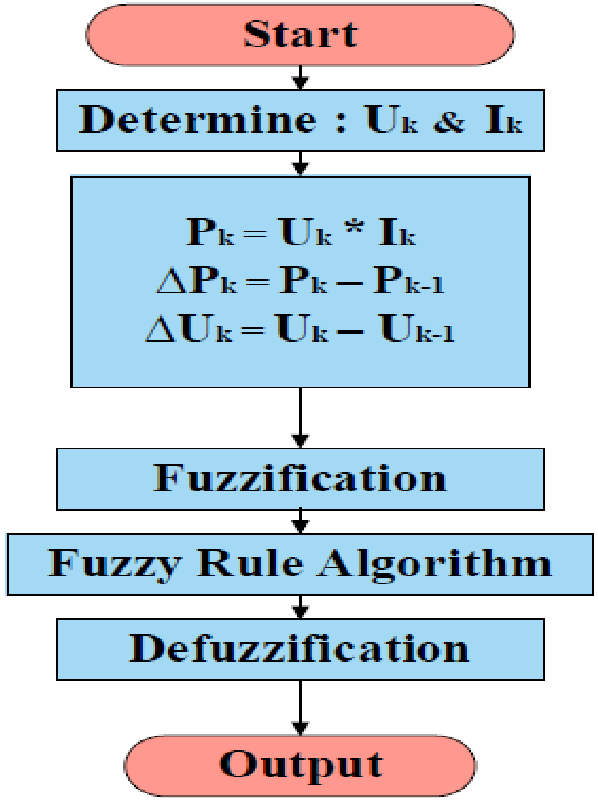


Figure 3.8 FLC algorithm flowchart

CHAPTER FOUR

4.1 RESULT AND DISCUSSIONS

In this section below, the power generated by the fuzzy logic controller and the hybrid components is simulated and described. The developed system model predicts that the solar power system will produce an output of about 56 kW when modeled and simulated first. The wind system model is performed next. This completes the design and simulation of the intelligent fuzzy logic controller.

4.1.1 Fuzzy logic (FLC) MPPT of solar PV

Fuzzy logic controllers (FLC) are particularly well-suited for photovoltaic (PV) systems, which are often non-linear and dynamic. Fuzzy sets excel in managing uncertainty and vagueness, making them ideal for such control operations (Safari & Mekhilef, 2011). Implementing fuzzy controllers has proven effective for both Maximum Power Point Tracking (MPPT) and power regulation in PV systems, offering robustness, quick response times, and simple design. Different researchs has shown that fuzzy logic achieves faster performance and smoother steady-state responses compared to the conventional Perturb and Observe (P&O) method. Additionally, a fuzzy logic controller using voltage detection has been proposed to enhance MPPT performance in hybrid systems.

Both Mamdani and Sugeno types of fuzzy control have been applied to improve the P&O and Incremental Conductance (IC) methods, leading to better response times and reduced oscillations (António, Vieira, & Mota, 2013). In a specific application, a fuzzy logic controller used two input variables: supply expectancy and predicted supply expectancy. This method prioritized load supply in stand-alone PV systems with multiple loads, optimizing power control.

Fuzzy logic control (FLC) has emerged as an advanced Maximum Power Point Tracking (MPPT) technique in photovoltaic systems. Unlike traditional control methods, fuzzy logic control is more robust and well-suited for handling nonlinear systems. It doesn’t require precise knowledge of the system’s mathematical model and is relatively straightforward to design. A fuzzy logic-based MPPT controller comprises three main components: Fuzzification, the Inference Engine, and Defuzzification.

Fuzzification involves converting input variables into fuzzy sets, the inference engine processes these fuzzy inputs to make decisions, and defuzzification translates the fuzzy conclusions back into precise control actions. This intelligent control strategy enhances the efficiency and adaptability of solar power systems, making it a popular choice in modern renewable energy applications.

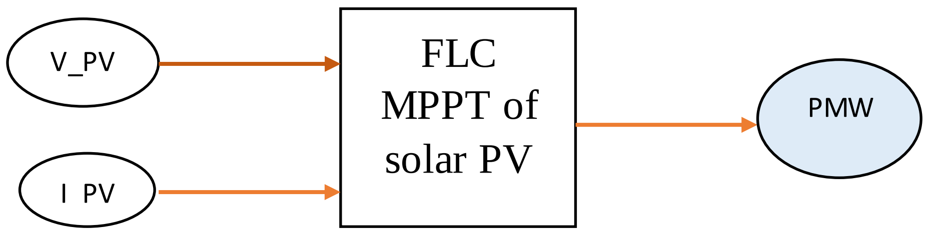


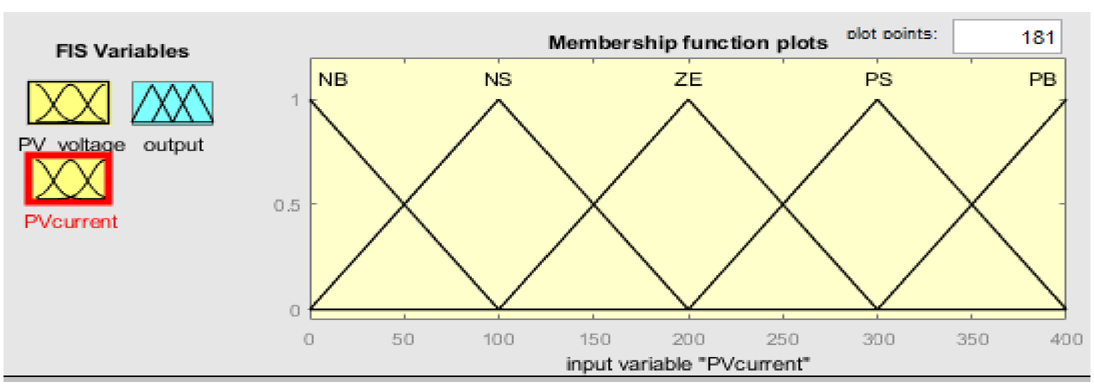
Figure 4.1 Fuzzy logic MPPT controller block diagram for photovoltaic system.

In this investigation, the Mamdani model for fuzzy logic controller. Equations (4.46) and (4.47), which define the error E(k) and the change in error dE(k), respectively, are the input variables for the controller. The output of the controller is the duty cycle DD. These inputs and outputs work together to optimize the performance of the MPPT system.

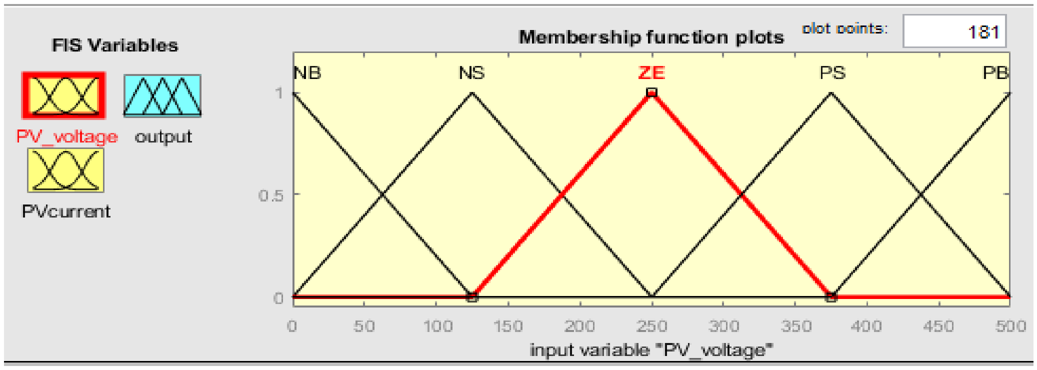
$$E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \qquad 4.46$$

$$dE(k) = E(k) - E(k-1) \qquad 4.47$$

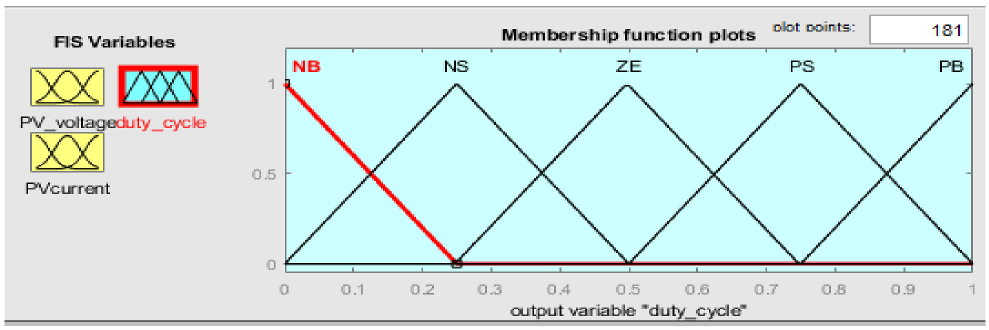
Here, P(k) represents the power and V(k) denotes the voltage of the PV generator, respectively.



a)



b)



c)

Figure 4. 2 Membership (a) input E, b) input dE, (c)output D

The fuzzification process converts both variables for input and output into fuzzy variables through membership functions assigned to linguistic terms. In this system there are five fuzzy subset: NB(negative big), NS(negative small), ZE(zero), PS(positive small), and PB(positive big). The input variables membership functions E(k) and dE(k), as well as the output variable D(k), are displayed in Figure 4.2.

Table 4.1 Fuzzy PV solar rule table rule

de\e	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

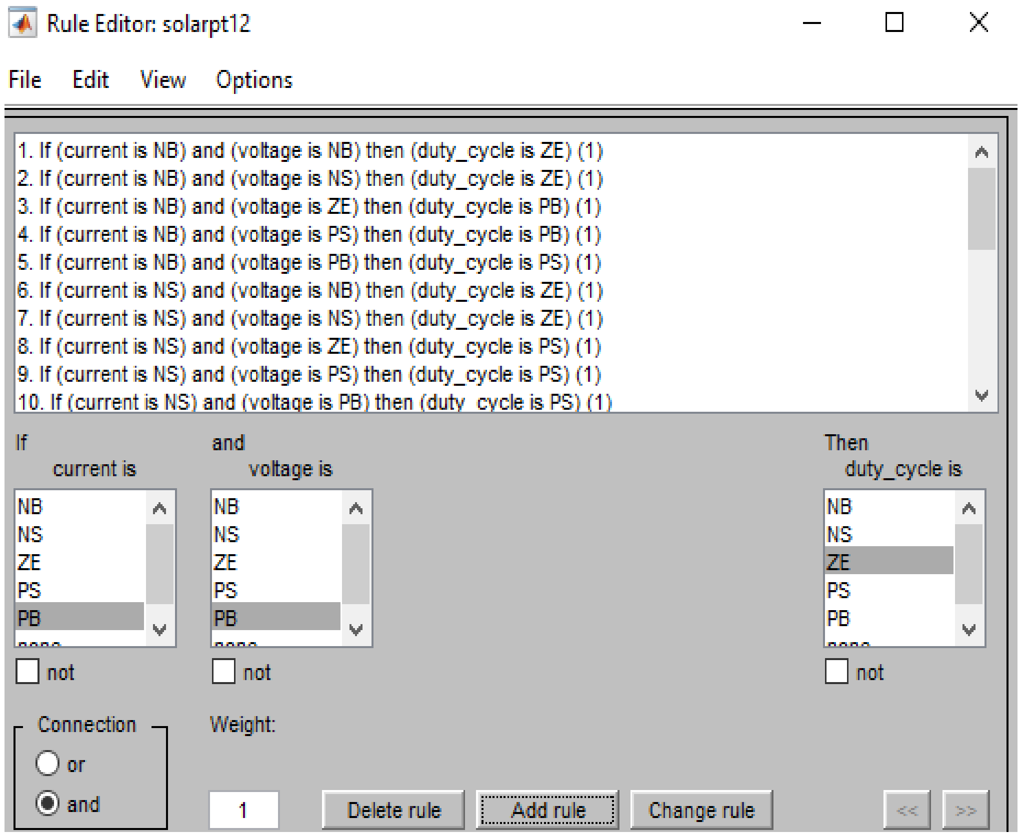


Figure 4.3 Membership functions of rules

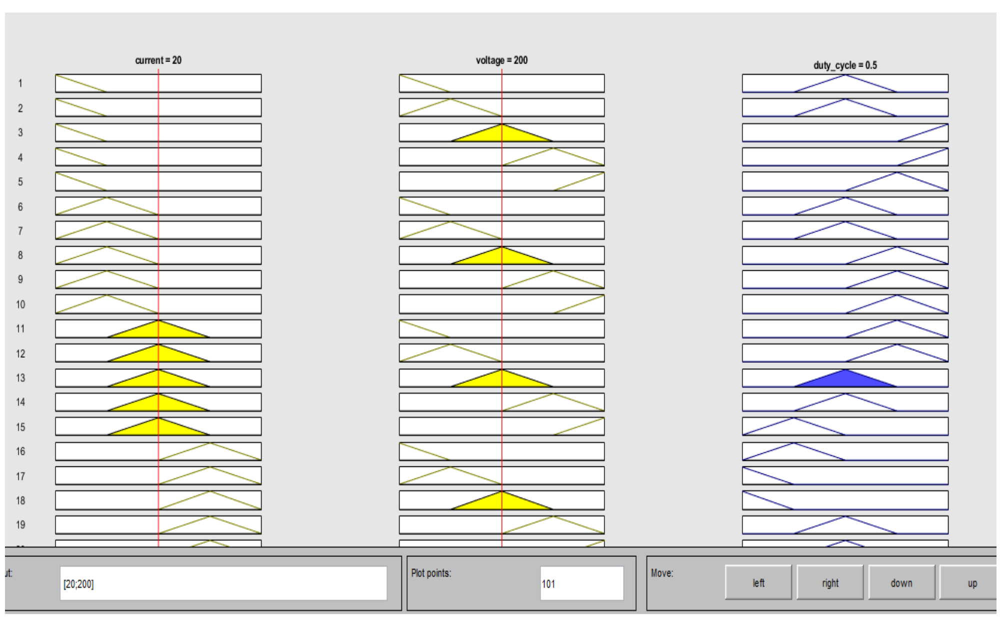


Figure 4.4 Membership function rule view

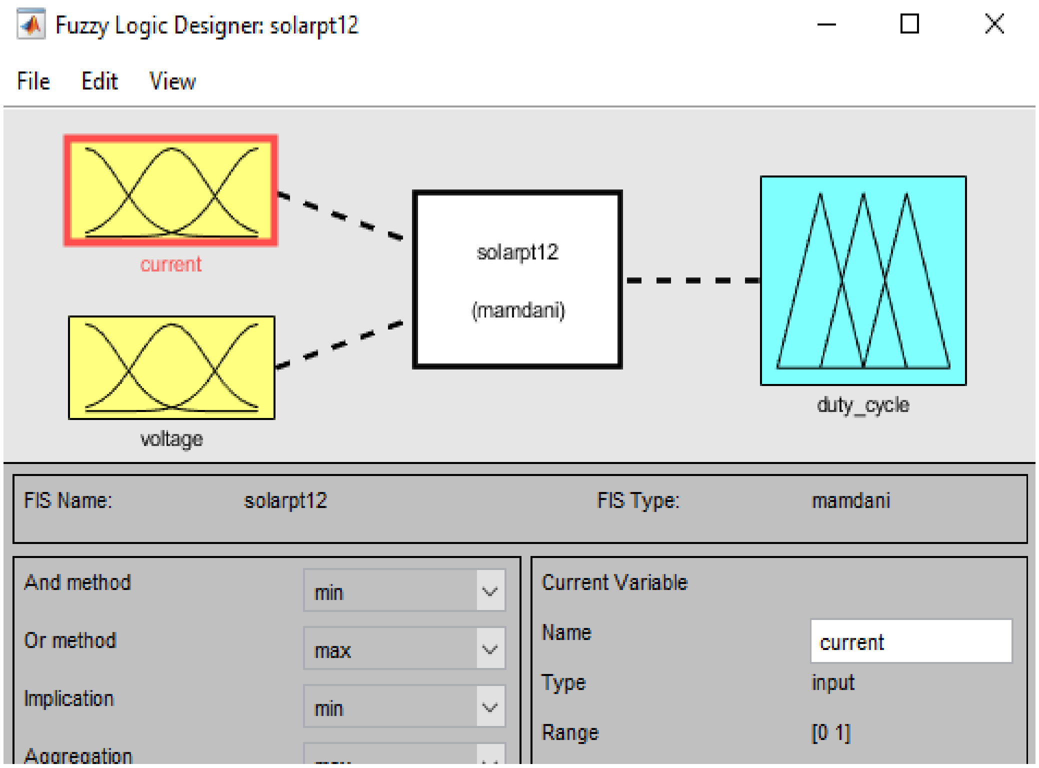


Figure 4.5 Fuzzy interface model of solar PV

4.1.2. Simulation of PV Result with fuzzy controller

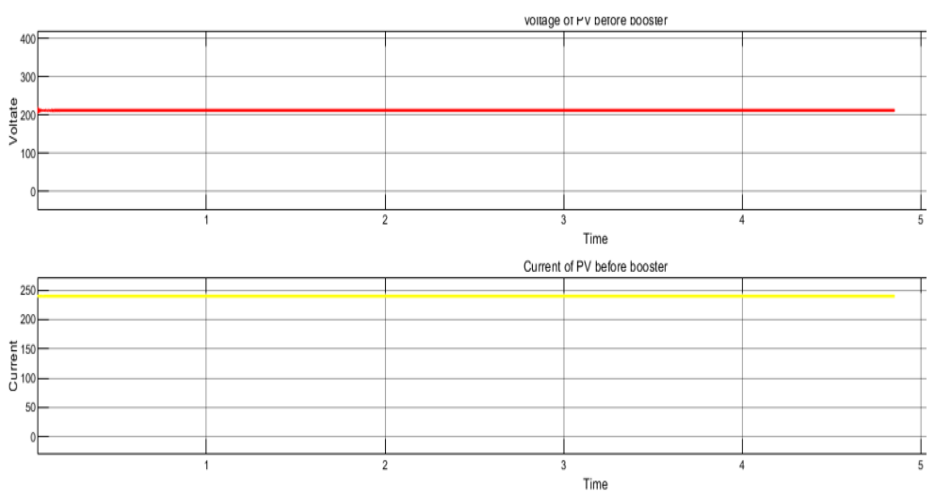


Figure 4.6 Voltage and current of PV before booster

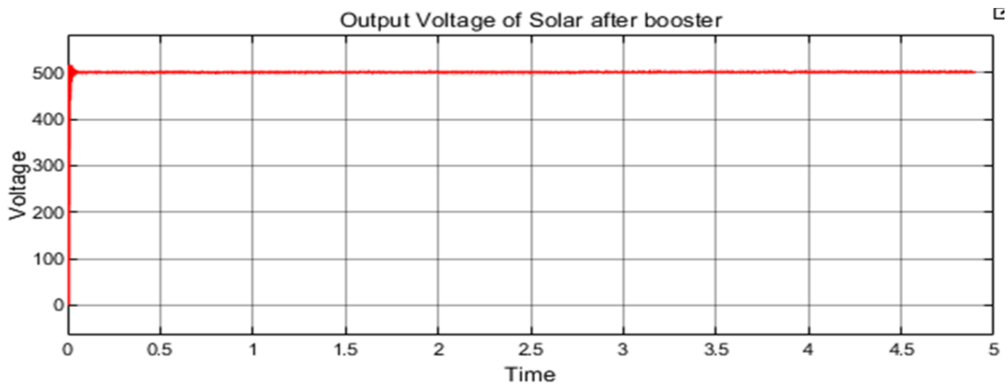


Figure 4.7 PV voltage output before and after Fuzzy MPPT

Figure 4.7 describes that the voltage output of PV cell before and after maximum power point tracking (MPPT) shows that the voltage output is greater than that of the voltage without MPPT. Therefore, it is clear that MPPT based Fuzzy logic controller is more effective than fuzzy Logic controller without MPPT as it is shown in the result.

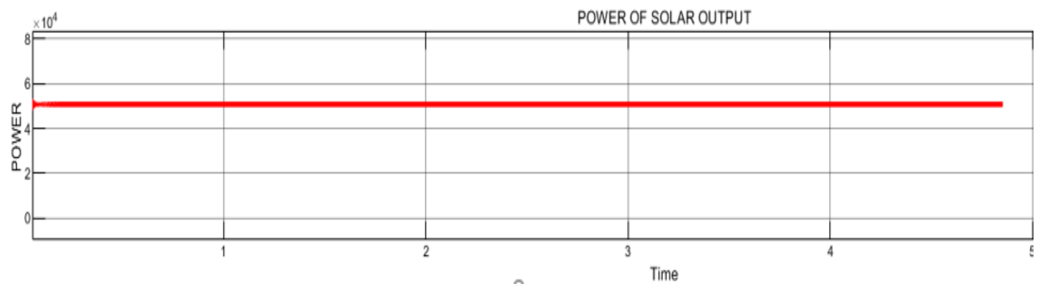


Figure 4. 8 PV power output solar PV

4.1.3 MPPT with fuzzy logic (FLC) for Wind

One of the clever ways utilized in wind systems to identify and monitor the operational point corresponding to the highest power regardless of wind speed is the fuzzy logic-based highest Power Point Tracking (MPPT) technology, which was recently introduced. This control is more reliable than traditional control methods since it doesn't require precise knowledge of the mathematical model of the system. The FLC MPPT controller block diagram for a wind system is displayed in figure 4.9

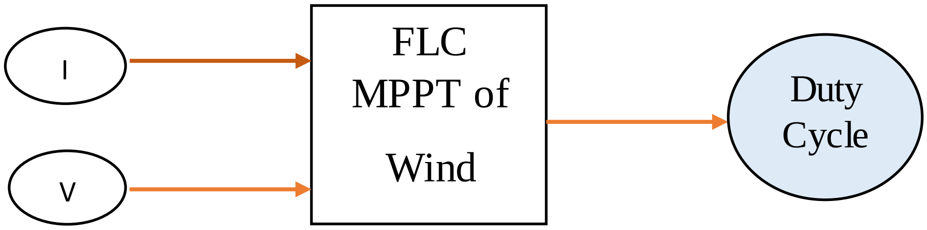


Figure 4.9 Block diagram of wind Fuzzy MPPT controller

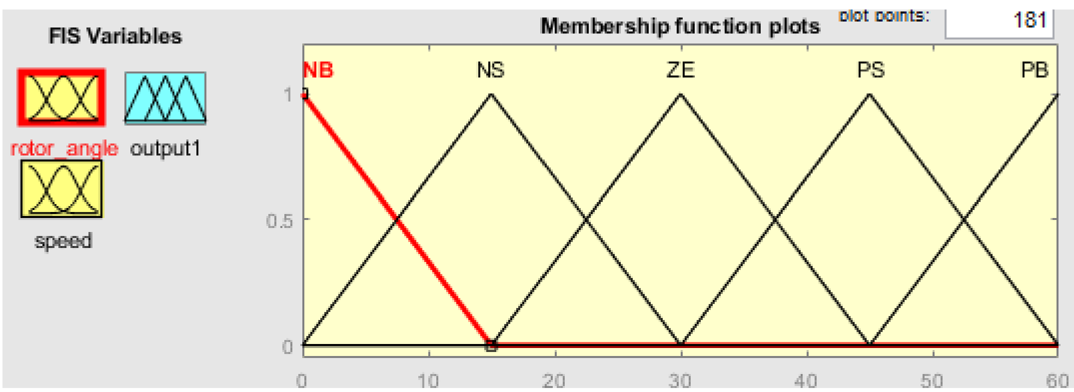
The input variables of the fuzzy controller are the error E(k) and the change of error dE(k) which

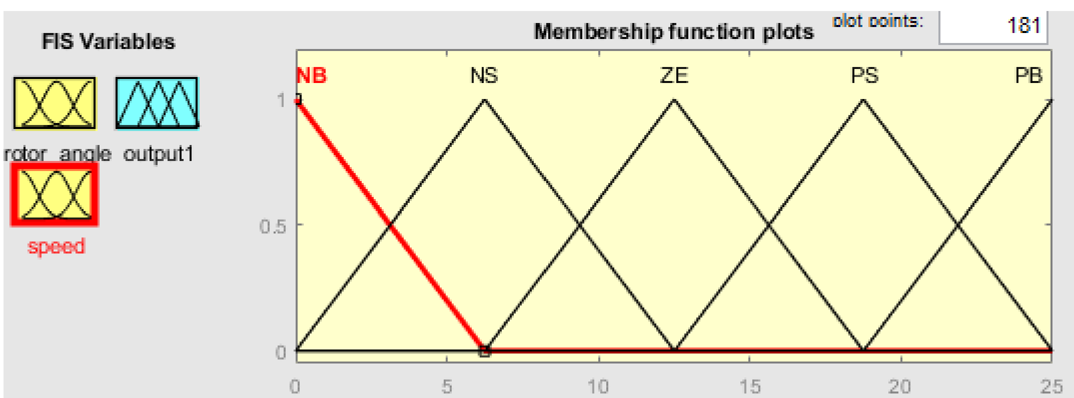
are defined by (4.48) and (4.49), while the output is the duty cycle D.

$$E(k) = \frac{P(k)-P(k-1)}{\omega(k)-\omega(k-1)} \quad 4.48$$

$$dE(k) = E(k) - E(k-1) \quad 4.49$$

Where P(k) denotes the wind generator's output power and ω(k) its rotor speed, respectively





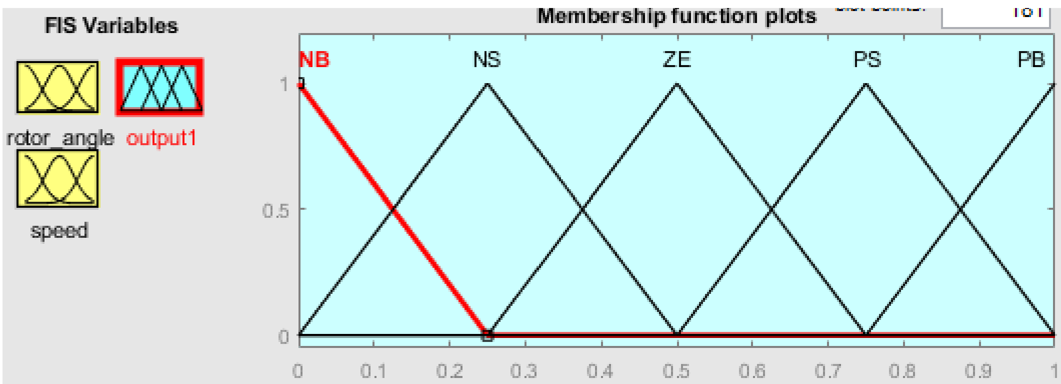


Figure 4.10 Membership functions for: (a) Input E, (b) Input dE, (c) Output D

Table 4.2 shows the fuzzy rules designed, using the MINMAX fuzzy implication method. And for the defuzzification step that used the center of gravity method.

Table 4.2 Fuzzy rule table for wind system

E3 / dE3	*NB*	*NS*	*Z*	*PS*	*PB*
NB	NB	NB	NS	NS	Z
NS	NB	NS	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PS	PB
PB	Z	PS	PB	PB	PB

4.1.4 Simulation result of wind

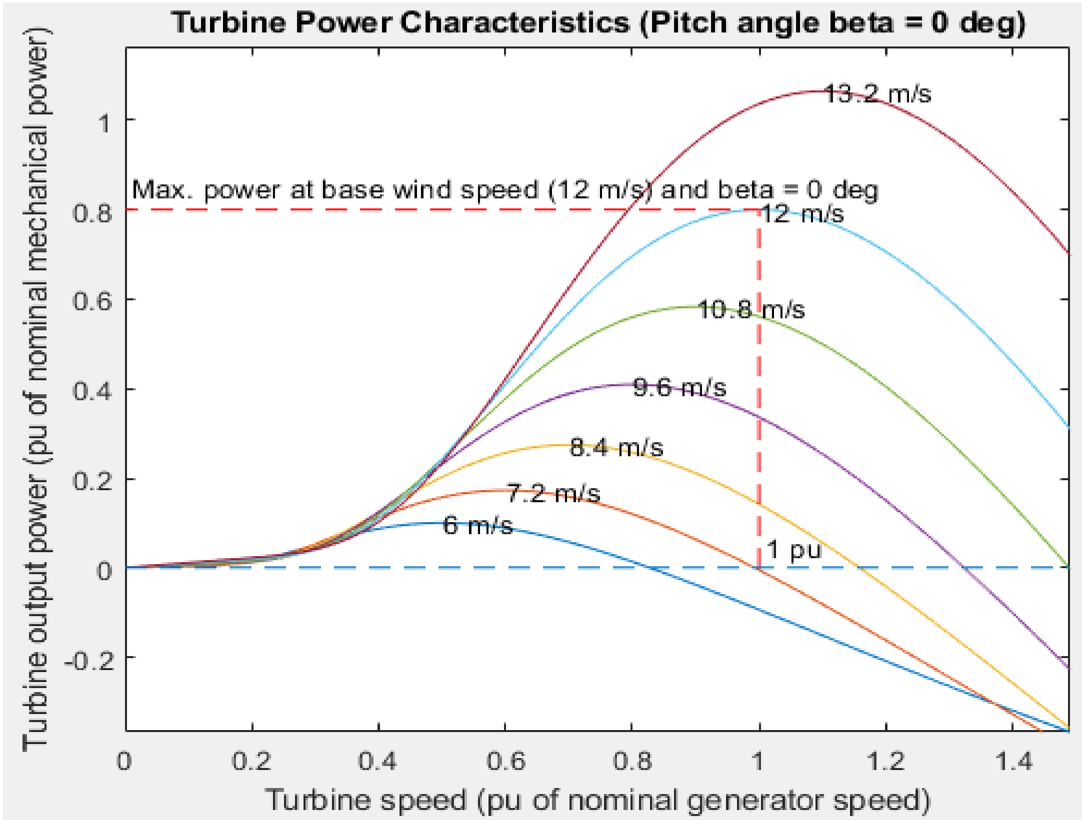


Figure 4.11 Wind turbine characteristic

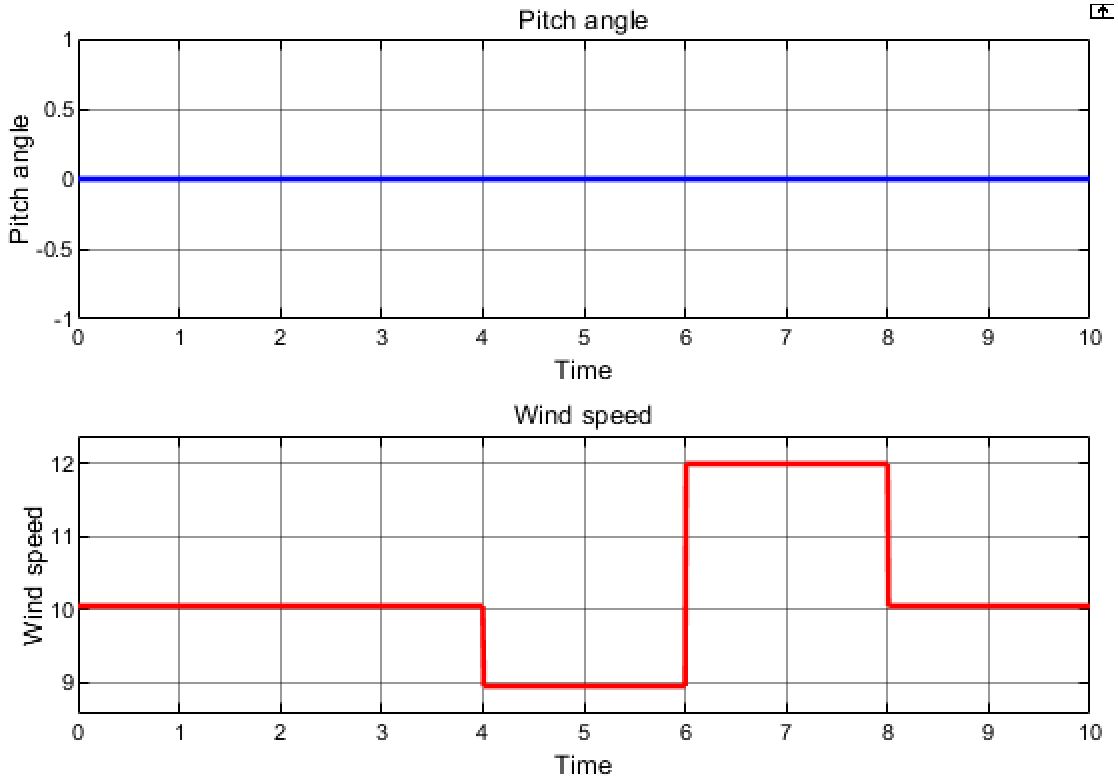
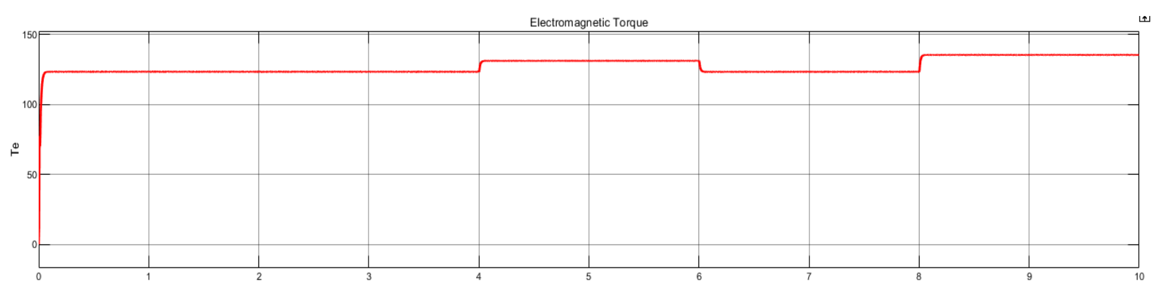


Figure 4.12 Pitch angle and wind speed

The simulated model results, as depicted in the figure below, indicate that the wind turbine is producing approximately 22 KW of power, despite the manufacturer's specification stating that the wind turbine's rated power is 25 KW. The reason for the wind turbine's lower power output is wind speed; the manufacturer's datasheet mentions that the desired wind speed is 10 to 13 m/s to achieve rated power, but the actual wind speed taken from site analysis and system losses results in the system producing approximately 22 KW of power. However, because the system also includes other resources, it is fully capable of meeting the load demand.



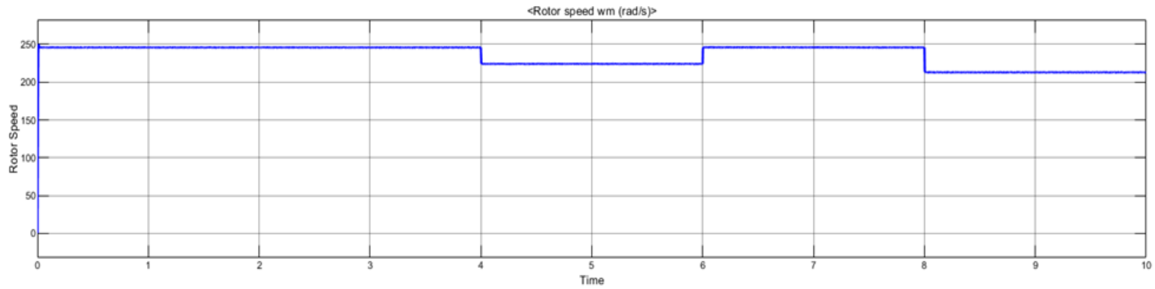


Figure 4.13 ElectricmagneticTorque and Rotor speed

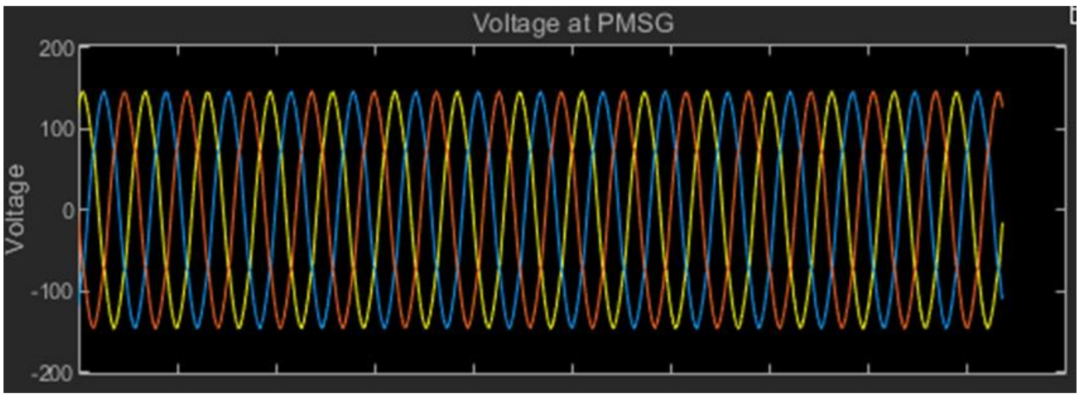
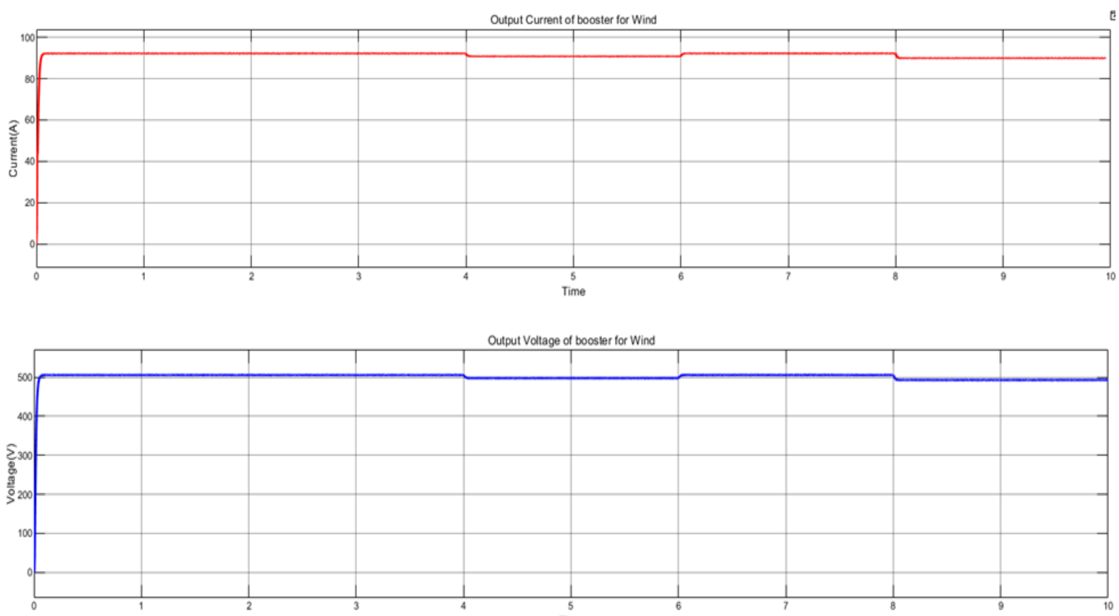


Figure 4.14 Three phase output voltage of PMSG

4.1.5. Simulation of Wind Result with fuzzy controller



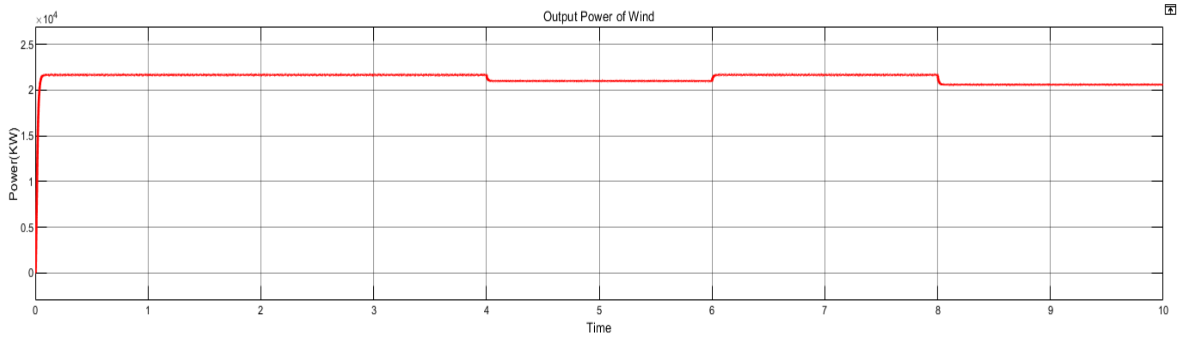


Figure 4. 15. Simulation of Wind Result

4.2 Proposed Model Using Fuzzy Logic Controller for the Hybrid System

4.2.1 Fuzzy Logic Controller Algorithm

Fuzzy logic controllers are a smart way to keep integrated energy sources under control and meet load needs in a variety of load conditions. Controller designs are created by defining the requirements, assigning language variables, and defining the controller's rules. This thesis work uses a fuzzy logic controller with four inputs and one output. The linguistic variables that make up the FLC's input are power demand (PD), battery (Bp), wind power (Wp), solar power (Sp), and power demand (Wp). The verbal variable that makes up its output is out power (Po).

The linguistic values of Sp,Bp, Sp + Wp, Sp + Bp, Wp + Bp, and Sp+Wp+Bp are present in the output linguistic variable. Three linguistic values Low, Medium, and High are assigned to each input language variable. Utilized are the triangular membership function for justification, the Mamdani inference system for processing rules, and the focal point of fuzzy logic processing and de-fuzzy analysis. The next sections covered the components of a typical fuzzy system: membership functions, rule base, inference process, and rule viewer. The following stage is to assess the controller's rules for the input values to determine whether or not the output is appropriate, after providing a membership function for each input output linguistic value and producing potential operational rules. It is believed that each component will provide a random signal in order to view the hybrid system's overall performance.

A) Fuzzy Interface Model

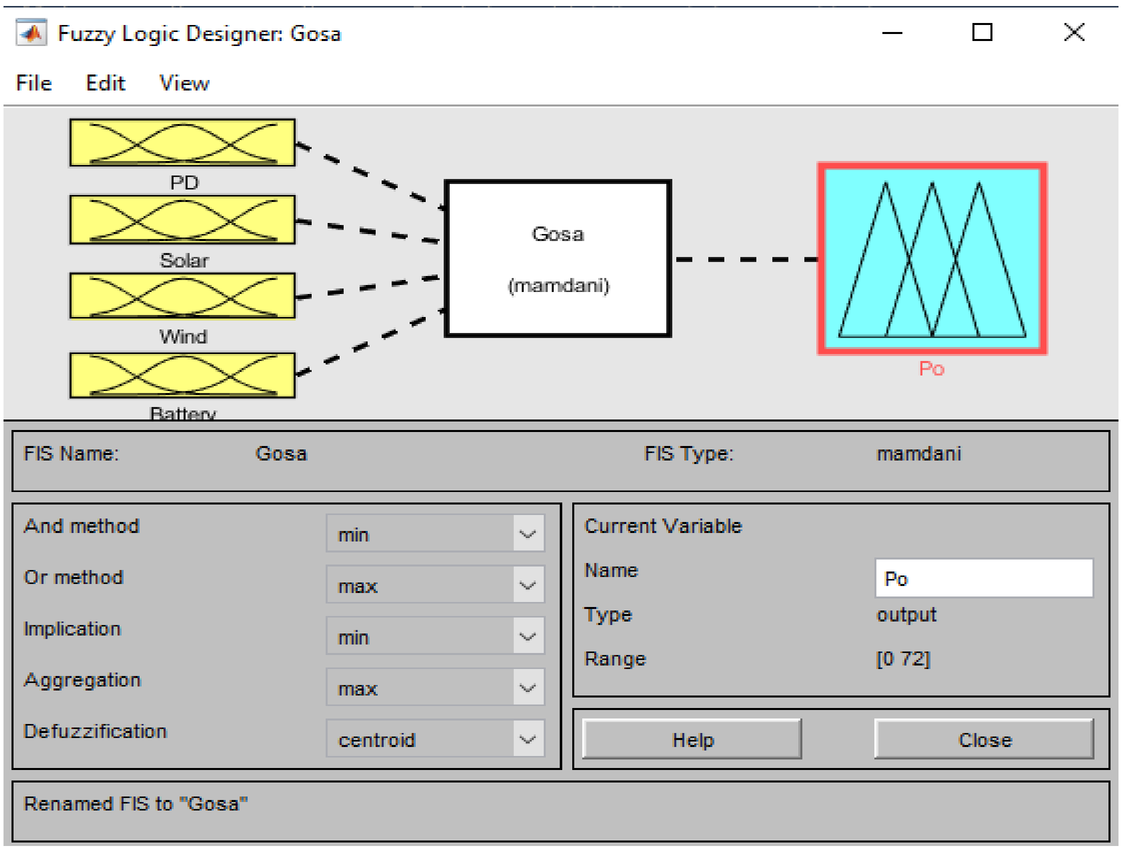


Figure 4.16 Fuzzy interface model

B) Power Demand's (PD) Membership Function

Among the language variables received is the power demand (PD), which has three linguistic values: low, medium, and big.

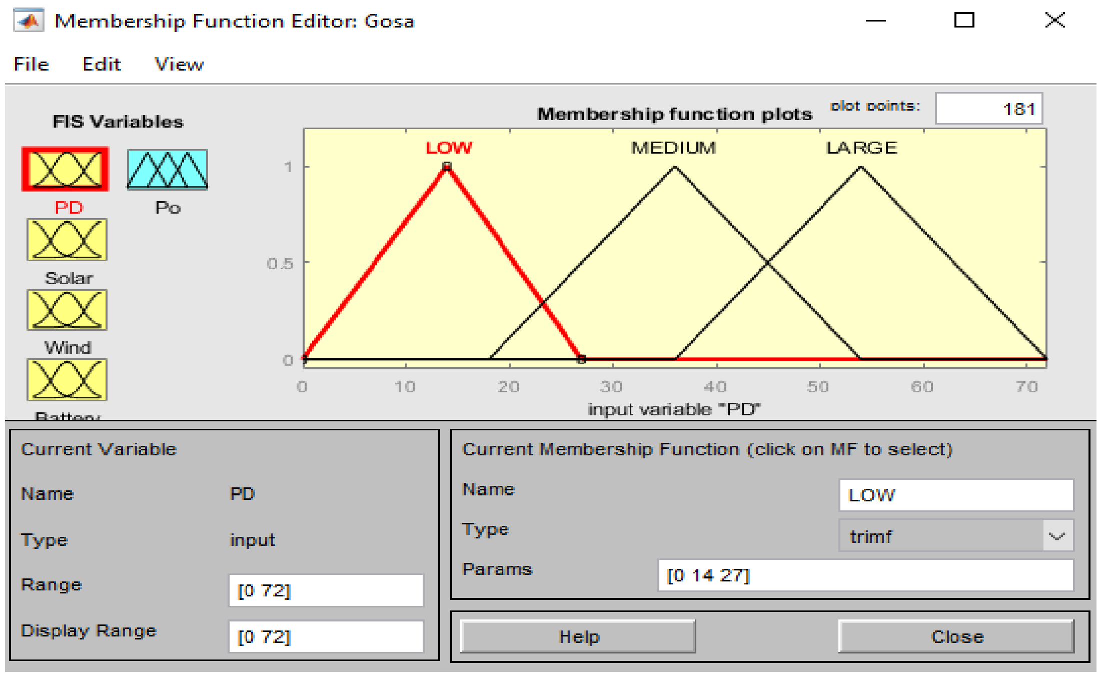


Figure 4.17 Membership function of power demand

C) Solar power (SP) membership function

Another input variable is solar power, which has three language values: small, medium, and huge.

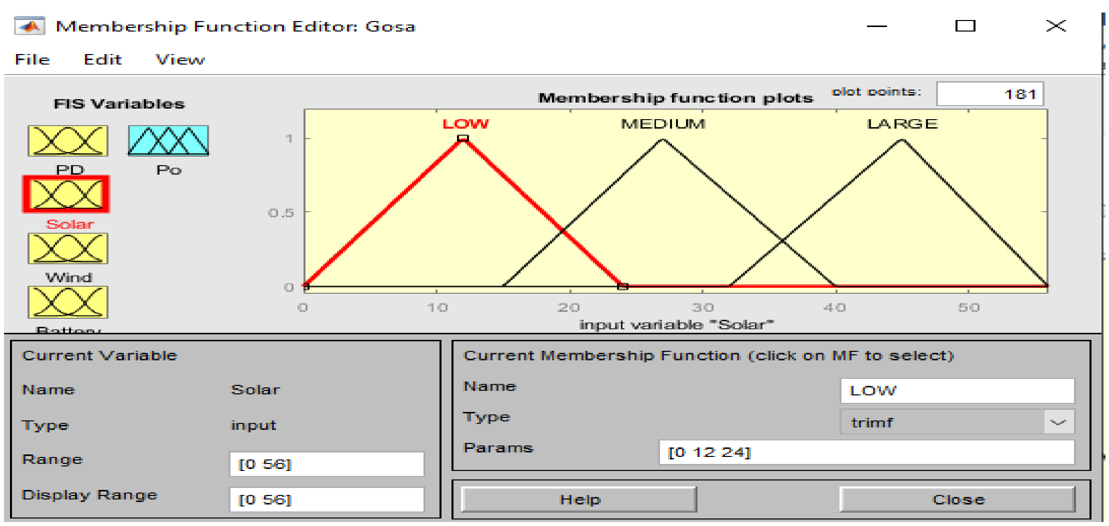


Figure 4.18 Membership function of solar power (SP)

D) Membership Function of Wind Power (WP)

Solar power is the third input linguistic variables having three linguistic values low, medium and large.

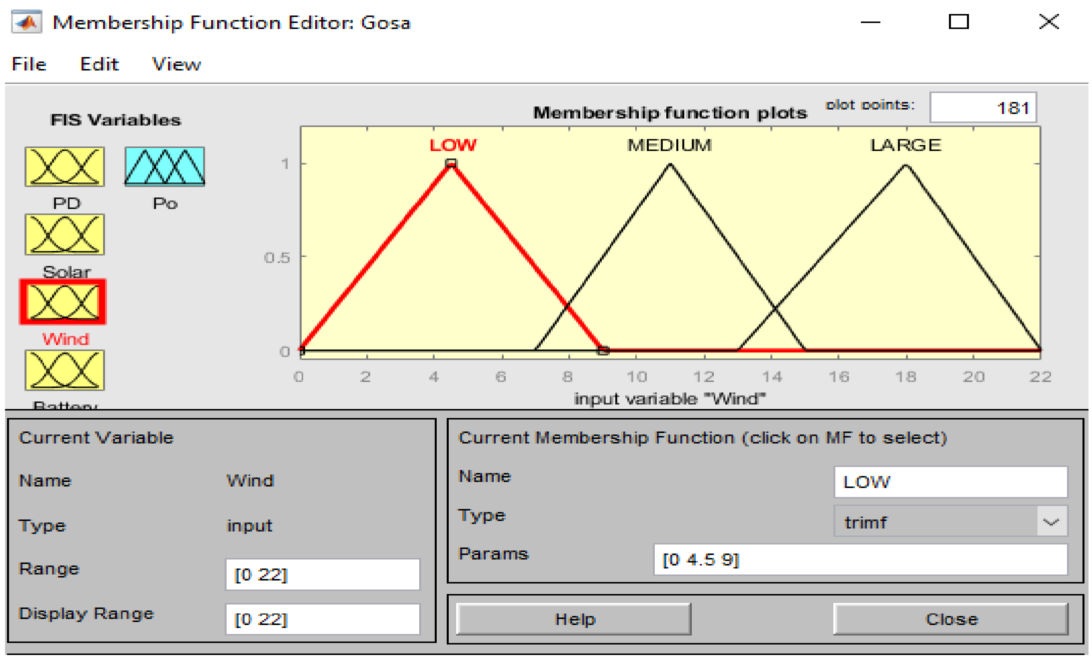


Figure 4. 19 Membership function of wind power

E) Membership Function of Battery Power (BP) with three linguistic values low, medium, and large battery power is the fourth input language variable.

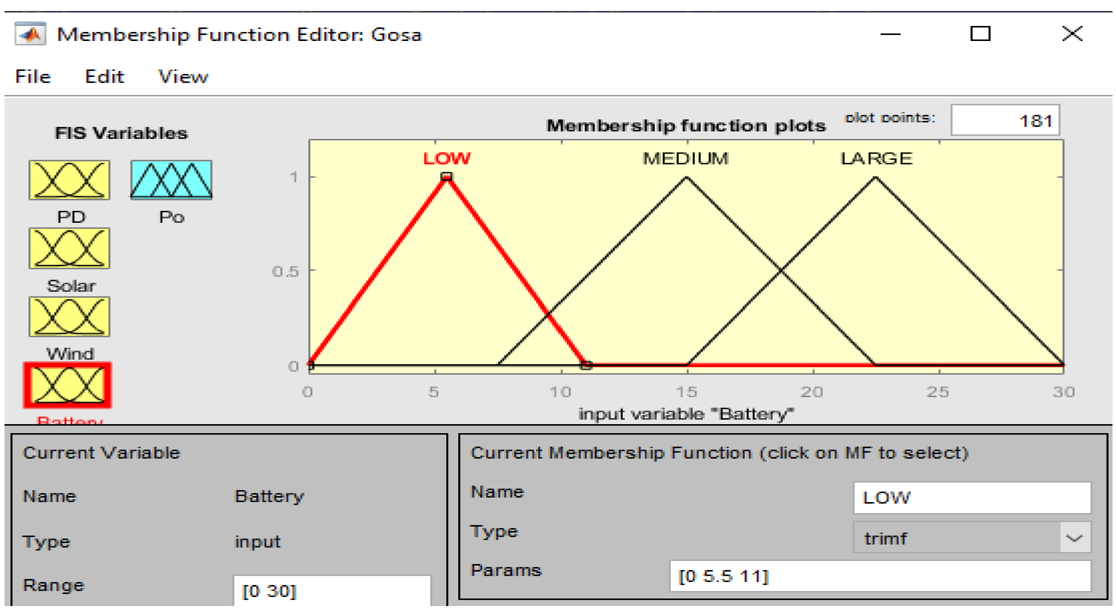


Figure 4.20 Member function of battery power

F) Membership function of output power (PO)

The only output linguistic variable is output power; it has: SP source, BP individual, SP+WP,WP+BP, SP+BP, WP+Sp+Bp.

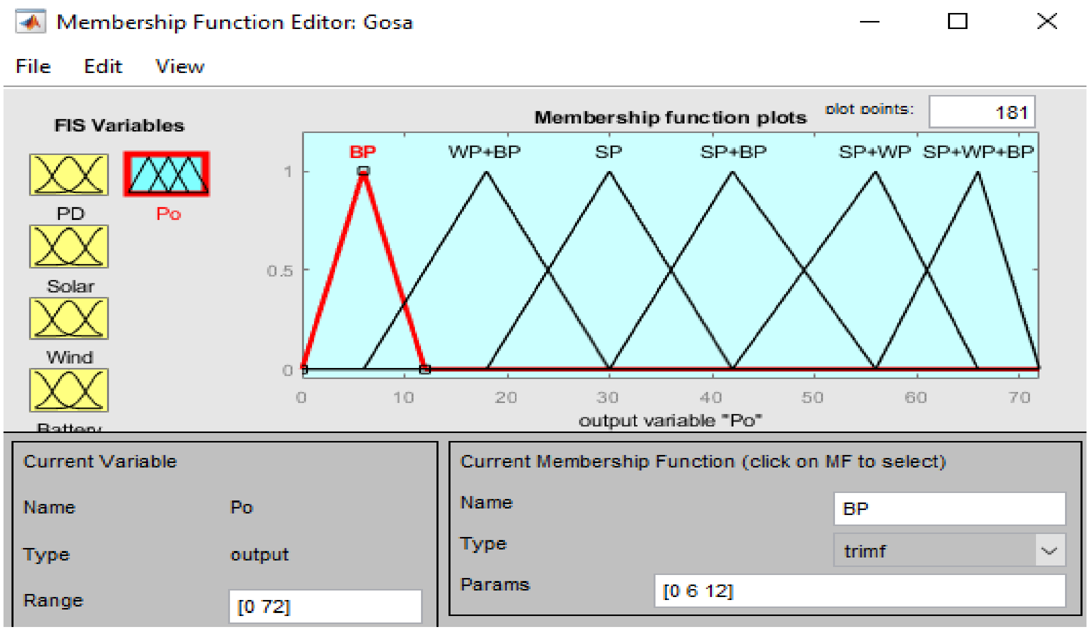


Figure 4.21 Output power (PO) membership function

G) Fuzzy Logic Rule Modeling in Real Time

Here is the model of fuzzy logic controller having four inputs and one output. In control box, a set of rules have been written. The system was operated in accordance to the rules set.

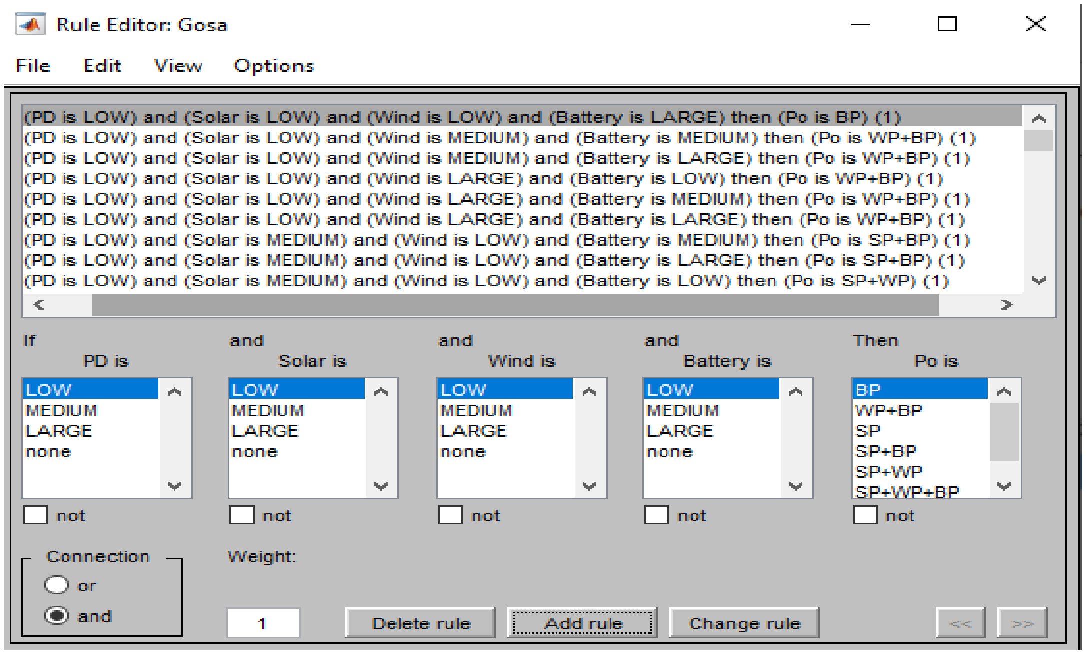


Figure 4.22 Fuzzy logic rule modeling in real time

It is possible to see whether the system is functioning in accordance with the written rules in MATLAB. An example of this is provided below, when solar and wind energy are the only sources of renewable energy are purposefully made to function in accordance with the decision to supply the demand power, which is approximately 72.84 kW, and the output power, which is also 72.84kW. This indicates that the fuzzy rule is functioning as intended in this typical scenario Figure 4.23 is used to evaluate the rules.

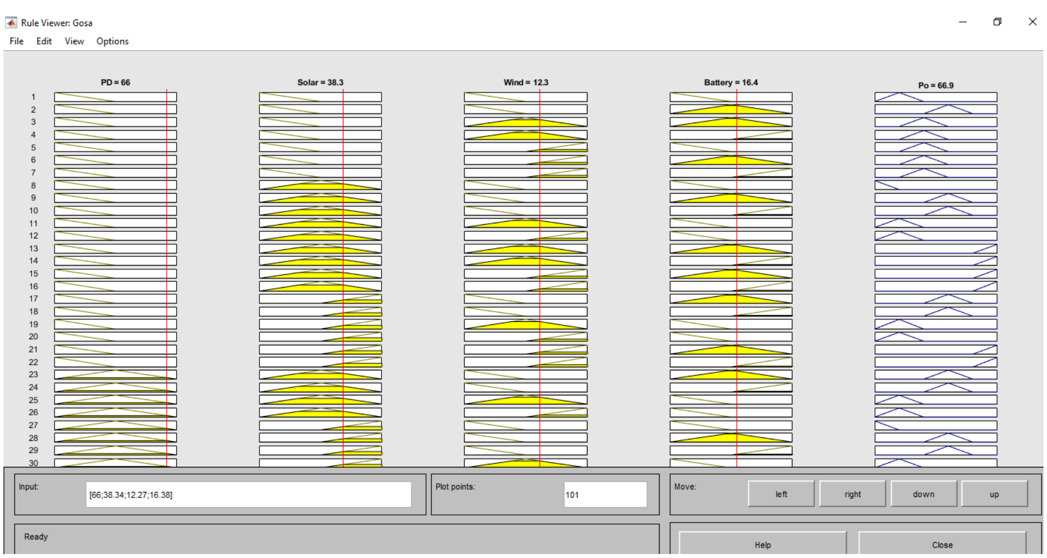


Figure 4.23 Member function rule viewer

Using the rule viewer, one can assess the rules specified in the rule editor after modeling the fuzzy logic controller. As a result, with the PD of 66 kW, for instance, the controller Po's appropriate output power was 66.9 kW with the difference 0.9 as shown in figure 4.24. This shows that the controller contributes to the efficient utilization of the resources available for the current power demand.

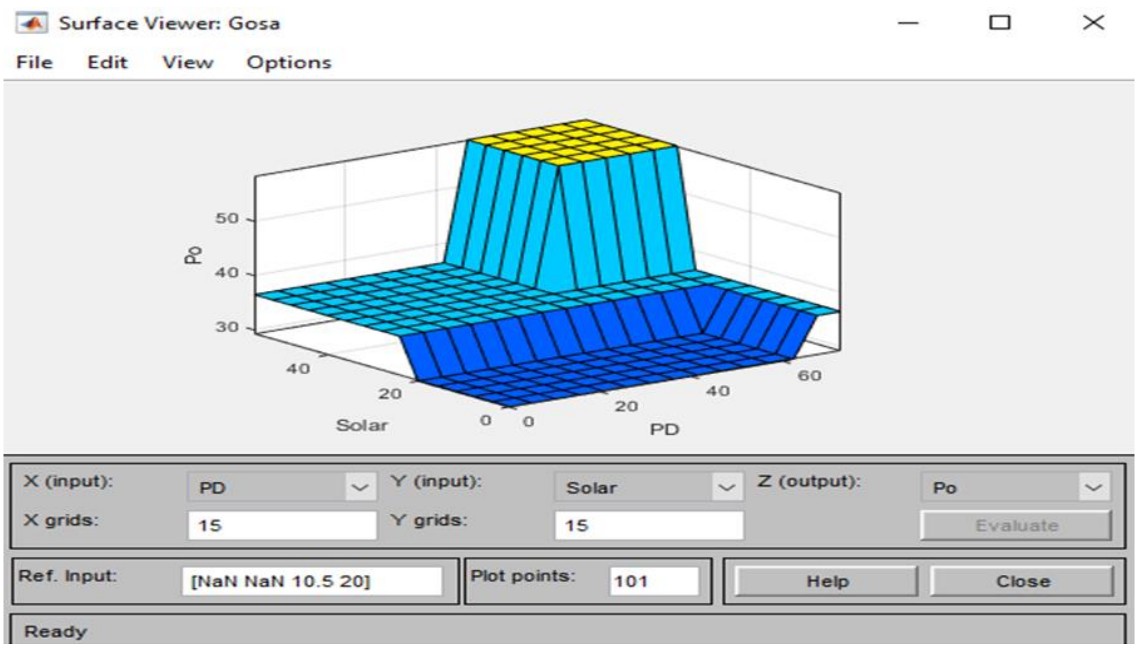


Figure 4.24 Membership functions of surface view

4.3 Overall fuzzy logic controller system

The controller's input parameters include power demand, battery power, solar power, and wind power. Pd, SP, WP, and BP denote the power that is required from the customer, wind, solar, and battery power, in that order. It is believed that each component power source produces electricity in the form of a Gaussian random signal generator. The rules specified in the fuzzy logic controller will determine how the multiport conditional switch acts.

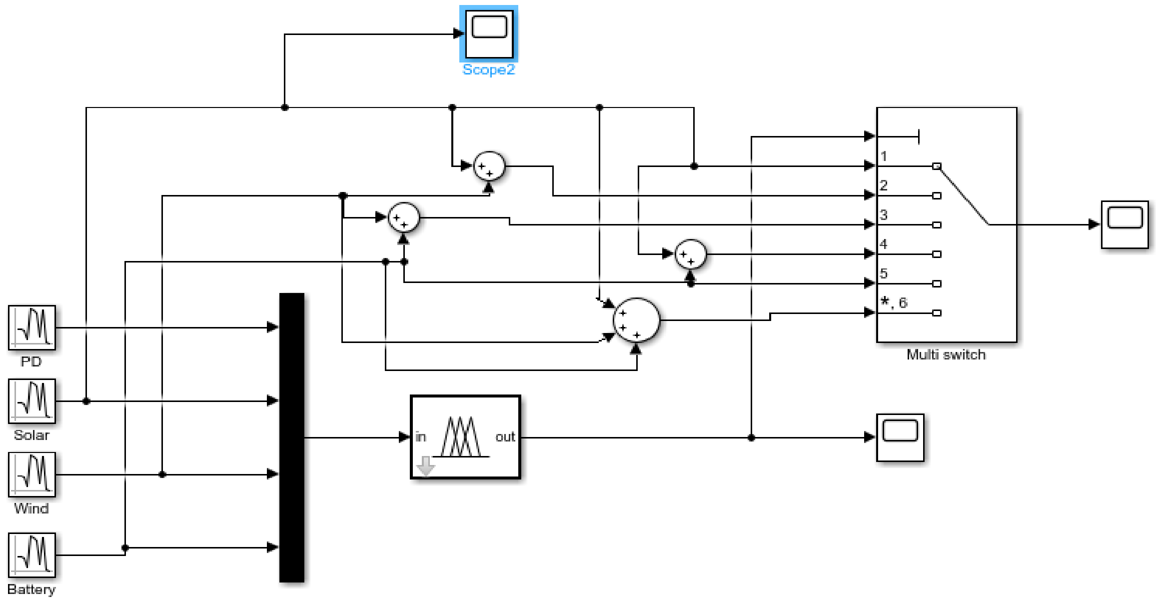


Figure 4.25 Overall hybrid system based on fuzzy logic

All of these input sources demand power, solar power, wind power, and battery will fluctuate periodically due to the intermittent nature of renewable energy resources. To determine whether the controller detects this variation and makes the appropriate decision to activate the multiport switch, a Gaussian random number generator is chosen as an input for each of these six variables. Various scenarios are tested to evaluate the effectiveness of this intelligent controller, and the results are listed below.

4.3.1. Case studies

It was feasible to consider various working conditions, such as low sun, high wind, medium battery, and other circumstances, in order to assess the constructed fuzzy logic controller. However, in this instance, the controller was given random numbers to determine whether or not it functions. The output power is displayed on the scopes. This indicates that the output power that will meet the required power can range from 0 to 72.84 kW.

4.3.2 Case study one

For instance, when the power demand (PD) is 72 kW, SP is 50 kW, WP is 20 kW, and Bp is 2 kW, the fuzzy logic controller's output power was displayed as shown by figure 4.20.

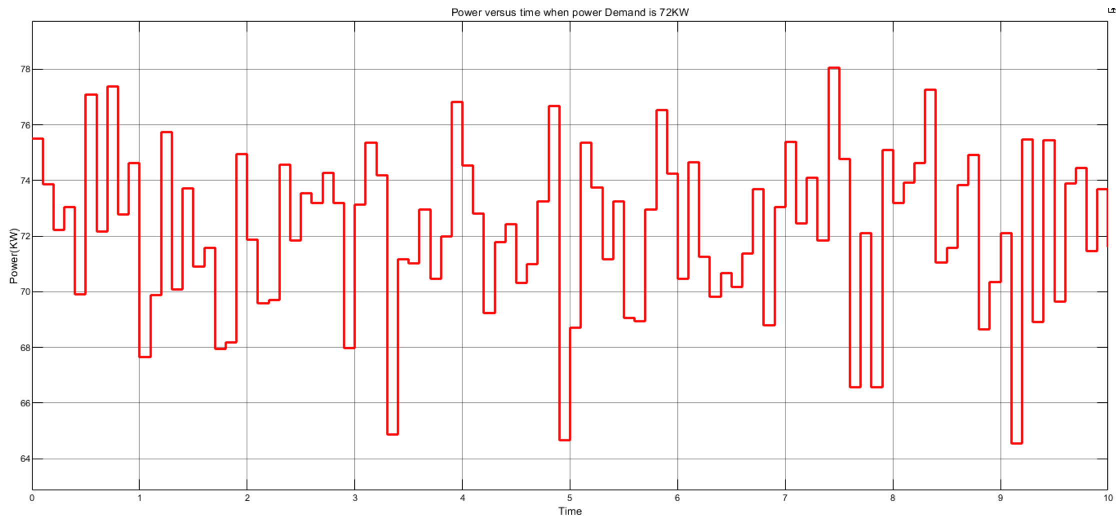


Figure 4.26 Simulation result of fuzzy logic controller case one

In addition to maximizing power supply utilization, the controller helps to meet customer power demands. This suggests a power need of about 72kW. The resources that are available can meet an output power of 72 kW, SP of 50 kW, WP of 20KW and BP of 2KW as shown in figure 4.26.

4.3.3 Case study two

If the power demand OD is 40 kW, SP = 25KW, WP=15KW, and BP = 0KW, then fuzzy logic output power will be indicated as shown in figure 4.27.

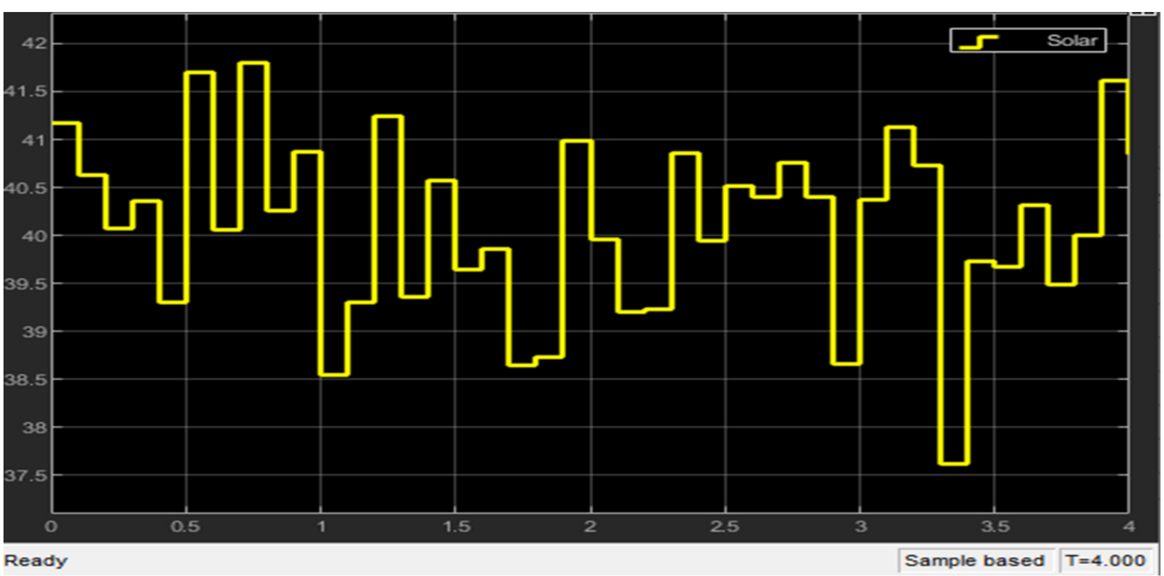


Figure. 4.27 Fuzzy logic controller simulation result of case study two

4.3.4 Case study three

For instance, if power demand is (PD) is 60 KW, SP is 35 KW, WP is 15KW, and BP is 10 kW, the output of fuzzy logic controller will be displayed as shown in figure 4.28 below.

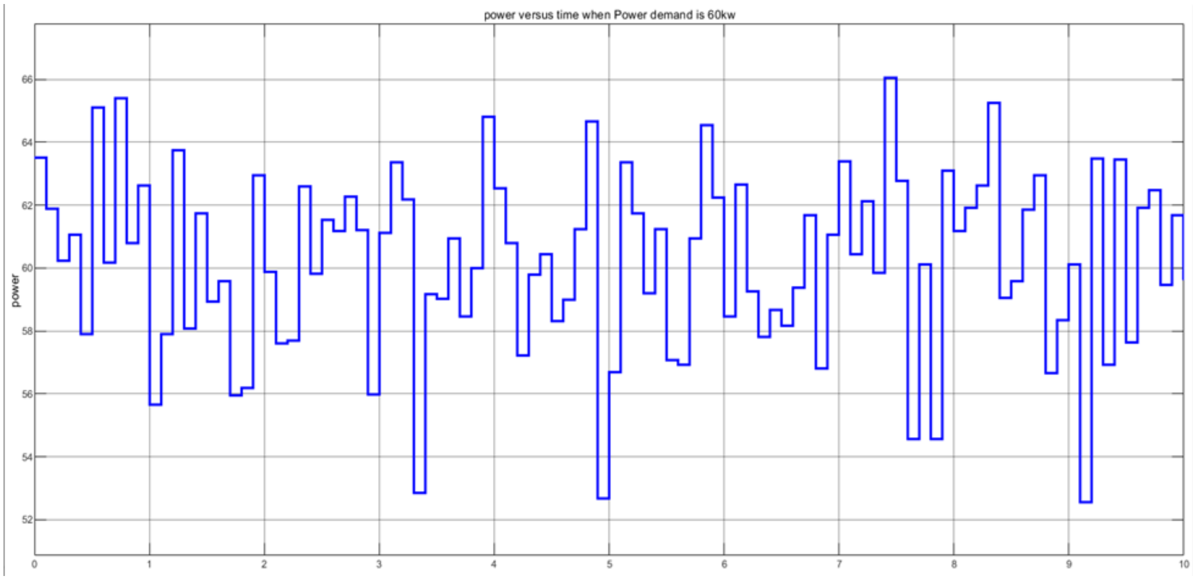


Figure 4.28 Simulation result of fuzzy logic of case three

4.3.5 Case study four

For instance, if the power demand is 15 KW, SP is 0 KW, WP is 0 KW, and BP is 15 kW, the output power of fuzzy controller's will be displayed as shown in the following figure 4.29.

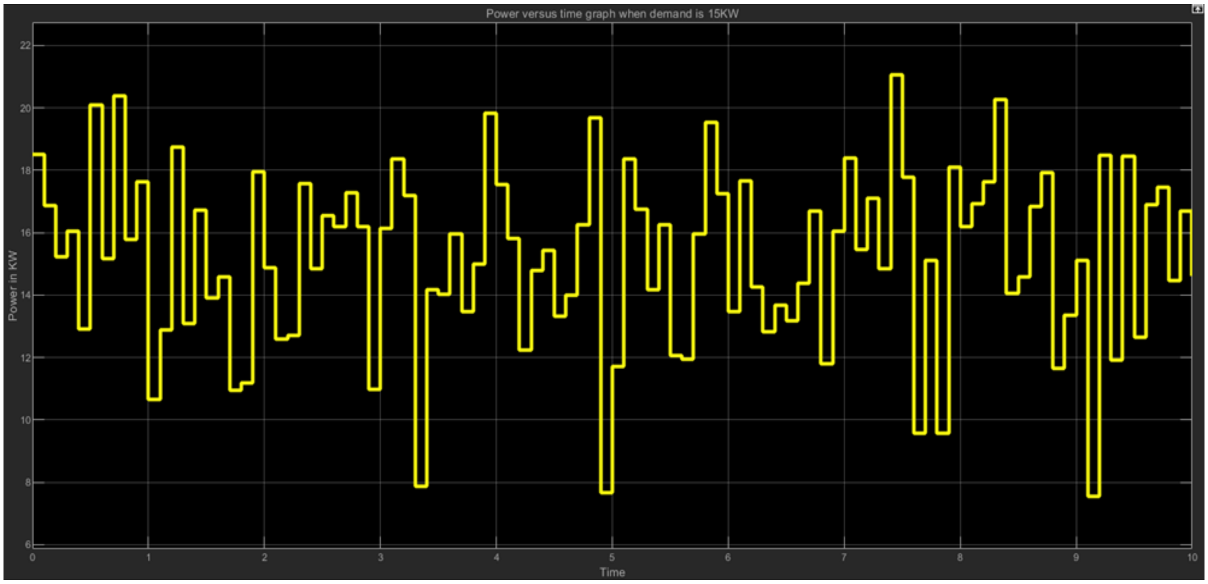


Figure.4.29 Simulationresult of fuzzy logic controller for case four

Real-time microcontrollers should be used to implement the controller or power management system. As a result, the Simulink system is programmed in Matlab using mat function, as seen in the appendix.

Table 4.3 Power Combination and switch port

Different Sources	Switch port
BP(battery)	1
SP (solar power)	2
WP+BP(wind +battery)	3
SP+BP(solar + battery)	4
WP+ SP (wind +solar)	5
SP+WP+BP(combination of all)	6

4.4 Hybrid System Designing by HOMER

A computer model used for many applications in the energy generation system is called the Hybrid Optimization Model for Electric Renewable (HOMER), which was created by the

National Renewable Energy Laboratory (NREL) in the United States. Its main purpose is to support the design of hybrid power systems by effectively evaluating different renewable energy technologies. HOMER optimizes device design by comparing a large variety of devices within particular constraints and sensitivity

A hybrid power system's life-cycle costs, including the entire cost of installation and operation over the system's lifetime, are modeled using HOMER. This makes HOMER an invaluable tool for designers, allowing them to compare various design options according to economic and technical standards. Additionally, HOMER facilitates the comprehension and measurement of the impacts of input changes or uncertainties. It offers cost-effective, optimal solutions to power system problems (N.R.E. Laboratory, 2011).

HOMER software is a powerful tool developed to optimize the design of microgrids and distributed energy systems. It's widely used for planning, designing, and analyzing the performance of hybrid renewable energy systems that combine different energy sources, such as solar, wind, and batteries.

HOMER simulates numerous system configurations to determine the best one. HOMER chooses the best configuration during the optimization process, taking into account all technical limitations and having the lowest life-cycle cost. The purpose of the optimization tool is to identify the best value for each variable of interest to the modeler. The optimal sizes and quantities of each component, which HOMER considers in its optimization process, are determined by the designer (Lilienthal, P. G. A. (2006).

Key Features of HOMER Software

Simulation: A hybrid energy system's operation is simulated by HOMER for a predetermined amount of time. It takes into account the fluctuation of energy and renewable resources (such as solar and wind) consumption patterns, and the performance of different system components.

Optimization: The software identifies the most cost-effective configuration of the system. It considers different sizes and types of components (solar panels, wind turbines, batteries, generators, etc.) to find the best combination that meets the desired reliability and performance criteria at the lowest cost.

Sensitivity Analysis: HOMER performs sensitivity analysis to understand how changes in inputs (e.g., fuel prices, component costs, renewable resource availability) affect the system's performance and economics.

System Sources: Comprehensive data, including energy resources, financial restrictions, control strategies, village load demand, renewable resources, component technical specifications, costs, and the kind of dispatch technique, are needed for HOMER to study the system. For this reason, solar, wind, and battery storage components are included in the Hybrid Energy System (HES) represented in this configuration.

Let as show below the solar resource input

Figure 4.30 Solar resource data of tulu gudo island

Figure 4.31 Wind resource data of selected site

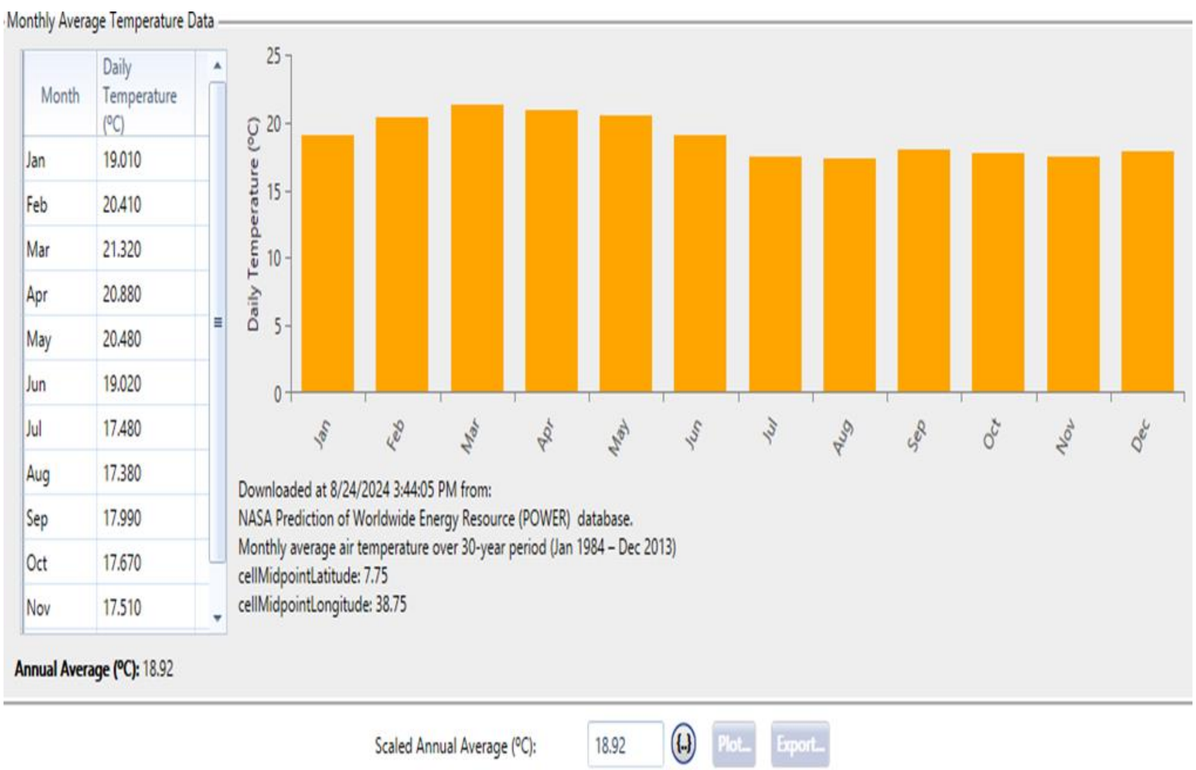


Figure 4.32 Temperature data of selected site

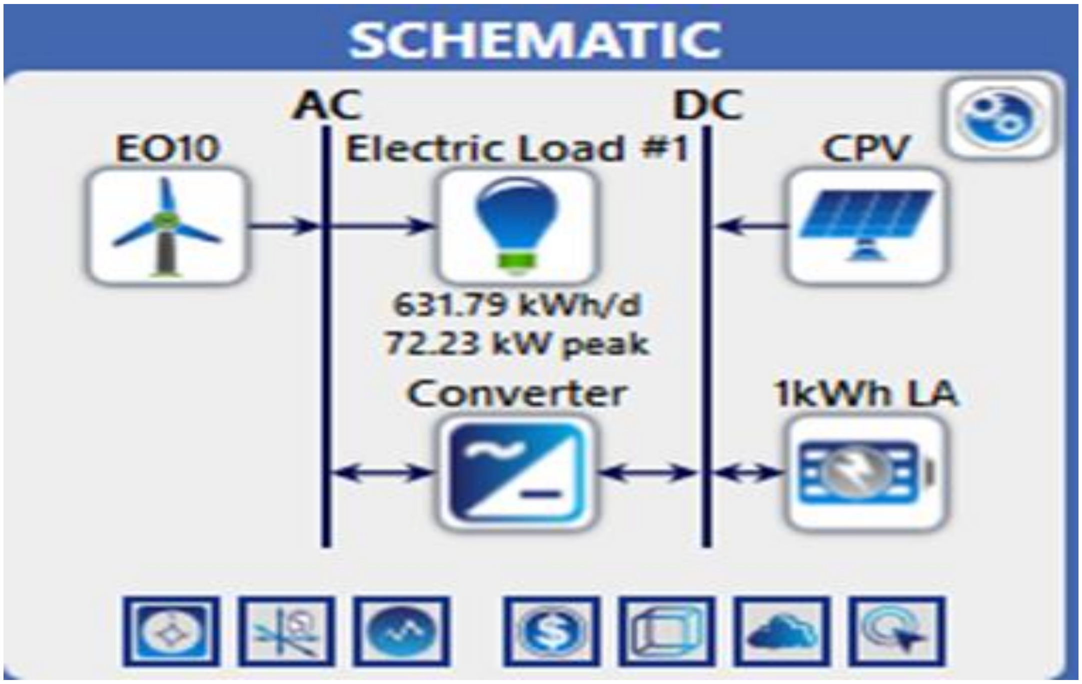


Figure 4.33 An isolated system's schematic configuration

For a given case study, the HOMER simulation is intended to determine the most economical and optimal renewable energy solution. The results are shown by HOMER in two categories: Overall Results and Categorized Results.

The most practical systems for each system architecture are listed in the Categorized Results, arranged from lowest to greatest Total Net Present Cost (NPC). On the other hand, the Overall Results, which are likewise arranged by Total NPC, offer a ranking of the most economical systems across all architectures.

Selecting the ideal system involves taking into consideration crucial elements such as Total Net Present Cost, Levelized Cost of Energy, Annual Fuel Consumption, Renewable Fraction, and Unmet Load Fraction. A thorough report is provided by HOMER for every workable system,

4.4.1 Optimization Result for Tulu Gudo Island

Following the simulation of every potential configuration for the system, HOMER displays a list of configurations arranged according to their Net Present Cost (NPC), or lifecycle cost. This makes it possible to compare several possibilities for system design.

A component's net present value (NPC) is calculated by deducting the present value of whatever income it produces during the project's lifetime from the present value of all expenses related to installing and maintaining it. The NPC is computed by HOMER for the system as a whole as well as for each individual component.

The outcomes of the HOMER optimization are shown in the picture below, classified. Just the configuration with the lowest Net Present Cost (NPC) is displayed for each design category. The optimum configurations shown in this figure can handle the system's overall load.

Different configurations have different initial capital, net present value (NPV), excess electricity, and Cost of Energy (COE), even when there are several options with the same renewable proportion. These factors affect the choice of the best system type.

Categorized Overall

Architecture										Cost	
					PV (kW)	Aeolos-V1kW	SSIG 12 170 (#)	Cybo1000N (kW)	Dispatch	NPC ($)	LCOE ($/kWh)
					228	132	848	122	CC	$472,932	$0.277
					369		1,158	127	CC	$537,967	$0.315

Figure 4.34 Homer simulation of optimization result

From figure 4.34 It is evident that wind farms and 228 KW PV module with 122 kW converters provide the most affordable setup. The NPC value for this configuration is 472,932 USD, and the COE is 0.277 USD/kWh.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis demonstrates how a freestanding hybrid solar/wind power generation system based on fuzzy logic is operated system has proven to be an extremely effective tool for improving the economic standing and way of life of the Tulu Gudo island residents of Dembel Lake. In addition to offering a way to generate electricity, it offers additional services in the area to lessen the labor-intensive nature of food processing. The goal of this thesis was to evaluate the potential of solar and wind resources. Power from renewable energy resources was harnessed to identify choices and create a basic design for certain essential hybrid solar-wind viable RES components that will produce electricity for the chosen sites.

The primary goal of this thesis is to demonstrate how island communities might benefit from using renewable energy sources to supply electricity. The hybrid system was developed to supply the islands with energy since they have residential loads, a primary school, a medical facility, and places of worship, and other facilities to enhance people's quality of life. It also includes infrastructure on the islands that are not connected to the central grid. Fuzzy logic controllers have been utilized to cost-effectively and efficiently use the generated power. By determining the kind and quantity of resources available, this intelligent control system chooses the best alternative source for an intelligent decision. Fuzzy rule editors have been used to write these rules, and MATLAB/Simulink has been utilized to simulate every part of the hybrid system.

This study demonstrates that developing a hybrid power system is more cost-effective and suitable for island communities with access to renewable energy sources. The findings encourage local public and private investors, particularly in Ethiopia, to adopt renewable energy and be persuaded that investing in hybrid power systems is sustainable. Based on simulation results, the ideal the setup of a renewable energy hybrid system is produced by combining photovoltaic panels, wind turbines, batteries, and converters. This system can be utilized as an off-grid solution for a chosen island of 250 households in Tulu Gudo, Lake Dembel, Ethiopia, the cost of energy per KWh is $0.277/KWh. The estimated electrical primary loads for the community are 631.787kWh/day.

5.2 Recommendation

The following points are highlighted in this thesis as suggestions. Ethiopia possesses abundant renewable energy resources that can be utilized to electrify an island using an off-grid method. But there are still a lot of issues that make it difficult to energize the island population, such as limited purchasing power, adverse conditions for using renewable energy, lack of knowledge about how to use these resources, not being connected to national grids, etc. Thus, to raise Ethiopia's low rate of island electrification, the public, commercial, and non-governmental sectors should work together.

• Other island settlements were not covered by the study; instead, it concentrated primarily on a portion of Ethiopia's Tulu Gudo island. Therefore, it would be beneficial for future researchers to extend this research to other locations and provide people with access to renewable energy resources.

I recommend that the concerned governmental entities closely monitor the state of research in intelligent energy control systems. The population's standard of living can be greatly improved by making efficient use of these resources with sophisticated intelligent controller

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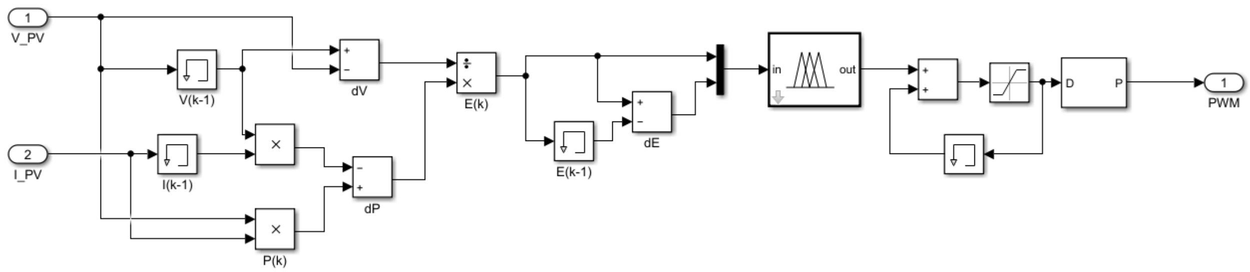
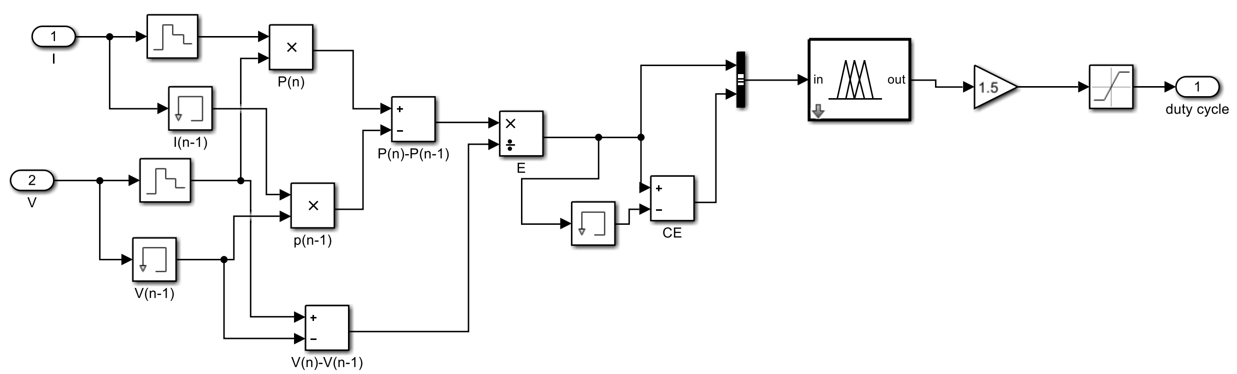
APPENDIX

A.

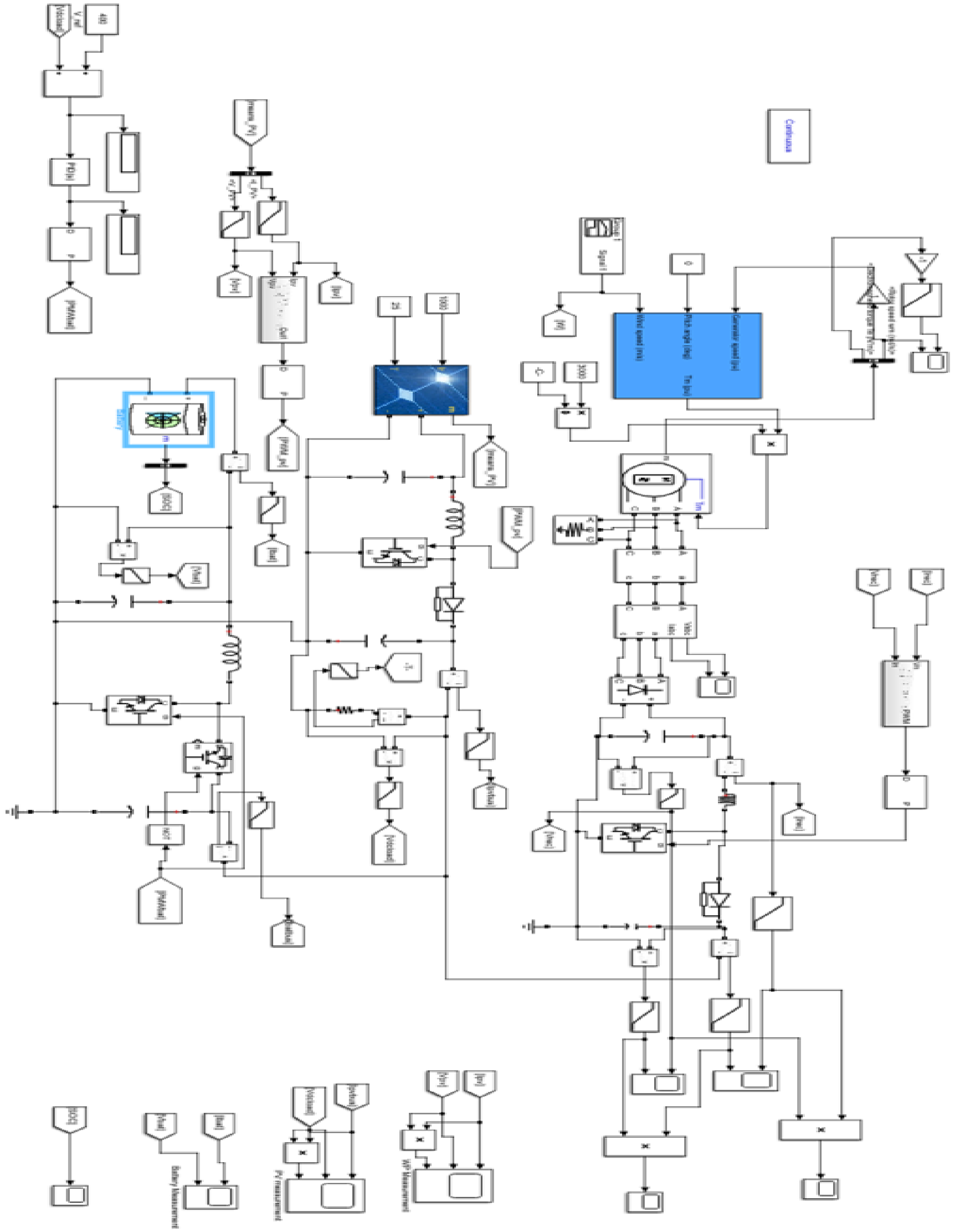


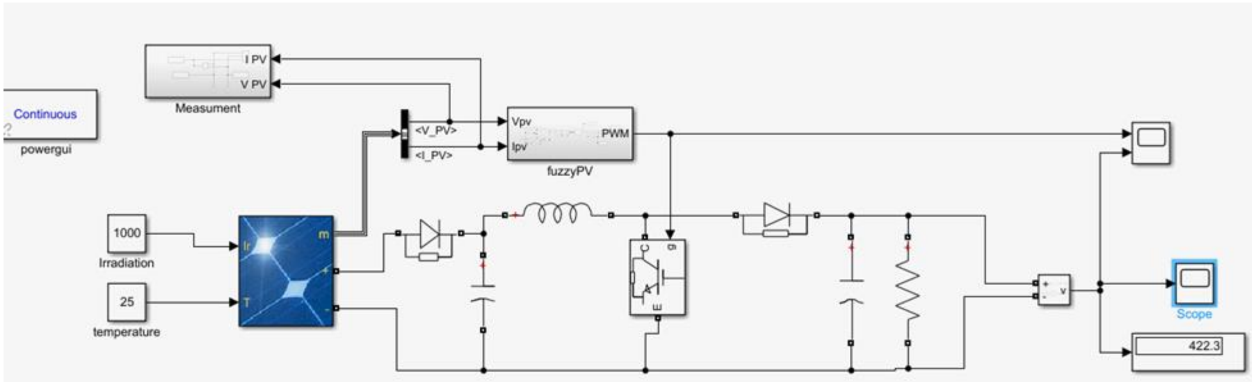
Simulink diagram of fuzzy logic MPPT controller for PV system.



Block diagram of fuzzy logic MPPT controller for wind energy

B. Over all Simulink diagram for the system





PV Simulink diagram for the system