Addis Ababa University
Addis Ababa Institute of Technology
School of Electrical and Computer Engineering

DESIGN AND SIMULATION OF HYBRID PHOTOVOLTAIC, WIND AND FUEL CELL DISTRIBUTED GENERATION SYSTEM FOR YEKATIT 12 REFERRAL HOSPITAL (FUZZY BASED)

A thesis submitted to Addis Ababa Institute of Technology, School of Graduate Studies, Addis Ababa University

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By

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LIST OF ABREVIATIONS

HAWT	………………..…	Horizontal Axis Wind Turbine
VAWT	……………….....	Vertical Axis Wind Turbine
FLC	………………..…	Fuzzy Logic Controller
DG	………………..…	Distributed Generation
PV	………………..…	Photo voltaic
FC	………………..…	Fuel Cell
AFC	………………..…	Alkaline Fuel Cell
MCFC	………………..…	Molten Carbonate Fuel Cell
PEM	………………..…	Polymer Electrolyte Fuel Cell
DMFC	………………..…	Direct Methanol Fuel Cell
SOFC	………………..…	Solid Oxide Fuel Cell
PI	………………..…	Proportional Integral
PID	………………..…	Proportional Integral Derivative
SM	………………..…	Synchronous Machine
TW	………………..…	Tera Watt
MW	………………..…	Mega Watt
MWH	………………..…	Mega Watt Hour
KW	………………..…	Kilo Watt
KWH	………………..…	Kilo Watt Hour
LD	………………..…	Load Demand
LF	………………..…	Load Factor
IC	………………..…	Installed Capacity
PL	………………..…	Peak Load
NME	………………..…	National Metrology Agency
NASA	………………..…	National Aeronautics and Space Administration

LIST OF NOTATIONS

Z_r	………………..…	Reference height in meters
Z	………………..	The height where wind speed is to be determined
Z_o	………………...	measure of surface roughness,
V(z)	………………...	wind speed in m/s at a height of z meters
$V(Z_r)$	………………...	wind speed at the reference height in m/s
$[\ ]^{TM}$	………………..…	Trade Mark
$(\ )^{-1}$	………………..…	Inverse
α	………………...	ground surface friction index
h	………………….	Height
V_1	…………………	wind speed measured at the reference height h_1,
V_2	…………………	estimated wind speed at height h_2,
W_s	…………………	mean sunrise hour angle
δ	…………………	solar declination angle for the average day in the month
ϕ	…………………	latitude of the selected site
H_o	…………………	average value of extraterrestrial solar radiation on horizontal surface for each month
S	…………………	monthly average of bright sunshine hours per day
S_o	………………….	average of the maximum daily
n	…………………	day of the year
Pu	…………………	per-unit
K_T	…………………	clearness index
Ns	…………………	number of solar panels connected in series
N_p	…………………	number of solar panels connected in parallel
I_{sc}	…………………	solar constant which has a value of 1367w/m^2

ABSTRACT

This thesis deals with the detailed design and simulation of hybrid distributed generation system model of solar/wind and fuel cell in Matlab Simulink, and the power generated from these combined three renewable energy sources serves as a small scale alternative source of electrical energy for four power sensitive departments (Emergency department, Maternity department, surgery department, and Neonatology department) of Yekatit 12 referral hospital with a load demand of around 40KW, and this load to be supplied using the three hybrid components, when the commercial main power is not available.

Due to the production cost and other associated advantages of solar power production over wind and fuel cell power production, 50% of the power demand which is around 20KW is produced from the solar panels, and 20% of the load demand which is around 8KW is produced from wind, and the remaining 30% of the load demand which is around 12KW is produced from the backup Fuel cell Technology which serves during solar power energy shortage seasons.

To use the produced power using the above mentioned three energy resources efficiently, fuzzy logic controller is used to make an intelligent decision by sensing the type and amount of resources available, then it selects the appropriate alternative source, and to perform this Fuzzy rule have been written in fuzzy rule editor and each components of the proposed hybrid system has been modeled using Matlab/Simulink.

Key Words: Fuel Cell Technology (FC), Fuzzy Logic Controller (FLC), SIMULINK® SimPowerSystems™/ MATLAB®

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

The availability of reliable and efficient power supply at an affordable cost is very crucial for the economic growth and development of a country. Thus, the search for reliable, long lasting sources of energy has been an ever-challenging task to mankind. This research is more urgent than today than ever before, due to the heavy dependence of modern life on energy especially in large cities like Addis Ababa.

Nowadays in Addis Ababa electric power becomes a backbone for every business and non-business endeavors and for the livelihood of every inhabitant, but electric power interruption becomes a serious problem throughout the city. The number of outages in Addis Ababa is very high and it takes a very long time for service restoration, due to this every aspect of business and day to day activity of residents is negatively affected especially in large hospitals that have power sensitive loads [6].

At present a special energy supply to selected sites or areas is becoming a big challenge; requiring reliable power supply even they are grid connected. To avoid problems caused by manmade, environmental and weather uncertainties, the reliability of a continuous production of power from renewable sources is increased by considering the possibility of integrating various sources creating hybrid energy system and this greatly reduces the intermittence and uncertainties of energy production.

It is known Ethiopia has huge renewable energy (Photovoltaic, Geothermal, Wind Energy, Biomass and Micro-Hydro) resources and if these resources are effectively used the livelihood of its population will be improved.

1.2 PROBLEM DISCRIPTION

Achieving Reliability of power supply in Addis Ababa has been a major challenge for the last many years and it will continue to be a challenge in the future, if an amicable solution is not found to the problem [8].

It is known that there is heavy dependence of modern life on energy especially in large cities like Addis Ababa, and this problem becomes worst in hospitals with power sensitive loads like Yekatit 12 Referral Hospital.

In Yekatit 12 referral hospital there is a frequent power interruption, and this causes a problem in the working area of the hospital, especially in the more power sensitive four departments' namely maternity room, neonatology department, emergency room and surgery room. And, when power is interrupted in these four departments it may become a cause for the death of many infants, pregnant mothers, patients in the surgery room and in the emergency rooms and others.

Even though the hospital has an old small capacity generator as a backup supply, this manual generator doesn't solve the problem as needed. In addition to the above problem the noisy sound and smoke of the generator by itself is also causing an additional illnesses and disturbance in the patient's treatment rooms and the working environment of the hospital in general. The existing diesel generator in the hospital operates manually and this is also causing a problem during emergency cases.

Finally, in my thesis work Fuzzy Based simulation and Design of hybrid PV/Wind and fuel cell distributed generation system will be implemented for Yekatit 12 referral hospital to increase the power reliability of the hospital.

1.3 MOTIVATION

Knowing the existence of frequent Power interruption in the capital city of Ethiopia is a headache for Ethiopian engineers and this problem becomes worst in big referral hospitals when it becomes the cause for death of mothers and infants. So, my motivation is to contribute for the production of Green and reliable back up power supply for the referral hospital.

1.4 OBJECTIVES OF THE THESIS

1.4.1 General Objective

The general objective of the thesis is:

- To design and simulate fuzzy based hybrid Wind, PV and fuel cell distributed generation system for yekatit-12 referral hospital.

1.4.2 Specific Objectives

The specific objectives of the thesis are;

i. To study the impact of power interruption in *Yakatit 12* referral hospital.
ii. Design and simulation of the proposed backup hybrid Distributed Generation (DG) components separately.
iii. Design and simulation of the fuzzy logic controller separately
iv. Simulation of the combined designed DG system and the fuzzy logic controller on Matlab Simulink 2016a.

1.5 CONTRIBUTION OF THE THESIS

The frequency of power interruption at the selected departments of the hospital will be reduced due to the implementation of the proposed hybrid PV/Wind and fuel cell distributed generation backup system.

In large hospitals outage of power affect human life and sensitive materials, these and related issues will be minimized as a result of this research.

1.6 LIMITATIONS OF THE STUDY

During working research papers there is always a limitation: the first limitation is lack of cooperation to get necessary and relevant information and recorded data from the workers in the selected site and other offices. The second limitation is because of the scope of the study it is not possible to model each component of the proposed hybrid DG system in Matlab/Simulink to generate the actual signal for the controller rather random signal generator is used. The third limitation is unable to get the research money at required time.

1.7 OUTLINE OF THE THESIS

This research paper consists of five chapters. The first chapter discusses about the general introduction, and chapter two explains the general concept of the proposed green energy production components namely the Photovoltaic, Fuel cell Technology and Wind, and literature review. Chapter three explains about the potential assessment of the three energy resources in the selected site, primary and secondary data gathering, data analysis, system modeling and designing each components capacity. Chapter four discusses about the simulation results of the hybrid components and the Fuzzy logic controller in Matlab/Simulink 2016a. Chapter five explains about conclusions, recommendation and future works.

CHAPTER 2
HYBRID ENERGY SOURCES AND CONTROL

2.1 INTRODUCTION

Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally (replenished). Renewable is an alternative to fossil fuels and was commonly called alternative energy in the 1970s and 1980s [14].

A Renewable energy system converts the energy found in sunlight, wind, falling-water, sea-waves, geothermal heat, or biomass into a form, we can use such as heat or electricity. Most of the renewable energy comes either indirectly or directly from the sun and wind and can never be exhausted, and therefore they are called renewable [15], and in this research paper the combination of three renewable energy resources namely solar, wind and fuel cell technologies are discussed in detail below.

2.2 COMPONENTS OF HYBRID ENERGY SOURCES

2.2.1 Wind Energy and its Basic Components

Wind is the movement of air caused by the irregular heating of the Earth's surface. It happens at all scales, from local breezes created by heating of land surfaces that lasts some minutes, to global winds caused from solar heating of the Earth. Wind power is the transformation of wind energy into more utile forms, typically electricity using wind turbines [17].

Horizontal Axis versus Vertical Axis Wind Turbine (HAWT Vs VAWT)

Most wind turbines built at present has a horizontal axis. The vertical axis Darrius machine has several advantages. First of all, it is omnidirectional and requires no yaw mechanism to continuously orient itself toward the wind direction. Secondly, its vertical shaft simplifies the installation of the gearbox and the electrical generator on the ground, making the structure much simpler. On the negative side, it normally requires guy wires attached to the top to support. This could limit its applications, particularly for the offshore sites. Overall the vertical axis machine has not been widely used because its output power cannot be easily controlled in high winds simply by changing the blade pitch [18].

Components of Wind Turbine

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power production capacity. Obviously, sites with steady high wind produce more energy over the year and the basic components of a wind turbine are listed below [18].

Rotor Blades

The rotor is the heart of a wind turbine. It consists of multiple rotor blades attached to the hub. The rotor converts the wind energy into a rotation. The Rotor Blades are a crucial and elementary part of a wind turbine. Various demands are placed on them, and they must withstand a very great load.

Gear Box

Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly and heavy part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and do not need gear boxes especially for small scale wind turbines [17].

Hub

The hub of wind turbine is that component that connects the blades to the main shaft and ultimately to the rest of the drive train. The hub transmits and must withstand all the loads generated by the blades. Hubs are generally made of steel, either welded or cast. Details in hubs differ considerably depending on the overall design philosophy of the turbine, but in general there are three basic types' namely rigid hubs, Teetering hubs and hubs for hinged blades.

Generator

The wind turbine generator converts mechanical energy to electrical energy.

Yaw Control

The yaw system of a wind turbine is the component responsible for the orientation of the wind turbine rotor towards the wind.

Nacelle

A Nacelle is a cover that houses all of the generating components in a wind turbine, including the generator, gearbox, drive train, and brake assembly.

Tower

The wind tower supports the turbine and the nacelle containing the mechanical gear, the electrical generator, the yaw mechanism, and its stall control. The main issue in the tower design is the structural dynamics. The tower vibration and the resulting fatigue cycles under wind speed fluctuation are avoided by design. Small scale towers range in height from 24-34m and its weight depends on the material from which it is manufactured [17].

Controller

The controller starts up the machine at wind speeds of about 3.5 to 7.2 meters per second (m/s) and shuts off the machine at about 30m/s [17].

Foundation

In order to guarantee the stability of a wind turbine a pile or a flat foundation is used, depending on the consistency of the underlying ground.

Wind power Control Mechanisms

Wind turbines are designed to produce electrical energy as cheaply cost as possible. Wind turbines are therefore generally designed so that they yield maximum output. In case of stronger winds, it is necessary to waste part of the excess energy of the wind in order to avoid damaging the wind turbine or the whole system. Thus, all wind turbines are therefore designed with some sort of power control. In general, there are three different ways of doing this safely on modern wind turbines [17].

a) Pitch Controlled Wind Turbines

On a pitch-controlled wind turbine the turbine's electronic controller checks the power output of the turbine several times in short period of time. When the power output becomes high, it sends order to the blade pitch mechanism which immediately pitches (turns) the rotor blades slightly out of the wind. Conversely, the blades are turned back into the wind whenever the wind drops again. The pitch Mechanism is usually operated using hydraulics.

b) Stall Controlled Wind Turbines

Stall (Passive) Controlled wind turbines have the rotor blades bolted onto the hub at a fixed angle. The geometry of the rotor blade profile, however has been aerodynamically designed to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade which is not facing the wind.

c) Active Stall Regulation

In this control mechanism the stall of the blade is actively controlled by pitching the blades, thus at low wind speeds, the blades are pitched similar to pitch a pitch-controlled wind turbine in order to achieve maximum efficiency, but at high wind speeds the blades go into a deeper stall by being pitched slightly into the direction opposite to that of a pitch-controlled wind turbine.

Advantages of using wind power

Wind energy is a clean fuel source. It doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas. In addition to this, wind is a domestic source of energy and it is inexhaustible. Other benefit is that wind turbines can be built on existing farms or ranches, and this greatly benefits the economy in rural areas. Although wind turbines can be very tall each takes up only a small plot of land, this means that the land below can still be used, especially the case in agricultural areas as farming still can continue.

Challenges and Disadvantages of Wind Power:

Wind power must compute with conventional generation sources on a cost basis. Depending on how a wind site is, the wind farm might not be cost competitive in less wind areas. Also good wind sites are often located in remote locations, far from cities where the electricity is needed, thus transmission lines must be built to bring the electricity from the wind farm to the city. Another challenge is, though wind turbines harm wildlife less than some conventional sources of electricity, turbine blades could damage local wildlife e.g. birds have been killed by flying into spinning turbine blades.

2.2.2 Understanding the solar Power Generation and its Components

Solar energy is radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies such as solar heating, Photovoltaic, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis.

Only a very small fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals whose life was dependent on the sun [16].

The earth receives 174,00 terawatts (TW) of incoming solar radiation (insolation) at the upper atmosphere, and approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses [Wikipedia].

The potential solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planet because factors such as geography, time variation, cloud cover, and the land available to humans limit the amount of solar energy that we can acquire [Wikipedia].

Photovoltaic (PV) Effect

Photovoltaic is a term which covers the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect. A typical photovoltaic system employs solar panels, each comprising a number of solar cells, which generate electrical power. PV installations may be ground-mounted, rooftop mounted or wall mounted. The mount may be fixed, or use a solar tracker to follow the sun across the sky.

Photovoltaic energy conversion in solar cells consists of two essential steps. First, absorption of light generates an electron-hole pair. The electron and hole are then separated by the structure of the device i.e. electrons to the negative terminal and holes to the positive terminal thus generating electrical power [19].

Photovoltaic Cell

A single PV cell is a thin semiconductor wafer made of two layers generally made of highly purified silicon (PV cells can be made of many different semiconductors). The layers have been doped with boron on one side and phosphorous on the other side, producing surplus of electrons on one side and a deficit of electrons on the other side.

Photovoltaic Modules

A PV module consists of many PV cells wired in parallel to increase current and in series to produce a higher voltage. The module is encapsulated with tempered glass or some other transparent material on the front surface, and with protective and waterproof material on the back surface. Since the amount of an electrical power output from a single cell is small, multiple cells are connected in series or parallel and/or series-parallel.

- **a) Series Wiring:** Series wiring is when the voltage of a solar is increased by wiring the positive of one solar module to the negative of another module. This is similar to installing batteries in a flashlight.
- **b) Parallel Wiring:** parallel wiring increases the current (amps) output of a solar array while keeping the voltage the same. Parallel wiring is when the positives of multiple modules are connected together and all the negatives for the same modules are connected together.
- **c) Series Parallel combination:** solar panels can be connected in series parallel combination to increase both the voltage and current output producing a higher wattage array.

PV Cell Technologies

The continuing development of efforts to produce more efficient low-cost cells have resulted in various types of PV technologies available in the market today, in terms of the conversion efficiency and the module cost. The major types are:

a) **Single – Crystalline Silicon:** it consists of silicon in which the crystal lattice of the entire solid is continuous, unbroken to its edges, and free of any grain boundary. Mono crystalline silicon can be prepared intrinsic consisting only exceedingly pure silicon, or doped, containing very small quantities of other elements added to change its semiconducting properties. The main advantage of Single crystalline is their higher efficiency, but are complicated to manufacture which makes them expensive comparing with the other technologies.

b) **Polycrystalline and Semi crystalline:** this is relatively a fast and low cost to manufacture thick crystalline cells. The conversion efficiency is lower, but the cost is much lower, giving a net reduction in cost per watt of power.

c) **Thin films:** these are new types of Photovoltaic entering the market. Copper Indium Diselenide, Cadmium Telluride, and Gallium Arsenide are all thin film materials. This technology uses much less material per square area of the cell, hence, is less expensive power watt of power generated [18].

d) **Amorphous Silicon:** is the non-crystalline form of silicon used for solar cells. Amorphous silicon differs from other allotropic variations such as mono crystalline and poly crystal silicon, that consists of a small grain, also known as crystallites. Amorphous silicon absorbs light more effectively than crystalline silicon, which leads a thin film PV technology. The greatest advantage of these cells is that amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible. Their disadvantage is their low efficiency, which is on the order of 6% [3].

Photovoltaic Power Converter/Inverter: PV inverter converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local off-grid electrical network. The inverter size should be 25-30% bigger than the total watts of the loads [3].

Advantages of Solar PV System: photovoltaic power system has many advantages such as short lead time to design, install and start up a new plant. They are also highly modular; hence, the plant economy is not a strong function of size. PVs have high power capability per unit. PVs have longer life time with little maintenance because of no moving parts. In addition to the above advantages PVs are highly mobile and portable because of their light weight.

Disadvantages of Solar PV system: Installing solar panels may save money in the long run, but it is not a cheap purchase upfront. Solar panels are inefficient and do not work at night, cool and cloudy season. Solar panels are made of polluting materials. Higher installation area requirement to produce much power is also a disadvantage.

2.2.3 Fuel Cell Technology

Fuel cells are electromechanical devices that use hydrogen (H_2), or H_2 – rich fuels, together with oxygen from air, to produce electricity and heat. However, there are many variants of this basic process, depending on the Fuel Cell type and the fuel used [20]. Fuel cell technology is based upon the simple combustion reaction given by equation-.

$$2H_2 + O_2 \leftrightarrow 2H_2O$$

The electrons can be harnessed to provide electricity in a consumable form through a simple circuit with a load. Problems arise when simple fuel cells are constructed. Simple fuel cells have a very small area of contact between the electrolyte, the electrode, and the gas fuel [21].

Types of fuel cells

Fuel Cells are classified primarily by the kind of electrolyte they employ. This classification determines the kind of electrochemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn affects the application for which these cells are most suitable. There are several types of fuel cells currently under development, such as polymer electrolyte membrane, direct methanol, alkaline, molten carbonate, solid oxide and Reversible Fuel Cell each with its own advantages, limitations, and potential applications.

Alkaline Fuel Cells:

The Alkaline Fuel Cell (AFC) is one of the most developed fuel cell technologies. Alkaline fuel cells consume hydrogen and pure oxygen producing portable water, heat and electricity. They are among the most efficient fuel cells, having a potential to reach 70% [20].

Molten Carbonate Fuel Cell: The defining characteristics of molten carbonate fuel cell (MCFC) is the material used for the electrolyte. The material is a molten mixture of alkali metal carbonates. The electrolyte is usually a binary mixture of lithium and potassium or, lithium and sodium carbonates which is held in in a ceramic matrix of $LiALO_2$ [20].

Polymer Electrolyte Fuel Cell (PEM): This type of Fuel Cell has the ability to operate at a very low temperature; this is the main attraction of PEM. Since they have the ability to deliver such high-power densities at this temperature they can be made smaller which reduces overall weight, cost to produce and specific volume. Since the PEM has am immobilized electrolyte membrane there is a simplification in the production process that in turn reduces corrosion, this provides for longer stack life [20].

Direct Methanol Fuel Cells (DMFC): The operation of the whole DMFC is similar to the operation of the PEM in terms of the physical manufacturing of the cell. The major difference is in the fuel cell supply. The fuel is a mixture of water and of methanol; it reacts directly at the anode according to the following chemical reaction [20].

$$CH - OH + 2H_2O \longrightarrow 6H^+ + 6e^- + CO_2$$

Phosphoric Acid Fuel Cells: Are much like proton exchange membrane fuel cells. They use a proton-conducting electrolyte. The chemical reactions use highly dispersed electro catalyst particles with carbon black. The electrode material is generally platinum. An inorganic acid of concentrated phosphoric acid is used as the electrolyte, hence the name of the fuel cell. The phosphoric acid fuel cell operates at approximately 180 up to 200^o C [20].

Solid Oxide Fuel Cell (SOFC): These cells, part of the broader category of ceramic fuel cells, are attractive due to their solid-state components. These cells unlike the high temperature MCFC, have a solid-state electrode, as well as solid state anode, cathode, and cell interconnects. Although there are several configurations for the SOFC the planar and tabular type are dramatically more advanced.

Fuel Cell System Components

For fuel cell to function efficiently, air must be circulated through the fuel cell for cooling and cathode reactant supply. To accomplish this, Compressors, turbines, ejectors, fans, blowers, and pumps are used.

Compressors: there are four major types of compressors that can be utilized in a fuel cell system. These include the Roots Compressor, the Lysholm or Screw Compressor, the Centrifugal or radial compressor, and the axial flow compressor [20].

Turbines: the hot gas exhausted by fuel cells can be harnessed into mechanical work through the use of turbines. The efficiency of a turbine determines whether or not it is economically viable to incorporate in to the fuel cell.

Ejector Circulators: It is the simplest pump. There are mechanically moving parts. Hydrogen fuel cells that use pressurized stored hydrogen use these types of pumps. Basically, ejector circulators use the stored mechanical energy in the pressurized gas to circulate the fuel around the cell.

Fans and Blowers: An easy and economical way to cool a fuel cell is to use fans and bowlers. A common fan such as the axial fan is effective in moving air over parts, but it is not effective across large pressure differences [20].

Membrane/Diaphragm Pumps: These are used to avoid the problem associated with closed system cooling such as in PEMs. Example, closed system cooling in small to medium sized PEMs creates back pressure of about 10kPa or 1m of water, therefore diaphragm pumps are ideal for such situations [20].

Why Fuel Cells are an Emerging Technology:

The reason for their desirability is that are extremely efficient, simple have virtually no emissions, and they run silent. Current fuel cells, which operated alone have efficiencies of about 40-55%, and when they are used with CHP they can reach efficiencies of 80%. They have virtually no moving parts, and in some cases are made entirely of solids. This not only simplifies the manufacturing process but also will allow the cells to have longer operational periods. The major disadvantage of the fuel cell is that it is currently more expensive than other forms of power conversion, but this is the barrier that soon to be broken [20].

Applications of Fuel Cell: the applications of fuel cells vary depending on the type of fuel cell to be used. Since fuel cells are capable of producing power anywhere in the 1 watt to Megawatt range they can be applied to almost any application that requires power [20]. On the smaller scale they can be used in cell phones, personal computers. In the 1Kw to 100Kw range a fuel cell can be used to power vehicles and finally in the 1MW to 10MW range fuel cells can be used to converts energy for distributed power uses.

2.3 TYPES OF CONTROLLERS

2.3.1 Proportional controller

Proportional controller is mostly used in first order processes with single energy storage to stabilize the unstable process. The main usage of this type of controller is to decrease the steady state error of the system. However, despite the reduction this controller can never manage to eliminate the steady state error of the system. We can use this controller only when our system is tolerable to a constant state error. Proportional controller also causes oscillation if sufficiently aggressive in the presence of lags and/or dead time [25].

2.3.2 PI Controller

PI controller is mainly used to eliminate the steady state error resulting from proportional controller. However, in terms of the speed of the response and overall stability of the system, PI have negative impact. This controller is mostly used in areas where speed of the system is not an issue. Since P-I controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations [25].

2.3.3 PID controller

PID controller has the optimum control dynamics including zero state steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and oscillations occurring in the output response of the system. One of the main advantages of P-I-D is that it can be used with a higher order processes including more than single energy storage [25].

2.3.4 Fuzzy Logic Controller

Fuzzy Logic means approximate reasoning, information granulation, computing with words and so on [24].

Ambiguity is always present in any realistic process. This ambiguity may arise from the interpretation of the data inputs and in the rules used to describe the relationships between the informative attributes. Fuzzy logic provides an inference structure that enables the human reasoning capabilities to be applied to artificial knowledge-based systems. Fuzzy logic provides a means for converting a linguistic strategy into a control actions and thus offers a high-level computation.

Fuzzification: Fuzzification is an important concept in fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy (crisp to fuzzy). By identifying some of the uncertainties present in the crisp values, we can form the fuzzy values. The conversion of fuzzy values is represented by the membership functions.

In any practical applications, in industries, etc. measurement of voltage or current there might be negligible error, and this causes imprecision in the data. This impression can be represented by the membership functions. Hence Fuzzification is performed. Thus, Fuzzification process may involve assigning membership values for the given crisp quantities.

Membership function assignments: Fuzziness in a fuzzy set is characterized by its membership functions. It classifies the element in the set, whether it is discrete or continuous. The membership functions can also be formed by graphical representations. The graphical representations may include shapes. There are certain restrictions regarding the shapes used. The rules formed to represent the fuzziness in an application are also fuzzy. The shape of the membership function is an important criterion that has to be considered. [24].

There are various methods to assign the membership values or the membership functions to the fuzzy variables. The assignment can be just done by intuition or by using some algorithms or logical procedures. Some of the methods for assigning the membership values are intuition, inference, rank ordering, angular fuzzy sets, neural networks, genetic algorithms, and inductive seasoning.

Knowledge base: the knowledge base of a fuzzy logic controller consists of a data base and a rule base. The basic function of the data base is to provide the necessary information for the proper functioning of the Fuzzification module, the rule based and defuzzification module. This information includes the meaning of linguistic values of the membership functions of the process state and the control output variables.

Inference engine: this provides the mechanism for referring to the rule base such that the appropriate rules are fired. There are several methodologies but the two most common methods used in fuzzy logic control are the max-min composition and the max-(algebraic) product composition. The inference or firing with this fuzzy relation is performed via the operations between the fuzzified crisp input and the fuzzy relation representing the meaning of the overall set of rules. As a result of the composition, one obtains the fuzzy set describing the fuzzy value of the overall control output.

Defuzzification: this means the fuzzy to crisp conversion. The fuzzy results generated cannot be used as such to the applications, hence it is necessary to convert the fuzzy quantities into crisp quantities for further processing. The defuzzification has the capability to reduce a fuzzy to a crisp single-valued quantity or as a set, or converting to the form in which fuzzy quantity is present. Defuzzification can also called as "rounding off" method. Defuzzification reduces the collection of membership function values into a single scalar quantity.

Defuzzification Methods: There are various defuzzification methods employed to convert the fuzzy quantities into crisp quantities. The output of an entire fuzzy process can be union of two or more fuzzy membership functions. There are seven methods used for defuzzifying the fuzzy output functions. They are:

i. **Max-membership principle**: This method is referred as the height method the defuzzified point or output is the point with the highest membership function.
ii. **Centroid method:** This is the most widely used method. This can be called as the center of gravity or center of area method, and the defuzzification point is the center of the area of the aggregated membership functions.
iii. **Weighted average method**: Weighting each membership function in the obtained output by its largest membership value forms this method.
iv. **Mean-max membership**: This method is related to max-membership principle, but the present of the maximum membership function need not be unique, meaning the maximum membership function need not be a single point, it can be a range. This method is also called middle of maxima method.
v. **Center of sums:** it involves the algebraic sum of individual output fuzzy sets instead of union. This method is similar to the weighted average method, but in

center of sums, the weights are the areas of the respective membership functions whereas in the weighted average method, the weights are individual membership values.

vi. **Center of largest area:** If the fuzzy set has two convex sub regions, then the center of gravity of the convex sub region with the largest area can be used to calculate the defuzzification value.

vii. **First of maxima or last of maxima:** The first point with the maximum membership function, or the last point with the maximum membership point can be taken as the defuzzification points [24].

2.4 LITERATURE REVIEW

Many papers regarding hybrid energy generation systems, fuzzy based hybrid energy generation systems, in particular, have been published. A great and considerable care is taken to recognize and summarize publicly available and provided research papers.

1. **Ajay Sharma, Anand Singh, Manish Khemariya, March 2013 [1].** Introduces about a new idea of designing an optimized PV-solar, wind hybrid energy system, Mobile Base station over conventional diesel generator for a particular site in village *imaliya* (*bhanpur*). The aim of this paper is to generate electricity and transferring it to mobile tower with extra electricity begging transfer to village. HOMER software is used for the analysis of sizing and sensitivity, performed in order to obtain the most feasible configuration of a hybrid renewable energy system. But the effect of the diesel generator on environmental (air) pollution is not discussed.
2. **M.Sedighizadeh. and A.Rezazadeh, 2007[2]** on this paper comparison between Batteries and Fuel cells is carried out in detail only for their Photovoltaic (PV) power backup options, so that their common and different attributes are compared; accordingly, the fuel cell is selected as the backup of photovoltaic system. According to this paper fuel cell systems produce very little amount of SO_2 and NO_x and other particulates in the fuel reforming process and their low CO_2 emissions result from high conversion efficiency.

3. **Melaku.M, 2014 [3]** in this paper a fuzzy logic controller-based hybrid solar/Micro-hydro/ Biomass power system for Barsoma village is designed. To use the produced power using the above mentioned three energy resources fuzzy logic controller is used to make an intelligent decision by sensing the type and amount of resources available, then it selects the appropriate alternative source, and to perform this Fuzzy rule have been written in fuzzy rule editor and each components of the proposed hybrid system has been modeled using Matlab/Simulink. But the since the Hybrid system is composed of Micro- hydro and Biomass it is only applicable in village areas only (not in large cities). In addition to this the Generator used in the Bio-mass is a dual fuel engine in case there will be shortage of input biomass still contributing its impact on environmental and air pollution. Also, the exact placement of these designed hybrid components is not discussed in detail.
4. **J.P. Sharma, Oct, 2015, [4],** this paper investigates the feasibility of stand-alone hybrid energy system to meet out electric load requirements of JK Lakshmipat university, Jaipur. And according to this paper in order to maintain a continuity of electricity supply, a single energy source is not a good option. So, it considered a hybrid system with wind turbine, solar Photovoltaic and diesel generator with integration of battery bank. The techno-economic analysis for the proposed hybrid system model has been performed using HOMER software. But variation of the load for month and a year are considered as only 10% and 20% respectively and intelligence decision making software is not used for load and supply power variations.

5. **Lovisa Bergman and Amanda Enocksson, 2015[5],** this paper proposes a renewable power generation system for Addis Ababa Institute of Technology (AAiT). The aim of hybridizing renewable energy sources is that the main load shall be covered by the available solar energy source and other sources shall function as a complement when there is a deficiency in the main resource. Four backups to the PV system are examined to find the optimal solution: battery, diesel generator, and the two hybrid systems with battery or diesel generator or grid, and the configurations made to find the optimized system were modelled in HOMER software. But in this paper, it is not proposed any intelligent decision-making software for load or supply energy capacity variations.

Even though this paper showed that PV is possible for Addis Ababa city, it only focuses on the design part not on the load and supply timely variations.

6. **Adisu Teshale,2012[6],** in this paper a wind/solar/diesel hybrid power for irrigation system is modelled and simulated in Matlab software and from this it concluded fuzzy logic-controlled hybrid power for irrigation system can effectively supply the intended power demand in different cases. Fuzzy logic controller is used to select the appropriate power source for water pump depending on the available resources. Accordingly, the possible power source can be solar energy alone, wind turbine alone, hybrid of wind and PV or diesel generator. This is performed on Matlab/Simulink thus fuzzy rule is written to make the intelligence decision, but in this paper environmental pollution due to the diesel generator is not considered.
7. **Mona.Eskandar, Thanaa F. El-shatter and Mohsen T. El-Hagry, 2002[7],** in this paper an energy system comprising three energy sources, namely: PV, wind and Fuel cell is proposed. Each of the three energy sources is controlled so as to deliver energy at optimum efficiency. Fuzzy logic controller is employed to achieve maximum power tracking (MPT), for both wind and PV energies, and to deliver this maximum power to a fixed DC voltage bus. The fixed DC bus supplies the load, while the excess power feeds the water electrolyzer used to generate hydrogen for supplying the fuel cells. Also, a management system is designed to manage the power flow between the system components in order to satisfy the load requirements throughout the whole day. A case study is done using practical data from El-Hammam site (Egypt), but in my paper I am not going to use MPT because the selected site is not known for its excess of renewable energy resources and the proposed hybrid system is going to produce small power to supply for some selected power sensitive loads or departments. Also, MPPT makes the overall system complicated and it is not effective for small scale power generating systems.
8. **Punyashree Pattanayak, 2015 [8],** this paper has a study and model design of a hybrid system comprising of solar and wind technology for small locality and the hybrid system is designed with the help of HOMER software. Also, it comprises the simulation data of each component used in project work and as well as the cost of the project during working and during step up. Finally, it concludes that rural electrification

presents different load patterns in relation to that of urban loads in terms of the daily variation expected and the yearly variation: rural patterns are smoother. But the control mechanism of the renewable energy resources is not discussed in detail, also urban load pattern is not analyzed in detail in this paper.

9. **J.M.Yang, K.W.E.Cheng, J.Wu,P.Dong, and B.Wong, 1999[9]**, on this paper an energy management system based on hierarchical fuzzy controller for the distributed hybrid wind-solar power system is designed based on the hierarchical fuzzy control, energy management system switches the mode of power supply and controls the load share according to the condition of wind power, solar radiation and load-requirement. Through the suitable allotter of the generation ratio from the wind power and photovoltaic cells, the distribution generation system combined with battery bank, can provide user with reliable electric power. The paper concluded the algorithm used has no complex operation, little rule library and fast implementing speed. But the additional cost due to the expensive cost of battery bank is not analyzed.
10. **Martin Galad, Pavol Spanik,2014[10],** This paper deals with the proposal of a model of PV solar cell and module, and the proposed PV module is verified bay Matlab simulation. Also, the influence of the temperature and solar irradiation on photovoltaic module is investigated and compared to the I-V characteristics of photovoltaic solar module sharp, that were used as the source of photovoltaic cell parameters. The paper concludes the proposed simple model of the PV solar module is enough, accurate and shall be used for development and simulation for a stand-alone power system, and when the influence of the temperature and solar irradiation are considered the solar irradiation influence was bigger than temperature influence especially when we focus on the decrease of solar irradiation. The impact on the output power was much heavier. But among the different types of PV solar modules only one PV module type is analyzed no other types of modules.
11. **Balachander.K, Kuppusamy.S, and P. Vijaykumar, 2012 [11],** this paper proposes analysis and comparative study of hybrid renewable Electric system, especially Photovoltaic Fuel cell hybrid system and wind Fuel cell hybrid system with hybrid optimization model for Electric Renewable for smart grid distributed generation system. The model can analyze all the available small power technologies individually

and in hybrid configurations to identify least-cost solutions to energy requirements. And the sensitivity analysis using HOMER indicates that PV/fuel cell hybrid system is feasible under specific metrological conditions, while photovoltaic system is more suitable. Also, from the proposed system it is clearly observed that PV energy has more impact in this hybrid system than the wind energy system.

12. **Pooja Sharma, Siddhartha P Duttaguta, Vivek Agarwal, 2009[12],** this paper analyses the practical problems occur when considering portable installations in urban as well as rural settings. It gives a specific example where due to logistical reasons only very light weight photovoltaic modules can be installed. And apart from weight, architectural constraints may also require the module lay out to be contoured. In this paper the performance of Flexible Photovoltaic (FPV) with moderate watt-peak /kg values and exposed to sustained insolation conditions has been investigated in the present work. Three different FPV technologies have been considered, namely mono-crystalline, poly-crystalline and amorphous silicon. A consistent improvement in performance prediction as compared to previous PV modules has been reported.
13. **Marco Liserre, Thilo Sauter, and John Y. Hung, March 2010 [13],** this paper analyses the evolution of renewable and non-renewable energy resources and compares these two energy resources in relation to environmental pollution. Finally, it concludes to avoid or to reduce the effect of diesel generators on environmental and air pollution in large cities especially in hospitals it is important to integrate renewable energy resources.

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

In this chapter assessment and analysis of the collected primary and secondary data, as well as the analysis of the hybrid DG components with the proposed fuzzy logic controller will be done.

3.2 DESCRIPTION OF STUDY AREA

Yekatit 12 Referral hospital one of the oldest and largest referral hospitals found in Addis Ababa city having latitude of 9.03^0N and longitude of 38.74^0E with an elevation of 2355 meters and this selected site is not known for its excess of green energy resources but it can be used for generating small scale power serving only for some selected power sensitive loads or departments not for the whole hospital.

3.3 DATA GATHERING

The data used in the design of the hybrid components are collected directly from the site (hospital) and from Ethiopian Metrology agency, and for perfectness of the analysis these data are compared with the NASA data obtained using the latitude and longitude of the site.

3.3.1 Primary Data

These data collected directly from the site and, are considered as a primary data, and this includes the total load of the four power sensitive departments and the capacity of the existing small generator in the hospital.

The size and cost of hybrid system components is highly influenced by the size of the electric loads. Thus, correctly analyzing the load demand or profile is an important step in designing Energy generation hybrid system. Nature of operation of loads and behavior of consumers are the parameters that determine the load profile. It was very difficult to analyze the load demand profile for Yekatit 12 referral hospital because there is not fixed formula to calculate the loads (varying from hour to hour), thus some of the loads are estimated by asking from staff members and the members of the operation and maintenance team of the hospital.

Generally, the main steps in estimating on how much electricity is required in a selected site is, first to list all the electrical appliances, estimate the duration these appliances are used, taking the power each appliance consumes, and for each appliance multiply the power rating in watts by consumption hour.

Table 3. 1 Total energy consumption of the four departments of the hospital

	Departments																								
	Surgery						Neonatalogy Dept											Maternity			Emergency			
Time	Lamp	Refrig	Defb	Steri	LTF	STF	Lamp	Ox Conc	BLF	PFCP	PTU	ID	II	CM	ACP	Refri	POX	Lamp	BFM-700	Eob	Lamp	Defb	Refri	Load(Kwh)
00:00-1:00	1440	110	–	.....		...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
1:00-2:00	1440	110	–.	.....		....	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
2:00-3:00	1440	110	–	.....		....	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
3:00-4:00	1440	110	–	.....		...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
4:00-5:00	1440	110	–	.....		...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
5:00-6:00	1440	110	–.	.....		...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
6:00-7:00	1440	110	1800	...	6000	3600	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	27.324
7:00-8:00	1440	110	1800	....	6000	3600	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	27.324
8:00-9:00	–.	110	1800	....	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
9:00-10:00	–.	110	1800	24,000	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	48.41
10:00-11:00	–.	110	1800	....	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
11:00-12:00	–.	110	1800	....	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
12:00-13:00	–.	110	1800	....	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
13:00-14:00	–.	110	1800	....	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
14:00-15:00	–.	110	1800	24,000	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	48.41
15:00-16:00	–.	110	1800	....	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
16:00-17:00	–.	110	1800	....	6000	3600	.....	2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
17:00-18:00		110	1800	....	6000	3600		2160	720	20	1500	1080	1344	1200	2100	110	216		720	720		900	110	24.41
18:00-19:00	1440	110	–	–	....	....	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
19:00-20:00	1440	110	–.	–.	...	...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
20:00-21:00	1440	110	–	–.	....	...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
21:00-22:00	1440	110	–.	–.	....	...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
22:00-23:00	1440	110	–	–.	...	...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
23:00-00:00	1440	110	–.		....	...	864	2160	720	20	1500	1080	1344	1200	2100	110	216	1152	720	720	720	900	110	17.186
Total Daily load	20160	2640	21600	48,000	72,000	43200	20736	51840	17280	480	36000	25920	32256	28800	50400	2640	5184	16128	17280	17280	10080	21600	2640	552.88

The total electric consumption of the surgery, Neonatology, Maternity and the Emergency Departments are 207.6Kwh, 271.24Kwh, 45.688Kwh and 24.32Kwh respectively giving a total load of the selected sites of the hospital about 552.83 KWh.

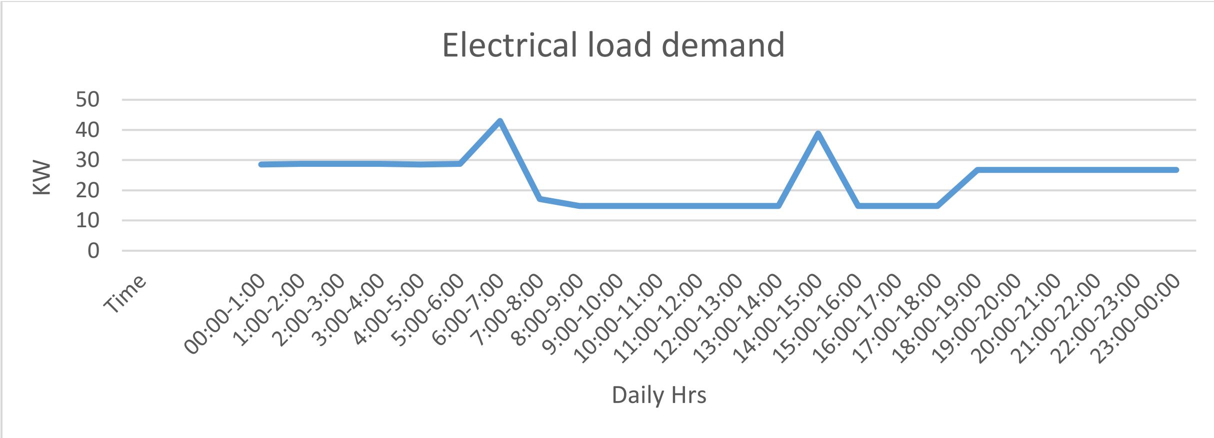

Figure 3. 1 Load profile of the four departments of the hospital

The total energy consumption of the selected sites of the hospital per day is about 552.88Kwh, and from this the annual energy consumption is 552.88Kwh*365 which is 201,801.2Kwh (201.801Mwh). Average load demand (LD) per hour is 23.1KW, and the peak load (PL) is calculated by dividing the average load demand by the load factor (LF), and taking 0.6 load factor,

$$PL = \frac{LD}{LF} = \frac{23.1KW}{0.6} = 38.5KW$$

Installed capacity (IC) = Peak Load + Loss, and assuming loss of 7% of peak load (PL) which gives 3.62KW, thus IC is 38.5KW + 2.6KW = 40KW. Therefore, the total load for the selected four power sensitive of the hospital is approximately around 40KW.

3.3.1.1 Existing Generator Capacity

The hospital has an old generator which operates manually, and due to its age and lack of timely delivered maintenances sometimes the generator becomes OFF by its own.

3.3.1.2 Availability of Area for installing the components

The hospital has many bare spaces, large walkways, and green area places and these areas and the rooftops can be used for installing small scale solar panels and small weight wind turbines.

3.3.2 Secondary Data

The wind and solar data which are collected from the Ethiopian metrology agency and NASA are considered as secondary data inputs,

3.3.2.1 Wind Energy Assessment and data analysis

most of the time the standard for recording wind speed data is at a height of 10 meters, but due to some technological difficulties if the standard data (wind speed at 10m height) is not available, it is also possible to record data at a height of 2 meters also and make mathematical approximation at any height. Unfortunately, the wind speed recorded data for the selected or proposed site is measured at 2m height every 15 minutes for five years (2012 - 2016) is collected from National Metrology of Ethiopia (NME) found in Addis Ababa, also using the latitude and longitude of the selected site a wind speed data at a height of 10m is recorded from NASA.

Using the original data sources collected from National Metrology of Ethiopia and NASA necessary Mathematical analysis and estimations are done to convert these data into suitable data format at the required turbine installation height. The monthly average wind speed data at a height of 2m height is given in *figure-3.2*.

This original wind speed data is first converted into the wind speed 10m (standard height) then to be used to calculate the estimated wind speed at a height of 28m using the famous logarithmic law given as follows [17]:

$$V(Z)\ln\left(\frac{Z_r}{Z_o}\right) = V(Z_r)\ln\left(\frac{Z}{Z_o}\right) \qquad (3.1)$$

Where; Z_r is reference height in meter

Z is the height where wind speed is to be determined

Z_o is measure of surface roughness,

V(z) is wind speed in m/s at a height of z meters

$V(Z_r)$ is wind speed at the reference height

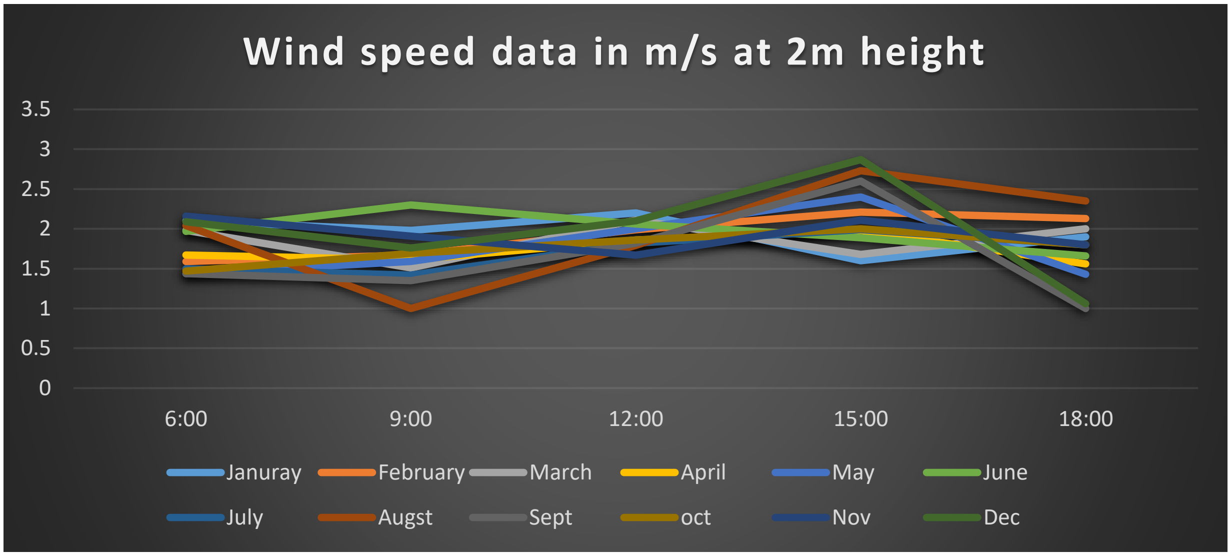

Figure 3. 2 Wind speed data in m/s at 2m height

using the power law the wind speed at a certain height above ground level can be given as follows [17]:

$$V_2 = V_1 \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{3.2}$$

Where: V_1 is wind speed measured at the reference height h_1,

V_2 is the estimated wind speed at height h_2, and

α is ground surface friction, given in a tabular form below

Table 3. 2 Different values of α

Terrain Type	Friction coefficient α
Lake, ocean, smooth, and hard ground	0.10
Foot-high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.20
Wooded country with many trees	0.25
Small town with some trees and shrubs	0.30
City with tall buildings	0.40

Table 3. 3 Measured and estimated wind speed data

Height	Jan	February	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avg 2m Measured	1.956	1.918	1.856	1.736	1.772	1.976	1.706	1.98	1.642	1.764	1.93	1.976
10m Esti	3.912	3.836	3.712	3.472	3.544	3.952	3.412	3.96	3.284	3.528	3.86	3.952
Avg 10m NASA	3.5	3.3	3.1	3	3	3.3	3.1	2.6	2.4	2.6	3	3.3
28m Esti	5.62	5.51	5.34	5	5.01	5.7	4.9	5.69	4.72	5.07	5.55	5.68

Since the selected site is a city with tall buildings a friction coefficient of 0.4 is used, and the resulting estimated wind speed at 28 meters of height is given above: So, it is assumed from the collected wind speed data it is possible to design a small wind turbine which operates at a small wind speed.

3.3.2.2 Solar Radiation Assessment and data analysis

The facilities for measuring and recording of global solar radiation are not easily available due to the cost and techniques involved. In this work the number of sunshine hours data is recorded every day using the sunshine hour recorder for four consecutive years (2012-2015) is collected.

The collected solar radiation data is analyzed and regression constants for the first order Angstrom-Prescott type correlations for the selected site are calculated using regression analysis. To do this analytical estimation the monthly average daily global solar radiation, altitude, latitude, declination angle of the day, the average day in the month and the sunshine hour data are used as the input data.

Linear Angstrom-Prescott regression equation related monthly average daily radiation to clear day radiation in a given location and average fraction of possible sunshine hour data which is given by the following equation.

$$\frac{H}{H_O} = a + b\left(\frac{S}{S_o}\right) \tag{3.3}$$

Where H is the monthly average of the daily global radiation on a horizontal surface, H_o is the average value of extraterrestrial solar radiation on horizontal surface for each month, S is the monthly average of bright sunshine hours per day, and S_o is the average of the maximum daily hours of sunshine and it can be calculated from Ma and Iqbal's formula (Ma and Iqbal, 1984) [23].

$$S_o = \frac{2}{15} W_s \qquad W_s = \cos^{-1}(\tan\delta \tan\phi) \tag{3.4}$$

Where; W_s is the mean sunrise hour angle

δ is the solar declination angle for the average day in the month

ϕ is the latitude of the selected site

The solar declination angle (δ) throughout the year can be well approximated by sine function and is given by the following equation,

$$\delta = 23.45 \sin\left[360\left(\frac{284+n}{365}\right)\right] \qquad [degrees] \tag{3.5}$$

Where; n is the day of the year.

The value of n for any day of the month "D "can be determined easily with aid of *table-3.4*.

Solar radiation on horizontal surface can be computed from the model of Duffie and Beckman, (1991) as follows;

$$H_o = \frac{86400 * I_{SC}}{\pi}\left\{1 + 0.033\cos\frac{360n}{365}\right\}\left\{\frac{2\pi W_s}{360}(\sin\phi\sin\delta) + (\cos\delta\cos\phi\sin W_s)\right\} \tag{3.6}$$

in J/m^2

Since there are 3600 seconds in an hour and 86400/3600 =24, the following equation gives the monthly average daily extraterrestrial solar radiation in Wh/m^2.

$$H_o = \frac{24 * I_{SC}}{\pi}\left\{1 + 0.033\cos\frac{360n}{365}\right\}\left\{\frac{2\pi W_s}{360}(\sin\phi\sin\delta) + (\cos\delta\cos\phi\sin W_s)\right\} \tag{3.7}$$

Where I_{sc} is the solar constant which has a value of 1367w/m^2,

W_s is the mean sun rise hour angle for the given month, n is the number of days of the year starting from first January.

Table 3. 4 Recommended average days for months and value of n (the day of the year) by months

Month	n for the day of the month, D	Date	Day of the year(n)	δ (degrees)
January	D	17	17	-20.92
February	31+D	16	47	-13.03
March	59+D	16	75	-2.44
April	90+D	15	105	9.42
May	120+D	15	135	18.81
June	151+D	11	162	23.15
July	181+D	17	198	21.22
August	212+D	16	228	13.53
September	243+D	15	258	2.24
October	273+D	15	288	-9.63
November	304+D	14	318	-18.95
December	334+D	10	344	-23.1

The monthly mean of daily global solar radiation, H was normalized by dividing with monthly mean of daily extraterrestrial solar radiation (H_O). It can be defined that clearness index (K_T) can as the ratio of the measured or observed horizontal terrestrial solar (H) to the calculated or predicted horizontal/ extraterrestrial solar radiation (H_o). It gives the percentage of the incoming solar radiation deflected by the sky and therefore indicates both availability of solar radiation and changes in atmospheric conditions in a given locality [Reference].

$$K_T = \frac{H}{H_o} \tag{3.8}$$

The regression coefficients "a" and "b" from the calculated monthly average global solar radiation has been obtained by considering the effects of latitude, elevation and sunshine hour given by the following equations;

$$a = -0.309 + 0.539 \cos\phi - 0.0639 \times h + 0.29\left(\frac{S}{S_o}\right) \tag{3.9}$$

$$b = 1.527 \mp -0.0926 \times h - 0.359\left(\frac{S}{S_o}\right) \tag{3.10}$$

Where h is the altitude of the selected site in kilometers (2.355Km)

δ is the calculated declination angle for the average day in the month

ϕ is the latitude of the selected site (9.03 degrees)

W_s is the calculated sunset hour angle

To make a reliable estimation of the daily average sunshine hour and to assess the availability of enough solar radiation in the selected site it is important to use a data collected for several years, and for this research a sunshine hour data of four recent consecutive years (2012-2015) is collected and the average of these four-year data of each month is considered as the average sunshine hour of the selected site (i.e. approximately).

Table 3. 5 The average daily sunshine hour of the site

		Year				**Daily**
NO	Month	**2012**	**2013**	**2014**	**2015**	**Average hrs. (S)**
1	January	9.37	8.78	8.7	9.35	9.05
2	February	9.975	9.41	8.42	9.46	9.31
3	March	9.974	9.45	8.54	9.72	9.42
4	April	4.58	6.85	7.96	7.51	6.725
5	May	7.05	5.78	6.23	5.68	6.29
6	June	4.07	4.92	5.1	3.74	4.45
7	July	2.24	2.9	2.27	3.67	2.77
8	August	2.746	2.24	2.22	3.3	2.625
9	September	4.133	5.2	3.44	4.9	4.42
10	October	8.077	6.89	6.57	8.35	7.47
11	November	9.59	8.22	8.53	8.03	8.59
12	December	9.23	9.66	9.15	7.51	8.88

So for designing the required solar photovoltaic panel it is considered an average sunshine hour data for all the years is tabulated below.

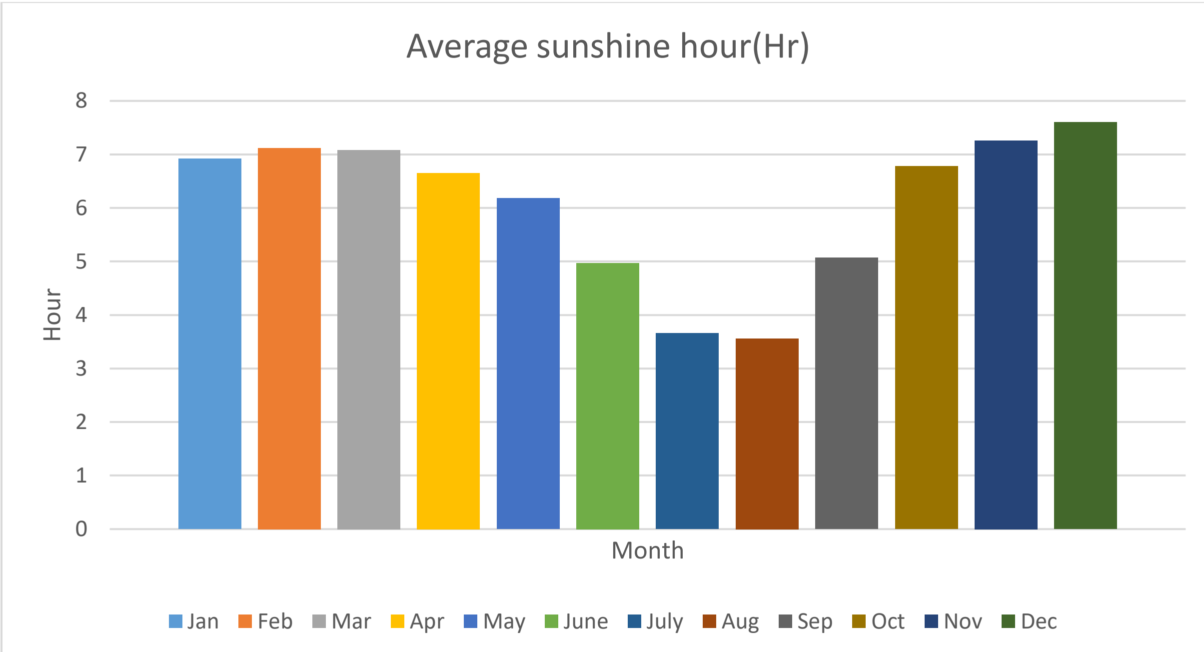

Figure 3. 3 Average sunshine-hour of the site

Using the linear Angstrom correlation model, it is possible to predict the monthly mean daily solar radiation from the measured sunshine hours per day and compared with the monthly mean daily solar radiation data collected from NASA, and tabulated below.

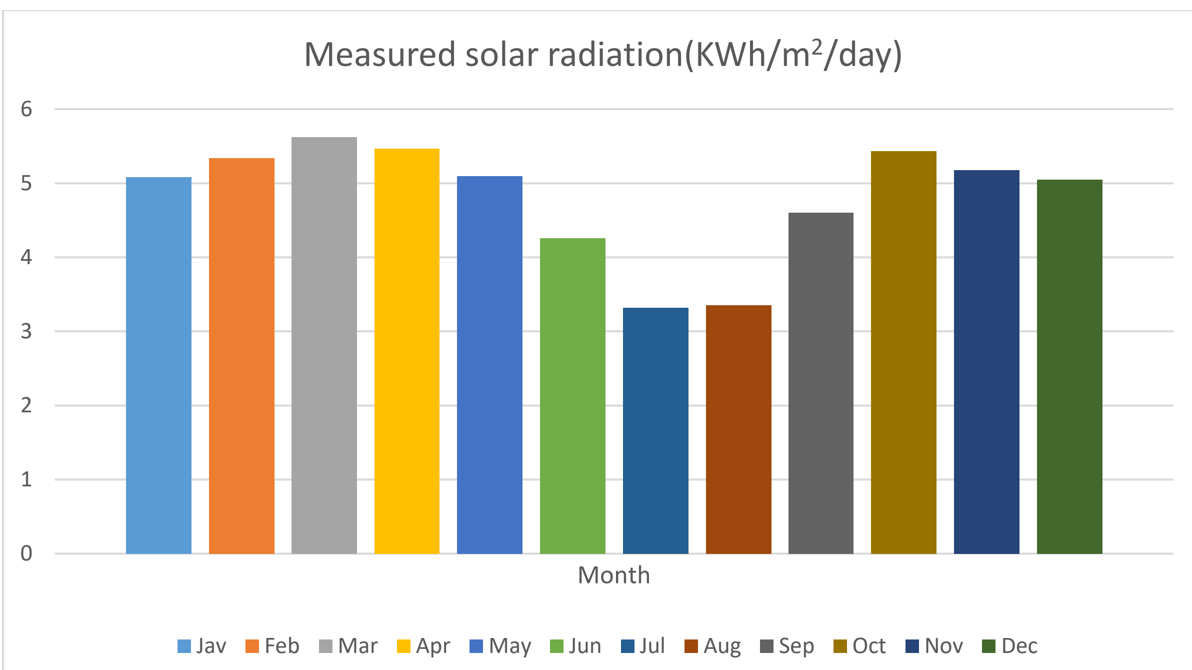

Figure 3. 4 Measured solar radiation

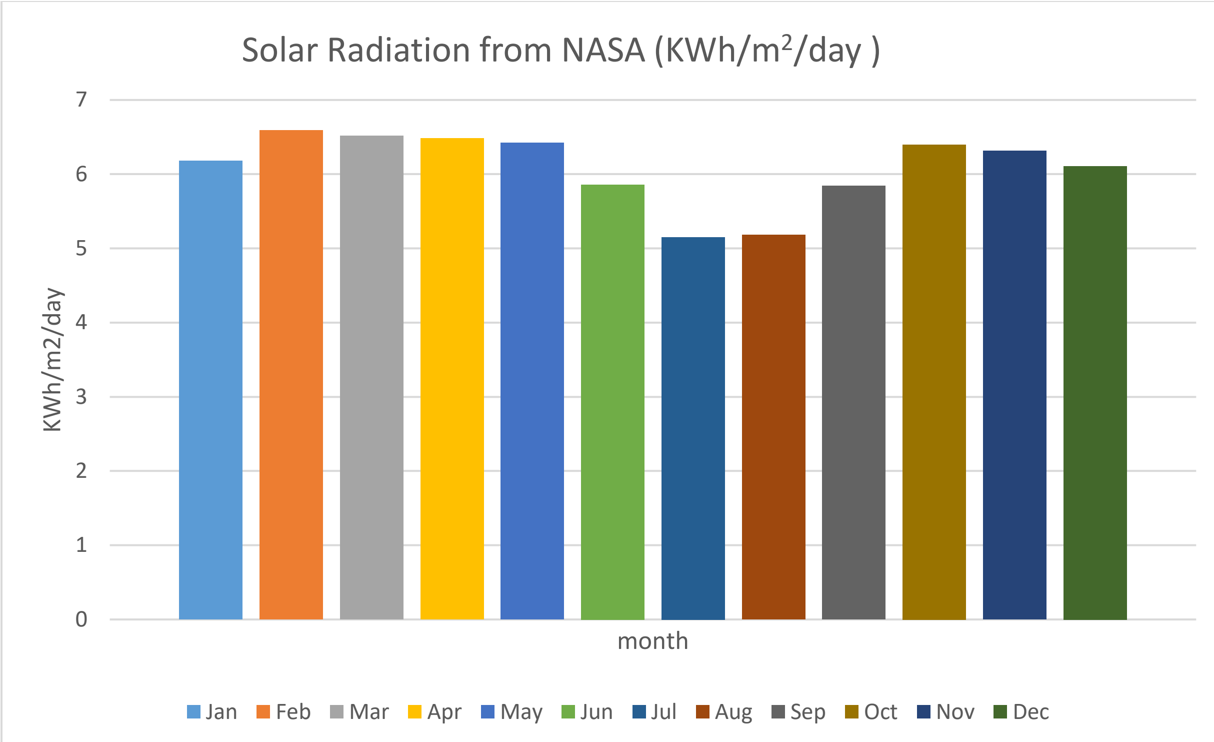

Figure 3. 5 Solar radiation taken from NASA

It can be seen that the measured solar radiation and the solar radiation data collected from NASA using the latitude and longitude of the proposed site have somewhat close values.

Table 3. 6 Summarized solar data

Date of month	D	δ (degree)	Ws (degree)	S (hr)	So (hr)	S/So	Ho (KWh/m2/d)	a	b	H (KWh/m2/d)
Jan-17	17	-20.92	86.56	6.92	11.54	0.599	9.013	0.246	0.53	5.078
Feb-16	47	-13.03	87.93	7.125	11.72	0.607	9.685	0.248	0.5	5.341
Mar-16	75	-2.44	89.65	7.085	11.95	0.592	10.293	0.244	0.51	5.619
Apr-15	105	9.42	91.48	6.65	12.19	0.545	10.522	0.231	0.53	5.469
May-15	135	18.81	93.09	6.185	12.41	0.498	10.372	0.217	0.55	5.091
Jun-11	162	23.15	93.84	4.975	12.51	0.397	10.21	0.187	0.58	4.26
Jul-17	198	21.22	93.84	3.66	12.51	0.292	10.232	0.144	0.62	3.32
Aug-16	228	13.53	92.17	3.56	12.28	0.289	10.393	0.143	0.62	3.348
Sep-15	258	2.24	89.65	5.06	11.95	0.423	10.319	0.182	0.624	4.601
Oct-15	288	-9.63	88.51	6.78	11.8	0.574	9.824	0.226	0.57	5.434
Nov-14	318	-18.95	86.9	7.26	11.58	0.626	9.141	0.254	0.5	5.182
Dec-10	344	-23.1	86.15	7.6	11.48	0.662	8.765	0.252	0.49	5.052
Average								**0.214**	**0.55**	**4.816**

3.3.2.3 Fuel Cell Energy analysis

There are several kinds of fuel cells, and each operates a bit differently. But in general terms, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips of them of their electrons. The hydrogen atoms then are ionized and carry a positive electrical charge. The negatively charged electrons provide the current through wires to work. If alternating current (AC) is needed, the DC output of the fuel cell must be routed through a conversion device called an inverter. Oxygen enters the fuel cell at the cathode end, and in some cell types it there combines with electrons returning from the electrical circuit and hydrogen ions that have travelled through the electrolyte from the anode. In other cells the oxygen picks up electrons and then travels through the electrolyte to the anode, where it combines with the hydrogen ions. Whether they combine at anode or cathode, together hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity.

3.4 SYSTEM MODELLING

The proposed hybrid system consists a wind, solar and Fuel cell technology as a backup, in which the energy to be produced from these renewable energy resources will be controlled using fuzzy logic controller.

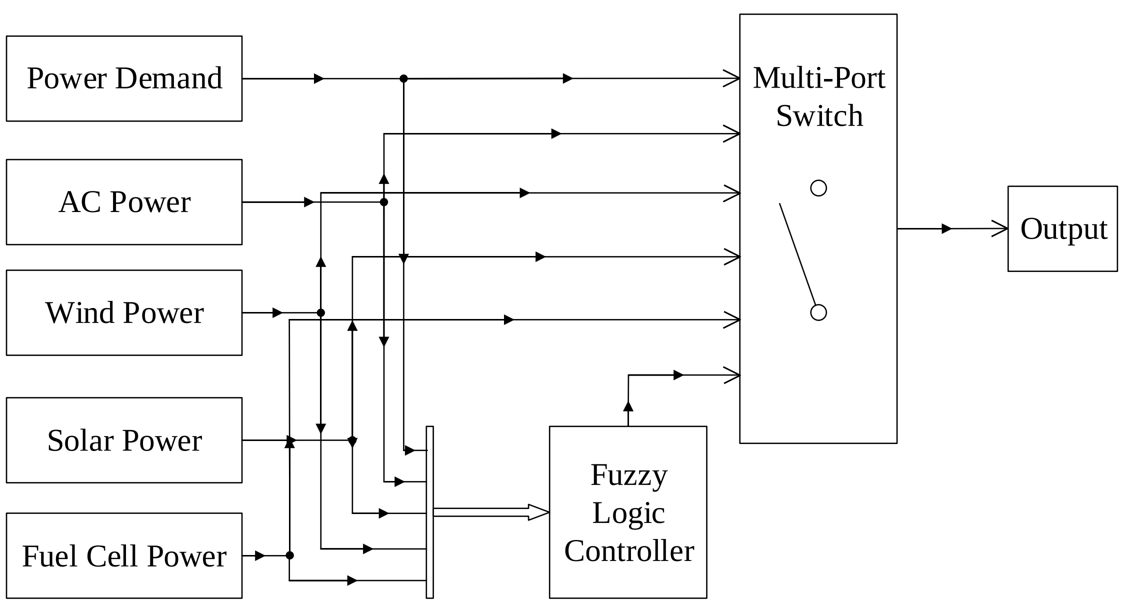

Figure 3. 6 Overall system block diagram

So, what the system do is, first it checks the availability of the commercial power if so the existing load will be served by the commercial power, else if the commercial power is OFF depending on the amount of the load the fuzzy logic controller makes the intelligent decision to switch the multi-port switch to the required load demand output.

3.5 LOAD SHARING OF THE HYBRID COMPONENTS

Hybrid solar, wind and Fuel Cell is an efficient system of producing energy especially in highly power sensitive departments in large cities [13], and comparing production costs and other associated advantages solar power production is preferable to wind power production. In this paper it is assumed 50% of the power demand which is around 20KW is to be produced from the solar panels, and 20% of the load demand which is around 8KW is to be produced from wind, and the rest 30% of the load demand which is around 12KW is to be produced from the backup Fuel cell Technology during solar power energy shortage seasons. These load distribution numbers are calculated from the load profile of the hospital, and from this the annual energy demand of the hospital during the day time (06:00-18:00) is around 346.748KWh, similarly the annual energy demand during the night time (18:00-6:00) is around 206.232KWh.

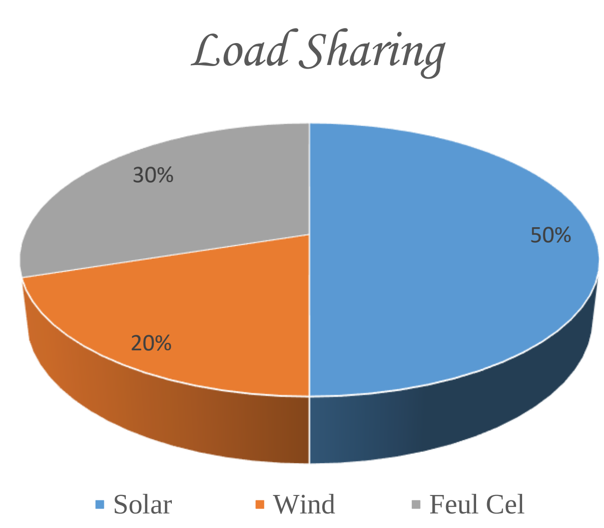

Figure 3. 7 Load sharing among the hybrid DG components

Much of the power to be generated is from the proposed hybrid DG system is from solar panel due to many associated advantages of solar power production compared to wind power production, to mention some, no moving parts in solar power production, solar panels require less monitoring, does not require expensive maintenance, totally silent in operation, and allows for quicker installation with less cable required.

3.5.1 Sizing of the hybrid system components

The first step in designing a solar PV after analyzing the availability of solar energy resource is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system, and the next step is size of the PV modules, because different size of PV modules will produce different amount of power to find out sizing of PV module, the total peak power to be produced is needed, and this depends on the size of the PV module and climate of the site location, and in this selected site the power demand to be produced from the solar PV module is around 20KW (considering 10% of system loss), the last step is to decide the number of PV modules, area of the total panels, and to determine the capacity of power converters. The power to be generated from the back up fuel cell technology is about 14kw considering 10% loss, also the power to be generated from the wind system is about 10kw considering 10% loss.

3.5.2 PV system designing

For this paper solar PV module with power rating of 100w is selected due to its electrical and mechanical advantages and its specification meeting the requirements (short circuit current of 5.14A and open circuit voltage of 22.2V).

To produce the required power from solar a 7 solar panel array, and each containing s 27 solar cells connected in series (Ns) is proposed. With the technical specification of the selected PV cell it is expected to produce a power of 3.08kw per array considering 30% efficiency, then producing a total power of approximately around 21kw (i.e. 7 arrays each producing 3.08kw).

Therefore, the total number of PV modules is 7 parallel strings each containing 27 modules connected in series PV modules.

3.5.3 Sizing of the Inverter

A solar system's inverter functions optimally within a predetermined operational 'window' (usually laid out in the inverter's specifications). As the power input from the system's solar panels goes up and down, the inverter's ability to efficiently convert it from DC electricity to AC electricity differs. As long as the input from the panels falls within the range of the window, the inverter can be considered to be operating optimally.

The input rating of the inverter should never be lower than the total watt hours of the appliances. For standalone systems, the inverter size should be 25-30% bigger than total watts of the appliances. In case of appliance type is motor or compressor then the inverter size should be minimum three times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting. For grid tie systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation. The calculated load is around 20KW then size of the inverter should be at least 24KW.

3.5.4 Battery Sizing

Batteries store direct current electrical energy for late use. This energy storage comes at a cost, however, since batteries reduce the efficiency and output of the PV system, typically by about 10 percent for lead acid batteries. The mathematical analysis for sizing the battery bank by considering UB-8D AGM 250 AH, 12V-DC system is formulated below:

The total average energy use is 19kw*12hr = 228KWh, and taking days of autonomy or the no-sun days of three days, the amount of energy storage required is $E_{rough} =$ 228KWh*3= 684KWh, and for energy safety, $E_{safe} = E_{rough}/MDOD$ = 684KWh/0.75= 912KWh, and the capacity of the battery bank needed can be evaluated: C= E_{safe}/V_b = 912KWh/12 =76000 Amps h, the total number of batteries is obtained by: $N_{batteries} = C/C_b$ = 76000/250 =304 Batteries.

The number of batteries in series equals to $N_s = V\ DC/V_b$ = 48/12 = 4

The number of parallel paths N_p is obtained = number of batteries/ N_S = 304/4 = 76

To make the system more reliable, the battery is charged both from commercial AC power via rectifier and directly from the solar panels.

3.5.5 Sizing of the voltage controller

According to the selected controller (Xantrex C-60, 48V, 60-A), the rated current of the controller I = $I_{SC} * N_P * F_{SAFE} = 5.14*7*1.25 = 45$*Amps (minimum battery charging current).* The controller load current is calculated as *19000VA/48V = 395.833A*, since controller current is rated at 60A, to supply 395.833A of current, 7 parallel connected controllers are required.

3.5.6 Wind Generator designing and sizing

To generate an 8KW power from the wind energy first it is necessary to look at the wind speed of the selected site, and the selected site at a height of about 28m (installing the wind turbine at the top of the building) it is assumed there will be a wind speed of around 5m/s, and by taking this consideration a Cyclone wind turbine with three blades which is capable of producing a 150w power is selected.

This type of three blade wind turbine is a variable wind speed which is a stall regulated. This means that the attack angle of the blade is such chosen so at wind speed higher than the rated wind speed, the turbulence appears and the output power goes down, thus the wind turbine is protected at higher wind speeds.

Table 3. 7 Wind turbine Cyclone 200w technical specifications

Rotor Diameter [m]:	2
Startup wind speed [m/s]:	3
Rated wind speed [m/s]:	5
Cut out wind speed [m/s]:	9
Maximum output power [w]	200
Output voltage [VDC]	12/24

3.5.7 Sizing of the fuel cell

30% of the load demand is to be produced from fuel cell, so to do so by considering the market availability of the different fuel cell technologies the capacity of the fuel cell selected for this work is one with capacity of 2.5kw and two with capacity of 6kw that generate a total power of around 14.5kw power.

CHAPTER 4
SIMULATION RESULTS AND DISCUSION

4.1 INTRODUCTION

The power generated from the hybrid components, and the fuzzy logic controller are simulated and discussed in the section below. First the solar power system model is modeled and simulated to give an output of around 20KW, according to the designed system model, and next single wind turbine system model, and single fuel cell technology with a capacity of producing 6KW, DC power are designed and simulated to give an output of around 150W, and 6KW, respectively. Finally the intelligent fuzzy logic controller is designed and simulated

4.2 SOLAR POWER GENERATION SYSTEM

The power to be generated from the solar panels is around 20KW, and in order to achieve this a solar panel with short circuit current of 5.14A and an open circuit voltage of 22.1V is selected by considering the solar data radiation of the selected site, and from these technical specifications of the proposed solar panels a string of 7 arrays each containing 27 solar cells connected in series is Required to generate a power of around 20Kw.

Since the hospital doesn't have a large flat area to install the solar panels, the panels are to be installed at different places of the hospital, and due to this these solar panels will not get the same solar radiation, and to consider this effect some of the solar panels are allowed to receive a solar radiation of 1000 KWh/m^2/day, and some to get a solar radiation of 800 KWh/m^2/day, and some of the solar panels are allowed to receive a solar radiation of 600 KWh/m^2/day.

4.2.1 Solar Panel Simulation Results

The Matlab simulation power generated from the proposed solar array is around 22KW, and this is shown in the current versus voltage curve and also in the power versus voltage curve as shown in *figure-4.2*.

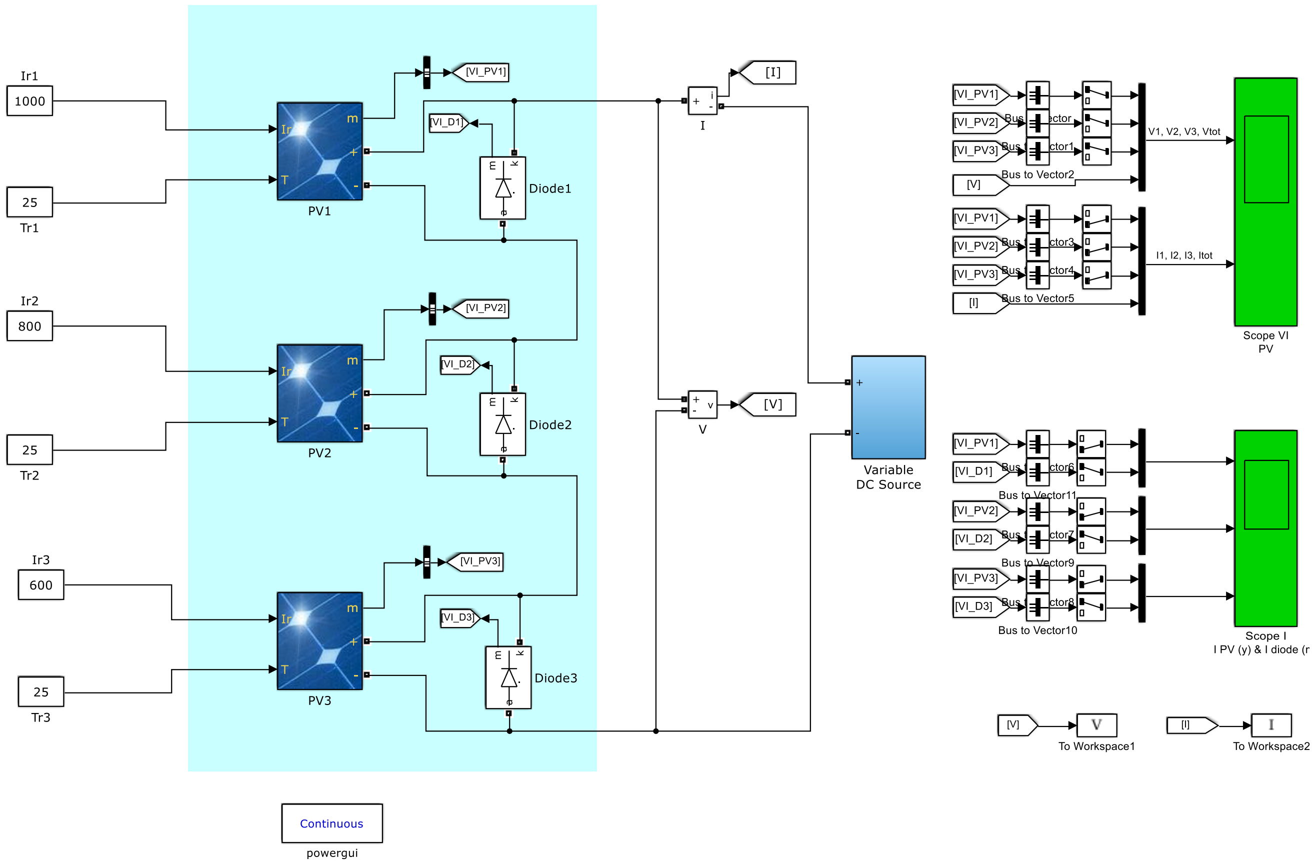

Figure 4. 1 SIMULINK® Realization of the solar panels

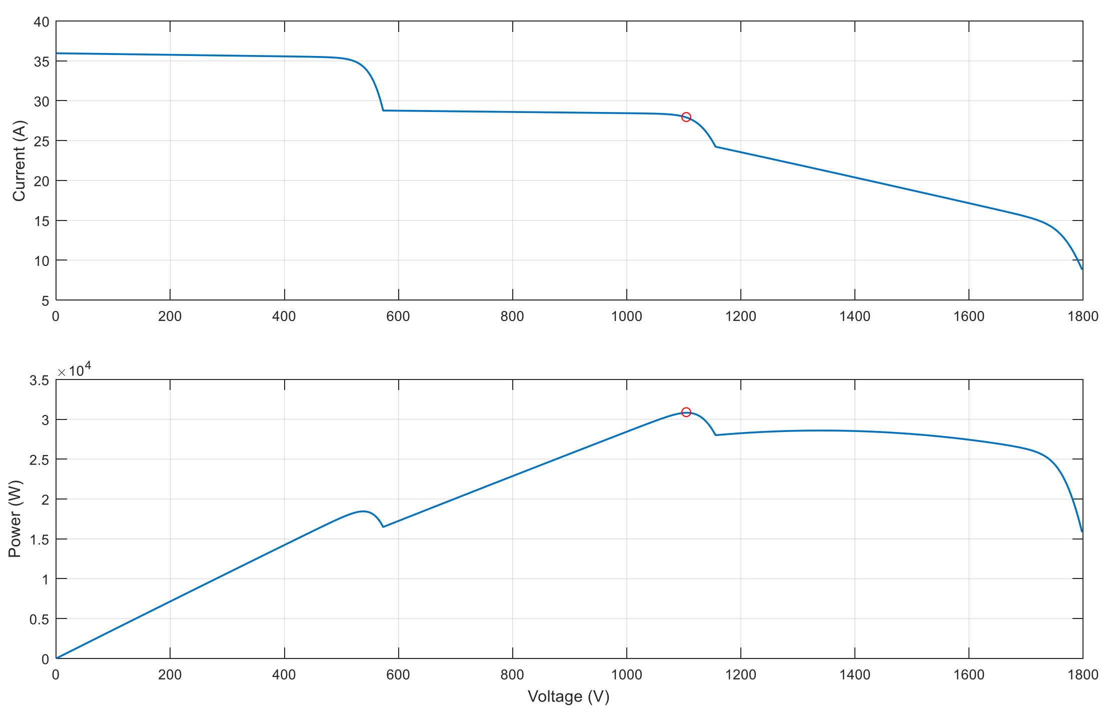

Figure 4. 2 V-I and P-V characteristics curve of the solar generated power

4.3 WIND POWER GENERATION SYSTEM

The Matlab simulation power generated from the proposed wind turbines is around 9KW, and to achieve this a wind turbine which generates a power of around 150W (considering the wind speed of the hospital, which is on average around 5m/s throughout the year), and to do this around 54 wind turbines are required. A synchronous generator is proposed or selected by considering the market availability of the generator, and its ability to operate a very low speeds making it suitable for the hospital.

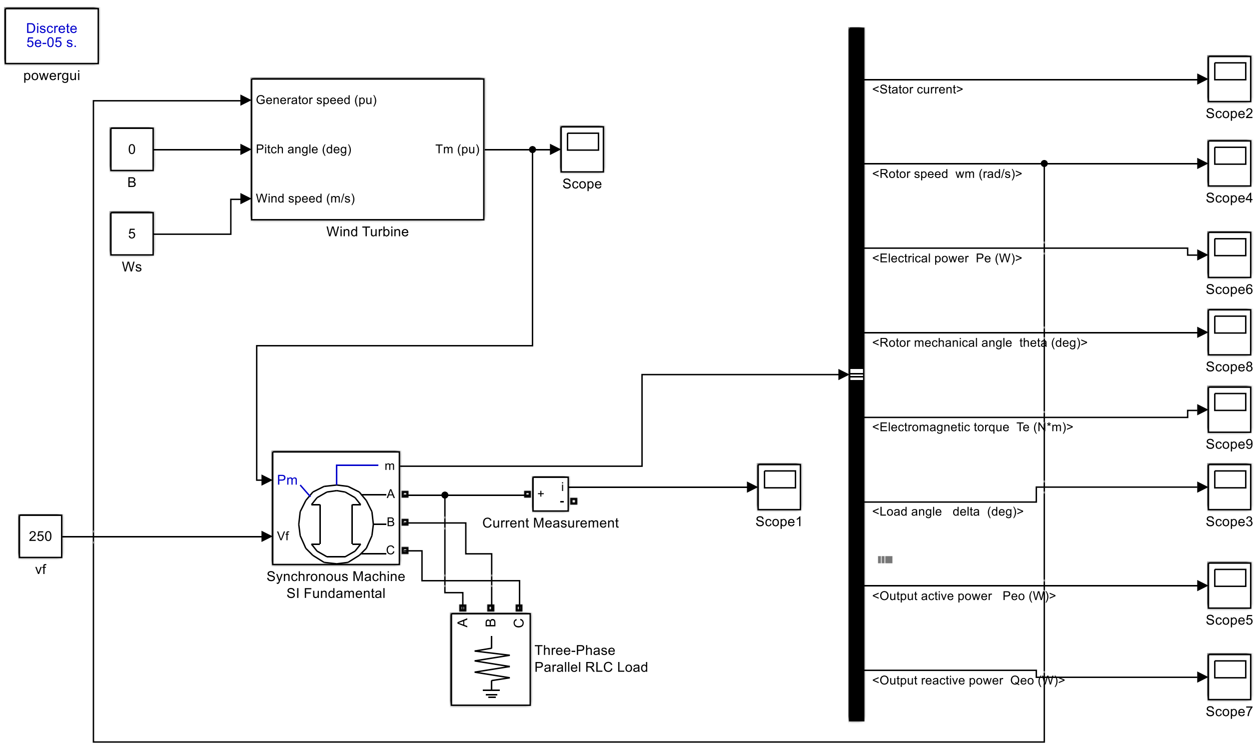

Figure 4. 3 SIMULINK® Realization of the wind turbine

4.3.1 Wind Turbine Simulation Result

As it can be seen from the Matlab simulation results, *figure-4.4* and *figure-4.5*, it is possible to generate a 150W from a single wind turbine, and it can be seen a single wind turbine producing an active power of around 150.5 watts at the given wind speed of around 5m/s.

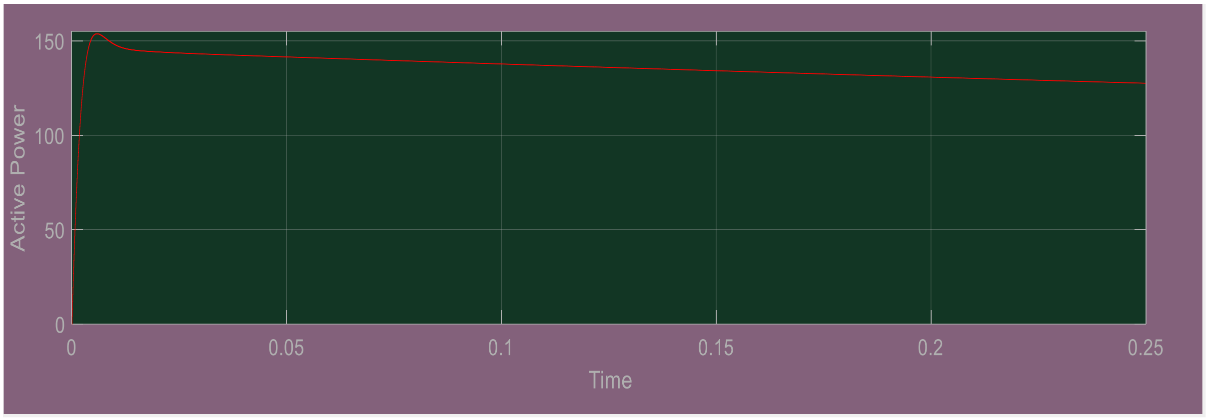

Figure 4. 4 Wind turbine active power output

Synchronous generator is used because of its associated advantages defined above such as its ability to operate at a very low rotor speed, and this is simulated and shown below, which varies between 156 and 157.1 rad/sec.

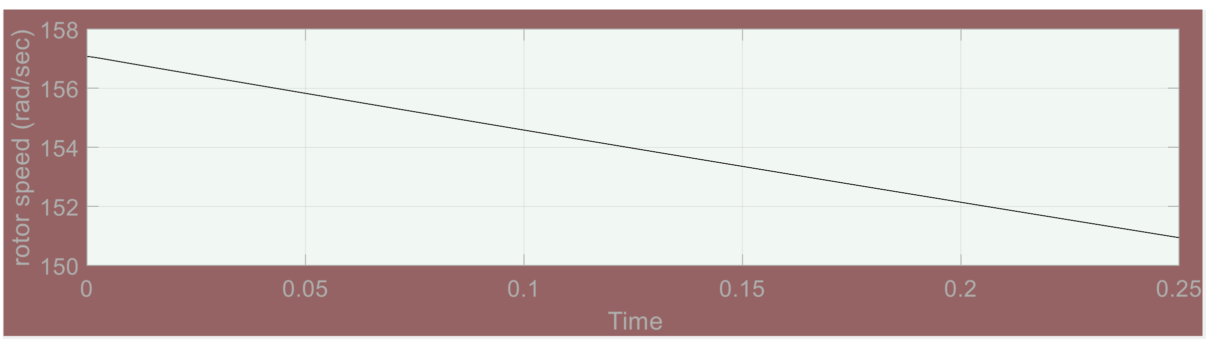

Figure 4. 5 Rotor speed of the generator in rad/sec

4.4 FUEL CELL TECHNOLOGY POWER GENERATION SYSTEM

The Matlab simulation power generated from the proposed Fuel cells is around 14KW, and to achieve this a fuel cell which can a DC power of 6KW and 2.5KW are proposed considering the market availability. So, to generate the proposed power two fuel cells with generating capacity of 6KW and one with capacity of 2.5KW are used.

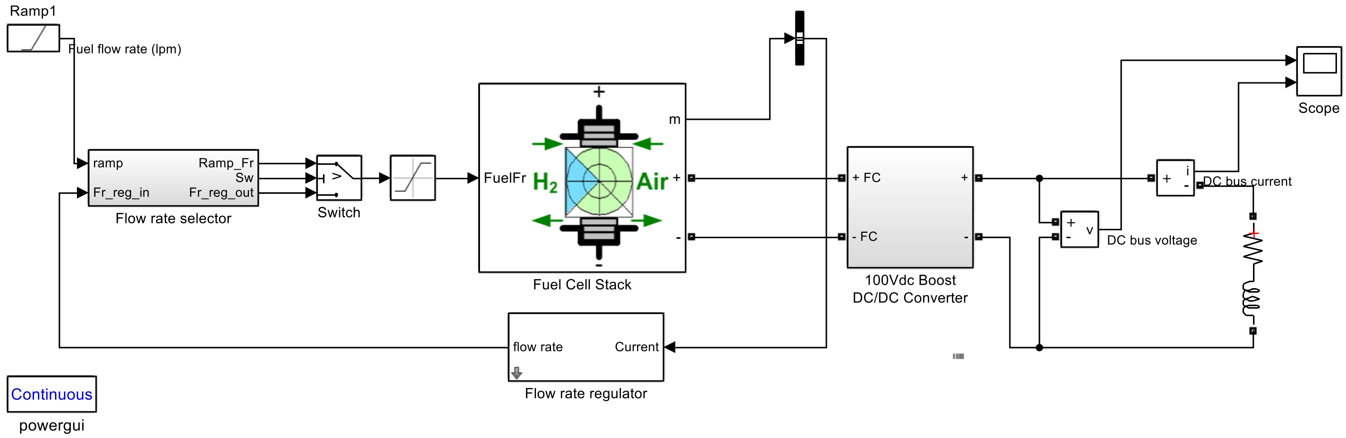

Figure 4. 6 SIMULINK® Realization of the fuel cell

4.4.1 Fuel Cell Simulation Result

As it can be seen from *figure-4.7*, a DC power of around 6KW is generated from the single Fuel Cell. So, by using two 6KW capacity fuel cells and one 2.5KW capacity, a total power of around 14KW can be produced.

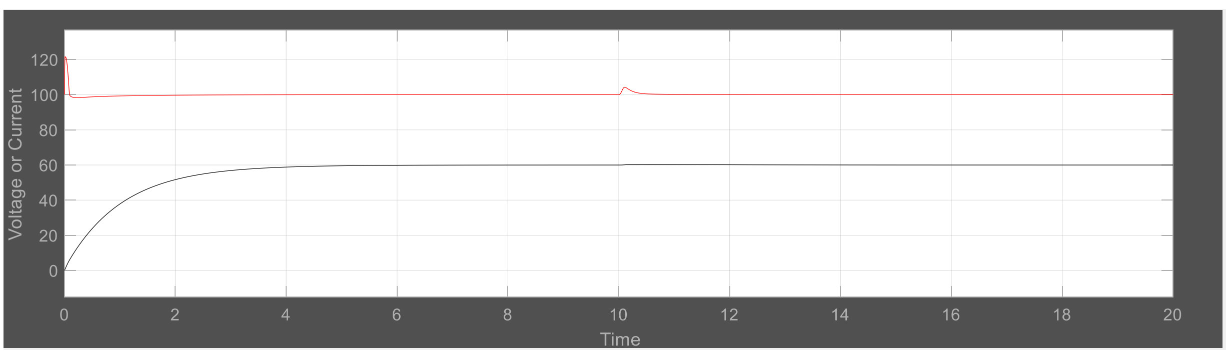

Figure 4. 7 DC bus voltage and DC bus current of 6KW fuel cell

4.5 FUZZY LOGIC CONTROLLER

The fuzzy logic controller has five variable inputs, namely demand power (P_d), Main power (M_p), Solar power (S_p), Wind power (W_p), and Fuel cell power (FC_p), but one crisp output power

(P_o).

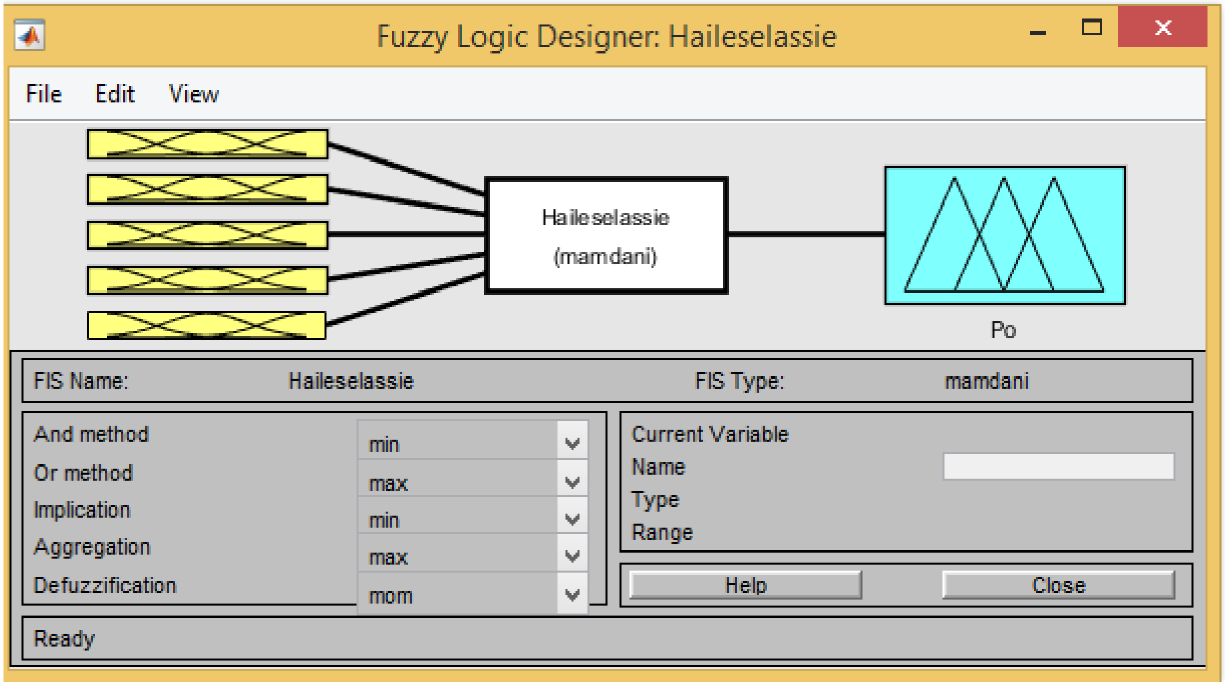

Figure 4. 8 MATLAB implementation of the Fuzzy logic control system

4.5.1 Member Functions

4.5.1.1 Membership Function of Demand Power, P_d

The demand power is one of the input linguistic variables having three linguistic variables called **Low** (0 7.5 7.5 17.5), **Medium** (10 20 30), and **High** (22 30 40 40). (*figure-4.9*)

4.5.1.2 Membership Function of Main Power, M_p

Commercial main AC power is the second input linguistic variable having Two linguistic values called **OFF** (0 2 2 4), and **ON** (2.5 5 40 40). (*figure-4.10*)

4.5.1.3 Membership Function of Solar Power, S_p

Solar power, Sp is the third linguistic variable having three linguistic values called **Low** (0 3 3 8.5), **Medium** (5 10.5 16), and **High** (12 16.5 22 22). (*figure-4.11*)

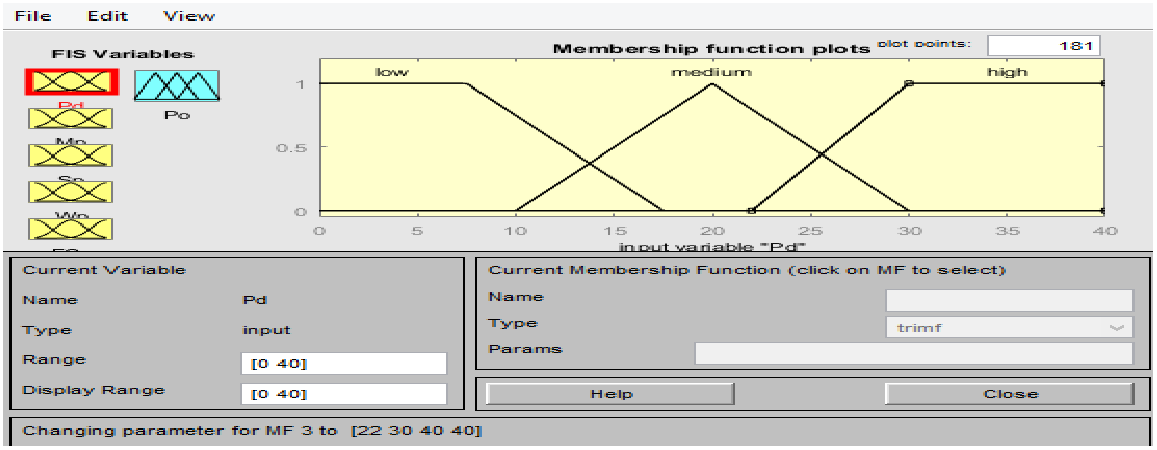

Figure 4. 9 Membership Function of Demand Power, P_d

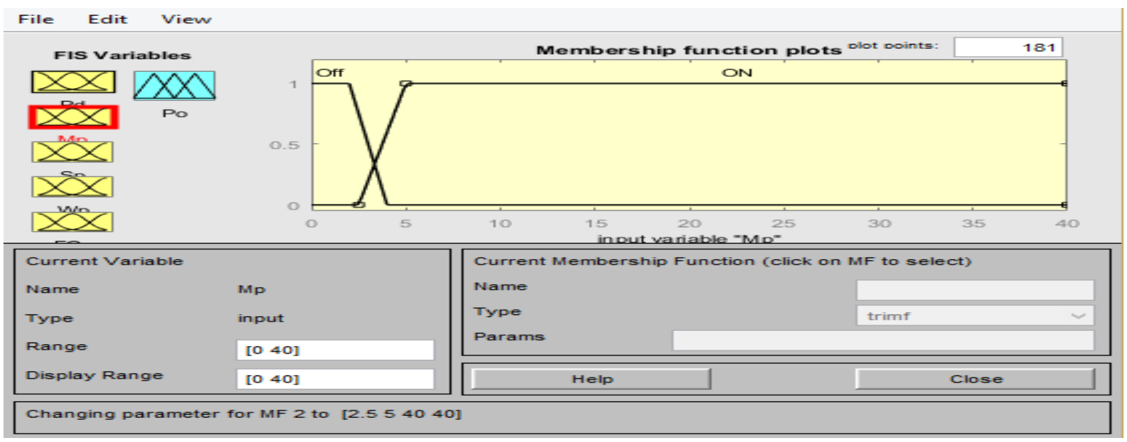

Figure 4. 10 Membership Function of Main Power, M_p

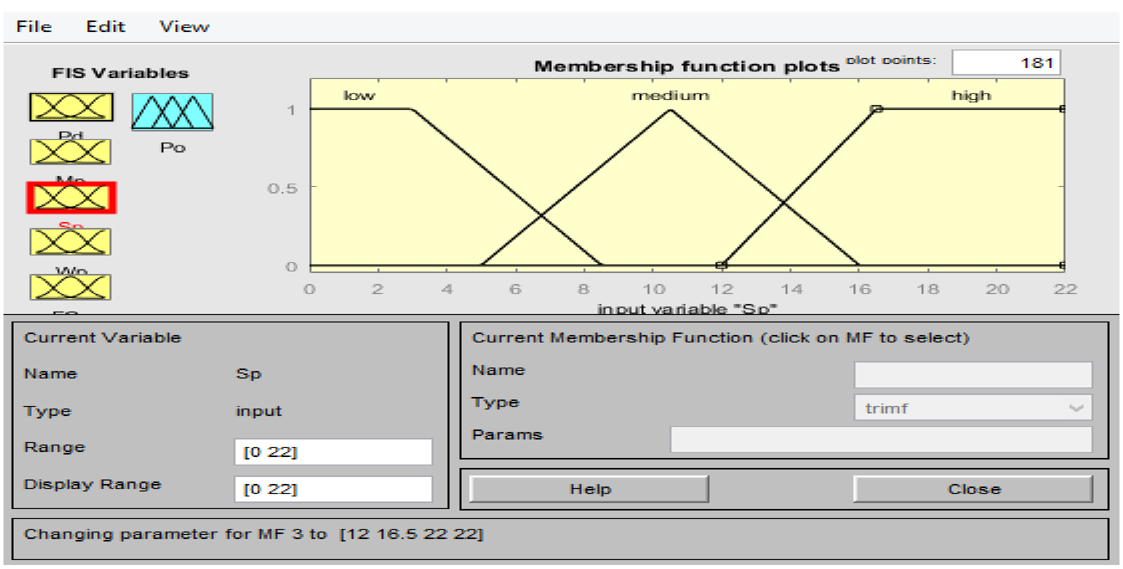

Figure 4. 11 Membership Function of Solar Power, S_p

4.5.1.4 Membership Function of Wind Power, W_P

Wind power, Wp is the fourth linguistic variable having three linguistic values called **Low** (0 1.5 1.5 3.5), **Medium** (1.75 4.25 6.75), and **High** (5 7 9 9). (*figure-4.12*)

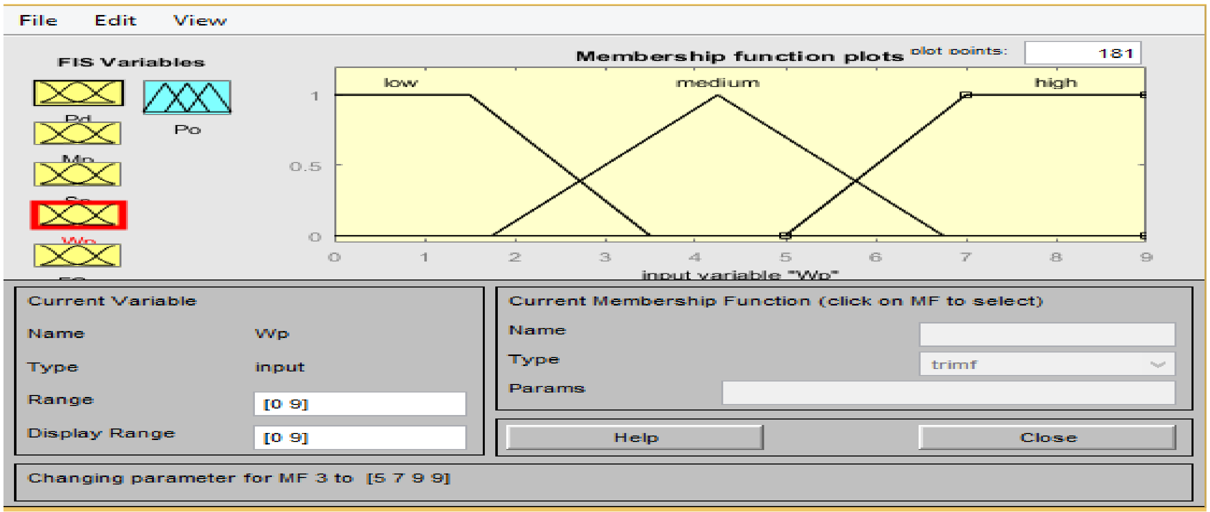

Figure 4. 12 Membership Function of Wind Power, W_p

4.5.1.5 Membership Function of Fuel cell, FC_P

Fuel cell power, FC_p is the fifth linguistic variable having three linguistic values called **Low** (0 2.5 2.5 6), **Medium** (2.75 6.5 10.5), and **High** (8 11.5 14.5 14.5). (*figure-4.13*)

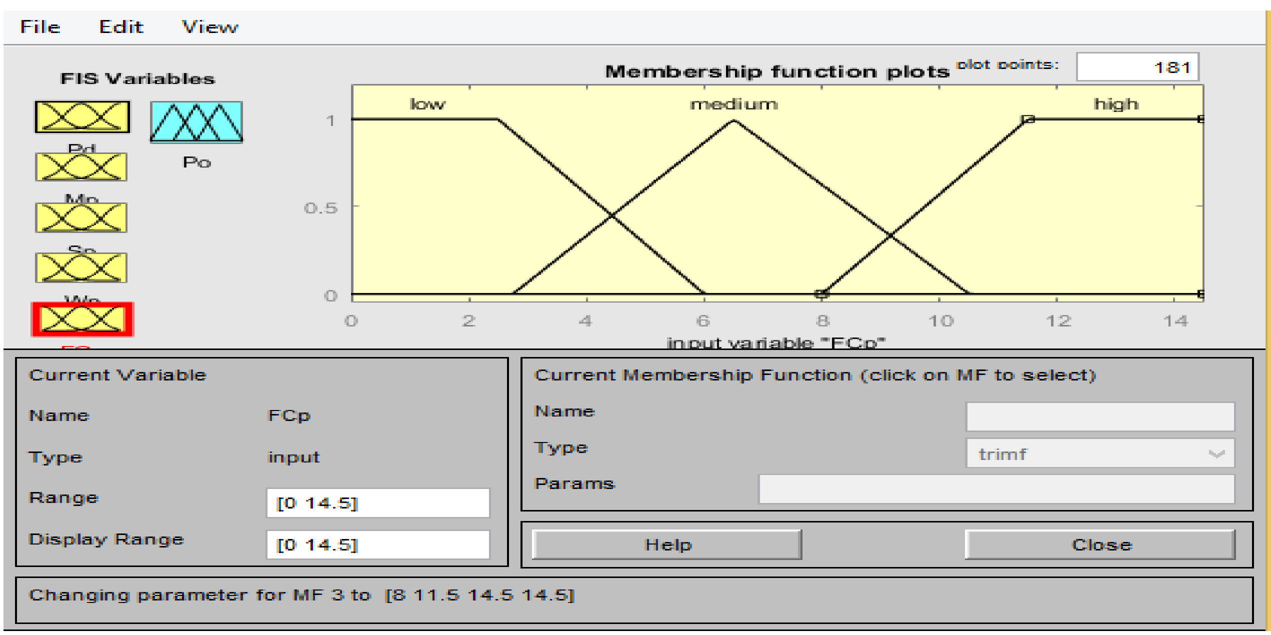

Figure 4. 13 Membership Function of Fuel Cell Power, FC_p

4.5.1.6 Membership Function of output power, P_o

The output power has Five linguistic values called Sp only (-6 0 6 12), Sp + Wp (10 15 20), Sp + FCp (15 22.5 30), Sp + Wp + FCp (25 32 39), Mp only (35 37.5 40 40). (*figure-4.14*)

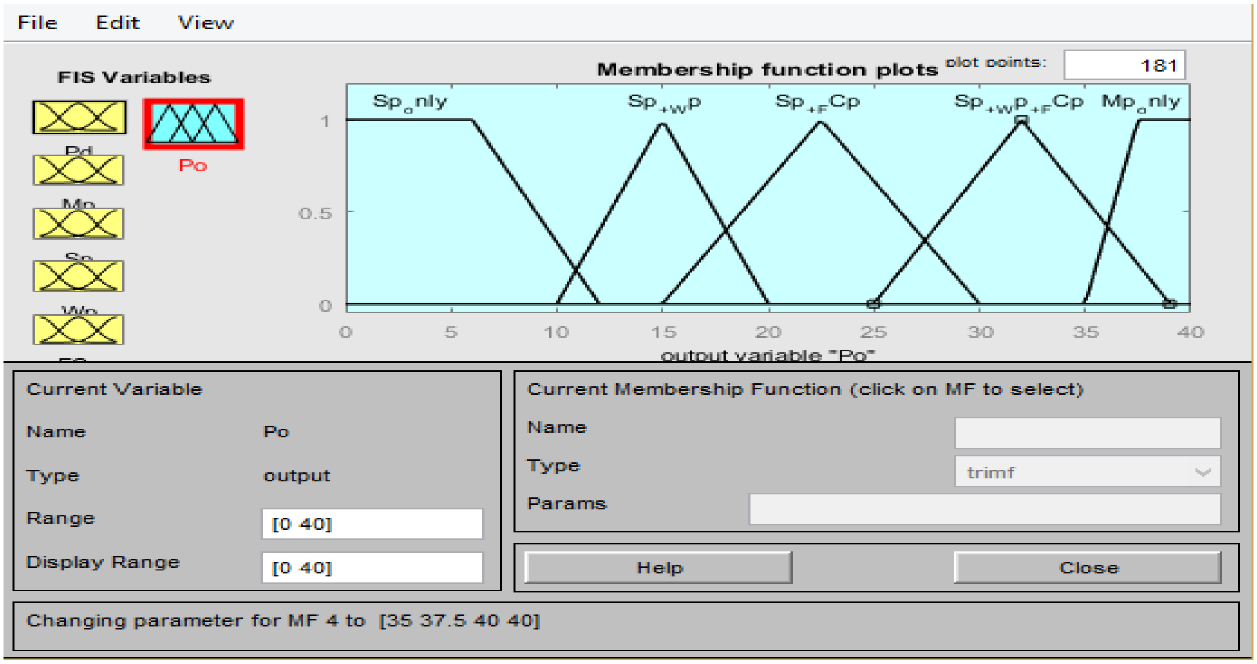

Figure 4. 14 Membership Function of Output Power, P_o

4.5.2 Modelling of Fuzzy Logic Control Rules

There are 130 IF…. THEN rules, and the overall system model is operated in accordance these rules, written in the rule editor.

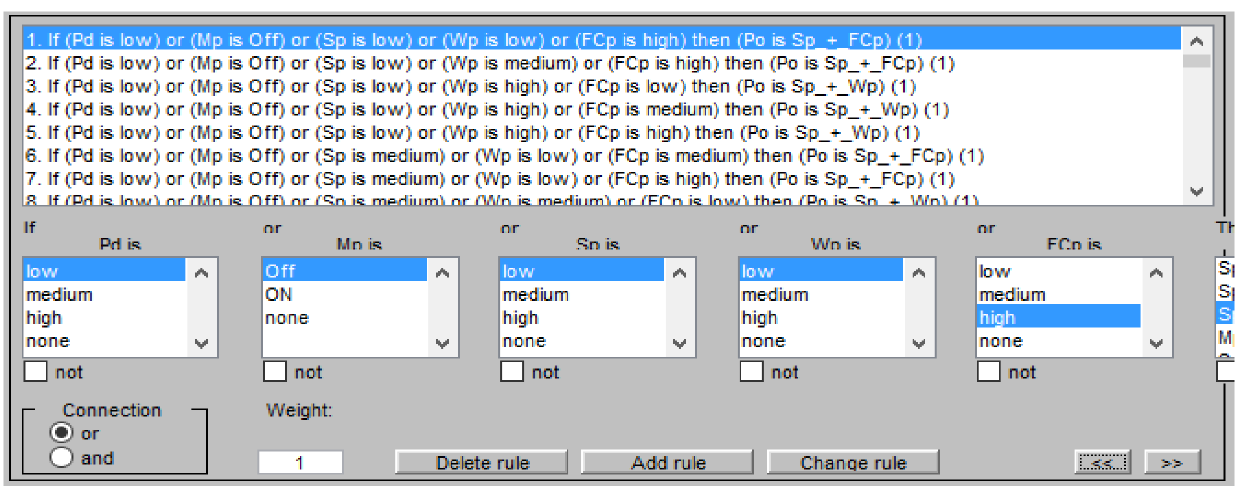

Figure 4. 15 Fuzzy logic rule editor view

In Matlab there is an opportunity to view if the system is operating in accordance the written rules, and below a typical example is given by deliberately making all the three renewable energy resources, namely solar power, wind power, and Fuel cell power, zero; and according to this typical example, the decision is to supply the demand power which is around 38.3KW from the commercial main power, and the output power is also 38.4KW, which shows the fuzzy rule is correctly working for this typical case.

Figure 4. 16 Fuzzy logic rule viewer when commercial power is available

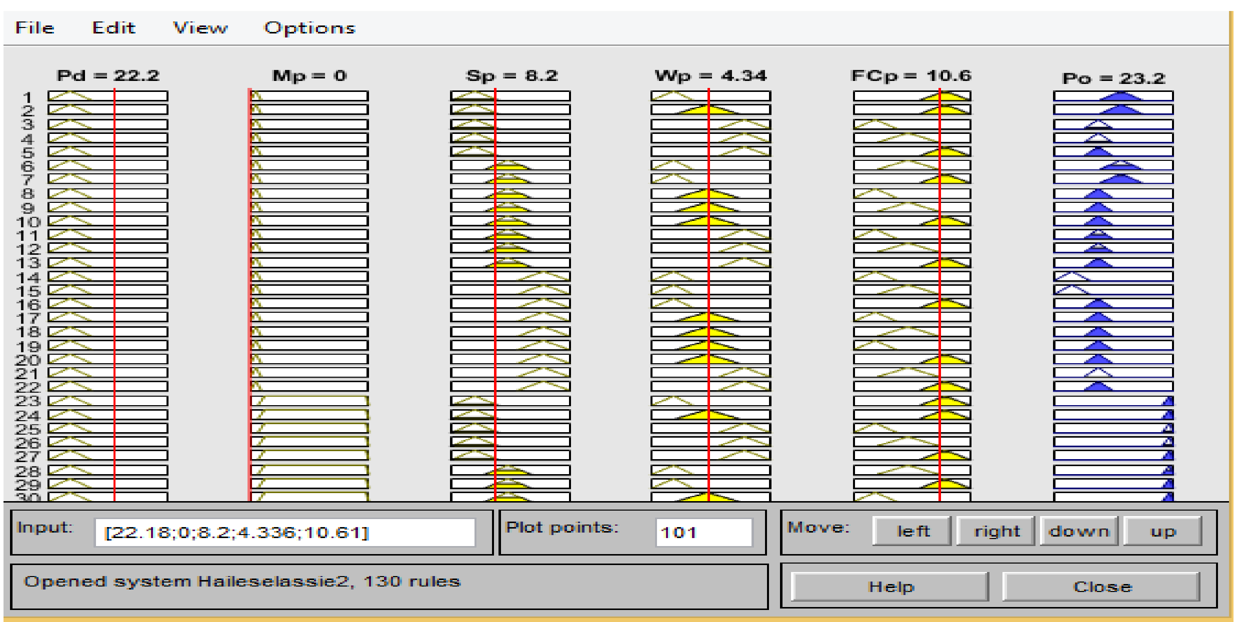

Figure 4. 17 Fuzzy logic rule viewer when commercial power is unavailable

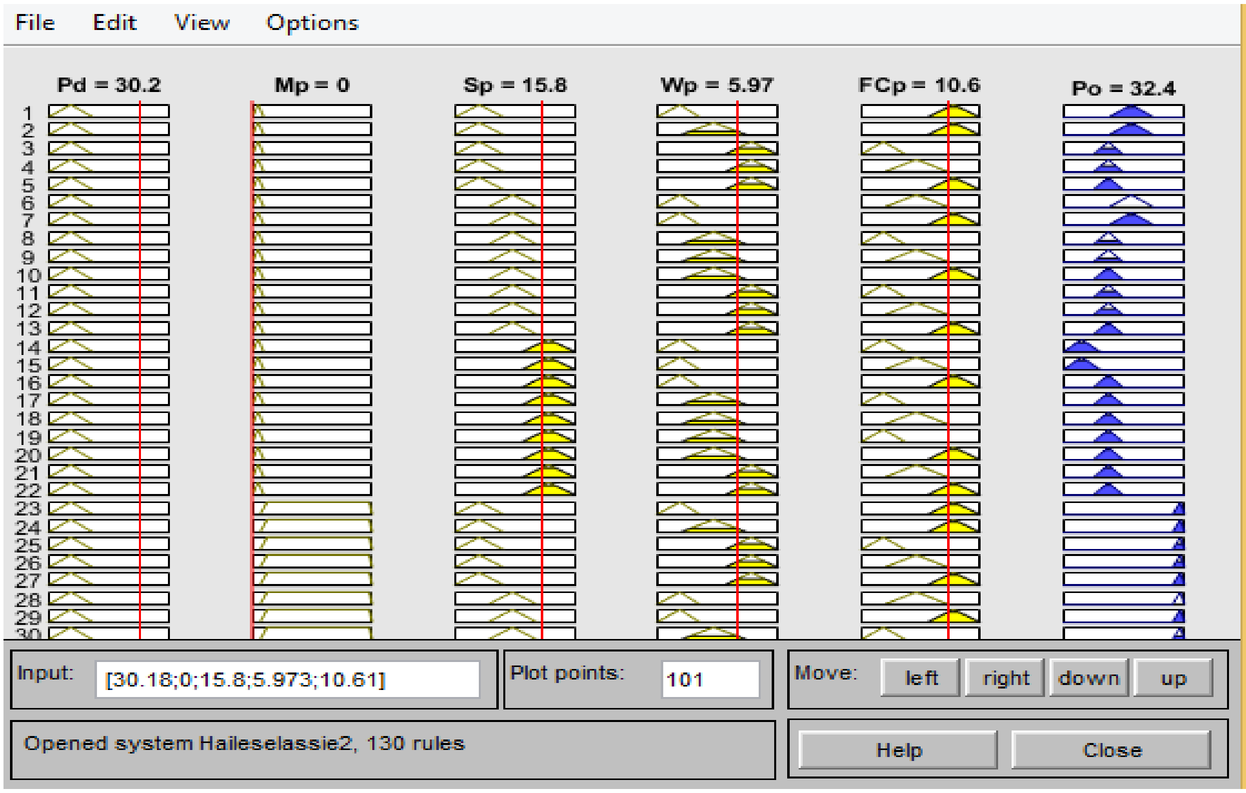

Figure 4. 18 Fuzzy logic rule viewer when commercial power is unavailable under variable load

4.6 OVERALL SYSTEM MODEL

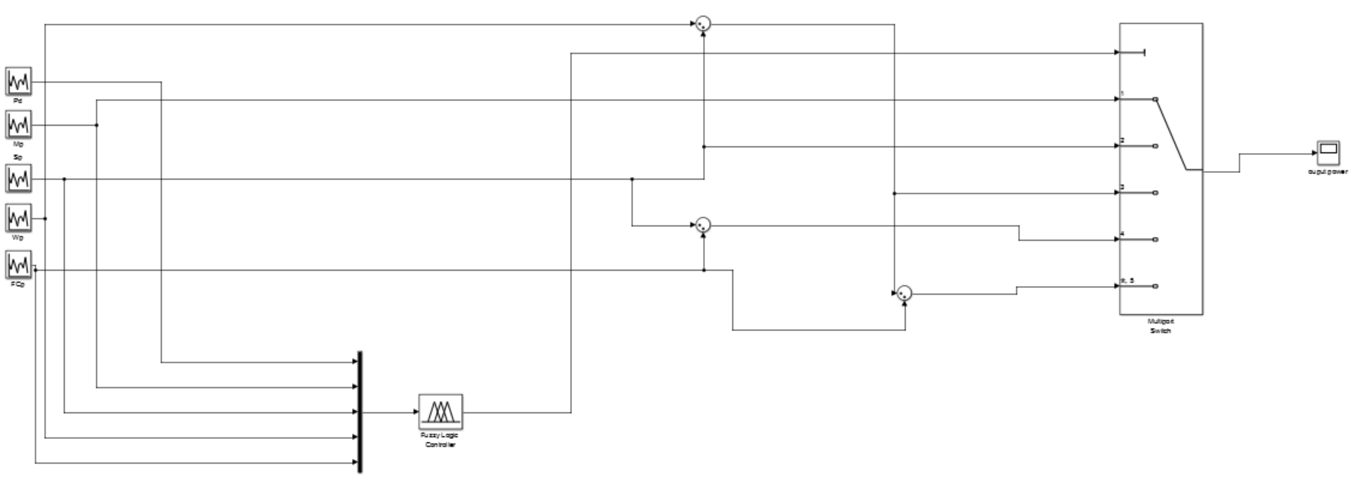

Figure 4. 19 SIMULINK® Realization of the overall system model

Because of the intermittent nature of renewable energy resources, all these input sources will vary from time to time, and in order to check if the controller notices this variation, and making a correct final decision to the multiport switch, a Gaussian random number generator is selected as an input for all these five variables (demand power, commercial main power, solar power, wind power, and fuel cell power), and different cases are taken to check the functionality of this intelligent controller, which are given below.

CASE STUDY ONE: If Demand power (Pd) is 11Kw, Main power (Mp) is OFF, Solar power (Sp) is 9Kw, Wind power (Wp) is 2.5KW, and Fuel cell Power (FCp) is 2Kw then the result of the fuzzy logic controller is given in the figure below.

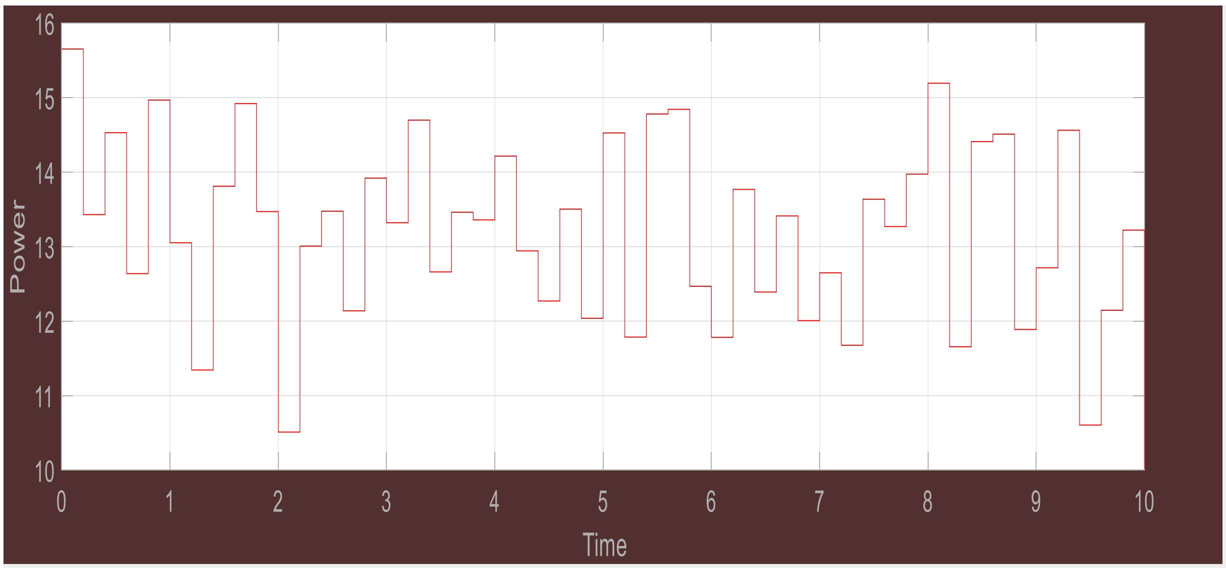

Figure 4. 20 Fuzzy logic controller output for Case-1

CASE STUDY TWO: IF for example Demand power (Pd) is 21 Kw, Main Power (Mp) is OF, Solar power (Sp) is 13KW, Wind Power (Wp) is 4Kw, and Fuel Cell power (FCp) is 6Kw then the output of the fuzzy logic controller is given in the figure shown below.

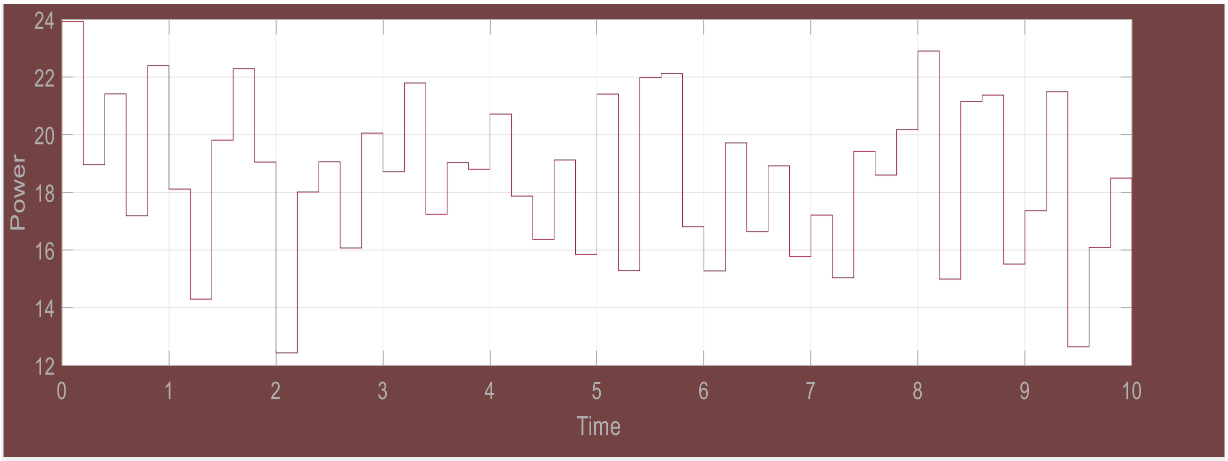

Figure 4. 21 Fuzzy logic controller output for Case-2

CASE STUDY THREE: IF demand power (Pd) is 32Kw, Main power (Mp) is OFF, solar power is 16kW, Wind power (Wp) is 7Kw, Fuel Cell power is (FCp) is 11Kw then the output of the fuzzy logic controller is shown in the figure below.

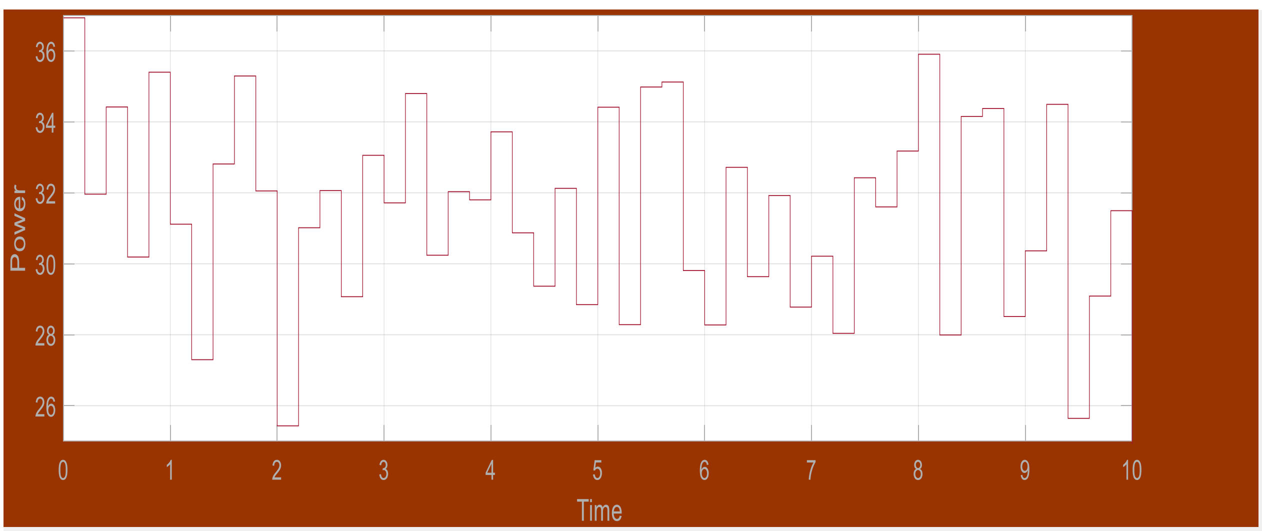

Figure 4. 22 Fuzzy logic controller output for Case-3

CHAPTER 5
CONCLUSSIONS, RECOMMENDATIONS AND FUTURE WORK

5.1 CONCLUSIONS

In this study a fuzzy logic controller for a hybrid distributed generation of solar/wind and fuel cell technology power system is implemented for Yekatit 12 referral hospital. This study is conducted in one of the oldest and largest hospitals found in Addis Ababa city, Yekatit 12 referral hospital, and this selected site has latitude of 9.03^0N and longitude of 38.74^0E with an elevation of 2355 meters.

Due to some technological difficulties in our country the standard measured wind speed data (wind speed at 10m height) is not available, in such circumstances it is also possible to record data at a height of 2 meters and make mathematical approximation at any required height. The wind speed recorded data for the selected or proposed site is measured at 2m height every 15 minutes for five years (2012-2016) is collected from National Metrology of Ethiopia (NME) found in Addis Ababa, also using the latitude and longitude of the selected site a wind speed data at a height of 10m is recorded from NASA, and mathematically comparing these two data the wind speed has an approximately similar values. The monthly average wind speed data of the site is greater than 5m/s, and a small wind turbine with power rating of 150W is used.

In this work the number of sunshine hours data is recorded every day using the sunshine hour recorder for four consecutive years (2012-2015) is collected. Using the linear Angstrom correlation model, the monthly mean daily solar radiation is predicted using the measured sunshine hours per day and this is compared with the monthly mean daily solar radiation data collected from NASA.

Correctly analyzing the load demand or profile is an important step in designing Energy generation hybrid system. Nature of operation of loads and behavior of consumers are the parameters that determine the load profile. It was very difficult to analyze the load demand profile for Yekatit 12 referral hospital because there is has not fixed formula to calculate the loads (varying from hour to hour), thus some of the loads are estimated by asking from staff members and the members of the operation and maintenance team of the hospital. The total electric consumption of the surgery, Neonatology, Maternity and the Emergency Departments are 201.6Kwh, 241.536Kwh, 45.688Kwh and 24.32Kwh respectively giving a total load of the selected sites of the hospital is about 511 KWh per day. . These load distribution numbers are calculated from the load profile of the hospital, and from this the annual energy demand of the hospital during the day time (06:00-18:00) is around 346.748KWh, similarly the annual energy demand during the night time (18:00-6:00) is around 206.232KWh.

In this paper it is assumed 50% of the power demand which is around 20KW is to be produced from the solar panels, and 20% of the load demand which is around 8KW is to be produced from wind, and the rest 30% of the load demand which is around 12KW is to be produced from the backup Fuel cell Technology during solar power energy shortage seasons.

The hospital doesn't have a large flat area to install the solar panels, the panels are to be installed at different places of the hospital (walk ways and parking areas), and due to this these solar panels will not get the same solar radiation, and to consider this effect some of the solar panels are allowed to receive a solar radiation of 1000 KWh/m^2/day, and some to get a solar radiation of 800 KWh/m^2/day, and some of the solar panels are allowed to receive a solar radiation of 600 KWh/m^2/day.

To use the produced power using the above mentioned three energy resources wisely, fuzzy logic controller is used to make an intelligent decision by sensing the type and amount of resources available, then it selects the appropriate alternative source, and to perform this Fuzzy rule have been written in fuzzy rule editor and each components of the proposed hybrid system has been modeled using Matlab/Simulink.

Generally it is possible to use combined distributed generation system of solar/wind, and fuel cell controlled via fuzzy logic controller to make an intelligent decision of determining the load demand, determining the availability of the renewable energy sources, and to determine the availability of the main commercial AC power, and finally make a decision of switching the multi-port switch.

5.2 RECOMMENDATION

Most of the time data handling in our country is very weak, this makes finding relevant data very difficult. So I recommend the concerned governmental body to give a due attention for such research works. It is known Ethiopia has huge renewable energy (Photovoltaic, Geothermal, Wind Energy, Biomass and Micro-Hydro) resources and if these resources are effectively used by using an intelligent controllers, the livelihood of its population can be improved, anybody who is interested in such works can use one of the different intelligent controllers and can contribute his/her own contribution in improving intelligent energy control mechanisms.

5.3 FUTURE WORK

In this work the hybrid combination of solar/wind, and fuel cell are implemented as a backup system to the main commercial AC power, Different combination of the available energy resources can be used as a future work.

This work focuses on a hospital found in Addis Ababa, and if we really need to start the efficient utilization of renewable energy resources, we should start it on schools and hospitals, and someone who is interested in energy efficient utilization technologies can design his/her own system model for any remote area site, and apply different type of intelligent energy control system.

REFERENCES

[1]. T Ajay Sharma, Anand Singh, Manish Khemariya, March 2013, HOMER Optimization based solar; Wind Energy and Diesel Generator based hybrid system.

[2]. M.Seidizadeh. and A.Rezazadeh, 2007, Comparison between Batteries and fuel cells for Photovoltaic system backup.

[3]. Melaku.M, 2014, Fuzzy logic controller based hybrid renewable power generation for Barsoma village.

[4]. J.P.Sharma, Oct, 2015, A Standalone Hybrid Energy system modelling for Academic institution.

[5]. Lovisa Bergman and Amanda Enocksson, Design of PV system with variations of hybrid system at Addis Ababa institute of Technology.

[6]. Adisu Teshale, 2012, Modelling and simulation of fuzzy logic based hybrid power for irrigation system in case of wonji-shoa villages.

[7]. Mona.Eskandar, Thanaa F.El-shatter and Mohsen T. El-Hagry, 2002[7], Energy flow and management of hybrid Wind/PV and Fuel cell generation system.

[8]. Punyashree Pattanayak, 2015 [8, Overcome of Energy crisis using hybrid Renewable Energy resources in India: HOMER Application**.**

[9]. J.M.Yang, K.W.E.Cheng, J.Wu,P.Dong, and B.Wong, 1999,The study of Energy Management System Based-on fuzzy control for Distributed Hybrid Wind and solar Power System.

[10]. Martin Galad, Pavol Spanik, 2014, Design of Photovoltaic solar Cell Module for Stand-alone Renewable System.

[11]. Balachander.K, Kuppusamy.S, and P.Vijaykumar, 2012, Comparative Study of Hybrid Photovoltaic-Fuel cell system/ Hybrid Wind-Fuel cell system for smart grid Distributed Generation System.

[12]. Pooja Sharma, Siddhartha P Duttaguta, Vivek Agarwal, 2009, Characterization and Modelling of Flexible Photovoltaic modules for portable power Applications.

[13]. Marco Liserre, Thilo Sauter, and John Y. Hung, March 2010, Future Energy systems by Integrating Renewable Energy sources into the smart power Grid through Industrial Electronics.

[14]. R.K.Behl, R.N.Chhibar, S.Jain, V.P.Bahl, N.El Bassam, 2013, Renewable Energy Sources and Their Applications.

[15]. Bureau of Energy Efficiency, Application of Non-Conventional and Renewable Energy Resources.

[16]. Eric W.Brown, 1988, an Introduction to Solar Energy.

[17]. Sisay Fitwi, 2014, Feasibility Study of Standalone PV/Wind and Biogas Hybrid System for Rural Electrification (A Case Study of Midrwa Community in Adigrat District).

[18]. Mukund.R Patel, Ph.D., P.E.1999, Wind and Solar Power Systems.

[19]. Tom Markvart and Luis Castaner, 2012, Principles of solar Cell Operation.

[20]. Leonardo Giorgi and Fabio Leccese, 2013, Fuel Cells: Technologies and Applications.

[21]. Chris Rayment and Scott Sherwin, May 2, 2003, Introduction to Fuel Cell Technology.

[22]. Getachew Bekele, Gelma Boneya, 2011, Design of a Photovoltaic- Wind Hybrid Power Generation System for Ethiopia Remote Area.

[23]. Frances Drake and Yacob Mulugeta, 21 May 1996, Assessment of Solar and Wind Energy Resource in Ethiopia. I. Solar Energy.

[24]. Introduction to Fuzzy logic using Matlab, 2007, S.N .Sivanadam, S.Sumathi and S.N Deepa

[25]. Yalemzerf Getnet, May 30, 2017 Design and simulation of Fuzzy logic based frequency controller for standalone micro hydro power plant,

APPENDIX

APPENDIX I:

Transfer Characteristics of Selected Solar Panels

```
close all;
clear all;
clc;
T=298;
Tr=298;
S=[1000 800 600 400 200];
ki=0.00023;
% Iscr=3.0;
Iscr=5.14;
Irr=0.000021;
k=1.38065*10^(-23);
q=1.6022*10^(-19);
a=2.15;
Eg=1.166;
%Np=7;
%Ns=27;
% Ipmax=4.95;
% Vpmax=17.2;
Np=7;
Ns=1;
Vo=[0:1:25];
for i=1:5
    Iph=(Iscr+ki*(T-Tr))*(S(i)/1000);
    Irs=Irr*((T/Tr)^3)*exp(q*Eg/(k*a)*((1/Tr)-(1/T)));
    Io=Np*Iph-Np*Irs*(exp(q/(k*T*a)*Vo./Ns)-1);
    Po=Vo.*Io;

    figure(1)
    plot(Vo,Io);
    axis([0 25 0 105]);
    xlabel('Voltage in volt');
    ylabel('Current in amp');
   hold on;
     figure(2)
    plot(Vo,Po);
    axis([0 25 0 2000]);
    xlabel('Voltage in volt');
    ylabel('Power in watt');
    hold on;
    figure(3)
    plot(Io,Po);
    axis([0 105 0 2000]);
    xlabel('Current in amp');
    ylabel('Power in watt');
  hold on;
end
```

Even at a solar irradiance of around 600 $KWh/m^2/day$, the output of seven solar panels connected in parallel delivers an, and a DC voltage of around 22.2 volts with a current of around 35 ampere.

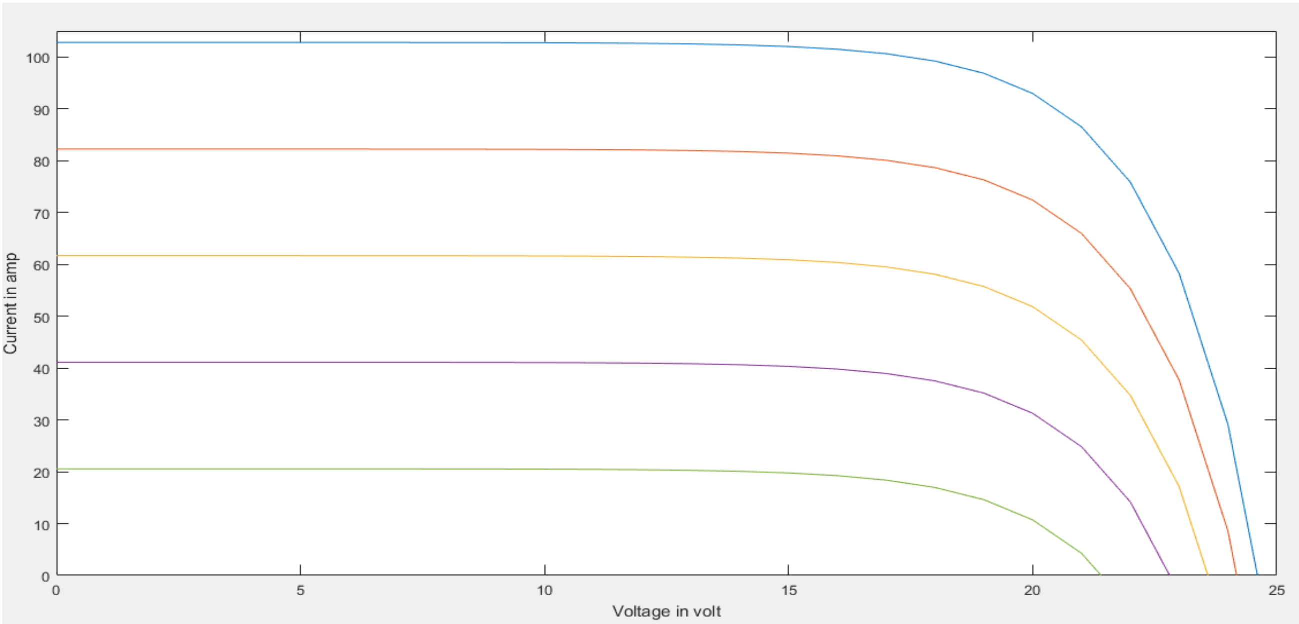

Figure: Appendix-I: 1 Voltage v Current Simulation Result

When we consider all the 27 solar panels connected in series, a total DC voltage of 600 volts, and an output power of close to 810W

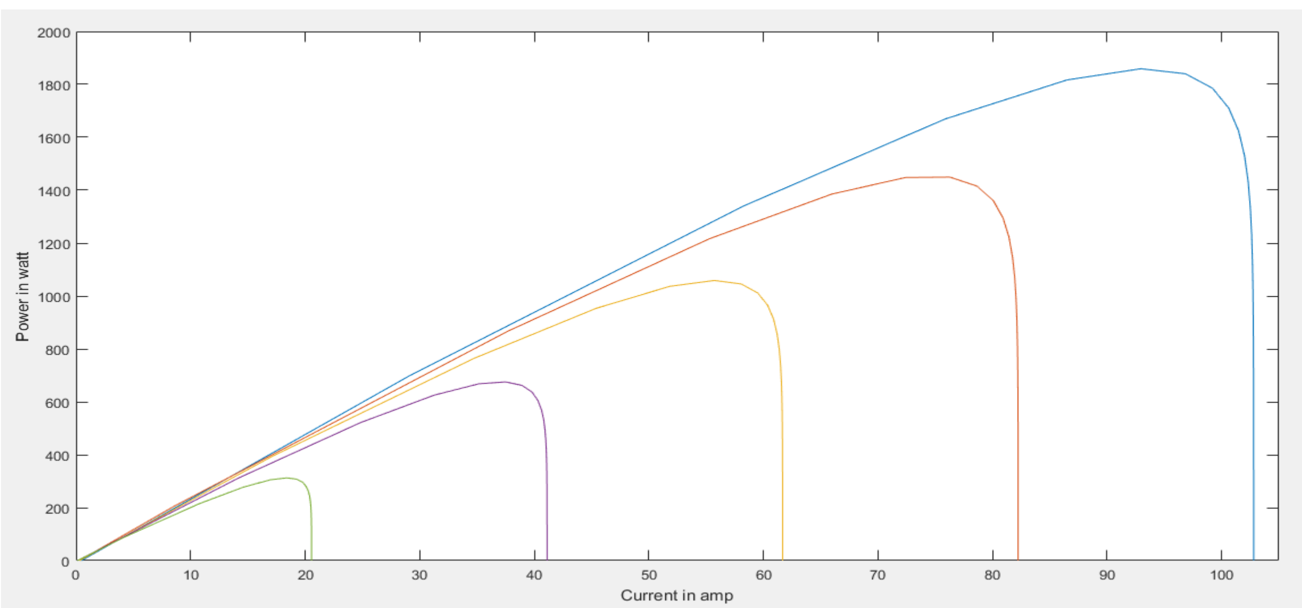

Figure: Appendix-I: 2 Current v Power Simulation Result

This produces a total DC power of around 21KW, which is the proposed and required power to be generated from the installed solar photovoltaic panels.

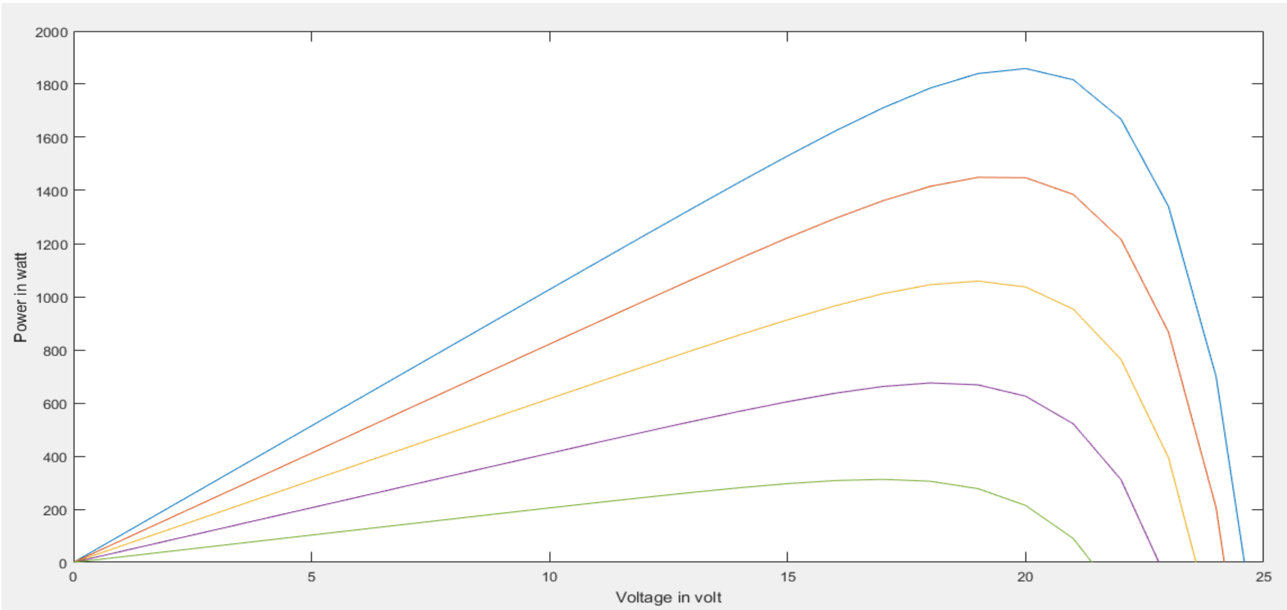

Figure: Appendix-I: 3 Voltage v Power Simulation Result

DECLARATION

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

Haileselassie Gebrehiwot Tesfay ____________________

Name Signature

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Submitted in: September 2018.

This thesis has been submitted for examination with my approval as a university advisor.

Dr. Getachew Bekele ____________________

Name Signature