SOURCE AND DEMAND SIDE ENERGY MANAGEMENT SYSTEM USING FUZZY LOGIC

Mohamedamin Sultan Abdulahi

A Thesis submitted to the Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the

Masters of Science Degree in Electrical Power and Control

Engineering (Electrical Power)

Office of Graduate Studies

Adama Science and Technology University

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DECLARATION

I hereby declare that this Master Thesis entitled "source and demand side energy management system using fuzzy logic)" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Mohamedamin Sultan ________________ **09/1/2021**

Name of Student **Signature** **Date**

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “source and demand side energy management system using fuzzy logic)” prepared under my guidance by **Mohamedamin Sultan** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Power and Control Engineering (Power). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr Tefara Terefe ________________ ________________________

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APPROVAL SHEET

I, the advisor of the thesis entitled "source and demand side energy management system using fuzzy logic)" and developed by Mohamedamin Sultan , hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis..

Dr Tefara Terefe ____________ **11/1/2021**

Advisor/Supervisor/ **Signature** **Date**

We, the undersigned, members of the board of examiners of the thesis by Mohamedamin Sultan have read and evaluated the thesis entitled "source and demand side energy management system using fuzzy logic)" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is for partial fulfillment of the requirement of the degree of Master of Science in Electrical Power and Control Engineering (Power).

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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LIST OF ACRONYMS

AC	Alternating current
ACS	annualized cost of the system,
BS	Battery status
C Rating	Measurement of current in which a battery is charged and discharged
CDCS	charge-discharge manipulate machine
CMS	Customers’ Management System
CO and CO2	carbon oxides
COA	center of area,
CSCs	customer service centers
CSP	Concentrated Solar Power
CSP	Concentrating Solar-thermal power
CSTP	concentrating solar- thermal power
DC	Direct current
DGs	Distributed generation
DM	demand management
DR	demand response
DRL	Daily Remaining Electricity Limit
DUSM	Demand and utility Side Management
EENS	Expected Energy not supplied
EEPU	The Ethiopian Electric Power Utility
EMS	energy management strategy
EMS	Energy management system
ESS	energy storage systems
FACTS	Flexible Alternating Current Transmission System
FC	fuel cell
FDMs	fuzzy decision makers
FLC	fuzzy logic controller
HRDS	human resource development society
HRES	hybrid renewable energy system
HWT	Horizontal axis wind turbines
LCE	the level energy cost,
LFR	Linear Fresnel reflector
LPSP	loss of power supply probability,
LS	load status
M&C	measurement and control (M&C)
MPPT	Maximum power point trucking
MPPT	maximum power point tracking
NASA	National Aeronautics and Space Administration
NO,NO2,N2O	Nitrogen Oxides

NPC	current net cost,
NREL	national renewable energy laboratory
P&O	perturb and observe
PB	battery power
PBP	payback period,
PEMFC	proton-exchange membrane fuel cells
PID	Proportional integral derivative
PTS	power transformation system
PV	Photovoltaic
SO2 and SO3	sulfur oxides
SOC	state of charging
STE	solar thermal energy
TEG	thermoelectric generation
TMY	typical metrological year
UC	ultra capacitors
V/F	Voltage/Frequency
VWT	vertical axis wind turbines
WT	wind turbine

ABSTRACT

Today and in the future, the increase of fuel price, deregulation, and environmental constraints give more opportunities for the usage of renewable energy sources (RES) in power systems. A microgrid concept is needed in order to integrate renewable sources in the electrical grid. It comprises a low voltage (LV) system with distributed energy resources (DERs) together with storage devices and flexible loads. The integration of RES into a microgrid can cause challenges and impacts on microgrid operation. The objective of this work is to design a scheme to control the energy flow of a hybrid renewable energy system with multiple renewable energy sources with an emphasis on solar and wind power and on multiple energy storage systems. The use of energy storage is necessary due to the intermittence of renewable energy sources and the resulting peak power mismatch between the sources and the load. In addition, the use of energy storage can increase the reliability and overall stability of the system. In this work, batteries are used as the primary energy storage system for short and medium-term storage, while the hydrogen fuel cell is used as long-term energy storage. Since power and demand are not completely predictable and have a time-varying nonlinear behavior, computational intelligence is introduced to solve this problem and provide an adequate control algorithm. The proposed methodology can be optimized so that the system is able to adapt to its working environment and provide the best results in certain circumstances. The controller has three main states such as discharge mode which allows the battery and hydrogen fuel cell to bear the load, balance mode when the supply power is equal to the demand, and the controller at rest, and finally, the charge mode which allows the battery and the electrolysis of water to receive excess energy and store it for later use. The system model is designed and simulated in the Matlab Simulink environment to check the proposed schema efficiency. Finally, the fuzzy logic controller is adopted to solve the optimal scheduling problem of the isolated microgrid. The simulation results indicate that the micro source scheduling strategy proposed in this paper can improve the operation economy and environmental conservation of the system. It can improve the reliability of microgrid power supply and reduce energy waste.

Keywords: Demand response, Demand-side management, Fuzzy logic, residential electrical energy control, supply-side management, time of use.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The goal of any power system is to deliver electricity to its customers in an economical and reliable manner. Unless this power is planned and maintained reliable, it causes adverse economic effect due to interruption costs and power outages on both the utility and its customers. The Ethiopian Electric Power Utility(EEPU) founded in 1956, is the state-owned utility in charge of electric power generation, transmission, distribution, sales service in the country and maintenance of the national grid. The company has been undergoing various continued transformations, such as via Customers' Management System (CMS), decentralization of Accounting and Billing system from once highly centralized down to the regional distribution offices, districts, and customer service centers (CSCs), and Prepayment (Metering) System, in an effort to realize its long term strategic vision of "becoming a center of excellence in providing quality electric service to everyone's doorstep and being competitive in energy export[1]." In my research studies, I focused on the energy management scheduling techniques that can be used to minimize the energy consumption Generation and load side power managements are mainly done for energy efficiency, sustainability, power loss minimization, voltage stability, power quality and operational problems. Control issues of voltage, frequency, power generation and active power conditioners are also considered as a part of power management. Decision makers are used with the controllers to manage the system operation in terms of power and energy management. The decision makers act as expert operators to decide what to do in case of events that require actions based on technical and operational knowledge. Therefore, fuzzy decision makers (FDMs) are used to store the expert's knowledge and decision-making abilities as fuzzy rules, which are processed by fuzzy reasoning algorithms [2]. Electrical electricity structures can be categorized into 5 sections: planning, generation, transmission, distribution and operation. Energy management is considered as one of the components in operation except protection, maintenance and marketing. Energy administration deals with preserving the generation and dissipation in balance by considering machine stability, sustainability, affectivity and fee optimization [3].

1.2Distributed generation and control

Electrical strength generation from wind and PV power systems maintains growing with the new installations in many countries. The renewable energy units are installed as large energy producing stations, which are typically called wind farms and/or PV farm. The PV systems are additionally mounted on the roofs in residential sites. A schematic one-line design of a disbursed technology with disbursed control is given in Figure 1. The generated energy from the disbursed generation units is accrued in a strength bus to be distributed to the loads[4]. The residential loads with PV gadgets on their roofs may also be powered without delay from these units. However, it is typically favored to sell the generated strength to the utility and purchase the required amount back from the utility in order to use the generated strength more correctly [5].

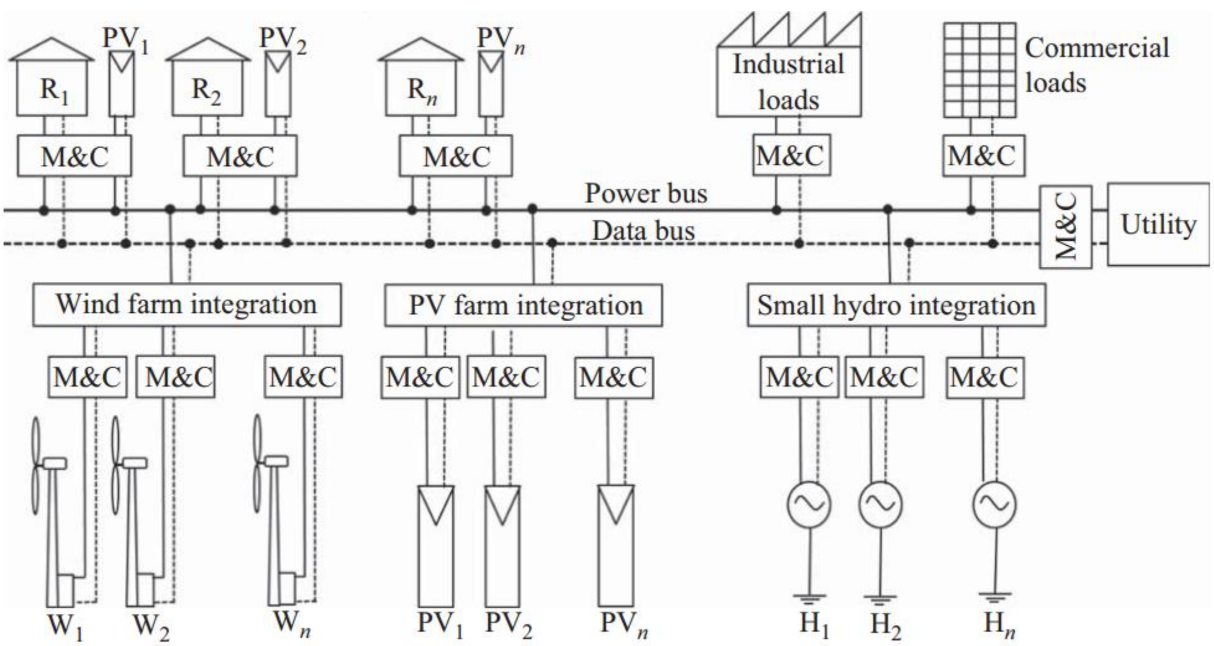


Figure 1.1 A distributed generation with distributed control

As shown in Figure 1.1, the power-generating gadgets and the masses are all linked to the identical distribution community such that any unexpected changes in hundreds or in producing gadgets affect the power network. Therefore, load dissipation and energy generation are monitored for gadget administration and manage purposes. Data is measured from each and every load and technology aspect and transmitted to a core the place the administration and manipulate selections are made [3]. This manage strategy is known as centralized controlling disbursed technology systems. The centralized management has been used widely in dispensed era[6]. However, the centralized manipulate requires tightly closed and fast data transmission from in all places in the network. The velocity of transmitted facts is very essential in real-time manage as the information protection is very essential for each manipulate and management. Development of smart gadget applied sciences has opened a new gate to a control strategy that is applicable in far off sites of distributed networks. This technique is referred to as disbursed control and can be used to manipulate load and generation sites proper where they are. Since facts is used by way of the controller at the dimension site, it will be quick enough for real-time manage as well as for quickly decision-making and management. Since data verbal exchange is minimized, the touchy records will be greater invulnerable with the dispensed control. In distributed manage scheme, the size and control (M&C) are performed domestically at every loading and producing unit. Every statistics is now not transferred to the central storage and control unit. The control and administration are processed separately for every load and era relying on neighborhood demand. Smart plugs, switches and decision makers are placed on the hundreds in terms of appliances and devices. Distributed manage has a greater flexible shape compared to that of centralized control [7]. The dispensed manipulate and management approach allows the energy utility employer to attain the clients through providing choice strength costs to run their hundreds at shifted times to forestall the over loadings and strength outages due to the fact of inadequate generation.

1.2 Centralized control of distributed renewable energy systems

The manipulate of disbursed generating is achieved normally by way of two approaches, centralized manage and disbursed control. In the centralized manage approach, all the measurements are transferred to a central laptop unit and the manage or management selections are made centrally by processing the algorithms in this computer. The centralized control of dispensed renewable electricity systems is discussed the use of a disbursed renewable strength integration scheme proven in Figure 1.2, which includes hybrid wind, PV, small hydro, and FC renewable energy schemes [8]

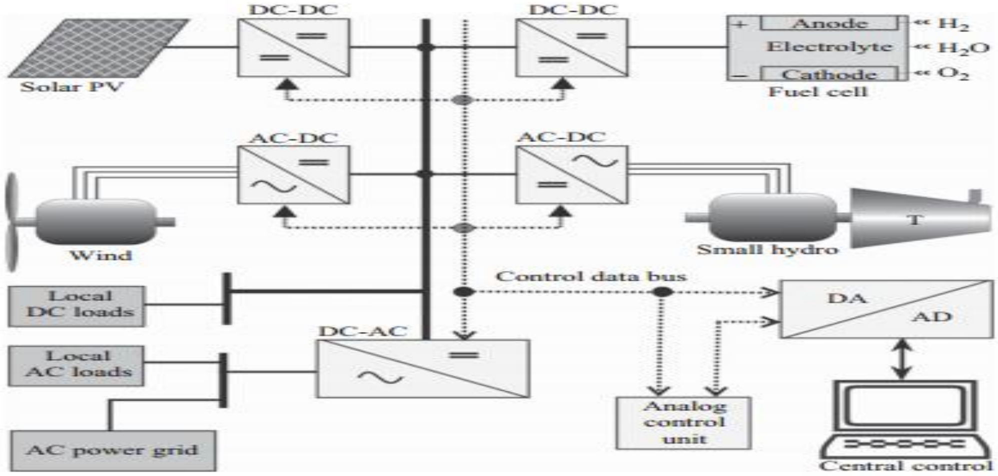


Figure 1.2 Distributed renewable energy system

The integration consists of a FACTS scheme topology, controller structure and interface converters for

(a) Maximum energy utilization

(b) low-cost implementation

(c) Conversion interface scheme robustness, effective control to minimize the impact of the renewable energy source on the host electrical grid or satisfactory performance for stand-alone operation

(d) Effective coordination and protection schemes for distributed energy systems

The manipulate schemes may additionally include classical PID, fuzzy, neural fuzzy, and another wise approach with adaptive. Derivative-free heuristic optimization strategies such as genetic algorithms, particle swarm optimization, ant colony, etc., may additionally be included for optimal parameter tuning of the controllers and decision-makers for maintaining power quality, system stability, and operational improvements. The stand-alone wind scheme is geared up with a novel modulated voltage/frequency (V/F) stabilization network, whilst the PV unit is utterly controlled for combining most on hand PV photo voltaic electricity utilization. Matching standards are utilized to make sure a entirely integrated hybrid wind, PV, FC, and small hydro renewable, low-cost, and low-maintenance useful device design[9]. The sample dispensed renewable power machine is controlled with the aid of the centralized control approach. Therefore, all data from generating units and hundreds are accumulated and saved in a pc to be used for manage and management purposes. The dotted lines in Figure 1.2 represent the data glide from size sites to the central control unit and vice versa. In this system, it has been assumed that all four generating units, PV, wind, FC, and small hydro, are positioned at the equal web page so that their output powers can be amassed on a common DC bus, which acts as a DC electricity pool. The FC in this machine is used as an energy storage unit beside the backup batteries. The electricity management of the gadget given in Figure 12.4 is done by using defining the primary obligations of the generating gadgets and the loading conditions. The availability of renewable sources is also every other key parameter. The power administration machine can be divided into three parts.

- Source management
- Load management
- Source and load management

Source management offers with the scheduling and the use of the electricity from renewable sources barring any scheduling on the load side. Whenever a load is turned on or off, the era is managed and controlled to furnish the required power. Since the generated energy from renewable sources relies upon on the availability of the generation, a selection has to be made beneath the modern-day circumstances. A approach to layout the generation-side management device can be developed as follows by assuming that getting energy from the utility grid is the last choice.

(a) The FC should be saved charged if the generation from the other sources is sufficient.

(b) The energy from the PV gadget needs to be used at its most capability as long as there is ample sunlight.

(c) The wind energy should be used to feed the masses if the PV system fails to supply.

(d) The FC have to be used if the strength generation from PV and wind fails to supply.

(e) The small hydro be used if PV, wind, and FC fail.

(f) The utility grid be used if all the others are not sufficient.

After determining the precedence use of the sources, a fuzzy rule base machine can be developed to system the source-side management system.

1.3 Demand and utility Side Management

There are basically two varieties of action for energy management: supply-side management, which includes the development of new generating devices and the control of demand the use of power conservation policies, and demand and utility aspect administration (DUSM), which entails the discount of waste and the use of greater environment friendly tools [10]. Most researchers outline DUSM as a program or set of things to do gear up by using the utility that affect the amount and timing of client use. DUSM is a ability to intervene in the use and the variety of modes of electricity consumption [11]. One of the desires of DUSM is to reduce the height tiers of energy demand all through the day. The customer-side demand administration (DM) can be achieved in numerous ways but all the DM techniques are primarily based on two aspects, reducing consumption and moving consumption . Scheduling the loads is also a famous technique of DM where some of the loads are selected whilst others are shifted. Authors K.E. Parameter et al. have described DSM as planning, implementation, and monitoring of the utility activities that influence the customer's use of electrical energy in approaches that changes the utility load shape [10], i.e., adjustments in the time pattern and magnitude of a utility's load. One kind of demand-side management is demand response, which focuses on rate indicators to handle top demand. Peak demand can be dealt with by way of either the usage of a price-based system, the place the electrical energy price fluctuates according to the load or with the aid of using an incentive-based system, where incentives are given to clients to limit load at height instances [11]. Demand response is a key thing of DSM. The Federal Energy Regulatory Commission defines demand response (DR) as "Changes in electric powered usage by means of end-use clients from their normal consumption patterns in response to modifications in the charge of electricity over time, or to incentive payments designed to induce decrease electrical energy use at instances of high wholesale market fees or when machine reliability is jeopardized". In different words, demand response (DR) is the approach to manipulate a customer's load all through height demand to the other time, when the demand is less. This helps in reducing the peak demand of the grid, and also in the discount of fees on the patron side. DR can be utilized to each residential and industrial loads and includes three exceptional concepts: strength consumption reduction, shifting consumption to intervals of low (or high)

1.4 Statement of the Problem

With the advancement of research to bridge the energy gap due to increased demand for energy relative to its supply, an unreliable alternative solution is unacceptable. Single-source renewable energy systems have proven to be considerably unreliable due to the climate dependent nature of the resources: therefore, hybrid renewable energy systems (HRES) have been and still are being developed to do so in the face of unreliable single-source renewable energy systems. These hybrid systems are constantly deployed and installed at consumer sites. Because some of the renewable energy sources can complement each other, multi-source alternative energy systems have great potential to provide customers with better and more reliable energy than a system based on a single resource. However, the problems related to the optimal system configuration, the correct electronic power supply interfaces and the energy management between the different power sources are still not resolved [12]. For the sake of efficiency and reliability, HRES should be monitored and controlled. This monitoring and control takes full advantage of the complementarity of renewable energy sources to provide constant and reliable power. Conventional techniques for monitoring and controlling energy flow in HRES have proven ineffective, hence the need for more efficient methods such as the use of fuzzy logic control for system optimization. The HRES application environment must also be taken into consideration in order to adequately adapt the system to the load requirements. Demand-side management at the consumer end side approves buyers to actively take part in their energy administration process. It helps them to use the provided strength successfully via shifting their utilization from top hour to off-peak durations with the help of the proposed model which shows the next day's strength demand at some stage in the day relying on the forecasted strength demand at a unique time and forced customer-side demand to shift their load to off-peak period by using limiting the strength delivering to them and the consumer can agenda their electrical energy utilization for the next 24hour. Both forecasting and scheduling motion are carried out through the proposed model. The model developed in this thesis is referred to as a fuzzy logic-based utility and demand side management system, we name it active because the model performs two activities at a time that are forecasting and scheduling. The success of this task (DUSM) is to help consumers with a better strength provider at a lower cost, decreasing equipment failure and reducing the length of blackouts.

1.5 Objectives of the Study

1.5.1 General Objective

The main objective of this project is to design fuzzy logic based utility and demand side energy management system model for monitoring and controlling a hybrid renewable energy system, and supplying reliable power to the end user.

1.5.2 Specific Objectives

- To look into the predominant causes of reliability issues of the electricity distribution system
- To draw relevant conclusions and suggestions from the result of the investigation.
- To focus on minimizing power consumption.
- To optimize the membership feature with a genetic algorithm for the design of fuzzy common sense controller
- To enhance a fuzzy logic model for equipment scheduling based totally on the forecasted value.
- To plan utility and demand-side administration model on Matlab Simulink.

1.6 Significance of the Study

The result of this investigation will bring benefits in both directions for both the consumer and the service provider in Ethiopia. The research contribution will modernize the country's traditional energy management. The result of the investigation will help the utility company to facilitate its service. Consumers also benefit from the research results in order to efficiently manage and control their consumption of electrical energy.

1.7 Scope of the study

HRESs differ in the number and type of renewable energy sources they are composed of. This project is limited to a HRES consisting of PV, wind, and battery system. The main focus of the work is to design the monitoring and control system for a HRES, end user management and not the entire HRES.

CHAPTER TWO

BACKGROUND AND RELATED WORK

2.1 Renewable Energy Resources

Renewable energy is energy that can be obtained from renewable natural resources and is sustainable and abundant compared to human life expectancy. .Wind, hydropower, tides, biomass, geothermal energy are also different examples of renewable resources. Renewable energies have enormous potential worldwide due to many concerns and factors. They pollute less than fossil fuels, they exist almost everywhere and could overall efficiency greater than as energy collection and conversion technologies improve. Additionally, the growths in global demand for advent smart grid concept are putting more pressure on the selection of these sources than the traditional ones. In this section, the focus is placed on the resources of solar and wind energy because they were selected as part of the investigation of the hybrid renewable energy system model. Solar and wind energy are chosen because of their availability almost everywhere on earth as compared to other renewable resources such as hydropower and geothermal energy, which are found in some places around the world and not depending on geographic features in others. Better a portable system, easy to transport, easy to install and compact like photovoltaic solar panels and wind turbines. many other reasons that encourage using solar and wind to assuring sustainable future generations life, reducing greenhouse emissions such as nitrogen oxides (NO, NO2 and N2O), sulfur oxides (SO2 and SO3), and carbon oxides (CO and CO2) and increasing energy sources diversification[12]. The CO2 emissions for solar PV are estimated to be 49.91 g on average with a low estimate of 1 g and a high estimate of 218 g per kWh while wind CO2 emissions are 34.11 g on average with a low estimate of 0.4 g and a high estimate of 364.8 g per kWh [13].

2.1.1 Solar Energy

The sun is the main source of most of the energy on earth. It rises in the sky every day and carries amounts of energy to heat and illuminate the earth's surface. It is the only star in our solar system and the closest that can deliver a tremendous amount. Energy for our house, the earth. It accounts for almost 99.85% of the total mass of the solar system. The average distance between the sun and the earth is 150, million km and sunlight takes eight minutes and

20 seconds to reach the earth [13]. Theoretically, the force of the sun on the earth's surface is 89,300 TW [14].The sun is powered by the nuclear fusion of hydrogen atoms and its surface temperature reaches 5,800 Kelvin while its core reaches a high level of 15.7 million K [15]. When the sun rises, the energy of sunlight is reflected or absorbed. About 51% of this is taken up by land and sea, and 16% by the atmosphere, which warms the earth and makes it suitable for all living species. 20% is reflected in the clouds, 6% in the atmosphere and others [13]. Plants are the oldest solar panels, collecting sunlight and converting it into chemical energy in the form of sugar and producing oxygen through a process called photosynthesis [16]. For a long time people viewed the sun as a great source of energy and began to think about how to convert this energy into useful forms. One of the trivial methods began with concentrating solar energy on a focal point for cooking food, and the first reported solar cooker was in India by Adams in 1878[13]. Heating water, distilling water or tumbling water with solar energy can be added to the list. By the end of the century to, with the increasing volatility in the price of fossil fuels, the increase in global warming and the need for energy security, many governments, industrial owners, scientists and engineers have considered the development of new technologies and methods of extraction the solar energy source and to generate electricity as a renewable, clean and sustainable energy source. Technologies took different directions, with some scientists and engineers focusing on converting sunlight into heat and then electricity, while others preferred direct conversion. In electricity based on a physical principle called the photoelectric effect [17]. Other semiconductor materials can convert solar heat into electricity, a process known as thermoelectric generation (TEG). However, it is still in its infancy, since some scientists have been working to increase its efficiency and reduce its production costs [18]. Both CT cells are solid state and direct current converters, which mean the runs quietly with no moving parts and less maintenance. On the other hand, solar thermal requires a much longer process and requires more parts to produce electricity.

2.1.2 Sun Energy form

Solar energy reaches the earth in the form of electromagnetic radiation with different wavelengths [19]. Follow this distribution: 6.6% ultraviolet, 44.7% visible light and 48.7% infrared, as shown in the picture:

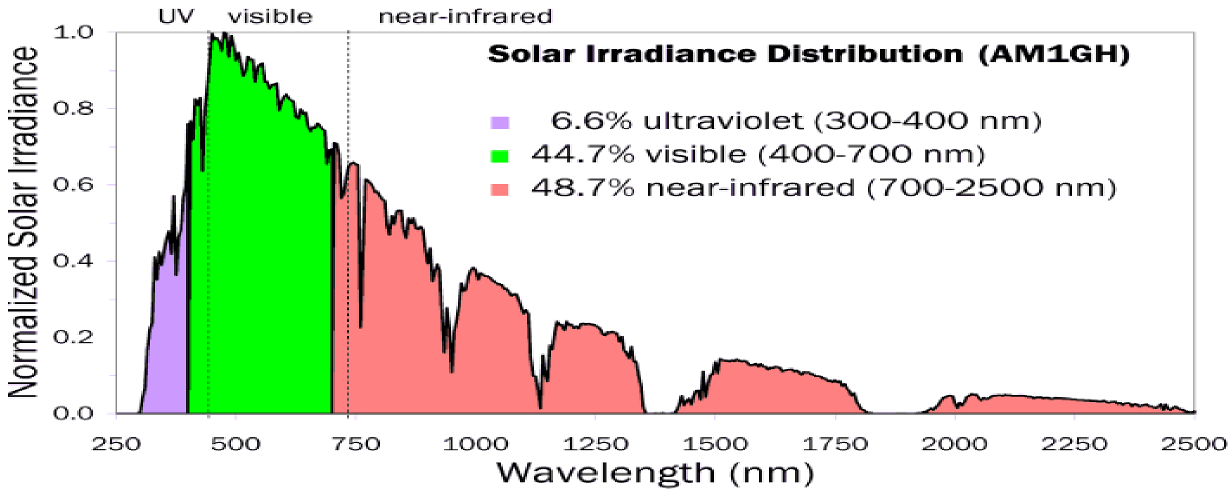


Figure 2.1 solar energy distribution (Tsao et al., 2006)

2.1.3 Sun Energy Harvesting techniques

There are many techniques currently in existence to collect solar energy and convert it into usable energy or electrical energy. This technology plays an important role in the renewable energy industry, solar type. Because of the 's competitive cost, low maintenance and easy installation, compatibility, quiet and direct power conversion, it is nominated as the first choice for inverters compared to Concentrated Solar Power (CSP) and other technologies. In 2016, China alone accounted for of the 85% of total photovoltaic installations worldwide[20]. The following figure breaks down the various solar technologies according to their operating principle.

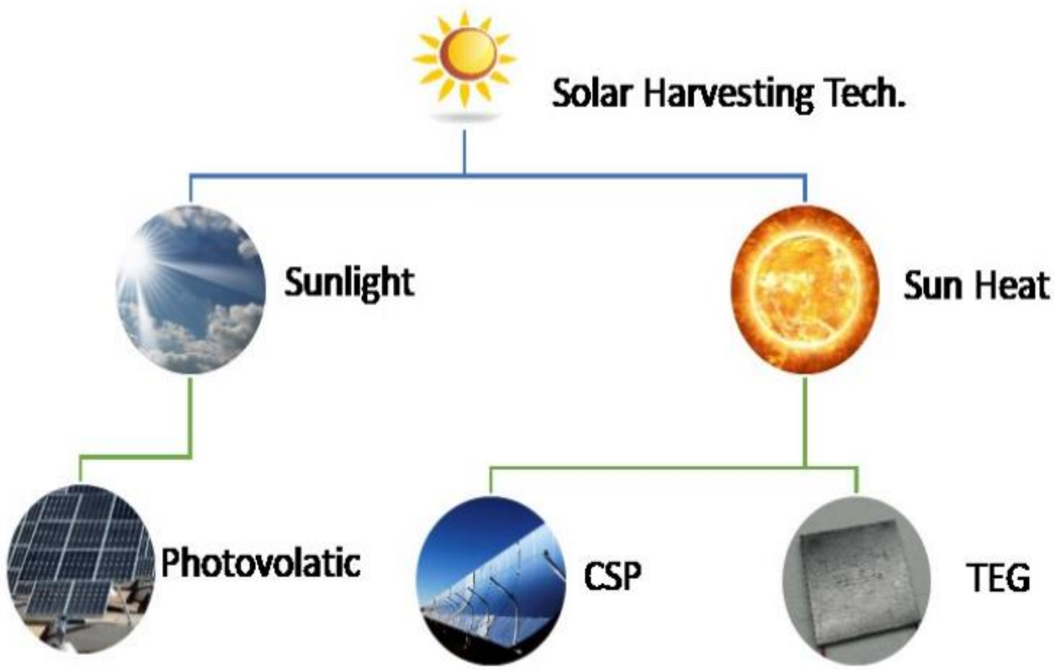


Figure 2.2 Solar Harvesting techniques[21]

2.1.4 Photovoltaic

A photovoltaic molecular is a semiconductor fabric that converts mild at once to electricity primarily based totally at the precept of photoelectric impact [20]. The first photoelectric impact located by French physicist Edmund Becquerel in 1839 [15]. wherein he observed it in Selenium [22]. Photovoltaic cells include or greater layers to create a permanent electric powered field. When mild moves the molecular, electrons get excited and make their manner to the engaging in a part of the molecular to the load [15]. Solar radiation and ambient temperature are the molecular inputs of photovoltaic, while electric current and voltage are the molecular outputs. Commercial molecular PV has very low conversion performance with a median of 1217% and in which a molecular supermono has a performance of 21%, as shown in the figure (Report, 2017). Since these cells still have lower yields and are climate-structured and feature non-linear output electricity, extracting the most viable electricity is an important goal for an efficient PV system.

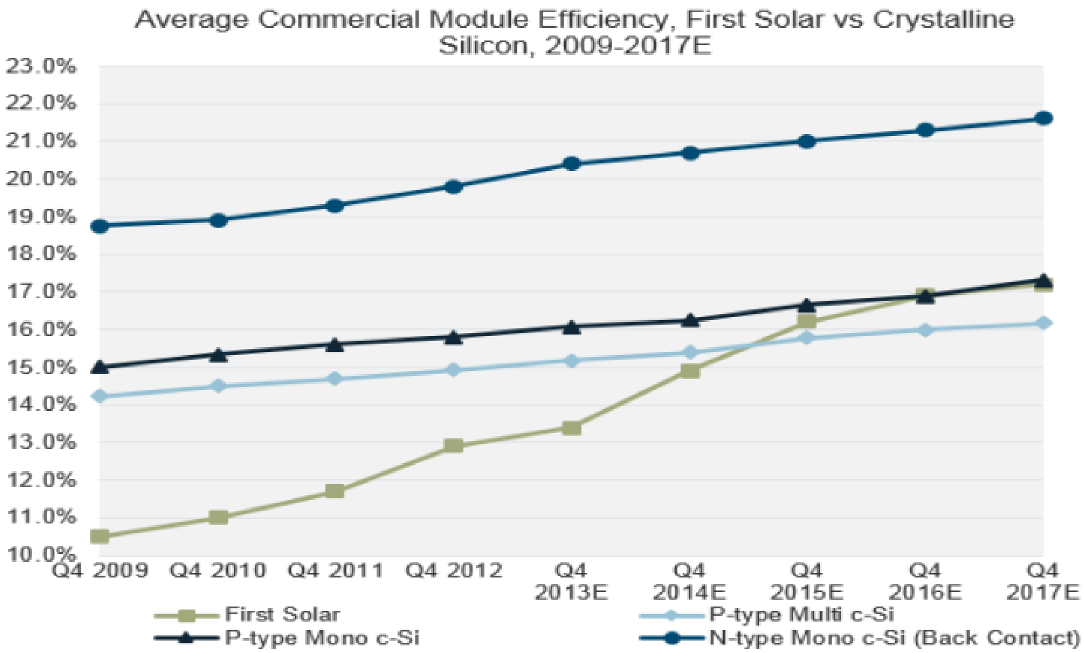


Figure 2.3 Average Commercial PV Efficiency [21]

The subsequent figure describes the function of a PV modern and voltage. Thus, the cell modern is proportional to sun irradiance at the same time as its voltage is inversely proportional to ambient temperature [21].

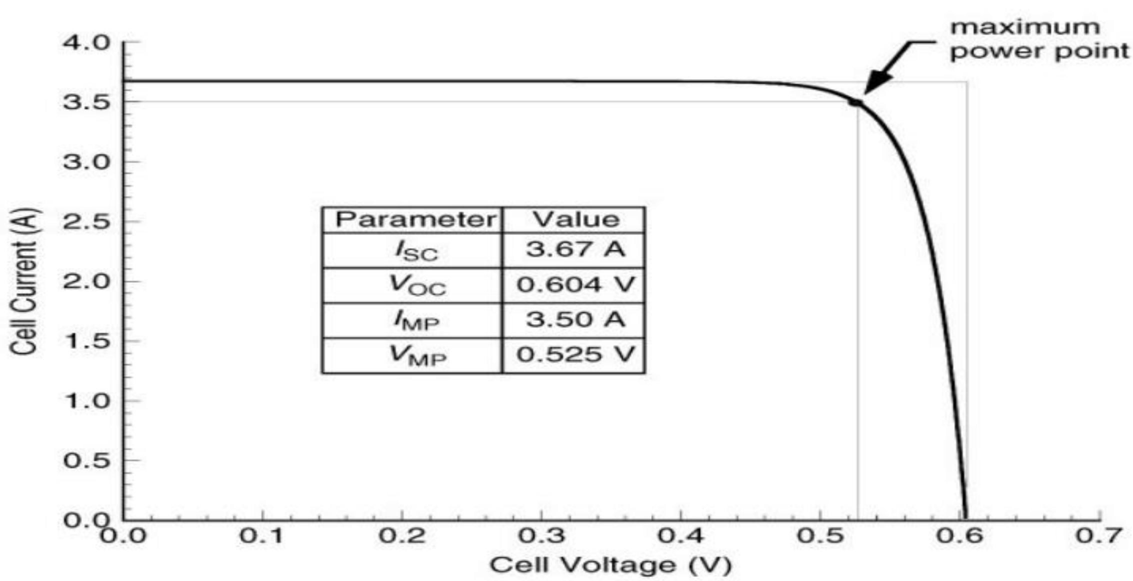


Figure 2.4 Current-Voltage characteristic for PV cell [21]**.**

The photovoltaic cell converts light with different wavelengths at the PN junction into electricity, generates electricity directly from the cell when it is connected to a load. According to [23] . the currently produced is given by

$$\boldsymbol{I_{total}} = \boldsymbol{I_0}\left(\boldsymbol{e^{qv/kt}} - \mathbf{1}\right) - \boldsymbol{I_L} \qquad 2.1$$

where k is Boltzmann's constant, I_O defines the current scale and q is the electrical charge of particles that make up the current I_{total}. Furthermore, I_L is the generated luminous flux and T the ambient temperature . Based on the solar radiation and the ambient temperature, two decisive physical parameters in photovoltaics, the photovoltaic cell corresponds to and produce open circuit voltage and closed circuit current [24]. The maximum available power can be determined by monitoring the maximum power point on the photovoltaic curve under different operating conditions, e.g. Irradiation changes (partial shading), temperature changes and load changes can be taken. This monitoring mechanism determines the best voltage reading of the system and is performed with the MPPT maximum power point tracker. The MPPT is the middle between the photovoltaic fields and the rest of the power system.It consists of a DC converter and a controller that monitors the photovoltaic current and voltage and, based on a specific algorithm, adjusts the duty cycle of the DC converter. Researchers have developed different approaches and techniques to design this algorithm. Algorithms in those documents [25], [26], [23]. The generic solar photovoltaic system consists of solar collectors, an MPPT controller and a DC-DC power converter, as shown in the following figure [26]:

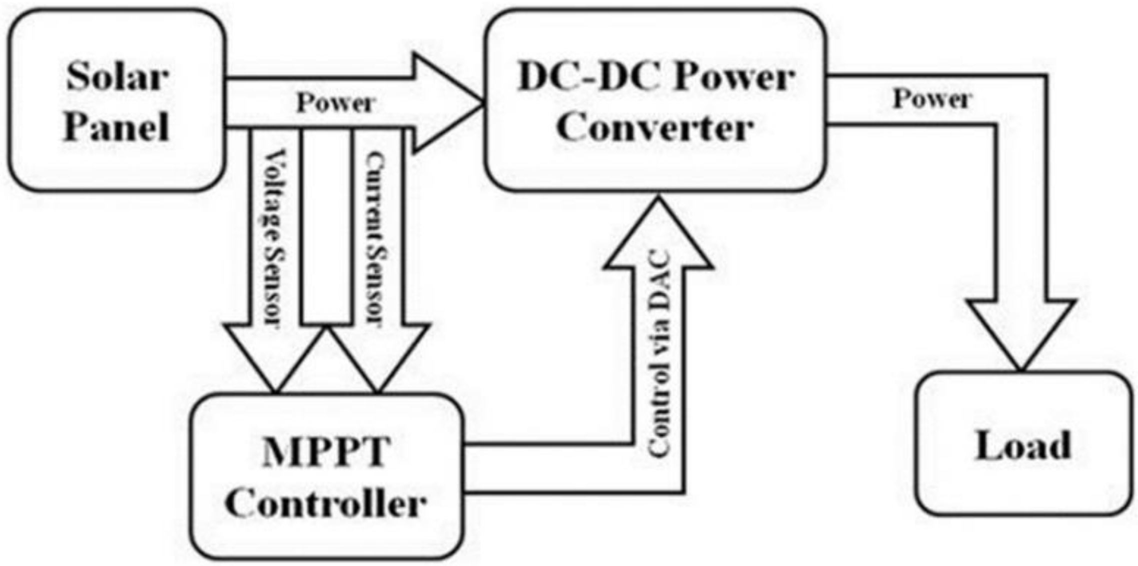


Figure 2.5 Solar PV System Components (Shiau et al., 2015)

2.1.5 Concentrated Solar Power

Concentrated solar energy, also known as solar thermal (STE), is the process of concentrating solar radiation and using its heat to heat a liquid that powers a steam turbine to power an electrical generator . It's another way of collecting solar radiation[27]. The solar heat is collected and concentrated to heat a liquid or gaseous fluid, usually oil or molten salt, then that fluid is passed through a heat exchanger to transfer the recovered heat to boiling water to drive a turbine steam. , the remaining fluid can be stored in a heat storage device for later use. The steam turbine is connected to an electrical generator to produce electrical energy for the system.The system is the speakeronus or an offgrid.In practice, the maximum CSP temperature extends with a concentration factor of more than 1000 ° C with a concentration factor of more than 10000 [28]. In 2016, the total CSP energy production increases to 4.8 GW, where Spain is the market leader with 2.3 GW of production, followed by the United States which produces 1.7 GW, as shown in the following figure [29].

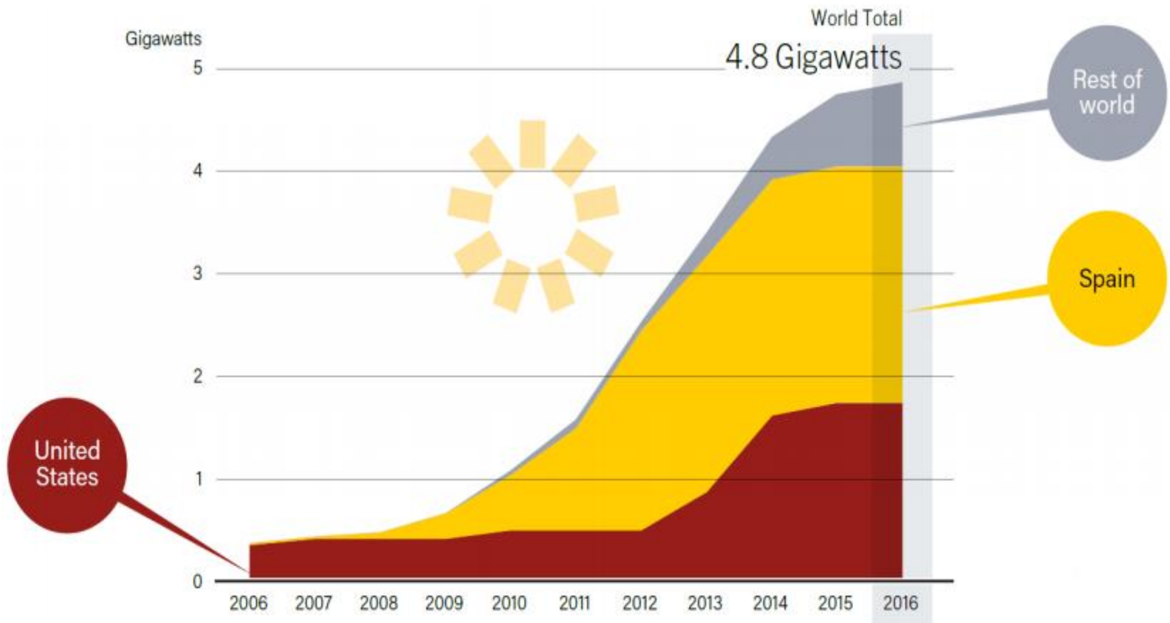


Figure 2.6 Concentrating Solar Thermal Power Global Capacity (Report, 2017)

There are different types of CSPs, as well as different configurations. The CSP has four main types of linear fresnel reflector (IFR), parabolic channel, center receiver and parabolic dish. The first two types are called single axis concentrators in which sunlight is focused on an absorber tube. While the other two types are called dual axis concentrators in which rays of the sun are focused on a central absorber at the focal point. Both types require a solar tracker that detects the position of the sun in the sky and then adjusts the concentrator accordingly for optimum power production [30]. The following figure shows the four types of CSP [31]:

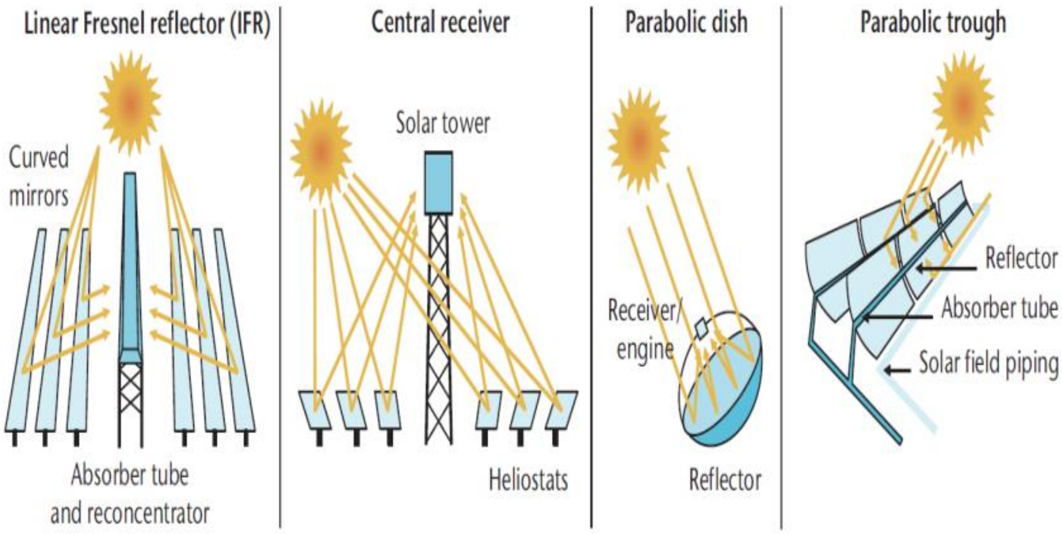


Figure 2.7 CSP Main Technologies (Narducci & Lorenzi, 2021)

Most current CSP projects use thermal storage units to store additional heat and supply it to the system when demand exceeds supply. Additionally, the most commonly used types are the parabolic channel and central receiver techniques [29].

2.1.6 Thermoelectric Generator

The Seebeck effect is a physical effect which illustrates the conversion of heat to electricity at the junction of two different materials appears mainly in conductors or semiconductors due to the movement of charge , Thomas Seebeck discovered this effect in 1821 [20]. TEG stands for Thermoelectric Generator . For many years, researchers have mainly focused on developing thermoelectric materials from semiconductor materials for several reasons:

1. They have low thermal conductivity which reduces heat flow from the hot side to the cold side.

2. They have high electrical conductivity, especially at high temperature, which increases the power factor of the material by since the power factor is $P = \alpha S$ where S is the Seebeck coefficient .

3.They have an excellent bandwidth electrical structure compared to metals. TEG works under difficult conditions like high temperature on the hot side and low temperature on the cold side, which can put stress and strain on the device. On the other hand, due to geometric constraints, the cell generates small voltages, so that the best possible way of avoiding these constraints is to connect the cells electrically in series and thermally in parallel. The following figures describe how it works [20].

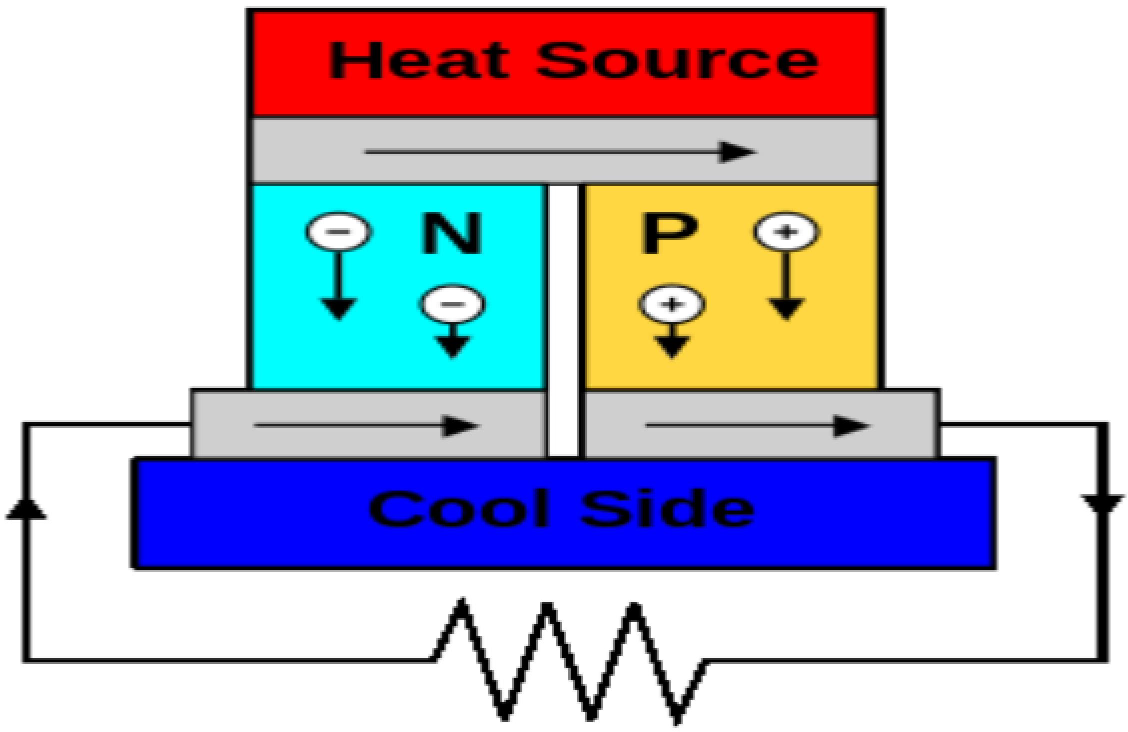


Figure 2.8 Charge Movement in Thermoelectric Cell (No Title, n.d.-b)

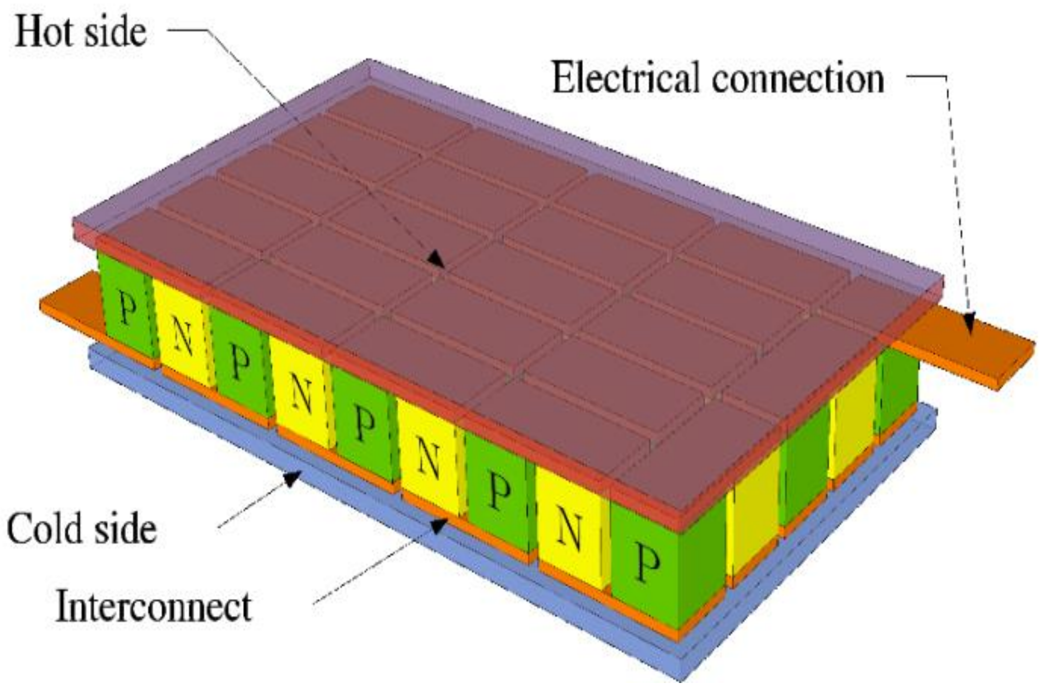


Figure 2.9 Thermoelectric Generator Module (No Title, n.d.-b)

There are three known materials that are used for TEG, bismuth telluride ($Bi2Te3$), lead telluride (PbTe), and silicon germanium (SiGe). The most typical TEG has an efficiency of 5 6% [20].

$$ZT=\frac{\textit{electrical conductivity} * \textit{temprature} * S^2}{\textit{Thermal conductivity}} \qquad \textbf{2.1}$$

The existing uses of TEG are diverse, such as the recovery of waste heat in cars, power plants and gas pipelines, where Gentherm is the world's largest manufacturer of TEGs. In addition, spacecraft use TEG radioisotopes to generate electricity, as in the spacecraft that sent to Saturn, CassiniHuygens, which has three TEG radioisotopes powered by 238Pu (plutonium) and the thermoelectric material used is SiGe [28]. However, this technology still has major disadvantages to its use, such as: 1. They are rare elements, therefore expensive to manufacture and require a high purification process for high efficiency. The current efficiency is still low compared to other technologies. Then the solution of these obstacles can be overcome through the use of thermal collectors, hybrid design through the creation of new and nano-structured materials. Since the cost of TEG is high, it is efficient to use solar thermal collectors to raise the hot side temperature and reduce the size of the TEG material. In addition, effective heat dissipation materials are used to have a large temperature gradient. There are two main types of solar thermal collectors: optical light concentrator and heat absorber. In a laboratory experiment, a heat absorber with a solar absorption of 94.4% is used to make a flat CTEG. Panel and the results were shocking in , they were able to increase the efficiency by 78 times (4%) by using a ZnSb alloy and a Bibase alloy with an efficiency of 0.5% and state that the efficiency is higher can be than 15 times (8%). many factors lead to such a result: nanostructured materials, selective surface, high thermal concentration, operation in an evacuated environment [31].

2.1.7 Solar thermal generator versus concentrated solar power

Both are heat engines and follow the Carnot principle. As an energy system, they are supposed to convert solar thermal into electricity[32]. STEG is noiseless, no moving parts, direct conversion, dependent on material properties, very low maintenance, robust - solid body, works for every temperature gradient, works in weightlessness, highly scalable size, can be small. However, the is expensive, has low efficiency, and has little market potential. On the other hand, CSP has working fluids, moving parts, multi-component system, requires regular maintenance, is material and system dependent, generally for large system applications, uses an existing industrial base and limited geographical locations due to federal regulations and environmental conditions, it is effective, especially at high Concentration ratios and storage elements[33].

2.1.8 Photovoltaics versus concentrated solar power

According to NREL, the most powerful photovoltaic cell tested in the laboratory has an efficiency of 46% in the laboratories of Fraunhofer ISE [28]. However, the highest commercial photovoltaic cell has an efficiency of about 21% [34]. PV has three main types of monocrystalline, multicrystalline and thin films, in addition to smaller ones.

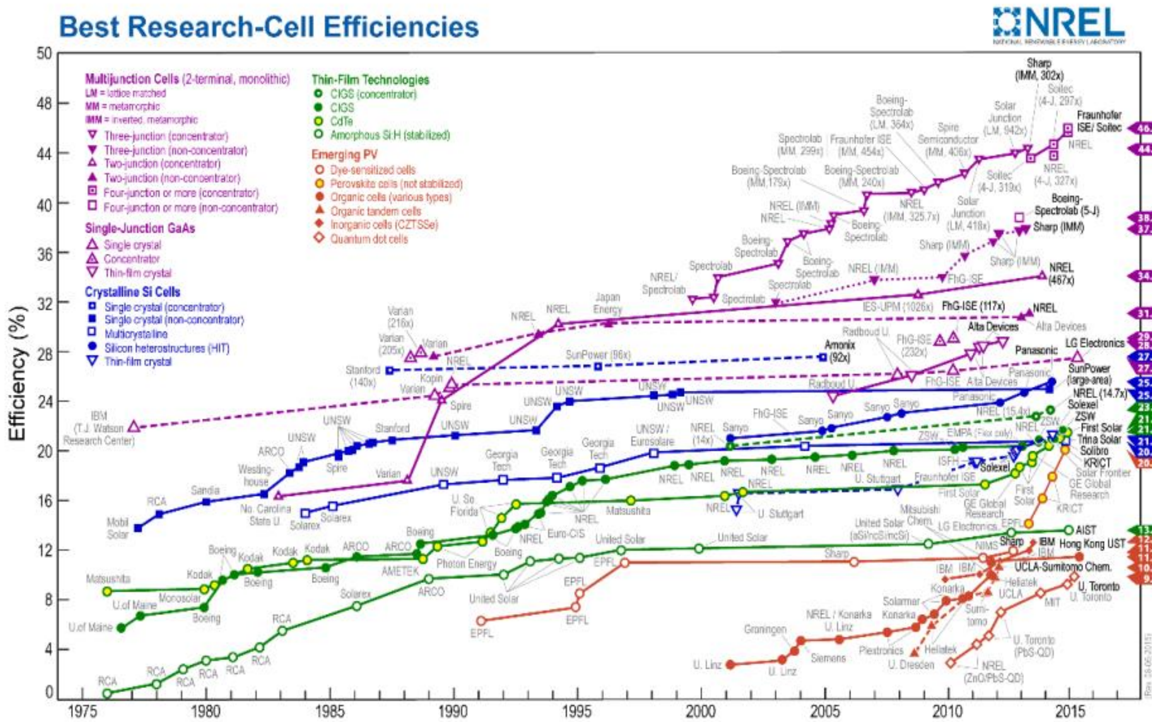


Figure 2.10 Top Research PV Cell Efficiencies (T. J. Price, 2005.)

On the other hand, concentrated solar power technology works as a heat engine and convert heat into work and follows Carnot's principle so their efficiency depends on concertation factor and the receiver temperature.The best commercial efficiency is around 49% for molten salt tower plus project according to Abengoa company where it is shown in next figure and compared with combined cycle efficiencies .CSP in sunny regions produces electricity cheaper than Solar PV[26]

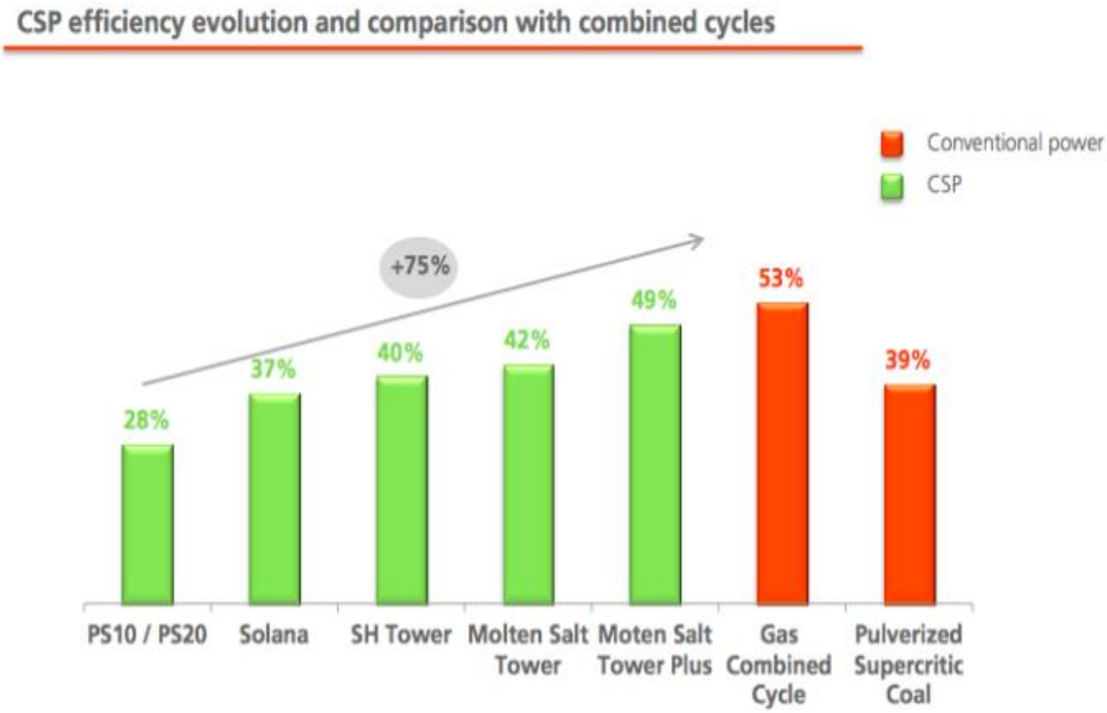


Figure 2.11 CSP Efficiency compared to combined cycles (El-tamaly & Ata, 2018)

2.1.9 Hybrid photovoltaic and thermoelectric generator

The synergy principle states that the amalgamation of different resources and components leads to higher work efficiency and gives many researchers the potential to develop hybrid sources of renewable energy for which each source would and would complement the other run a highly efficient system. PV and TEG share many similarities that help designers build systems that incorporate them for better quality and efficiency of power delivery. Both are quiet, scalable, only dependent on materials and produce direct electricity. He did a great job designing the and analyzing these systems[35].

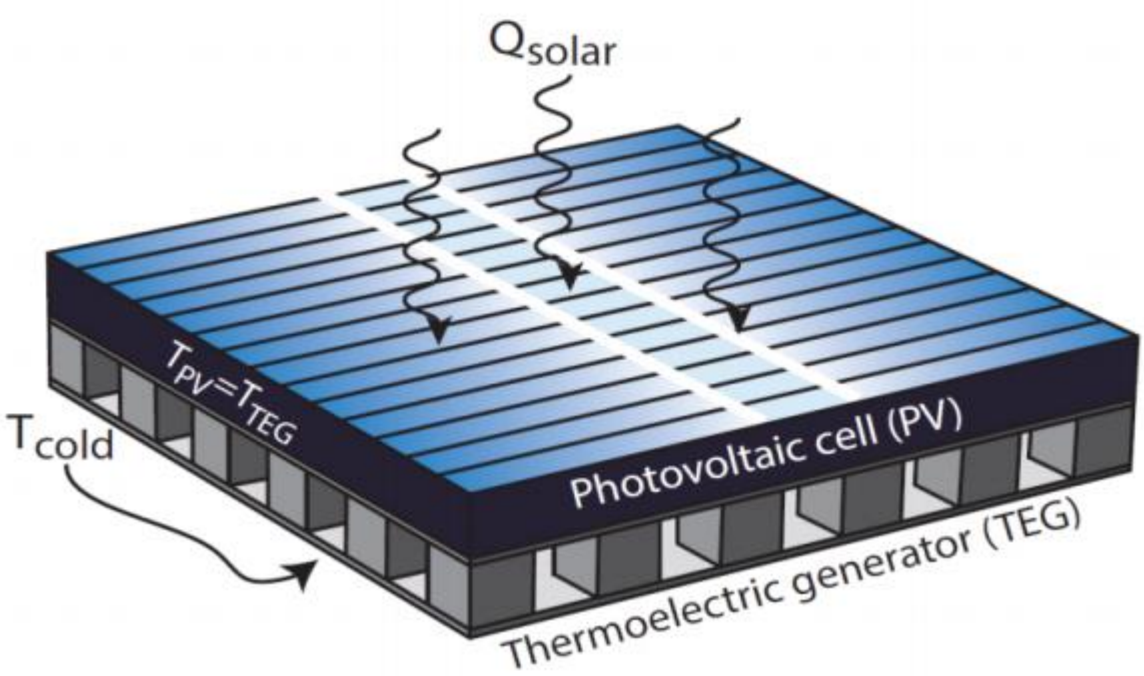


Figure 2.12 Hybrid PV-TEG Cell (Wu et al., 2018)

Through many types of research, the total production of photovoltaics plus TEG with solar thermal collectors will increase, but without them the overall efficiency could be lower than with stand-alone photovoltaics. Photovoltaics convert part of the spectrum into electricity and most of it is converted into heat. So some research is using a wavelength splitter to pass up to 800nm to the PV while the rest is reflected. This graphic illustrates the idea of the separator [4].

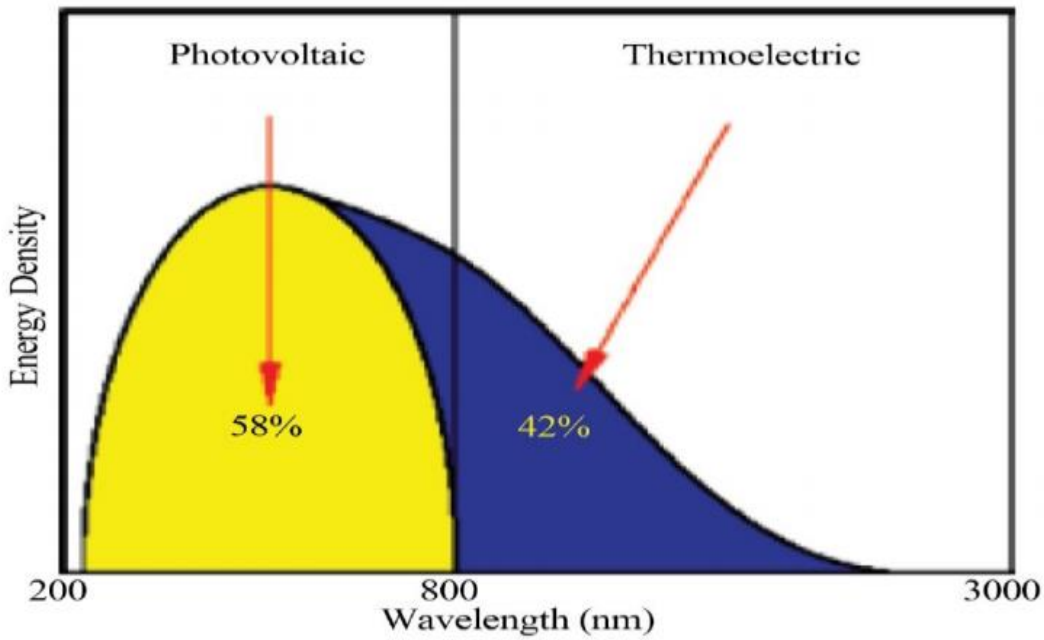


Figure 2.13 Solar Radiation Spectrum Separator (Narducci & Lorenzi, 2021)

Another study shows that certain types of PV blend well with TEG due to their thermal properties. The TEG must have a maximum operating temperature below 200 degrees Celsius, otherwise the PV efficiency drops quickly and with it the overall efficiency [31].

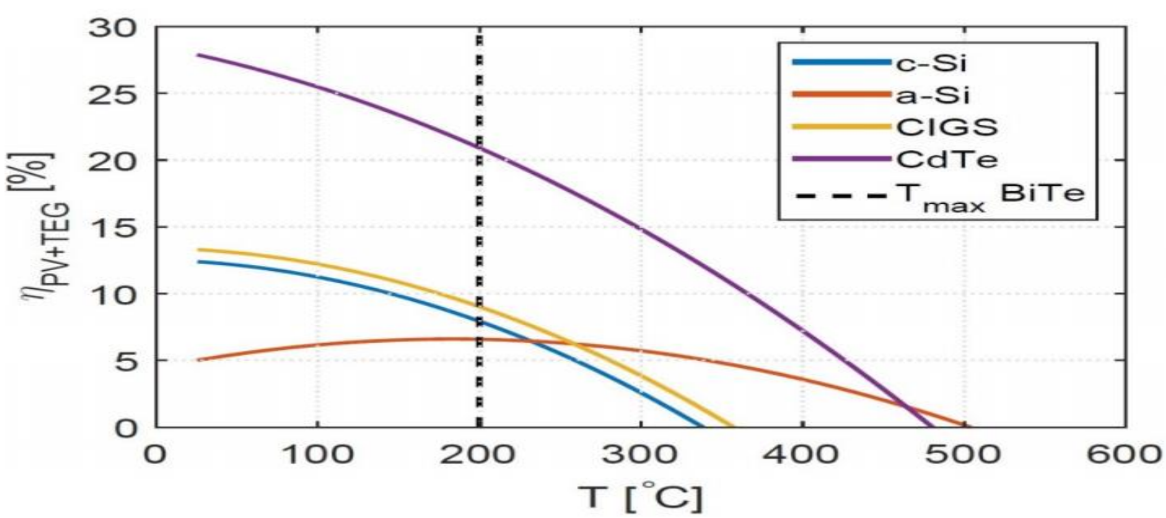


Figure 2.14 PV+TEG Cell Efficiency (Narducci & Lorenzi, 2021)

2.2 Wind Energy

In the last few years, wind power generation has great potential worldwide that even exceeds photovoltaics and is one of the fastest growing renewable energies in the world [36]. By 2016, global wind power generation was 487 GW, up 55, GW from 2015. The five largest countries in wind power generation are China, the United States, Germany, India and Brazil. More than 90 countries have commercial wind power generation and 29, of them exceed one gigawatt capacity in 2016 [37]. With current policy, the estimated electricity generation would reach 977 GW by 2030.The first inspiration for using a windmill to generate electricity came in July 1887 in Scotland from Professor James Blyth of Anderson's College, who designed a 10 meter high windmill and installed it in the garden of his vacation home vacation [38]. The wind is the flow of air mass as a natural phenomenon due to the differential atmospheric pressure. Different atmospheric pressure forces the air to move from an area of higher pressure to a lower one. The differential is generated by the different air temperature and the terrain of the earth's surface. The sun's heat is reflected from the earth's surface to the surrounding air and because the sun's heat is not evenly distributed over the earth. the difference in air temperature arises, which leads to the development of the wind [39]. Therefore, the winds have different directions and speed patterns, as the following figure shows how the winds circulate around the earth [39].

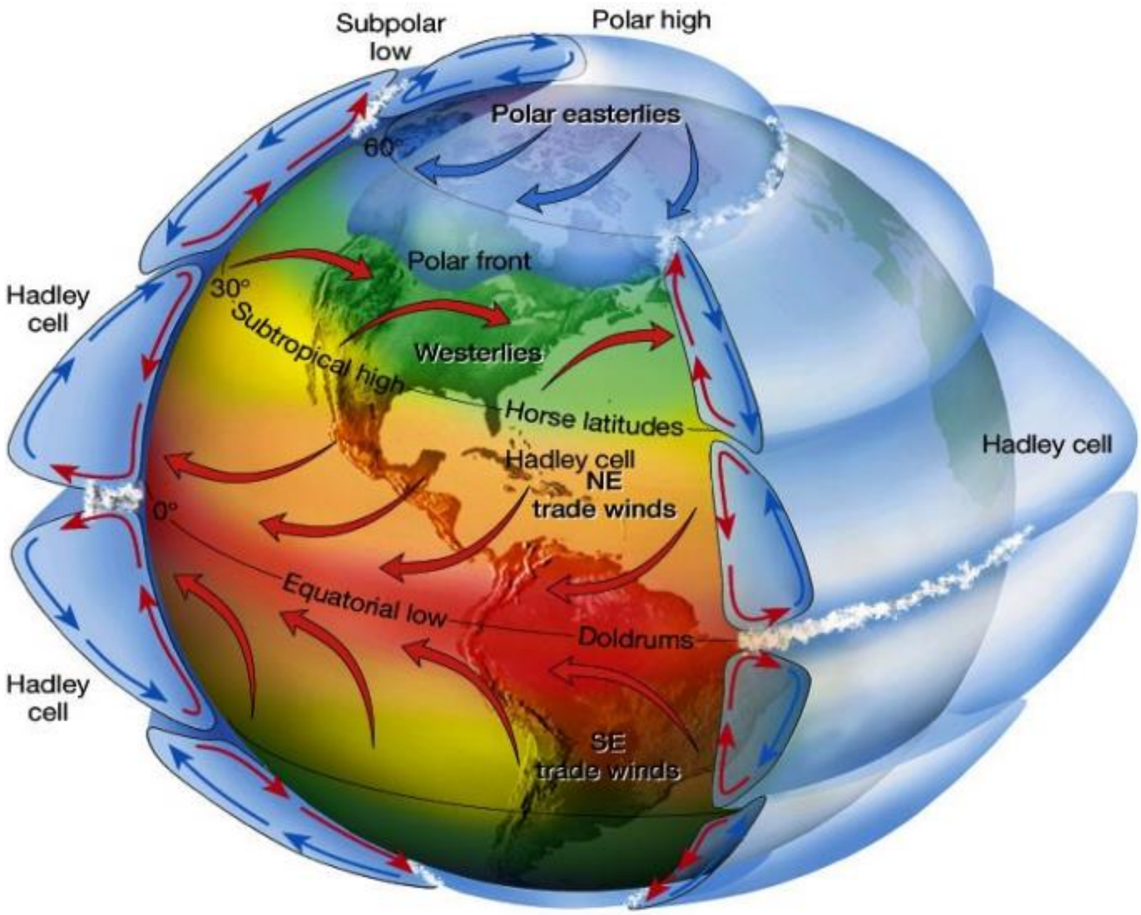


Figure 2.15 Global Circulation of Winds (Venkataraman et al., 2018)

The wind has long been used by humans to move their sails, which made navigation possible at the time. Also in rural communities, the wind powers windmills to pump well water to the surface of the land, and some windmills are used to grind grain, such as the Dutch windmill on the Danish island of Bornholm, shown in the following image.

Figure 2.16 Dutch windmill on the Danish island of Bornholm (CC BY 3.0)

Nowadays, as the world is hungry for strength and wind is handy free renewable in all places so the hazard of harvesting wind and funding wind mills initiatives is profitable and worthy. In the 1970s, the world became more fascinated in wind electricity and began growing some wind turbines. There have been reasons for this interest. Oil price inflated in the mid-1970s in contrast with the developments in materials, aerodynamic analysis, and computer-aid software. Those motives gave the birth to advance and establish good sized amounts of wind farms . Later, wind turbines become extra famous and investment captivating due to the fact of its high-power output per unit and the usage of the old technology of Electrical power generators. In addition, they are low maintenance, use little land, robust, have direct power conversion, low noise and uses existing power infrastructure such as transmission lines. However, they have three drawbacks. First, energy output is tough to control. Second, wind farms are better for peaking applications. Third, adequate wind velocity has to exist so wind turbine can produce electricity and this speed is called cut-in velocity [36]

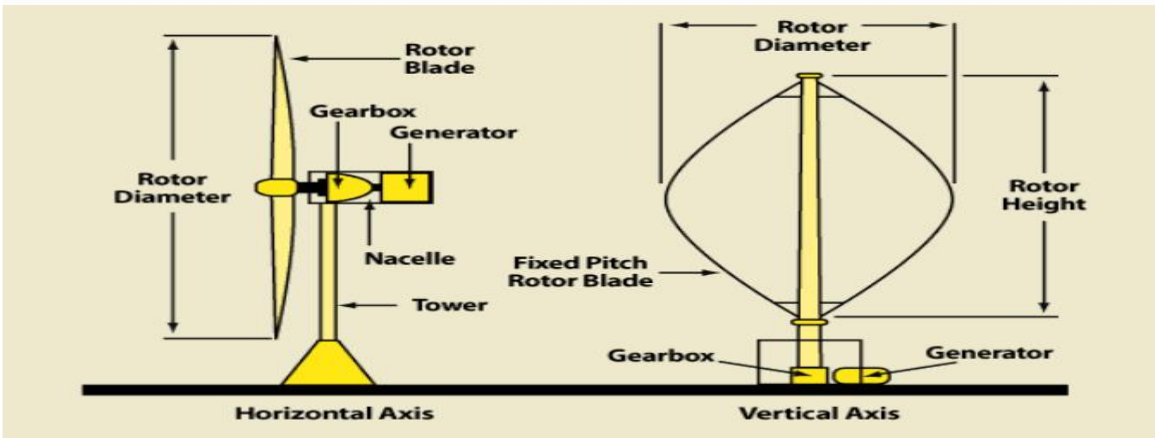


Figure 2.17 Horizontal-axis and Vertical-axis Wind Turbines (Schreck & Robinson, 2007)

There are two types of wind turbines, horizontal axis and vertical axis, and in this work by the aim is to focus on the horizontal type for many reasons, such as the horizontal turbine being more powerful in very strong winds and easier to cut speeds and the data collected. There are horizontal wind turbines in Alberta, but horizontal wind turbines require yaw control to match wind direction. a farm or even a lamp post. Most of the investors, however, are looking for larger ones because they generate more power at a lower cost per unit. The Horizontalaxis Wind Turbines (HWT), the most commercial type, have the main rotor shaft and electrical generator on top of a tower and must point into the wind, which requires yaw control of the . The rotor blades rotate vertically and lock into place. Wind energy in explains mechanical energy according to the laws of aerodynamics and then drives an electrical generator. Vertical axis wind turbines (VWT), on the other hand, have the main rotor axis vertical and the generator is below it.The rotor spins at very low and high speeds, which gives this type a wide operating range for the . In addition, the rotor does not have to be exposed to the wind and the wind can be harvested from different directions of the Energy Association [38]shows the difference between HWT and VWT:

The basic components of a wind turbine with a horizontal axis are three such as rotor, nacelle and tower. The rotor, which accounts for about 20% of the cost of the wind turbine [40], consists of a group of blades, generally three, but it can be two or more and these blades receive wind and convert the force of the wind into force mechanics the equation:

$$\boldsymbol{P_{eff} = C_p \eta_{gear} \eta_{gen} \eta_{ele} P_w = \frac{1}{2}\left(\eta_t \rho A \bar{u} 3\right)} \qquad \mathbf{2}$$

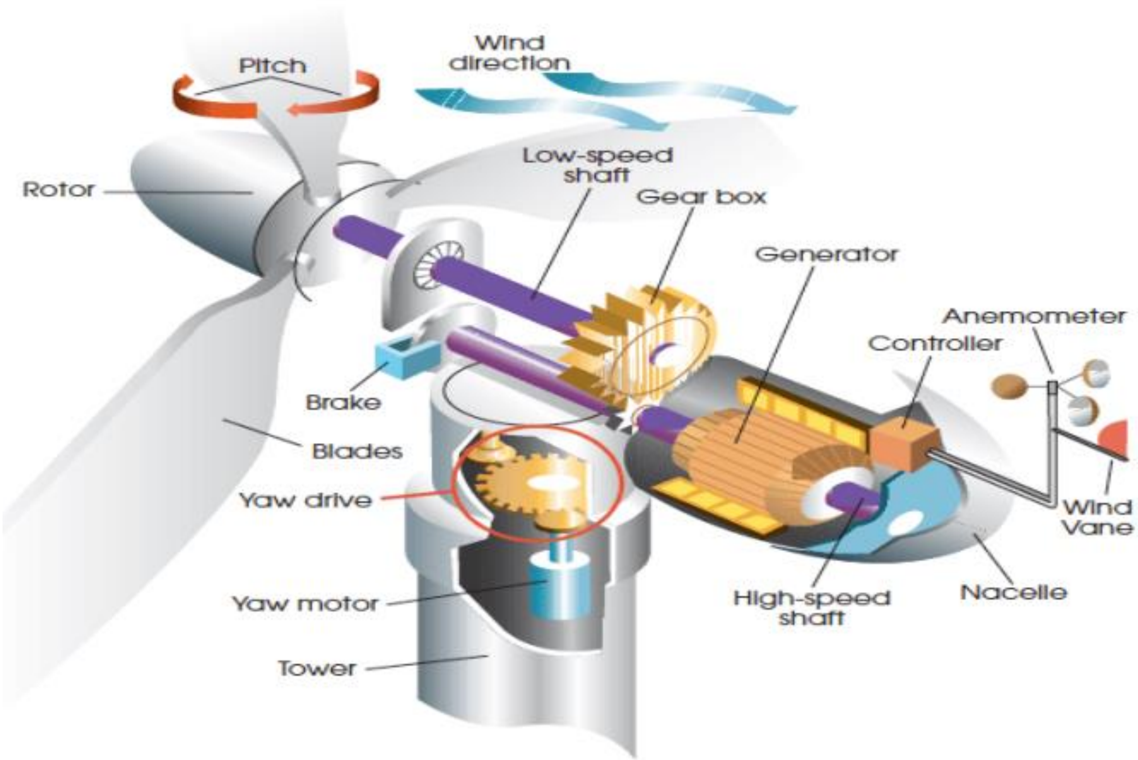


Figure 2.18 Wind Turbine Components (Ziazi et al., 2017)

Here $Peff$ is the percentage of the nominal power, Pw the mechanical power in moving air, ρ the density of the air, A is the area covered by the rotor blades and u the air speed. Accordingly, the Betz law specifies the maximum achievable extraction of wind energy by a wind turbine as 59.3% of the total kinetic energy of the air flowing through the turbine [40]. The second part is the nacelle, which mainly houses and protects the mechanical and electrical components The first part of the nacelle is a gearbox that converts the low wind speed into a high speed suitable for generating electricity The generator is the second component , which accounts for about 34% of the cost of the wind turbine, generate electricity with a certain frequency of AC [41]. The third component is the controller, which controls power conditioning and the rotor switches. The last part is the tower that supports the nacelle and rotor. It includes the rotor-azimuth drive and the motor and accounts for around 15% of the cost of the wind turbine [41].This figure [37] illustrates further details on the components of wind turbines:The typical wind turbine has an output proportional to the wind speed. Wind speed controls the generated power and most typical wind turbines have a limit wind speed at which no power output is generated and as the wind speed increases, so does the power output. However, above a certain wind speed this increase stops and the output remains stable. This speed is referred to as the nominal output speed. The shutdown wind speed occurs when the turbine cannot safely operate beyond that speed. The output power is proportional to the cubic meter of the wind speed and to the dimensions of the rotor.Theoretically, when the wind speed duplicates, wind energy increases in an eight factor. Overall efficiency is typically 30 to 40% and most of the turbines are now designed and built on a commercial scale, with the average turbine rated at 2, to 3 MW [36]. The following figure describes the relationship between the power output and the wind speed of . [37]:

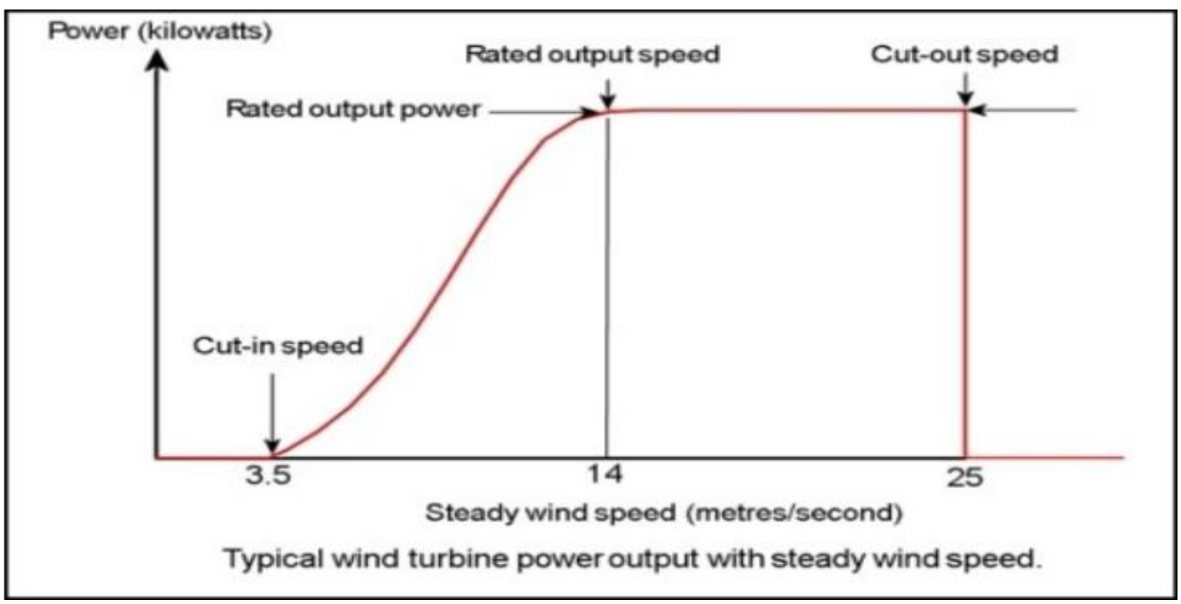


Figure 2.19 Output power vs Wind Speed (Ziazi et al., 2017)

In general, wind power generation is defined by three characteristics such as:

- Type of wind turbine, either horizontal or vertical.

➢ Installation on land or offshore. Network connectivity, either attached or standalone. wind turbines are getting bigger and more powerful. Its size continues to grow for economic and environmental reasons. The average size of a onshore grid wind turbine increased from 0.05 MW in 1985 to 2.0 MW in 2014, while the largest wind turbine to date has an output of 8.0 MW with a rotor diameter of 164 meters . Dong Energy is one of the pioneering companies in the wind industry that developed an illustration to compare the size of wind turbines to a Boeing 7478, as shown in the following figure:

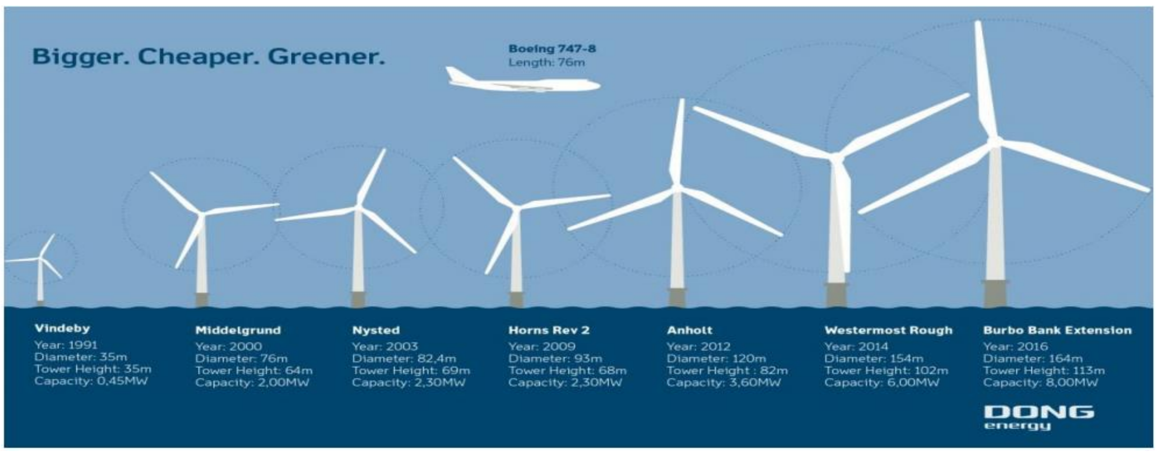


Figure 2.20 Several Commercial Wind Turbines Sizes (credit for DONG Energy)

2.3 Energy Storage Systems

Mostly the supply does not correspond to the demand and with renewable energy production it is even worse because the energy production as supply is not linear and always variable over time because the availability of energy depends on weather conditions. , power interruptions and blackouts occur and create system challenges that affect power quality, reliability, and resilience. As a result, power interruptions and outages occur and create system challenges that affect power quality, reliability, and robustness of the power supply. a possibility to save and vice versa scenario if the demand is higher than power supply needs additional energy to be in the system, otherwise the system will shut down and will cause a power failure. Therefore, having a storage system as a means of storing excess energy and releasing it when needed and leveling out power output is essential in the design of a modern renewable energy system. . However, there are several ways to store energy in different forms. These forms are mechanical, electrical, chemical, thermal and electrochemical. The following table illustrates these different types with some examples [42]:

Table 2.1 Electrical energy storage type

Mechanical	Electrical	Chemical	thermal	electrochemical
Pumped hydro Compressed air Flywheel	**Double-layer capacitor** **Superconducting magnetic coil**	**Hydrogen fuel**	**Sensible heat storage as molten salt**	**Secondary batteries** **Flow batteries**

Most electrical storage machine has three integral elements as power transformation system (PTS), central storage and charge-discharge manipulate machine (CDCS) [43]. Different types of electrical storage systems have different power and electricity ratings as shown in subsequent discern [43]:

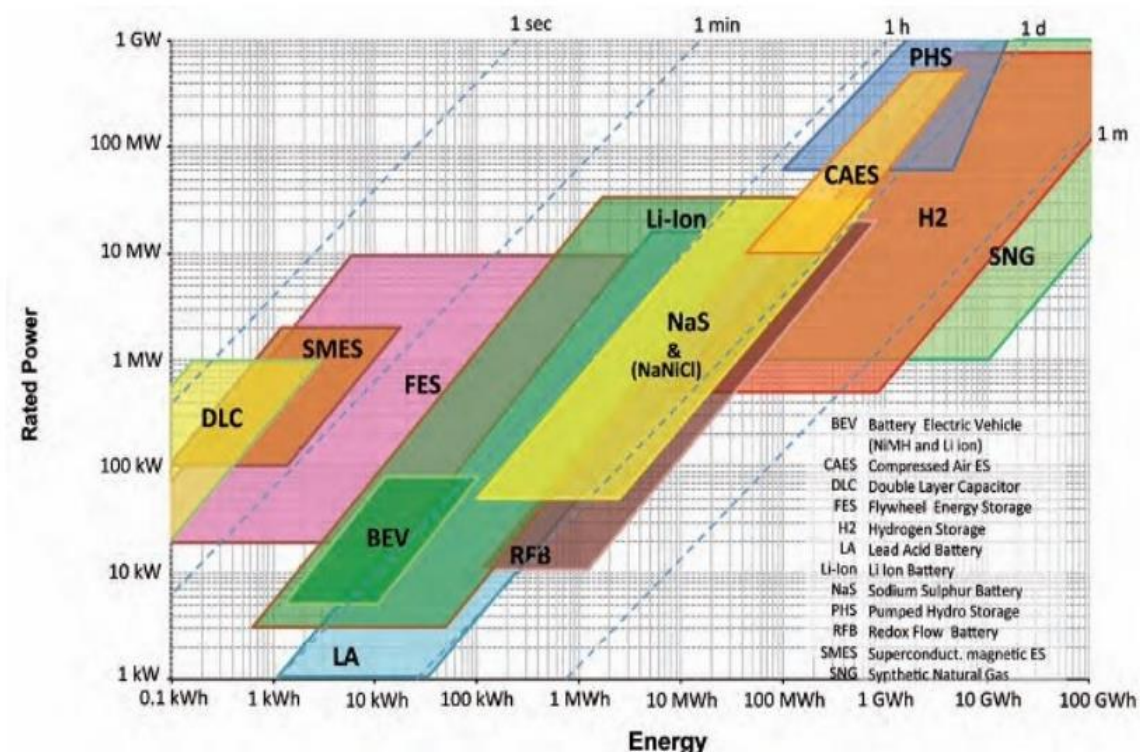


Figure 2.21 Rated Power vs Energy Capacity of ESS (Li & Dong, 2019)

The focus here is on batteries and hydrogen as the proposed system, as they are highly scalable, portable and dimensionally suitable for off-grid energy system applications. Two different types are used to give the system medium term storage like batteries with a fast response rate. and hydrogen as a reservoir of long-term storage in the event that no input energy is drawn from the renewable system to cover the energy of the house for approximately a planned period of and in this work the period of one week. Hydrogen tanks can be added to increase capacity without the need to expand the fuel cells, as the tanks are separate from the fuel cells' power generation, as opposed to batteries, which act as storage and power generation [44].

2.3.1 Battery Energy Storage

Batteries are fascinating considering the fact that they save huge quantity of energy in the chemical bonds and release it when the chemical reaction takes a place. A battery is a system that consists of electrochemical cells which convert chemical strength into electrical one. The phone basically is shaped from three components as a superb electrode, a poor electrode, and liquid or solid electrolyte. A chemical response happens when the two electrodes are linked where electrons from terrible terminal omit via to the wonderful terminal [44],. For the chemical reaction to be completed, proton, fantastic ion, passes via the electrolyte. The following figure illustrates the principle behind a galvanic battery mobile :

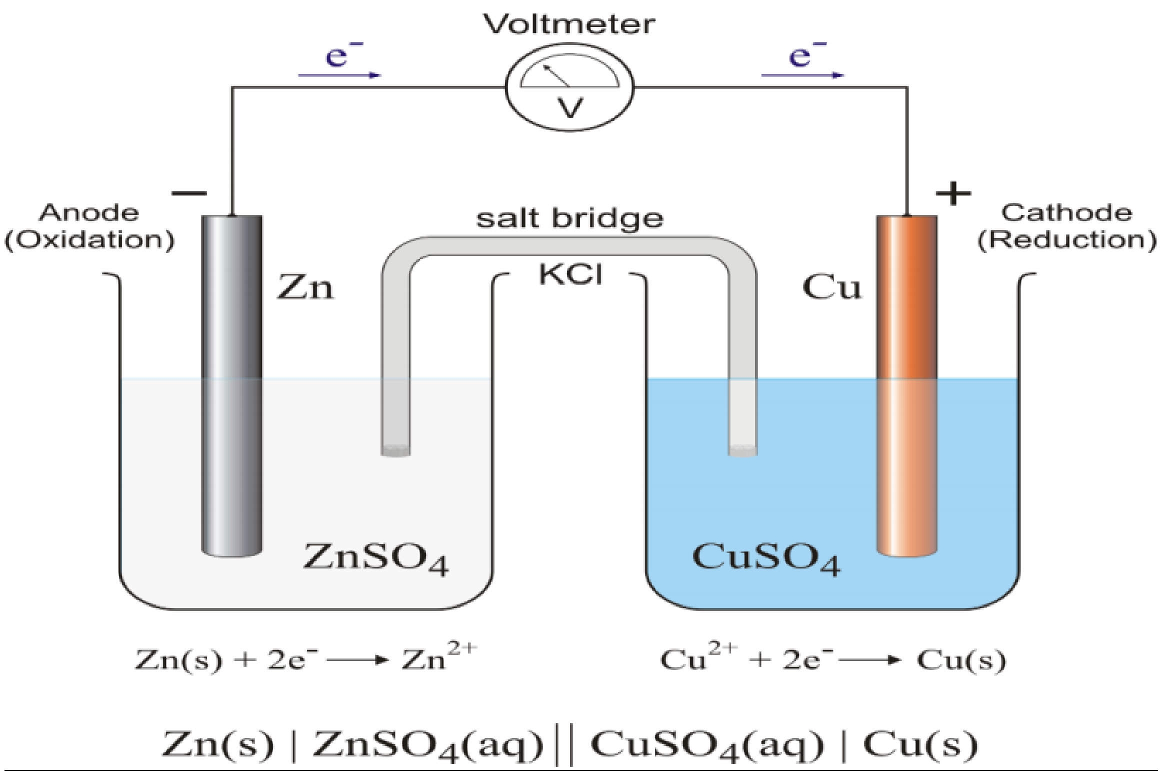


Figure 2.22 Galvanic Battery Cell (Swami Nathan et al., 2015)

Different types of batteries are manufactured to meet different application needs. They can be used for small applications like a hand watch to large applications like a smart grid battery storage system . Basically there are two types of batteries like: primary batteries that can only be used once. secondary batteries that can be recharged after being drained several times or in cycles. Batteries can be connected in series, parallel, or a combination of both to provide the required operating voltage and current for the system. Batteries differ based on the chemical reaction of the and the elements involved in that reaction. Therefore, different elements and chemical reactions lead to different types of batteries. The most common types of secondary batteries that can be used in off-grid systems are lead acid, nickel-cadmium, nickel-metal hydride and lithium-ion . The following table compares the properties of these batteries [45]:

As can be seen from the table, the lithium-ion battery has better properties and is more suitable for off-grid system application. These properties can be represented as follows:

- The high energy density is in comparison to other battery types, which leads to a small storage space.
- High specific power required for the off-grid system as it is the main source of power after renewables.
- High charging / recharging efficiency, therefore useful for deep discharge.
- The lowest self-discharge rate compared to a moth, allowing the battery to remain charged for an extended period of time.
- A constant number of cycles that extend the life of this battery storage system.

These characteristics made the lithium-ion battery grow rapidly as in 2015 it became the most popular form of storage in the world with 85.6% of the world's energy storage system and a promising technology [8]. Therefore, the lithium-ion battery model will be used in this thesis work. In the simulation, the battery model is designed and simulated in MATLAB SimPowerSystems ™ Simulink and this battery model discussed in article [45][5] is chosen to be linked to the entire proposed system. The model represents distinct types of batteries and the user can choose which type. The lithium-ion battery is chosen and is connected to an electrical circuit to simulate the charge / discharge modes. Lithiumion battery consists of Lithium Cobalt Oxide to form a positive electrode, Carbon to form a negative electrode and a very thin sheet of micropunctured plastic to form a separator that passes only positive ions.The battery is then modeled mathematically as described in the literature and fully discussed in this paper .The equivalent battery model is shown in the following figure which basically has a voltage controlled source with serial resistor [5]:

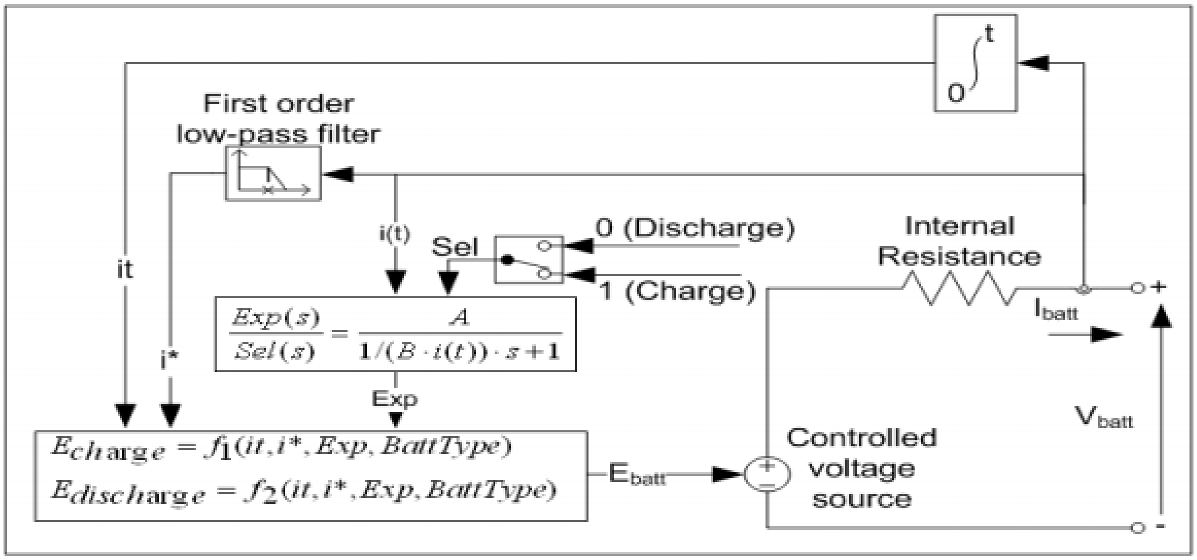


Figure 2.23 Battery Equivalent Model (Liu et al., 2019)

The charging characteristics of the lithium-ion battery in terms of amperage and voltage are described in the following figure, which will help design the correct charging circuit to avoid overvoltages and current charges and to keep the battery safe. The current should not exceed the maximum discharge current, which depends on the C-rate (capacity) and the cut-off discharge, if the undervoltage level is reached or the cell exceeds the temperature limits . In addition to both modes, a voltage equalization circuit must be installed to monitor the voltage level of each individual cell and to avoid voltage deviations between them.

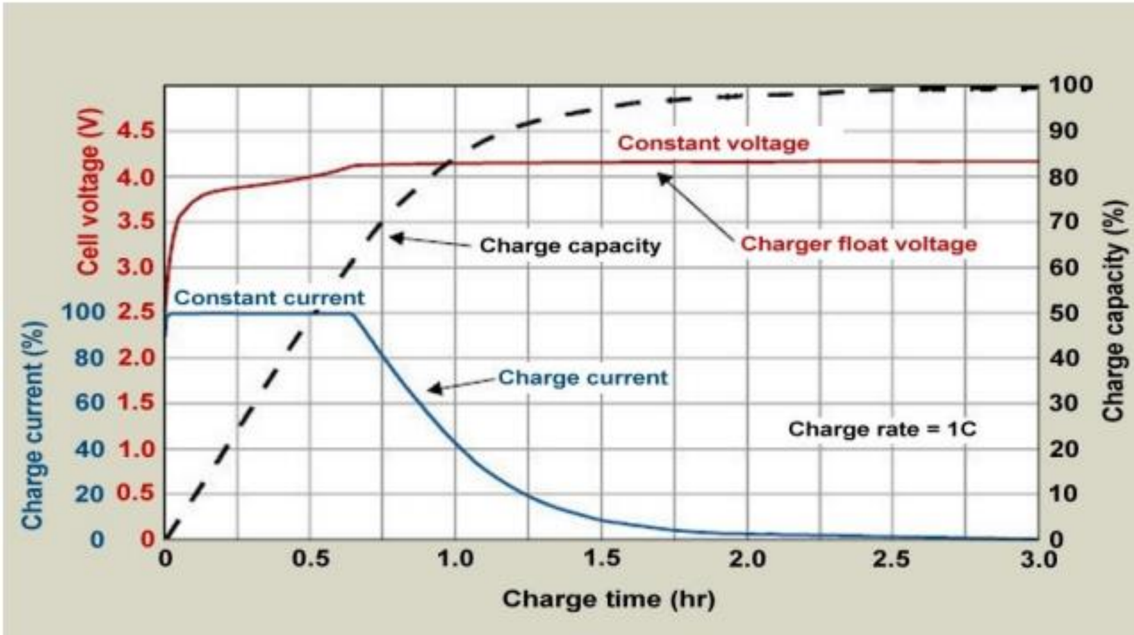


Figure 2.24 Lithium-ion Charging Characteristics (Liu et al., 2019)

The life of a battery is measured by the life cycle of the battery, i.e. H. the number of full charge / discharge cycles the battery can go through before its capacity falls below 80% of its original capacity [5].

2.3.2 Hydrogen Energy Storage

Hydrogen is the most considerable component in the universe of extra than 90% of all atoms [46]. It is the simplest and smallest component with one proton and one electron. It is a fuel at general nation stipulations and is odorless, colorless, tasteless and nontoxic. Fusion of hydrogen atoms produces different factors as helium and a large quantity of energy. As an example, our most important supply of energy, sun, is fueled by using hydrogen fusion for hundreds of thousands of years. On earth, hydrogen rarely located pure and is constantly chemically bonded. water is the most compound of hydrogen [47]. Hydrogen is by and large used in various chemical functions such as petrochemical cracking and in ammonia production. Another use of hydrogen is in the field of energy as an energy carrier. For example, the aerospace industry uses hydrogen to power large space rockets [47]. Many scientists are investigating the idea of using hydrogen as an energy carrier, as in their studies such as

Ohta 1979, Nitsch and Voigt 1988, Scoot and Hafele 1990 and others [48]. Hydrogen is clean, sustainable and abundant and, when burned, creates water with no greenhouse gas emissions, a promising future as a fuel. It can be produced through various chemical reactions such as: B. Hydrogen, which can be produced by various industrial processes [49]:

- Steam reforming of natural gas.
- Chemical reduction of coal.
- Solar hydrogen by artificial photosynthesis.
- Partial oxidation of heavy oils.
- Thermal decomposition of water.
- Electrolysis of water.

However, in the application of generating hydrogen in an offgrid energy storage system, water electrolysis is the target since water can split into hydrogen and oxygen where hydrogen can be stored in tanks for later use.A typical Hydrogen storage system consists of Water electrolysis to produce hydrogen from surplus power, hydrogen storage tank to store the generated hydrogen for later use and a fuel cell system to reproduce electricity when needed by using the stored hydrogen.

Water Electrolysis

It is used to avoid legacy operation as this application targets the autonomous system outside the network. The electrolysis of water is an electrochemical process that converts water into hydrogen and oxygen with the help of electricity and requires additional temperature to complete the process. endothermic. The general enthalpy of reaction requires 237 KJ / mol to generate two hydrogen atoms and release one oxygen atom. As early as 1800, the chemist Johann Wilhelm Ritter was the first scientist to use the electrolysis of water to generate hydrogen [50].

Usually, oxygen is released into the atmosphere for economic purposes and to keep the size of the system as small as possible. The electrolysis of water has many types such as alkaline, acidic and high temperature electrolysis where at 1700 ° C the water decomposes to form hydrogen, but here the focus will be on the alkaline electrolysis as it is the most dominant and uses the excess electricity generated for the project [10].

The electrolysis cell requires a minimum of 1.23 V and 2 electron faradays to start functioning and generate hydrogen. Adding heat to the cell lowers the required voltage [51]. Many cells are stacked to form an alkaline electrolyzer.There are two categories of alkaline electrolyzers as conventional and advanced [10]. The classic uses potassium hydroxide with a concentration of 200% by weight because water is not very conductive of electricity, it is necessary to add acid or alkali to allow the reaction. The preference for choosing potassium hydroxide is due to optimum conductivity and corrosion resistance. The electrolyser operates at a pressure of 1 to 30 bar with a temperature of 70 to 100 ° C [49]. The total hydrogen generated is then stored at normal pressure or pressurized to a certain pressure level for higher fuel density. Here is a figure describing the design of Alkaline electrolysis cell and show the difference between monopolar and bipolar one:

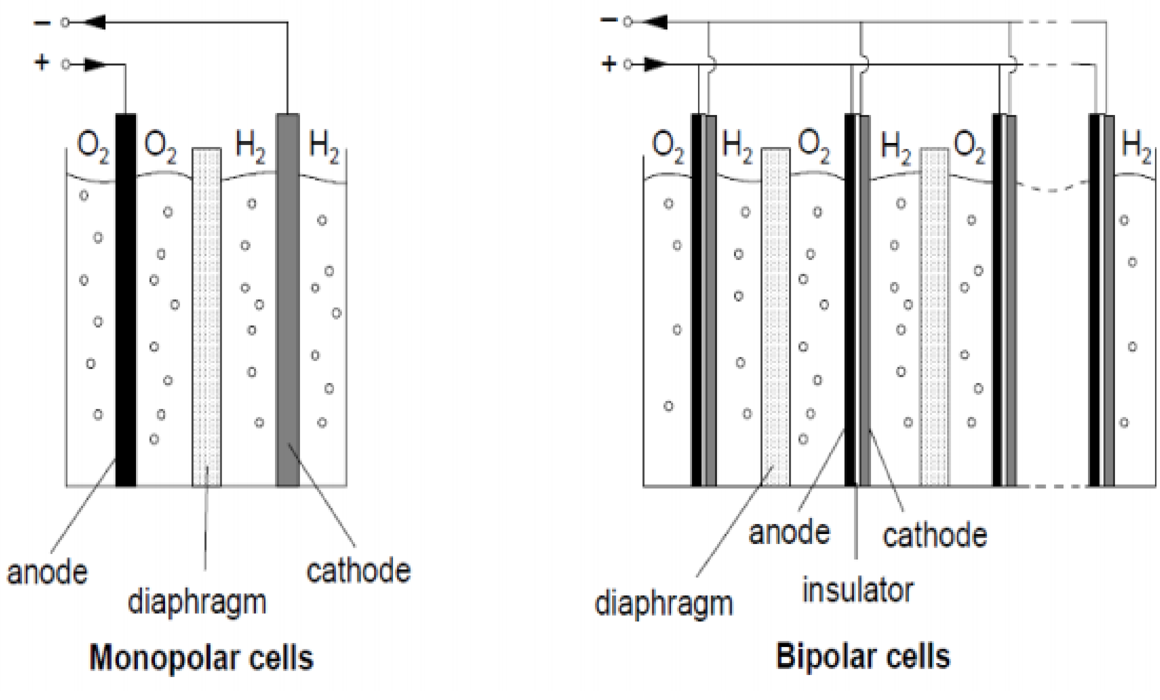


Figure 2.25 Alkaline electrolysis Cell (Gupta & Raut, 2021)

Hydrogen Storage

The second step after producing hydrogen is storage. Since hydrogen is a very light gas with a low density of 0.08245 kg / m3 under normal conditions, it has to be compressed under high pressure or liquefied at very low temperature or chemically bound to metal hydrides or super-activated carbon [52]. However, for off-grid applications the first two methods can be used and hydrogen compression is the most popular option for the small amount of storage. Salt pipe systems or caverns with a volume of several 100,000 m³ are used [53].

Hydrogen Fuel cell

The hydrogen fuel cell is considered to be a very promising technology because it has the property of converting chemical energy directly into electrical energy. It's like batteries, but uses fuel from an external source, such as a hydrogen tank, and will continue to produce electricity as long as fuel is available. It is unclear who invented the fuel cell. The chemist Christian Friedrich carried out an experiment in 1838 and the Englishman William Grove discovered the basis. The chemist Christian Friedrich carried out an experiment in 1838 and the Englishman William Grove discovered the basic functional principle of a fuel cell in 1839 by reversing the process of electrolysis of water to generate electricity from hydrogen and oxygen and invented the fuel cell, which was almost the same principle. so far [54] By 1963, NASA had developed hydrogen fuel cells to power satellites and space capsules. The American ship also uses them for submarines [55]. To generate electricity, a pure hydrogen gas or a fuel containing a hydrocarbon stream is fed to the anode (negative electrode) and oxygen from the air or any oxidation compound to the cathode (positive electrode).The two electrodes are separated by an electrolyte that allows the passage of protons, and the waste of this reaction is water [56]. Heat is released as a by-product. The figure shows the course of the reaction and the components of the cell:

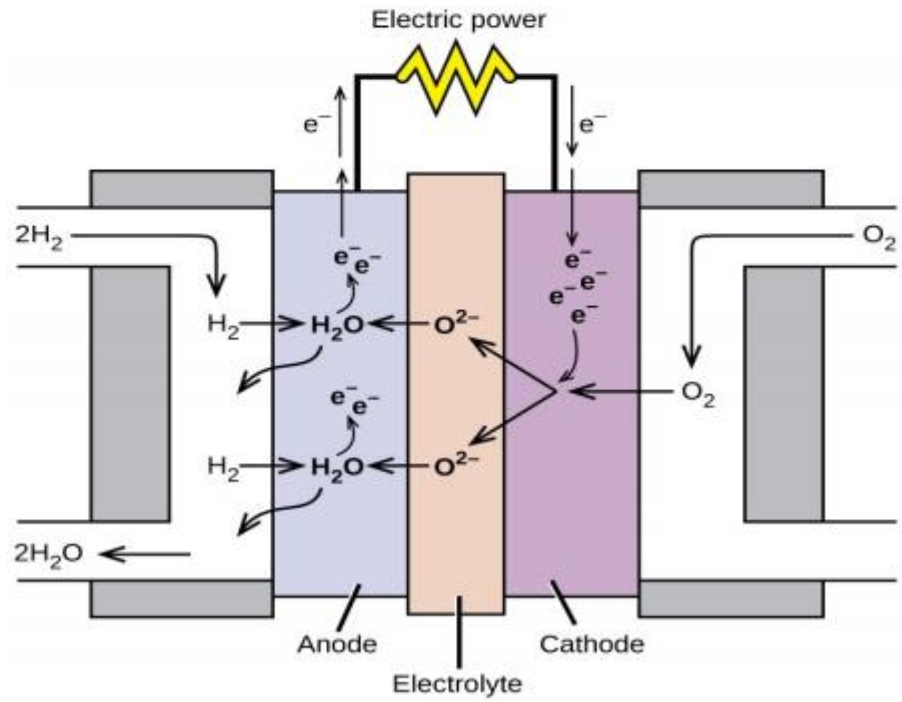


Figure 2.26 Generic Fuel Cell (Preface by Rice University CC)

A fuel cell runs quietly and efficiently and uses hydrogen as fuel to generate electricity, water and heat and does not have to be recharged. Water waste is therefore considered to be emission-free and environmentally friendly electricity generation [57]. There are several types of fuel cells based on the type of electrolyte membrane. Each type has different cell efficiency and temperature operating range characteristics. The following table explains more [57]:

The most frequently used type of fuel cell is the proton-electron membrane (PEM) due to the low operating temperature suitable for residential applications, the high efficiency between 40 and 60% and the quick start [57]. The PEM cell consists of two electrodes that are separated by a proton-conducting polymer membrane. The negative electrode is supplied with hydrogen gas, while air or oxygen flows into the positive electrode. The electrons flow from the negative to the positive electrode through an electrical charge that creates a differential voltage. The hydrogen proton simultaneously passes the membrane and reacts with oxygen to form water, generating some heat.A platinum catalyst is used to promote the splitting of hydrogen into a positive ion and an electron [57].

In recent years, further advancements have been made in the design of fuel cells, and more and more companies have committed to bringing them to market. However, the market capitalization is still small compared to batteries due to the high price of the fuel cell and the hydrogen system which requires many components to function fully [58].

2.4 Hybrid Power Systems

An electrical power system is a network of electrical components designed to supply, transmit, store, and use electricity. Power generation, transmission systems that transmit power from the supply side to the consumer, and the distribution network , which processes the power and then feeds it into households and end users. The first large-scale network was designed in New York in 1882 by inventor Thomas Edison and his company The Edison Electric Light Company. The network was originally developed to operate around 3000 lamps for 59 customers with an electric steam generator in [35].

Since then, the traditional grid was once designed to work in a vertical structure as generation, transmission and distribution with the help of strength controllers, electricity protection system and SCADA device for overall grid monitoring, to hold reliability, stability, and efficiency. However, this format is facing challenges in today’s electricity market such as energy losses in transmission which are commonly from 7% to 12% and different challenges [59]. To overcome those challenges, the thought of the smart grid is introduced, authorized and viewed as the new development of the present utility grid [44]. The simple concept in the back of clever grid is to enhance communication between one of a kind component of the system, make two-way energy flow and, add real-time measurement instruments. As a result, the grid will work with choicest strength generation based on high statistics fantastic monitoring and forecasting and additionally the grid will be protected in opposition to threats from inner system failures or exterior threats [9].

2.4.1 Smart Power Grid

The smart grid encompasses a wide variety of new devices and systems, including smart meters, smart appliances, renewable energy systems and perhaps more in the future. intelligent network as well as a high quality two-way communication system. The Smart Grid

Policy is organized in Europe under the European Smart Grid Technology Platform and is described in the USA according to the legal code 17381 [43]

According to the book Smart Grid by James Momoh , the smart grid can:

- Manipulate uncertainties in timetables and energy transfers through the network.
- Cooperate with renewable energy from either microgrid customers.
- Optimizing the quality and reliability of energy transmission and meeting demand.
- Dealing with unpredictable events and uncertainties in any operation and planning for better forecasting.

Here is a figure of a possible scenario of an energy system based on smart grid technology discussed and presented by Marco Liserre, Thilo Sauter and John Y. Hung in their article "Future Energy Systems" in 2010 [43].

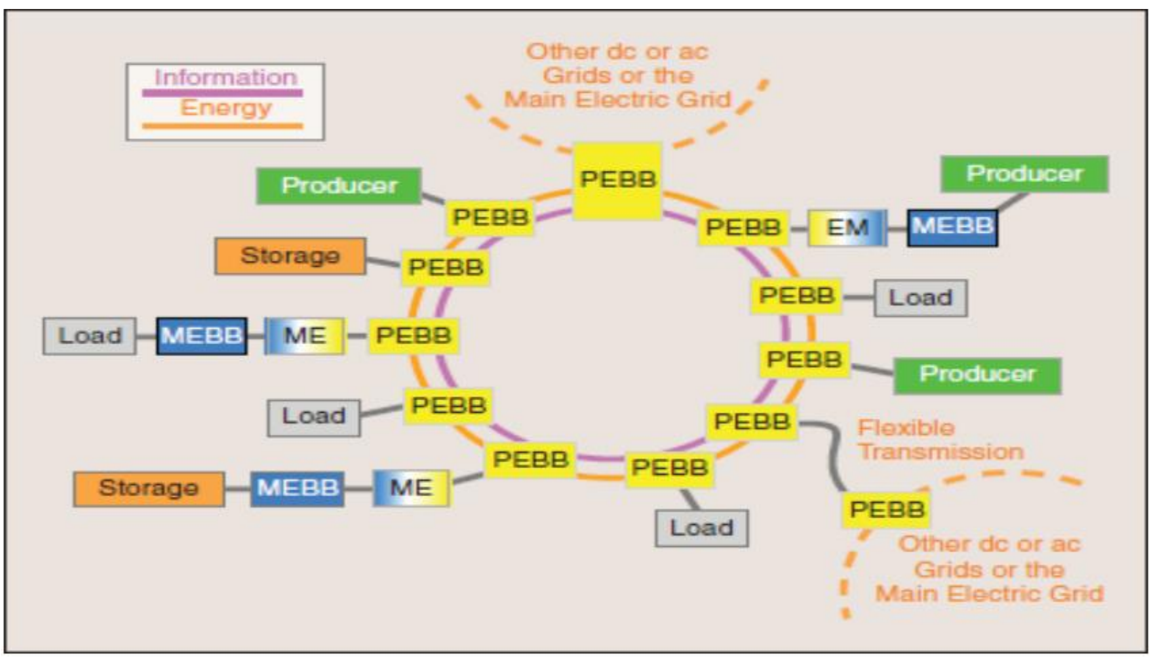


Figure 2.27 possible scenario of a power system based on smart grid technology (Ekaba et al., 2021)

As shown in the figure, the smart grid is made up of two circles: the outside representing the flow of energy while the inside represents the flow of data on the communication channels. Different parties join the network as producers, energy accumulators and consumers. The main block of control, transformation and conversion of the power flow between the different parts is the power electronics and the way of controlling this network is discussed in several documents such as [60]. Power electronics play a key role in managing the energy flow between parts and will be discussed later in this section.

In summary, a smart grid design enables the energy industry to observe and control parts of the electricity system with a higher temporal and spatial resolution. Another purpose of this design is to exchange information in real time in order to optimize Operate as efficiently as possible. The smart grid design would manage every part of the grid at all times, from high frequency switching in microseconds to variations in solar and wind production in minutes. It would reduce the future impact of carbon emissions from power generation on a scale of a decade [61][62].

2.4.2 Stand-Alone Power System

On the different side, there are smaller power systems to support targeted purposes. Those systems can be linked to the grid or can work independently where in this case it is known as stand-alone power system. Those systems can be discovered in hospitals, industry, commercial malls and remote site houses and communities. Some of them are used for emergency conditions such as uninterruptible electricity supply, UPS. Those stand-alone structures are divided into two major categories as grid-tie and off-grid power system. The grid tie system has a characteristic of being connected to the main grid so when more power is required and the system isn't capable, the system receive power from the grid and when more power is generated, the system can sell that power to the grid. The 2nd type is the off-grid system which is definitely unbiased of the grid and is designed normally to help homes, industries and remote-area communities that is technically challenging to be linked to the grid or the grid power transmission is expensive and not economically feasible. Self-contained systems mainly consist of a power source, a converter, and a power consumer. However, in order to achieve higher power quality and overall reliability and stability of the power system, additional components must be added to the system as multiple energy. Sources, Energy Storage and General Energy Flow Regulator. This system is called; Off-Grid Hybrid System An off-grid hybrid system is a collection of at least two power sources with at least one energy storage device to supply a consumer without a grid connection and has power converters that enable the flow of energy between these components under the supervision and management of one component Energy flow regulator [62]. Power sources vary depending on the application, location and purpose of the system, but here in this article the focus is on the off-grid renewable hybrid system is the main topic, so the next section will elaborate and discuss this further.

2.4.3 Renewable Hybrid Off-Grid Power System

The off-grid renewable hybrid system is generally popular as a hybrid renewable energy system, HRES [63], and is designed to harvest renewable energy and use that energy independently and efficiently for provide a specific load such as a house, neighborhood or village or even on a larger scale. The system uses energy storage units to balance supply demand, supports power quality and improves system reliability and the ability to work alone. The storage is mainly implemented as a bank of batteries, but other solutions exist, in particular fuel cells, etc. [64]. Most system designers aim to use dissimilar renewable sources, as opposed to energy storage, to overcome the constraints and limitations of each component. Conversely, load behavior is indeed an important factor in the design of such an HRIS and is generally divided into four categories such as baseload, intermediate, peak, intermittent, or non-programmable [64].Renewable energy resources and the selection of solar and wind power over others are well discussed in section 2.1 of this chapter while the energy storage system and the selection of batteries and fuel cells are discussed. discussed in section 2.2. However, the other components of HRDS will be discussed in section 2.3.

- **System configuration and links**

There are several configurations for connecting renewable power supplies with multiple energy storage units to provide AC and DC load [65]. Three main configurations covering most of those available would be described as follows:

1. Power generation coupled to the DC bus line:

   Renewable energy sources and energy storage systems are connected to a DC bus main line . DC converter. The battery is controlled by a battery management system and protected against overcharging and discharging, then it supplies the DC loads with power as required.The hydrogen system is also connected via a DC / DC converter. DC loads can be connected directly to the DC main line and AC loads can be supplied by a DC / AC inverter.

2. Electricity production coupled to the AC bus line:

   Renewable energy sources and energy storage units are connected to a main AC bus line. Converter / AC for stable coupling . Solar PV requires a DC / AC inverter. The battery is monitored and protected against overcharging and discharging by a battery management system, then the powers a two-way master inverter.Hydrogen system is also connect using a bidirectional master inverter.AC loads can be directly connected to the main AC line and DC loads can be supplied by an AC/DC converter.

3. Electricity production coupled to the AC / DC bus line:

   DC generation sources and DC energy storage units are connected to the main DC line while the AC production sources and DC energy storage units are connected to the main line DC. AC power are connected to the main AC line. The two lines are connected through a two-way master inverter that supplies AC loads. and DC loads can be powered by an AC / DC converter.

   In this thesis work, the configuration of the DC bus line is used and the following figure illustrates the general DC bus line as mentioned in [66]:

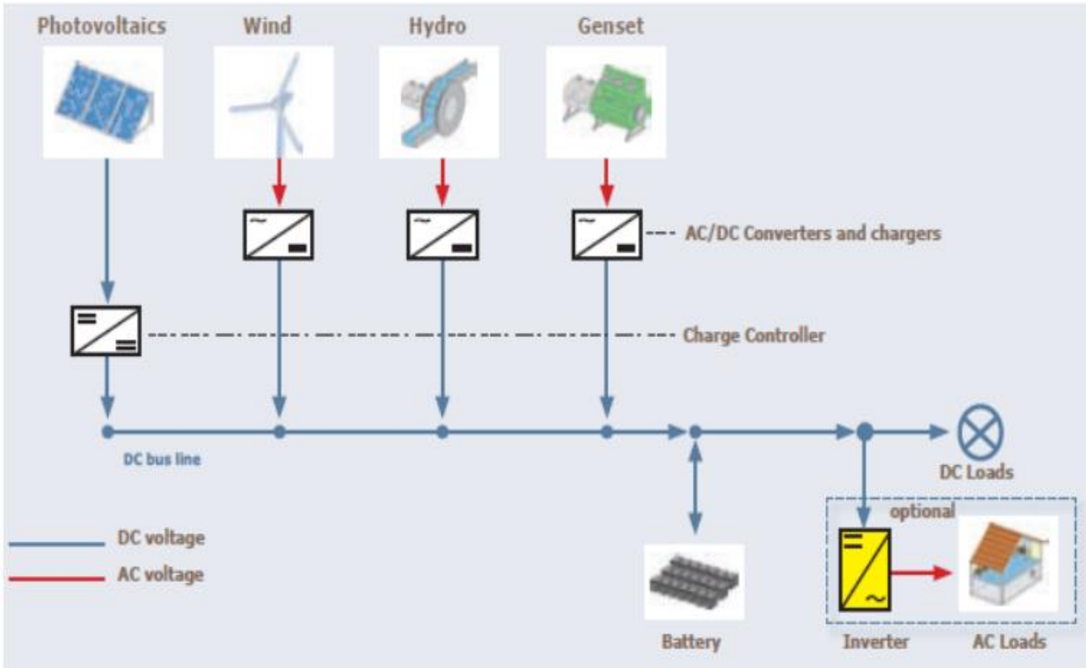


Figure 2.28 Electricity Generation using DC Bus Line (Sakharkar, 2021)

2.4.4 Power Electronics

A power converter is an electronic circuit made up of several passive and active electronic components to perform power conversion. Power converters mainly consist of two stages such as a power stage and a control stage . In the power stage, power is transferred from one system to another while the control stage controls this amount of power by controlling the voltage and current values . Power converters are divided into four categories according to their use for:

- DC to AC power rectifier.
- AC to DC inverter.
- DC to DC power converter.
- AC to AC power converter with the same or different frequencies.

The use of the power converter is generally to condition, maximize and match the power between two circuits . A DC-AC power rectifier is used to change the current from alternating current to direct current to match the circuit followed by direct current . While the DC-AC inverter converts direct current to power an alternating current circuit. DC-DC and AC-AC power converters are designed to change voltage or current between two circuits or frequencies like in AC-AC converter. The following figure has collected the types:

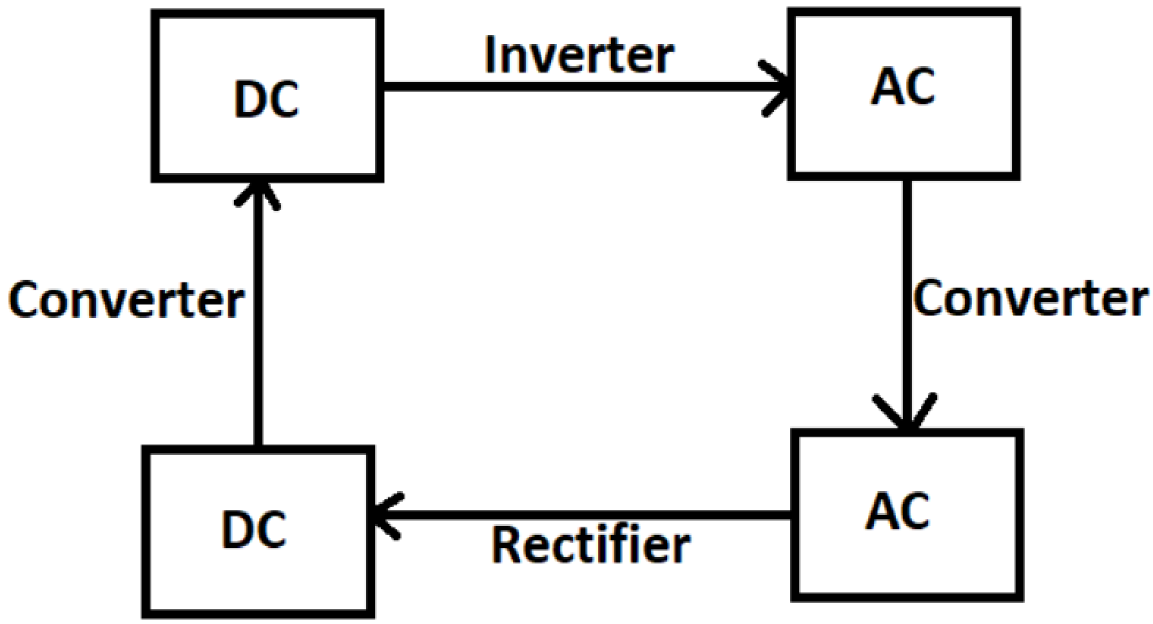


Figure 2.29 Power Converter Types

Power converters are the heart of the hybrid power system as they are used for a number of purposes such as controlling the flow of power or extracting maximum power by changing the resistance of the circuit as in the MPPT power extraction (to ensure maximum power extraction) or could be used to adjust the output voltage with variable load to keep the system rigid and reliable (to improve the power quality of).

In power electronics, the passive components of the circuit are inductors, capacitors and resistors while the active ones are switching transistors. Plus a circuit that controls the switching frequency of this transistor. The DC-DC circuit, for example, can step-up or step-down or both. A step-up converter has an output voltage greater than the input voltage and the step-down converter is a step-down which reduces the input voltage. Both converters have a D value which can be controlled by an external control circuit.The circuit breaker duty cycle, D, determines the relationship between the input and output voltages. The operating ratio of the switch varies from 0 to 1 [48]. Control of the power flow can be achieved by controlling the switching ratio of each power converter and controlling the power supply protection circuits. Definitions and additional details on the power converters, their operation and design can be found in this book as well as in this article .

Protection circuits are used to prevent injury or damage to the system during faults. The most common type is the fuse which cuts the current when it exceeds a certain threshold. In addition, there is a mechanical and electrical protection circuit which has a control input and can be monitored by the main controller . These elements are strongly recommended in the design of hybrid energy systems to have overall control of the different parts of the system .

2.4.5 Power Flow Control

HRES emphasizes a more complex control mechanism than a single power system. Optimal system performance requires an advanced and superior supervisory controller that searches for multiple combined components and matches them[67]. In particular, the exchange of energy between the solar photovoltaic, the wind turbine, the battery, the water chlorinator, the fuel cell and the load must be well regulated to ensure that the captured energy is delivered and stored. as much as possible. Although there are several system components, such as a fuel cell, that you control, they must be managed as a whole for the system to operate efficiently and integrated. The supervisory controller guarantees maximum power from renewable sources and a smooth power flow in the main bus and the stability of the bus voltage[36].

The supervisory controller takes input data from solar PV, wind turbine, battery system, hydrogen tank and charges at a specific sample rate. Based on this data, the supervisory controller commands the controller of each individual component to take some action to power the load without interruption or a lower output power quality. In addition, the supervisory controller is responsible for controlling the battery within certain limits in order to avoid stress and shorten its life and prevent the from running out of storage space. It also makes operational decisions based on designed rules and policies [50]. It assists with loading / replenishment and adjusts storage systems accordingly.You can add other objectives to the list of prudential design requirements.

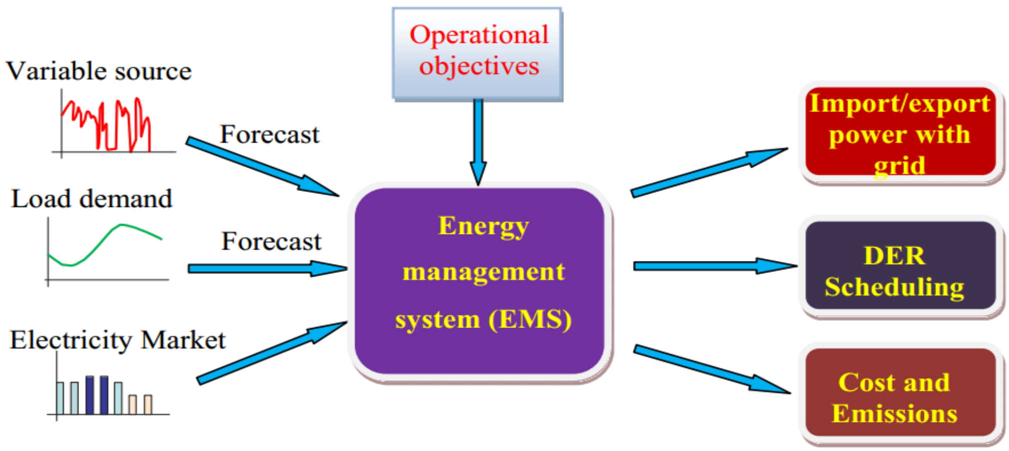


Figure 2.30 The EMS in a microgrid

CHAPTER THREE

MATERIALS AND METHODS

3.1 Data Collection

The hybrid renewable energy system consists of Photovoltaic (PV), Wind turbine generator (WTG), and battery storage. Distribution of power in the system is monitored using a fuzzy logic controller. To start designing any electrical system, the designer must first know how much energy the consumer needs and how consumer demand behavior changes throughout the day and over the seasons. solar photovoltaic, wind turbines and energy storage systems. Long ago, meteorological databases were designed and structured to collect meteorological data such as direct and global solar radiation, wind speed and direction, ambient temperature, rain perception and humidity. relative to an hourly rate to represent the weather map of a given area. The most common database to describe a given climate is called (TMY), a typical metrological year of which presents a series of weather phenomena for the location being searched, while always provides annual averages consistent with long-term averages. for that particular location. . For global data collection, NASA recorded weather data and provided it to the public on its website under NASA Surface weatherology and Solar Energy: Global Data Sets and is also developing a specific web page for energy renewable solar [68]. Since 1983, they started collecting various meteorological data around the world and manipulating monthly and annual average values. Based on this database, researchers can get an idea of the climate of any place in the world and use the data to design, model and simulate the systems they propose. Additionally, NREL has established a National Solar Radiation Database for the United States as well as Guam and Puerto Rico for solar research .They created three different databases one after the other, and the latest database has a data resolution of 30 minutes . In addition, Canada has created a meteorological database of locations across Canada for the period between 1998 and 2014 [43]. Additionally, one of the inspiring websites for easily viewing and downloading solar data is a website designed by the Gatton Solar Research Facility at the University of Queensland in Australia. This website offers a very high data lifespan and resolution of one minute of solar data. These interesting data can be found on the website of the Gatton Solar Research Facility [7]

While wind data is hard to find in regular databases, as most databases focus more on solar and wind speed collected for weather forecasts that do not show elevation of this wind speed. The choice on the left is to take data from NASA or take data provided by local weather . Wind data is collected directly from a weather station installed near a meter project. Adama one wind farm is located in the middle of Ethiopia, about 98Km from Addis Ababa and 3Km from Adama, with altitude elevation of 1824m which is approximate to 1976m. Adama/Nazret Wind Park is located in a strip of land, stretching from north east to southwest. Air density at the wind site is 1.004 kg/m3. The installed capacity of Adama one wind farm is 51MW with 34units of 1500kw wind turbines. The project was officially commenced on June 14, 2011 with contract construction period of 12 months. The total investment is USD117 million, of which 85% from the preferential buyer credit of the Export-Import Bank of China and 15% by local currency. The installed capacity of the project is 51MW with 34 GW77/1.5MW units and the project will produce 157.4GWh of power annually to the grid through a 132kv step-up substation and an extension bay of Adama substation connected with 4.7km 132kv transmission line and 20km 33kv collecting line. The project has attached great attention of both Ethiopia and Chinese Governments, as it is the first state-of-art wind power project in Ethiopia supported by preferential buyer credit of Chinese government. The project is progressed smoothly with the effort of all related parties. On March 31, 2012. The first wind turbine generator generated power and connected with the national grid. On April 22, 2012, the last wind turbine generator was erected successfully and the fist wind turbine generator were put into commissioning and commercial operation on April 6, 2012. According to wind energy resources evaluation and calculation of power generation amount of wind farm and in consideration of various losses and auxiliary power, Adama I wind has an average annual energy output of 162.7 GWh. Through comparison and contrast of their technical and economic indexes, the feasibility study determined the Goldwind GW77/1500kW as the proposed turbine.

The monthly average values of solar radiation (kWh/m2/day) on the horizontal surface data obtained from NMSA at Adama branch which is measured one times per day.

Year	2012 kwh/m^2	2013 kwh/m^2	2014 kwh/m^2	2015 kwh/m^2	2016 kwh/m^2	**Monthly average**	**Annual average**
January	5.13	5.65	5.18	4.62	5.10	**5.14**	
February	6.22	6.00	5.80	5.58	5.27	**5.77**	
March	5.79	6.35	4.68	5.32	5.35	**5.50**	
April	6.16	5.29	5.95	6.01	5.44	**5.77**	**5.013**
May	5.60	5.45	5.12	5.51	5.71	**5.47**	
June	5.02	5.08	4.34	4.58	4.79	**4.76**	
July	3.97	4.25	3.90	4.64	3.86	**4.12**	
August	4.25	3.94	3.96	4.59	4.06	**4.16**	
September	4.56	4.58	4.66	4.63	4.78	**4.64**	
October	4.15	4.54	5.18	5.56	5.63	**5.01**	
November	5.44	4.63	5.03	5.37	5.19	**5.13**	
December	5.07	4.76	4.73	4.39	4.90	**4.77**	

Table 3.1 Monthly average solar radiation [Source: NMSA at Adama branch]

It can be seen from Table 2; the minimum radiation is 3.86 kWh/m2/day in July, 2016 and the maximum average radiation is 6.22 kWh/m2/day is gained in February, 2012.

3.2 System Sizing

Sizing of the units is essential to ensure the lowest system cost with maximum reliability of the system power supply. Optimal unit sizing balances reliable system operation and lowers the current net cost of the system. and blackout. Therefore, there are two main factors for sizing units such as [69]:

- Economic Factor
- Power Reliability Factor

And researchers have designed parameters, tools, and methodologies to assess these factors. For the economic factor, there are several parameters to evaluate the system from an economic point of view and here we are dealing with five tools. First, the level energy cost, LCE, which is the estimate of energy production, including periodic and non-periodic costs over the life of the system. It is calculated as the ratio between the total annual system cost, ACS, and the annual electricity production as:

$$LCE = \frac{ACS}{Total\ Electrcity} \qquad 3.1$$

Second, the annualized cost of the system, ACS, which represents the total annual capital, replacement, operation and maintenance costs. It is formed as:

$$ACS = Captial\ Cost + Replacement\ Cost + Maintenance\ Cost \qquad \mathbf{3.2}$$

Third, the current net cost, NPC, which represents the life cycle cost of HRDS. Displays the system cash flow discounted using the current method. It is a set of capital, maintenance, replacement and slave component costs calculated at present value. The NPC can be calculated using the following equation:

$$NPC = \frac{Total\ annual\ cost}{Capital\ recover\ factor} \qquad \mathbf{3.3}$$

Fourth, the internal rate of return, IRR, which is the true investment interest of the system over its lifetime. It has several names such as return on investment and time adjusted rate of return. Finally, the payback period, PBP, is the duration of the investment to recover the initial cost of capital of the system.

For the power reliability factor, this section deals with three functions such as:

1. Probability of power loss: Represents the ratio of power loss to load demand at a given time.
2. Expected energy not supplied (EENS): this is the expected energy not supplied to the load when the load is greater than the power generated. This quantity is illustrated by the following equation:

$$\mathbf{EENS} = \sum_{k=1}^{8760} L * D \qquad \mathbf{3.4}$$

Where L is the average annual demand and D is the period during which the demand is not satisfied.

3. Autonomy level: this is the percentage of period for which the load is satisfied. It can be calculated as the inverse of the duration of the pressure drop compared to the total running time as:

$$\textbf{Level of autonomy} = 1 - \frac{Duration\ of\ loss\ of\ load}{Total\ operation\ duration} \qquad \mathbf{3.5}$$

The next step in unit sizing is to determine the methodology for evaluating and optimizing the above tools and functions. Researchers focus on different optimization goals and methodologies depending on the system and the operational requirements of their systems. In the literature different methodologies have been used and here some should be discussed as follows:

1) Artificial intelligence approach: number of approaches have been reported as genetic algorithms, artificial neural networks, particle swarm optimization, harmony search, ant colony optimization and other. This approach can handle the nonlinearity of the system and most of them don't require weather data availability to sizing system components [70]. For example, Hongxing Yang designed power reliability model based on loss of power supply probability plus an economic model based on annualized system cost using genetic algorithms approach [71].

2) Multi-objective approach: where optimization tools are used to solve the optimization problem for more than one objective.

3) Iterative approach: where optimal performance for the hybrid renewable energy system is achieved using a program that recurs till the final solution is optimum. In this approach, usually, net present cost, NPC, or levelized cost of energy, LCE, tools are used to optimize the system cost whereas loss of power supply probability, LPSP, the function is used to achieve power reliability.

4) Analytical approach: where a computational model is used to find system feasibility by characterizing each component of the system. Then, several system configurations are

evaluated by comparing single or multiple performance indexes and the best fit is the optimum sizing.

5) Probabilistic approach: this approach studies the changes in power resources or demand and then a risk model can be derived. However, this approach does not recognize the change in the dynamic of the system performance.

6) Graphical construction approach: it is one of the linear optimization tools that works only for two decision variables.

7) Commercially available computer tools: they are the most common tools for evaluating the system performance and analyze its cost and power reliability. Energy

production cost of different system configurations can be easily visualized using these tools to find the optimum configuration for best performance. Several tools are available for designing of hybrid renewable energy systems, such as HOMER, HYBRID2, and HOGA.We intend to size each component based on certain factors. The main factors to focus on are the maximum power supply and the balance between consumer demand and renewable energy production in one year. These factors are in part the power reliability factor discussed above, and some tools such as power probability losses can be part of this sizing method.

3.3 System designing approaches

Numerous studies have examined the role of energy storage systems (ESS) such as batteries and fuel cells (FCs) in the hybrid renewable energy system (HRES) [72][73]. According to[74], thanks to their rapid ramping capability, fuel cell systems can alleviate the problems associated with intermittent power generation in DGs. This phenomenon was observed in [74] where a computer model to simulate a transient operation of a tubular solid oxide fuel cell was proposed. to assess cell responses to different load demands and to define transient limitations and control requirements. The logic-based supervisor controller was proposed in [75] with FC supplying power to the load and ultracapacitors (UC) assisting during transients. However, the combination of FC and UC is not economically feasible.

Since the focus of this work is not on transients, the use of expensive CPUs should be avoided. An important advantage of a large UC is the high discharge rate required to provide a rapid RH response. Therefore, other technologies must be used to achieve more desirable results. The problem of slow battery response can be overcome by exploiting the fast response characteristics of fuel cells [76] to damp oscillations caused by frequent load and generation changes within a smart grid.

A full review of the different methods[77] revealed that there are still issues to be resolved, mainly related to failures affecting end consumers. Further work on storage and FC and storage can be found in [78], where an electrical equivalent was developed and proposed the circuit of a fuel cell generation system for control purposes based on the fuzzy logic controller (FLC). Focused on the response time for the load variation of 25% of rated power at full load. Although all the studies cited obtain good results for their specific purposes, did not consider controlling the flow of HRES power using a fuzzy logic controller to use the excess power to generate hydrogen from the water. This would not only improve the stability of the entire system, but also effectively manage the energy storage elements, extending the life of the entire storage system and adequately meeting demand.

This contribution describes a new fuzzy logic controller for HRES with several types of storage. The proposed scheme solves the problems related to consumer needs highlighted in [79]. The solution focuses on satisfying supply on the demand side by ensuring the safety of the Li-ion battery and maintaining its efficiency and reliability. A complete evaluation of the proposed scheme and validation of its effectiveness is performed using MATLAB SimPowerSystems ™ using real world solar, wind and load data. Although there is a specific controller for each component of the system, there must be an overall controller to manage the operation of the HRES system and the flow of energy between its components to the designated target and in an integrated manner. This global controller must organize the interaction of the energy flow in the power line and ensure a good quality of power supply to the load by monitoring the level of energy stored in the energy storage units[80].

3.4 Our system modeling

This section describes and discusses various subsystems of the proposed project. Each subsystem is modeled individually in Matlab Simulink. Electronic power converters, which are the coupling components for the power flow, are not discussed in this section because they are considered 100 power converters with "ideal" efficiency in this work.

3.4.1 System Dynamics

The system used in this study is a simplified model of an intelligent electrical system using wind and solar power. The configuration of the system used is shown in the following figure. The solar source generates most of its energy during the day and is used to meet the high daily demand due to the high consumption of electricity for air conditioning and to support daily activities.

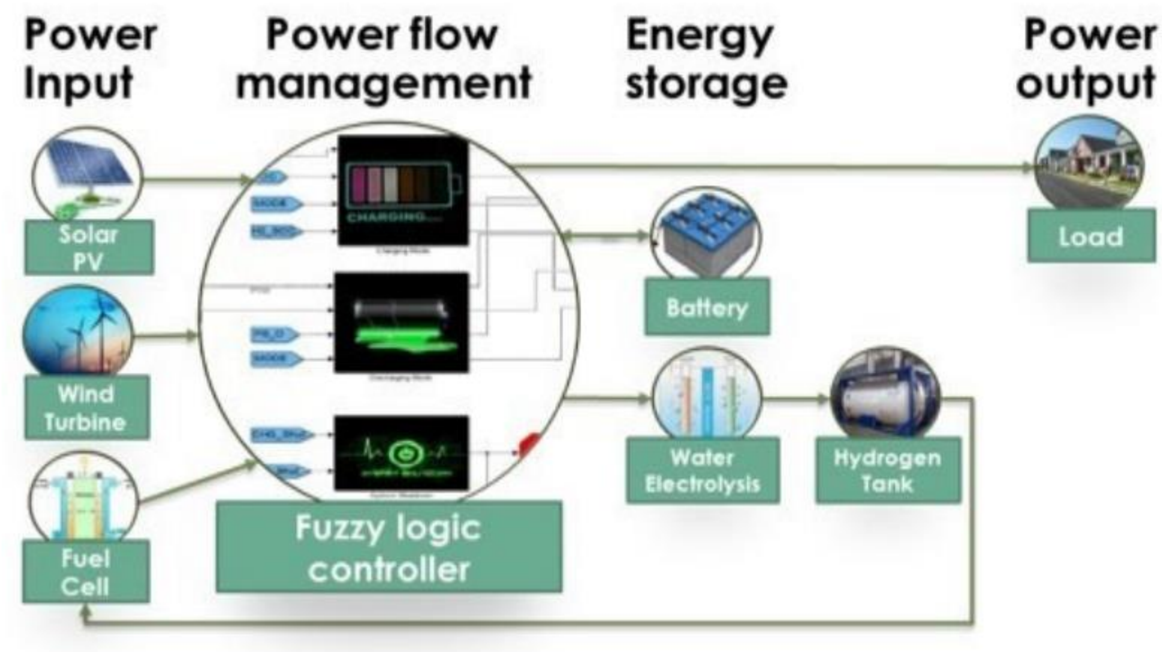


Figure 3.1 The Studied Smart Power System

On the other hand, the availability of wind power, the WP is distributed during the day with more power seen at night. Therefore, the combination of the two sources provides sufficient total power to power the load. In addition, the system has two energy storage elements: a battery bank and a complete hydrogen system capable of generating hydrogen from water using excess energy and generating electricity from hydrogen using hydrogen FC if needed.

The primary supervisory controller directs the energy flow to the load and to and from the energy storage elements using two modes of operation. In charge mode, the FLC allocates a percentage of the excess power to the battery and the remaining power to the water electrolysis, based on three inputs to the FLC. Likewise, in discharge mode, the FLC allocates a Percentage of power required by the battery and fuel cells to hydrogen based on three inputs from the FLC As the system relies only on energy storage elements to manage the surplus and the power required (i.e. not connected to the grid); it is called an off-grid hybrid renewable energy system [81],[82],[83],[84]. All connections between subsystems are DC connections and power is converted to AC before feeding the load through DCAC inverters with assumed ideal efficiency.

3.4.2 Solar Photovoltaic Subsystem

In this thesis, it is assumed that the maximum power point tracker (MPPT) is used to extract the maximum possible power from the PV and that a DC-DC power converter is used to match the MPPT output voltage with the voltage of the system. Photovoltaic cells work on the basis of the photoelectric effect. [85]. Photovoltaic cells convert light with different wavelengths into current at their PN junction, producing electricity directly from the cells when they are connected to a load. The current produced is given by

$$I_{total} = I_0\left(e^{qv/kt} - 1\right) - I_L \qquad 3.6$$

where k is Boltzmann's constant, $I0$ defines the scale of the current and q is the electric charge of the particles making up the current $Itotal$. In addition, IL is the current generated by light and is the ambient temperature. Based on solar radiation and ambient temperature, which are two crucial physical quantities in PV technology, the PV cell matches and produces open-circuit voltage and closed-circuit current . Then the photovoltaic cells are connected to an MPPT which is connected to a DC-DC power converter and finally to the DC bus of the system. For simulation purposes, actual solar energy data is collected from a photovoltaic panel installed on the roof of a house which supplies the solar data to the smart meter.Then, this data is provided to the Matlab Simulink model via Matlab mfile.

3.4.3 Wind Turbine Subsystem

A wind turbine converts the kinetic energy of the air in terms of air speed into electrical energy using an electric generator. Wind energy is the result of air speed, air density and rotor area [86],[36]. The mechanical power extracted from the rotor, which drives the electric generator, can be calculated according to:

$$P_{eff} = C_p \eta_{gear} \eta_{gen} \eta_{ele} P_w = \frac{1}{2}\left(\eta_t \rho A \bar{u} 3\right) \qquad 3.7$$

where is the percentage of rated power, is the mechanical power in moving air, is the air density, is the area swept by the rotor blades, and is the air speed. This power is applied to the rotor of the electric generator to produce electricity. The WP is only generated after a certain startup speed. It then increases the speed until it reaches a stable nominal value and remains constant until the wind turbine reaches cut-out speed . It is assumed that the wind turbine is operating at the point of maximum power. After that, it is connected to the MPPT, ACDC power converter and finally to the system.For simulation purposes, wind energy data from a location in Alberta is fed to the Matlab Simulink model for the best simulation result.

3.4.4 Battery Subsystem

In this work, batteries are used as the primary energy storage system for short and medium term storage. This subsystem is based on the generic battery pack supplied by Simscape Power Systems in the Simulink environment [87]. The battery type chosen is a rechargeable lithium-ion battery with a capacity of 5 kWh with charging and discharging power limits of 2C. The detailed model of the battery system, including the equivalent circuit for charge and discharge modes, can be found in [87]. The battery is connected to the system via a two-way DC-DC converter with ideal efficiency and behavior and is controlled by a battery management system which receives control signals from the main controller.This figure shows the designed battery subsystem:

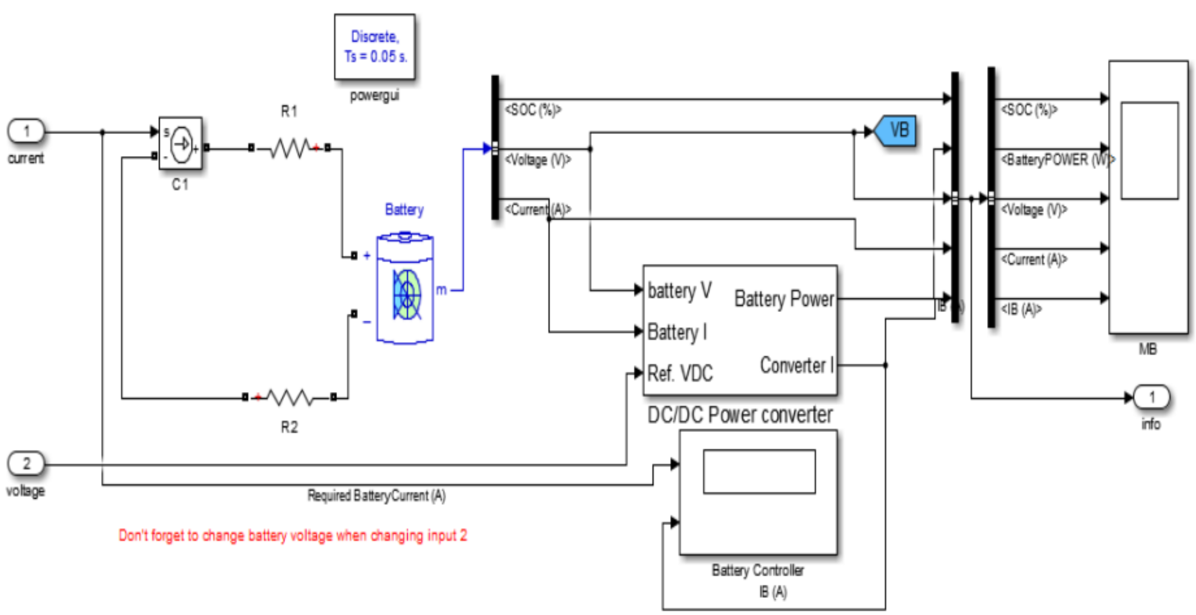


Figure 3.2 Battery subsystem Scheme

3.4.5 Hydrogen Subsystem

Hydrogen fuel represents long-term storage to store extra energy in large amount for days and supports the battery subsystem when a high load is applied to prevent damage to the battery, the battery will not not working sufficiently or shortening its lifespan. Ignoring the hydrogen compressor and other auxiliary components, this work considers a hydrogen subsystem consisting of three main blocks, namely hydrogen production, hydrogen storage, and hydrogen fuel cells. . In charge mode, hydrogen is generated from the excess power distributed by the fuzzy controller. This power allows electrolysis of water which then generates hydrogen. The moles of hydrogen generated are given by the following chemical equation [52]:

$$2H_2O + \ electrical\, energy \rightarrow 2H_2 + \ O_2 \qquad \textbf{3.8}$$

The model of water electrolysis in this project is based totally on a model cited in [11] and is expressed mathematically as :

$$\eta H_2 = \frac{\eta F * \eta C * ie}{2F} \qquad \textbf{3.9}$$

where ƞ$H2$ is the rate of hydrogen produced, is the Faraday efficiency, F is the Faraday constant, is the number of electrolytic cells and is the electric current in the cell. The figure below shows the proposed design of the water electrolysis subsystem:

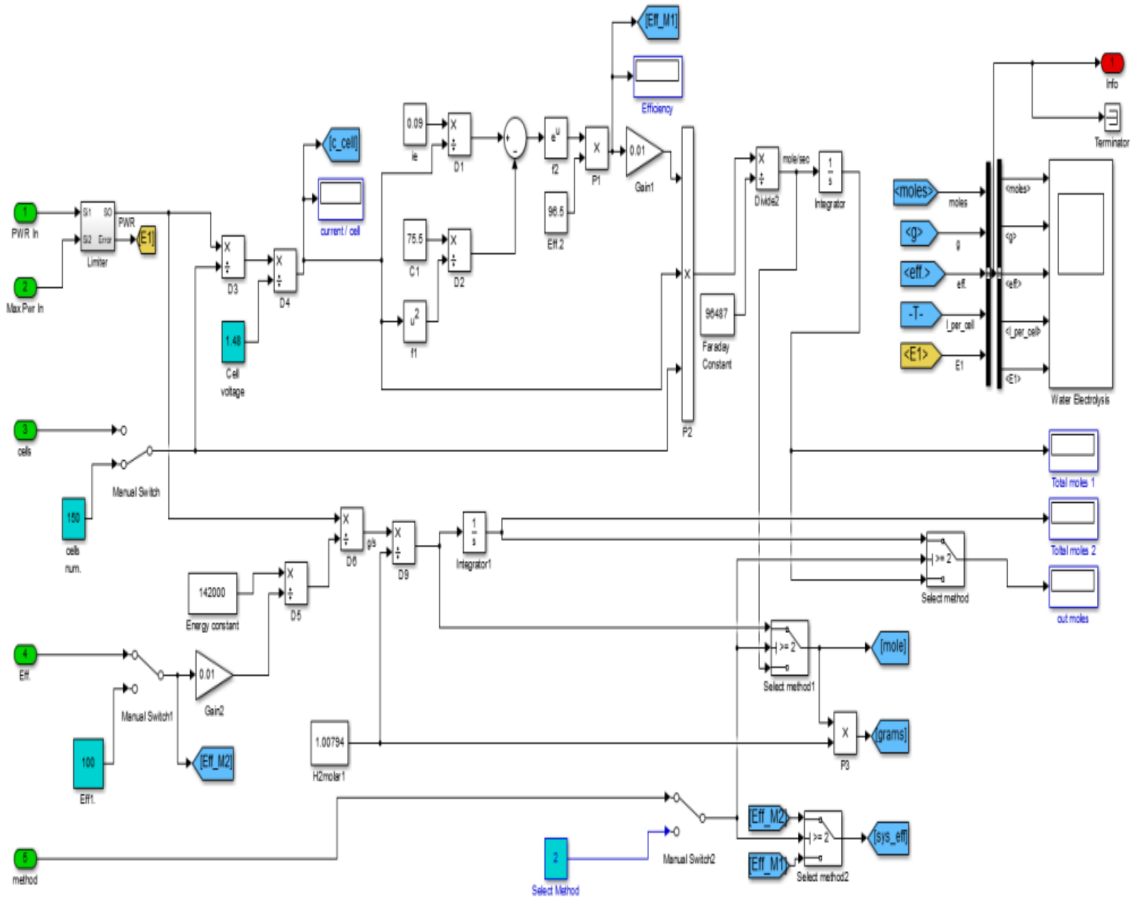


Figure 3.3 Water Electrolysis subsystem Scheme

Once the hydrogen is generated, it requires accumulation with certain parameters. The maximum capacity of the storage used is 30 kg which alone can provide a charge of 10 kWh for 4 days and 22.3 hours if a 100% fuel cell is used. The core of the hydrogen storage model is based on a model described in [88]. This storage model is indicated by

$$P_b\text{-}P_{bi} = \frac{Z*NH_2*R*T_b}{MH_2*V_b} \qquad \textbf{3.10}$$

where is the pressure of the tank, is the initial pressure, Z is the compression factor, $NH2$ is the quantity of hydrogen in moles, R is the gas constant, is the temperature of the tank, $MH2$ is the molar mass of hydrogen and Vb is the The figure below shows the design of the proposed hydrogen storage subsystem:

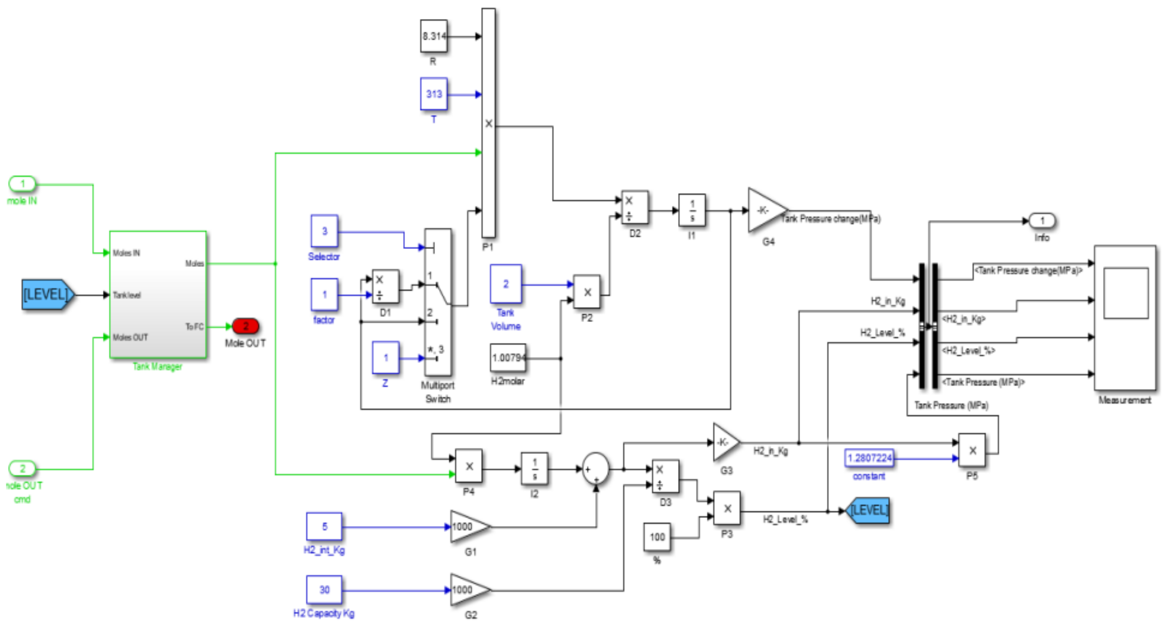


Figure 3.4 Hydrogen Tank subsystem Scheme

In discharge mode, the FLC requests fuel cells to convert hydrogen into electrical energy in order to provide the charge. There are many types of fuel cells. The fuel cell model used in this work is based on equation (6), in which the outputs are water, which can be recycled, and electricity.

Electrical power generated = $N_{H_2} * M_{H_2} * \eta_{FC} * E_C$ **3.11**

In equation (6), this is the efficiency of the fuel cell and EC is the theoretical energy factor equivalent to 39.4 kWh / Kg or 142 KJ / g . The figure below shows the proposed design of the hydrogen fuel cell subsystem.

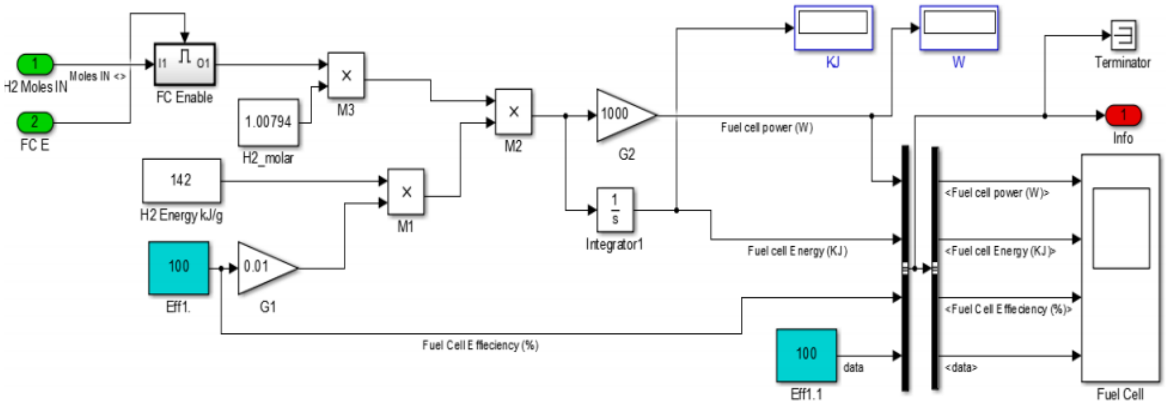


Figure 3.5 Hydrogen Fuel Cell subsystem Scheme

3.4.6 Demand and Load Power Subsystem

The electricity load determination is the first to be considered in any modeling tool. The primary load input, which is taken as a sample, is estimated for modeling and analysis of hybrid system. In this thesis, the proposed energy system should meet the load demand of the community but two hundred households loads are taken for sample modeling. This subsystem represents the power required on the demand side. It helps us understand how much energy needs to be generated each second, so that the system responds to that amount. In the simulations described, this data is obtained from a Awash melkasa electiric utility. Serving loads is the reason for the existence of power systems, so the modeling of power system begins with the modeling of the load or loads. The daily power demand and energy need for the community of two households are estimated by considering basic domestic appliances listed in the Table 3.2 . From the Table 3.2 the total power and energy consumption can be calculated. The total maximum load of an assumed house is 6,916Watt and energy consumption is 16.049 kwh/day. If the assumption is taken for 200 households of the town, the power demand and the energy consumed are 1.3832MW and 3.2098MWh/day respectively.The exisisting power system from koka 2 fedor 4 are 10 distribution transformer in the town and their ratings are as follows: 100KVA four, 315KVA two, and 200KVA four and tolal 615KVA. During off peak around 5.535Mwh energy saved to the batery and fuel cell per day. The load data are obtained from interview conducted for 2 peoples randomly about their energy usage, type of appliances they used and time of usage in the day.

No	Appliances per house	Rating (W)	Hourly used per day	Number of units	Consumption per day (kWh/day)	Assumed usage time interval (hr)
1	Stove	1500	3	1	4.500	7-8,19-20,11-12
2	Electric Mitad	2500	1	1	2.500	6-7
3	CFL	11	6	4	0.264	18-24
4	LED light bulbs	9	6	4	0.216	18-24
5	Washing machine	500	1	1	0.500	9-10
6	Electric Iron	400	2	1	0.800	21-23
7	Laptop	50	3	1	0.150	19-20,7-8,13-14
8	Toaster	600	1	1	0.600	22-23
9	Coffee maker	600	1	1	0.600	12-13
10	Refrigerator	105	24	1	2.520	1-24
11	Mobile charger	3	3	1	0.009	19-20,7-8,12-13
12	Internet modem	10	24	1	0.240	1-24
13	Air conditioner	400	6	1	2.400	11-17
14	Television	150	5	1	0.750	19-22,7-8,13-14

Table 3.2 daily power demand

3.5 Fuzzy Logic Control

3.5.1 Introduction to fuzzy logic

This chapter deals with fuzzy logic and fuzzy logic control systems. Next, our fuzzy logic controller proposal for the renewable energy hybrid system is discussed in detail. Fuzzy logic controllers are found in a large number of products such as washing machines, heaters, air conditioning, and camera autofocus. The success of fuzzy logic controllers (FLC) is due to their ability to handle knowledge represented in linguistic form instead. FLC is designed based on the experience of the expert or user of the system rather than modeling the system mathematically and then trying to solve complex equations like control engineers did.This concept gives the strength and motivation to formulate fuzzy logic while Lofti Zadeh developed and established fuzzy set theory in 1965.

The main advantage of fuzzy logic is its ability to implement experience and knowledge of a system which can sometimes be difficult to derive its mathematical model accurately and completely or poorly defined or the input data is not not precise . Fuzzy logic is a rule-based system designed by linguistic fuzzy rules, which relates the output control to the input data. Fuzzy rules come in the form of ifthen rules in which an expert should apply them in a way that covers all possible conditions that the system should experience.

Any fuzzy system has four components to function, such as fuzzification, rule-based inference, rules, and defuzzification. Fuzzy logic can receive inaccurate input which will be converted to fuzzy values such as the degree of membership in linguistic fuzzy sets, so that the rule-based system will infer the correct result. rule-based linguistic output value and type of inference (here using Mamdani inference) will be the result of fuzzy output that requires a defuzzification process that converts those linguistic values to real values (most of the defuzzification used is the center of area, COA). The rules are based on expert experience and are a collection of ifthen instructions which contain all the information to control the system. The fuzzy algorithm includes 25 fuzzy rules as shown in Table 1 The fuzzy inference engine is the heart of the fuzzy system and makes a logical decision based on fuzzy sets and the result is a fuzzy linguistic value.The following figure shows the complete components of the fuzzy logic system:[89]

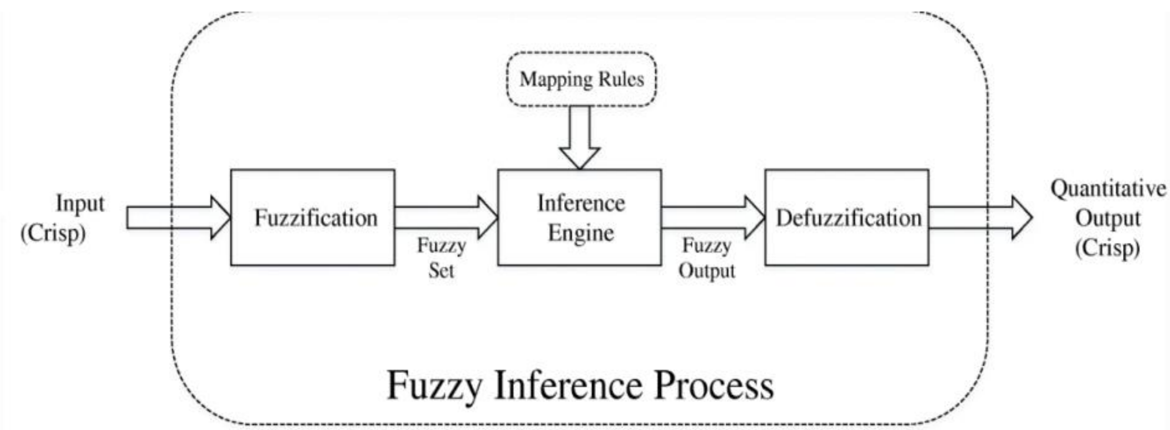


Figure 3.6 Fuzzy logic system block diagram (Skalna et al., 2015)

3.5.2 Fuzzy Control System Design

The function of a control mechanism is to maintain certain objectives of the system at different desired values. The ideal control system is a linear system that directly links its inputs to outputs. However, in practice, the instabilities affect the output of the controlled system and cause a deviation from the proposed set points. The control mechanism is divided into two main models: an open loop system and a closed loop system. The closed loop system uses signal feedback to correct the output of the controller to achieve the desired value.The study of control theory includes the main characteristics of control such as stability, precision, speed of response, sensitivity and performance . The control of a complex system such as HRIS is difficult to achieve using conditional methods. Therefore, the FLC is a more suitable solution as it covers a wide range of possible work situations with an acceptable level of uncertainty or a lack of future information. The FLC is the closest reasoning to the human approach to decision making which gives the FLC priority to be selected for the control of a complex system such as HRES.

3.5.3 MPPT PV control systems

The output characteristics of the PV model with different solar irradiation and cell temperature are not linear. In addition, solar irradiation is unpredictable, resulting in a continuous change in the MPP of the PV module, as shown in figure 4.2

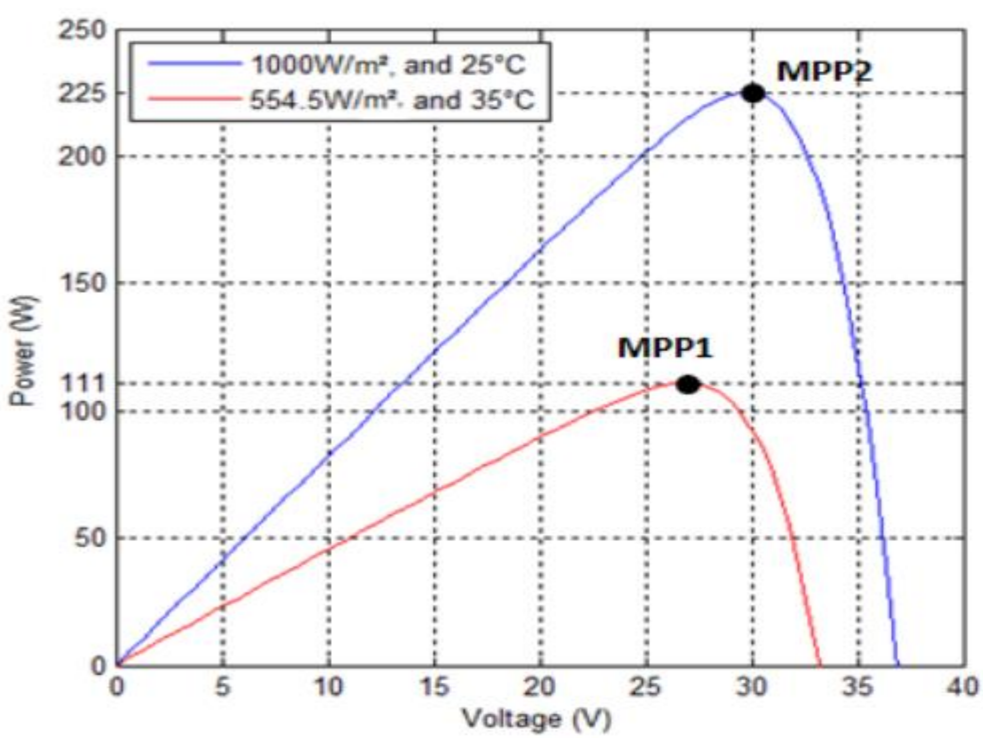


Figure 3.7 MPP of a PV module under different conditions

Thus, tracking the maximum power point (MPP) of a photovoltaic generator is an essential part of a photovoltaic system. As such, many techniques for maximum power point tracking (MPPT) have been developed and implemented (Esram and Chapman 2007). Among these techniques is bottom-up MPPT like preturb and Observe (P&O), which is a simple algorithm that does not require prior knowledge of the characteristics of the PV module and is easy to implement with analog and digital circuitry.

3.5.4 Energy distribution strategy

The energy management strategy (EMS) should determine the power shared between the PV, wind turbine, PEMFC cell and battery while meeting the energy requirements of the load against the dynamic restrictions of the battery and the FC stack. In this work, the EMS acts under certain scenarios, as shown in Figure 4-3

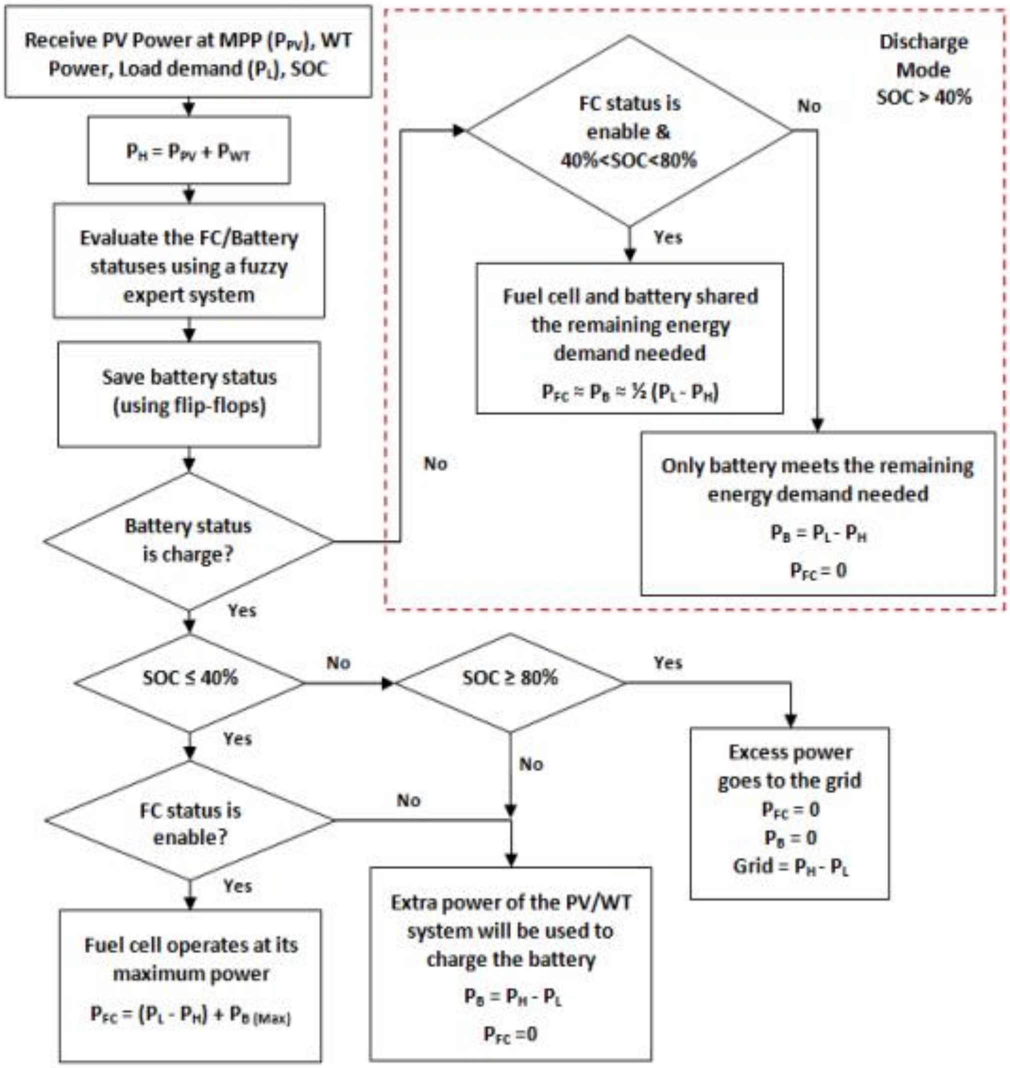


Figure 3.8 Proposed energy management system algorithm

Hybrid energy systems Energy management based on artificial intelligence Frequent fluctuations in energy demand and unpredictable load profiles are inevitable. In addition, nonlinear subsystems add to the complexity of the hybrid system structure. Therefore, an advanced fuzzy expert system will be presented according to weather fluctuations, state of charging SOC. Figure 3.9 shows the fuzzy expert system proposed for EMS.

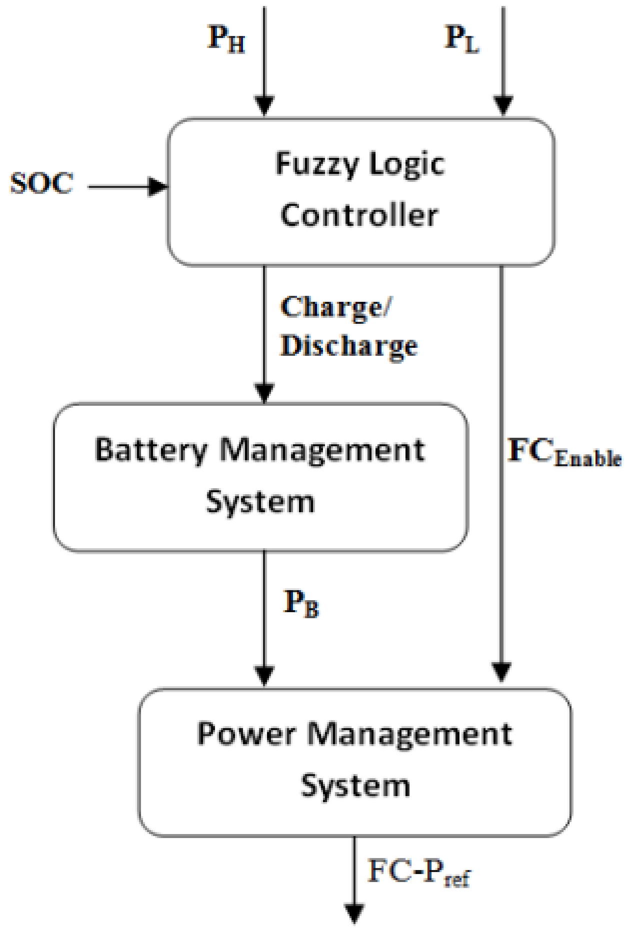


Figure 3.9 Proposed fuzzy expert system for EMS

A fuzzy logic controller (FLC) is used to decide the optimal operation of the PEMFC battery system. there are five possible operating modes.

- In grid mode, excess PV / WT power goes into the grid. In this case, the back-up power system is deactivated (fuel cell / battery).
- In charge mode, the storage battery is charged by the PV / WT when the charge demand is less than the generated power or / and is charged by the fuel cell when the SOC is low.
- In battery mode, energy demand is supplied only by the battery when the fuel cell is turned off. This mode is suitable for low power demand.

- In hybrid mode, the fuel cell and battery system help meet the remaining energy demand needed:

$$\boldsymbol{P(t)_L - P(t)_H = P(t)_{FC} + P(t)_B} \qquad \textbf{3.12}$$

This mode is suitable for high power demand.

The FLC and the battery management system keep the SOC at a reasonable level (40-80%). In addition, they prevent a voltage breakdown by controlling the required battery power (PB), as shown in Figure 4.3 An SR type flip-flop was used to store the battery status (BS) as shown in Figure 4.5

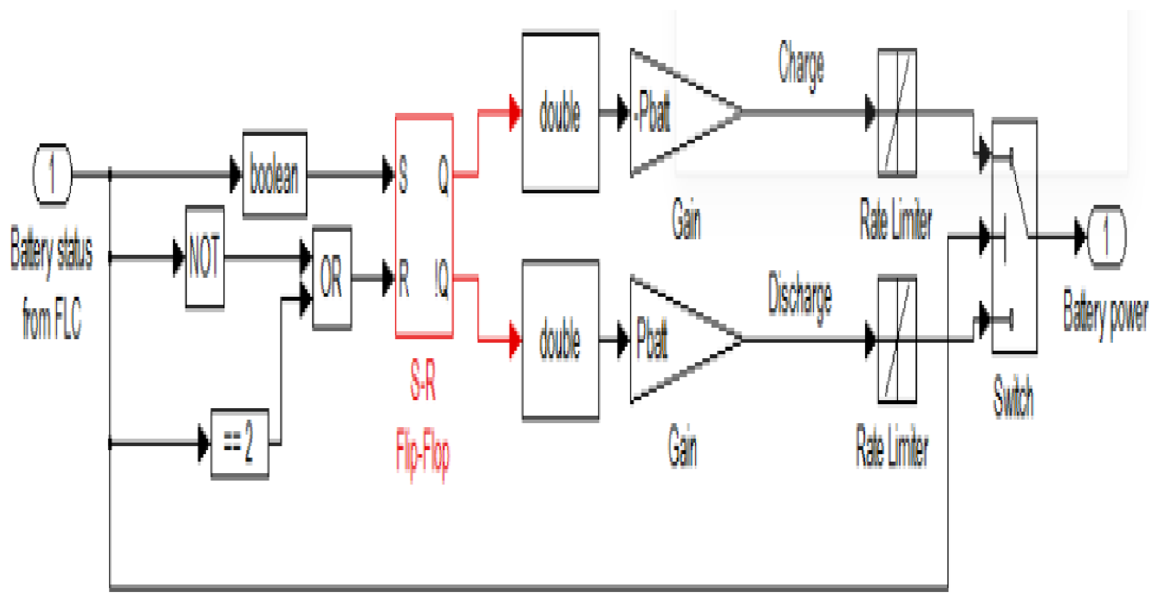


Figure 3.10 S-R type flip-flop for storing battery status

3.5.4.1 Derivation of fuzzy logic controller for EMS

The block diagram of fuzzy logic controller is shown in Figure 4.6

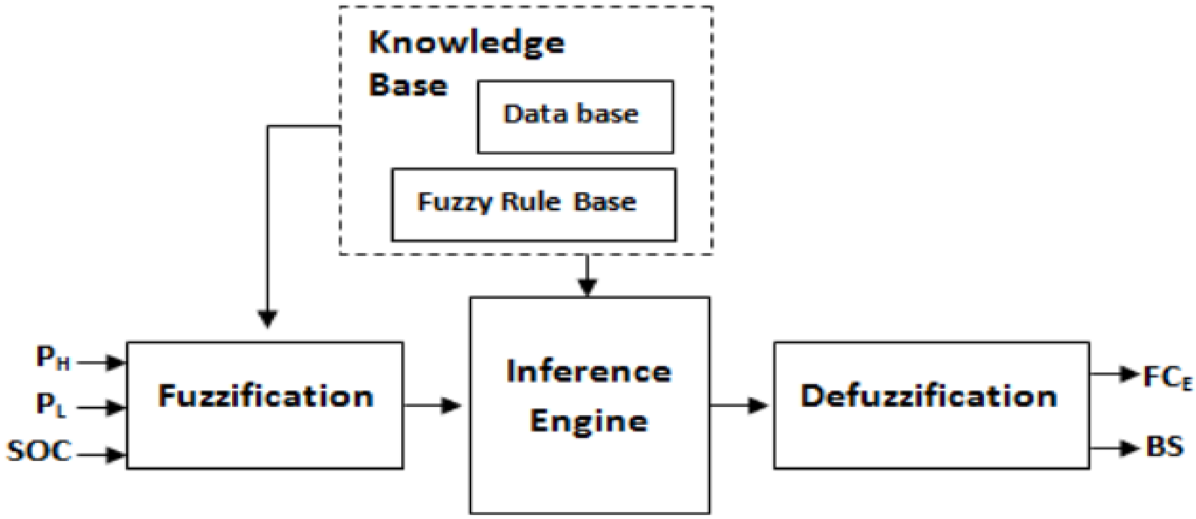
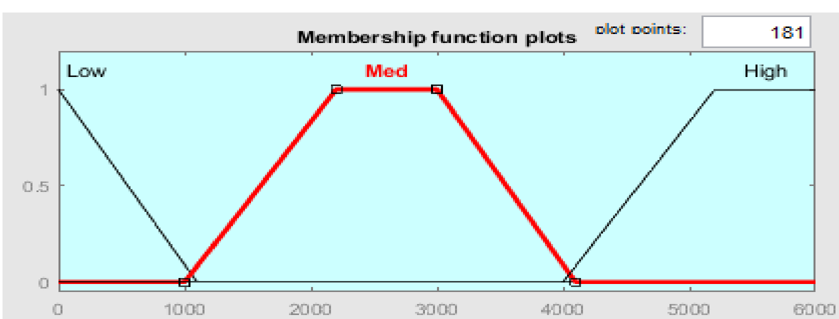
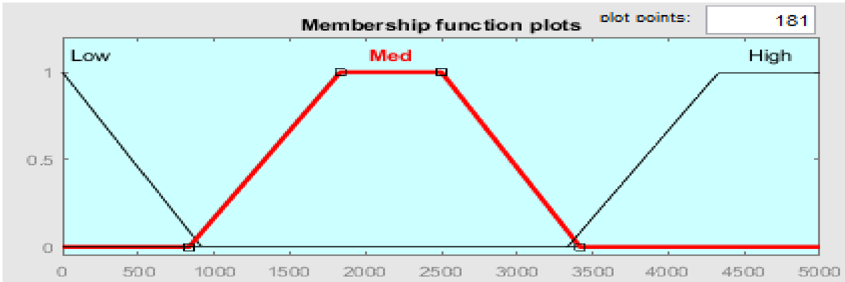


Figure 3.11 Block diagram of fuzzy logic controller for EMS

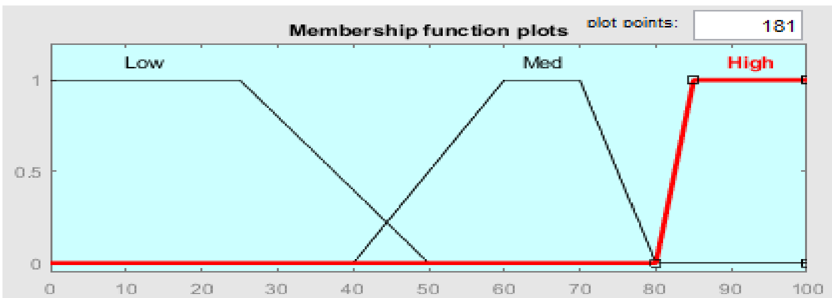
The FLC links the outputs to the inputs using a list of ifthen statements called rules. The if part of the rules describes fuzzy sets (regions) of input variables. To facilitate the calculation, the fuzzy variables PH, PL and SOC are described by singleton fuzzy, which means that the measured value of these variables is used in the interface process without being fuzzy. In particular the fuzzy rules are of the form: Rule i: IF PH is Ai and PL is Bi and SOC is Ci, THEN FCE is Di and BS is Ei Where Ai, Bi and Ci are fuzzy subsets in their universes of speech, and Di, Ei are fuzzy singletons. Each universe of discourse is divided into three fuzzy subsets: L (low), M (medium) and H (high). The fuzzy subsets and membership form are shown in Figure 3.12.



Hybridpower



demandpower



BatterySOC,%

Figure 3.12 Membership functions of the FLC of utility side

These membership degrees are evaluated to obtain the output controller, and subsequent parts of all rules are averaged and weighted according to these membership degrees. The core of the fuzzy controller rule set is shown below.

1-3 IF P_H is L and P_L is L\M\H and SOC is L, THEN FC_E is ON and BS is CO

4-6 IF P_H is M and P_L is L\M\H and SOC is L, THEN FC_E is OFF\ON\ON and BS is CO

7-9 IF P_H is H and P_L is L\M\H and SOC is L, THEN FC_E is OFF\OFF\ON and BS is CO

10-12 IF P_H is L and P_L is L\M\H and SOC is M, THEN FC_E is OFF\ON\ON and BS is CD

13-15 IF P_H is M and P_L is L\M\H and SOC is M, THEN FC_E is OFF\OFF\ON and BS is CD

16-18 IF P_H is H and P_L is L\M\H and SOC is M, THEN FC_E is OFF and BS is CD

19-21 IF P_H is L and P_L is L\M\H and SOC is H, THEN FC_E is OFF and BS is DO

22-24 IF P_H is M and P_L is L\M\H and SOC is H, THEN FC_E is OFF and BS is DO

25-27 IF P_H is H and P_L is L\M\H and SOC is H, THEN FC_E is OFF and BS is DO

Note: CO means charge only, DO means discharge only, and CD means charge or discharge.

For example, if we assume that PH, PL, and SOC are 600, 641, and 48.2, respectively. Then, according to figure 4.7, PH and PL belong to L and SOC belong to L and M (rules 1 and 10). The two possible combinations are therefore: (1) PH is L, PL is L and SOC is L (2) PH is L PL is L and SOC is M. For each case, we calculate the weighting factor using the fuzzy operator AND (product), as shown in figure 7.17, and obtain the corresponding singleton values Di and Ei . Ei can be 0 (DO), 1 (CO) or 2 (CD 19). Therefore, the backup power system is # 40; FC / battery and n ° 41; the condition is calculated using the center of gravity method (Negnevitsky 2004).This gives FCE = 0.159 0 (off) and BS = 1.8 ≈ 2 (the battery is working in normal mode; it can discharge or charge. In this case, the will discharge 41 W when charging).

3.6 Designing the MISO rule based fuzzy logic for residential energy controller

3.6.1 Creating and labelling the membership functions (MFs)

- **Input Load Consumption**

Load consumption has been identified as one of the variables impacting high and increasing energy costs in households. The control at inlet was sampled for a total consumption of 15 kw / h. The amount of consumption is converted to% age of the remaining daily limit using the following equation.

$$\textit{Load consumption}\ \% = \frac{\textit{load consumption}}{\textit{daily maximum power}} \mathrm{X100\%} \qquad 3.13$$

The membership function parameters of the consumption were sampled as shown in Figure 4.4 within a range from 0 to 100%

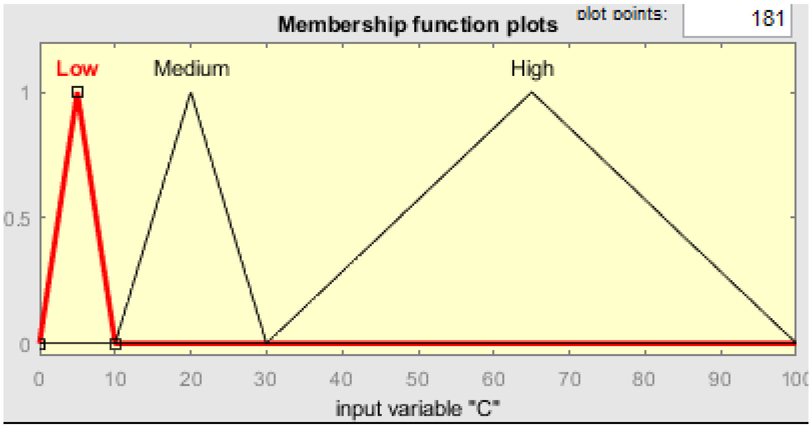


Figure 3.13 Appliance load consumption membership functions (kw in %)

mathematical equations of the membership functions shown in Figure 3.13 as follows:

$$\mu(\mathbf{C})_{Low}=\begin{cases} 0 & C \leq 0 \\ \frac{C}{5} & 0 < C < 5 \\ \frac{10-c}{5} & 5 < C < 10 \\ 0 & C \geq 10 \end{cases} \qquad 3.14$$

$$\mu(\mathbf{C})_{Medium}=\begin{cases} 0 & C \leq 10 \\ \frac{C-10}{10} & 10 < C < 20 \\ \frac{30-C}{10} & 20 < C < 30 \\ 0 & C \geq 30 \end{cases} \qquad 3.15$$

$$\mu(\mathbf{C})_{High}=\begin{cases} 0 & C \leq 30 \\ \frac{C-30}{35} & 30 < C < 65 \\ \frac{100-c}{35} & 65 < C < 100 \\ 0 & C \geq 100 \end{cases} \qquad 3.16$$

where C is the load consumption in %

- **Input Electricity Price (P) in cents**

Advanced metering infrastructure commonly referred to as smart metering has the advantage of providing customers with real-time energy consumption, energy cost data for helps customers know how to effectively manage their consumption. Reducing consumption during peak periods can lead to reduced costs and demand . In this study to facilitate the two-way communication that AMI is capable of, Figure 4.5 illustrates the membership functions at the cost of electricity read from smart meter during peak, normal and off-peak periods. Prices are set at cents for each period and billed per second.

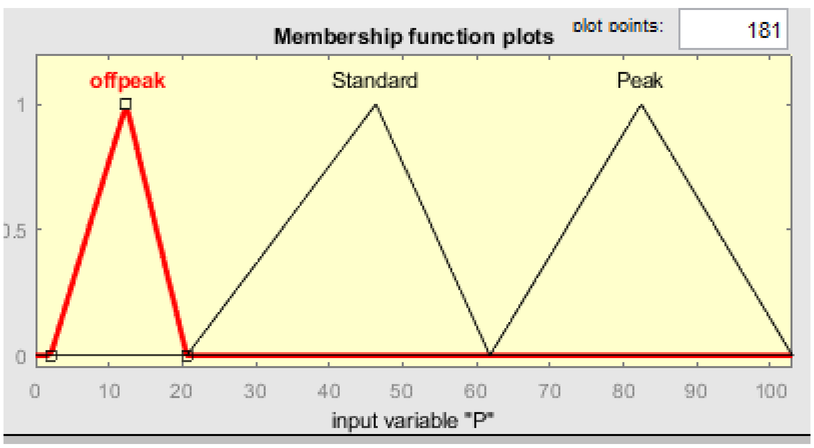


Figure 3.14 Electricity price membership functions in cents

Three membership functions in Figure 3.14 were designed to separate the demand response tariffs namely off peak that cost 15c, standard that costs 45c, and peak that cost 80c.

$$\mu(\mathbf{P})_{off\ peak}=\begin{cases} \mathbf{0} & \mathbf{p} \leq \mathbf{5} \\ \frac{\boldsymbol{P-5}}{\mathbf{10}} & \mathbf{5} < \boldsymbol{p} < \mathbf{15} \\ \frac{\boldsymbol{20-P}}{\mathbf{5}} & \mathbf{15} < \boldsymbol{p} < \mathbf{20} \\ \mathbf{0} & \boldsymbol{p} \geq \mathbf{20} \end{cases} \qquad \mathbf{3.17}$$

$$\mu(\mathbf{P})_{standard}=\begin{cases} \mathbf{0} & \mathbf{p} \le \mathbf{20} \\ \frac{P-20}{25} & 20 < p < 45 \\ \frac{60-P}{15} & 45 < p < 60 \\ \mathbf{0} & p \ge 60 \end{cases} \quad 3.18$$

$$\mu(\mathbf{P})_{peak}=\begin{cases} \mathbf{0} & \mathbf{p} \le \mathbf{60} \\ \frac{P-60}{20} & 60 < p < 80 \\ \frac{100-P}{20} & 80 < p < 100 \\ \mathbf{0} & p \ge 100 \end{cases} \quad 3.19$$

- **Daily Remaining Electricity Limit (DRL) entry**

The prepaid smart meter was chosen for the study with the user's desired amount of electricity . The daily remaining electricity limit was then calculated by subtracting electricity used from the initial daily limit. The remaining daily limit in% of age was then the fuzzy input of the controller with three triangular membership functions (minor, sufficient and adequate) as shown in Figure 4.6.

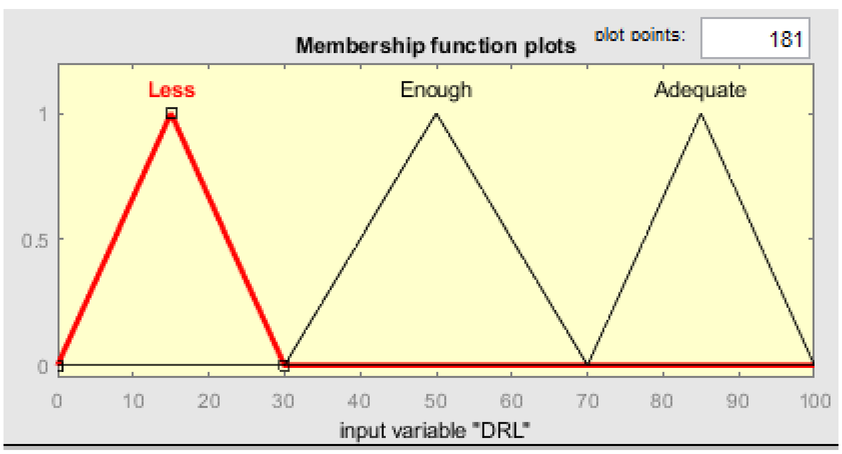


Figure 3.15 Daily Remaining Electricity Limit membership functions (kw in %)

The triangular membership functions of the available electricity are mathematically expressed by the following equations:

$$\mu(\mathbf{DRL})_{Less} = \begin{cases} \mathbf{0} & \mathbf{DRL} \leq \mathbf{0} \\ \frac{\mathbf{DRL}}{\mathbf{15}} & \mathbf{0} < \mathbf{DRL} < \mathbf{15} \\ \frac{\mathbf{30-DRL}}{\mathbf{15}} & \mathbf{15} < \mathbf{DRL} < \mathbf{30} \\ \mathbf{0} & \mathbf{DRL} \geq \mathbf{30} \end{cases} \qquad \mathbf{4}$$

$$\mu(\mathbf{DRL})_{enough} = \begin{cases} \mathbf{0} & \mathbf{DRL} \leq \mathbf{30} \\ \frac{\mathbf{DRL-30}}{\mathbf{20}} & \mathbf{30} < \mathbf{DRL} < \mathbf{50} \\ \frac{\mathbf{70-DRL}}{\mathbf{20}} & \mathbf{50} < \mathbf{DRL} < \mathbf{70} \\ \mathbf{0} & \mathbf{DRL} \geq \mathbf{70} \end{cases} \qquad \mathbf{3.21}$$

$$\mu(\mathbf{DRL})_{adequate} = \begin{cases} \mathbf{0} & \mathbf{DRL} \leq \mathbf{7\,0} \\ \frac{\mathbf{DRL-70}}{\mathbf{15}} & \mathbf{70} < \mathbf{DRL} < \mathbf{85} \\ \frac{\mathbf{100-DRL}}{\mathbf{15}} & \mathbf{85} < \mathbf{DRL} < \mathbf{100} \\ \mathbf{0} & \mathbf{DRL} \geq \mathbf{100} \end{cases} \qquad \mathbf{3.22}$$

- **Output load status (LS)**

The state of charge was the only output from the controller. Figure 3.16 shows the membership function at the output of the system. The defuzzified output value determines whether, for a specific amount of time, the appliance should be turned on or off based on the aggregation of the outputs of all the specified rules. . For presentation purposes in this study, the ON and OFF values have been converted to% .

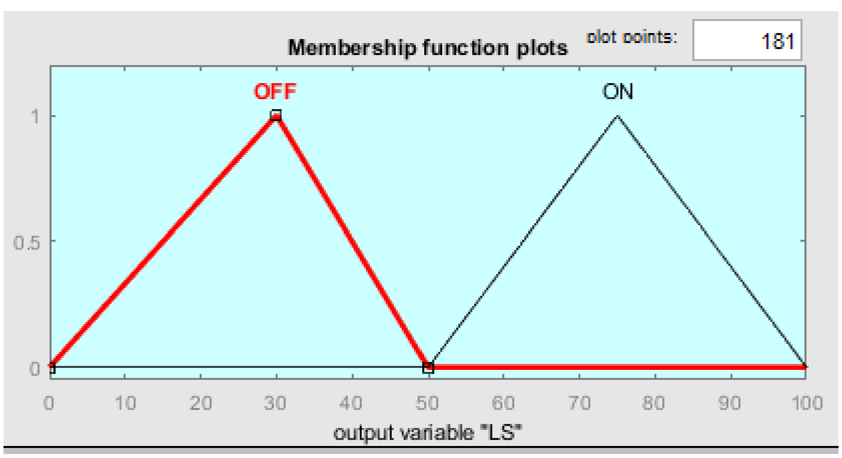


Figure 3.16 Load status of the appliance membership functions in %)

Figure 3.16 is a MATLAB snapshot showing the plots of membership functions for the output variable "Lstatus". The universe of speech is the range of voltage signals which must activate respectively "off" or "on" which disconnects or connects the load. Signal levels between 0 and 50 will activate the "OFF" function, while signal levels between 50 and 100 will activate the "ON" state.

Mathematical expression of Figure 3.16 is:

$$\mu(\mathbf{LS})_{Less}=\begin{cases} \mathbf{0} & \mathbf{LS} \leq \mathbf{0} \\ \frac{\mathbf{LS}}{\mathbf{25}} & \mathbf{0} < \mathbf{LS} < \mathbf{25} \\ \frac{\mathbf{50-LS}}{\mathbf{25}} & \mathbf{25} < \mathbf{LS} < \mathbf{50} \\ \mathbf{0} & \mathbf{LS} \geq \mathbf{50} \end{cases} \qquad \mathbf{3.23}$$

$$\mu(\mathbf{LS})_{Less}=\begin{cases} \mathbf{0} & \mathbf{LS} \leq \mathbf{5\,0} \\ \frac{\mathbf{LS-50}}{\mathbf{25}} & \mathbf{50} < \mathbf{LS} < \mathbf{75} \\ \frac{\mathbf{100-LS}}{\mathbf{25}} & \mathbf{75} < \mathbf{LS} < \mathbf{100} \\ \mathbf{0} & \mathbf{LS} \geq \mathbf{100} \end{cases} \qquad \mathbf{3.23}$$

3.6.2 Building fuzzy rules

Fuzzy rules are important for mapping input and output variables. It is a series of linguistic statements that describe how decisions are made by the fuzzy controller. The state of the rule satisfies to some extent in fuzzy logic, and each rule will affect the result of the collection depending on the degree of fulfillment [10]. The fuzzy state evaluation rules in this study were derived using the heuristic method in which the rule collection was formed by analyzing the behavior of the controlled process. The summary of the rules designed in this study is presented as follows.

Table 3.3 Designed fuzzy logic controller rules

Rule	**Load consumption**	**Price**	**Remaining daily limit**	**Load Status(output)**
1	Low			ON
2	Medium	Off-Peak	Adequate	ON
3	Medium	Off-Peak	Enough	ON
4	Medium	Off-Peak	Less	OFF

5	Medium	Standard	Adequate	ON
6	Medium	Standard	Enough	ON
7	Medium	Standard	Less	OFF
8	Medium	Peak	Adequate	OFF
9	Medium	Peak	Enough	OFF
10	Medium	Peak	Less	OFF
11	High	Off-Peak	Adequate	ON
12	High	Off-Peak	Enough	ON
13	High	Off-Peak	Less	OFF
14	High	Standard	Adequate	ON
15	High	Standard	Enough	ON
16	High	Standard	Less	OFF
17	High	Peak	Adequate	OFF
18	High	Peak	Enough	OFF
19	High	Peak	Less	OFF

The objective considered when designing the rules was to control residential electricity and improve consumption. Many variables can meet this objective, but for this study only the price of electricity, the consumption of the load, the day and the number of days desired by the consumer to use a given quantity of electricity during a period of time. of time have been studied. Rules were activated using the max of min (AND) method in which the minimum value of precedent was taken to allow the controller to activate more than one rule condition at the same time but with different strengths . The rules were structured as follows:

Rule 4: IF Consumption is "Medium" AND Price is "Off-peak" AND Available Electricity is "Less" THEN Load Status is "OFF"

3.6.3 Choosing deffuzzification method

The final control in the fuzzy controller is based not only on the rule base, but also on the chosen inference mechanism [89]. Choosing the proper defuzzification method of the fuzzy controller plays an important role in performance. There are many defuzzification methods that can be used by the fuzzy controller, but the accuracy of the method depends on the controlling application. The most widely used methods are the centroid methods and the maximum of the mean method. The existing literature as advanced by [45]. has suggested criteria for choosing the defuzzification method which has continuity, plausibility, computational complexity and disambiguation. the maximum mean method was chosen as the appropriate method for the controller in this study.The center of gravity, as studies show, brings stability and precision to the controller. This is evidenced by its ability to: • No big change resulting from the output with the small change in the input. • The defuzzed output was central to the support of the resulting membership function and had a high degree of membership function.

Chapter Four

RESULT AND DISCUSSIONS

This section presents the results of Predicted Energy Rule Viewer, Surface Viewer, Rule , and Surface View for appliance planning. Finally, the overall result of the simulation for the model proposed by exchanging the input parameters. the load participate in the management of the demand .The method introduces online energy management using a hierarchical controller between four energy sources: photovoltaic (PV) panels, wind turbine, battery and fuel cell (FC) .

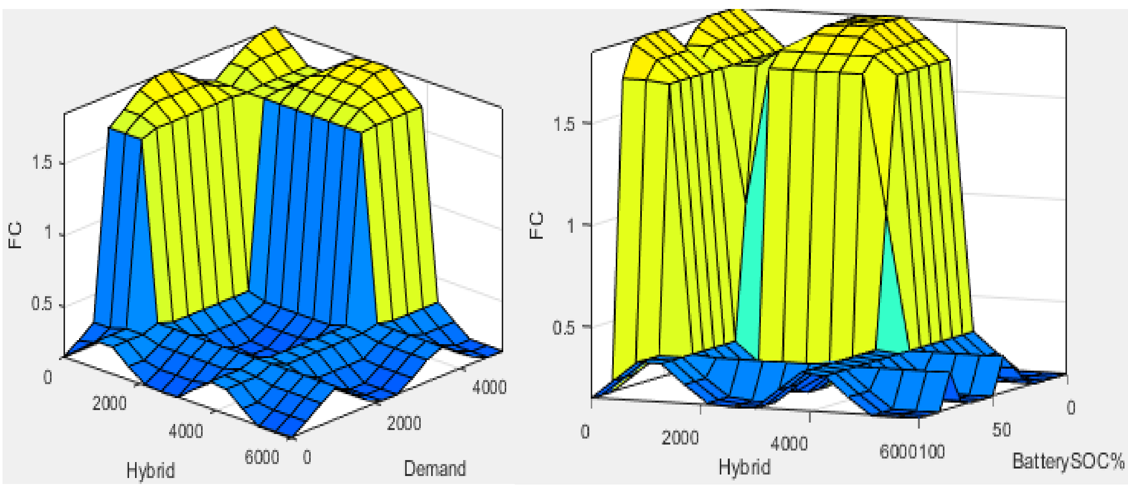


Figure 4.1 a Figure 4.1 b

Figure 4.1 Surface plot for FC

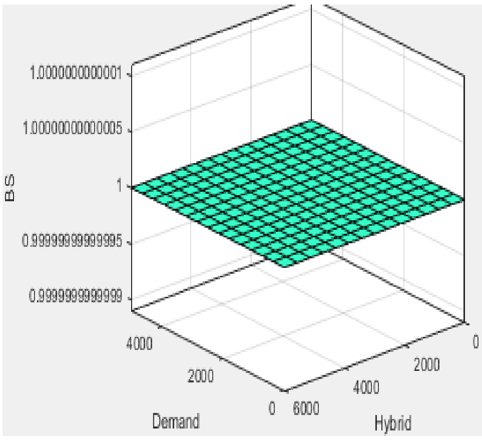


Figure 4.2 a

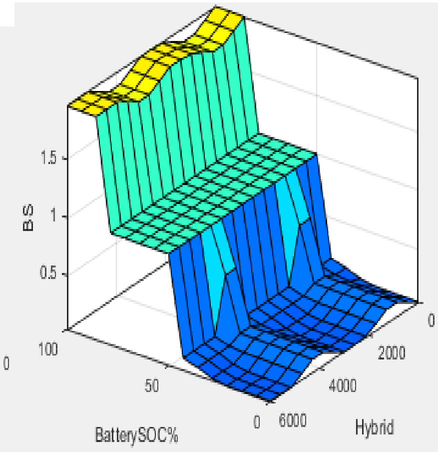


Figure 4.2 b

Figure 4.2 Surface plot for Battery status

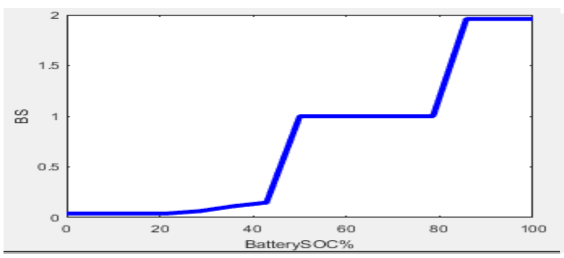


Figure 4.3 a

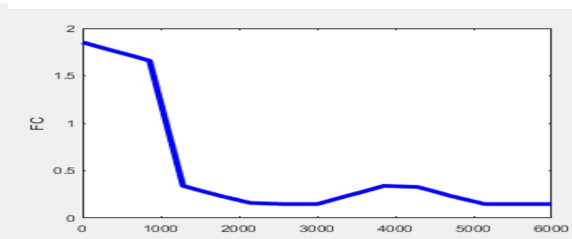


Figure 4.3 b

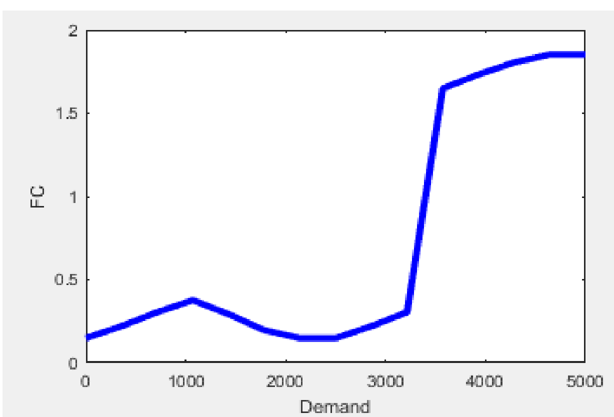


Figure 4.3 c

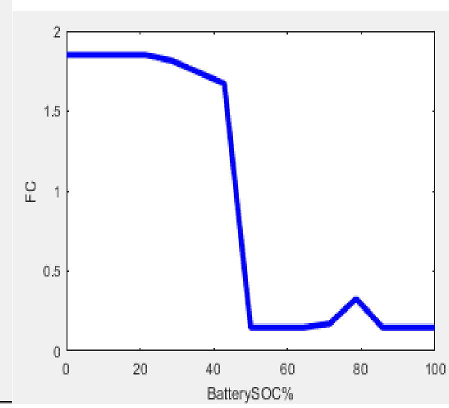


Figure 4.3 d

Figure 4.3 Surface plot for FC and Bstatus

Figures 4.4a , 4.4 b and 4.4 c show the matlab simulink plots generated for the output variables "Battery status" , "FC" , and input variable respectively. The plots show the overall behaviour of the system at a glance.

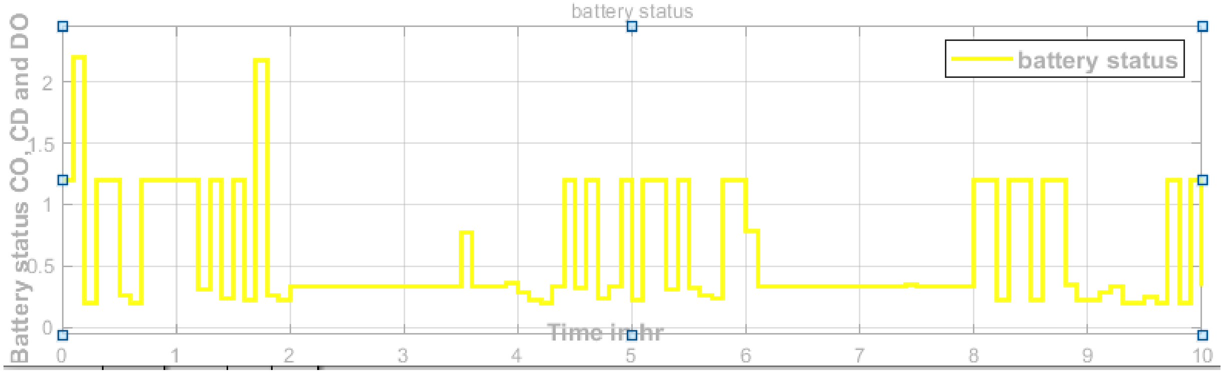


Figure 4.4 a

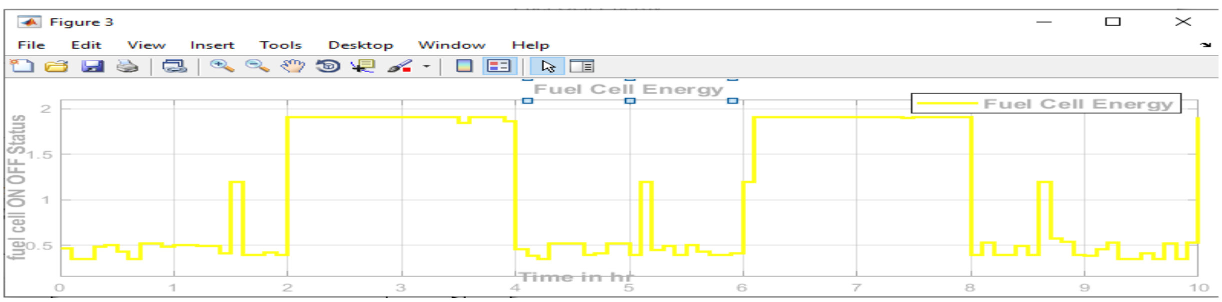


Figure 4.4 b

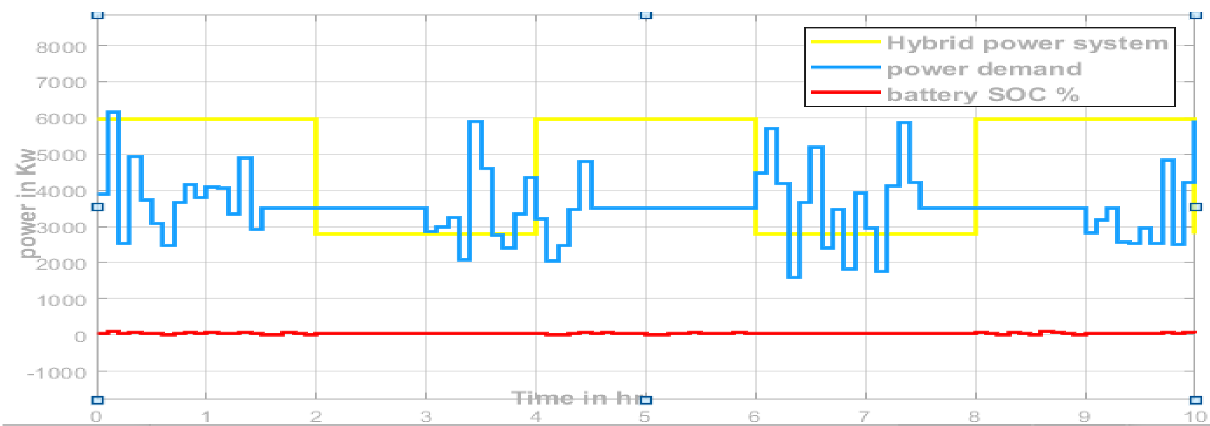


Figure 4.4 c

Figure 4.4 Simulation result of the proposed system

4.1 Test cases, Results, and Discussion

4.1.1 Case 1:In this case we simulate a scenario where all loads are turned on giving a total of 5000W of load demand. Hybrid 3000W. The battery SOC is 37%. It follows that:

PH= 3000W; PL= 5000W; Pdiff = 2000W , SOC = 37%.

A snapshot from the MATLAB simulation is shown in Figure 53.

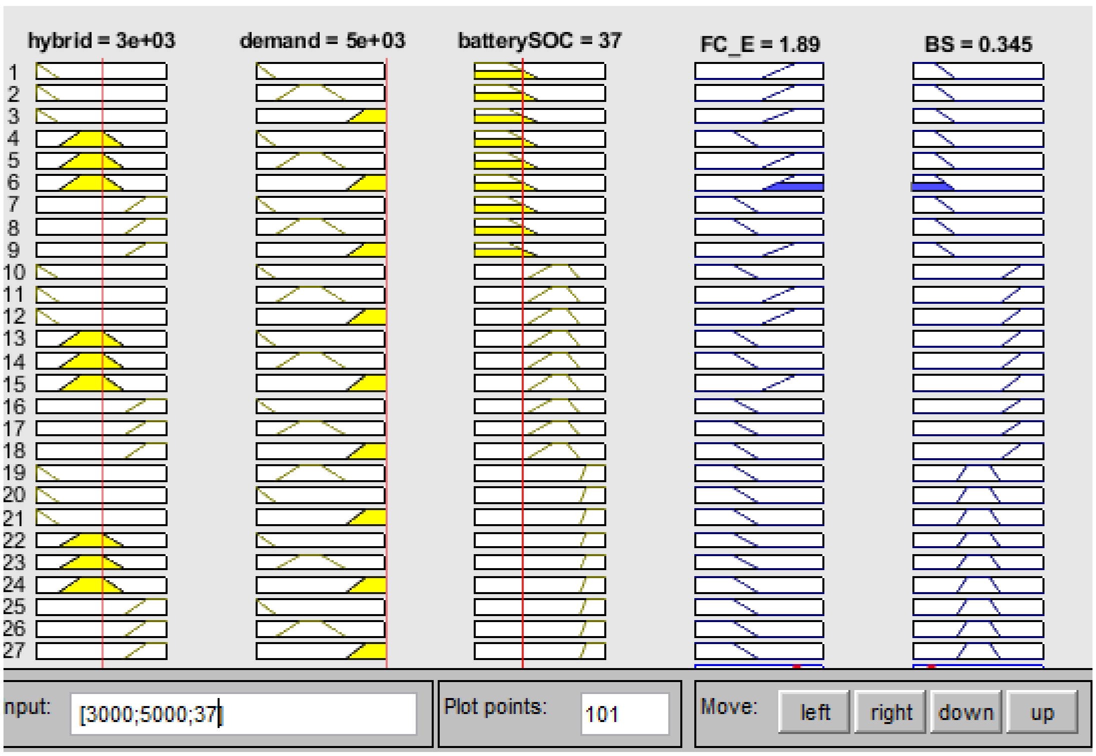


Figure 4.5 Case 1 Result

In case 1, the power difference between the hybrid power supply and the load demand was 2000W, implying that the hybrid power supply was not sufficient to meet the total load demand. At the same time, the battery state-of-charge was 37% indicating that the battery was not charged enough to make up for the deficiency in the supply. The expected result is that FCE 'ON' supply the load. Simultaneously, the power from the hybrid source, though not sufficient to meet the demand could be used to charge the battery. In figure 53, this expectation was achieved by the fuzzy logic control as seen in the defuzzified value for battery status (0.34), which trigger the FCE “ON” and battery charged only “CO” status for the FCE status and battery status respectively and FCE supply 2000w load.

4.1.2 Case 2:In this case, all loads but the some load are turned on. This gives a total of 4000W load demand. Hybrid 3000w SOC 80

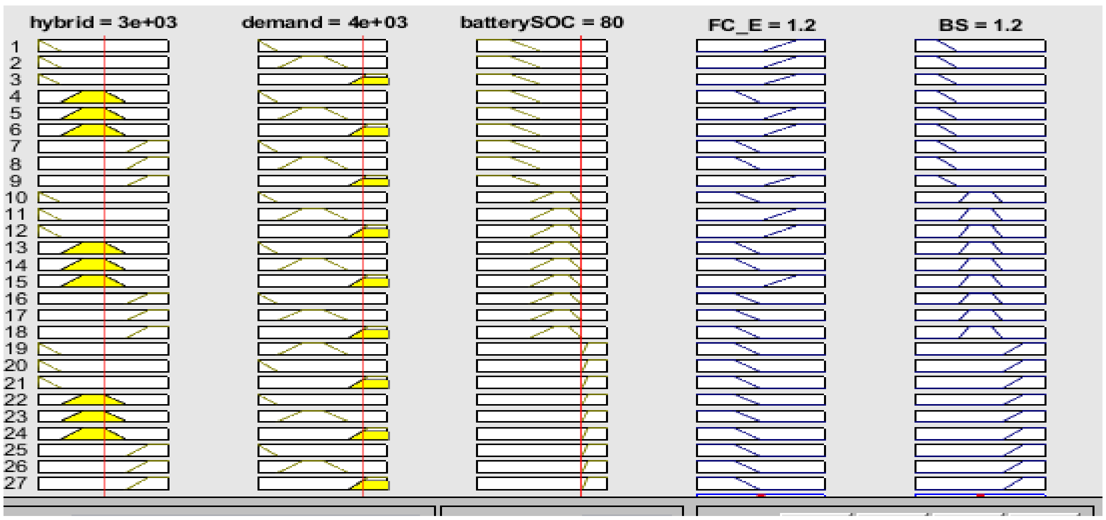


Figure 4.6 Case 2 Result

Case 2 implies:

PH = 3000w; PL = 4000; Pdiff = -1000; COS = 80%. The result is shown in Figure 54. In case 2, the power difference was negative, implying insufficient power, but the battery state of charge was 80%, which meant that the battery could be discharged to compensate for the lack of power. An expert decision would be to discharge the battery to provide the remainder of the charging demand. This result was produced by the fuzzy controller as shown in Figure 54. "FCB" was deactivated by the 1.2 V signal and become “OFF” state comdition at this stage battery become charging and discharging condition.

4.1.3 Case 3

In this case, only the refrigerator, television, and the two fans and some load are turned on. The weather is assumed to be a bit dry with no wind. The resulting output from the PV is 1000W and 0W from the Wind. The battery SOC is 48%. The case simulation is shown in Figure 55 .

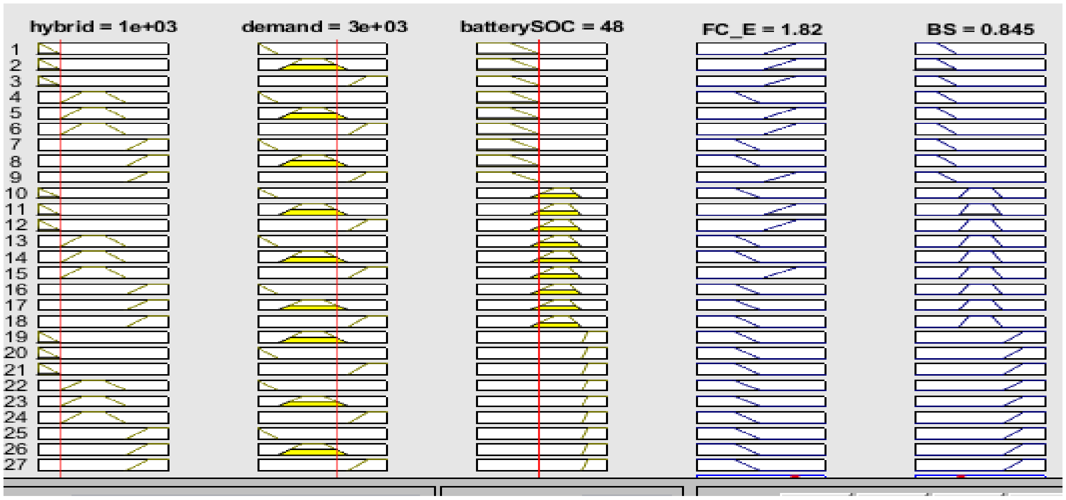


Figure 4.7 Case 3 Result

It sows : PH= 1000W; PL= 3000W; Pdiff = 2000W, SOC = 48%

Given the inputs in Case 3, the power difference was negative, implying insufficient power, but the battery state of charge was 48%, which meant that the battery could be some how discharged to compensate for the lack of power. An expert decision would be to discharge the battery to provide the remainder of the charging demand. This result was produced by the fuzzy controller as shown in Figure 55. "FCB" was activated by the 1.82 V signal and become “ON” state comdition to sopport the battery. at this stage battery become charging and discharging condition.

4.1.4 Case 4:

In this scenario, it is night time and a bit windy outside the house. All lights are turned on, the two laptops are in full use, plugged in and charging, and the refrigerator is also running. Due to darkness the PV has 0W output, and the WTG is generation 1000W. Battery SOC is 95%.

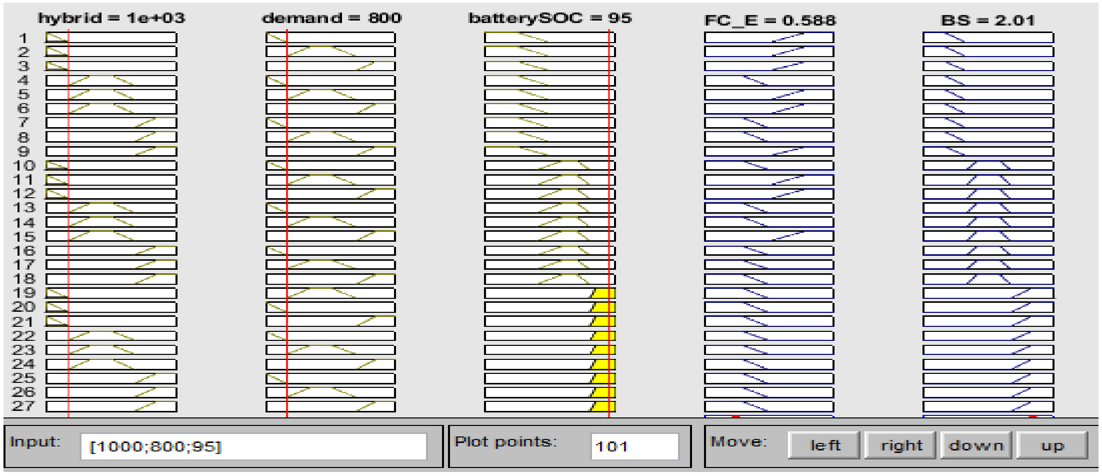


Figure 4.8 Case 4 Result

The result is:

PH= 1000W; PL= 800W; Pdiff = 200w; SOC = 95%.

Case 4 is a scenario where the hybrid power is sufficient to cover the load demand. Surplus supply power of was used to charge the battery in trickle charge mode because the SOC is 95%. This result obtained from the fuzzy logic controller is shown in Figure 56. The 0.588 "FCstatus" signal FC become disconnected. while the 2.01V "Bstatus" signal keeps the battery in float mode . In each of the test cases, it was observed that the fuzzy logic controller was able to accurately obtain the results of an expert decision for the behavior of the system given a set of inputs .

From the figure 52 c load profile it is evident that the average power demand is less than 2.4kW. The load profile during peak load periods varies from 3 to 4.5kW, as illustrated in Figure 52 (c). However, due to weather condition, the output power of the PV/WT system varies. Therefore, a PEM fuel cell with a reversible ESS was added to the renewable power system. The battery bank system is capable of sustaining the extra load of 1.3kW for 1h during peak load demand periods. While, the 6kW PEMFC can meets the remaining extra power and protect the battery from over-discharging.

4.2 presantation of Demande side results and analysis

4.2.1 Simulation scenario 1: Low demand price and sufficient electricity

Fuzzy logic system to manage the amount of electricity available according to the consumer's wishes during a given period and to improve electricity consumption by programming household appliances according to ToU tariffs.

Table 4.1 Parameters for tariffs

Price	**Time**	**Parameters in cents**
Off Peak	**22:00-07:00**	**15**
Medium Peak	**07:00-08:00** **10:00-18:00** **20:00-22:00**	**45**
Peak	**08:00-10:00** **18:00-20:00**	**80**

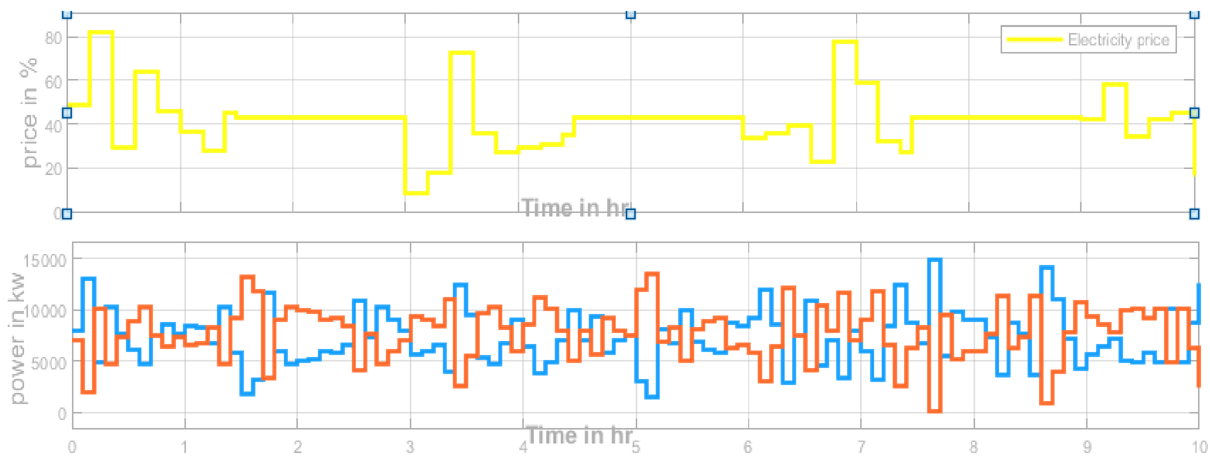


Figure 4.9 shows the simulation for the demand side

The low, medium, and high load consumption was sampled between 04:49 and 06:59 and the state of charge was active. This implies that fuzzy logic may have invoked rules 1, 2 and 11 which were summed up based on low, medium or high load consumption, while the price was off peak and the remaining daily limit was adequate. In this case, the state of charge was activated.

4.2.2 Simulation scenario 2: Standard price and adequate electricity

This simulation evaluates the behavior of fuzzy logic when checking the consumption of the load, because the tariff was standard and the daily tariff remaining from the electricity limit was still adequate. As shown in Figure 4.9, the price went from 15 cents to 45 cents at 7:00 a.m until 8:00 a.m. In addition, during this period, the active state of the difference in load consumption has been observed because the remaining daily electricity was always adequate. Rule 1 was sampled between 7:00 a.m. and 7:10 a.m. with low load consumption. Rule 5 was invoked between 7:11 am and 7:16 am with average load consumption while rule 14 for high load consumption was invoked from 7:19 am to 7:59 am. Fuzzy rules were obseved during peak period and adequate remaining daily electricity limit. The charge consumption was 80% high at 8:00 a.m., as shown in Figure 5.3, and the 's state of charge was off for one minute.

4.2.3 Simulation scenario 3: Peak price and adequate electricity

Fuzzy logic invoked rules 8 and 17 which show that if the consumption of load is medium or high and the price is peak or the price is adequate, then the state of load was OFF. From 8:01 am to 9:59 am during the peak period, fuzzy logic invoked rule 1 to only allow the low power ON state.

4.2.4 Simulation scenario 4: Standard price and enough electricity

At 10:50 am the current started to be sufficient, that is, less than 70% and more than 30% as shown in Figure 4.9, which meant that the remaining daily current limit was , it was no longer sufficient, but sufficient. The state of charge stayed ON from 10:50 a.m. to 3:30 p.m. as the 's fuzzy logic called rules 1, 6, and 15 which allowed the 's low, medium, and high charge consumption to be ON when the price was on Standard and the remaining daily limit is sufficient.

4.2.5 Simulation scenario 5: Standard, peak price and less electricity

Between 3:32 p.m. and 5:59 p.m. the price was standard and the remaining daily limit was lower with load consumption at 100% of the remaining daily limit and the load was turned off in accordance with rules 7 and 16. The only charge allowed was the load which was 10% and less (low load consumption). At 6:00 p.m. the price peaked with a lower daily residual limit also from this period at 11:59 p.m. only 10% of the daily residual limit was activated.

4.2.5 Simulation scenario 6: Fuzzy logic rule testing

Fuzzy logic rules for orderly device shutdowns to manage the amount of power for a period of time and to improve the planning of devices in response to ToU tariffs. The fuzzy logic rules listed in Table 5.3 were developed to switch off devices in an orderly manner in order to control power consumption.

Table 4.2 Fuzzy logic Rules designed to switch OFF the appliances

Rule	Load consumption	Price	Remaining daily limit	Load Status(output)
4	Medium	Off-Peak	Less	OFF
8	Medium	Peak	Adequate	OFF
9	Medium	Peak	Enough	OFF
10	Medium	Peak	Less	OFF
13	High	Off-Peak	Less	OFF
16	High	Standard	Less	OFF
17	High	Peak	Adequate	OFF
18	High	Peak	Enough	OFF
19	High	Peak	Less	OFF

The OFF state of charge has been classified under the output membership functions in Figure 4.10 as any range from 0 to 50%. The rules for switching off luminaires were designed and tested before the real-time simulation. The following figures show the rule test for fuzzy logic rules selected for device shutdown. Average load consumption at off-peak rate with lower daily residual electricity limit. The state of charge was OFF as invoked by rule 4 and showed in Figure 4.10

Figure 4.10 Rule 4 checked

Rule 7 was checked and shown in the following figure when the average load consumption during the normal tariff and minus the remaining daily limit for electricity was switched off.

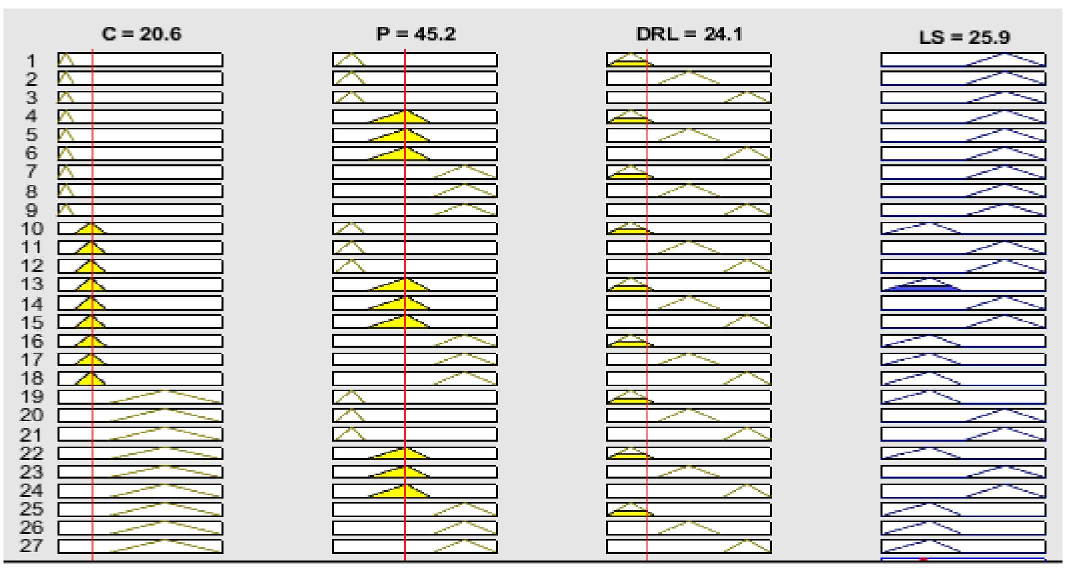


Figure 4.11 Rule 7 checked

Figure 4.12 shows the high load consumption sampled at a reduced tariff with a lower daily residual electricity limit. Rule 13 was invoked to stop the charge

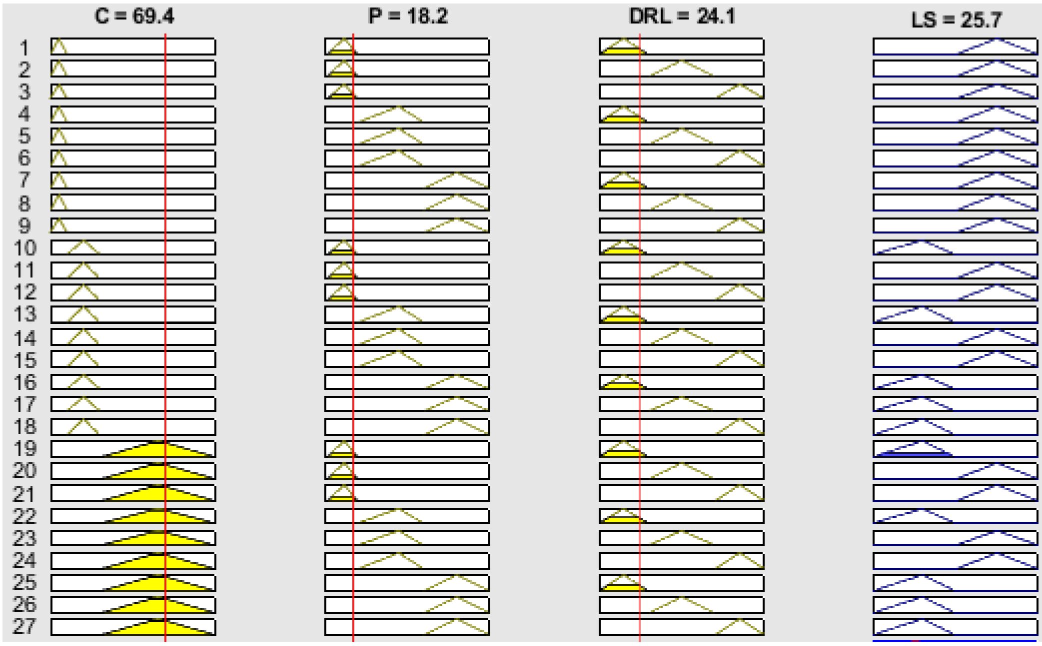


Figure 4.12 Rule 13 checked

The following figures shows the Surface view Z-output for the inputs and output.

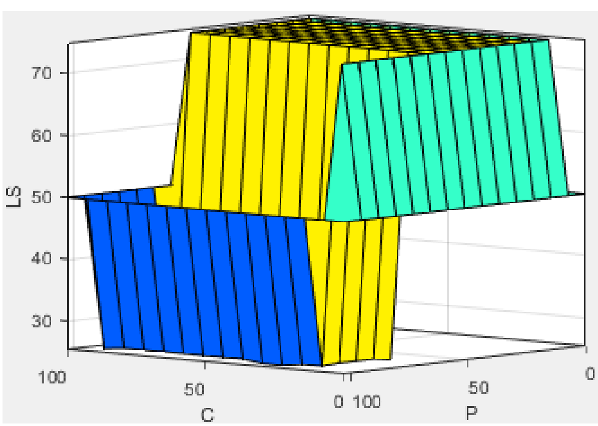


Figure 4.13 Surface view Z-output of electricity price (y-input) and load consumption (x-input)

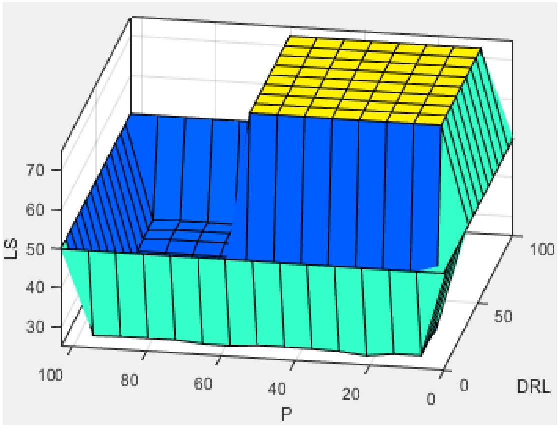


Figure 4.14 Surface view Z-output of remaining daily limit (y-input) and price (x-input)

To invoke rules 1, 2, 3, 4 and 5, the load consumption must be between 0 and 30% of the remaining daily limit, therefore the medium and low load consumption must be enabled. The output of the Z surface view for load consumption was as shown in Figure 4.15

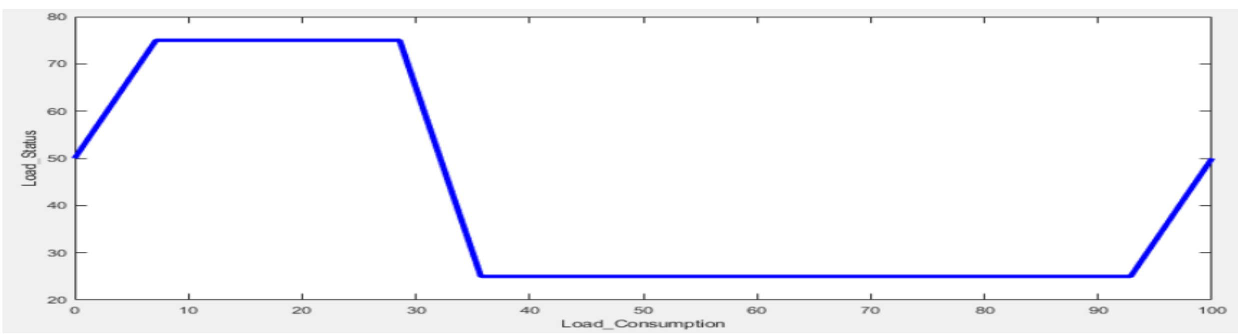


Figure 4.15 Load Status surface view Z output

When electricity price is off peak, the load status is more likely to be ON for the load consumption as shown in Figure 4.16

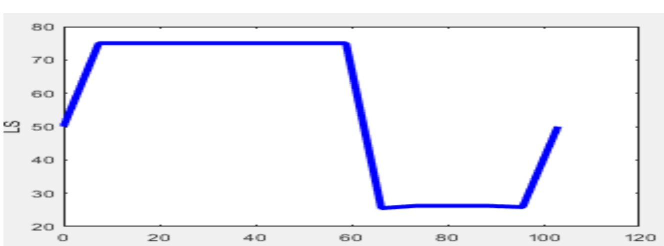


Figure 4.16 Electricity Price surface view Z output

On status was invoked mostly when the remaining daily limit was more than 60% of the electricity daily limit. The z surface view for the remaining daily limit was as shown in Figure 4.17.

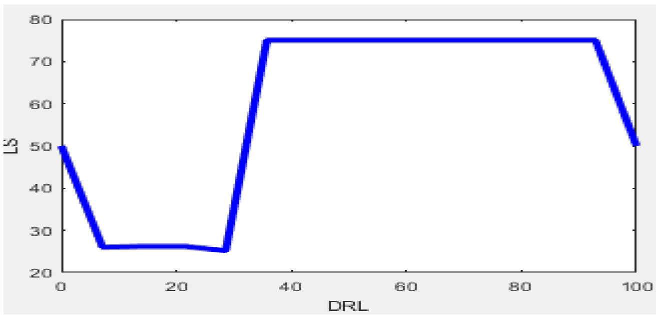


Figure 4.17 Remaining daily limit surface view Z output

4.2.6 Summary

This chapter presented the results of this study which was studied using the fuzzy logic controller . The fundamental objective was to control the consumption and the cost of electricity by considering tariffs, load consumption and the daily remaining power limit as input and state of charge as the only output. For the actual state of the output (≥ 50%), the system was able to calculate the amount of electricity used for that particular runtime and subtract it from the original calculated daily limit electricity. Logica Fuzzy activated system was simulated to manage the amount of electricity available as desired by the consumer during a given period of time and to improve electricity consumption   by programming home appliances in response to ToU tariffs. The simulation lasted 24 hours and the results were sorted by price and   daily residual electricity limit. Finally, what-if scenario 7 tested fuzzy logic controller rules designed to shut down the device in order to increase power consumption by programming devices in response to uptime rates. The results were presented from the z-surface view for each entry versus exit.

Conclusion and Recommendation

Conclusion

The benefits of hybrid renewable energy systems cannot be underestimated. However, the struggle to overcome the inefficiencies and unreliability caused by the intermittent nature of renewable energy sources is still ongoing. Some researchers have focused on extracting as much energy as possible from renewable sources by developing and using different algorithms for detecting the maximum power point, others have focused on improving the efficiency of the converter to minimize losses incurred during power conversions. However, other researchers have attempted to make improvements in the field of energy storage.And many researchers have followed the path of optimizing the management of energy flows in HRES, and this is where this project fits. Much work has been done to monitor and control energy flows in HRES, but many of them use conventional techniques that do not offer the ease of implementation, efficiency and reliability introduced by using artificial intelligence (AI) methods. Based on fuzzy logic, was able to control the consumption of the residential load by programming the devices as desired by the consumer taking into account the schedules of use of the tariffs and the remaining quantity of electricity. The implemented model can help the utility company to better manage its operations, reduce network outages and damage to equipment.Project results showed that the use of fuzzy logic to monitor supply power, load demand, and battery charge and discharge for the purpose of proper management of energy flow produced desirable results,as seen in the test case scenarios. This work demonstrated that the use of fuzzy logic control in the management of energy flows in hybrid renewable energy systems offers the advantage of ease of design of the control since there is no need to develop complex mathematical models as required in conventional control techniques. The fuzzy inference system simply emulates and automates expert decision making for the behavior of the system.With an easy to develop control design, you get a more cost effective solution. Even from exisisting system During off peak around 5.535Mwh energy saved to the batery and fuel cell per day.

Recommendations

- Other artificial intelligence techniques, such as artificial neural networks (ANN) and genetic algorithms, could be used to fine-tune the fuzzy logic control system on-line.
- To a greater extent, load optimization could be integrated into the control unit to further optimize power flow management.

- For example, if the supply is less than the full demand, some loads can be supplied by the available power, while other loads are switched off, instead of separating the entire load using a defined load prioritization management algorithm.
- This could be built into the control unit. For a more robust system, real-time user feedback can be incorporated to detect malfunctions, detect alarms, and collect and record statistical data.
- The work could be continued by developing a conventional proportional-integral controller for comparison with the fuzzy logic controller in order to evaluate other performance parameters such as settling time and maximum overshoot.
- The simulation can be carried out with the MATLAB / SIMULINK environment.

REFERENCES

[1] EEPCo., “Ethiopian Power Sector Development, Powering Africa.,” *https//pubs.naruc.org/pub.cfm?id=537C14D4-2354-D714-511E-CB19B0D7EBD9 (Accssesd 10 Sept. 2021)*, p. 117, 2014, [Online]. Available: https://pubs.naruc.org/pub.cfm?id=537C14D4-2354-D714-511E-CB19B0D7EBD9.

[2] C. a C. T. S. Uninova, “Fuzzy Decision Making2010.ppt,” *Optimization*, 2010.

[3] O. Christou, “Energy security in turbulent times towards the european green deal,” *Polit. Gov.*, vol. 9, no. 3, pp. 360–369, 2021, doi: 10.17645/pag.v9i3.4336.

[4] S. jun Wu, S. Wang, C. jun Yang, and K. ren Xie, “Energy management for thermoelectric generators based on maximum power point and load power tracking,” *Energy Convers. Manag.*, vol. 177, no. September, pp. 55–63, 2018, doi: 10.1016/j.enconman.2018.09.040.

[5] J. Liu, X. Chen, S. Cao, and H. Yang, “Overview on hybrid solar photovoltaic-electrical energy storage technologies for power supply to buildings,” *Energy Convers. Manag.*, vol. 187, no. February, pp. 103–121, 2019, doi: 10.1016/j.enconman.2019.02.080.

[6] Zaheeruddin and M. Manas, “Renewable energy management through microgrid central controller design: An approach to integrate solar, wind and biomass with battery,” *Energy Reports*, vol. 1, pp. 156–163, 2015, doi: 10.1016/j.egyr.2015.06.003.

[7] Á. O. Topa Gavilema, J. D. Álvarez, J. L. Torres Moreno, and M. P. García, “Towards optimal management in microgrids: An overview,” *Energies*, vol. 14, no. 16, pp. 1–25, 2021, doi: 10.3390/en14165202.

[8] WIPO, “Patent-based Technology Analysis Report – Alternative Energy,” *World Intellect. Prop. Off.*, p. 116, 2009.

[9] A. Mohammadnia, A. Rezania, B. M. Ziapour, F. Sedaghati, and L. Rosendahl, “Hybrid

energy harvesting system to maximize power generation from solar energy," *Energy Convers. Manag.*, vol. 205, no. August 2019, p. 112352, 2020, doi: 10.1016/j.enconman.2019.112352.

[10] H. M. Hussain and P. H. J. Nardelli, "A Heuristic-based Home Energy Management System for Demand Response," *Proc. - 2020 IEEE Conf. Ind. Cyberphysical Syst. ICPS 2020*, pp. 285–290, 2020, doi: 10.1109/ICPS48405.2020.9274742.

[11] M. Yue, S. Jemei, R. Gouriveau, and N. Zerhouni, "Review on health-conscious energy management strategies for fuel cell hybrid electric vehicles: Degradation models and strategies," *Int. J. Hydrogen Energy*, vol. 44, no. 13, pp. 6844–6861, 2019, doi: 10.1016/j.ijhydene.2019.01.190.

[12] S. Code, "Lecture Notes on Renewable Energy Sources."

[13] H. Project *et al.*, "Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics," 2012.

[14] A. C. Technologies, *RENEWABLE ENERGY*. .

[15] L. Jia and L. Tong, "Dynamic Pricing and Distributed Energy Management for Demand Response," pp. 1–9.

[16] J. Tsao, B. E. Science, N. Lewis, and G. Crabtree, "Solar FAQs," pp. 1–24, 2006.

[17] A. Luque and S. Hegedus, *Handbook of Photovoltaic Science*. .

[18] L. Hughes, N. Bristow, T. Korochkina, P. Sanchez, and D. Gomez, "Assessing the potential of steel as a substrate for building integrated photovoltaic applications," vol. 229, no. August, pp. 209–223, 2018, doi: 10.1016/j.apenergy.2018.07.119.

[19] S. A. Kalogirou, "Solar Energy Engineering Processes and Systems."

[20] "No Title."

[21] C. Solar, B. Conference, and R. Paper, "ADVANCED ALGORITHM FOR MPPT CONTROL OF PHOTOVOLTAIC SYSTEMS C . Liu , B . Wu and R . Cheung," 2004.

[22] A. Physics, “SOLAR COOKERS WITH THERMAL ENERGY STORAGE : A SUSTAINABLE COOKING SOLUTION FOR DEVELOPING COUNTRIES INAUGURAL LECTURE PRESENTED BY NORTH-WEST UNIVERSITY MAFIKENG CAMPUS Solar Cookers with Thermal Energy Storage : A Sustainable Cooking Solution for Develop,” no. August, 2019.

[23] I. E. Agency, “Technology Roadmap,” 2014.

[24] A. P. K. Yadav, S. Thirumaliah, and G. Haritha, “Comparison of MPPT Algorithms for DC-DC Converters Based PV Systems,” vol. 1, no. 1, pp. 18–23, 2012.

[25] R. Song, “Control Strategies for Distributed Energy Resources in Islanded Microgrids Ruihao Song A thesis in fulfilment of the requirements for the degree of Master of Philosophy School of Electrical Engineering and Telecommunications Faculty of Engineering,” no. October, 2018.

[26] J. Shiau, Y. Wei, and B. Chen, “A Study on the Fuzzy-Logic-Based Solar Power MPPT Algorithms Using Different Fuzzy Input Variables,” pp. 100–127, 2015, doi: 10.3390/a8020100.

[27] ICID, “Solar Powered Irrigation Systems in India: Lessons for Africa Through a FAO Study Tour Draft Report (2019) International Commission on Irrigation and Drainage (ICID),” 2019.

[28] *Concepts in Photobiology Photosynthesis and Photomorphogenesis*. .

[29] G. S. Report, *Renewables 2017 global status report 2017*. 2017.

[30] E. Sofronova, “AN INTRODUCTION TO SOLAR CELL,” vol. 14, pp. 481–491, 2016, doi: 10.5937/jaes14-10879.

[31] D. Narducci and B. Lorenzi, “Economic Convenience of Hybrid Thermoelectric-Photovoltaic Solar Harvesters,” *ACS Appl. Energy Mater.*, vol. 4, no. 4, pp. 4029–4037, Apr. 2021, doi: 10.1021/ACSAEM.1C00394/SUPPL_FILE/AE1C00394_SI_001.PDF.

[32] P. M. K. Gowtham, K. A. Ramesh Kumar, “Experimental Investigation of Portable

Solar Thermal Energy Storage System using Fatty Acid as a Phase Change Material," *Int. J. Eng. Res. Technol.*, vol. 5, no. 8, pp. 289–297, 2016.

[33] Sharad Mandloi and Dr. Shriram Dravid, "Analysis of Hybrid Solar Thermal and Wind Energies Combined in Compressed Air for Power Generation," *Int. J. Eng. Res.*, vol. V9, no. 02, pp. 666–670, 2020, doi: 10.17577/ijertv9is020406.

[34] V. Quaschning, *Understanding Renewable Energy Systems*. .

[35] P. H. H. El-tamaly and E. S. I. H. Ata, "Optimum Design of Photovoltaic / Regenerative Fuel Cell Power System for a Remote Telecom Station," pp. 1958–1964, 2018.

[36] S. Venkataraman, C. Ziesler, P. Johnson, and S. Van Kempen, "Integrated Wind, Solar, and Energy Storage: Designing Plants with a Better Generation Profile and Lower Overall Cost," *IEEE Power Energy Mag.*, vol. 16, no. 3, pp. 74–83, 2018, doi: 10.1109/MPE.2018.2793478.

[37] R. Ziazi, K. Mohammadi, and N. Goudarzi, "Techno-economic assessment of utilizing wind energy for hydrogen production through electrolysis," *Am. Soc. Mech. Eng. Power Div. POWER*, vol. 2, pp. 1–12, 2017, doi: 10.1115/POWER-ICOPE2017-3675.

[38] S. J. Schreck and M. C. Robinson, "Horizontal axis wind turbine blade aerodynamics in experiments and modeling," *IEEE Trans. Energy Convers.*, vol. 22, no. 1, pp. 61–70, 2007, doi: 10.1109/TEC.2006.889620.

[39] M. Younis, S. Y. Alnouri, B. J. Abu Tarboush, and M. N. Ahmad, "Renewable biofuel production from biomass: a review for biomass pelletization, characterization, and thermal conversion techniques," *Int. J. Green Energy*, vol. 15, no. 13, pp. 837–863, 2018, doi: 10.1080/15435075.2018.1529581.

[40] S. R. Shah, R. Kumar, K. Raahemifar, and A. S. Fung, "Design, modeling and economic performance of a vertical axis wind turbine," *Energy Reports*, vol. 4, pp. 619–623, 2018, doi: 10.1016/j.egyr.2018.09.007.

[41] A. Tummala, R. K. Velamati, D. K. Sinha, V. Indraja, and V. H. Krishna, "A review on

small scale wind turbines," *Renew. Sustain. Energy Rev.*, vol. 56, pp. 1351–1371, 2016, doi: 10.1016/j.rser.2015.12.027.

[42] G. Ramkumar, "Efficiency Improvement of Thermal Energy Storage using PCM," *Int. J. Eng. Res. Technol.*, vol. 8, no. 06, pp. 6–8, 2020.

[43] T. Li and M. Dong, "Residential energy storage management with bidirectional energy control," *IEEE Trans. Smart Grid*, vol. 10, no. 4, pp. 3596–3611, 2019, doi: 10.1109/TSG.2018.2832621.

[44] A. K. G and S. Kumar, "Fuzzy based Hybrid Energy Storage System Micro Grids Integration for Power Quality Improvement," vol. 8, no. 04, pp. 245–247, 2019.

[45] M. Swami Nathan, R. Rajasekaran, and P. Usha Rani, "Rules based functional control of bidirectional DC-DC converter for stand-alone PV with hybrid energy storage system," *ICIIECS 2015 - 2015 IEEE Int. Conf. Innov. Information, Embed. Commun. Syst.*, vol. 3, no. 16, pp. 1–6, 2015, doi: 10.1109/ICIIECS.2015.7193273.

[46] S. M. Khadri, "Experimental Performance Analysis of A Diesel Engine Fueled with Bio-Fuel Blends As Alternatives," vol. 9, no. 15, pp. 113–117, 2021.

[47] G. G. Chethan, "Performance Study of Pongamia Pinnata Biodiesel- Diesel Blend Fueled CI Engine with Aluminum Oxide Nanoparticle As Additives," vol. 9, no. 15, pp. 123–128, 2021.

[48] P. K. Gupta and M. Raut, "Transmission of Solar Energy using Fiber - Optics," vol. 10, no. 10, pp. 63–68, 2021.

[49] P. Anu, B. S. Sowmya, S. L. P. R, and B. S. Yogananda, "Power Quality Analysis in Grid Connected Wind Energy Conversion System," vol. 10, no. 09, pp. 136–139, 2021.

[50] A. I. O. Akwukwaegbu, F. I. Izuegbunam, and M. C. Ndinechi, "Voltage Stability Analysis of 86-Bus 330KV Nigeria Power Grid Based on Reserved Energy Potential via Continuation Power Flow Technique," vol. 10, no. 10, pp. 475–493, 2021.

[51] M. Alsemaan, "Power System Planning with Renewables Energy," vol. 10, no. 12, pp.

208–212, 2021.

[52] P. R. Sakharkar, “Vibration Analysis of Twin Cylinder Diesel Engine Fueled with Blends of Cottonseed Oil in Comparision with Diesel at Fixed Compression Ratio and Injection Time,” vol. 10, no. 03, pp. 471–481, 2021.

[53] B. Ashok and C. Vembaiyan, “Thermal Analysis of Hydrogen Fuel Cell Inter Cooling by using Heat Exchanger,” *Int. J. Eng. Res.*, vol. V6, no. 05, pp. 632–636, 2017, doi: 10.17577/ijertv6is050400.

[54] H. Harish and U. N. Kempaiah, “Studies on Process Feasibility of using Acetylene and Diesel as A Fuel in CI Engines,” vol. 10, no. 01, pp. 621–626, 2021.

[55] S. Priya and P. Brijesh, “Studies on Crude Glycerol Degradation and Hydrogen Production by Photofermentation,” vol. 10, no. 11, pp. 205–208, 2021.

[56] E. S. Udoetok and T. T. Charalampopoulos, “Stoichiometry Effects in Proton Exchange Membrane Fuel Cells,” vol. 10, no. 05, pp. 11–16, 2021.

[57] P. Kumar, “Review of Hydrogen Powered 4-Stroke S . I . Engine (HHO Engine),” vol. 8, no. 10, pp. 241–243, 2020.

[58] E. A. Ajayi, F. T. Ademiluyi, C. P. Ukpaka, and P. Harcourt, “Physiochemical Properties of Fuel Oil from Pyrolysis of Palm Kernel Shell,” vol. 10, no. 07, pp. 425–434, 2021.

[59] F. G. Dawson, G. Alexander, and P. L. Hofmann, *Solar Powered Irrigation.*, vol. 3, no. 5. 1979.

[60] I. Diop, G. Abdul-nour, and D. Komljenovic, “Overview of Strategic Approach to Asset Management and Decision-Making,” vol. 10, no. 12, pp. 64–89, 2021.

[61] M. Mugunthadevi and S. Ranjani, “Non Super Conducting Fault Current Limiter for Energy Management of AC- DC Microgrids,” vol. 6, no. 07, pp. 6–8, 2018.

[62] N. Rathore, “Modelling of a Multi-array PV Grid System with Energy Storage Systems,” vol. 10, no. 05, pp. 930–935, 2021.

[63] Mohamed Shafi C and Vipin Krishna R, "Improved Energy Storage Management and Strategies for PV Connected Smart Microgrids," *Int. J. Eng. Res.*, vol. V6, no. 05, pp. 280–285, 2017, doi: 10.17577/ijertv6is050171.

[64] M. Prathyush and E. A. Jasmin, "Fuzzy Logic Based Energy Management System Design for AC Microgrid," *Proc. Int. Conf. Inven. Commun. Comput. Technol. ICICCT 2018*, vol. 8, no. 10, pp. 411–414, 2018, doi: 10.1109/ICICCT.2018.8473317.

[65] N. Bhuvaneswari, "Energy Management Strategies Improved in Microgrid using a Non Linear Model Predictive Control," vol. 4, no. 16, pp. 1–5, 2016.

[66] Jis Sunny C and Jyothi P Thomas, "An Optimal Energy Management Strategy for Standalone DC Microgrids," *Int. J. Eng. Res.*, vol. V6, no. 04, pp. 382–388, 2017, doi: 10.17577/ijertv6is040404.

[67] C. Good, I. Andresen, and A. G. Hestnes, "Solar energy for net zero energy buildings - A comparison between solar thermal, PV and photovoltaic-thermal (PV/T) systems," *Sol. Energy*, vol. 122, no. 2015, pp. 986–996, 2015, doi: 10.1016/j.solener.2015.10.013.

[68] J. Q. Zhong, A. T. Fragoso, A. J. Wells, and J. S. Wettlaufer, *Finite-sample-size effects on convection in mushy layers*, vol. 704. 2012.

[69] C. F. Calvillo, A. Sánchez-Miralles, and J. Villar, "Energy management and planning in smart cities," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 273–287, 2016, doi: 10.1016/j.rser.2015.10.133.

[70] J. P. Doub, "No 主観的健康感を中心とした在宅高齢者における 健康関連指標に関する共分散構造分析Title," p. 262, 2012.

[71] J. Zheng, "Short-term Load Forecasting Using Neural Network For Future Smart Grid Application," 2014.

[72] O. Gulich, "LAPPEENRANTA UNIVERSITY OF TECHNOLOGY Faculty of Technology Electrical Engineering," *LAPPEENRANTA Univ. Technol.*, 2010.

[73] I. Mader, "Adapting big data analytics for smart grid security," no. July, 2016.

[74] J. Runge and R. Zmeureanu, “Forecasting energy use in buildings using artificial neural networks: A review,” *Energies*, vol. 12, no. 17, 2019, doi: 10.3390/en12173254.

[75] S. S. Ali and B. J. Choi, “State-of-the-art artificial intelligence techniques for distributed smart grids: A review,” *Electron.*, vol. 9, no. 6, pp. 1–28, 2020, doi: 10.3390/electronics9061030.

[76] S. Chatterjee, “DigitalCommons @ USU Demand Side Management in Smart Grid using Big Data Analytics Tung Thanh Nguyen ! PhD,” 2017.

[77] W. Scholarship, J. Wang, and S. Pirathayini, “Deep Learning on Smart Meter Data: Non-Intrusive Load Deep Learning on Smart Meter Data: Non-Intrusive Load Monitoring and Stealthy Black-Box Attacks Monitoring and Stealthy Black-Box Attacks,” 2020, [Online]. Available: https://ir.lib.uwo.ca/etdhttps://ir.lib.uwo.ca/etd/6891.

[78] A. BEYENE, “Neural Network Based Demand Response Analysis in Smart Grid,” 2020, [Online]. Available: http://ir.bdu.edu.et/handle/123456789/10371.

[79] M. O. K. Halifa and M. O. A. Rikiez, “a Lgorithms for E Nergy M Anagement in M Icro - Grids,” no. December, pp. 70–80, 2016.

[80] W. Yao, “Analysis on the Application of the Artificial Intelligence Neural Network on the New Energy Micro Grid,” vol. 150, no. Macmc, pp. 758–763, 2018, doi: 10.2991/macmc-17.2018.144.

[81] S. M. M. I. Diaz E. F. Combarro et al, *Machine Learning Applied to Go*, vol. 15, no. 2. 2017.

[82] R. F. Olimid, *Provable secure constant-round group key agreement protocol based on secret sharing*, vol. 239. 2014.

[83] G. C. Swanepoel, “Microgrid energy management system based on artificial intelligence,” no. May, 2019, [Online]. Available: http://repository.nwu.ac.za/handle/10394/34268.

[84] I. Antonopoulos *et al.*, “Artificial intelligence and machine learning approaches to energy demand-side response: A systematic review,” *Renew. Sustain. Energy Rev.*, vol. 130, no. February, p. 109899, 2020, doi: 10.1016/j.rser.2020.109899.

[85] S. Zhou, “Design and Development of Energy Management System for Smart Homes & Buildings,” *Thesis*, no. November, 2014.

[86] X. Zhang, “Machine Learning and Big Data Analytics for the Smart Grid,” *Georg. Inst. Technol.*, no. August, 2017.

[87] Melese Loha Anjulo, “Power Management of Standalone Hybrid PV-Micro Hydro Battery Energy Storage System using Fuzzy Logic Controller,” *Int. J. Eng. Res.*, vol. V8, no. 07, pp. 875–881, 2019, doi: 10.17577/ijertv8is070182.

[88] F. R. Ismagilov, V. E. Vavilov, A. H. Miniyarov, and R. R. Urazbakhtin, “Super high-speed electric motor with amorphous magnetic circuit for the hydrogen fuel cell air supply system,” *Int. J. Hydrogen Energy*, vol. 43, no. 24, pp. 11180–11189, 2018, doi: 10.1016/j.ijhydene.2018.04.185.

[89] I. Skalna, B. Basiura, J. Duda, J. Opi, and T. Pe, *Advances in Fuzzy Decision Making*. 2015.

APPENDICES

Appendix A: Off peak price and adequate electricity

Load Status	Price (cents)	Load Consumption (kw/	Remaining Daily limit (kw in %)
75,060247	15	24,648567	98,788543
75,115227	15	24,731547	98,457087
75,15445	15	24,82878	98,071515
75,075054	15	24,928507	97,679179
74,996733	15	25,070875	97,124496
74,998768	15	7,297213	97,032037
74,999371	15	7,303727	96,945489
75,000185	15	7,312481	96,829436
75,001396	15	7,325428	96,658307
75,109998	15	97,390051	96,093811
75,022002	15	88,875673	94,791204
74,800141	15	100	93,465977
75,032297	15	56,897631	93,306165
75,022443	15	57,323481	92,613003
74,998728	15	57,774293	91,890345
75,006843	15	57,979013	91,565886
75,009802	15	4,335543	91,449976
75,005637	15	2,793105	91,240644
75,006135	15	2,800624	90,99569
75,006534	15	2,806673	90,799585
75,006847	15	2,811429	90,645958

75,107186	15	9,505312	90,624468
75,105788	15	9,508576	90,593359
75,070207	15	9,579682	89,920924
75,044743	15	1,567795	89,545396
75,044414	15	1,569387	89,454526
75,044109	15	1,57086	89,370676
75,043834	15	1,572191	89,295016
75,043579	15	1,573428	89,224816
75,043343	15	1,574577	89,159686
75,043146	15	1,575535	89,105476

Appendix B: Standard price and adequate electricity

Load Status	Price(cents)	Load Consumption (kw/h)	Remaining Daily Limit (kw in %)
75,043124	45	1,575638	89,099626
75,043082	45	1,575845	89,087926
74,992857	45	8,891839	89,047386
74,991293	45	8,897994	88,985797
74,989713	45	8,904156	88,924208
74,988115	45	8,910328	88,862619
74,800141	45	29,873036	88,811907
74,800141	45	29,905299	88,716093
74,800141	45	29,975025	88,509726
74,800141	45	30,040063	88,318099
75,084678	45	33,126983	88,066804

75,087575	45	33,166662	87,961446
75,093186	45	33,246306	87,750729
75,022999	45	52,441043	87,050569
75,050346	45	40,787878	86,856077
75,046851	45	40,903747	86,610039
75,043394	45	41,020276	86,364
75,039976	45	41,137471	86,117961
75,036595	45	41,255337	85,871922
75,033251	45	41,373881	85,625884
75,031658	45	41,431024	85,507785
75,030074	45	41,488326	85,389686
75,028498	45	41,545786	85,271588
75,0268	45	41,608214	85,143648
75,025241	45	41,666007	85,025549
75,018333	45	50,947921	84,9031
75,011848	45	62,363175	84,751933
75,012044	45	62,493095	84,575739
75,012436	45	62,754564	84,223351
75,011903	45	63,0072	83,885645
75,010662	45	63,272999	83,533257
75,009462	45	63,529835	83,195552
75,011073	45	63,788764	82,857847
74,800141	45	100	82,28198
74,800141	45	100	81,120524
74,800141	45	100	80,47515

Appendix C: Peak price and adequate electricity

Load Status	Price(cents)	Load Consumption(kw/h)	Remaining Daily Limit(kw in %)
24,673469	80	100	79,829775
75,006866	80	7,382888	79,798875
75,007027	80	7,384554	79,780872
75,007188	80	7,38622	79,762869
75,00735	80	7,387888	79,744866
75,007511	80	7,389556	79,726863
75,008308	80	7,397757	79,638484
75,009095	80	7,405823	79,551742
75,009244	80	7,407347	79,535375
74,800141	80	10,000278	79,506701
74,800141	80	10,000278	79,484617
74,800141	80	10,000278	79,462539
74,800141	80	10,000278	79,440467
74,800141	80	10,000278	79,215683
74,800141	80	10,000278	78,789907
74,800141	80	10,000278	78,58661
74,800141	80	10,000278	78,39037
74,800141	80	10,000278	78,201138
74,800141	80	10,000278	78,016697
74,800141	80	10,000278	77,839177
74,800141	80	10,000278	77,66422
74,800141	80	10,000278	77,498267

Appendix D: Standard price and enough electricity

Load Status	Price(cents)	Load Consumption(kw/h)	Remaining Daily limit (kw in %age)
74,800141	45	100	77,473812
74,800141	45	100	75,590846
74,800141	45	100	73,756787
74,800141	45	100	71,971637
74,800141	45	100	70,235395
74,800141	45	100	68,523607
74,800141	45	100	66,836273
74,800141	45	100	65,197847
74,800141	45	100	63,583876
74,800141	45	100	61,994358
74,800141	45	100	60,429295
74,800141	45	100	58,888686
74,800141	45	100	57,396985
74,800141	45	100	55,905284
74,800141	45	100	54,462491
74,800141	45	100	53,019698
74,800141	45	100	51,60136
74,800141	45	100	50,231929
74,800141	45	100	48,862499
74,800141	45	100	47,517523
74,800141	45	100	46,172546
74,800141	45	100	44,876478

74,800141	45	100	43,58041
74,800141	45	100	42,284342
74,800141	45	100	41,037183
74,800141	45	100	39,765569
74,800141	45	100	38,542863
74,800141	45	100	37,320157
74,800141	45	100	36,097451
74,800141	45	100	34,8992
74,800141	45	100	33,725402
74,800141	45	100	32,551605
74,800141	45	100	31,377807
74,800141	45	100	30,228464

Appendix E: Standard, peak price and less electricity

Load Status	Price(cents)	Load Consumption (kw/h)	Remaining Daily limit (kw in %age)
24,673469	45	100	29,983923
24,673469	45	10,000278	29,98309
24,673469	45	10,000278	29,982257
24,673469	45	10,000278	29,981424
24,673469	45	10,000278	29,972264
24,673469	45	10,000278	29,953951
24,673469	45	10,000278	29,915698
24,673469	45	10,000278	29,877493
24,673469	45	10,000278	29,840166

24,673469	45	10,000278	29,802885
24,673469	45	10,000278	29,766478
24,673469	45	10,000278	29,730116
24,673469	45	10,000278	29,693798
24,673469	45	10,000278	29,658348
24,673469	45	10,000278	29,622941
24,673469	45	10,000278	29,586754
24,673469	45	10,000278	29,552253
24,673469	45	10,000278	29,517792
24,673469	45	10,000278	29,483371
24,673469	45	10,000278	29,450627
24,673469	80	10,000278	29,449809
24,673469	80	10,000278	29,417102
24,673469	80	10,000278	29,383615
24,673469	80	10,000278	29,350167
24,673469	80	10,000278	29,31757
24,673469	80	10,000278	29,28501
24,673469	80	10,000278	29,253299
24,673469	80	10,000278	29,221622
24,673469	80	10,000278	29,18998
24,673469	80	10,000278	29,159181
24,673469	80	10,000278	29,128415
24,673469	80	10,000278	29,098491
24,673469	80	10,000278	29,083136

Appendix F Technical Parameters of WTGS

WTGS model	GW66/1500kW	GW70/1500kW	GW77/1500kW	GW82/1500kW	GW87/1500kW
Security level	IEC I A	IEC I A /IEC II A	IEC II A/ IEC III A	IEC III A	IEC III B
Rated power	1500kW	1500kW	1500kW	1500kW	1500kW
Inverter output voltage	620V	620V	620V	620V	620V
Diameter of rotor	66 m	70.34 m	76.84m	82.34m	86.6-88.3m
Swept area	3421 m^2	3885.9 m^2	4637.3m^2	5324.9 m^2	5874 ~ 6112 m^2
Hub height	65 m	65/85 m	65/85m	70m	70/75/85 m
Scope of rotation speed of rotor	10.6-20.5 rpm	8.8-19 rpm	8.8-17.3 rpm	8.8-17.3 rpm	8.8-17.3 rpm
Rated speed	20.5 rpm	19 rpm	17.3 rpm	17.3 rpm	17.3 rpm
Rated wind speed	13.1 m/s	12 m/s	11 m/s	10.3 m/s	9.9 m/s
Cut-in wind speed	3 m/s	3 m/s	3 m/s	3 m/s	3 m/s
Cut-out wind speed	27 m/s	25 m/s	22 m/s	22 m/s	22 m/s
Maximum survival wind speed (3 seconds)	78m/s	70m/s	59.5 m/s	52.5 m/s	52.5 m/s
Maximum allowable maintenance wind speed	11m/s	11m/s	11m/s	11m/s	11m/s
Scope of operating temperature	-30 ℃ – 40 ℃	-30 ℃ – 40 ℃	-30 ℃ – 40 ℃	-30 ℃ – 40 ℃	-30 ℃ – 40 ℃
Survival temperature of WTGS	-40 ℃ – 50 ℃	-40 ℃ – 50 ℃	-40 ℃ – 50 ℃	-40 ℃ – 50 ℃	-40 ℃ – 50 ℃
Design service life	≥20 years	≥20 years	≥20 years	≥20 years	≥20 years
Lightning protection design standard	IEC61400-24; IEC62305	IEC61400-24; IEC62305	IEC61400-24; IEC62305	IEC61400-24; IEC62305	IEC61400-24; IEC62305