Design, Analysis and Modeling Of Solar Based-Stand- Alone System

For Rural Electrification

Case Study on Hanchebi Village

Melkamu Sisay

A Thesis Submited To

The Departement Of Electrical And Computer Enginnering

Scool Of Electrical Enginnering

Presented In Partially Fullfillment Of The Requirements For The

Degree of Master Science In Electrical Power and Control

Enginnering(power enginnering)

Office of Graduate Studies

Adama Science and Technology University

June ,2023

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DECLARATION

I hereby declare that this Master Thesis entitled “Design, Analysis and Modeling of Solar-Based Stand-Alone System for Rural electrification (A case study on Hanchebi village) ” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

Melkamu Sisay	_______________	____________
Name of student	signature	date

RECOMENDATION

I. The advisors of this thesis, hereby certify that I have read the revised version of the thesis entitled" **Design, Analysis and Modeling of Solar-Based Stand-Alone System for Rural Electrification (A case study on hanchebi village)** prepared under my guidance by **melkamu sisay jebo** submitted in partial fulfillment of the requirements for the degree of master science in power engineering, therefore ,I recommended the submission of revised version of the thesis to the department following the application procedures

Tafesse Asirat	______________	______________
Major Advisors	Signature	Date

APPROVAL SHETS

We, the undersigned, members of the Board of Examiners of the thesis by melkamu sisay have read and evaluated the thesis entitled “Design, Analysis and Modeling of Solar-Based Stand-Alone System for Rural electrification (A case study on hanchebi village) ” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in power engineering.

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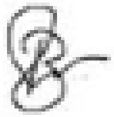
Dr. C S Reddy		
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Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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LIST OF ACRONYMS AND ABBREVIATION

AC	Alternating current
AD	Daily Autonomy
BC	Battery Capacity
BESS	Battery energy storage system
Ah	Ampere hour
DC	Direct current
EREDPC	Ethiopian Rural Energy Development and Promotion Center
FLC	Fuzzy Logic Control
GW	Giga watt
IGBT	Insulated gate bipolar transistor
Kwh	Kilo watt hour
MATLAB	Matrix laboratory
MPPT	Maximum power point tracking
Mw	Mega watt
Nm	Number of modules
Nser	Number of necessary series connected module
Pv	Photovoltaic
PWM	Pulse width modulation
Tv	Television
VA	Voltage Ampere
Ddc-link	DC link voltage
Vphase	Rms value of phase voltage
Vmp	PV module at maximum power
VSI	Voltage source inverter

ABSTRACT

One of the best sources of clean, free and readily available renewable energy is solar power. Due to the growing demand for electricity, renewable energy is now the best alternative to electrification, especially for rural areas. This paper Discussed The Design, Analysis and Modeling of Solar-Based Stand-Alone System for Rural electrification (case study on hanchebi village) In SNNPR Region,. The load demand required to electrify the village is 2.3562 MWh per day for 922 households. The sizing of PV, battery and inverter was evaluated based on demand load. Part of the model is a PV module connected to a DC-DC boost converter. A fuzzy logic MPPT algorithm was used to control the output voltage of DC-DC boost converter Applying fuzzy logic MPPT algorithm for the DC-DC Boost converter is 600V with the input voltage 348V at different irradiance and temperature variation and three phase output voltage supplied to the load and current are 380V and 20A respectively. A battery energy storage system "BESS" is integrated into the system to act as a backup and to keep the load powered during the night. In this design system, the inverter is primarily used to power the AC load.. System performance is evaluated and simulations are run in MATLAB/Simulink. Simulation results show that the proposed system can sufficiently meet the energy demand of hanchebi village.

Key Words: Rural Electrification, Off grid PV system, National grids, DC-to –DC Converter, Fuzzy logic, Inverter.

CHAPTER ONE

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Everything around us needs energy. Earth's population is increasing time to time, and this increase is closely related to the amount of energy consumed. All devices and Equipment's of all kinds need some form of energy to work. As fossil fuel reserves are being depleted, it is important to identify viable renewable energy sources that can reduce our dependence on fossil fuels(Khamisani, 2018). Solar energy is one of the main sources of clean, abundant, renewable energy that not only creates an alternative source of energy, but also reduces environmental degradation. Today's society is paying more attention to this kind of clean energy and the transition to electrical energy. This is interesting because it prevents pollution that can occur with other types of energy sources (Umar Abdi, 2019). The Photovoltaic standalone system is gaining its high importance mostly for rural application like pv water pumping, solar lighting, battery charging etc. Considering environmental effects and scarcity of fossil fuel the trend has developed towards the use of more and more renewable energy. The solar energy availability and the zero cost of harvesting this energy in addition to the easy usage and other all are representing the merits of this source of energy compared to others source of energy (Attia & Del Ama Gonzalo, 2019). A solar PV system is considered to be one of the most attractive renewable energy resources due to its provision of sustainable, clean and safe energy. In addition, it can be installed almost anywhere with different capacities and the operating cost of this resource is low (Saleem et al., 2021). Ethiopia is one of the countries gifted with renewable energy resources such as hydro, solar, wind and geothermal. Thus, renewable energy sources are options for off-grid electricity supply in the country (Thesis, 2015 development of hybrid renewable energy system for rural area in ethiopia case in Tulu-Dimtu). As the cost of solar energy is decreasing, photovoltaic power is superior to renewable energy sources and is widely used in many countries. It is believed that developing countries, such as Ethiopia, need adequate energy supplies to solve their people's basic problems, but it is necessary to use various energy options to achieve this. Most of Ethiopian peoples (around 85% of) the population was living in rural areas, mostly in towns and villages, where the connection rate was below 2%.Therefore, Off-grid electrification was the responsibility of Ethiopian Rural Energy Development and Promotion

Center (EREDPC) under the Ministry of Energy and Mines On the other hand, On the other hand, Ethiopia is one of the countries gifted with renewable energy resources such as hydro, solar, wind and geothermal. Therefore, it is technically and economically difficult to meet the power demand in remote areas with lower population densities than in urban areas. Off-grid renewable energy sources are therefore a good option for providing access to electricity to rural populations who live dispersedly and far from the mains grid and lives dispersal(Mokennen Weldegiyorgis et al., 2021).a standalone PV system consists of the transformation of photovoltaic electricity to AC loads available at the consumer's sites. Access to modern energy, particularly in rural and distant places, would considerably contribute to the reduction of poverty, the improvement of healthcare and education, and the facilitation of contemporary information and communication networks. Additionally, it will decrease commuting between cities, the use of fossil fuels, deforestation, and environmental pollution(Attia & Del Ama Gonzalo, 2019). The greatest alternative for off-grid homes is seen to be the generation of electricity using PV cells. However, a number of elements, such as the climate, sunshine, and dust, are limits the production of solar electricity. When there isn't enough sunlight, one solution for supplying energy is to employ batteries as energy-storage systems(Bhatia,nd.).Photovoltaic (PV) systems are growing in popularity and are widely used to convert solar energy for use in electrical power applications. By using sunlight, direct current energy can be generated without polluting the environment. Inverters convert direct current to alternating current and can be used locally or returned to the utility company. The output power of the PV module, which is a nonlinear current source, is affected by the working voltage of the terminals. To improve the efficiency of the PV module, the MPPT must be able to precisely track the operating point where the greatest power is provided, which is continually changing``

1.2 STATEMENTS OF THE PROBLEMS

Millions of people in Africa rely on kerosene lamps and candles to light their homes and burns woods on open fires to cook and heat water. This is dangerous, harmful, polluting and expensive. Access to electrical energy is essential for accelerating economic development through improved health and living standards. However, Ethiopia has long suffered from a electric power crisis. Hanchebi village also one which faces with electric power problems. To reduce these problems there are some alternatives ways are there from alternatives ways the use of Solar system technologies for electricity production is proposed for the population in rural villages of Ethiopia located in SNNPE Region in Gedio zone for Hanchebi village that is far from national electric power grid. As we know the solar PV panels are produce variable DC voltage. So, to produce the regulated DC voltage DC-DC boost converter with Fuzzy based MPPT controller and VSI is proposed in this thesis to supply demand AC load

1.3 GENERAL AND SPECIFIC OBJECTIVES

1.3.1 GENERAL OBJECTIVES

The general objectives of this study is to Design, Analysis and Modeling of Solar-Based Stand-Alone System for Rural electrification (case study on hanchebi village)

1.3.2 SPECIFIC OBJECTIVES

- Study the load demand of the village
- To Design PV system based on village demand load
- To design DC-to –DC converter
- To design fuzzy logic controller based MPPT
- Model overall system with matlab simulik

1.4 SIGNIFICANCE OF THE STUDY

The solar energy availability and the zero cost of harvesting this energy in addition to the easy usage more advantage of compared with others source of energy and solve the problems of electricity of hanichebi village that far away from main national electric power grid.1.5

1.5 SCOPE OF THE STUDY

The scope of this work is the design and simulation of a DC-DC boost converter with fuzzy-based MPPT, BESS, and VSI control approaches using MATLAB, as described in the objectives of the thesis of the work.

1.6 THESIS OUTLINES

This thesis is organized into five chapters as follows.

The First Chapter is about the Introduction

The Second Chapter Presented Theoretical Background and Literature Review

The Third Chapter Presented metrology, Data Collection and Analysis

The Fourth Chapter discussed with Simulation Result and Discussion

The Fifth Chapter Presented the Research Conclusions and Recommendations.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Theoretical Back ground.

Renewable energy research is currently one of the popular topics among scientists, with the aim of effectively and efficiently using available energy sources and preventing environmental degradation from their use. To facilitate the transition from fossil fuels to other sustainable energy sources, power generation from renewable sources, especially solar, wind, hydropower and biomass, is expected to become an even more important research topic in the future. The need for this transition means that energy prices are rising at alarming rates around the world today, which cripple the global economy of the developed world and hinder the efforts of developing countries to achieve their goals of reducing acute poverty, this is particularly obvious. (Thesis, 2015 development of hybrid renewable energy system for rural area in ethiopia case in Tulu-Dimtu)

2.2 Standalone Photovoltaic System Components

2.2.1 Photovoltaic cell

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current. However a photovoltaic cell is different from a photodiode. In a photodiode light falls on n channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased

2.2.2 PV Cells, Modules and Arrays

The basic building blocks of PV construction include cells, modules and arrays. Individual PV cells are connected into modules (called "PV modules") to generate higher current, and modules are connected into arrays ("PV arrays"). Depending on the latest requirements and voltage requirements, PV generators are connected in different ways either series or parallel. PV cells or modules are usually connected in series to generate voltage, but strings of PV cells or modules can also be connected in parallel to generate current.

(Yasin, 2018)

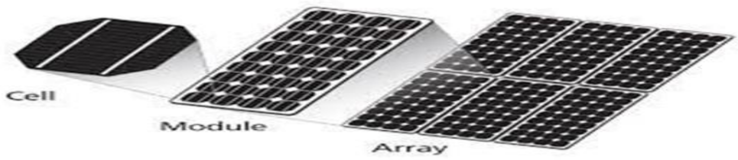


Figure 2.1 Pv Cells, Modules and arrays(Yasin, 2018)

2.2.3 PV modeling

A PV array consists of several photovoltaic cells in series and parallel connections. Series Connections are responsible for increasing the voltage of the module whereas the parallel Connection is responsible for increasing the current in the array. Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

2.2.4 Solar energy

We receive energy from the sun primarily in the form of heat and light. There are mainly two types of photovoltaic systems, as shown in Figure 2.1. A solar thermal system stores heat to heat water and a photovoltaic power generation system converts sunlight directly into electricity.

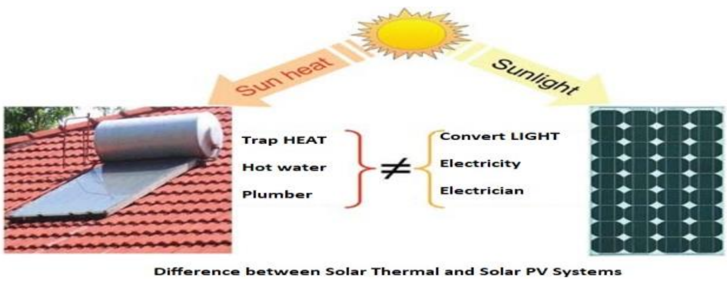


Figure 2.2 Solar Thermal and Solar PV system(Bhatia, n.d.)

The word photovoltaic comes from “photo,” meaning light, and “voltaic,” which refers to producing electricity. And that's exactly what photovoltaic systems do turn light into electricity! Direct or diffuse light (usually sunlight) shining on the solar cells induces the photovoltaic effect, generating DC electric power. This DC power can be used, stored in a battery system, or fed into an inverter that converts DC into alternating current “AC”, so that it can feed into one of the building’s AC distribution boards (“ACDB”) without affecting the quality of power supply(Bhatia, n.d.)

2.2.5 PV Technology

The basic unit of a photovoltaic system is the photovoltaic cell. Photovoltaic (PV) cells are made of at least two layers of semiconducting material, usually silicon, doped with special additives. One layer has a positive charge, the other negative. Light falling on the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates.

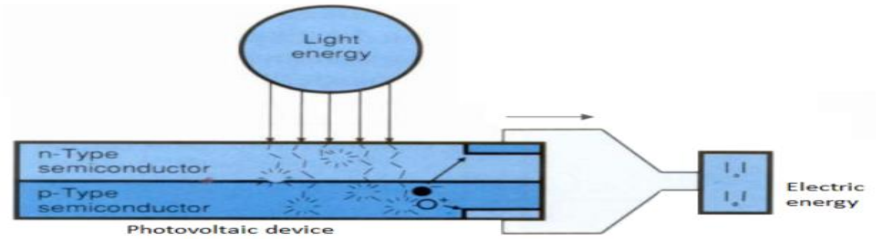


Figure 2.3 photovoltaic device(Bhatia, n.d.)

Note that PV cell is just a converter, changing light energy into electricity. It is not a storage device, like a battery(Bhatia, n.d.)

2.2.6 Types of PV module

Modules can be classified according to cell type as mono crystalline, poly crystalline and

Amorphous. The three types of photovoltaic cells made from silicon are:

- Mono-crystalline Silicon – also known as single-crystal silicon
- Poly-crystalline Silicon – also known as multi-crystal silicon
- Amorphous Silicon

2.2.6.1 Mono crystalline

In order to produce this type of cell, used silicon must be extremely pure which means it is the most expensive type of solar cell. However, they are the most efficient type of PV panels .their performance is somewhat better in low light conditions. They are usually blue-grey in color and have a fairly uniform consistency(Bhatia, n.d.)

Figure 2.4 Mono crystalline modules(Bhatia, n.d.)

2.2.6.2 Polycrystalline

Polycrystalline (or multi-crystalline) silicon produces the next most efficient type of PV cell and is the most popular choice as it provides an excellent balance of performance and economy. Recent improvements in polycrystalline panel technology are bringing these modules closer to monocrystalline in size, efficiency and heat toleranc characteristics(Bhatia, n.d.)

Figure 2.5 polycrystalline PV panel(Bhatia, n.d.)

2.2.6.3 Amorphous

Amorphous (or thin-film) silicon uses the least amount of silicon and also produces the least efficient PV cells. This means thin film system take up more area than the other two which is an important factor to consider in relation to possible future upgrdes(Bhatia, n.d.)

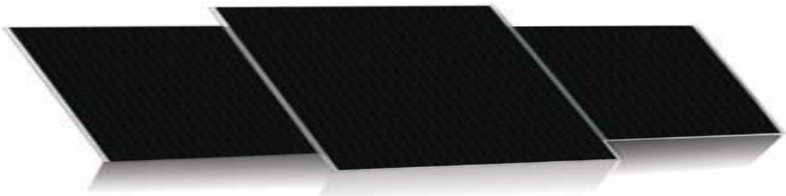


Figure 2.6 Amorphous PV panel(Bhatia, n.d.)

Factors that affect the performance of the solar module are

- Load resistance
- Sunlight intensity
- Cell temperature
- Shading

Load resistance – when the loads appropriately match with a module V-I curve, the module will operate at the maximum point that results in the highest possible efficiency.

Radiation –solar radiation directly proportional to the power output from the module.

Cells temperature – an increase in temperature from the standard operating temperature of 250C causes reduction of voltage and module operate less efficiently.

Shading – even partial shading of a solar module influences its characteristics curve and will result in massive output reduction. The shaded cell is considered as load and produces a negative voltage which is equal to the sum of all the open circuit voltages of fully irradiated cells. Thus, the shaded cell produces heat to cause the hot spot effect and the cell will be damaged permanently. It is possible to prevent this effect by wiring a bypass diode in anti-parallel to bypass the cell in the event of shading. The output reduction in the event of shading depends on module wiring (series or parallel). Shading can be caused by dust or any other shadowing effects.

2.2.7 The Electrical Equivalent circuit for PV cell

The level of irradiance (irradiance) on the surface of a PV cell and the ambient temperature have a large effect on current and voltage output. An increase in irradiance leads to an increase in PV output current, while an increase in temperature leads to a decrease in output voltage. A PV generator consists of multiple PV cells connected in parallel and series to produce the required output voltage and current. A diode is placed in parallel with a photocurrent source to form a solar cell. (Suryoatmojo et al., 2022)

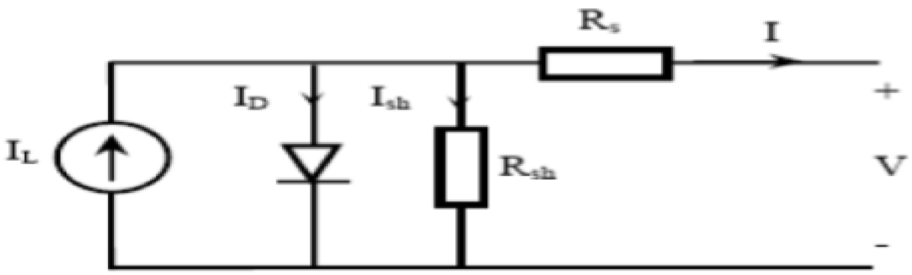


Figure 2.7 The Equivalent Circuit model of a solar cell

2.2.8 Working principles of solar panels

Sun is a powerhouse of energy and this energy moves around in the form of electromagnetic radiations. These radiations are of several types such as light, radio waves, etc. depending upon the wavelength of the radiations emitted. A very less percentage of sun's radiations reach the earth's atmosphere in the form of visible light. Solar cells use this visible light to make electrons. Different wavelength of light is used by different solar cells. Solar cells are made up of semiconductor materials, such as silicon, which is used to produce electricity. The electricity is conducted as a stream of tiny particles called electrons and the stream is called electric current. Two main types of electric currents are; DC (direct current) in which the flow of current is in the same direction while in AC (Alternating current) it may reverse the direction of current. A typical solar cell has two layers of silicon, which is n-type at the top and p-type at the bottom. When sunlight strikes the solar cell, the electrons are absorbed by silicon, they flow between n and p-layers to produce electric current and the current leaves the cell through the metal contact(Mountassir et al., 2022). The electricity generated is of AC type.

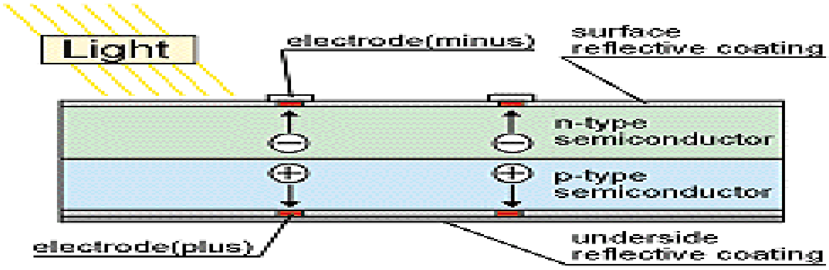


Fig 2.8 the working principles of solar panels(Mountassir et al., 2022)

2.3 DC-DC converter

MPPT has two important components to reach the maximum point, the controller algorithm and the DC-DC converter. In the selection of DC-DC converters must consider several factors including the input and output power flow, cost, flexibility, and response to PV characteristics. At this MPPT will use a Boost Converter. This converter is able to provide higher output voltages compared to the input voltage .In its use the converter uses a switching system to regulate the duty cycle by giving a PWM signal (pulse width modulation).DC-to-DC converter has the benefit of adjusting its output voltage even with fluctuations in the DC input voltage by converting one DC power level to another. This converter can be used in a PV system whose PV output is unreliable and variable. The DC-link capacitor of the inverter improves the DC output voltage stability in a PV system that uses both DC and AC converters, limiting the impact of PV variation on the inverter AC output. These converters may be used in conjunction with DC voltage control and stabilization capabilities, depending on the size or capacity of the PV output voltage, to supply the correct voltage level for the inverter input stage. In order to always ensure the operation point on the maximum power point, or close to it, specific circuit, called Maximum Power Point Tracker (MPPT), is employed. Usually, the MPPT is achieved by interposing a power converter (DC-DC converter) between the PV generator and the load (battery), thus, acting on the converter duty cycle (D) it is possible to guarantee the operation point as being the MPPT . Fig. 4 shows the circuit of the buck converter, whose output voltage (Vb) is less than or equal to the input voltage Vi (PV generator voltage)(Bendib et al., 2014) This converter is stepping-up (Boost), or stepping-down (Buck) the output voltage. Based on pulse width modulation strategy, the duty cycle (D) of the gate drive pulses can be controlled to control the duty time of the connected power electronic switch. The relation of the converter output voltage (Vo) with respect to the converter input voltage (Vin) and the duty cycle *D* of the converter switch is explained in. For stepping down the input voltage, *D* should be less than 0.5, the converter in this condition works as buck converter. For stepping up the input voltage, *D* should be greater than 0.5, and the Converter works as boost converter The boost converter output voltage values can be found by the equation:

$$V_O = V_S \left(\frac{1}{(1-D)}\right)$$

Inductor value by declaring the value of L according to the desired value of ΔI□, the equation is obtained

$$L = \frac{V_S D T}{\Delta I_L} = \frac{V_S D}{\Delta I_L f}$$

Capacitance values can be found by the equation:

$$C = \frac{D}{R\left(\frac{\Delta V_O}{V_O}\right) f}$$

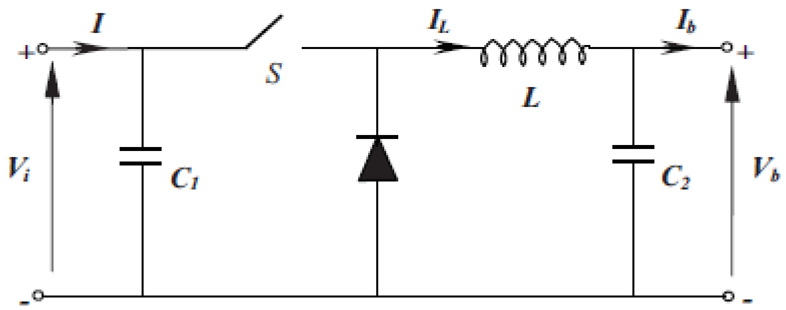


Figure 2.9 DC-DC buck-boost converter circuits

The switch S operates at a high frequency to produce a chopped output voltage. This converter is suitable for use when the array voltage is high and the battery voltage is low. The power flow is controlled by adjusting the on/off duty cycle of the switching. The average output voltage is given by equation

2.4 Maximum power point tracking (MPPT)

Making renewable energy technology has increased rapidly in recent years which are to meet the world's increasing electricity needs. Therefore, almost all countries try to implement energy saving programs, namely by using renewable energy; one example is the use of solar energy. To apply it into an electrical energy, solar energy is processed using a tool that is photovoltaic (PV). However, the efficiency generated from PV is still very low at 18% - 20% and is strongly influenced by irradiation and ambient temperature. This is because PV is a non –liner energy source. Therefore we need a method so that the power generated by PV is always maximal or at the MPP (Maximum Power Point) point(Suryoatmojo et al., 2022)

2.4.1 MPPT Controller Methods

The DC-DC converter in the PV system divides the load from the generator operating point (voltage and current), and it is arranged by an online search algorithm for the maximum power point, which is known as the Maximum Power Point Tracking (MPPT). Most energy tracking systems have claimed efficiencies of more than 90%, which makes their usage highly attractive for both medium- to high-power and low-power PV systems. The most well-known MPPT techniques or algorithms can roughly be divided into two categories: traditional techniques like the Incremental Conductance (IC) method, Perturbation and Observation (P&O) method, and Ripple Correlation Control (RCC) method, and evolving techniques like fuzzy logic control (FLC) based MPPT method, neural network (ANN), and sliding mode control (SMC) algorithms. On the other hand, these approaches have drawbacks such difficulty, high cost, complexity, and instability. The study's findings demonstrated that FLC offers good performance in both the steady-state and dynamic response when compared (Baramadeh et al., 2021)to other approaches. The FLC approach has an excellent performance in the transient state and a weak fluctuation in the steady state. Because FLC is reliable, relatively simple to construct, and does not require knowledge of the precise PV model, it is suitable for achieving MPPT for PV systems. FLC is more stable and suited for non-linear regulation, which is a desirable need for extending battery life Therefore, FLC is used in this study to monitor the MPPT of a PV module.

2.5. MPPT USING FUZZY LOGIC CONTROLLER

The maximum power point monitoring devices are used by the dc to dc converters to indemnity the output voltage of the solar panel in order to maintain the voltage at the value that maximizes the output power. The conceptual fuzzy MPP controller calculates the power from the equation ($P = V \times I$) to extract the controller inputs with voltage after measuring the voltage and current at the solar panel output. The waveform of the duty cycle of the PWM used to toggle the dc to dc converter is represented by the fuzzy controller’s wavy output .The concept principal of MPPT Fuzzy Logic Controller as follows. The output power of PV is examined by the FLC in each sample (Time_k) and then defines the change in power with respect to voltage (dp/dv). If this value (dp/dv) is big ger than zero, the controller modifies the pulse width modulation (PWM) duty cycle to increase the voltage until the power is maximum or the value (dp/dv) = 0, if this value is lower than zero the controller changes the PWM service cycle to reduce the voltage until the power is maximum and so on. FLC has two inputs that are: error and change of error, as well as an output feeding the modulation of pulse width to control the DC-DC converter. The input signals depend on the instantaneous power and output voltage values which in turn effected by ambient atmospheric like radiation and temperature. The two FLC input variables error (E(k)) and change of error (ΔE(k)) at sampled times k are calculated by

$$\Delta E(k) = E(k) - E(k-1) \quad E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)}$$

where P(k) and V(k) are the instant power and voltage respectively of the PV generator. The input E(k) point to whether the load running point in moment k is to the left or right of power-voltage characteristics maximum power point for the PV module, whereas the input ΔE(k) specifies the trend of movement of that point. Mamdani process of FLC for the MPPT, is utilized to perform the fuzzy inference. Fuzzification, inference engine, and defuzzification are the three essential components for FLC(Baramadeh et al., 2021)

These are 1. Fuzzification

2. Inference engine

3. Defuzzification

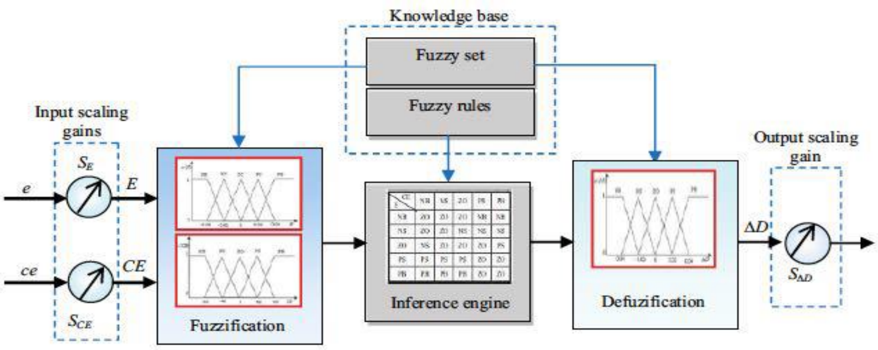


Figure 2.10 Structure of fuzzy logic controller(Sasi, 2017)

2.5.1 Fuzzification

During fuzzification, numerical input variables are converted into linguistic variable based on a membership function. For this MPPT, the actual voltage and current of PV module measured continuously and the power can be calculated as P=VxI. The control is determined based on satisfaction of two proposed input control variable, namely the error E (which represents the slope of P-V characteristic) and change of error CE at the instant sampling k. The variable E and CE are exprexed as follows

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

$$\Delta E(k) = E(k) - E(k-1)$$

where P(k) is the power and V(k) is voltage of PV module. The change in duty ratio (ΔD) of the DC-DC Converter is used as the output of the controller. Therefore, the control is done by changing this duty ratio according to the slope E(k) in order to track the operation point to the optimal point where the slope is zero. the input variables of the fuzzy controller (E, CE) are converted to the linguistic variables such as PB (positive big), PS (positive small), ZO (zero), NS (negative small), and NB (negative big) using basic fuzzy subset. Figure 8 shows the membership grades of five basic fuzzy subsets for input and output variables(Samosir & Gusmedi, n.d.)

2.5.2 Inference engine

The inference engine applies a rule to the fuzzy input to determine the fuzzy output. Therefore, before the rule can be evaluated, the real input value must be fuzzified to obtain an appropriate linguistic value. the fuzzy controller rule table, where all the matrix entries are fuzzy sets of the error (E), the change of error (CE) and the change of duty ratio (ΔD) to converter. These rules are employed to control the DC-DC converter so that the MPPT of the PV module is reached. The main idea of the rules are to bring the operation point of PV module to the MPP by increasing or decreasing the duty ratio of DC-DC Converter depending on the position of the operation point from the MPP(Samosir & Gusmedi, n.d.)

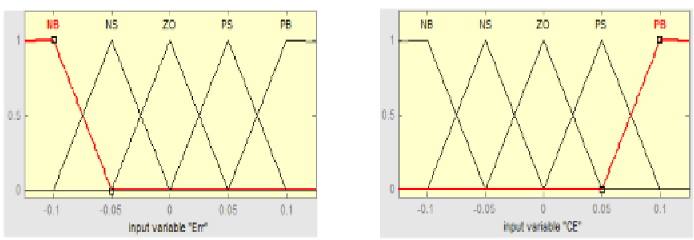


Figure 2.11 Membership function a) input E, b) input CE and

2.5.3 Deffuzzification

Since the DC-DC converter require a precise control signal D at its entry, it is necessary to transform the output of fuzzy controller from fuzzy information into deterministic information. This transformation is called defuzzification. In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable. Defuzzification can be performed normally by two algorithms; Center of Area (COA) and the Max Criterion Method (MCM). The most widely used defuzzification method is the determination of the center of gravity (COA) of the final combined fuzzy set. The final combined fuzzy set is defined by the unification of all outputs of the fuzzy rule set, using the maximum aggregation method. The center of gravity (ΔD) is computed by(Samosir & Gusmedi, n.d.)

2.6 Battery

A battery is a device that stores direct current (DC) electrical strength in electrochemical structure for later use. The quantity of energy that will be saved or delivered from the battery is managed through the battery charge controller. Electrical energy is saved in a battery in the electrochemical structure and is the most extensively used system for electricity shop in a variety of applications(Lachore et al., 2020) In stand-alone photovoltaic systems, the electrical power produced via the PV panel can't usually be used when it is produced. Because the demand for power does no longer usually coincide with its production; electrical storage batteries are in many instances used in PV systems.

The major features of a storage battery in a PV machine are to

✓ To keep electrical energy when it is produced using the PV panel and to provide electricity to electrical masses as wanted or on-demand.

✓ To furnish strength to electrical hundreds at secure voltages and currents, by suppressing or ‘smoothing out ‘transients that may also happen in PV systems.

✓ To supply surge or excessive peak running currents to electrical loads or appliances

Types of Batteries

The most utilized types of batteries are:

- Lead-acid (Pb-acid) Battery
- Nickel-cadmium (NiCd) Battery
- Nickel- metal hydride (NiMH) Battery
- Lithium-ion (Li-ion) Battery

2.6.1 Lead-acid

This is the foremost common type of rechargeable battery utilized nowadays since development, and execution overtaken a cost ratio proportion, indeed though it has the slightest vitality thickness by weight and volume. During discharge of lead acidic battery water and lead, sulfate is formed, and this water dilutes the sulfuric acid electrolyte and the specific gravity of the electrolyte decreases with the decreasing state of charge. Additionally, during the charging time, the lead oxide layer is formed at both negative and positive plat at the time of charging(Lachore et al., 2020)

2.6.2 Nickel-cadmium batteries

Nickel-cadmium (Ni-cad) batteries are secondary or rechargeable batteries. It has attractive performance compare to Lead-acid for both standalone and grid-connected solar system the advantage includes long life of battery, very small cost of maintenance, relatively secured from battery excessive discharges, low-temperature capacity retention, and non-critical voltage regulation requirements. The main disadvantage of nickel-cadmium batteries is their high cost and limited availability compared to lead-acid designs(Lachore et al., 2020)

2.6.3 Nickel-Metal Hydride.

The NiMH is an extension of NiCd technology and affords improvement in energy density over that in NiCd. The primary building difference is that the anode is made of a metal hydride this eliminates the environmental worries of cadmium. Another performance enhancement is that it has a negligible memory effect. The NiMH, however, is less capable of turning in high peak power, has a high self-discharge rate, and is inclined to harm due to overcharging. Compared to NiCd, NiMH is highly-priced at present, although the future price is expected to drop significantly. This expectation is primarily based on modern improvement programs targeted for large-scale purposes of this technology in electric vehicles(Lachore et al., 2020)

2.6.4 Lithium-Ion battery

A kind of battery composed of lithium, the lightest metal, and the metal that has the perfect electrochemical potential. However, Lithium is an unstable metal, so Lithium-Ion batteries are made from lithium ions from chemicals. Because of its lightness and excessive energy density, Lithium-Ion batteries are great for transportable devices, such as notebook computers. Besides, Lithium-Ion batteries have no reminiscence influence and do no longer use poisonous metals, such as lead, mercury, or cadmium. The only disbenefit to Lithium-Ion batteries is that they are presently extra luxurious than NiCad and NiMH batteries(Lachore et al., 2020)

2.7 Charge Controller

It is the element to protect the battery towards risking situations as overloads and over-discharge. The battery charge controller works as a voltage regulator. The principal characteristic of a charge controller (CR) is to disconnect the module or array from the battery when the battery is charged to a preset degree and disconnect the load (which is linked to the battery) when the battery is discharged to the preset level. The controller's common efficiencies vary from 95% to 98%. Advanced CR also senses the battery temperature and adjusts the charging contemporary accordingly

2.8 Inverter

The inverter is an electronic device that converts DC voltage into the AC voltage of the required magnitude and frequency. In solar PV applications Inverter are used to electricity the equipment/devices that function from the AC source. To avoid energy loss, inverters are circuits that convert power from a DC source to an AC load as efficiently as possible. They can be categorized according on the number of outputs, the type of inputs, and the sort of modulation they use to achieve energy conversion. Because the load is typically not resistive, inverters are four-quadrant converters with bipolar output voltage and bidirectional output current; however, bi-directionality may also be a desired feature(Castellini, 2019) Depending on the type of supply source and the associated topology of the power circuit, the dc to ac converters, also known as inverters, are classified into two types voltage source inverters (VSIs) and current source inverters (CSIs). Three-phase (VSIs) are categorized as single-phase half and full bridge voltage source inverters. Three-phase VSIs handle medium to high power applications, whereas single-phase VSIs handle low to midrange power applications. These topologies' primary goal is to offer a three-phase voltage source with controllable voltage amplitude, phase, and frequency. In order to produce controllable frequency and ac voltage magnitudes using various pulse width modulation (PWM) strategies, three-phase dc/ac voltage source inverters are widely used in motor drives, active filters, and unified power flow controllers in power systems and uninterrupted power supplies. The six switches on a typical three-phase inverter are switched based on the modulation method. Typically, a diode-bridge rectifier, an LC or C filter, and a utility power supply provide the input direct current (dc). A three-phase, two-level voltage source inverter is the topology that suggests this paper

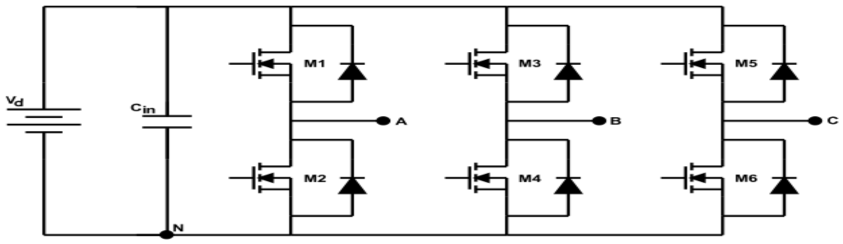


Figure 2.12 Three-phase Full –Bridge Inverter(Castellini, 2019)

2.9 LC Filter

In high-power applications, an effective inverter system generates an output voltage signal that is stable, smooth, and has a low THD value. A high harmonics issue in the three-phase inverter system affects the load system. Filters are therefore needed in the inverter system to reduce the harmonic influence on the loads. Along with the quality of the DC input voltage, the design and performance of the filter also have an impact on the inverter's output quality. Therefore, adding a filter to the inverter system's input side may improve the output quality. In an inverter system application, a higher order LC passive filter may be used to reduce higher harmonics components and system design cost(Attia & Del Ama Gonzalo, 2019)

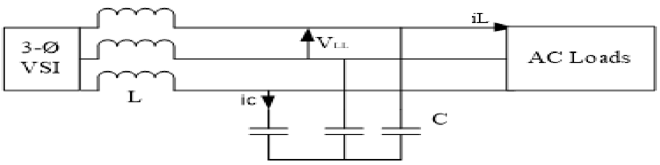


Figure 2.13 LC Filter

2.10 Empirical literature Review

The work of this study is necessary based on what has been already done by other researchers on topics related to the work. So as to look in to the works of these scholars and get necessary and important information related to the topic, different literature will be referred from different available sources such as books, papers, journals, internets, and others

Umar Abdi,2019(Umar Abdi, 2019)"Load Assessments and Design of Solar Power System for Rural Electrification" Discussed the load demand assessment of the rural area and designing of the solar power capacity that can generate the amount of power assessed from the house hold of the village. The methodology of the paper Discussed by knowing the number house hold in the village then and asking their plan what they want to use if they electrified. Then depending on their plan the rating of the electric device rating is identified and the load is determined. Thus, Load demand assessment shows that the amount power required by the village is 25274KWh per day including five years forecast

Khamisani,2018 (Khamisani, 2018) “Design Methodology of Off-Grid PV Solar Powered System (A Case Study of Solar Powered Bus Shelter)” The Paper Discuses on how methodology of off grid systems/stand-alone systems can help to reduce the dependency of grid and allow us to live in self-sufficient manners without reliance on one or more public utilities.

Iqbal &Tariq,2019(Iqbal & Tariq Iqbal, 2019)” Design and Analysis of a Stand-Alone PV System for a Rural House in Pakistan” It Discuses thermal modeling of a typical rural house in Pakistan has been done using BEopt, to determine the hourly load profile. Using the load data, the design of a stand-alone PV system has been completed using HOMER Pro. The designed system consists of a 5.8 kW PV with eight batteries of 12 V, 255 Ah, and a 1.4 kW inverter. The system analyses show that such system can support mainly lighting and appliance load in a rural house. The dynamic model of the designed system has been simulated in MATLAB-Simulink

Diouri et al,2019(Diouri et al., 2019)” Modeling and Design of Single-Phase PV Inverter with MPPT Algorithm Applied to the Boost Converter Using Back-Stepping Control in Standalone Mode”. The World Bank estimated that 22.69% of the world’s rural population was not able to access electricity, since the source of power is often located geographically far from the consumers, requiring expensive distribution of this electricity by using transmission lines. According to the World Bank, 8.26% of the worldwide-transmitted power in lost due to losses associated with transmission lines. Onaway to circumvent these issues is to use distributed power generation units based on photovoltaic systems.

Mandelli et al,2016(Mandelli et al., 2016) “Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review”. Access to electric power supply has always had a significant role in promoting improvements in all the society sectors, nevertheless nowadays 1.3 billion of people still do not have electricity access. Moreover, most of them live in rural areas of developing countries which are often isolated, scattered populated and characterized by poor infrastructure and services. In this situation, the growing consideration towards the target of universal access to energy has emphasized the role of rural electrification, and off-grid small-scale generation represents one of the most appropriate options

Venkateshkumar,n.d(Venkateshkumar, n.d.) PV energy generation is not constant throughout the day due to the changes in weather. The efficiency of power generation is very low (the range of efficiency is only 9–17% in low irradiation regions).Therefore, MPPT technologies have an important role in PV power generation for optimal power generation at various weather conditions. The paper, discussed and analyzed fuzzy logic controller-based MPPT controller for 20 kW PV system.

Oton & Iqbal,n.d(Oton & Iqbal, n.d.)"presented the load analysis and design of stand-alone solar PV system for Uyo High School, Uyo, Akwa Ibom state in Nigeria". The system was designed for a load of 7.5 kW and the proposed system will satisfactorily meet the power needs of the school. The dynamic simulation was carried out in MATLAB/Simulink and the system performance was evaluated.

Adebayo et al.,2019(Adebayo et al., 2019) Discussed to design of solar powered unit for Ilokun Community rural electrification. The sizing of PV array, sizing of the charge controller and sizing of the battery were carried out. The total energy that will be demanded by areas was 78000W. The houses were sectioned into 8 areas and each area has its own PV system and components to avoid total black out in the whole community in case of power failure. This solar rural electrification can be done for a large community, Town, Local Governments and States et

Cho et al.,2019(Cho et al., 2019)Stand Alone Solar PV System with Battery Backup System for Gonpinaing Village, Mandalay Division" It discussed to design calculation of stand- alone solar PV system with battery backup system (60kW).The Paper Discussed the load calculation, solar radiation or sunshine hours and main components of the proposed solar PV system are considered. Moreover, panel size selecting, battery capacity, inverter sizing and charge controller sizing are calculated and chosen. The main aim of this project is to supply the electricity without having national grid.

Ali,2018(Ali, 2018) "Design Considerations of Stand-Alone Solar Photovoltaic Systems" the detailed guidelines and technical considerations needed in the design process of a solar PV system is presented for stand-alone application The technical considerations for assessing the load energy demand on daily basis and sizing of the different components of solar system including PV panels, charge controller, storage batteries, inverter and other appurtenances such as cables etc. required for the design configuration and installation of a solar PV system are given in this work.it Discuses on designing and installing a solar PV power system suitable for stand-alone operation in sustaining the small housing and business communities both in rural and urban areas

Jounal & Vol,n.d(Journal & Vol, n.d.) "Discused on Design of stand-alone solar energy for rural dwellers in Zamfara state, Nigeria" The size of the photovoltaic array depends on the energy required for a rural dweller. Therefore, it takes an organized and technical approach to predict the minimum energy demand of rural inhabitant. The load demand had forecasted; the PV module, DC-DC boost converter, transformer less inverter had designed and simulated using MATLAB/Simulink in this work.

CHAPTER THREE

3. METHODOLOGY AND DATA COLLECTION

3.1 INTRODUCTION

In this chapter assessment and analysis of the collected data is presented and based on that the design of the Renewable solar system for Electrification of selected site is accomplished. the complete schematic diagram of the proposed system is shown in the figure 3.1. It consists of the following main stages before getting the pure AC powers for the purpose of high energy efficiency of PV system. All these components are presented together with their mathematical models in detail in this chapter.

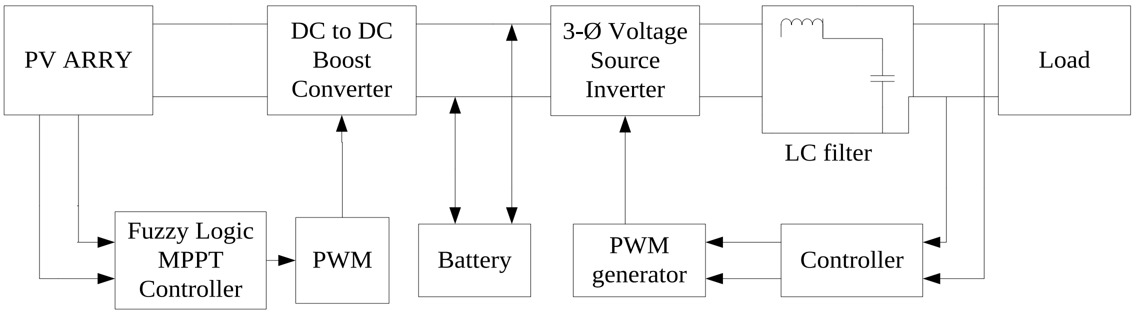


Figure 3.1 General Block Diagram of proposed systems

3.2 DESCRPTION OF CASE STUDY AREA

Hanichebi are kebele which is located in Gedio Zone in Kochore Woreda , with a latitude of 6'00.00N, longitude38'14 60,00'E and off with an elevation of 2531 meter. The total population of Hanichebi kebele is 4517 with a total householder of 922 and the total power demand is required for hanchebi kebele are 2.35625MWh/day

3.3 PV ARRAY

Our solar panel plates with photovoltaic cells are called a PV array. They absorb solar energy, and photovoltaic activity creates an electron current. They are positioned at a specific angle on the ground outside. The charge controller amplifies this electrical charge. It adjusts the current to the system's specifications before sending it to the storage battery. As most of our household appliances and industrial machinery run on AC, an off-grid converter/inverter is fitted to convert DC into AC because PV cells and dry batteries supply DC current. The load calculation is the first and most important stage. We have to point out each and every load that will be including in the system. We can then estimate missing values by taking their standard value against each appliance

3.4 BOOST CONVERTER

The second block after the PV array is a basic DC-DC converter of type boost that steps up the voltage from low input voltage, coming from the PV array, into high output voltage, going to the input of the inverter. The input of the boost converter is connected to the PV array in order to achieve the MPPT in different atmospheric conditions. Its output is connected to an H-bridge inverter in order to obtain a higher voltage that can be supplied to the AC load without using a transformer(Diouri et al., 2019) For adjusting the duty cycle of the PWM-applied switch on the DC-DC converter, an MPPT technique is established in the FLC block (IGBT).

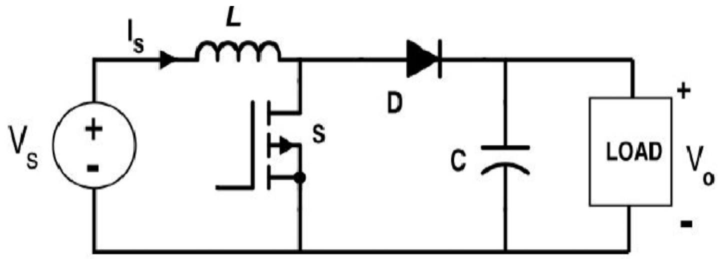


Figure 3.2 DC-DC Boost Converter(Muzaffar & Iqbal, 2020)

3.4.1 Steady State Analysis of dc-dc boost converter

The boost converter's steady state analysis may be completed in two sub-intervals under the assumption of small-ripple approximation. Switch is in the on state and diode is off in the first sub-interval. Switch is in the off state and the diode is on in the second sub-interval. In first sub-interval, circuit becomes as shown in Fig.3.3 the following equations can be derived; thereby, Vd is input dc link voltage, VL is voltage across the inductor, V is boosted output voltage, RC is series capacitor resistance, R is load resistor, Ic is capacitor current and I is input current.

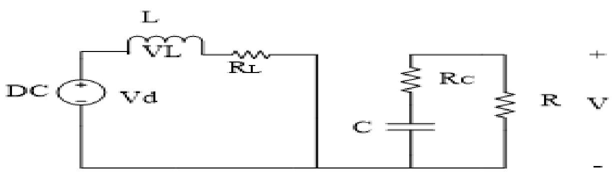


Figure 3.3 Switches on State of Boost Converter

$$V_d = V_L + I_L R_L \text{.......} 3.1$$

$$I_C = -\frac{V_C}{(R+R_C)} \text{.......} 3.2$$

$$V = \frac{R.V_C}{(R+R_C)} \text{.......} 3.3$$

By inserting equation 3.2 into 3.3 we can gate $I_C = -\frac{V}{R}$.................................... 3.4

Circuits can be transformed in to when switch is off position

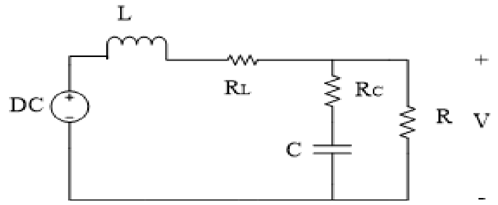


Figure 3.4 switch off position of boost converter

$$V_d = V_L + I.R_L + V_D + V \text{.......} 3.5$$

$$I_C = I - \frac{V}{R} \text{.......} 3.6$$

Inductor voltage is equal to zero in one period as well as capacitor current value. These waveforms

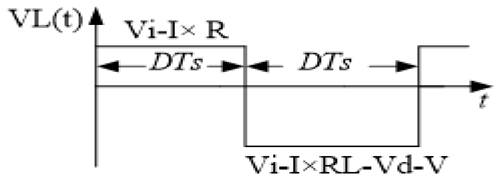


Figure 3.5 Inductor voltage waveform

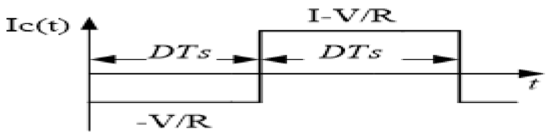


Figure 3.6 Capacitor Curent waveform

$$D.(V_d - I.R_L) + D'.(V_d - I.R_L - V_D - V) = 0 \text{.......} 3.7 .$$

$$D.\left(-\frac{V}{R}\right) + D'.\left(I - \frac{V}{R}\right) \text{.......} 3.8$$

Based on the Eq 3.7 and Eq 3.8 DC equivalent circuits is derived as

$$\frac{\mathrm{V}}{\mathrm{V_d}} = \frac{1}{\mathrm{D'}}..\left(\frac{1}{1+\frac{\mathrm{R_L}}{\mathrm{D'^2.R}}}\right) \ldots\ldots\ldots 3.9$$

3.5 DATA COLLECTION AND ANALYSIS

For the Thesis work to be effectively and efficiently completed, data gathering is a necessary step in the design and optimization of PV systems. This includes the selection of the case study area at which the project will be implemented for future work, load profile analysis for the selected case study area. Analyzing the solar irradiation in the chosen area and assessing the renewable resources that are accessible while considering the topography of the area and the geographical features of that particular place. This paper presents the designing of solar for the village that is no electrified before by utility of the country. This village (Hanichebi village) is found in SNNPE Gedio Zone around 400KM far from Addis Ababa and situated on map latitude of 6’00.00N, longitude38’14 60,00’E

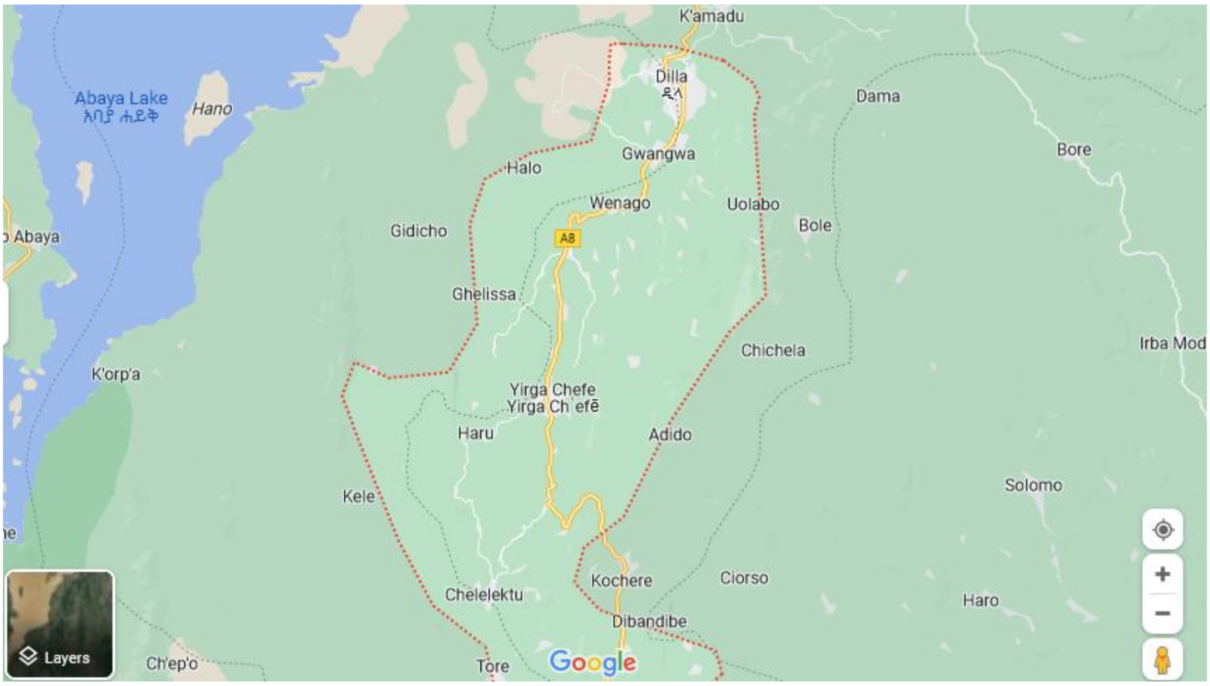


Figure 3.7 Location of village

The number of household living in proposed village is Nine hundred twenty two households. As the village is going to be electrified for the first time the load type considered is domestic load like lighting, Television, Radio, refrigerator, Electric stove and oven, washing machine and Charger. In addition to this one health care center, two public schools and two religion prayer church are there. Thus the total demand for which the system is designed is the sum of individual power consumption.

3.5.1 Average High and Low Temperature in Gedio Zone

Table 3.1 average temperature in Gedio zone

Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Seb	Oct	Nov	Dec
High	80.6	84.2	84.2	80.6	78.8	75.2	71.6	73.4	75.2	75.2	78.8	78.8
Temp	67	70.7	70.7	70	67.1	64.4	62.6	64.4	64.4	64.3	66.1	65.3
Low	53.6	55.4	57.2	57.2	55.4	53.6	53.6	55.4	53.6	53.4	53.4	51.8

3.5.2 Average solar energy in Gedio zone

Table 3.2 Average solar energy around in gedio zone

Monthly	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Seb	Oct	No	dec
Solar energy (kwh)	6.7	7.1	7.1	6.7	6.8	6.1	5.4	5.8	6.5	6.9	6.8	6.6

3.6 Load Estimation

Residential load: is the load that should meet by the energy providing system as it requires immediately; which includes lighting, refrigeration, TV, radio, and others. In load estimation the electricity consumption in each household is considered to be the same and constant throughout the year. The load determination of the village was performed for the total number of population and householder respectively is 4517 and 922. During load estimation, the nature of load has been thoroughly analyzed to come up with sustainable energy demand satisfaction since electric load is varying time to time and seasonal bases. In this energy design system, the selection of appliances was reflected for the low wattage for the affordability of electric energy access.

Deferrable load: is electrical load that must be met within some time period, but the exact timing is not important. Water pumping is a common example. In Hanichebi kebeles almost all are farmer they use a water pump for irrigation purposes. The number of Household living in Hanchebi village is nine hundred twenty-two (922) household. The load type to be considered for the village are domestic load like Lighting, Television, Radio, Refrigerator, Electric stove and Charger, Computer and Grain and grinding mill. In addition to this two public school, one health center and Two Prayer place thus are religious are in the considered in selected site

3.6.1 Home Appliance Load Estimation

Table 3.3 home appliance load and running time of hanchebi village

NO	Appliance device	Rating power(W)	Quantity	Working hours	Power in watts	Energy consumption(wh/day)
1	lighting	18W	1844	4	33192	132768
2	Radio	15W	450	15	6750	101250
3	TV	100W	100	6	10000	60000
4	stove	1500W	100	1	150000	150000
5	Phone charger	7W	900	2	6300	12600
6	Grain and pepper grind mill	2000W	3	2	6000	12000
total					281.24kw	468.61.6kwh/day

3.6.2 Loads in two primary School

Table 3.4 loads in two primary school

No	Appliance device	Rating power(W)	Quantity	Working hours	Power in watts	Energy consumption(wh/day)
1	Lighting	18	20	4	360	1440
2	computer	200	2	4	400	1600
3	printer	350	2	1	700	700
total					1.460kw	3.740kwh/day

3.6.3 Loads in health center (health post)

Table 3.5 loads in health center (health post)

NO	Appliance device	Rating power(W)	Quantity	Working hours	Power in watts	Energy consumption(wh/day)
1	Lighting bulb	18	10	12	180	2160

2	refrigerator	300	1	24	300	7200
3	computer	200	2	8	400	3200
4	television	100	1	8	100	800
total					0.98kw	11.20kwh/day

3.6.4 Load in two prayer place (church)

Table 3.6 Load in two prayer place (church)

No	Appliance device	Rating power(W)	Quantity	Working hours	Power in watts	Energy consumption(wh/day)
1	Lighting bulb	18	12	4	216	864
2	Speakers and Amplifier	700	2	2	1400	2800
	Total				1.616kw	3.664kwh/day

The total energy consumption in one day is the sum of different service site in the village and that is 0.48722M Wh/day and 0.285MWatt without considering operating hours.

3.6.5 The Summary of Load Demand Assessed From the Proposed Village

Table 3.7 the Summary of Load Demand Assessed From the Proposed Village

Energy Consumption Devices	Rating Per Day(KWH/DAY)
Lighting	137.23kwh/day
Radio	101.25kwh/day
Television	60.8kwh/day
Stove	1470kwh/day
Phone charger	12.6kwh/day
Grain and pepper grind mill	90kwh/day

Computer	4.8kwh/day
Printer	0.7kwh/day
Refrigerator	7.2kwh/day
Speaker and Amplifier	2.8kwh/day
TOTAL	1887.38kwh/day or 1.88738Mwh/day

The total load demand of the village is 487.204KWh per day. The solar system is designed by considering this load and forecasting policy of the country. The Government's future plan for the power market sector has been separated into short, medium, and long term plans of 5, 10, and 25 years, respectively, to meet the demand for energy brought on by the national economic growth(Umar Abdi, 2019)

Table 3.8 Data used for forecasting to satisfy the demand of the proposed villag

Current peak load MWh/day	Annual load growth in % (EEP) data	Planning of future load demand in year		
1.8873Mwh/day	5 %	Short term	Medium term	Long term
		5	10	25

As a result, the village's load demand, including the forecast, is determined as follows. Thus, five percent (5%) present load demand is:

$$P_{5\,\%\,of\,load} = 0.05 * \frac{0.487.2MWh}{day} = 0.0243MWh/day$$

The load forecast calculation is Present load plus five percent of the present load

Table 3.9 Load forecast for five year of the proposed village

Base year load Mwh/day	1st year load Mwh/day	2nd year load Mwh/day	3rd year load Mwh/day	4th year load Mwh/day	5th year load Mwh/day

1.885Mwh/ day	1.97925Mwh/ day	2.0735Mwh/ day	2.16775Mwh/ day	2.262Mwh/ day	2.35625Mwh/ day

Therefore, the solar system design should be designed to tolerate the load increment for five years that is up to 2.35625MWh/day. By multiplying the total daily watt-hours of all the appliances by 1.3 (the energy lost in the system), we can calculate the total daily watt-hours that must be supplied by solar PV modules

Total PV panel's energy needed is 2.35625Mwh/day*1.3…………………...3.10

=3.063125Mwh/day

Where,

The value 1.3 represents the scaling factor that is used to with stand the over voltage and surges happen in the system(Ali, 2018)

3.7 Calculation of PV Array Size

The solar system is designed for the worst months which produce minimum solar radiation in the selected village. From the solar radiation the minimum solar radiation is 5.4kwh$/m^2/day$.

3.7.1 Technical specification data (STC) of solar panel

Table's 3.7.1 Technical specification data (STC) of solar panel PowMr 370W Mon crystalline Solar Solar PV module

Model	D-370W-39V
Optimum Operating Voltage (Vmp)	38.67V
Optimum Operating Current (Imp)	9.56A
Open - Circuit Voltage (Voc)	48.09V
Short - Circuit Current (Isc)	10.07A
Maximum Power at STC (Pmax)	370W
Cell Efficiency	18.55%
Operating Module Temperature	-40 °C to +85 °C
Maximum System Voltage	1000VDC
Maximum Series Fuse Rating	20A
Power Tolerance	±5%
Solar Cell	Mono-crystalline

No. of Cells	72 (6 × 12)
Dimensions	1952× 996× 40 mm
Weight	22.0kgs
Front Glass	3.2 mm tempered glass
Frame	Anodized aluminum alloy
Junction Box	IP65 rated
Output Cables	1*4mm2
Connectors	Optional
Nominal Operating Cell Temperature (NOCT)	45±2°C
Temperature Coefficient of Pmax	-0.44 %/°C
Temperature Coefficient of Voc	-0.33 %/°C
Temperature Coefficient of Isc	0.03 %/°C
Cell Efficiency	18.55%

Solar PV specification rating PowMr 370W Mon crystalline Solar Panel 48Voc Solar PV module was chosen for the proposed system

Then the number of PV modules Array required for the system is

N_{module}=total PV panels energy/solar irradiation*max power at STC(Pmax)

$$N_{module} = \frac{3.063125Mwh/day}{5.4kwh/m^2/day*370} = 1026 \text{ PV Module needed}$$

3.8 inverter Sizing

Never be the inverter's input rating fall below the entire wattage of the demand load. The inverter's nominal voltage must match that of the battery. The inverter's input rating has to be 25–30% more than the total wattage of the demand load. The total watt of our appliance is 0.285Mwatt

$$\text{Inverter Size}=\frac{0.285Mw*130}{100} = 0.3705\text{Mwatt}$$

However, there are no inverters available on the market with such a high-power rating. Therefore, in our instance, a 360kw inverter is chosen

The number of necessary series-connected modules per string and parallel strings determined by the DC-DC boost converter input voltage value and the inverter power.

The rated DC input voltage for the boost converter is normally chosen half the output voltage, i.e. the DC-Link voltage. Considering that the output voltage of a string of series connected

PV modules is the sum of the component modules, and also considering the minimum DC-Link voltage for the inverter, one can obtain the number of PV modules connected

in series *NSER* based on(Popa et al., n.d.)

$$N_{ser} = \frac{1}{2}\frac{V_{dc-link}}{V_{MP}} \qquad 3.13$$

WHERE

N_{SER} = number of necessary series connected modules;

$V_{DC-LINK}$ = the DC-Link voltage at the inverter input;

V_{MP}= PV module voltage at maximum power point

It is possible to choose a lower input voltage for the inverter, but as the voltage drops (while maintaining a constant output voltage), a larger current will pass through the DC-DC boost converter. As a result, IGBTs with greater ratings are required. The minimum DC-Link voltage for the inverter can be computed with(Popa et al., n.d.)

$$v_{Dc-link} \geq 2\sqrt{2}.v_{phase} \qquad 3.14$$

WHERE v_{phase} =the RMS value of the phase voltage at inverters output.

$$v_{phase} = \frac{380}{\sqrt{2}} = 219.4v \qquad 3.15$$

$$v_{Dc-link} \geq 2\sqrt{2}.v_{phase} \qquad 3.16$$

$$v_{Dc-link} \geq 2\sqrt{2}.219 = 620.54$$

Hence; the DC-Link must greater than 620.54V and thus 700V of DC-Link voltage are selected. Half of the output of the DC-Link voltage is chosen as the rated DC input voltage for the boost converter

$$v_{pv} = \frac{700}{2} = 350 \qquad 3.17$$

$$n_{ser} = \frac{1}{2} * \frac{700}{38.67} = 9.05 \text{...} 3.18$$

The required number of series PV modules connected in series are nine (9). The maximum power of a series connected PV string:

$$p_{srtring} = p_{ser} * p_{mp} = 9 * 370 = 3330 = 3.33kw \text{................................} 3.19$$

Where p_{ser} is PV module connected in series?

P_{mp} Is the maximum power at STC(Pmax)

Once the number of series connected modules is set, the number of strings in parallel is computed based on the rated power of one inverter. One selected a 360 kW 2-level inverter offered by IGBT manufacturer Semikron. The necessary number of strings in parallel becomes(Popa et al., n.d.)

$$n_{par} = \frac{p_{inv}}{p_{srting}} \text{...} 3.20$$

$$n_{parall} = \frac{360}{3.33} = 108.1$$

Thus, in order to obtain an installed power of 1.885MW, we need a number of inverters *INV* and PV arrays *PV ARRAYS* given by

$$n_{inv} = n_{ARRAYS} = \frac{p_{TOTMAX}}{p_{INV}} = \frac{1.885MW}{360KW} = 5.23 \text{..} 3.21$$

With p_{TOTMAX} =desired installed power for the PV plant

Using the PV plant's design specifications and data from the datasheet, a simulation of a field with PV cells matching to one of the 5 inverters is performed in the MATLAB Simulink module for the proposed thesis.

For the maximum of the 360kw and a worst-case efficiency of 85%, the RMS current through inverter is given by

$$i_{inv\_RMS} = \frac{p_{inv}}{3v_{Phase}} * 0.85 = 464.9A \text{...} 3.22$$

Sizing the PWM coils inductance is done considering a 5% ripple current from the peak value of the injected current, which is:

$$i_{inv\_peak} = i_{inv\_RMS} * \sqrt{2} = 464.9 * \sqrt{2} = 655.4A \ldots\ldots 3.23$$

Therefore; the peak- to- peak value of current ripple is:

$$i_{Ripple\_peak} = 0.05 * i_{inv-peak} \ldots\ldots 3.24$$

0.05*655.4A=32.77A

The PWM coils inductance is calculated with

$$L_{Pwm} = \frac{(\sqrt{3}.v_{DC})}{(12.\delta.f_{com}.i_{Ripple\_peak})} \ldots\ldots 3.25$$

Where,

δ =The Overload Factors

fCOM = the switching frequency of the inverter.

The overload factor δ generated by transients varies within the range (Popa et al., n.d.) 120...180% . One selected a value of 150% for δ and a switching frequency of 10 kHz, considering a compromise between the high cost and bulkiness of the PWM coils for a low switching frequency and the higher losses at a

High switching frequency. Also, a higher switching frequency offers a lower THD for the injected current and PCC voltage

$$l_{Pwm} = \frac{(\sqrt{3}.700)}{(12 * 0.15 * 10000 * 32.78)} = 0.002055HZ$$

The value of the DC-link capacitor was calculated to limit the DC-link voltage ripple to 5% of the DC-Link voltage. For a sinusoidal waveform, the average value of the current I_{AVG} is 63.6% from the peak value or 0.9 from the RMS value

$$i_{AVG} = 0.9 * i_{INV\_RMS} \ldots\ldots 3.26$$

0.9*464.9A=418.4

The peak-to-peak ripple value of the DC-Link voltage is imposed to 5%:

$$V_{RIPPLE\_PEAK} = 0.05 * V_{DC\_LINK} \ldots\ldots 3.27$$

$$0.05*700=35V$$

The capacitor's value C_{DC_LINK} can be calculated with:

$$c_{DC\_LINK} \geq \frac{i_{INV\_AVG}}{2*W*v_{RIPPLE\_PEAK}} \quad \ldots\ldots 3.28$$

$$c_{DC\_LINK} \geq \frac{i_{INV\_AVG}}{2*W*v_{RIPPLE\_PEAK}} \geq \frac{418.4}{2*314*35} \geq 19.03mf$$

Where: W =2pif the angular frequency corresponding to the 50

Hz grid. The rated voltage *VRATED_CDC* is recommended to be at least 20 % higher than the operating volt age;

$$v_{Rated\_\mathrm{CDC}} \geq 120\%*v_{DC\_LINK} \quad \ldots\ldots 3.29$$

$$v_{Rated\_\mathrm{CDC}} \geq 120\%*v_{DC\_LINK} \geq 1.2*700 \geq 840$$

If the efficiency η of the converter is estimated to be 90%.

The duty cycle D_{MAX} at the minimum input voltage V_{MIN} can be computed with:

$$d_{Max} = 1 - \frac{v_{\min*\eta}}{v_{DC\_Link}} \quad \ldots\ldots 3.30$$

$$d_{Max} = 1 - \frac{300*0.9}{700} = 0.6143$$

The maximum current through the IGBT can be computed with:

$$i_{IGBT\_MAX} = 2*i_{OUT\_RMS}*(d_{MAX}+1) \quad \ldots\ldots 3.31$$

$$I_{IGBT\_MAX} = 2*464.9\,\mathrm{A}*1.61 = 1496.9\mathrm{A}$$

Sizing the L_{BOOST} coil inductance is done considering a 5% ripple current from the maximum current through the IGBT. Hence, the peak-to-peak value of current ripple is

$$i_{RIPPLE\_PEAK} = 0.05*i_{IGBT\_MAX} \quad \ldots\ldots 3.32$$

$$i_{RIPPLE\_PEAK} = 0.05*1496.9\,\mathrm{A} = 74.8\mathrm{A}$$

The minimum L_{BOOST} coil inductance is calculated with:

$$l_{BOOST} \geq \frac{v_{MIN*}(v_{DC\_LINK} - v_{MIN})}{i_{RIPPLE\_PEAK*} f_{COM\_BOOST} * v_{DC\_LINK}} \text{ 8.446ηH} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.33$$

$$c_{IN} = \frac{i_O * \text{d}^\wedge 2}{(0.02)*(1-d)*v_{IN}*f_{sw}} \text{ l} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ...3.34$$

$$c_{IN} = \frac{464.9*0.61^\wedge 2}{(0.02)*(1-0.61)*350*10000} = 6.33\text{mf}$$

$$c_{out} \geq \frac{v_O * \text{d}}{\text{r}* f_s * v_O} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ...3.35$$

$$c_{out} \geq \frac{700*0.61}{0.963*10000*700} \geq 5.6mf$$

3.9 Battery Sizing and Selection

To ensure the availability of energy at night and under cloudy conditions, the photovoltaic modules must store energy in some type of storage during the peak sunlight hours. The different types of rechargeable batteries are available in market but the most commonly used type is lead-acid because they are readily available, cost-effective, longevity and more suitable for stand-alone solar electric power systems The capacity of batteries are expressed in ampere-hour (Ah). The various factors are considered during the selection and sizing of batteries or battery bank. These factors include the appliances total load, inverter size and efficiency, days of autonomy, discharge depth and the battery nominal voltage. However, among all factors, the factor of autonomy days is very important one. These days represents the number of cloudy days in a row that might occur and for which the batteries will need to supply energy to the load. Usually, 3 days is considered as a standard for number of autonomy days. Thus, the battery size or capacity should be increased to 1.5-3 times more to make it oversize rather than undersize. The simplest relationship used to determine the size of batteries or battery bank for a certain load demand is as follow(Ali, 2018).

Deep cycle batteries are the type that is often advised. A deep cycle battery is made to be quickly recharged after being rapidly discharged to low energy or to cycle charged and discharged repeatedly every day for years. The battery should have adequate capacity to hold the necessary amount of energy for both the day and the night to obtain the necessary deep-cycle battery ampere-hour capacity

Battery Capacity (Ah) = $\frac{Total\ energy\ demand\ load \times Day\ of\ autonomy}{Battery\ loss \times Depth\ of\ discharge \times Nominal\ voltage}$ ……………...3.36

Where; Battery loss=0.85

Depth of charge= 0.6

Nominal Voltage= 48v

Days of autonomy =1.5

Battery Capacity (Ah) = $\frac{1.885Mw*1.5}{0.85*0.6*48V}$ =115502.5Ah

Autonomy is the number of days that the system need to operate when there is no power produced by PV panel(Shukla et al., 2016)

Number of batteries required = $\frac{required\ battery\ capacity}{selected\ battery\ capacity}$= $\frac{115502.5}{200}$ =570……………..3.37

Then the selected battery should be rated at 200Ah and 12V.

Number of series batteries = $\frac{Nominal\ system\ voltage}{Nominal\ battery\ voltage}$= $\frac{360}{12}$ =30…………………….....3.38

No of parallel batteries = $\frac{Number\ of\ batteries\ required}{Number\ of\ series\ batteries}$= $\frac{577.5}{30}$ =19……………………..3.39

The size of solar batteries can range from less than 100 Ah, to more than 1,000 amp-hours in single battery

3.10 Fuzzy Logic Controller Based MPPT

PV energy generation is not constant throughout the day due to the changes in weather. The efficiency of power generation is very low (the range of efficiency is only 9–17% in low irradiation regions). Therefore, MPPT technologies have an important role in PV power generation for optimal power generation at various weather conditions(Venkateshkumar, n.d.)

The maximum power point monitoring devices are used by the dc to dc converters to indemnity the output voltage of the solar panel in order to maintain the voltage at the value that maximizes the output power. The conceptual fuzzy MPPT controller calculates the power from the equation (P = V × I) to extract the controller inputs with voltage after measuring the voltage and current at the solar panel output. The waveform of the duty cycle of the PWM used to toggle the dc to dc converter is represented by the fuzzy controller's wavy output(Baramadeh et al., 2021) FLC has two inputs that are: error and change of error, as well as an output feeding the modulation of pulse width to control the DC-DC converter. The input signals depend on the instantaneous power and output voltage values which in turn effected by ambient atmospheric like radiation and temperature. The two FLC input variables error (E(k)) and change of error (ΔE(k)) at sampled times k are calculated by

$$E(K) = \frac{p(K) - p(K-1)}{v(K) - v(K-1)} \qquad 3.40$$

$$\Delta E(K) = E(K) - E(K-1) \qquad 3.41$$

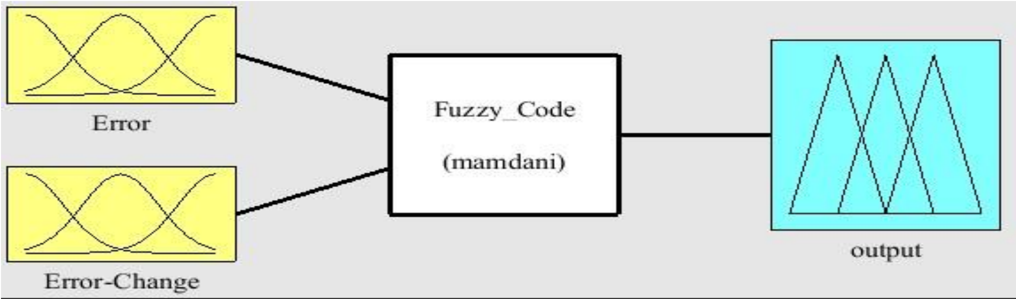


Figure 3.8 FIS diagram of the proposed fuzzy controller

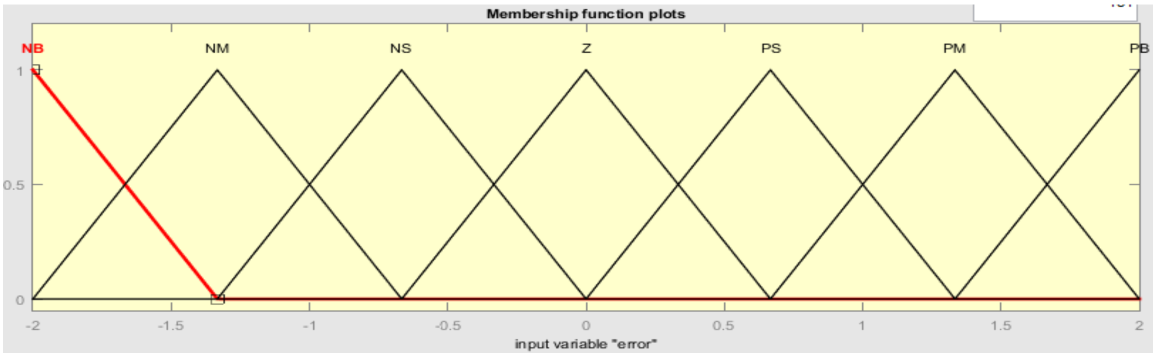


Figure 3.9 Membership functions for input variable (Error).

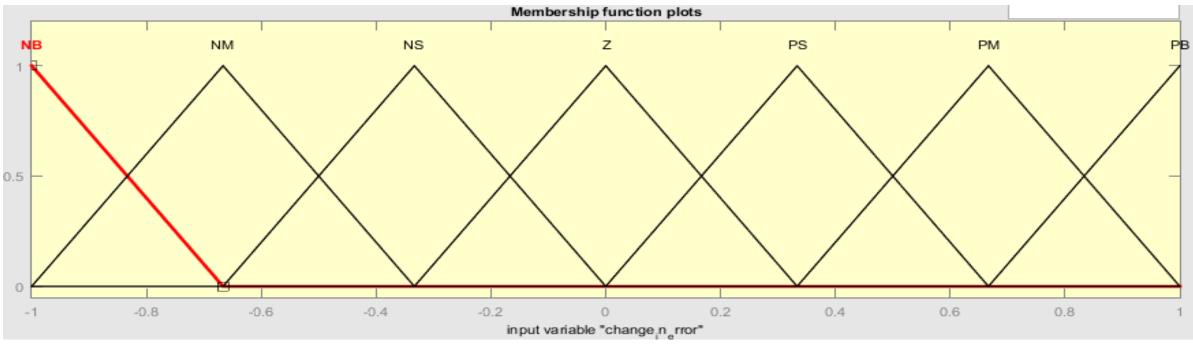


Figure 3.10 Membership functions for input variable (Change in Error).

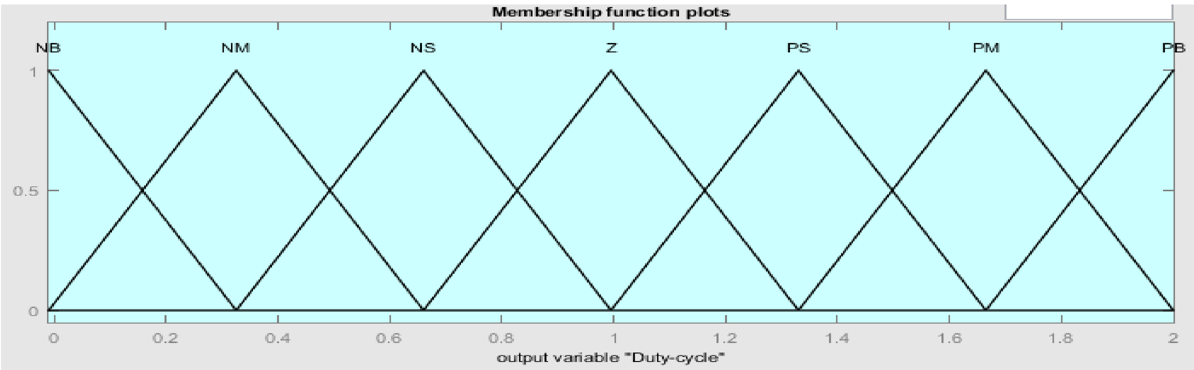


Figure 3.11 Membership function for output variable (Duty cycle).

The error E(k) and change of error E(k) input variables are transformed into linguistic as fuzzy inputs throughout the fuzzification process applying a membership function like NB (Negative big), NM (Negative medium), BS (Negative small), Z (Zero), PS (Positive small), PM (Positive medium), PB (Positive big). Shows the membership grades of seven basic fuzzy subsets for inputs and outputs.

Tables 3.10 Fuzzy memberships function with symbols.

Fuzzy memberships function	Symbols
Negative big	NB
Negative medium	NM
Negative small	NS
Zero	Z
Positive small	PS
Positive medium	PM
Positive big	PB

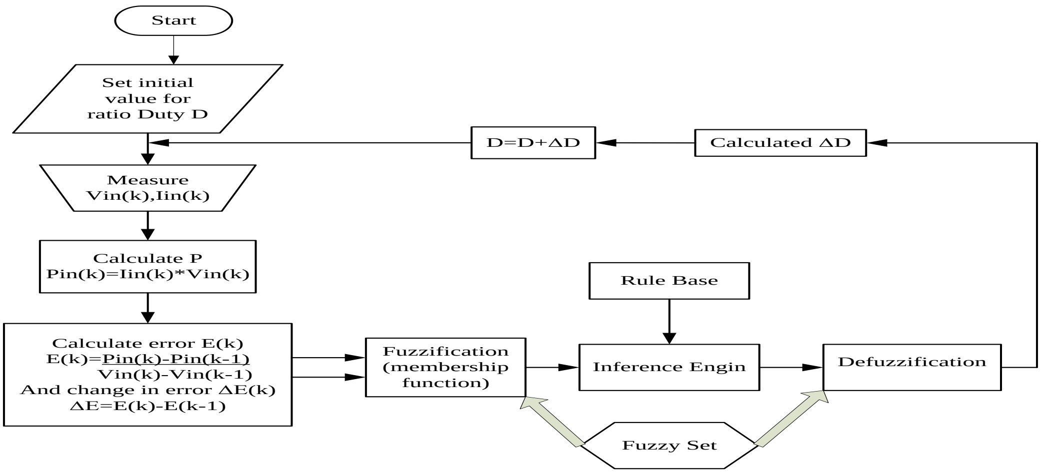


Figure 3.12 The flowchart of FLC for MPPT(Baramadeh et al., 2021)

3.11 Design of Fuzzy controller for BESS

Fuzzy control theory is applied to achieve system optimization for solar systems for batteries in charge and discharge modes, the difference between the actual load and the total generated power is taken into consideration. The battery's SOC and life cycle are directly correlated. This can maintain the SOC of the battery with fuzzy control in order to extend the life of the battery

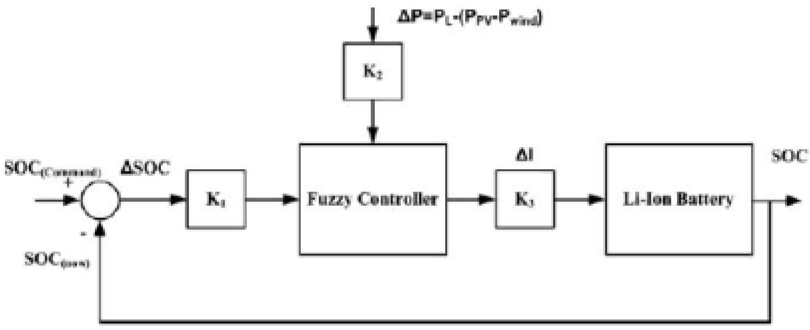


Figure 3.13 Block diagram of fuzzy control to maintain desired SOC of the batter

The fuzzy controller is intended to be in charging mode or discharging mode for the proposed system in order to achieve the appropriate SOC value. SOC and P serve as the fuzzy control's input variables, and I serve as the output variable

$$\Delta soc = sco_{comand} - sco_{new} \quad \text{...3.42}$$

$$P = p_L - p_{PV} \quad \text{...3.43}$$

The input and output membership function contain five grades: NB (negative big), NS (negative small), ZO (zero), PS(positive small), PB (positive big),

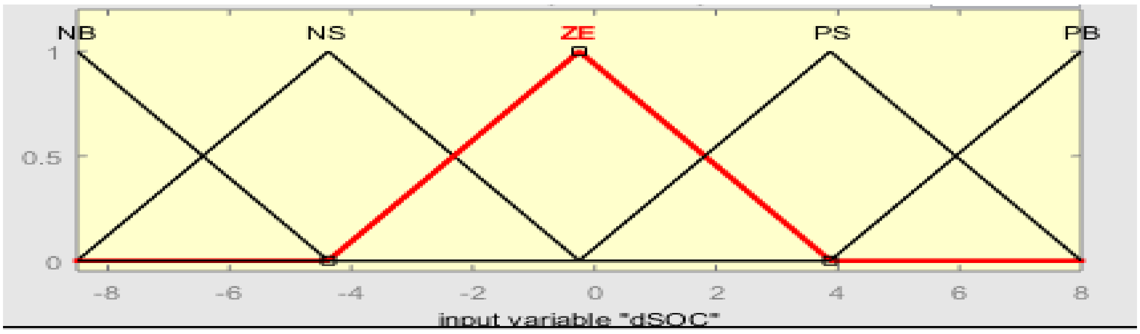


Figure 3.14 Membership function for input variable (ΔSOC)

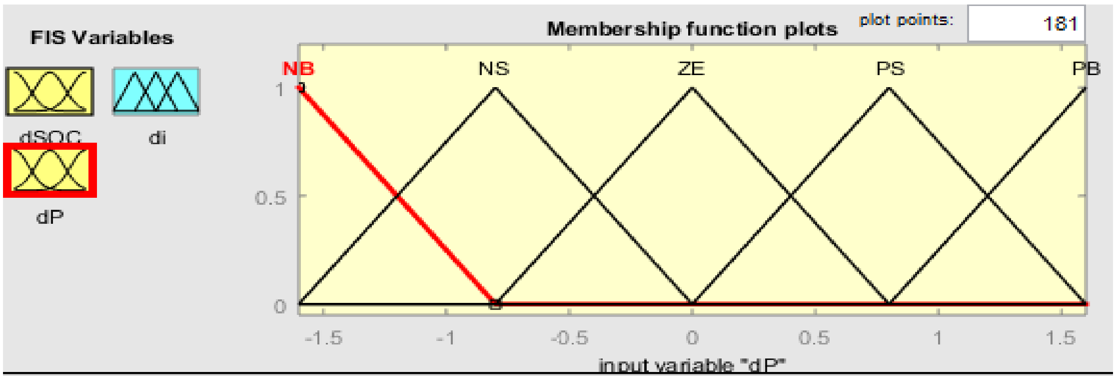


Figure 3.15Membership function for input variable (ΔP)

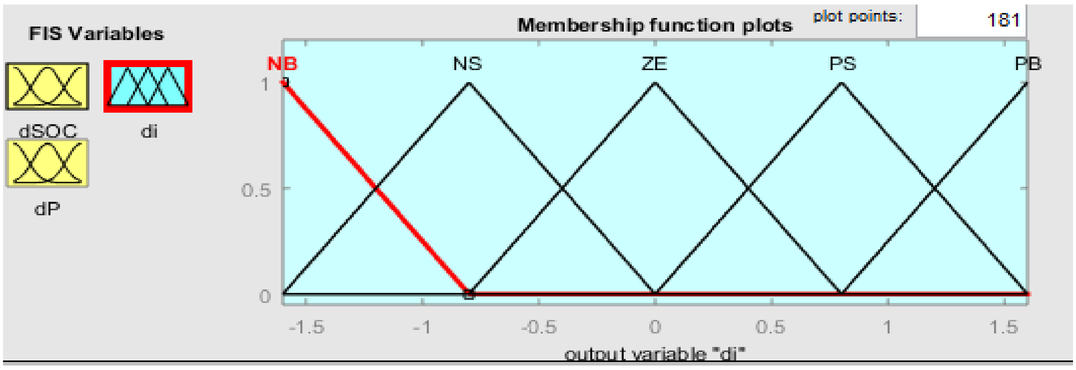


Figure 3.16 Membership function output variable (ΔI)

Table 3.11 The 5 × 5 fuzzy control rule that was used in the system

ΔI (output)	ΔP (input)					
ΔSOC (input)		NB	NS	ZE	PS	PB
	NB	PB	PB	PB	PB	PB
	NS	PB	PB	PS	PS	PB
	ZE	ZE	ZE	ZE	PS	PB
	PS	NS	NS	NS	NS	PB
	PB	NB	NB	NB	NB	PB

If variable P is NB and input variable SOC is NS (greater than the SOC command and the membership degree is small). However, when the input variables P and SOC are NB and PS, respectively, the output variable I is NS (little charging current) and PS (big amount of electricity to sell) (smaller than the SOC command and the membership degree is small). We can determine the membership grade and substitute it into the fuzzy control rules to get the output current for the battery's charge and discharge variance I by inputting the scaling factors K1 and K2. If P is negative, the load is not receiving enough energy from renewable sources. Since the battery must run in charging mode, a negative SOC indicates that the battery's SOC is higher than the demand SOC. The battery must therefore be used in discharge mode(Anitha et al., 2015)

3.12 LC filter Design

DC-AC converter that is connected to photovoltaic power system is, uses pulse width modulation (PWM) that generate sinusoidal waveform with additional harmonics in its output. Pulse width modulation (PWM), which produces sinusoidal waveforms with extra harmonics in its output, is used by a DC to AC converter that is connected to a load. In order to reduce the harmonics in the produced AC voltage, filters are often used. Filter reduces high frequency switching and protects load from transient voltage(Paper et al., 2021)

The following information is needed in order to determine filter components: Output phase voltage (En), active power (P), source voltage (Vdc), frequency (f) and switching frequency (fsw=10KHz). If the output voltage is expected in 380V/50Hz. The maximum current and basic impedance is calculated based on phase Voltage (220V) and active power (359.3kW)

$$I_{max} = \frac{P\times\sqrt{2}}{V_{ph}} = \frac{359300\times\sqrt{2}}{220} = 2309.67A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.50$$

$$Z_b = \frac{E^2}{P} = \frac{(220)^2}{359300} = 0.1347\Omega \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.51$$

$$C_b = \frac{1}{2\pi\times 50\times 0.1347} = 0.02364F \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.52$$

$$C_f = 0.05\times C_b = 0.05\times 0.02364 = 1.18215mF \ldots\ldots\ldots\ldots\ldots 3.53$$

By using ΔI_{Lmax} 10% of I_{max}, L_f are determined by

$$L_f = \frac{V_{DC}}{6\times F_{sw}\times\Delta I_{Lmax}} = \frac{700}{6\times 10000\times 230.967} = 50.512\mu F \ \ldots\ldots\ldots\ldots\ 3.54$$

3.13 RL load calculation for the proposed system.

To determine the load System parameters the following data are required:

RMS line voltage, UL rms: 380 V

RMS line current, I_L rms: 222.74 A

Power factor, PF: 0.8

Load Type: inductive (lagging)

Required

U_{ph-rms}, I_{ph-rms},, φ, |S|, P, Q, S, Rph, Xph, Zph

Solution

RMS phase voltage, U_{ph-rms} …………………………………………………………3.55

$$\frac{UL}{\sqrt{3}} = \frac{380}{\sqrt{3}} = 219.393V$$

RMS phase current, I_{ph-rms} ……………………………………………………..…3.56

$$I_{ph-rms} = I_L = 222.74A$$

Phase shift, φ $\quad \varphi = cos^{-1}(PF) = cos^{-1}(0.8) = 36.87^{\circ}$ ……………………….....3.57

Total apparent power, |S| ……………………………………………………………3.58

$$|S| = \sqrt{3} * U_L * I_L = \sqrt{3} * 380 * 222.74 = 146.603KVA$$

Total active power, P…………………………………………………………………..3.59

$$P = |S| * PF = 146.603KVA * 0.8 = 117.282kW$$

Total reactive power, Q…………………………………………………….…….3.60

$$Q = |S| * sin(\varphi) = 146.603KVA * sin(36.87^{\circ}) = 87.962\ kvar$$

Total complex power, S………………………………………………………………..3.61

$$S = P + jQ = 117.282 + j87.962\ KVA$$

Load resistance per phase, R_{Ph}………………………………………………………..3.62

$$R_{Ph} = \frac{PF*U_{Ph}}{I_{Ph}} = \frac{0.8*219.393}{222.74} = 787.979m\Omega$$

Load reactance per phase, X_{Ph}……………………………………………………...3.63

$$X_{Ph} = \frac{sin(\varphi)*U_{Ph}}{I_{Ph}} = \frac{sin(36.87°)*219.393}{222.74} = 590.986m\Omega$$

$$X_L = 2\pi fL \quad \text{…………………………………………….....3.64}$$

$$L = \frac{X_L}{2\pi f} = \frac{0.591}{2*50*3.14} = 1.882mH \quad \text{………………………………3.65}$$

Complex load impedance per phase, Z_{Ph}

Complex rectangular form

$$Z_{Ph} = R_{Ph} + jX_{Ph} = 0.788 + j0.591\Omega \quad \text{……………………….3.66}$$

Polar form

$$Z_{Ph} = |Z| < \varphi = \sqrt{r^2 + x^2} < tan^{-1}(\frac{X_{Ph}}{R_{Ph}}) \quad \text{…………………...3.67}$$

$$Z_{Ph} = \sqrt{(787.979)^2 + (590.986)^2} < tan^{-1}(\frac{590.986}{787.979} \quad _{Ph} = 0.985 < 36.87$$

CHAPTER FOUR

4. SIMULATION DISCUSSION AND RESULTS

4.1 Introduction

This chapter presents MATLAB simulations, results, and considerations for a three-phase inverter for a stand-alone photovoltaic system at a selected site. MATLAB/SIMULINK was used to model and simulate the load and power generation system at the proposed site. Therefore, the focus of this part is the results and analysis of his MATLAB simulations and component designs for one site. Both DC/DC boost converter with duty cycle control with fuzzy MPPT and DC/AC control with proportional/integral (PI) control were used to model a single PV array.

4.2 Simulink model of Fuzzy logic controller.

Fuzzy outputs are produced by an inference engine by applying rules to fuzzy inputs. Before evaluating the rules, the actual input values should be fuzzed to produce the appropriate linguistic values. The fuzzy logic controller and MPPT algorithm are combined in the system. An MPPT file stored in a fuzzy logic controller containing rules and membership functions can be used to determine the maximum output voltage of a solar panel. The gate driver receives the output of the fuzzy logic controller after the fuzzy block receives voltage and current change signals from the PV solar array.

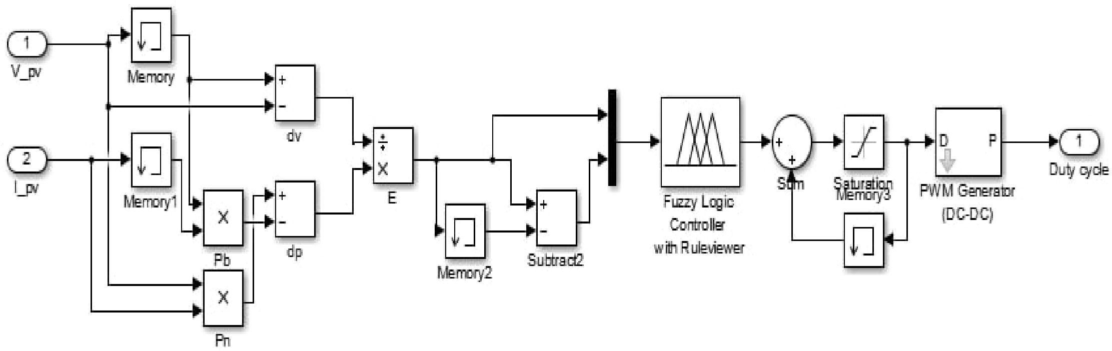


Figure 4.1 Simulink model of fuzzy logic controller

4.3 Fuzzy MPPT based PV boost converter.

The performance of the fuzzy logic controller under various weather situations, such as fluctuating irradiance (400, 600, 800, and 1000 $W/_{m^2}$) and at 25℃, has been simulated in the MATLAB environment. At constant temperature and varying irradiance, the boost converter duty cycle output signal of the fuzzy controller is analyzed.

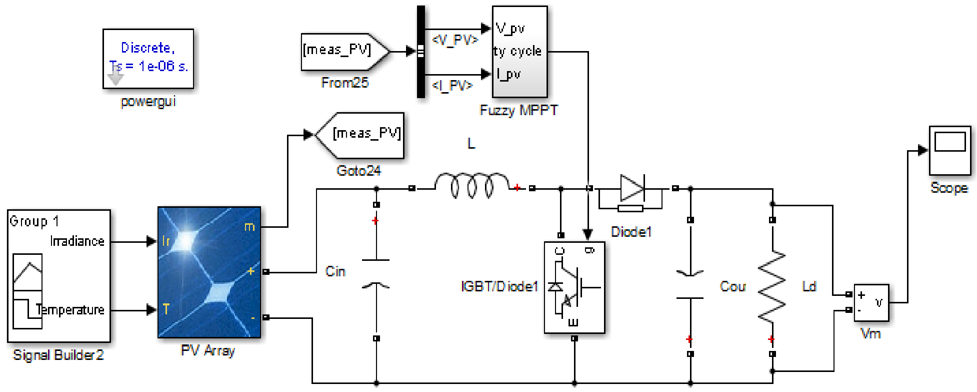


Figure 4.2 Simulink Model of Fuzzy MPPT boost converter

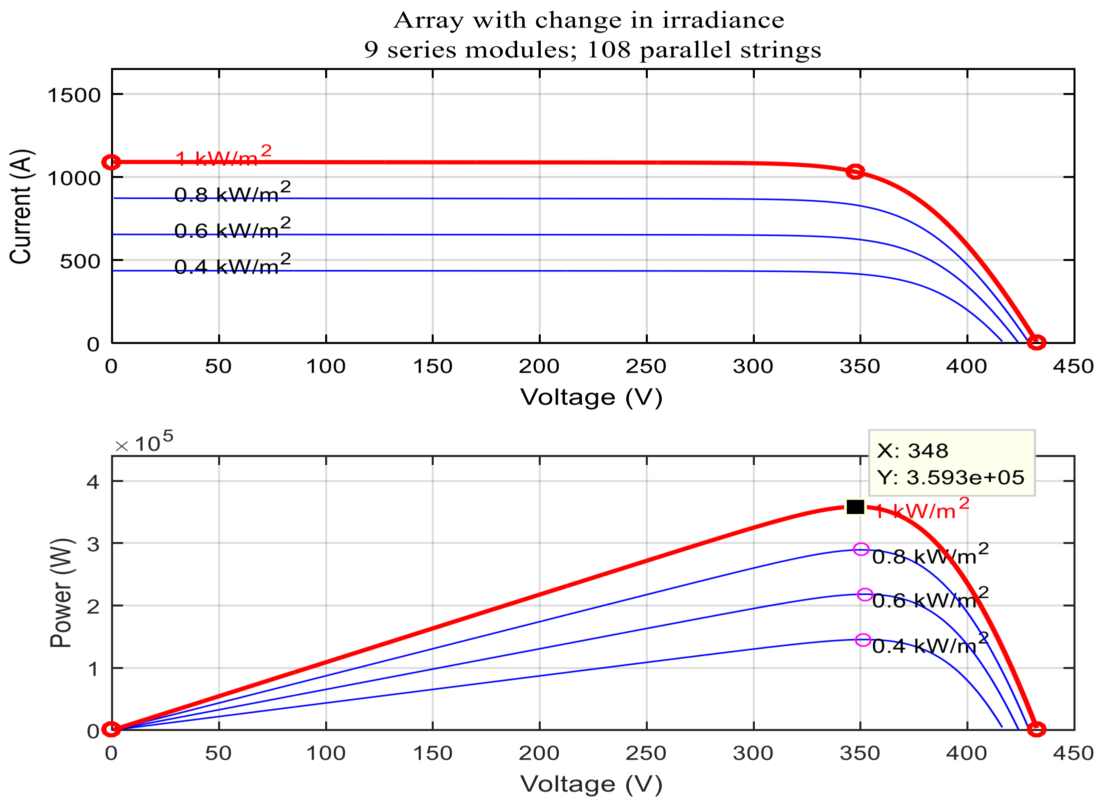


Figure 4.3 P-V and I-V curves under changing in solar Radiations

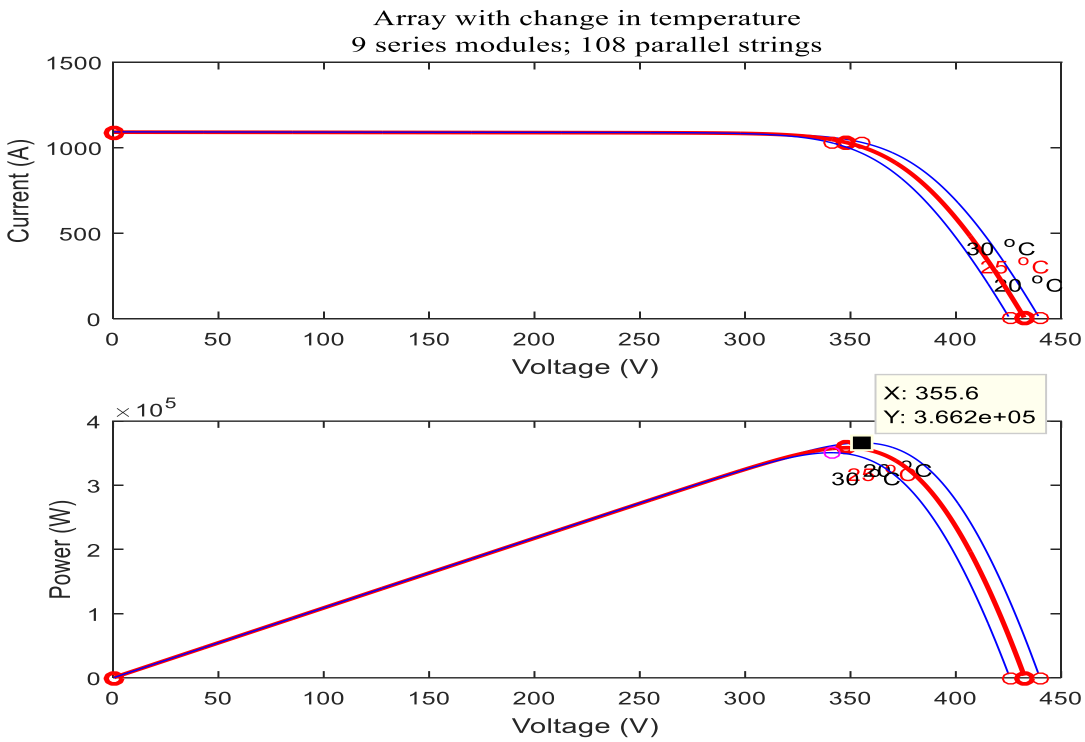


Figure 4.4 P-V and I-V curves under changing in Temperature.

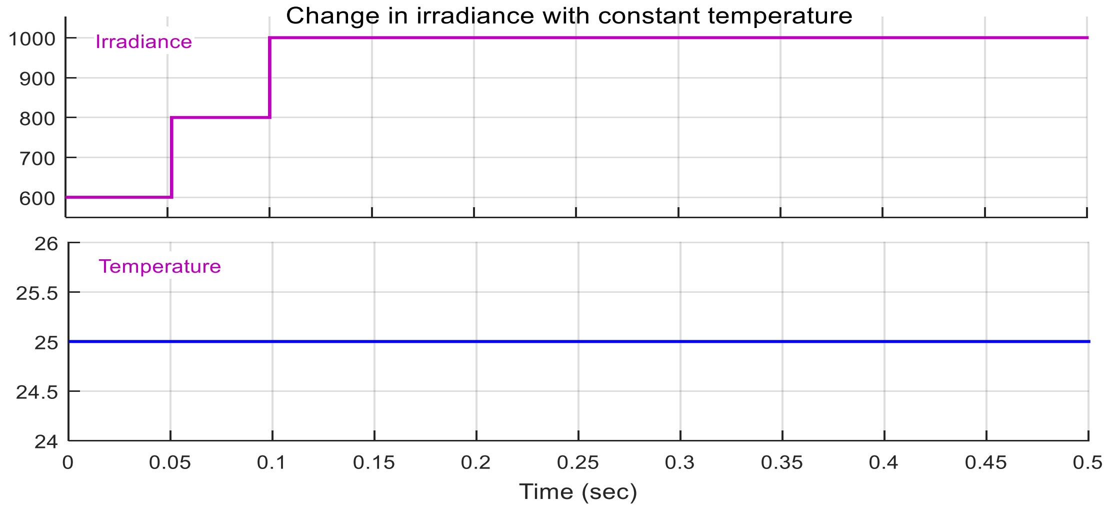


Figure 4.5 Change in irradiation level at constant temperature.

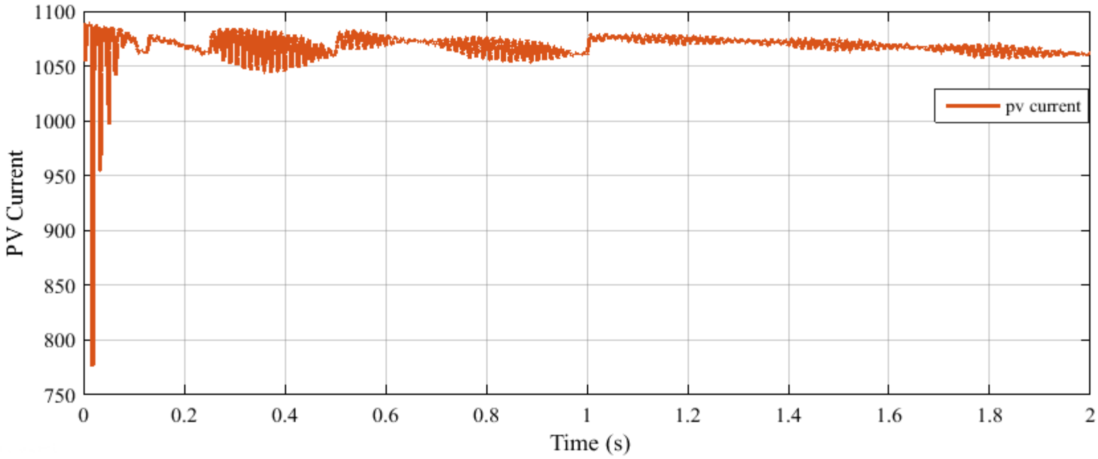


Figure 4.6 PV Current output simulation

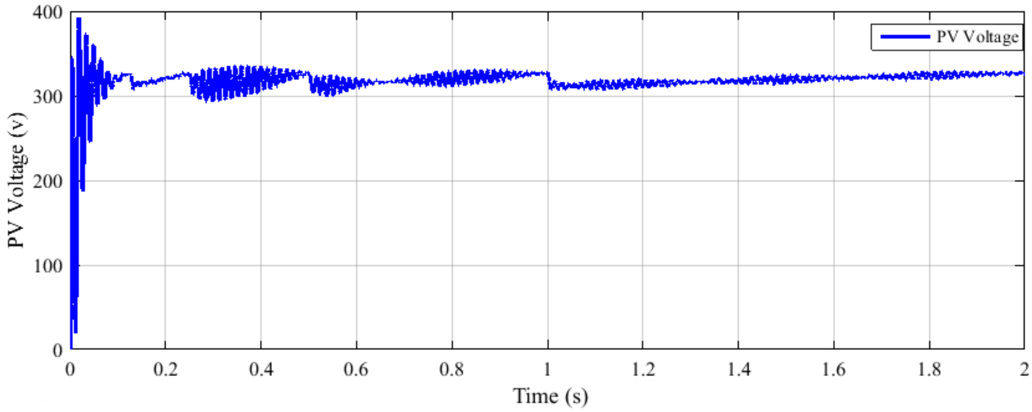


Figure4.7 PV Voltage output simulation.

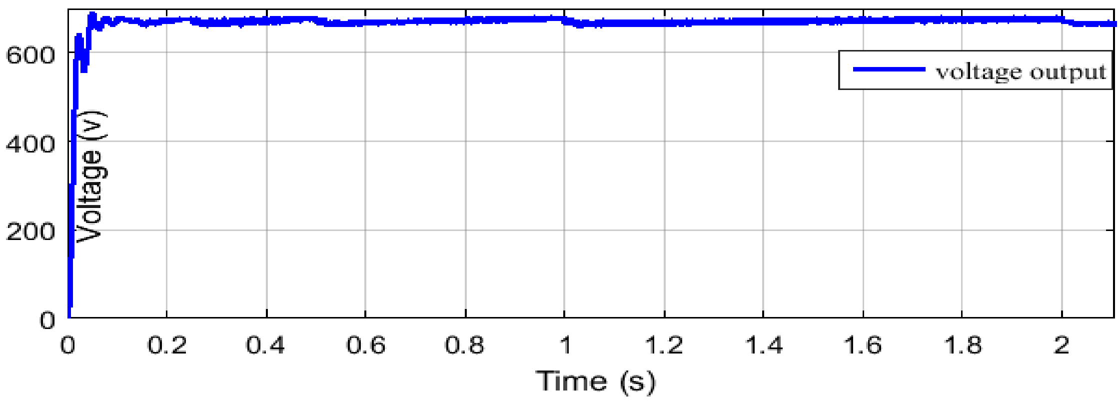


Figure4.8 Boost Output Voltage using FLC based MPPT

4.4 Battery energy storage system (BESS).

The energy problem can be resolved with a solar PV system and by energy storage options like batteries. Batteries can be used to store the DC voltage produced by a solar panel for later use.when the PV produce the power greater than the required load, the battery can be charged only when it falls below the allowed maximum value. The battery will supply the load if the load demand is greater than the PV generated power and the battery voltage is greater than the minimal value, which indicates that the battery is in the discharging condition

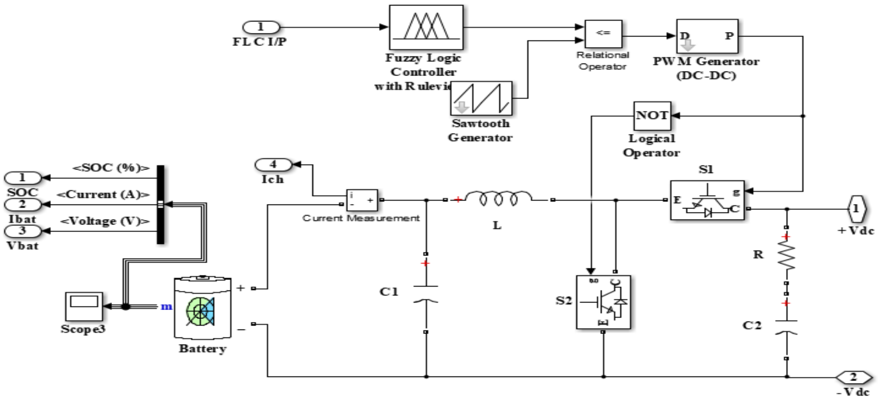


Figure 4.9 Simulink model of Battery energy storage system

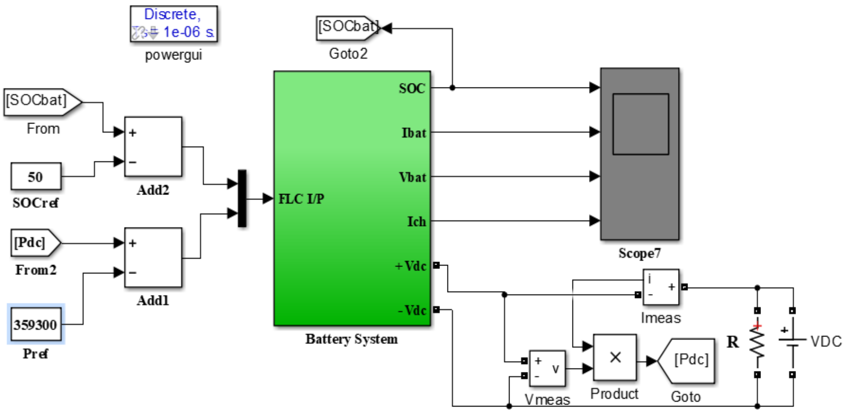
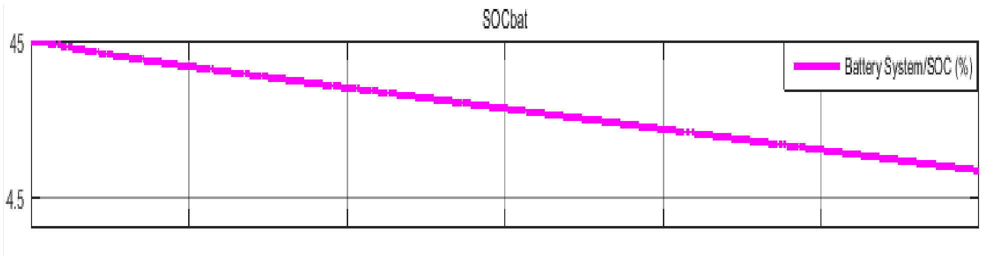


Figure 4.10 Simulink model of Battery energy storage system



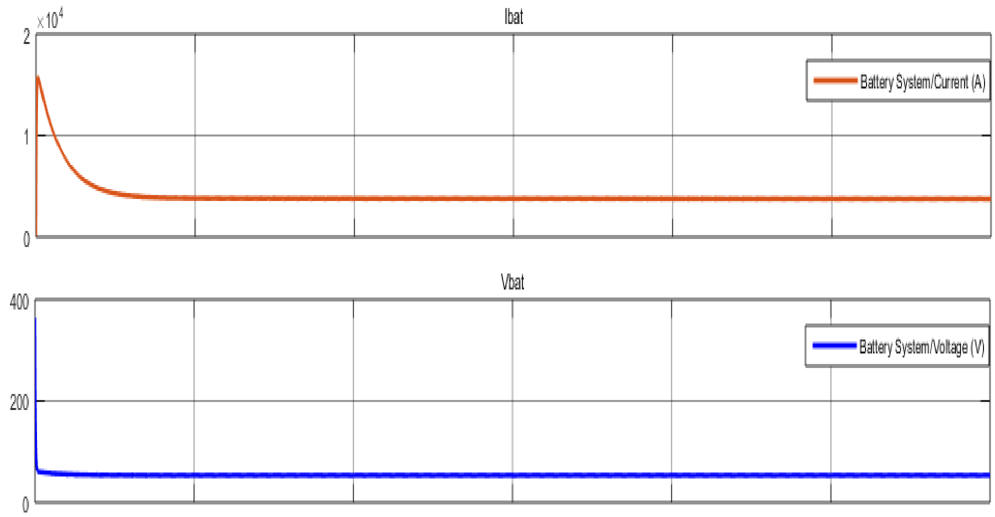


Figure 4.11 Battery SOC, current and voltage simulation during discharging

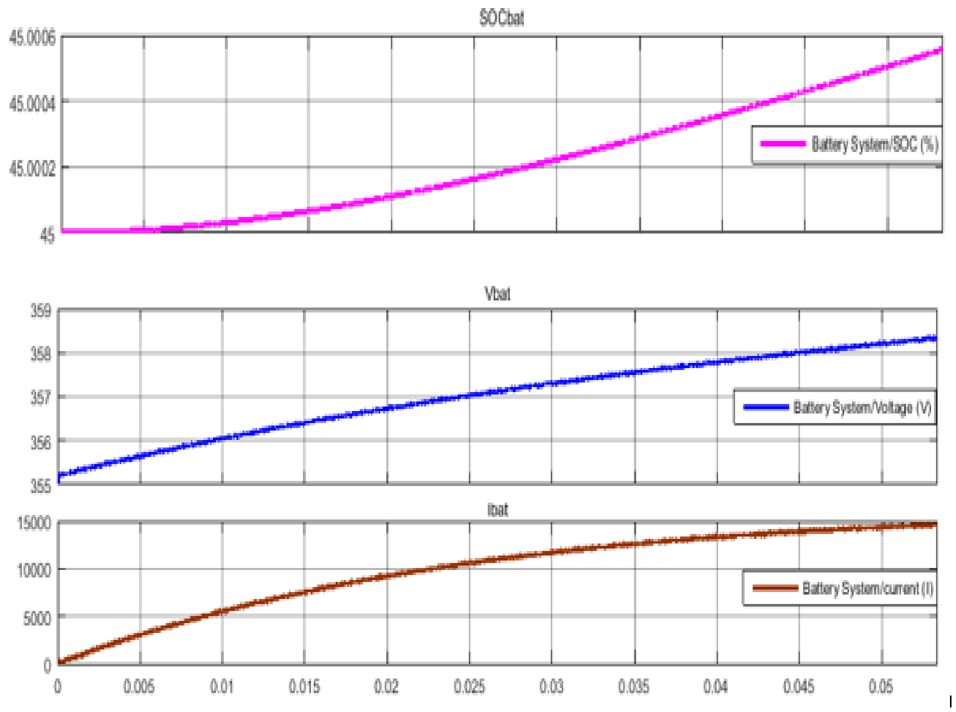


Figure 4.12 Battery SOC, current and voltage simulation during charging

The properties of the battery storage system are shown by the simulation results in Figs. 4.12 and 4.13. For the period of discharge mode $P_V < P_{Load}$ however the battery is charged and also provide power. The battery is currently working in complementary boost mode at this time. On the other side, when the battery is being charged, $P_V > P_{Load}$ and the PV panels supply power to the load at maximum power but the extra power generated by the PV panels were used to charge the battery. From the simulation results, the system achieves power balance, and the battery SOC maintains the target value to prolong battery life. The battery charging and discharging control process is non-linear, time-varying, and involves time delays. A system for generating renewable energy uses a fuzzy control unit for battery charging and discharging. Based on the simulation findings fuzzy techniques demonstrate that the control unit has a good performance

4.5 Three-phase inverter model.

The main purpose of voltage source inverters is to convert a regulated DC voltage into a three-phase AC voltage. The Insulated Gate Bipolar Transistor (IGBT) switches were implemented in inverter devices. Controlling the IGBT switches ON/OFF to produce the required output waveform for the inverter output voltage. To complete this objective, the pulse width modulation (PWM) technique is frequently used

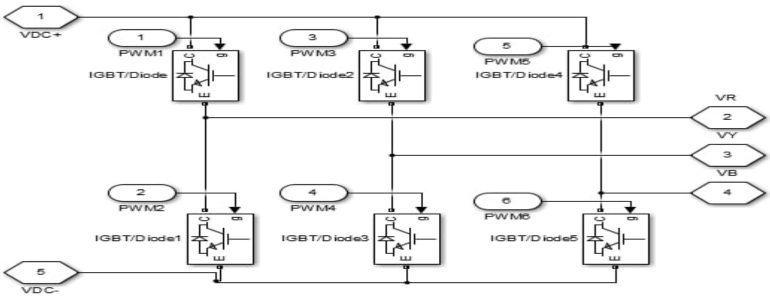


Figure 4.13 Simulink model of Three-phase inverter

4.6 Three-phase inverter PI controller

A control system consists of two major controllers: an AC-side controller for the inverter and a PV-side controller for maximum power point tracking (MPPT). The DC-link voltage that fed the inverter is controlled on the PV-side. The PI controller was used to control the three-phase VSI. The three-phase load voltage and current are sensed by the PI controller and compares the values to the d and q coordinates. It is necessary to measure the inverter current from the inverter side and compare the three-phase variable to d and q. The voltage loop control and the inner current loop are the two PI control loops. The load voltage V d and V q in a voltage loop control system are compared to the reference voltage V d and V q to produce an error, which is then delivered to a PI controller to obtain the reference current I d and I q. The generated reference currents I d and I q in the current loop are compared to the actual inverter current to determine the error. To produce the reference volt, the error was passed to the PI controller. To produce the reference volt, the error was sent to the PI controller. Finally, the reference voltage is compared between d-q and abc and sent to PWM to produce the three-phase control signal.

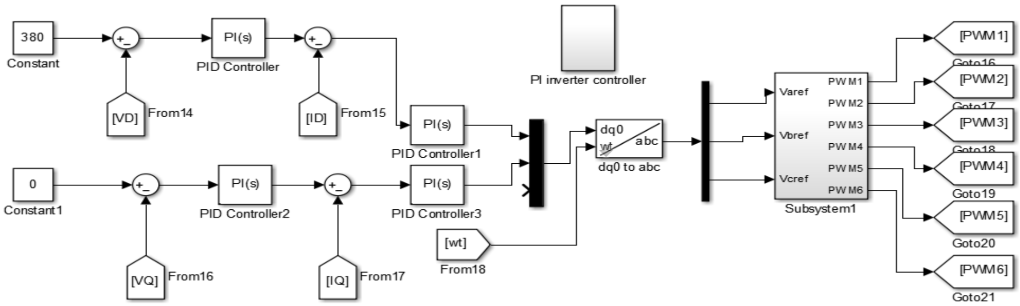


Figure 4.14 The Simulink model of Thee-phase inverter PI control

4.7 Result of solar-based Three-phase stand-alone inverter

The MATLAB/Simulink platform was used to model and simulate the system. The solar array's maximum point (MPPT) tracking changes as sun irradiation and temperature fluctuate. Fuzzy logic is easy to develop and doesn't require knowledge of the precise PV model, it has been used to track the maximum power point (MPPT) of PV modules. In this simulation, a FL controller is used to feed the output of the PV system to the DC to DC converter. This block uses fuzzy logic MPPT to maintain the output DC-link voltage at 640V, by controlling the duty cycle of the converter, and supply power to both the three-phase inverter and battery storage bank. The main purpose of the voltage source inverters is to transform a regulated DC-link voltage into a three-phase AC voltage. Through its nature of switch, the inverter produced harmonics. The LC filter was modeled to handle these harmonics in order to minimize high frequency switching and safeguard our load against transient voltage.

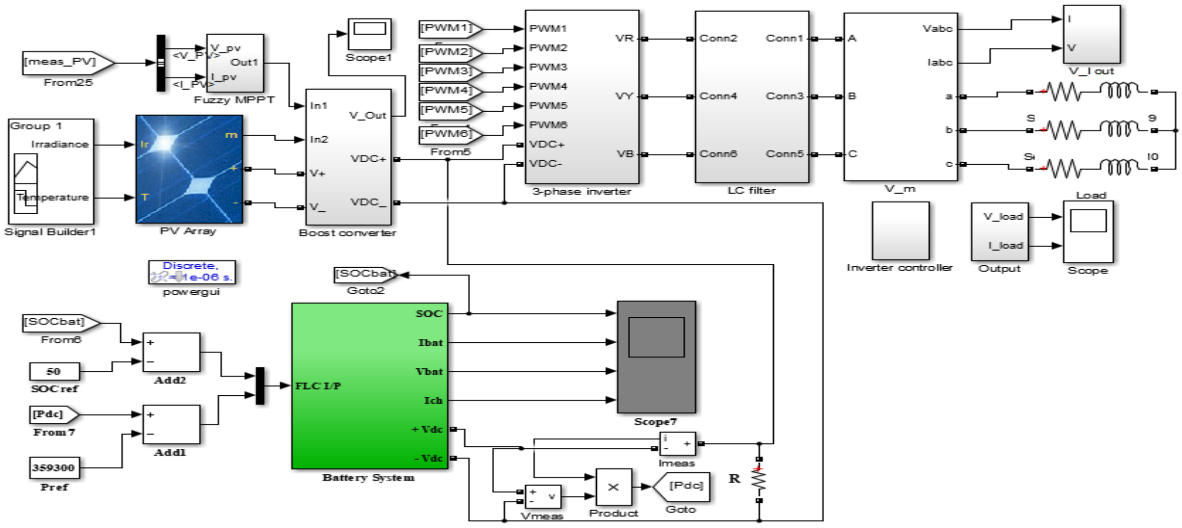


Figure 4.15 Simulink implementation of PV Three-phase stand-alone inverter with battery storag

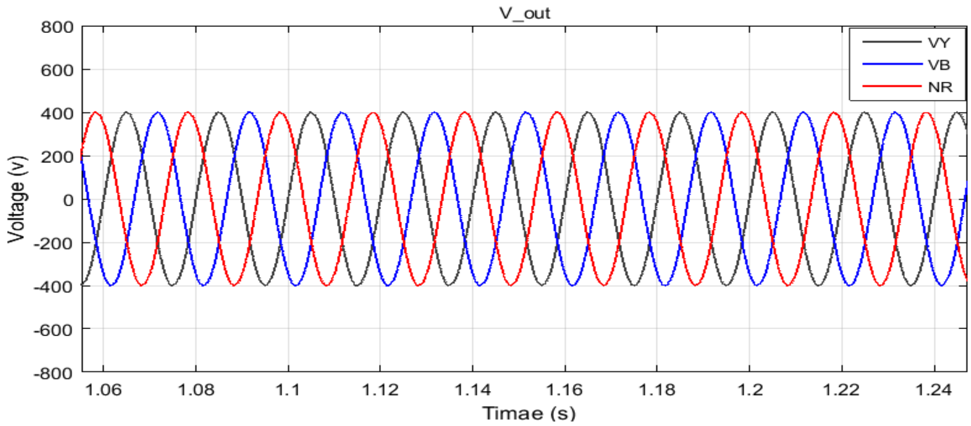


Figure 4.16 Three-phase out put voltage supplied the load.

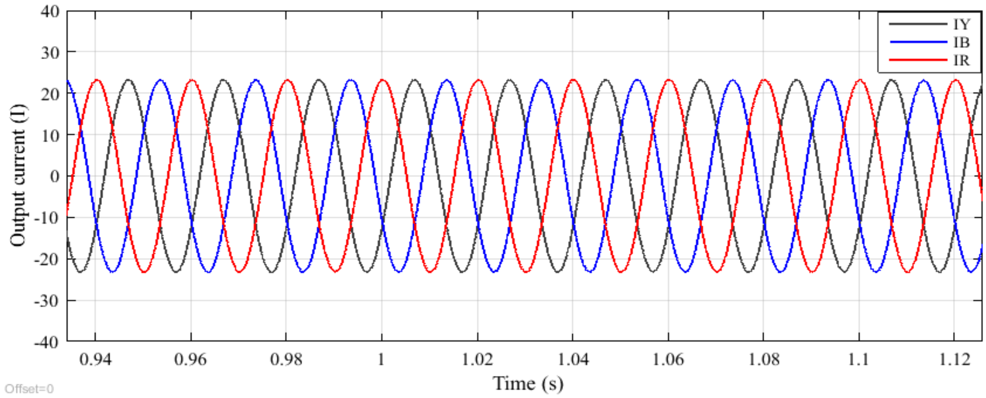


Figure 4.17 Three-phase output load current simulation

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This thesis paper is conducted on Design, Analysis and Modeling of solar-based Rural Electrification of PV system for proposed village. First to assess the total load demand profile of the selected village (Hanchebi). Then based on these load profiles, a study for stand-alone electric power supply for the community in Hanchebi village (922 house holders) was done after collections of data's which was estimated to have a peak demand load of 2.3562Mwh/day. In the Simulink simulations, the PV system output is fed to the block of DC to DC converter with a controller. The algorithm of fuzzy logic based maximum power point tracking (MPPT) has been designed to control the duty cycle of boost converter. It maintains the output voltage and feds the battery bank storage and inverter. The output of PV solar system is enough to meet load demand under normal conditions and the battery bank is in state of charge. During night time the PV solar panel is not generating the power, the battery start discharging and supply the demand load. The result of the simulation shows that the proposed fuzzy logic algorithm has a good and effective performance for tracking maximum power from the solar PV panels. The MPPT is implemented using the boost converter since the VSI requires a high and regulated DC voltage the control unit is made up of an inner current loop that controls the output current provided to the load and an outside voltage loop that extracts the direct reference current. We see that in simulation result how voltage is varies with variation of temperature and irradiance. Since all voltages and currents have DC values at the dq reference frame, the PI controller is utilized because it provided the highest performance at DC variables. Also,. This indicates that both boost converter and inverter controller have a good and effective performance for the designed system. Therefore, the result was acceptable, and the simulated outcome satisfied the load requirements for the village of Hanchebi village

5.2 RECOMENDATION

As seen from the simulation, it is preferable to implement solar power for rural electrification. To enhance and expand private investor participation in solar energy system projects, the government should encourage and provide the necessary support. To be able to deliver solar-generated power electricity, the government should support the project for solar energy systems at all levels through training and education. Additionally, the community gain more knowledge after technical training if it is combined with sales, which may result in future employment and revenue. The government must also provide funding for solar energy projects and research. This benefits local economies and creates a positive feedback that can help millions of Ethiopian who lived in rural villages overcome their economic and social challenges.

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