A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF ÇANKIRI KARATEKİN UNIVERSITY

GREEN AND SUSTAINABLE CELLULAR BASE STATIONS POWERED BY RENEWABLE ENERGY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ELECTRICAL AND ELECTRONICS ENGINEERING

BY

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ÇANKIRI

2023

GREEN AND SUSTAINABLE CELLULAR BASE STATIONS POWERED RENEWABLE ENERGY

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June 2023

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science

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Inam Abbas Razooqi AL-SADDAEE

ABSTRACT

GREEN AND SUSTAINABLE CELLULAR BASE STATIONS POWERED RENEWABLE ENERGY

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This research focuses on design and simulation of a hybrid energy management system, which utilizes solar and wind energy as dual power sources. The research is motivated by energy scarcity and unreliability in certain locations, highlighting the importance of renewable energy sources. The main objective is the development of an effective, efficient, and robust control system of the energy. So, this study aims to optimize the performance of energy modules. The methodology and algorithm has been developed and utilized to enhance efficiency of hybrid power sources. The maximum power point tracking (MPPT) of the solar modules will be maximized through this method, facilitating optimal power conversion from solar to load. The aim is to increase the efficiency of solar cells by optimizing the MPPT algorithm, providing a reliable, stable electricity supply with minimal disruptions. In this study, a hybrid system with solar and wind turbine energy sources has been simulated. The implementation of a fuzzy logic controller using the MPPT algorithm is presented to extract maximum possible power from the source efficiently and powerfully.

2023, 67 pages

Keywords: Hybrid system, MPPT, Fuzzy logic controller, Photovoltaic, Energy management system, Microgrid

ÖZET

YENİLENEBİLİR ENERJİ İLE GÜÇLENEN YEŞİL VE SÜRDÜRÜLEBİLİR HÜCRE BAZ İSTASYONLARI

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Bu çalışmada, güneş ve rüzgar enerjisini çift güç kaynağı olarak kullanan bir hibrit enerji yönetim sisteminin tasarım ve simülasyonu yapılmıştır. Enerji üretiminin bazı yerlerde kısıtlı veya verimli olmaması nedeniyle yenilenebilir enerji kaynaklarının önemini artmaktadır. Çalışmanın amacı; etkili, verimli ve kararlı bir enerji kontrol sisteminin geliştirilmesidir. Bu nedenle, enerji modüllerinin performansını optimize etmeyi hedeflemektedir. Hibrit güç kaynaklarının verimliliğini artırmak için metodoloji ve algoritma geliştirilmiş ve kullanılmıştır. Bu yöntemle, maksimum güç noktası izlemesi (MPPT) kullanılarak güneş enerjisi modüllerinin maksimum güç noktası maksimize edilecek, böylece güneşten yüke optimal güç dönüşümünü sağlanacaktır. Hedef, MPPT algoritmasını optimize ederek güneş hücrelerinin verimliliğini artırmak, minimum kesintiyle güvenilir, stabil bir elektrik tedariki sağlamaktır. Bu çalışmada, hem güneş hem de rüzgar türbini enerji kaynaklarını kapsayan bir hibrit sistemin simülasyonu yapılmıştır. Kaynaktan maksimum olası gücü verimli ve güçlü bir şekilde çıkarmak için MPPT algoritmasını kullanan bir bulanık mantık denetleyicisi sunulmuştur.

2023, 67 sayfa

Anahtar Kelimeler: Hibrit sistem, MPPT, Bulanık mantık denetleyicisi, Fotovoltaik, Enerji yönetim sistemi, Mikro şebeke

PREFACE AND ACKNOWLEDGEMENTS

Praise be to God, who has led me and given me the strength to finish my thesis for master degree. I want to thank everyone who helped me finish my thesis, and I want to say thanks to my advisor, Prof. Dr. Murat ARI and Research assistant Mahmud Esad YİĞİT. Also, many thanks to my mother, father, brothers, and spouse, who have always supported and encouraged me, even my beloved children deserve my gratitude for their constant support and good comments at difficult times. I also want to thank all of my coworkers and colleagues for always encouraging me to reach my goals and helping me to do so.

Inam Abbas Razooqi AL-SADDAEE
Çankırı-2023

CONTENTS

LIST OF SYMBOLS

K_i	Cell short circuit current temperature coefficient
T	Cell temperature
q	Charge of electrons
V	Diode voltage
I_O	Diode’s reverse saturation current
E_g	Energy band gap of the semiconductor
A	Ideality factor
$I_{PV_{STC}}$	Light generated current under standard test condition
$I_{O_{STC}}$	Nominal saturation current
G_{STC}	Nominal solar irradiation in W/m^2
I_{PV}	Photocurrent current
R_S	Series resistance
$I_{SC_{STC}}$	Short circuit current at standard test condition
R_P	Shunt resistance
T_{STC}	The te at standard test condition
V_T	Thermal voltage
G	Solar irradiation in W/m^2

LIST OF FIGURES

1. INTRODUCTION

The importance of electrical energy for social and economic growth is now well acknowledged. Unfortunately, one third of the world's population still resides in developing and transition countries without electricity (Jahid *et al.* 2018). By 2020, it is predicted that there will be 8 billion people on the planet (Farooq *et al.* 2017). The figure demonstrates that emerging countries, where the majority of people reside in rural, isolated locations, are experiencing the greatest population growth. Geographical, financial, and societal limitations make electricity grid expansion difficult and expensive. Diesel generators have traditionally been used to provide power to rural areas, but this approach has proven to be both costly and detrimental to the environment due to high fuel consumption and maintenance needs. As such, it is increasingly being viewed as an unsuitable solution. Utilizing wind, solar, and hydro power that is already present in the area is an attractive choice. Modular, scalable, and task-oriented implementation of various energy sources can supply economical and sustainable energy supplies, especially in outlying areas. It was suggested during the international engineering conference in 2000 that energy supply, distribution, and use may be improved. Many distributed hybrid power systems (HPS) have been set up across the world to realize this objective. These installations represent the fulfillment of this promise, since they represent a dramatic departure from the use of diesel generators in favor of greener and more efficient forms of power generation.

1.1 Structure of Hybrid Power System

A wind solar hybrid system is a combination of renewable energy sources, specifically wind and solar, used to generate electricity. This system utilizes small wind turbines and solar panels to produce power. To grasp the functioning of a hybrid solar and wind power system, it is important to understand how individual solar and wind power systems work. A solar power system involves the use of solar panels to generate electricity from sunlight. It is a setup that harnesses solar energy. On the other hand, a wind power system employs wind power generators and turbines to produce wind electric power. The wind turbine, which consists of two or three blades, rotates in response to the wind, with its rotation axis aligned with the wind direction. The gearbox plays a crucial role in mechanically transmitting energy between devices. There are different types of wind turbines, but the most common ones are vertical and horizontal axis turbines. Solar energy systems comprise solar photovoltaic cells, solar panels, and energy storage batteries. The solar-generated electricity, known as direct current (DC) power, can be used to power DC loads and also stored in batteries for later use with AC loads. It's worth noting that solar energy is only available during daylight hours, while wind energy is accessible throughout the day depending on weather conditions. To provide reliable electricity throughout the year, the wind solar hybrid system takes use of the synergistic relationship between the two sources of energy. The wind antenna generator and tower, photovoltaic solar panels, batteries, cables, charge controller, and inverter make up the core components of the system. AC appliances and battery packs can both benefit from the electricity produced by the wind-solar hybrid system. To take advantage of the larger wind speeds at greater heights, the Windaero generator must be installed on a tower that is at least 18 meters above the ground.

1.2 Problem Formulation

One of the most prevalent sources of alternative and renewable energy in the world, solar energy is a gift from Mother Nature. Education and research are under process and a lot of work has been completed to convert this solar energy into a usable electrical form of energy. It is observed that the Sun can transfer almost 1500 Watt/ square-meter solar irradiance on earth, but due to multiple atmospheric layers and other loss factors, only energy of about 1000 Watt/ square-meter can be obtained on earth. While designing the PV array system it is ensured that almost one meter square of PV array can convert the solar energy to 1000 watts power will be maximum efficient PV array. To create a design for the PV array solar cell structure, the various semi-conductor materials are dopped to form the PV array layers, along with protective layers for safety and maximum refraction to get an efficient design.

In order to optimize the solar power output of a photovoltaic (PV) array, various algorithms and techniques are employed to maximize its efficiency. One such algorithm is the perturbation and observation algorithm, which involves determining the previous and current states of the solar PV voltages and currents to ensure the maximum power output of the PV array. The Maximum Power Point Tracking (MPPT) technique is another method used to achieve the maximum power from the PV source. This technique relies on implementing the MPPT algorithm, the details of which will be discussed in subsequent chapters. Error and change in error signals are created in the MPPT method by continuously monitoring the solar PV voltages. The controller, which might be PI, PID, or Fuzzy Logic, receives these signals and uses them to make adjustments. Obtaining maximum power from the PV source while reducing output response oscillations, overshoot, and steady-state error is the fundamental goal of the MPPT algorithm. When the rate of change of power with respect to voltage is zero, that point is the maximum power point. When the rate of change of power relative to the varying solar output voltages equals zero, the PV system has reached its maximum power output.

1.3 Research Objective

Primarily, we have to make sure the complete modeling of the Hybrid system includes the subsystems and components of the systems with a wind turbine, solar PV array, inverters, converter, and load sections. Secondly, it is required to design the fuzzy logic controller for the Hybrid system in MATLAB. To make Simulink modeling and implement the fuzzy logic controller to the Simulink model. Make simulation-based testing and acquire the simulation results. Perform design of wind power control system and their simulation will be on MATLAB, Simulink.

1.4 Methodology

In this section, the focus will be on, Introduction to MPPT, and the study of different techniques for MPPT. Modeling and Implementation of Solar system with MPPT control. Simulation based Testing. Data acquisition, Results, and outcomes. Observations for expected outcomes and results.

1.5 Structure of the Work

This thesis is organized as follows:

In the second chapter a brief description of the stability in terms of voltage and frequency, between a conventional network and a remote network made up of renewable energy sources. Giving a general overview of Nepal, the availability of electricity, and the advancement of energy systems based on renewable energy sources are the goals of Chapter 3. Chapter 4 is significant in this paper because all the power transformers for HPS small hydroelectric power stations technical details are provided for a wind turbine generator made up of an induction generator, a battery system, and a diesel generator made up of a synchronous generator with a tank. They are modeled using equations in mathematics. They are modeled using equations in mathematics. The behavior of all the mentioned transducers is explained in detail. Chapter 5's main focus is on how to combine various simulation transducer models to create HPS. The newly developed monitoring strategy to discover the optimal power transmission pattern based on online inputs obtained from the environment, reservoir and network frequency is described in detail. The development platform is the Matlab/Simulink software. The designed HPS has been tested under various weather scenarios and with varying river water levels, enabling the observation of the diesel generator set's on and off behavior. Achieving energy balance in the isolated network (i.e., maintenance of frequency and voltage) is described. In chapter 6, the different transducers are validated Make comparisons between the results of experiments and simulations. Chapter 7 explains the development of a hardware-based PEM. The gadget was created in a way that it functions similarly to Simulink.

2. LITERATURE REVIEW

For thousands of years, humans have used water pumping and wind as a source of navigation and irrigation. As far back as 5,000 years BC, people used wind power to drive boats along the Nile River. By 200 BC, people in Persia and China were pumping water and grinding grain with wooden wind-driven water mills. The trend and use of small wind turbines began to fade when power lines were built to carry electricity, and they remained limited to rural regions. New means of exploiting wind energy as a stable and commercial power source emerged in the 1990s (Jahid *et al.* 2018). In 1903, the Wright Brothers succeeded in creating the first aeroplane. The introduction of the areophane sparked the concept of commercial onshore wind turbines (Jahid *et al.* 2018). In this chapter, a set of literature survey will be presented regarding the topic of thesis.

Jahid *et al.* (2018) presented that the data-oriented servings including multimedia communication and online gaming as well as HD video streaming over cellular networks that have evolved safely in the past five years. Mobile network providers have had to extend their base station network to keep up with the ever-increasing volume of data and customers (BSs). Today, there are more than four million bachelor's degrees in existence worldwide.

In a study conducted by (Farooq *et al.* 2017), it was highlighted that the energy consumption of mobile networks has experienced a significant increase. These networks alone account for approximately 57% of the total energy consumption in the mobile communication industry. This surge in energy consumption has resulted in a substantial rise in operating costs (OPEX) for cellular networks, primarily attributed to high power bills. In fact, the energy usage of cellular networks accounted for over $22 billion of OPEX in 2014. Cellular service providers are constantly increasing network coverage to embrace rural areas globally to solve this problem and attract a wider client base. They are also looking at other areas and services that may bring in another billion customers. However, physical and economic hurdles have slowed progress in electrifying these remote communities. Because of this, cellular network operators in these unserved areas have had to resort to using diesel generators to power their base stations. Due to the lack of grid-based energy in rural locations, cellular network providers must rely on diesel generators as shown in Figure 2.1 and Figure 2.2. Due to the continuous expenditures and maintenance requirements of diesel generators, this condition has put a financial strain on the operators. Sustainable and inexpensive options to powering these outlying base stations are now being explored.

Jahid *et al.* (2018) presented that a feasible alternative for those network organizations looking to expand and serve additional clients is not to run their back-end systems off of distributed generation (DG).

Operators of cellular networks strive to make their networks more energy-efficient to keep their businesses profitable while also reducing their impact on the environment. Mobile networks are a major source of greenhouse gas emissions (GHG). By 2020, the mobile sector's carbon dioxide emissions will amount to 179 million tons, or 51% of the entire ICT industry's carbon footprint

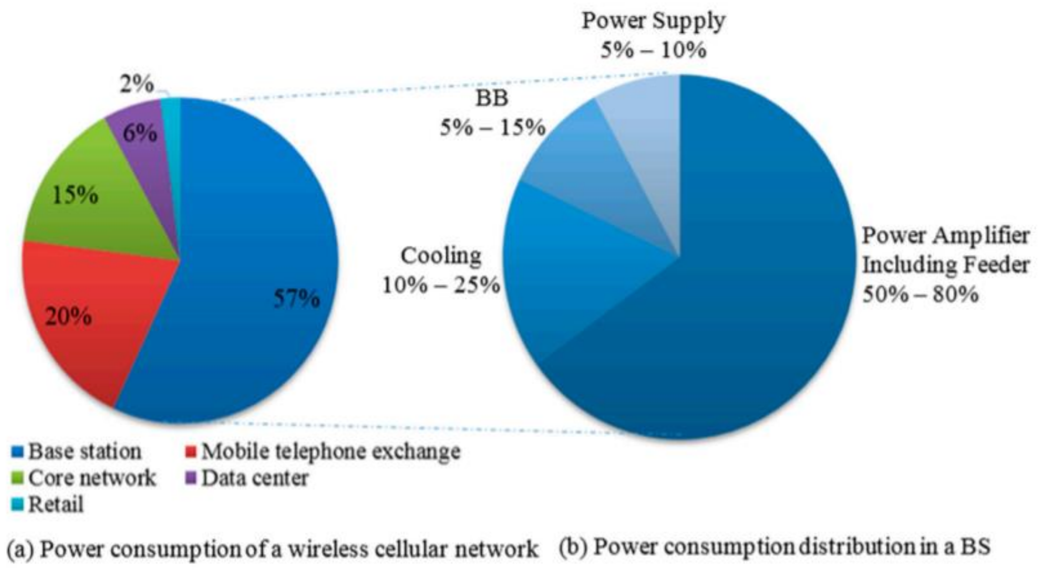


Figure 2.1 Component breakdown and bachelor's degree in energy consumption for a cellular network (Hasan *et al.* 2011)

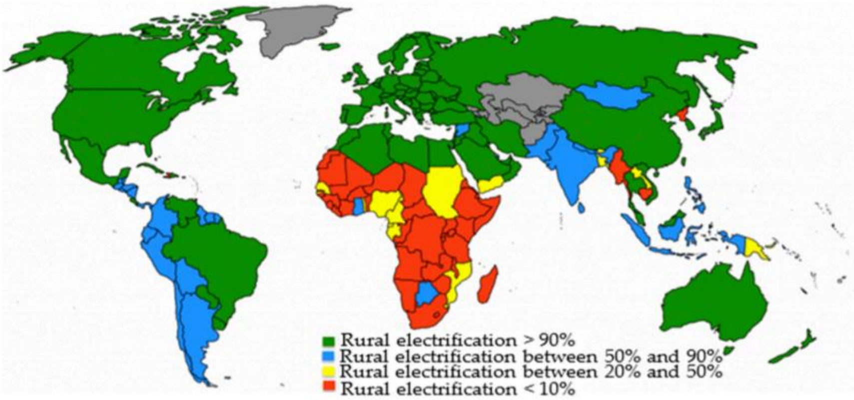


Figure 2.2 Progress in rural electrification across the world

Kanwal *et al.* (2017) presented that as a result, cellular network operators are under pressure to fulfill environmental conservation and OPEX reduction requirements. Researchers, vendors, and mobile service providers have a challenge for improving the energy efficiency of (cellular networks) due to the expected economic and environmental impact in the next few years. Because of this, a new field of study called "green communication" has just been developed. The major goal of the green-communication project is increasing the energy efficiency of BSs, decrease OPEX, and eliminate GHG emissions. First and foremost, cellular network operators are attempting to implement green practices in two key ways. Energy-efficient hardware is used in the first strategy to lower BSs energy depletion at the equipment level and to provide these stations with low-cost power sources.

Aris *et al.* (2015) presented that Network resources might be wasted if they are not utilized effectively. That's why the second technique promotes network components to be regulated according to traffic load variation. According to this study, BSs powered by renewable energy sources provide long-term benefits for the cellular industry.

In other study, (Safwat *et al.* 2018) delved into several areas of investigation pertinent to renewable energy solutions for mobile base stations. They not only proposed research recommendations but also scrutinized relevant literature. The study further assessed the potential for renewable capacity solutions and identified prospective geographic locations suited for renewable energy-powered base stations. There was a specific focus on case studies concerning the application of renewable energy in various open issues, which included fuel cells, mobile grids, solar panel systems, and wind turbines. They also discussed the current status of the deployment of renewable energy base stations.

Ismail *et al.* (2014) presented that throughout the previous decade, we've seen programs like EARTH, eWIN, OPERA-Net, and Green Radio. New energy-efficient technology, deployment methodologies, and network management solutions were the goals of the successful EARTH project. Cellular networks' energy efficiency has been the subject of several types of research over the previous decade. In two ways, the environmental and financial impact of BSs may be minimized. Energy-efficient hardware may, first and foremost, reduce the amount of energy used by BSs and, second, make it easier for BSs to switch to renewable energy systems (RESs) as their primary power sources.

Jahid *et al.* (2018), demonstrated that network elements could be efficiently controlled considering two facets: (a) network operation and management, and (b) network planning deployment, both sensitive to the oscillations in traffic load.

As we progress into an era where internet access and wireless devices become more affordable and readily available, a surge in mobile user numbers and their subsequent data traffic is foreseeable. Such growth is posing significant challenges to existing ICT networks which are grappling with escalating energy consumption driven by the ever-growing traffic volumes. This surge in energy usage can be linked back to the proliferation of wireless devices and their accompanying applications.

Dutta *et al.* (2015) presented that global mobile traffic is expected to expand by 45 percent per year to 69 exabytes per month by 2020, according to current estimates. As a result, the worldwide telecommunications sector's annual power usage has climbed from 219 Tira watt per hour in 2007 to 354 Tira watt per hour in 2012, a 10% yearly growth rate. There will be a ten percent yearly rise in energy usage between 2013 and 2018 under this scenario.

Abrol *et al.* (2016) presented that if the appropriate measures are not implemented, the ICT industry might consume up to 51% of global power in 2030 as a result of the rapid growth and upgrade of cellular infrastructure throughout the world.

Bousia *et al.* (2016) presented that as a result, the telecom business has been cited as the most energy intensive consumer of the ICT department, it is responsible for higher greenhouse gas emissions and operating costs (OPEX). Global warming pollution has been linked to 2.5 to 4% of all carbon dioxide emissions from the telecommunications industry, a figure that has been generally acknowledged. Wireless carriers are under growing pressure to cut their energy use as demand for ICT services decreases throughout the world.

According to (Carvalho *et al.* 2016) highlighted the strain that current energy consumption practices put on the electrical grid, impacting the economy adversely. They asserted that energy efficiency (EE) is paramount for cellular carriers to curb high costs and carbon emissions, while preserving their operational scale and ensuring the quality of service (QoS). As the expansion of commercial networks and deployment of diesel generators (DGs) are becoming less desirable due to reliability issues, high operational costs, and environmental concerns, alternatives are being sought. Rural base stations (BSs), typically powered by DGs due to unreliable or non-existent commercial grids, exemplify this.

The disadvantages of employing DGs to power the BSs were discussed by (Alsharoa *et al.* 2015). Problems with traditional energy sources like coal, oil, and natural gas, such as decreased efficiency, frequent operating and maintenance expenses, and environmental and health dangers related with acid rain and global warming, make DGs less enticing. As a result of issues like these, it is expected that the demand for environmentally friendly cellular communications would rise dramatically in the near future.

Focusing on green technology, (Alsharif *et al.* 2015), underscored the environmental, economic, and energy dimensions. They suggested the goal of green communications is to reduce operational expenses (OPEX), eliminate greenhouse gas emissions, diminish reliance on external energy suppliers, and facilitate lower energy prices. They pointed to energy harvesting (EH) technology as a means to utilize renewable energy from readily available ambient sources, such as sun, wind, biogas, and others, within green wireless networking.

Gandotra *et al.* (2017), emphasized the increasing rate of energy consumption in the ICT industry. They argue for the need to replace fossil fuels with non-polluting, sustainable, and cost-effective renewable energy sources. They outlined the difficulties and high costs associated with transporting nonrenewable energy sources to remote base stations, given the challenges of distance and harsh terrains.

Chamola *et al.* (2016) presented that Renewable energy generated close to home is the most cost-effective way to power BSs in remote locations. However, developing a viable renewable-based power generating system for distant places is complicated by the extremely dynamic nature of the availability of sources, which can change at any given moment. Mismatches between the amount of energy harvested and BS load fluctuations can lead to power outages and decreased service quality.

Hassan *et al.* (2015) presented that Next-generation cellular networks' base stations are built to run on hybrid power, which might improve the network's overall efficiency in the long term. The dependability and quality of services (QoS) of green cell networks can be improved by the use of a variety of renewable energy resources. It is possible to mitigate the growing energy problem and shortfall in commercial grid supply by integrating PV and wind power at the site. Constrained area for RE harvestings on-site, such as the installation of enough solar panels, wind turbines, hardly surrounded by renewable energy outputs. To improve cellular network energy efficiency (EE), researchers have been looking into ways to share energy among numerous collocated BSs via a smart grid or external physical power cables. Resistance power lines aren't practical or economically feasible for large cellular networks. This technology is not suitable for long-distance communication lines because of the high installation costs, enormous resistive power losses, and the correct way of limiting.

Chia *et al.* (2014) presented that Using physical cabling to connect BSs in local zones may be a viable option for exchanging energy. For long-distance communication, the use of smart grid infrastructure rather than external physical lines is becoming more commonplace. Furthermore, because electricity lines are permanent, extra care and attention must be paid to them during installation.

Ghazzai *et al.* (2016) presented that as long as there is enough locally generated renewable energy (RE) to cover its own energy needs, it is useful to collaborate with BSs to distribute surplus energy from its storage.

Due to the tremendous rise in energy consumption and the finite supply of fossil fuels, eco-sustainability has recently attracted substantial attention. Reduced energy costs and increasing awareness of global climate change have sparked interest in green cellular communication, which has gained traction in both urban and rural regions alike. Several studies are now being undertaken on the deployment of renewable energy sources such as photovoltaic solar panels in the RAN infrastructure. New solar-powered cellular base stations are described in detail by researchers.

Zhang *et al.* (2017) presented that current implementation and operating issues with these base stations are also addressed, along with a few key solution options. Researchers have developed a heuristic approach for determining the most cost-effective option for a solar PV-powered LTE microcell base station.

The feasibility of a self-sustaining Heterogeneous Grid Cell Solar Power System was examined by (Alsharif *et al.* 2017), with particular attention paid to the specifics of solar radiation exposure in South Korea. They hypothesized that energy efficiency (EE) and average on-grid demand may be greatly improved by combining base station (BS) sleep mode with renewable energy sources even without hardware changes.However, the volume of vehicle traffic and the unpredictability of solar energy sources are not taken into account in this work. While there are many advantages to using renewable energy, there are also some disadvantages. These include power losses during conversion and storage, transient loads, and the possibility of natural catastrophes causing system instability. The development of hybrid energy sources, however, has made it possible for Long-Term Evolution (LTE) base stations to make use of renewable energy, which is a major step forward in the movement towards greener technology.

Gong *et al.* (2014) presented that the use of solar PV/WT hybrid technology to power far-flung LTE base stations can cut down operational costs. The results of this investigation, however, show that BS does not meet the criteria for a realistically high arrival volume. A greedy algorithm based on tempo-spatial properties is proposed by the authors as a way to reduce traditional grid energy. For macro-BSs, researchers examined the viability of a combination PV/DG/Battery power supply solution to maximize green energy use. It has been thoroughly studied in terms of optimal system design, energy consumption, and carbon footprints for the homogenous networks covered. Only renewable energy generated at the site can meet the site's needs, and BS will never compromise its performance in return for sharing green energy. As a result, radio access network (RAN) base station (BS) energy usage might be particularly inefficient during low or off-traffic hours.

Alsharif *et al.* (2016) presented that a simple method for reducing power consumption in cellular networks is to modify transceiver transmission power in line with traffic volume. An algorithm that relies on sleep mode is less effective when the traffic load is high since it doesn't have the ability to turn off redundant BSs during off-peak hours. A hybrid-power LTE network is examined in this study, which includes aspects such as long-term reliability and technological optimization in energy management. In Patenga, where there is a lot of sunshine and wind, it is conceivable to employ renewable energy sources as an inexpensive and efficient alternative to traditional supply.

Chiang *et al.* (2016) presented that Methods have been developed to evaluate the potential of local renewable energies and study areas' need for electricity, allowing for energy sharing mechanisms.

To avoid service disruptions in the cellular mobile industry, power sources must be ecologically, economically, and socially sustainable. In terms of cost-effectiveness, efficiency, sustainability, and reliability, renewable energy advances can match the objectives of BSs. Off-grid and developed countries beset by power disruptions can benefit from this long-term solution. It takes more energy to run BSs in cellular networks. Small coverage regions and very erratic traffic patterns have emerged from intensive BS deployments, which necessitates the use of sleep mode.

Energy may be conserved by keeping track of network activity and deciding whether or not to switch on or off certain network components as needed. In a wide range of investigations, protected regions, signal conversion units, cooling equipment, a full BS, a whole network, etc, sleep and active modes are frequently used. When enough BSS nodes are in place, the network's core operations can continue to run smoothly. Hardware modifications are not required to assess and deploy sleep mode solutions because of the existing design of BSs.

Jahid *et al.* (2017a) pointed out potential drawbacks when network elements are frequently activated and deactivated. These actions could result in a diminished radio coverage and quality of service (QoS) of the network. Some base stations (BSs) may be unable to be turned off during peak traffic times, rendering the sleep mode algorithm useless. Several previous methods have been investigated and analyzed; these include energy management in isolated cellular networks and multi-radio access technology with an on/off mode. In low-traffic conditions, the researchers advise turning down one or more BSs to allow for many networks, or even the same network, to cover the same physical area.

When the UE gets closer to the base station, data rates and transmit power might increase while transmitting power decreases. Heterogeneous networks (HetNet), small cells, and user-cooperative relay systems all help UE and increase energy efficiency by shortening the distance between them BSS. HetNet deployments, on the other hand, have dominated the contemporary research scene (multilayer network).

Micro, Pico, and other tiny cells serve low-mobility users in a Heterogeneous Network (HetNet), whereas macro base stations (BSs) link and service high-mobility users. In this configuration, the transmit power, range, power consumption, access, reconnection, and operating procedures of each BS type are different. Due to their low transmission power, high data rate, and low power consumption, tiny cell BSs may be used to increase network capacity and minimize energy usage. Over 40,000 tiny cells were deployed in 2015, and that figure is expected to grow with the introduction of 5G technology, they said. It is predicted that four times as many 5G tiny cells would be required to cover the same coverage area. By 2020, they predicted, tiny cells will increase energy consumption in typical macrocell networks by 5%, using an extra 4.4 TWh of power.

Oviroh *et al.* (2018) presented that it is possible to enhance by reducing the number of small cell BS stations and optimizing energy efficiency, it is possible to improve spectral efficiency and reduce radio interference from surrounding cells. As a result, earlier research has focused on the following concerns: Optimizing small cell layouts that sit on top of larger cells (macro-cells) and establishing Energy models for both large and small cell BS. In micro-BSs with high user density, the power model reacts to traffic load changes to increase energy efficiency.

Macro and micro-BS models are studied in this study. In combination with other network design elements, micro-BSs may save a large amount of power and traffic capacity. Micro BSs Analyzing the average number of microsites per macrocell, the average Cell size, changes in the number of small and large sites can be improved the network's cell structure. Small cell BS installations can save a significant amount of energy by employing sleep mode techniques. Transceivers may be turned on and off in response to variations in traffic demand, which reduces energy usage while still ensuring energy efficiency in a dispersed traffic environment. Micro and macro-BSs have been studied to see if they should be introduced to get the optimal density of BSs while keeping Quality of Service in mind. As a result of the increased traffic, interior interference, and resource management that come with deploying small cell BSs in sleep mode, several practical issues must be addressed.

Saini *et al.* (2014) presented that when millimeter wave (mmWave) frequencies are incorporated in 5G systems, the switch-off approach for tiny cells in 5G can of interest to researchers, suppliers and mobile service providers. Moreover, several methods have been considered. Some of the most popular distributed antenna system (DAS) designs have been designed to increase the cellular network's spectrum efficiency, coverage uniformity, and energy efficiency. The PA is the BS' largest energy user.

In order to attain high energy efficiency, (Hossain *et al.* 2018) emphasized the significance of reevaluating the design and use of mobile communications technology. They choose base station (BS) sleep mode solutions to reduce the overall energy consumption of cellular networks due to their low deployment costs and absence of equipment modification requirements. Their suggestion is that hardware like power amplifiers (PAs), signal processing units (SPUs), cooling equipment, or even the whole broadcast system, should only be "activated and communicated" when necessary. This is especially effective for low-traffic cellular networks. However, they cautioned that there are some situations in which sleep mode-based algorithms would not perform effectively, such as when numerous BSs can't be switched off due to high traffic demand. One strategy that has been suggested is to power BSs with renewable energy sources that are accessible, affordable, and capable of supplying the power needs of cellular networks during peak hours. The experts pointed out that despite these energy sources' benefits, their supply is usually inconsistent.

Jahid *et al.* (2017b) presented that Non-renewable energy sources, such as batteries, must be connected to renewable energy systems (DG or grid backup power) to ensure supply, increase system dependability, or avoid mobile service disruptions. A wide variety of renewable resources (such as sunlight, wind, and rain) may be found in a wide variety of locales, and these resources can be harnessed to provide renewable energy. In the cellular communications industry, renewable energy sources such as solar and wind are used often since they are available in a wide range of countries. Renewable energy sources like solar and wind may become more commonplace in rural and isolated locations and developing countries over the next several decades.

Holtkamp *et al.* (2013) presented that directly from the renewable or non-renewable energy source is supplied into the cellular battery system (BS), which can be autonomous or hybrid in design. Renewable energy sources, such as solar radiation and wind speed, are essential to creating the optimal renewable energy design. It is because of this that the supply of these resources might be unpredictable and unreliable.

Jahid *et al.* (2018) Provided that renewable energy systems must be combined with non-renewable energy sources (such as DG or grid backup power) and/or energy storage (batteries) to secure power supplies, enhance system reliability, and reduce mobile outages. When the RES fails, when the BS demands more power than the RES can provide, or when the batteries are fully discharged, the backup DG powers the cellular BS (DOD).

3. MATERIALS AND METHODS

Continuous power supply for the end-users is ensured by hybrid power systems (HPS). These systems combine several energy sources, including battery backup as well as wind and diesel, solar PV and diesel, wind PV, and wind-photovoltaic-diesel. In this thesis, a hybrid system (photovoltaic- wind) will be used.

3.1 Solar Photovoltaic Systems

Solar energy is mostly converted into electricity via photovoltaic (PV) systems. It is utilized by numerous industries worldwide. One of the renewable energy sources with the highest growth over the past ten years is solar electricity. When it comes to installation, cost, and the environment, PV has several significant qualities. It is appropriate for boosting the capacity of electricity utilities as well as for residential, commercial, industrial, and other regions. Additionally, because it depends on sunshine, it is benign and has little impact on the environment. Furthermore, since a PV system has no moving parts that could break, installing one is not difficult. The PV system is so beneficial in many businesses due to these advantages. The efficiency of the PV cell is significantly influenced by temperature, and as temperature rises, so does the short circuit current (Jahid *et al.* 2016).

3.1.1 PV output characteristics

The relationship between current and output voltage on a typical I-V characteristic curve of a solar cell summarizes the main electrical properties of a photovoltaic cell or module. The amount of solar radiation (insolation) that strikes the cell determines how much current (I) flows through it, whereas an increase in the solar cell's temperature lowers its voltage (V).

We may make I-V curves of a solar cell to show current versus voltage for a photovoltaic device because solar cells generate direct electrical current (DC) and current voltage equals power.

Characteristics of I-V Solar Cells the relation between voltage and current under current conditions of temperature and irradiation is compiled up in the curves, which are mainly a graphical representation of the operation of a solar cell or module. I-V curves provide the knowledge needed to create a solar system that can operate as close to the ideal power point (MPP) as possible (Figure 3.1).

The current-voltage (I-V) characteristics of a typical silicon photovoltaic cell operating under a given condition are shown in the above diagram. The output voltage and current of a single solar cell or solar panel is what determines how much power it can produce (I x V). For a specific radiation intensity, the power curve above can be derived by multiplying all voltages, from short-circuit to open-circuit, point for point.

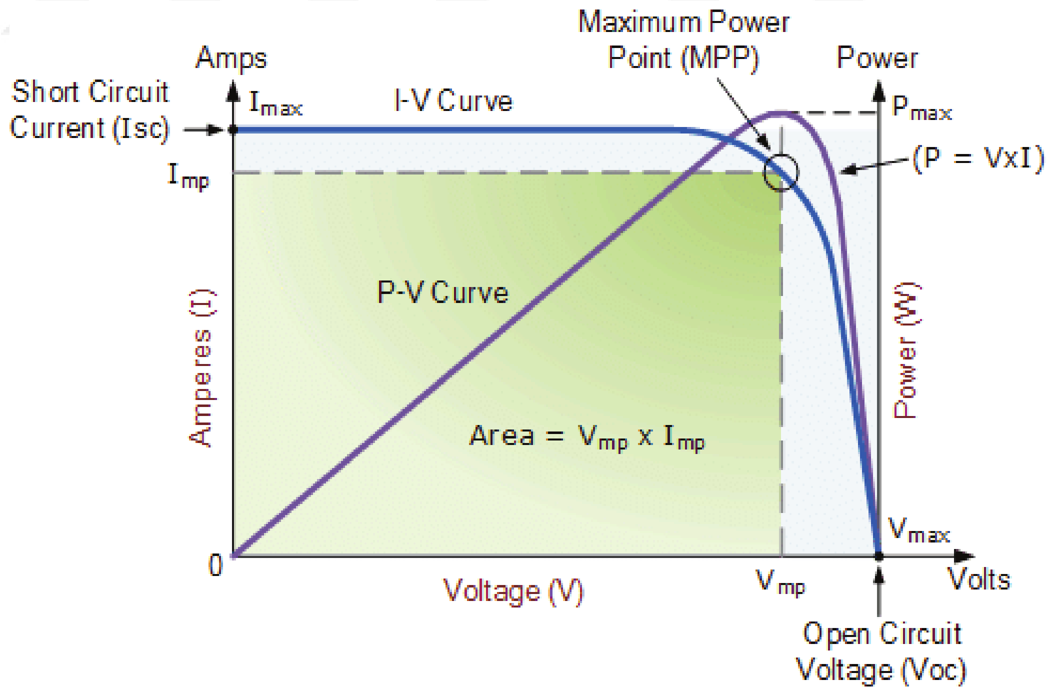


Figure 3.1 AC Single Diode Model representation of solar cell

3.1.2 Modeling of PV system

The solar cell is the essential component of a PV power system. However, it is rarely used by itself since it cannot supply an electrical equipment with significant voltage and power. To get the highest voltage and production of power possible, several photovoltaic cells are connected in parallel or in series. Cells linked in series raise the output voltage while those connected in parallel increase the current. The solar panel or array is made up of a number of electrically connected modules that work in series and parallel to produce the necessary current and voltage, and subsequently the power.

In a photovoltaic power system, semiconductors that exhibit the photovoltaic effect are used to direct current electricity is produced by converting sun energy. Solar panels with a number of cells each containing a semiconducting substance are used to generate PV electricity. It produces electricity as long as light is shining on the solar cells. Electricity quits when the light goes out.

Silicon, the semiconductor material that is currently one of the elements of PV cells that is most often employed in the semiconductor sector. In essence, the semiconductor material absorbs some of the light that enters the cell. Electrons in semiconductors become free to flow when energy knocks them loose. In PV cells, one or more electric fields work to guide the flow of liberated electrons caused by light absorption. The current created by the electron flow can be used externally by adding metal connections to the PV cell's top and bottom. This current and the cell's voltage together define how much electricity, in Watts, a solar cell can produce, which results from its internal electric field or fields (Aris and Shabani 2015).

A photovoltaic array is nothing more than the serial or parallel connecting of several PV modules Figure 3.2. In order to satisfy the load need, because the power provided by individual modules might not be enough to meet the demands of trading applications, the modules are secured in a grid or as an array. In an array, the modules are connected similarly to how a module's cells are connected. The modules are frequently initially connected in serial fashion when building a PV array to achieve the desired voltage before being joined in parallel to provide more current as needed.

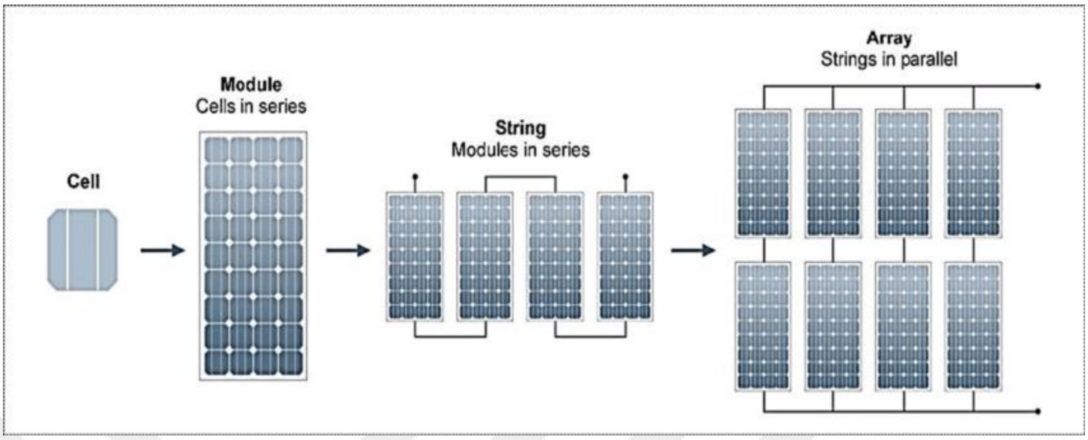


Figure 3.2 Configuration of cell, module and array (Holtkamp *et al.* 2013)

The PV array is a stationary piece of equipment that can be installed in a specific location to collect sunlight and turn it into power. When the sun is perpendicular to the PV array, the quantity of irradiance received by the array is at its highest. Nevertheless, as the seasons and the day progress, the sun's position in relation to the earth changes. There can therefore be no direction in which the PV array will receive the most irradiation. The solar azimuth and solar altitude can be used to describe the sun's position. While solar altitude denotes the angle of the sun with respect to the horizon of the earth, where the north corresponds to an angle of zero degrees and grows clockwise, solar azimuth denotes the angle along the horizon (Kanwal *et al.* 2017). When considering time and day of the year for a specific location, solar altitude and solar azimuth alter. Additionally, solar constant denotes the average pace at which radiant energy from the sun is received on earth. The solar constant can be written as follows equations for any day of the year.

The photovoltaic system uses sunlight to transform it directly into power without harming the environment. PV cells, which are merely basic p-n junction devices, make up the foundation of a PV array. The corresponding circuit of a PV cell is shown in Figure 3.3 (Jahid *et al.* 2018).

A current source (photocurrent), a diode in parallel with it, a resistor in series to represent an internal resistance to the passage of current, and a shunt resistance to represent a leakage current are the elements of an analogous circuit. We can specify the current that is sent to the load as in Equation (3.1).

$$\boldsymbol{I = I_{PV} - I_O\left[exp\left(\frac{V+IR_S}{aV_T}\right) - 1\right] - \left(\frac{V+IR_S}{R_P}\right)} \quad (3.1)$$

Where: Io Reverse Saturation Current, IPV Photocurrent, and V the diode's voltage across a criterion of ideality, Rs series resistance, V T thermal voltage, and Rp shunt resistance.

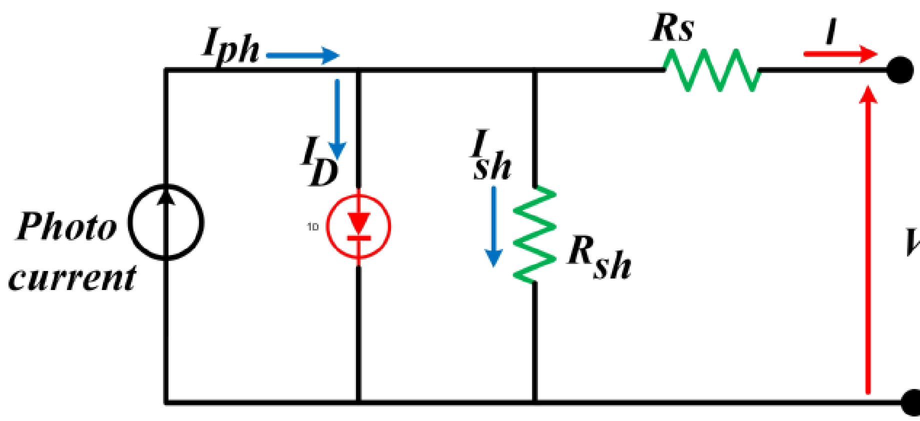


Figure 3.3 AC Single Diode Model representation of solar cell

The photocurrent of a PV cell, which is influenced by temperature and radiation, can be written as in Equation (3.2).

$$I_{PV} = \left(I_{PV\_STC} + K_i\Delta T\right)\frac{G}{G_{STC}} \quad (3.2)$$

Where K_i Cell's short circuit current temperature coefficient, G Solar irradiation in W/m2, T Cell'stemperature, G_{STC} Nominal solar irradiation in W/m2, $\boldsymbol{I_{PV\_STC}}$ Light generated current under standard test condition.

According to the cubic function of temperature, the reverse saturation current varies as in Equation (3.3).

$$I_O = I_{O\_STC} \left(\frac{T_{STC}}{T}\right)^3 exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \quad (3.3)$$

Where: I_{O_STC} current nominal saturation, E_g the power bandgap of semiconductors, T_{STC} the temperature in the standard test condition, Q Electrons charge.

As a function of temperature, as indicated in Equation (3.4), the reverse saturation current may be improved even more.

$$I_O = \frac{(I_{SC\_STC}+K_i\Delta T)}{exp\left[\frac{(V_{OC\_STC}+K_V\Delta T)}{aV_T}\right]-1} \quad (3.4)$$

Where: I_{SC_STC} Short circuit current at standard test condition, V_{OC_STC} Open circuit voltage at standard test condition, K_V Temperature coefficient of open circuit voltage

For greater accuracy and for a variety of goals, many authors suggested more sophisticated models. Some versions include an extra diode to represent the outcome of the recombination of carriers. Additionally, other writers used three-diode models. That took into account influences from various additional variables not before taken into account. However, we utilize a single diode model for our work because it is simpler.

The variation in series resistance Rs has a much greater impact on a PV cell's efficiency than it does on the cell's fluctuation in shunt resistance Rp. It can be expected that Rp will be an enormous a tiny leakage current to ground value since the R of the cell is inversely proportional to the leakage current transformed in the drop.

In order to meet our desired need, we used a combination of photovoltaic cells because the total power generated by a single photovoltaic cell is relatively low. The term "PV array" refers to this PV cell grid. The PV array's Equations (3.5) for Figure 3.4.

$$I = I_{PV}N_P - I_O N_P \left[exp\left(\frac{V+IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S}\right) - 1\right] - \left[\frac{V+IR_S\left(\frac{N_S}{NP}\right)}{R_P\left(\frac{N_S}{NP}\right)}\right] \tag{3.5}$$

Where: N_S The number of cells of the series, N_P Parallel cell count.

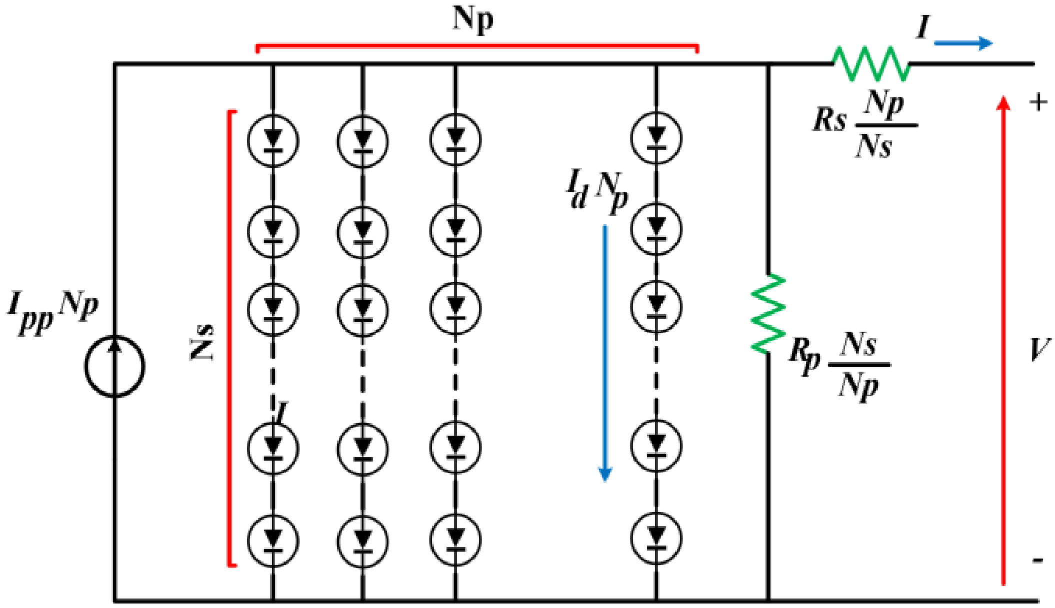
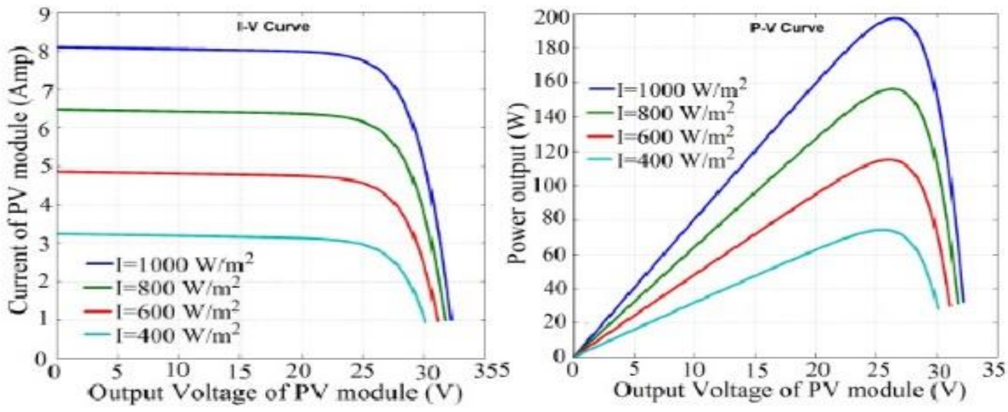


Figure 3.4 Representation of photovoltaic module

PV cell efficiency can be more significantly impacted by a modest variation in series resistance than by a variation in shunt resistance. Shunt resistance is taken to be infinite and can be viewed as open for extremely low leakage currents to the ground. After taking into account Equation (3.6) may be used to represent the model's mathematical equation, which is shunt resistance infinite.

$$I = I_{PV}N_P - I_O N_P \left[exp\left(\frac{V+IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S}\right) - 1\right] \tag{3.6}$$

Figure 3.5 shows the characteristics of I-V and P-V photovoltaic modules.



(a) (b)

Figure 3.5 PV module's: a) I-V characteristics curve and b) P-V characteristics curve (Jahid *et al.* 2018)

The cell open circuit voltage V and the cell short circuit current Isc are the two primary variables that are used to communicate electrical performance.

The maximum power is in Equation (3.7).

$$P_{max} = V_{max} I_{max} \tag{3.7}$$

3.1.3 Maximum power point tracking MPPT

Maximum Power Point Tracking, or MPPT, is an unrivaled technology that you can use in an assortment of situations to improve power production from turbines and PV solar modules. The MPPT controller can track the maximum current and voltage (VI) and disclose the voltage generated by solar panels in real-time so that the battery can be charged at the fastest rate possible. To coordinate with solar panels, batteries and workloads, MPPT can be used in photovoltaic converters.

Many people are unclear regarding MPPT In fact, Maximum PowerPoint Tracking controls the state of the electrical unit to store more energy in batteries effectively. The use of MPPT can efficiently address the issue of conventional power usage in rural and tourist areas without contributing to pollution.

The MPPT controller's operating voltage and the output power of PV cells are connected; a PV cell can only provide its maximum output when running at the best voltage.

Figure 3.6 represents an application around the MPPT for a set of readings.

Sunshine intensity=1000W / m, U = 24V, I = 1A; U = 30V, I = 0.9A; U = 36V, I = 0.7A; Outputs maximum power when u=30.

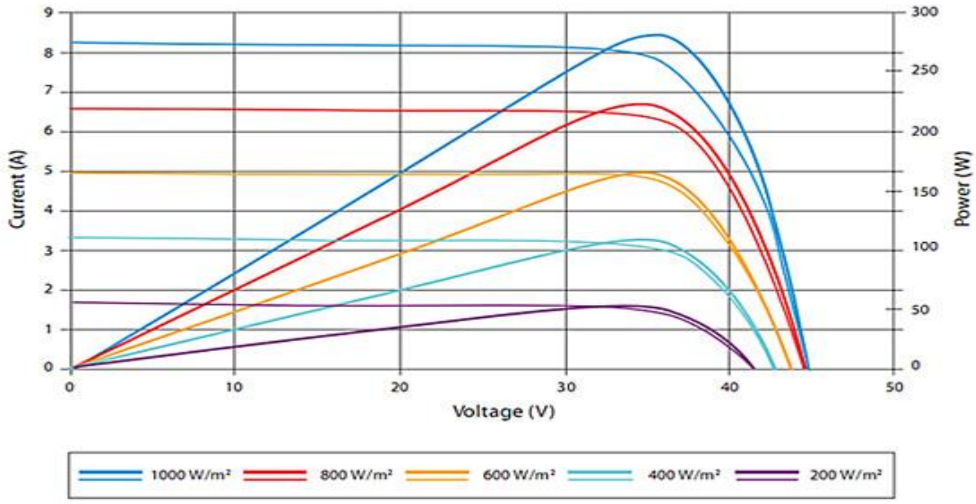


Figure 3.6 MPPT characteristics curve

1. MPPT techniques (perturb and observe, hill climbing)

The proposed Perturb and Observe algorithm is a modification to the traditional technique that constricts the algorithm's search space, lowering complexity and enhancing the traditional algorithm's performance in both constant and variable weather circumstances (Figure 3.7).

The main propertease of the Perturb and observe techniques:

1. The P&O approach works by adjusting the PV panel's operating voltage or current until it produces the maximum power.
2. The tracker worked by regularly increasing or decreasing solar array voltage.
3. To sense the PV array voltage, we merely utilize a voltage sensor.
4. When the environment changes quickly, the hill-climbing strategy fails.

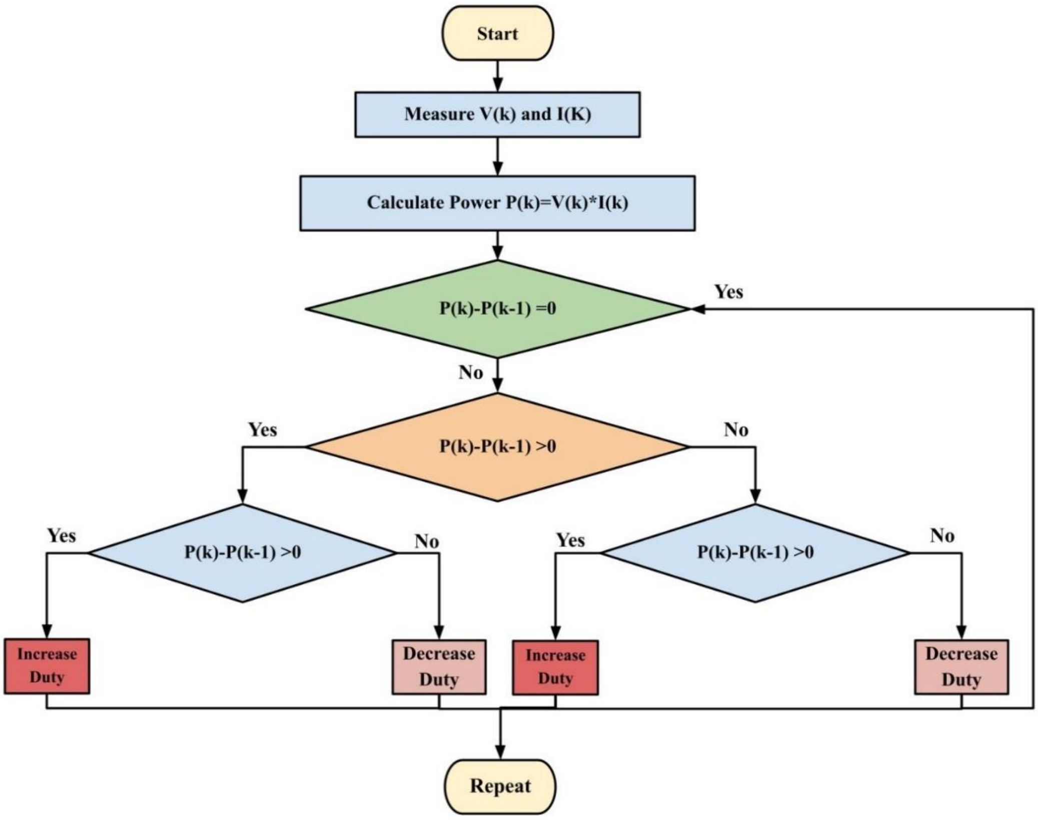


Figure 3.7 P&O algorithm flow diagram

2. Fuzzy MPPT technique

Due to its ability to manage system nonlinearity, Intelligent MPPTs with fuzzy logic have gained more popularity. Standard methods in PV are shown to be less effective for monitoring MPP than the fuzzy MPPT (FMPPT). Systems due to the lack of accurate modeling of PV modules and uncertainty in the performance of PV system due to fluctuating irradiance and temperature. FMPPT can handle uncertainty like unmodeled physical quantities, nonlinearity, and erratic fluctuations in the PV system's operational point. This MPPT technique increases the selection of the duty cycle's variable step size, which raises the photovoltaic system's performance. The idea behind this technique is to calculate the variable step in accordance with the Power-Voltage characteristic of a solar module's slope value. The right duty cycle value is then provided.

The three functional building blocks are fuzzification, rule inference, and defuzzification. Elements that make up the fuzzy controller. In the suggested system, The FLC's output is a change in duty cycle, and its input variables are error (e) and error change (Ce). The chosen input and the chosen output variable have an impact on the fuzzy MPPT algorithm's design considerations and effectiveness. The duty ratio command is often the output variable of the FMPPT algorithm, which is used to modify the PV module's operating point in order to increase power output. The slope of the PV module's P-V curve and variations in this slope are the most often used input variables for FMPPT.

Throughout the fuzzification process, the input variables e & Ce and the output variable d are changed into linguistic variables by applying membership function values. These variables are expressed as NB (negative big), at different fuzzy levels, NS (negative small), ZE (zero), PS (positive small), and PB (positive big). In this work, triangle membership functions are taken into consideration, presuming that there is only one dominant fuzzy subset for each given input. Figure 3.8 displays the membership functions for e, Ce, and d. Heuristic defining rules are essential for modeling the FMPPT, and the fuzzy rule base a collection of if-then rules is utilized to handle fuzzified inputs. Based on experimental knowledge of the issue or PV system characteristics, fuzzy rules are discovered. The number of linguistic variables in the input Membership functions determines the number of rules. 25 fuzzy control rules are included in the study's fuzzy rules. A control output is produced by a fuzzy inference system's composition operation, which formulates a logical judgment based on fuzzy rules. In this study, the Max-Min composition operation was used in conjunction with the Mamdani fuzzy inference method (Figure 3.9).

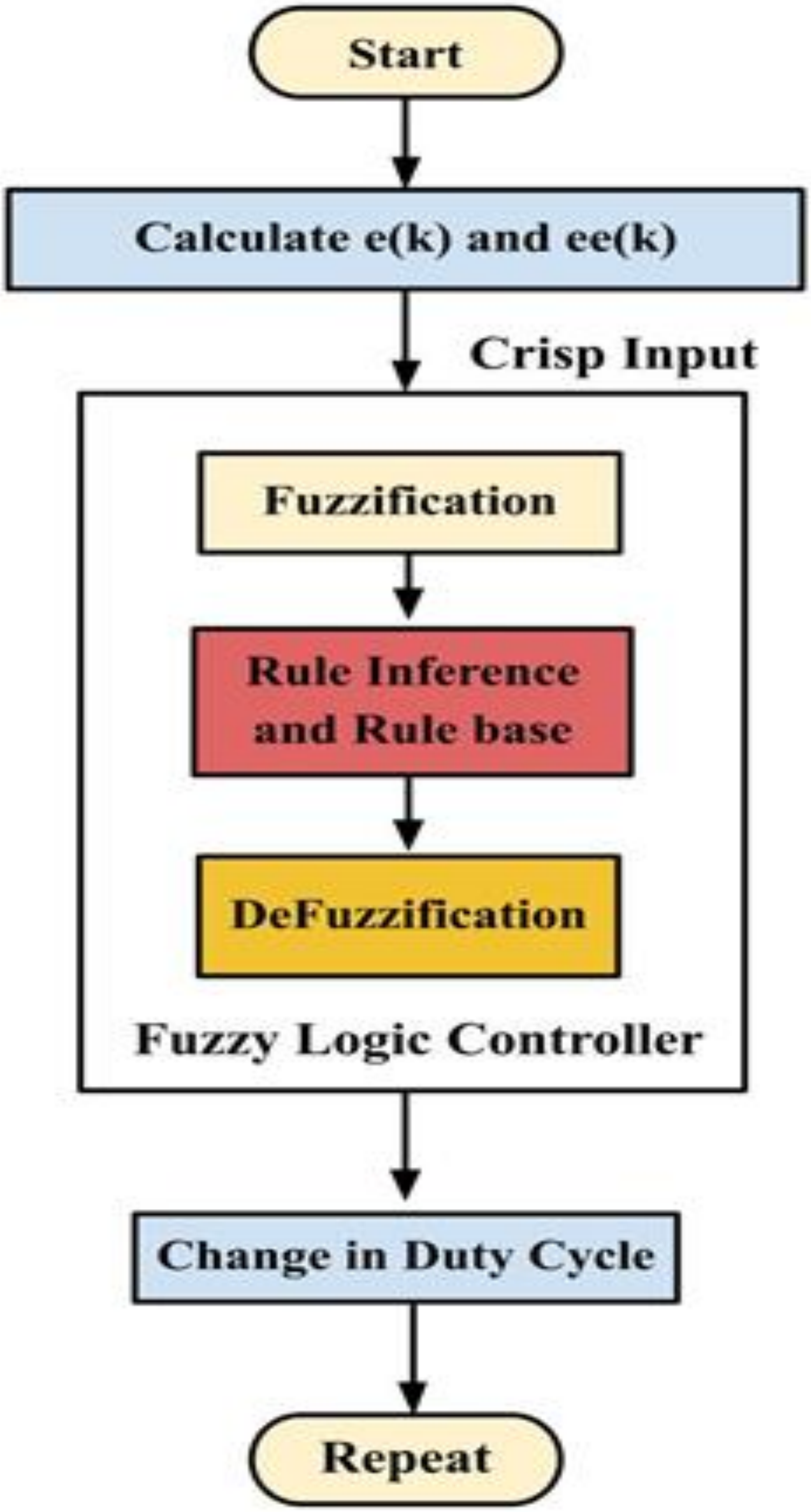


Figure 3.8 Flow chart of fuzzy logic based MPPT

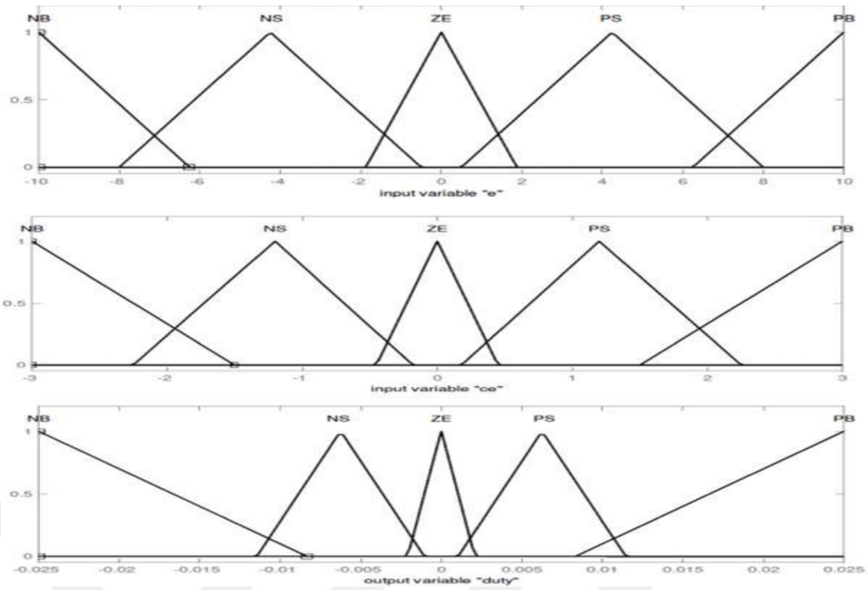


Figure 3.9 Fuzzy membership function of e, ce and Δd

3.2 Wind Energy

One of the most quickly developing renewable energy sources is wind energy. Lower prices are contributing to an increase in use worldwide. The most recent data from IRENA show that during the previous 20 years, installed wind power capacity has increased by roughly 75%, going from 7.5 gigawatts in 1997 to about 564 gigawatts in 2018. The amount of wind energy produced doubled between 2009 and 2013, and in 2016, wind energy accounted for 16% of the electricity generated by renewable sources. Strong winds can be found all throughout the world, although they usually work best for producing wind energy in isolated locations. Offshore wind power offers enormous promise.

In excess of a century ago, the first turbines were built. Engineers began experimenting with utilizing wind power to produce energy after the electric generator was created in the 1830s. However, the new wind energy is thought to have been developed In Denmark, where horizontal axis wind turbines were developed in 1891 and the 22.8-meter-long wind turbines first entered service in 1897. The United States and the United Kingdom both produced wind energy in 1887 and 1888.

Wind energy produces electricity by utilizing the kinetic energy of moving air. Using wind turbines and other wind energy conversion technology, this is converted into electrical energy. When wind first encounters a wind turbine's blades, the turbine connected to those blades begins to rotate. Kinetic energy is converted into rotational energy by rotating a shaft attached to a generator, which then uses electromagnetism to create electrical energy.

The size of the turbine and the length of its blades determine how much electricity can be generated by the wind. Both the square of the wind speed and the size of the rotor are inversely related to the output. The potential for wind energy should theoretically grow by eight when wind speed doubles.

Over time, wind turbines' capacity has increased. Turbines had rotor diameters of 15 meters and rated capacities of 0.05 megawatts on average in 1985. (MW). Modern wind energy projects use turbines with capacities ranging from 2 MW onshore to 3 MW offshore.

Rotor diameters up to 164 meters and an 8 MW capacity are features of the wind turbines that are now for sale. The typical wind turbine in 2014 has a 2 MW capacity, up from 1.6 MW in 2009.

3.2.1 Wind speed and energy

A form of solar energy is an energy of wind. Wind energy is the process of harnessing the wind to produce energy. Wind turbines use the kinetic energy of the wind to generate mechanical power. A renewable energy source that controls the overall power of the wind is wind energy. The wind turbines that transform kinetic energy into mechanical power, and from there into electricity that serves as a valuable source. Equation (3.8) provides the formula for wind energy.

$$P = \frac{1}{2}\rho A V^3 \tag{3.8}$$

Where: ρ is density of air, A is the swept area of turbine, V is the wind speed.

By the end of the day, if the breeze speed replicates, the breeze has eight times more vitality. The vitality of the wind varies with the solid form of the breeze speed.

Minor differences in wind speed have a big impact on the quantity of energy in the breeze.

3. Air density

The turbine gains greater vigour as the sky becomes thicker. With height and temperature, the thickness of the air changes. At high altitudes, the atmosphere is less dense than at sea level, and warm air is less compressed than frigid air.

4. Turbine swept area

The diameter of the spinning part of the rotor, or the cleared area, determines how much power the turbine can generate from the wind. Because the rotor's position span is the cleared zone, a little increase in edge length has a significant impact on the turbine's available power.

3.2.2 Wind power's fundamental equation

The amount of air (volume), the speed (velocity), and the mass (density) of the air moving across the area of interest determine wind power (flux). KE - Kinetic Energy expression in Equatıon (3.9)

$$Ke = \frac{1}{2}mv^2 \tag{3.9}$$

Where: m represents the mass, v represent the velocity.

Power is kinetic energy per unit time in Equation (3.10)

$$P = \frac{1}{2} m v^2 \tag{3.10}$$

According to fluid mechanics terminology as in Equation (3.11):

$$mass\ flow\ rate = density * volume\ flux \tag{3.11}$$

The mass flow rate will become Equation (3.12).

$$\frac{dm}{dt} = \rho * A * V \tag{3.12}$$

The above expression comes from the equation of continuity. States the law of conservation of mass Equation (3.13) and (3.14).

$$m' = \rho * A * V \tag{3.13}$$

$$P = \frac{1}{2} \rho A V^3 \tag{3.14}$$

Rotor swept are in Equation (3.15):

$$rotor\ wept\ area = A = \pi r^2 \tag{3.15}$$

Where: r is the radius of rotor turbine.

3.2.3 Mathematical turbine power calculations

Using kinetic energy from a fluid, such as water, steam, air, or combustion gases, a turbine is a device that transforms that energy into spinning motion. Typically, propulsion systems, engines, and electrical generation use turbines. Because they transport and manipulate energy, turbines are machines (more specifically, turbomachines). Currently, steel is one of the most often used materials for simple turbine blades. A simple turbine allows fluid to enter the turbine, pushing the blades. In order to capture some of the energy in rotational motion, these blades rotate as the fluid passes past them. All mathematical turbine power calculations will be shown in this section as in Eqautions (3.16) - (3.27)

$$E = W = Fs \tag{3.16}$$

$$F = ma \tag{3.17}$$

Hence:

$$E = mas \tag{3.18}$$

Using third equation of motion:

$$v^2 = u^2 + 2as \tag{3.19}$$

$$(v^2 - u^2)/2s \tag{3.20}$$

As initial velocity is kept as zero:

$$a = \frac{v^2}{2s} \tag{3.21}$$

Derive governing equations will be:

$$E = \frac{1}{2}mv^2 \tag{3.22}$$

The power in wind is given as:

$$P = \frac{dE}{dt} = \frac{1}{2}v^2\frac{dm}{dt} \tag{3.23}$$

$$\frac{dm}{dt} = \rho A\frac{dx}{dt} \tag{3.24}$$

$$\frac{dx}{dt} = v \tag{3.25}$$

$$\frac{dm}{dt} = \rho A v \tag{3.26}$$

$$P = \frac{1}{2}\rho A V^3 \tag{3.27}$$

3.2.4 The wind power coefficient

Albert Betz, a German scientist, concluded that no wind turbine can transform more of the wind's kinetic energy into mechanical energy than 16/27 (59.3%). This remains known as Betz's Law or the Betz Limit. The maximum theoretical energy efficiency for any wind turbine Wind turbines can only extract up to 59% of the energy carried by the wind under current design, which is 0.59 as shows in Equation (3.28) also Wind calibri (Body) shows in Figure 3.10.

$$C_{pmax} = 0.59 \tag{3.28}$$

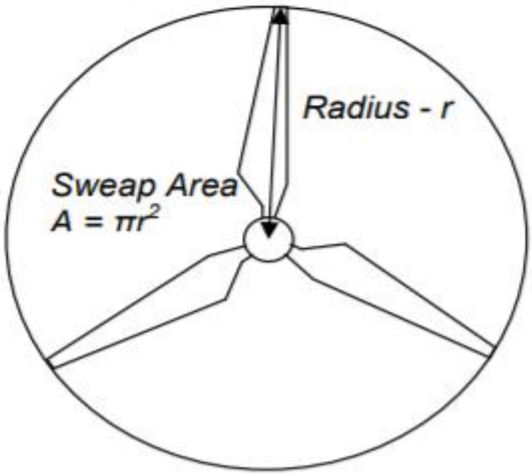


Figure 3.10 Wind calibri (body)

Calculations with given data illustrated in Equation (3.29) - (3.35)

$$Blade\ Length = 2\ m \tag{3.29}$$

$$wind\ speed = 4\ m/s \tag{3.30}$$

$$air\ density\ \rho = 1.23\ kg/m^3 \tag{3.31}$$

$$power\ coefficient\ Cp = 0.4 \tag{3.32}$$

$$l = r = 2 \tag{3.33}$$

$$A = \pi r^2 \tag{3.34}$$

$$A = 12.56 \tag{3.35}$$

The overall power converted from wind energy to rotational energy of turbine illustrated in Equation (3.36)

$$P_{avall} = \frac{1}{2}\rho A v^3 C_p \tag{3.36}$$

$$P_{avall} = 1876\ watts \tag{3.37}$$

The power factor is not a fixed value as defined in the main question; it varies with the turbine tip speed ratio which explained in Equations (3.38), (3.39) and (3.40).

$$\lambda = \frac{\text{blade tip speed}}{wind\ speed} \tag{3.38}$$

$$blade\ tip\ speed = \frac{(rotational\ speed\ (rpm) * \pi * D)}{60} \tag{3.39}$$

$$\text{Energy} = \text{Power} \times \text{Time} \tag{3.40}$$

3.3 Constructing a Model for the Proposed Comprehensive Hybrid System

The complete Hybrid system is divided into different sections. There is included a Wind energy section, solar PV energy sections, converters, a grid, Fuzzy MPPT Control, and monitoring section, etc. The complete model system Simulink model also included the subsystem blocks as well. The grid block is a subsystem. MPPT FLC is a subsystem block. Figure 3.11 is shown the complete comprehensive model with different sections and subsystems that will be used in this thesis.

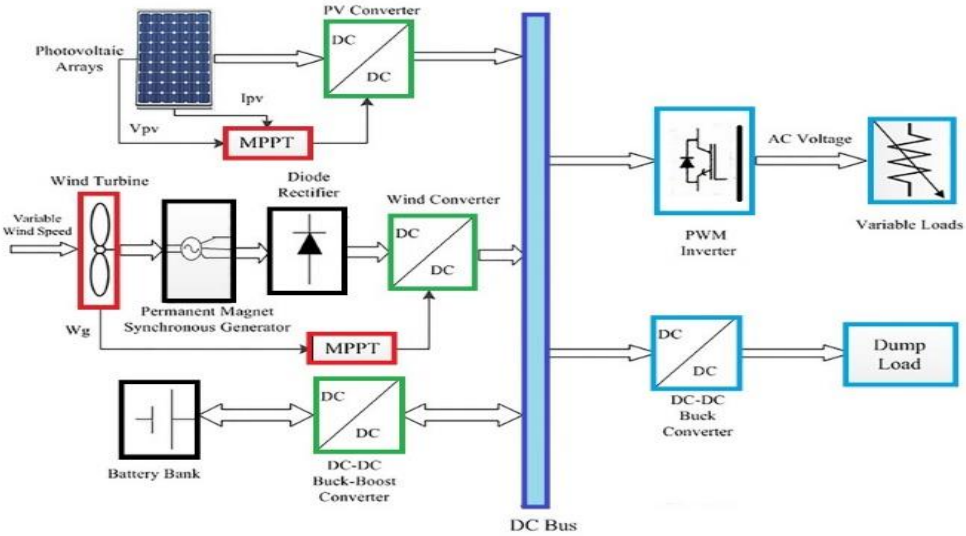


Figure 3.11 Complete hybrid system model block layout

3.3.1 Wind energy section

In Figure 3.12, the wind energy section features a Simulink block for the wind turbine. This block receives inputs such as the generator speed, the pitch angle of the turbine blade, and the wind speed. The output from this wind turbine block is mechanical rotation expressed as mechanical torque. This torque is supplied to the Permanent Magnet Synchronous Motor (PMSM) alternator, which, in turn, is capable of generating electrical energy based on the torque produced by the wind turbine.

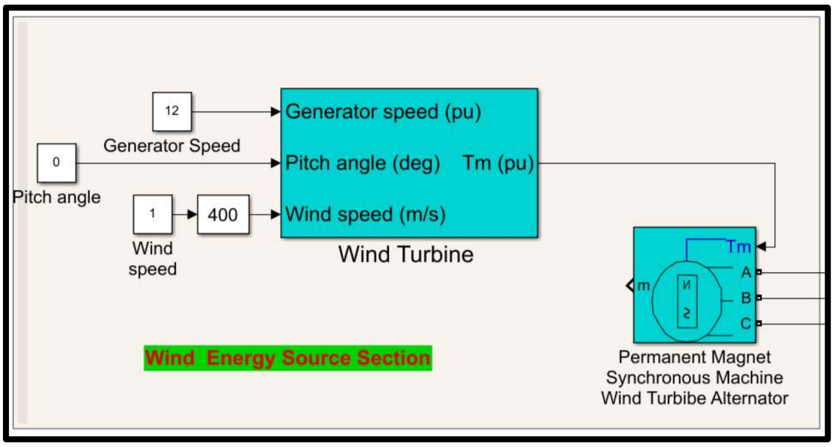


Figure 3.12 Wind energy section

3.3.2 Wind energy source AC to DC converter

Wind power source, as shown in Figure 3.13, incorporates an AC-DC converter unit. This three-phase AC-DC converter can transform the AC source derived from the alternator into DC, utilizing a universal full bridge rectifier.

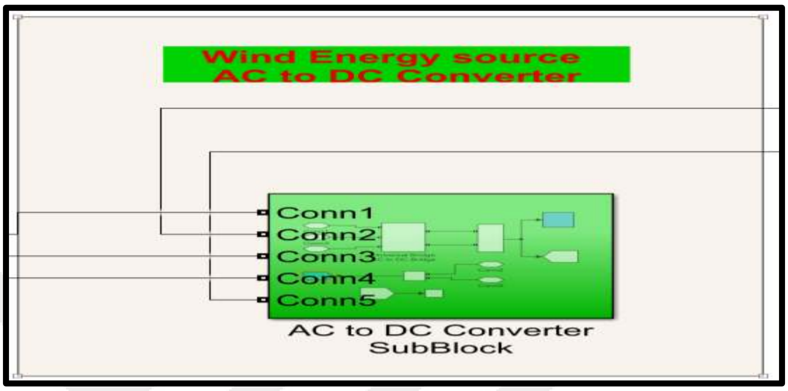


Figure 3.13 Wind power AC-DC converter

3.3.3 AC to DC converter subsystem

As depicted in Figure 3.14, a subsystem encapsulates the elements of the three-phase AC-DC converter, which includes a full bridge rectifier, along with blocks for voltage and current measurements.

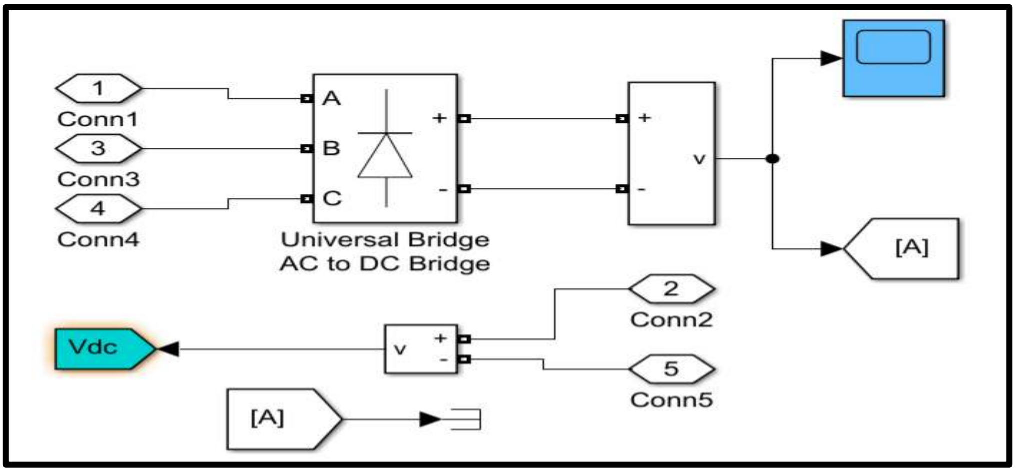


Figure 3.14 AC to DC converter subsystem

3.3.4 Microgrid section

The microgrid in Figure 3.15 has the ability to distribute the electrical power obtained from the hybrid source of wind energy as well as the solar PV power source distributed to the load depending upon the load requirements.

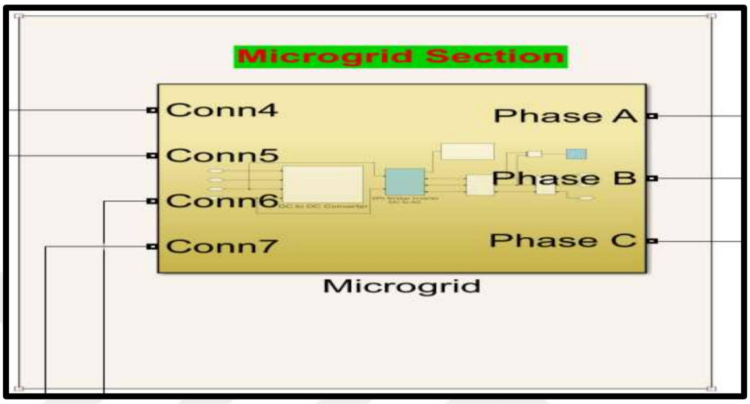


Figure 3.15 Microgrid section the simulation program

The microgrid has subsystem components including the DC-DC converter to deliver the required output voltages towards the load controlled by the PWM-signals Figure 3.16. The 3-phase inverter has the ability to invert the DC to AC, and the three-phase inverter proved the AC output for the load. The LC filter removes the unwanted noise and improves the power factor.

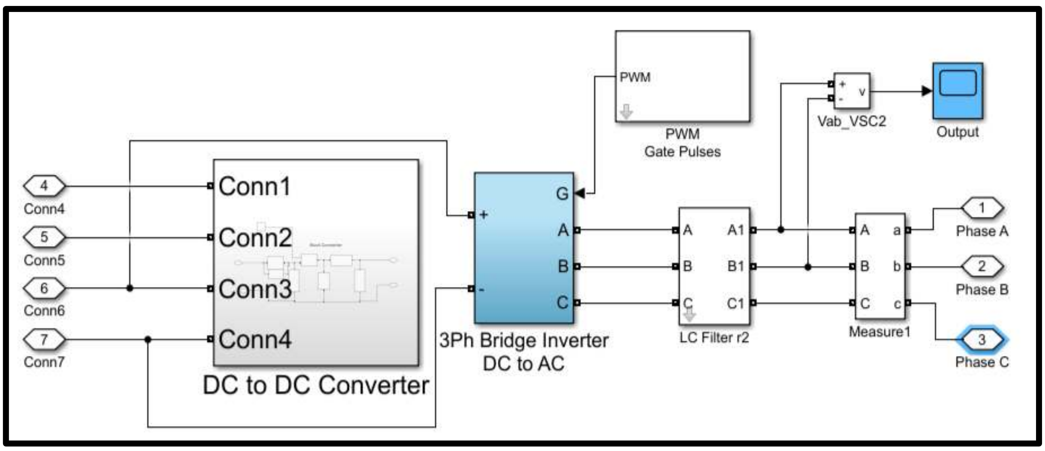


Figure 3.16 Microgrid subsystem block diagram

3.3.5 DC to DC converters

The microgrid has subsystem components including the DC-to-DC converter to deliver the required output voltages towards the load controlled by the PWM signal (Figure 3.17).

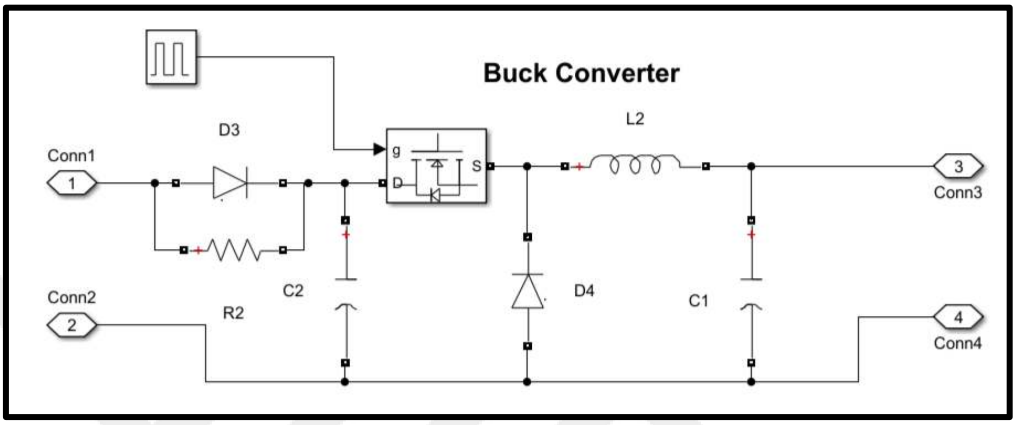


Figure 3.17 Microgrid buck converter circuit

3.3.6 Three phase inverter subsection

The inverter contains six full-bridge power MOSFETS that act as a directional controlled switch to provide AC output waveform. There are six MOSFET controlled by separate gate pulsed derived by PWM signals (Figure 3.18).

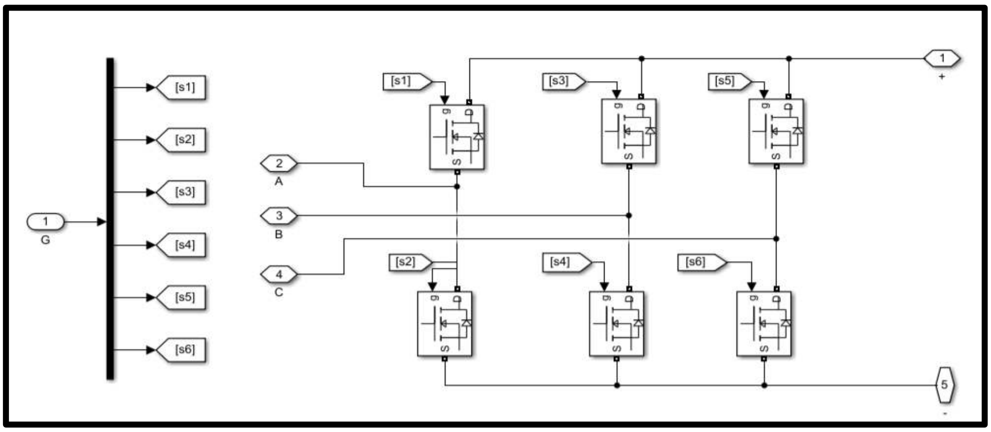


Figure 3.18 Three-phase inverter subsystem

3.3.7 PV Solar Energy Management System Based on Fuzzy Logic

The section on solar photovoltaic (PV) encompasses a comprehensive energy management system. This includes a Maximum Power Point Tracking (MPPT) controller utilizing a fuzzy logic control algorithm, a derived boost converter regulated by the MPPT controller, and a lithium-ion battery for storing energy from the solar PV. All of these components are illustrated in Figure 3.19.

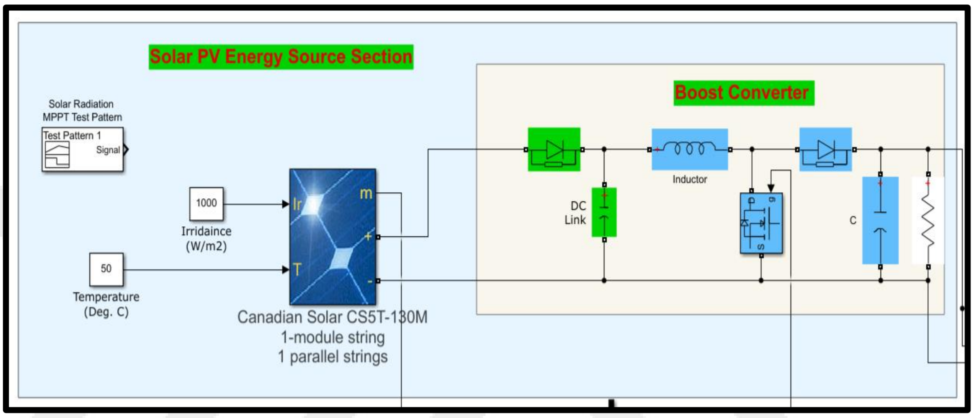


Figure 3.19 Solar PV energy system

The solar PV and Energy storage section in Figure 3.20 has a boost converter and solar energy storage section PV.

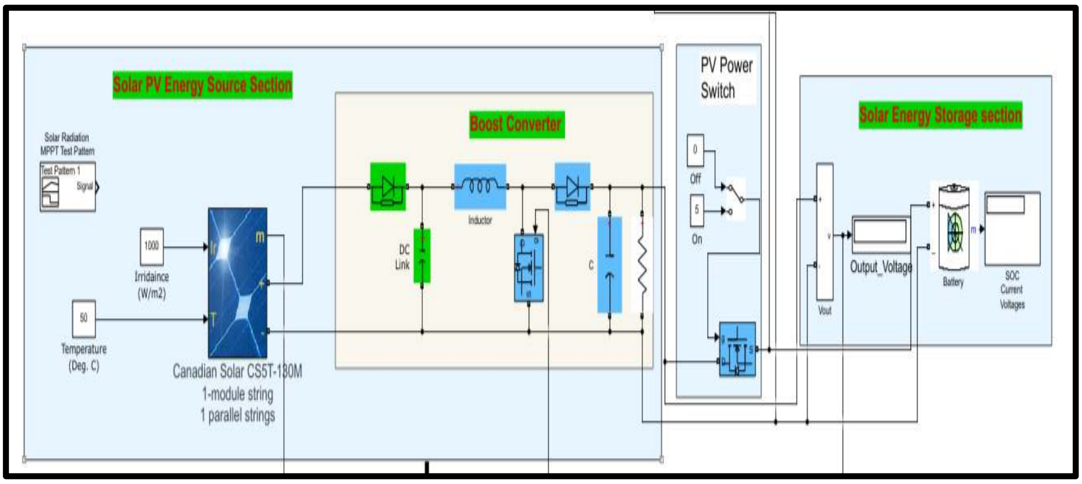


Figure 3.20 PV with energy storage system

The MPPT in the Figure 3.21 The innovative maximum power point control unit (21) extracts the most output power from the solar PV module that is feasible. To draw electricity from the PV array module, the MPPT features a fuzzy logic controller unit. Intelligently as well as robust output behavior can be achieved.

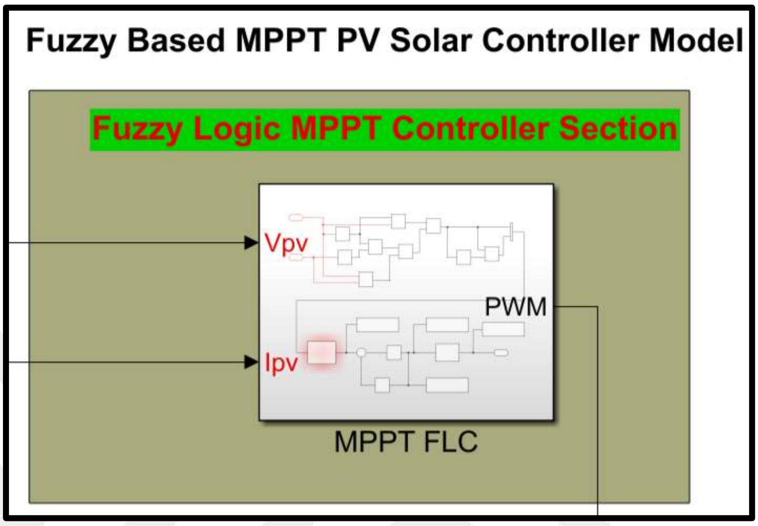


Figure 3.21 MPPT with fuzzy logic controller

The Fuzzy MPPT subsection in the Figure 3.22 has the fuzzy logic controller as well as digital to PWM generator block. The error, as well as the change in error signal, are generated with the use of a memory block. The monitoring section in the Figure 3.23, monitors all the outputs and outcomes of the complete hybrid energy management system.

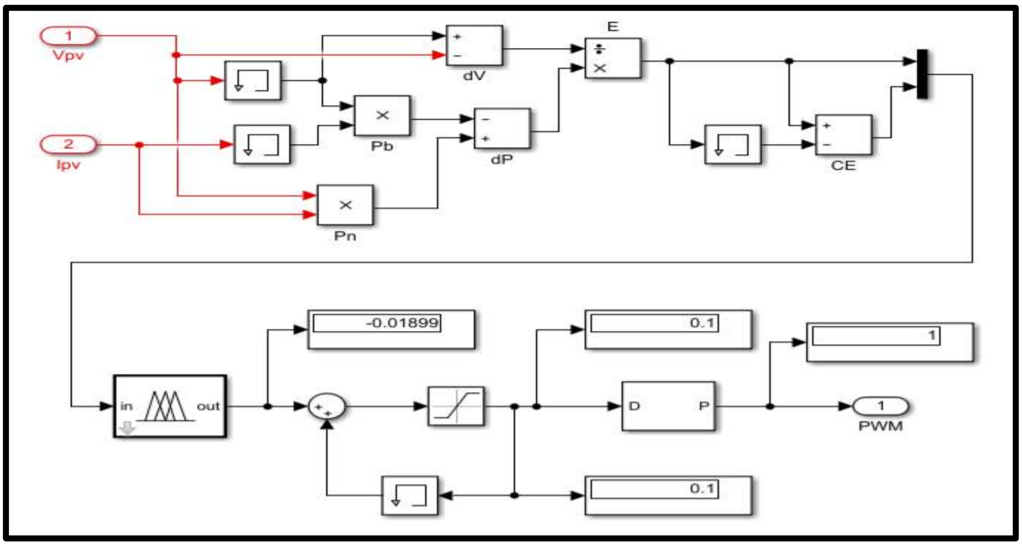


Figure 3.22 Fuzzy MPPT subsection

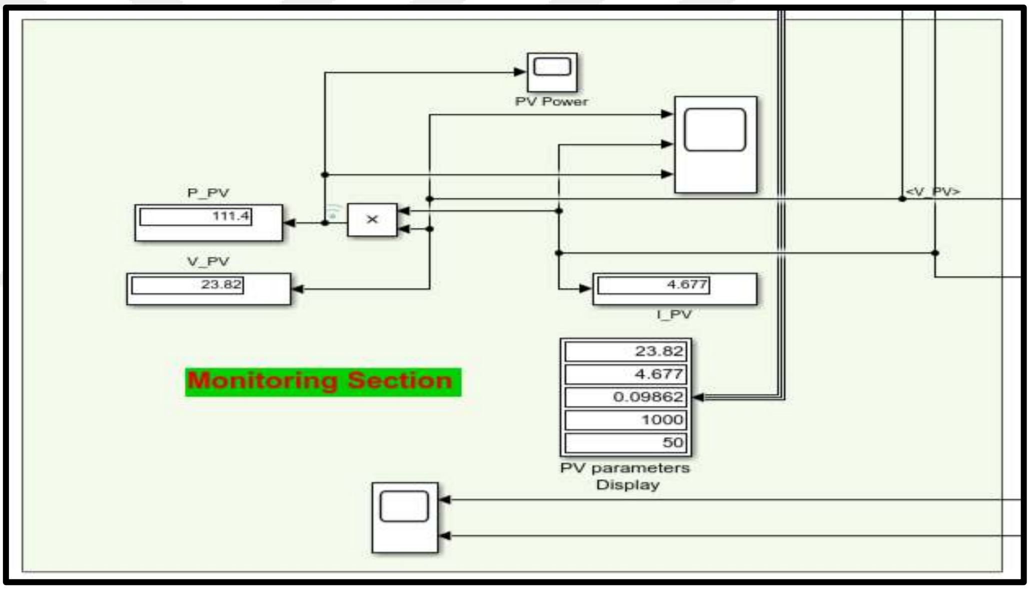


Figure 3.23 Outputs and outcomes of the complete hybrid energy management system

The power transfer switch in Figure 3.24 is available in the microgrid unit to control the direction of power from the hybrid source to load.

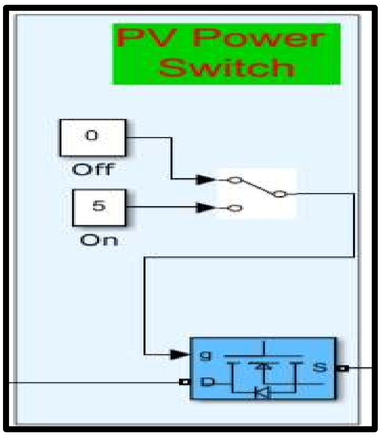


Figure 3.24 PV power switch

3.3.8 Three phase AC load section

In Figure 3.25, a three-phase RLC load is utilized to evaluate the output power in its purest form, aiming for maximum efficiency and maximum power, while eliminating oscillations and disturbances.

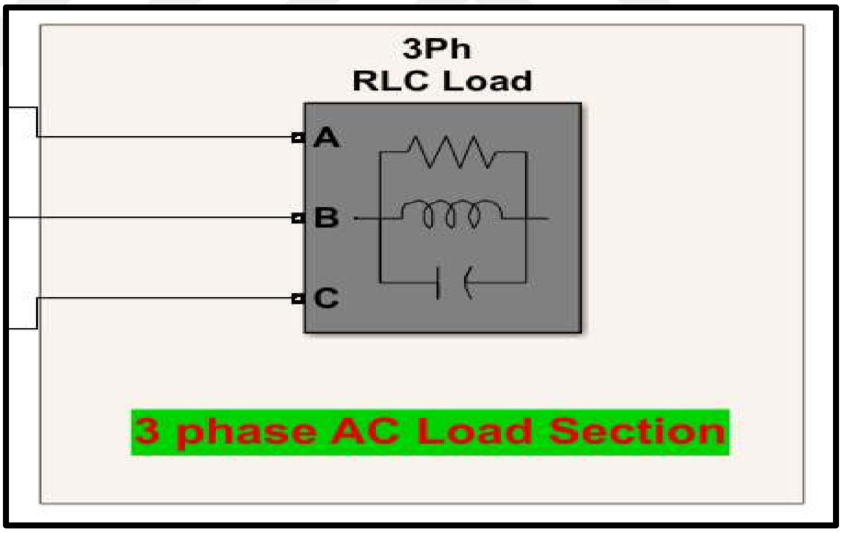


Figure 3.25 AC load section

4. RESULTS AND DISCUSSION

In thise chapter, the final design of the proposed system will be presented with all the results for this system. A three-phase RLC load is employed to assess the output power in its most unadulterated form, aiming to achieve the greatest possible efficiency and power while avoiding oscillations and disturbances. Figure 4.1 illustrates the final system, which incorporates both the solar and wind energy systems along with an AC load.

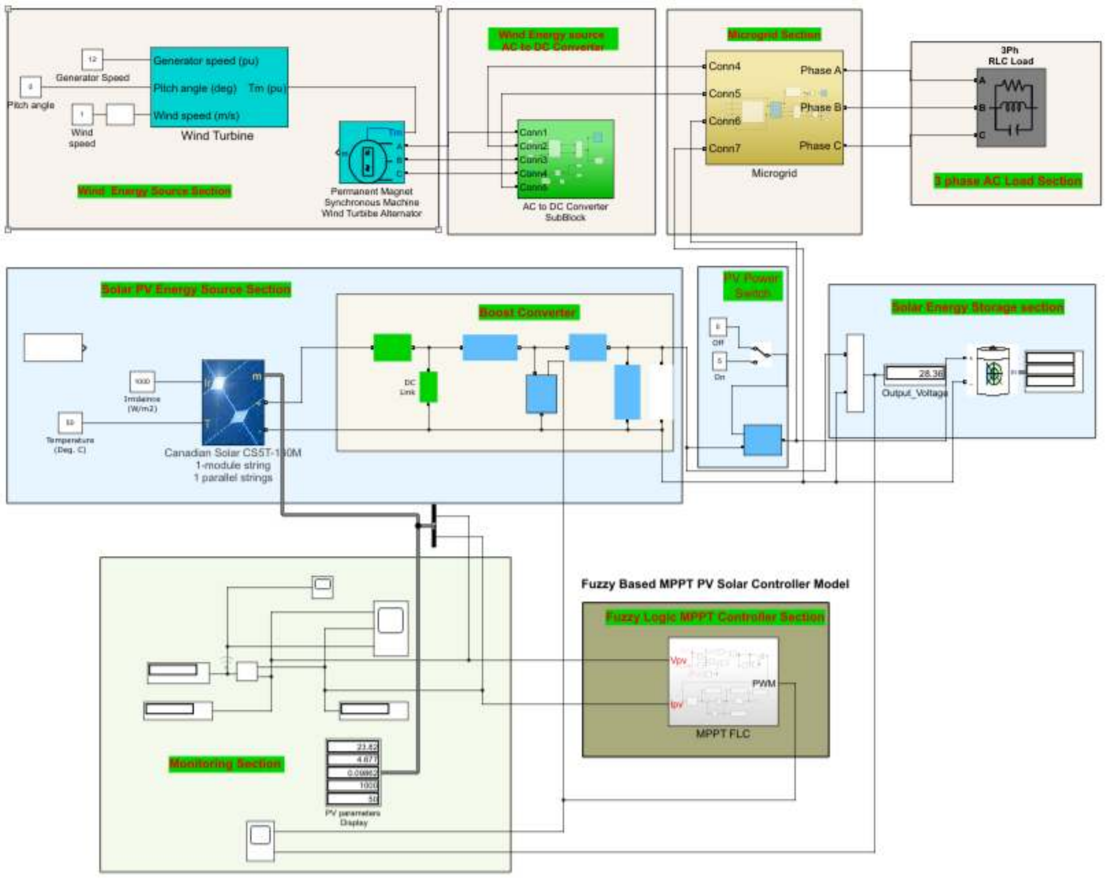


Figure 4.1 Final proposed system

4.1 FLC for MPPT Design

Initially, the Fuzzy Logic Toolbox function is called using the Matlab command window as shown in Figure 4.2. After the code is written, the main window of Fuzzy will open to load the main parameters, as shown in Figure 4.3. The fuzzy logic console window is available in Figure 4.3 for the FLC design of MPPT.

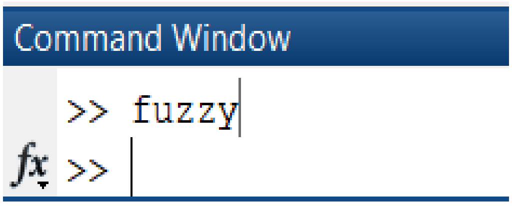


Figure 4.2 Matlab command window

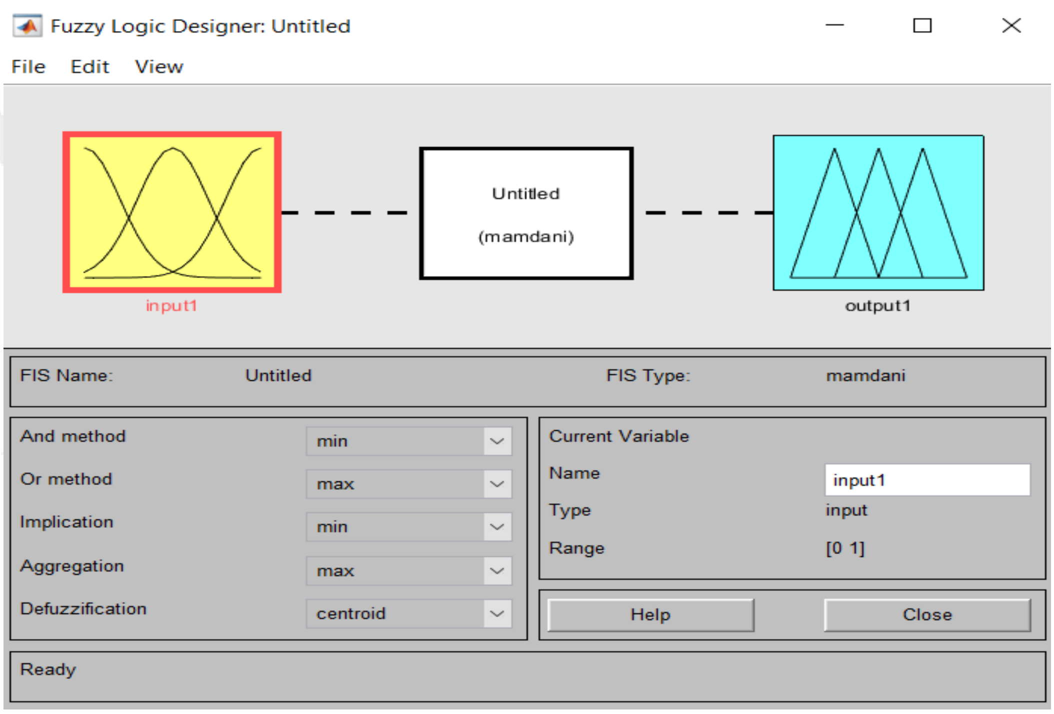


Figure 4.3 The fuzzy logic toolbox window will appear

4.1.1 Define the input and output of FLC

Figure 4.4 shown the input and output of the Fuzzy logic control toolbox, the first input is voltage and second input is power, assigned for design of FLC for MPPT.

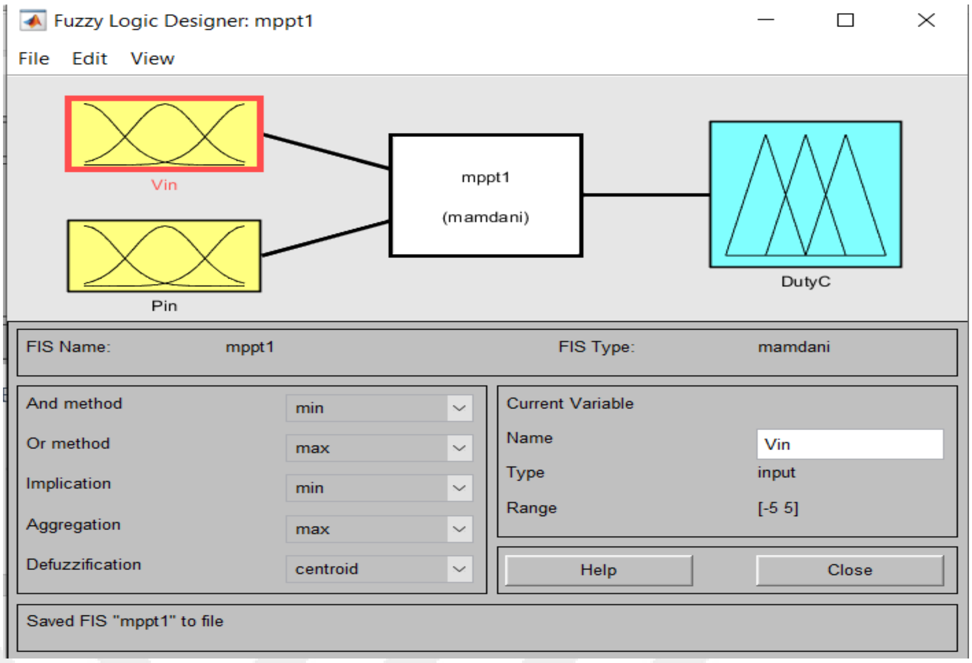


Figure 4.4 FLC input and output

4.1.2 Membership function determination and input scoping 1

The membership functions in Figure 4.5 used are triangular with maximum overlapping to get the smooth, optimized output results, there are total 7 7 inputs membership functions used.

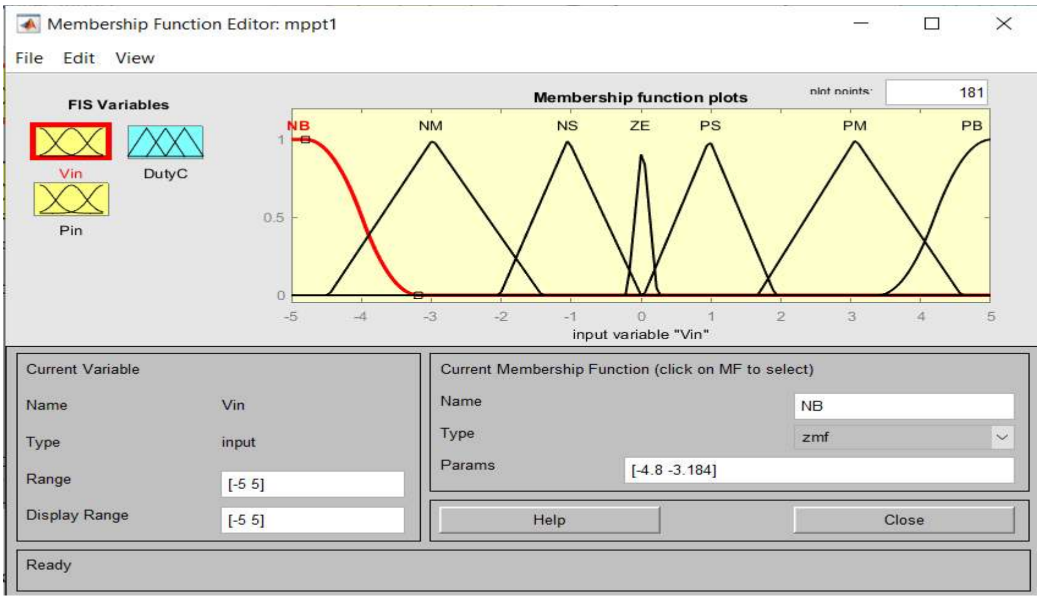


Figure 4.5 Input membership function

4.1.3 Power input membership function

The second input is power input membership function with power input is shown in the Figure 4.6.

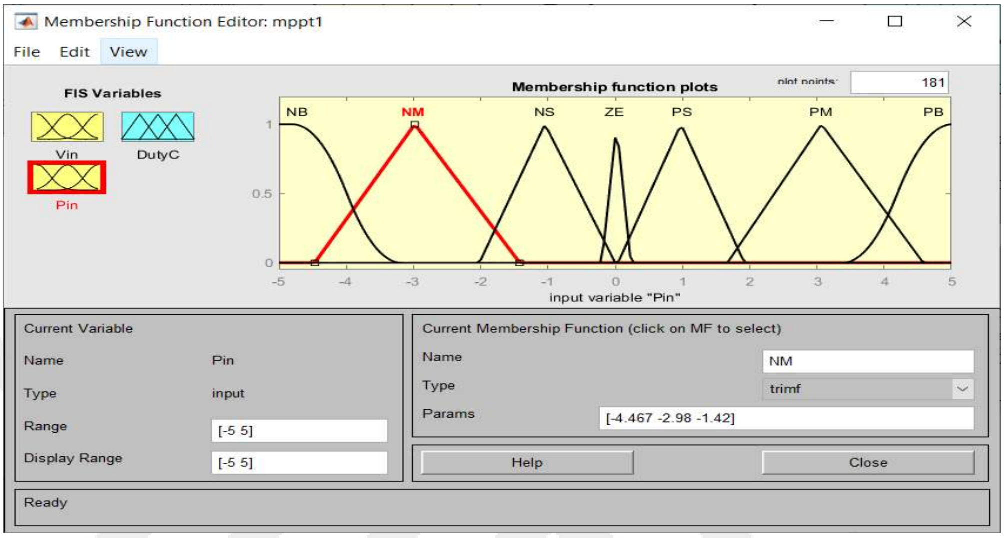


Figure 4.6 Power in membership function

4.1.4 Duty-cycle output membership function

The third input is Duty-Cycle membership function is presented in the Figure 4.7.

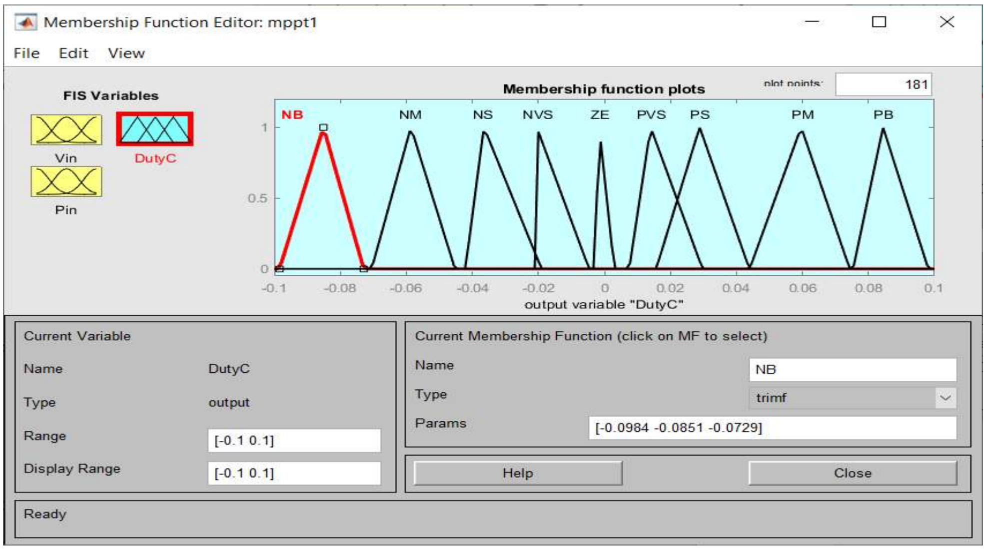


Figure 4.7 Duty-cycle output membership function

4.1.5 Assign the rules

The output used for control signal is duty cycle. The maximum duty cycle denotes by 0.1 and minimum denotes by -0.1 Figure 4.8.

$$\text{Rules No.} = \text{ Mebership functions of first I/o} * \text{Mebership functions of second I/o}$$

$$\text{Number of Rules} = 7 * 7 = 49$$

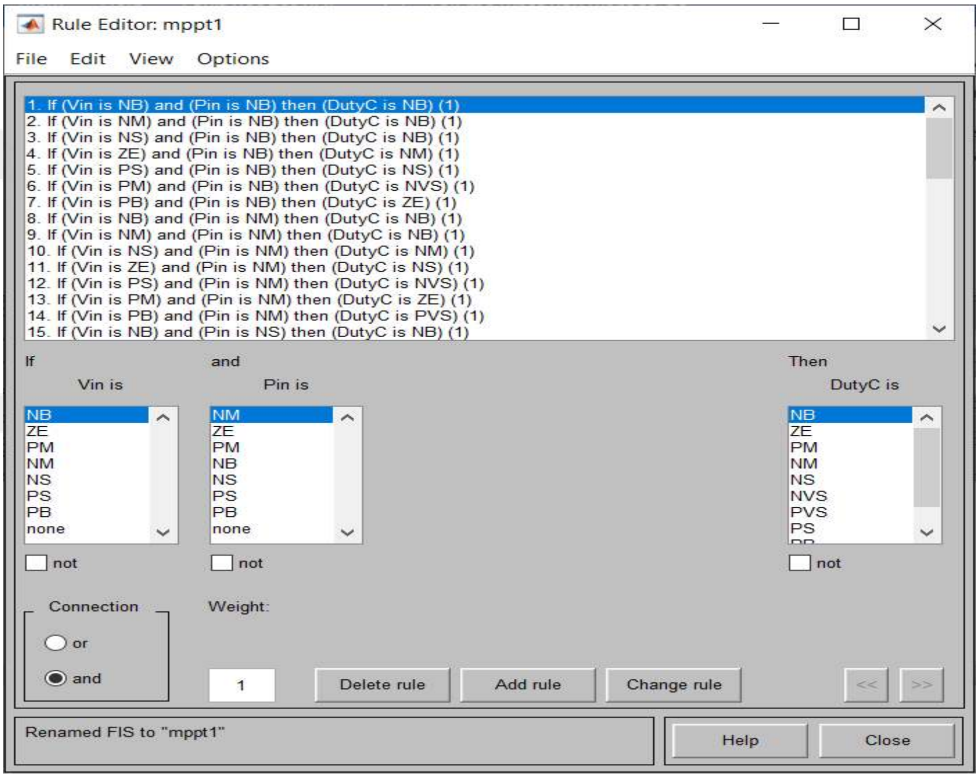


Figure 4.8 Assign the rules window

As there are 49 rules are used in Figure 4.9, and we have used the Mamdani inference system for rules assignment. For Mamdani inference there is and implication used.

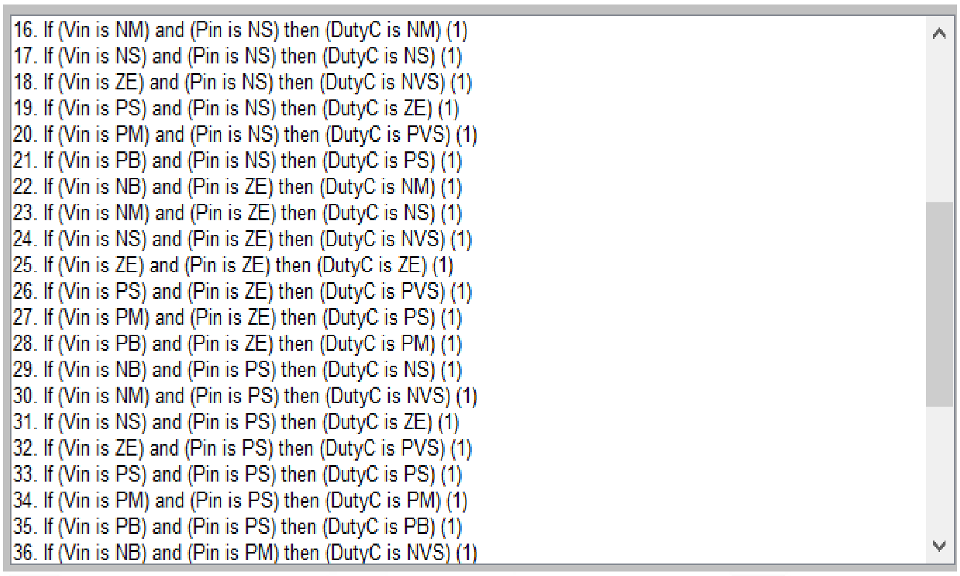

16. If (Vin is NM) and (Pin is NS) then (DutyC is NM) (1)
17. If (Vin is NS) and (Pin is NS) then (DutyC is NS) (1)
18. If (Vin is ZE) and (Pin is NS) then (DutyC is NVS) (1)
19. If (Vin is PS) and (Pin is NS) then (DutyC is ZE) (1)
20. If (Vin is PM) and (Pin is NS) then (DutyC is PVS) (1)
21. If (Vin is PB) and (Pin is NS) then (DutyC is PS) (1)
22. If (Vin is NB) and (Pin is ZE) then (DutyC is NM) (1)
23. If (Vin is NM) and (Pin is ZE) then (DutyC is NS) (1)
24. If (Vin is NS) and (Pin is ZE) then (DutyC is NVS) (1)
25. If (Vin is ZE) and (Pin is ZE) then (DutyC is ZE) (1)
26. If (Vin is PS) and (Pin is ZE) then (DutyC is PVS) (1)
27. If (Vin is PM) and (Pin is ZE) then (DutyC is PS) (1)
28. If (Vin is PB) and (Pin is ZE) then (DutyC is PM) (1)
29. If (Vin is NB) and (Pin is PS) then (DutyC is NS) (1)
30. If (Vin is NM) and (Pin is PS) then (DutyC is NVS) (1)
31. If (Vin is NS) and (Pin is PS) then (DutyC is ZE) (1)
32. If (Vin is ZE) and (Pin is PS) then (DutyC is PVS) (1)
33. If (Vin is PS) and (Pin is PS) then (DutyC is PS) (1)
34. If (Vin is PM) and (Pin is PS) then (DutyC is PM) (1)
35. If (Vin is PB) and (Pin is PS) then (DutyC is PB) (1)
36. If (Vin is NB) and (Pin is PM) then (DutyC is NVS) (1)

Figure 4.9 The rules

4.1.6 The validity of FLC with surface plots

The surface plot in Figure 4.10 shows that there is a direct relationship between the input as well as output, Figure 4.10 shows the surface plot Duty cycle and Voltage-in and Figure 4.10 shows the plot Duty cycle and Power-in. The surface plot indicates that there is direct relation between the second input as well as control output. We are using power as and input on x axis as well as duty cycle as output on y axis. The performance of the system can be investigated with the help of a rule viewer in Figure 4.11. Slides the inputs and observes the behavior of the system by output as Duty cycle output are presented in the Figure 4.12.

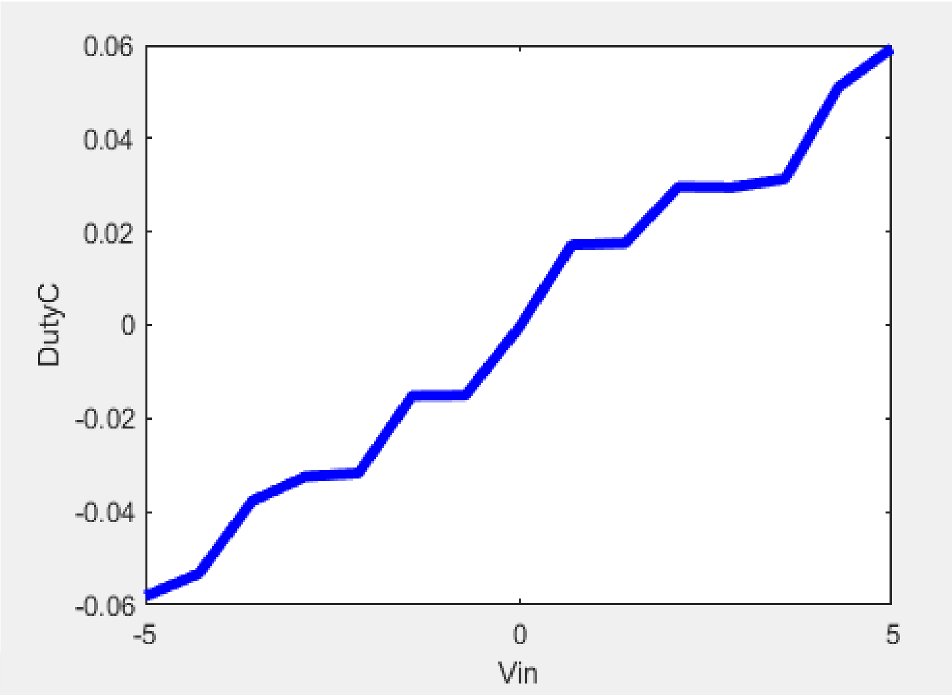


Figure 4.10 The relation between duty cycle and voltage

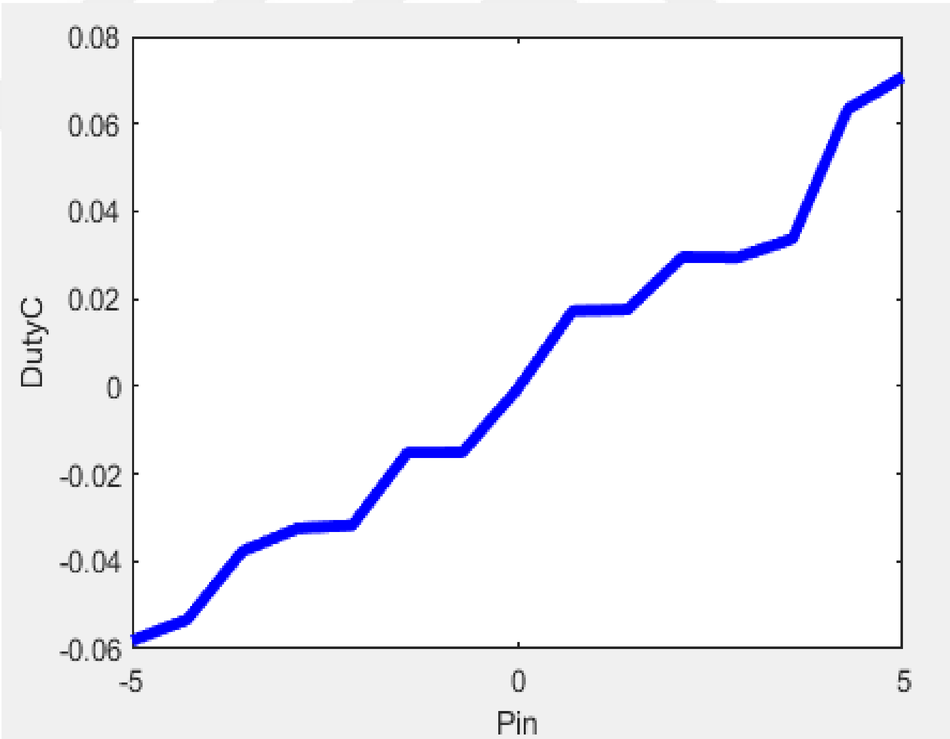


Figure 4.11 The relation between duty cycle and power

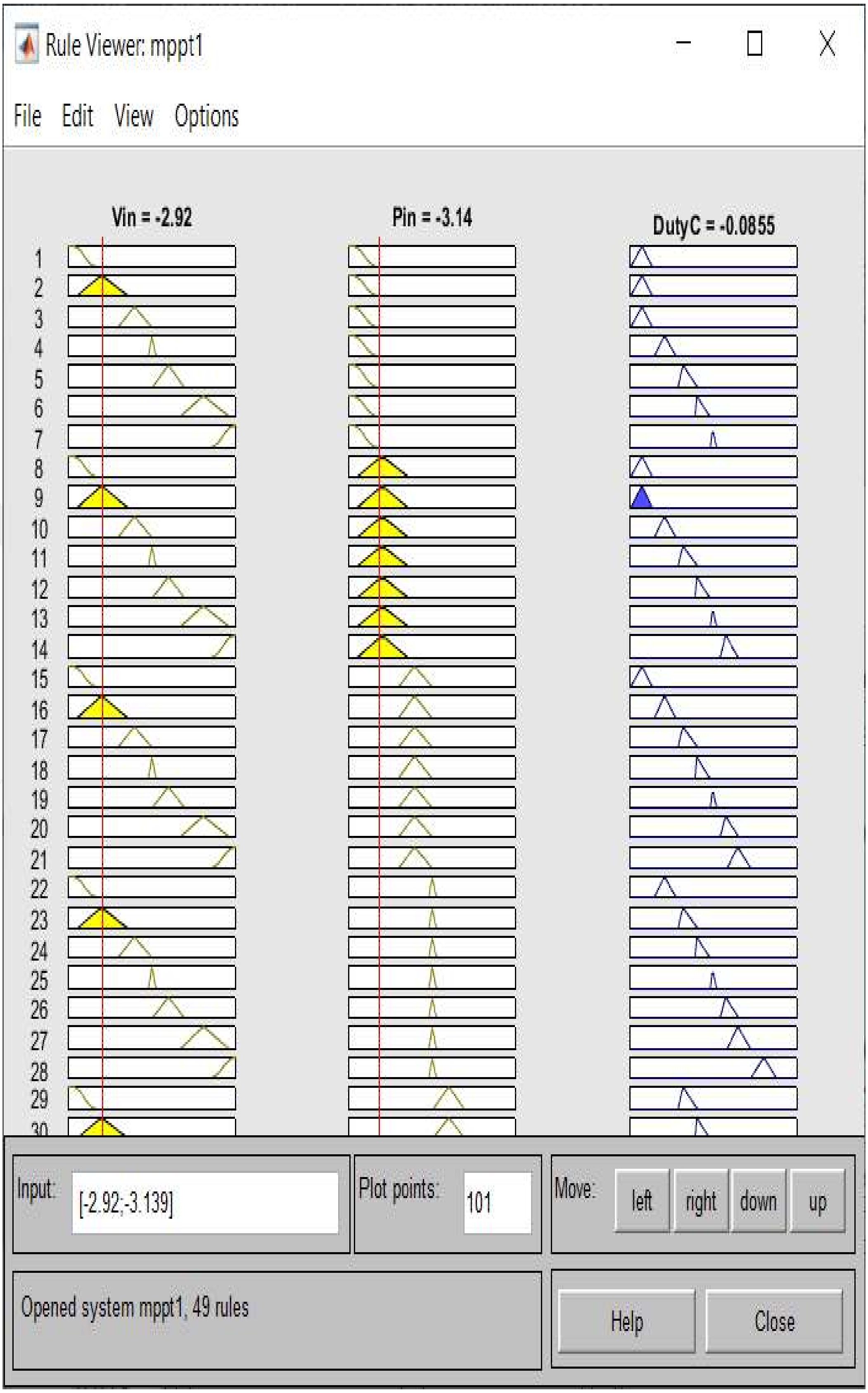


Figure 4.12 The rules viewer to observe the output of FLC

4.2 Wind Turbine Parameters and Results

The characteristics that make up a turbine's operation include the opening angle of the blades, power, torque, and rotational speed at a specific wind speed. These variables affect how well the complete assembly performs. Figure 4.13 the main parameter of wind turbine parameter in matlab simulink.

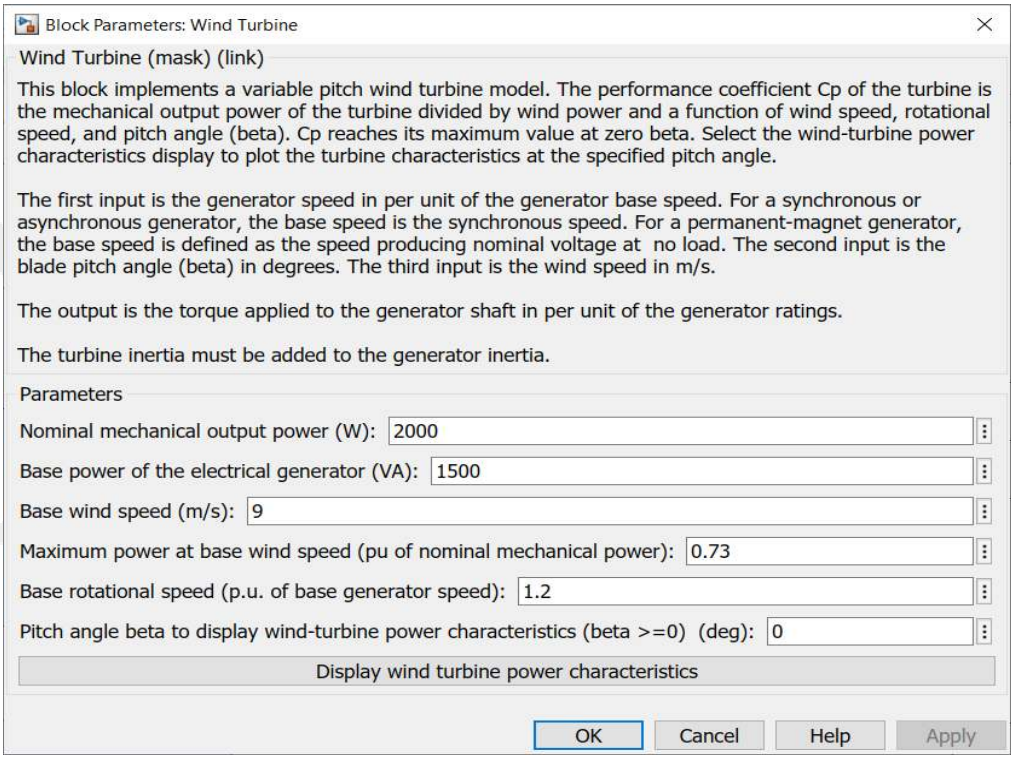


Figure 4.13 Wind turbine parameters

One of the most important aspects of a wind turbine is its power curve, which displays the relationship between output power and hub height wind speed. Power curve assists in energy assessment, warranty drafting, and turbine performance assessment. The maximum power obtained by wind turbines can be observed as well as visualized in the Figure 4.14. The alternator used for wind turbine has three phase and back emf produced is sin wave. The rotor of the alternate is round-type. And the wind turbine torque is applied to alternator Figure 4.15.

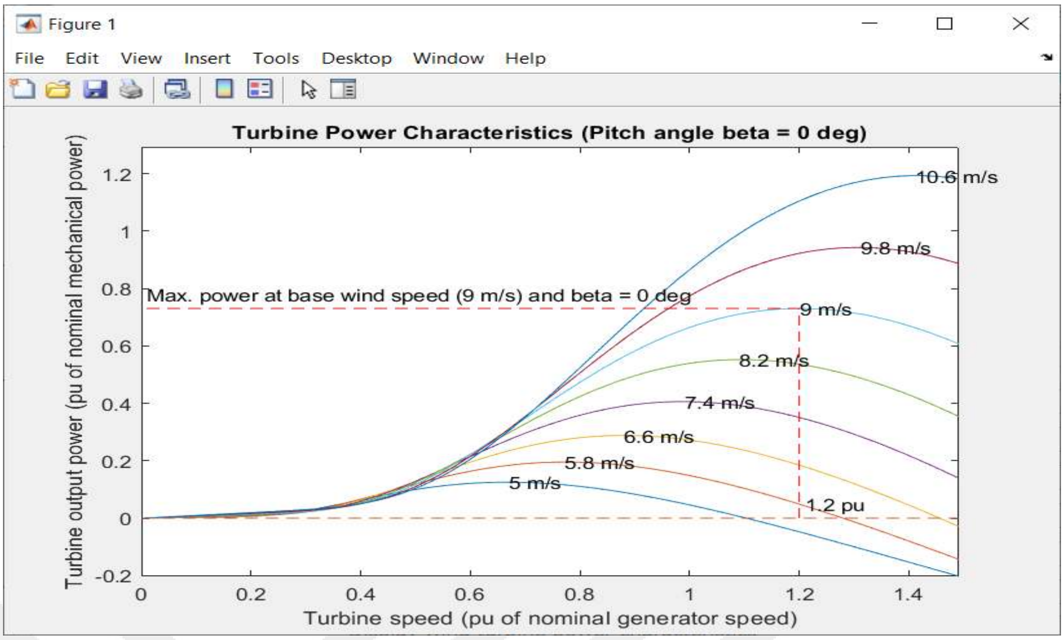


Figure 4.14 Wind turbine characteristic curve

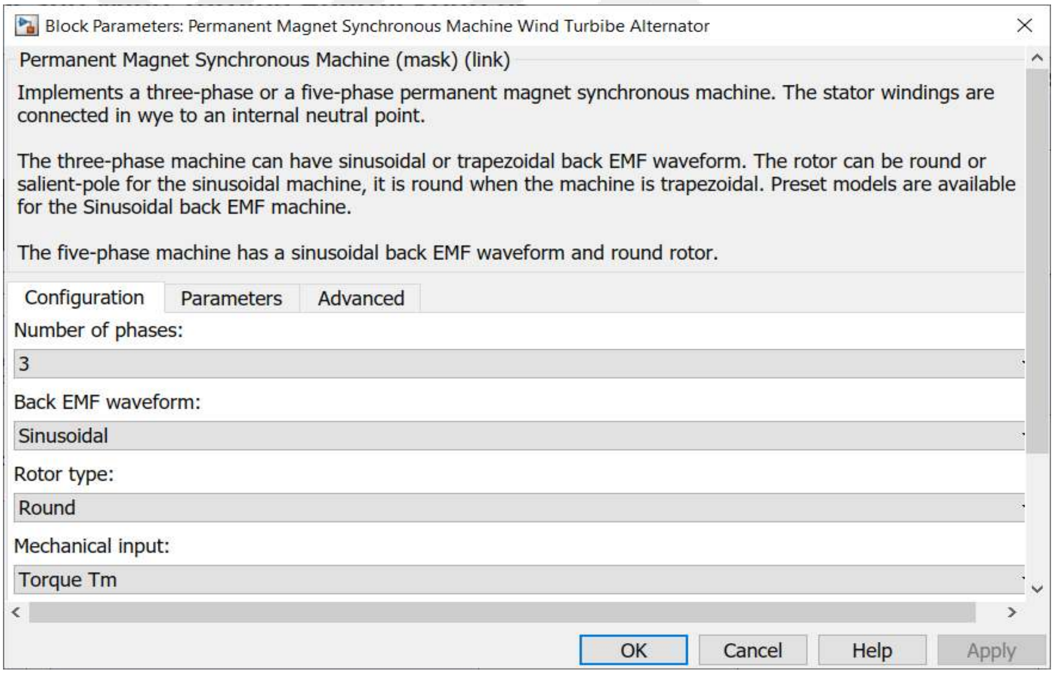


Figure 4.15 The configuration parameter

The generator or alternator electrical parameters in Figure 4.16 can be observed from Figure 4.16.

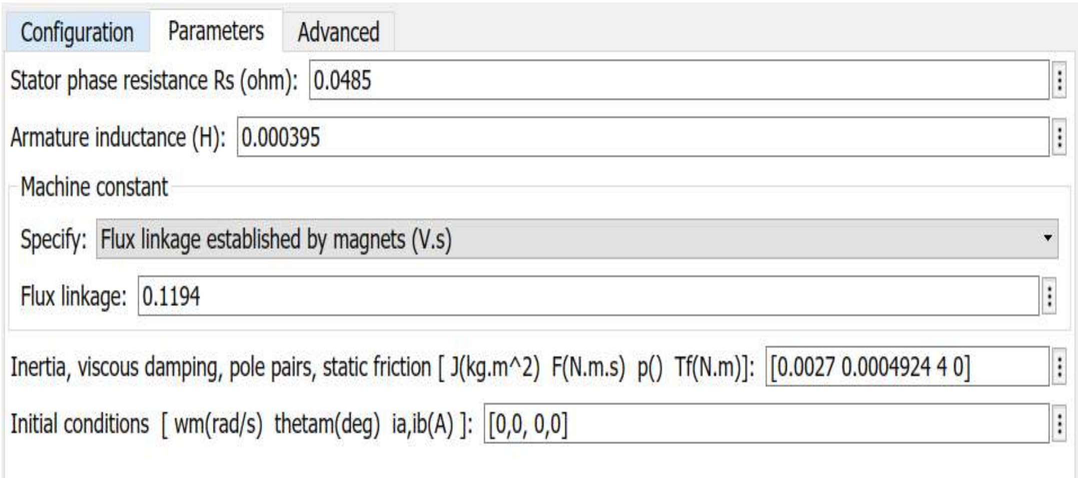


Figure 4. 16 The alternator parameter

As a result of using a DC-to-DC converter, a constant voltage is obtained from this circuit with different generator speeds or different wind speeds. Figure 4.17 presents the six-gate driver PWM voltage for three phase inverter MOSFET Transistors.

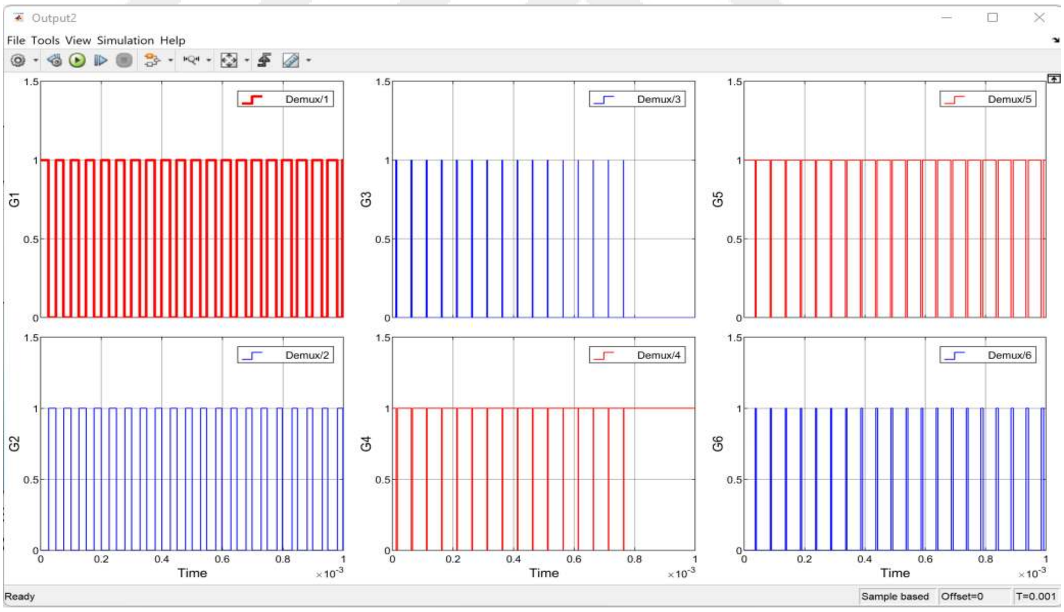


Figure 4.17 Six gate driver PWM

4.3 PV Array Model Parameters and Results

A practical technique to store and examine such a collection is using model arrays. A single MATLAB® array contains a collection of various linear models called a model array. With relation to all models gathered into a single model array. The PV array model and block parameters can be seen in Figure 4.18.

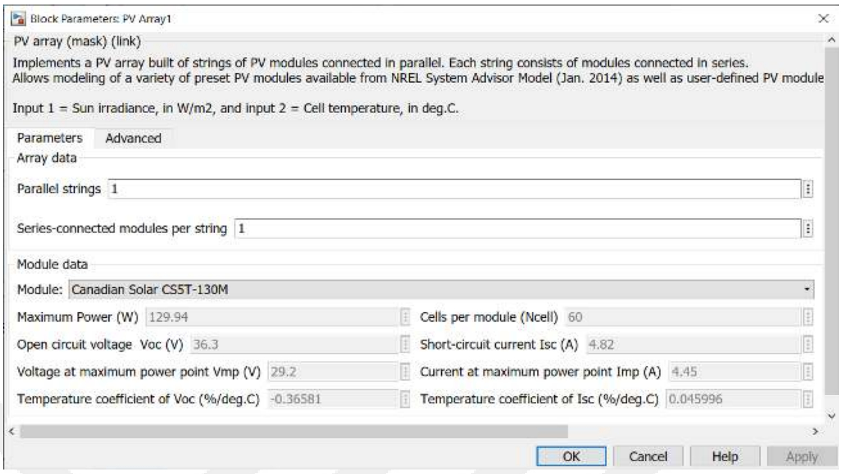


Figure 4.18 The PV array parameters

Figure 4.19 shows the I-v and P-V parameters for a purpose of analysis as well as simulation-based testing, we applied the input temperature as 50 C. we plot the characteristic curve to set as benchmarked to get and obtain the maximum power from the PV array model.

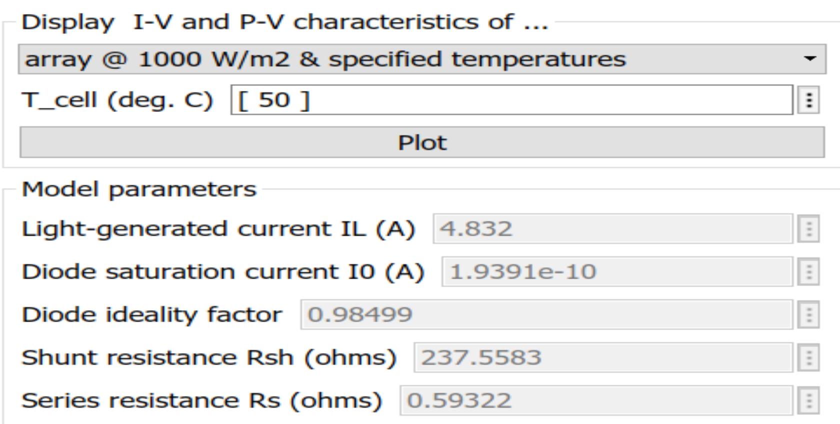


Figure 4.19 I-V and P-V characteristics parameters

Figure 4.20 curve is used as benchmark and this is the characteristic curve of the PV array model block and this is the expected output maximum power from the PV array.

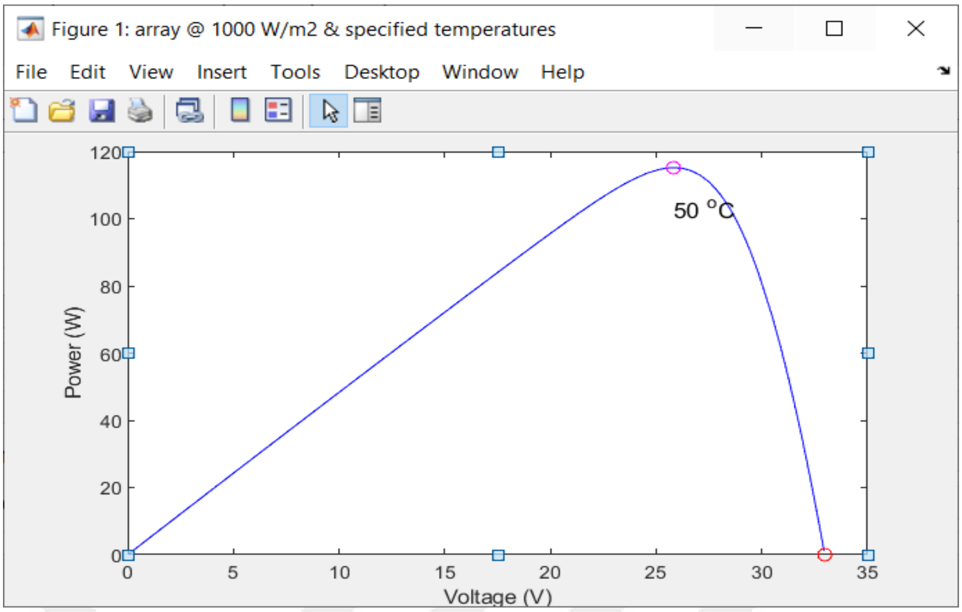


Figure 4.20 The PV characteristic Plot

After running the model for 1 seconds and observe the outputs and response of hybrid system as shown in Figure 4.21. By simulation of the system, we obtain the maximum power from PV array about 111.4 and voltage of module almost 23, the current is almost 4.6 Ampere and these are the parameters obtained at 50 degree centigrade and 1000 watt / meter square solar irradiance.

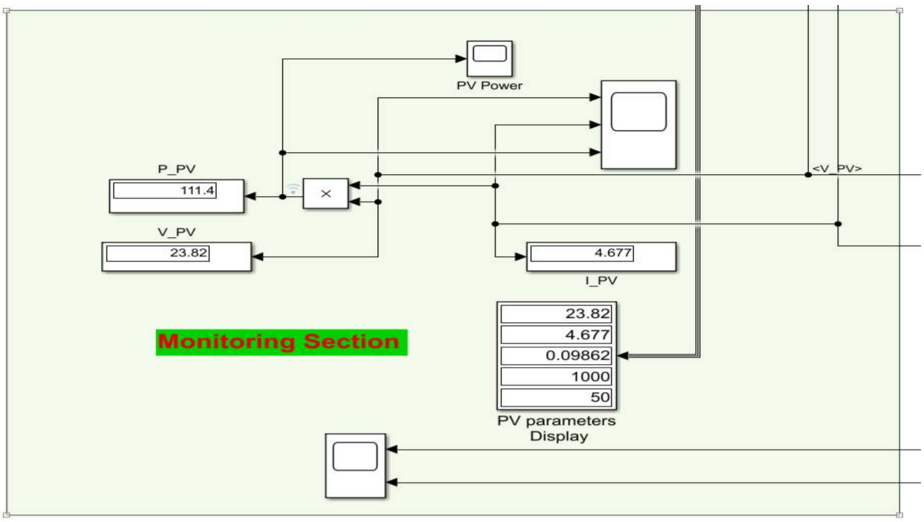


Figure 4.21 Simulation results under temperature 50C

Figure 4.22 demonstrates various parameters related to solar PV, including voltage, current of PV, diode current, solar irradiance, and applied temperature. Meanwhile, Figure 4.23 displays the desired maximum power output acquired from the solar PV array power, achieved by implementing the fuzzy Maximum Power Point Tracking (MPPT) controller.

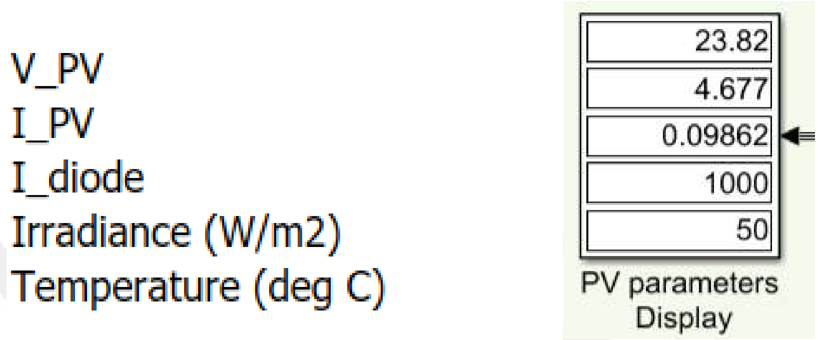


Figure 4.22 Results of the system (volatge, current of PV, current of diode, solar irridinace 50C)

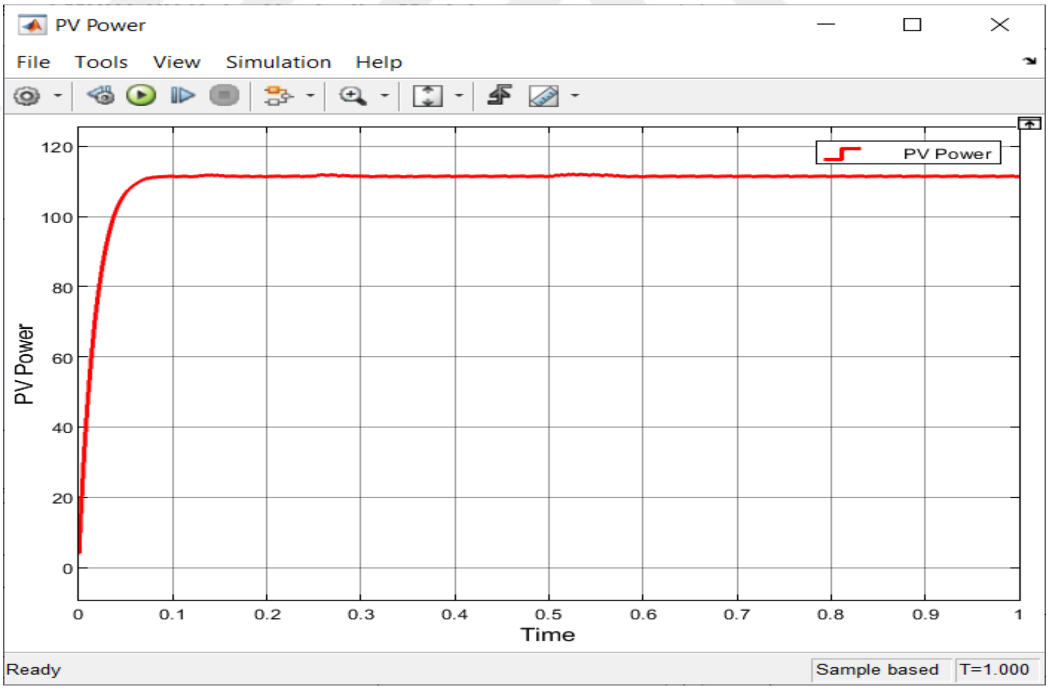


Figure 4.23 Output power of the PV

Figure 4.24 present the PV converter output voltages that can be observed and visualized with the help of the scope plot. The voltages have some disturbances because of the switching behavior of MOSFETS.

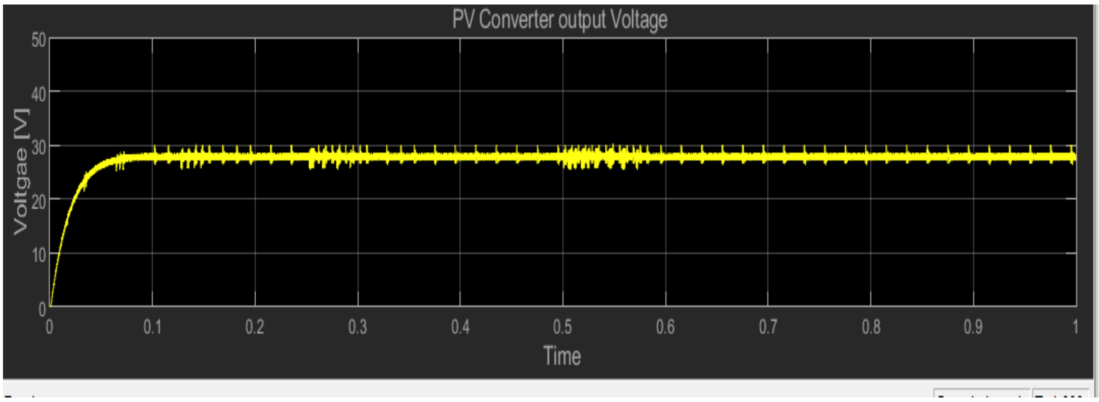


Figure 4.24 PV converter voltage

The PV converter PWM duty cycle waveform in Figure 4.25 can be observed and visualized with the help of output response and scope view. This PWM signal is generated with the help of a PWM generator and this controlled signal is obtained with the help of an MPPT controller.

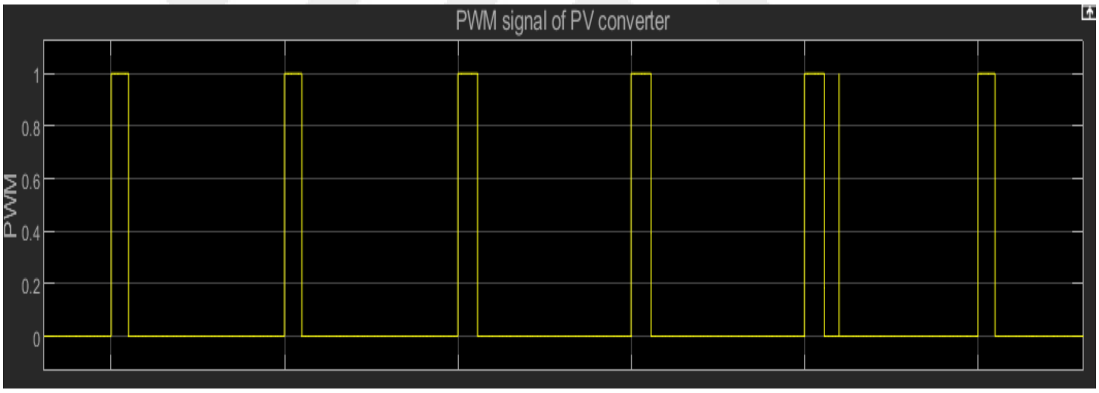


Figure 4.25 PWM duty cycle waveform

The three phase output voltages at the load side can be observed with Figure 4.25 scope view. It is noticed have the output voltages has almost pure waveform without disturbances and noise after 0.02 S.

After turn on the power transfer switch to acquire more power from the hybrid source. The maximum power obtained from solar and wind turbine sources can be visualized and noticed from the mentioned in Figure 4.26, it is noticed that the output power is the maximum power we obtained from the hybrid source. The maximum power is almost 150 watts which resemble the bench-marked characteristic results. It is observed that with the implementation of MPPT along with fuzzy control system implementation we can not only obtain the maximum possible power output we can also achieve the electrical power output with minimum oscillations and fluctuations in the response due to applied load or under overload conditions (Figure 4.27).

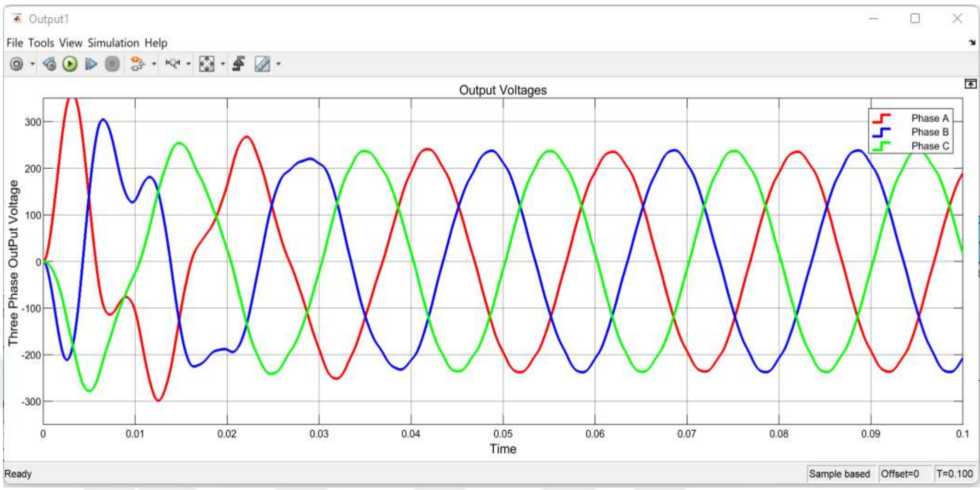


Figure 4.26 Three-phase output load voltages

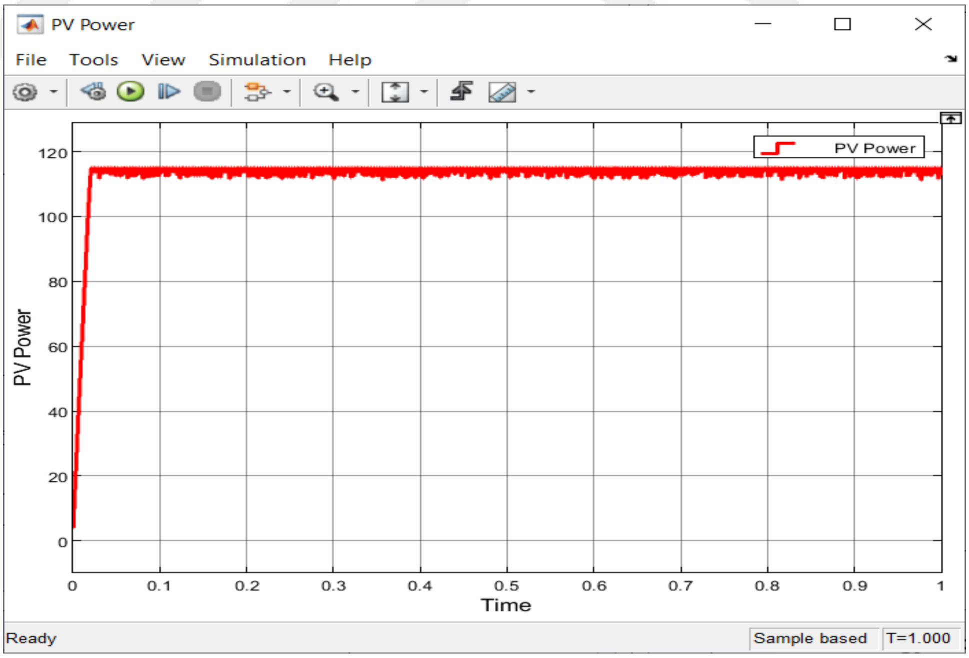


Figure 4.27 Maximum power waveform when power delivering from PV to Grid

A set of PV characteristic shows in Figure 4.28 for the output PV voltage, current, power for different temperatures ranging from (10C° to 50C°).

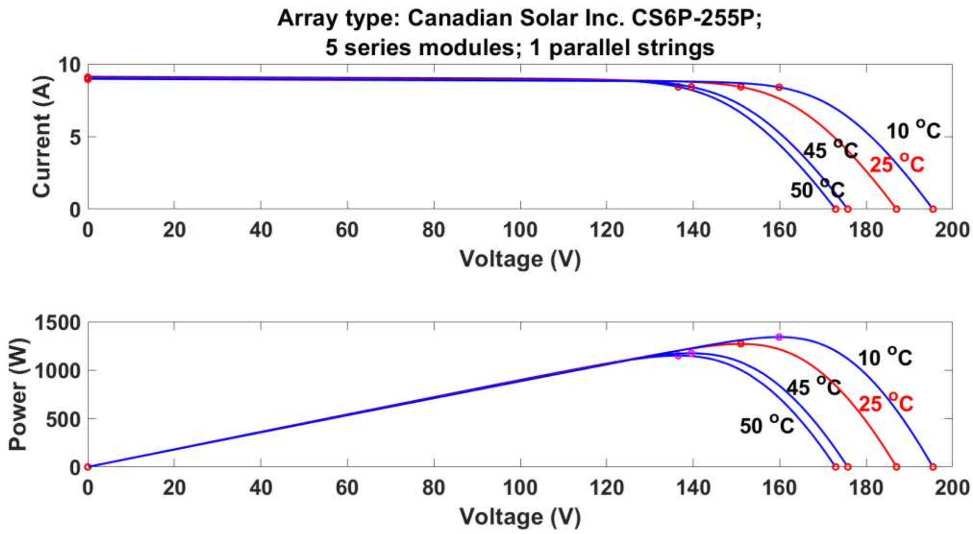


Figure 4.28 PV output voltage, current and power and voltage for different temperature

Also, Figure 4.29 shows the effect of different irradiation to proposed system

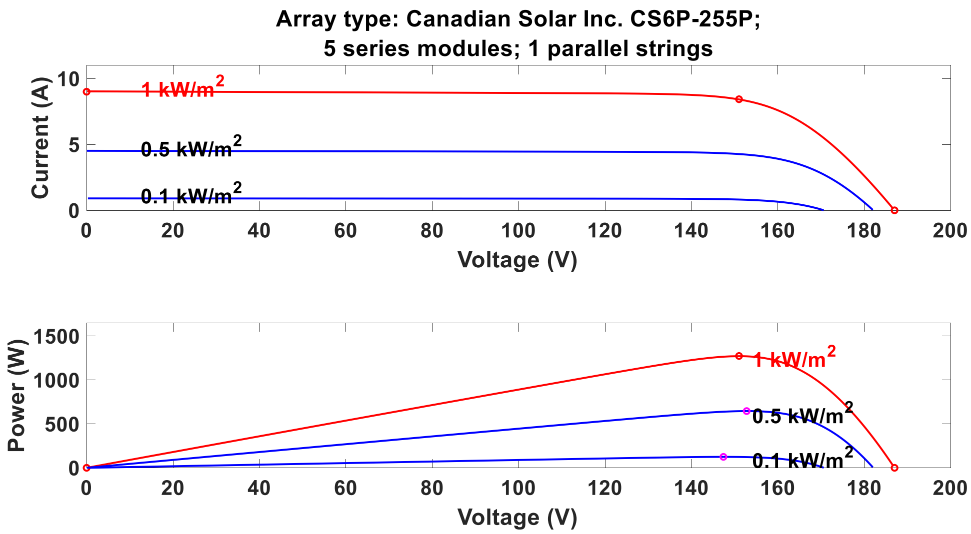


Figure 4.29 PV output voltage, current and power and voltage for different irradation

5. CONCLUSIONS AND RECOMMENDATION

A thorough examination of several maximum power point tracking techniques was conducted. Under typical and variable atmospheric circumstances, the Incremental Conductance algorithm outperforms all other approaches. Under varying air circumstances, the power output achieved from the incremental conductance approach is higher than that obtained from other methods. Maximum Power Point Tracking method plays a big role in grid connected photovoltaic system. The most appropriate MPPT approach is selected depending on the cost of implementation, the number of sensors required, and the complexity. As a consequence, the fuzzy logic controller-based MPPT approach produces improved outcomes for both residential and industrial applications. The research-based design and implementation of "Inertial Control by Fuzzy Logic Controller in Offshore Wind Energy System" concludes that the system design is robust and shows optimum performance despite inertial impact disturbances on the wind turbine system. The system is designed by critical and technical design approach and methodology.

In order to implement the advance based controller or intelligent based controller or fuzzy logic-based controller for the designing and implementation of off shore wind energy system we have to completely analyzed the system and thorough research-based study of literature work. For the purpose of planning and implementing a wind energy system, we designed a control strategy for the wind turbine system. In order to obtain robust, optimum and desired performance of offshore wind turbine despite the effect of disturbance such as inertia, we have to design and implement the advance or intelligence-based controller such as fuzzy logic controller to control the output response of the system of wind energy system. The fuzzy logic controller is designed in such a way that it acquires the error signal and apply the fuzzification and defuzzification via fuzzy logic assigned rules and provide the controlled output for so that we can get the controlled output response for inertia control of offshore wind energy system of wind turbine. In order to ensure the output simulation and get the output electrical power we engaged the Permanent Magnet Synchronous Generator PMSM to acquire the electrical output power and analyze the results. With the comprehensive analysis and simulation-based testing of wind energy system for offshore wind turbine it is concluded that the system is designed in the way that the system undergoes the robust performances despite the effect of disturbances.

The design and research work can be extended to develop the Artificial Neural Network ANN based design of offshore Wind energy system with hybrid solar PV array model to show more and accurate optimum and desire Performance despite the effect of Disturbances. The later research will be based on the analysis and design of Wind Turbine Blades angle control. There will be design and implementation of an AI-based controller to control the speed of generator speed in the presence of disturbances. The later research will be based on design and implementation of Fuzzy logic controller to control the speed of Permanent Magnet Synchronous Motor under Variable Load Conditions such as applied Torque on PMSM.

Future works for this study are oriented towards practical implementation and further optimization. The immediate step is to implement this project in remote regions, thereby allowing residents to harness the sun and wind energy for their daily needs, promoting a sustainable lifestyle while lessening dependency on non-renewable sources of energy. Additionally, the integration of these standalone energy production units with the main electrical network can provide a resilient and versatile energy distribution system, optimizing the use of produced energy by transferring excess power back to the grid. Furthermore, while the initial project focuses on integrating solar and wind energy systems, there is an opportunity to expand to other renewable sources like hydro and geothermal energy in future iterations, fostering a holistic approach towards renewable energy harnessing. The research findings from this project could be instrumental in driving policy changes and encouraging infrastructure development in underserved areas, with potential implications for energy access, rural development, and climate action.

REFERENCES

Abrol, R. and Jha, K. 2016. Power optimization in 5G networks: A step towards green communication. IEEE Access, 4(1): 1355-1374.

Alsharif, M. H., and Kim, J. 2016. Hybrid off-grid SPV/WTG power system for remote cellular base stations towards green and sustainable cellular networks in South Korea. Energies, 10(1): 1-9.

Alsharif, M. H. 2017. Optimization design and economic analysis of energy management strategy based on photovoltaic/energy storage for heterogeneous cellular networks using the HOMER model. Solar Energy, 147(1): 133-150.

Alsharif, M. H., Nordin, R. and Ismail, M. 2015. Energy optimisation of hybrid off-grid system for remote telecommunication base station deployment in Malaysia. EURASIP J. Wireless Commun. Netw, 2015(1):64.

Alsharoa, A., Ghazzai H., Yaacoub E. and Alouini M. S. 2015. On the dual-decomposition-based resource and power allocation with sleeping strategy for heterogeneous networks, In 81st IEEE Veh. Technol. Conf. (VTC Spring 2015), pp. 223-229, Glasgow, Scotland.

Aris, M. and Shabani, B. 2015. Sustainable power supply solutions for offgrid base stations. Energies, 8(10):10904-10941.

Bousia, A., Kartsakli, E., Antonopoulos, A., Alonso, L. and Verikoukis, C. 2016. Multiobjective auction-based switching off scheme in heterogeneous networks to bid or not to bid. IEEE Trans. Veh. Technol, PP (99): 1-1.

Carvalho, G. H. S., Woungang, I., Anpalagan, A. and Hossain, E. 2016. Qosaware energy-efficient joint radio resource management in multi-rat heterogeneous networks. IEEE Trans. Veh. Technol, 65(8): 6343-6365.

Chamola, V. and Sikdar, B. 2016. Solar powered cellular base stations: Current scenario, issues and proposed solutions. IEEE Commun. Mag., 54(5):108-114.

Saini, R. and Chauhan, P. 2014. A review on integrated renewable energy system-based power generation for stand-alone applications: Configurations, storage options, sizing methodologies and control. Renew. Sustain. Energy Rev. 38(1): 99-120.

Chia, Y.K., Sun, S. and Zhang, R. 2014. Energy cooperation in cellular networks with renewable powered base stations. IEEE Trans. Wireless Commun. 13(12): 6996-7010.

Chiang, Y. and Liao, W. 2016. Green multicell cooperation in heterogeneous networks with hybrid energy sources. IEEE Trans. Wireless Commun. 15(2): 7911-7925.

Dutta, S., T. Geiger, and Lanvin B. 2015. The global information technology report: ICTs for inclusive growth. World Economic Forum, Geneva, Switzerland, Tech. Rep.

Farooq, M. J., H. Ghazzai, A. Kadri, H. ElSawy and Alouini M. 2017. A hybrid energy sharing framework for green cellular networks. IEEE Trans. Commun. 65(2): 918-934.

Gandotra, P., Jha, R. K., and Jain, S. 2017. Green communication in next generation cellular networks: A survey. IEEE Access, 5: 11727-11758.

Ghazzai, H., Yaacoub E., Kadri A., H. Yanikomeroglu, and Alouini M. 2016. Next-generation environment-aware cellular networks: Modern green techniques and implementation challenges. IEEE Access, 4: 5010-5029.

Gong, J., Thompson, J. S., Zhou, S. and Niu, Z. 2014. Base station sleeping and resource allocation in renewable energy powered cellular networks. IEEE Trans. Commun. 62(11): 3801-3813.

Holtkamp, H., Auer, G., Giannini, V., and Haas, H. 2013. A parameterized base station power model. IEEE Commun. Lett. 17(11): 2033-2035.

Hasan, Z., Boostanimehr and Bhargava, H. 2011. Green cellular networks: A survey, some research issues, and challenges. IEEE Commun. Surv. Tutor. 13: 524-540.

Hassan, H. A. H., Pelov, A. and Nuaymi, L. 2015. Integrating cellular networks, smart grid, and renewable energy: Analysis, architecture, and challenges. IEEE Access, 3: 2755-2770.

Hossain, M. S., Jahid, A. and Rahman, D. M. F. 2018. Quantifying potential of hybrid PV/WT power supplies for off-grid LTE base station, In: Proc. IEEE Int. Conf. Comput., Commun, Chem., Mater. Electron. Eng. (IC4ME2), pp. 1-5, Rajshahi, Bangladesh.

Ismail, M., W. Zhuang, E. Serpedin, and K. Qaraqe, 2014. A survey on green mobile networking: From the perspectives of network operators and mobile users. IEEE Commun. Surveys Tuts, 17(3): 1535-1556.

Jahid, and Hossain, M. S. 2017a. Energy-cost aware hybrid power system for off-grid base stations under green cellular networks, In Proc. IEEE Int. Conf. Electr. Inf. Commun. Technol. (EICT), pp. 1-6, Khulna, Bangladesh

Jahid and Hossain, M. S. 2017b. Feasibility analysis of solar powered base stations for sustainable heterogeneous networks. In Proc. IEEE Region 10 Humanitarian Technol. Conf., pp. 686-690, Dhaka, Bangladesh.

Jahid and Hossain, S. 2018. Intelligent energy cooperation framework for green cellular base stations, In Proc. IEEE Int. Conf. Comput., Commun. Chem., Mater. Electron. Eng. (IC4ME2), pp. 1-6., Rajshahi, Bangladesh.

Jahid, A., Shams B., and Hossain M. F. 2018. Green energy driven cellular networks with JT CoMP technique. Phys. Commun., 28(1): 58-68.

Jahid, A. S., Ahmad, and Hossain, M. F. 2016. Energy efficient BS cooperation in DPS coMP based cellular networks with hybrid power supply, In Proc. IEEE Int. Conf. Comput. Inf. Technol. (ICCIT), pp. 93–98, Dhaka, Bangladesh.

Jahid, A., Monju, Hossain, M.K.H. and Hossain, M.F. 2018. Renewable energy assisted cost aware sustainable off-grid base stations with energy cooperation.IEEE Access, 6: 60900-60920.

Kanwal, K., Safdar, G. A., Ur-Rehman, M. and Yang X. 2017. Energy management in LTE networks. IEEE Access, 5: 4264-4284,

Oviroh, P. O.2018. The energy cost analysis of hybrid systems and diesel generators in powering selected base transceiver station locations in Nigeria. Energies, 11(3): 687.

Safwat, M. A., 2018. Framework for multi-operator collaboration for green communication. IEEE Access, 6: 850-865.

Zhang, Y., Meo M., Gerboni, R. and Marsan, M. A. 2017. Minimum cost solar power systems for LTE macro base stations. Comput. Netw.112 (1): 12-23.