Design and Analysis of Solar Powered Water Pumping System Using DC to AC Converter For Garbicha Kebele

Hamza Gadisa Megersa

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

School of Electrical Engineering and Computing

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

Office of Graduate Studies

Adama Science and Technology University

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By:

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Advisor: Palanivel Panjamoorthy, (Ph.D.)

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Approval Board of Examiners

We undersigned member of the Board of Examiners of the Final Open defense by Hamza Gadisa Megersa have read and evaluated his thesis entitled" Design and Analysis of Solar Powered Water Pumping System Using DC-AC Converter for Garbicha kebele(Bishoftu)" and examined the candidate. This is to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master's of Science in Electrical Power and Control Engineering (specialization in Power Electronics).

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Department chair person name	signature	Date
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Declaration

I hereby declared that this M.Sc thesis entitled Design and Analysis of Solar-powered Water Pumping System Using DC-AC Converter for Garbicha kebele(Bishoftu), has been compiled by me under the supervision of Palanivel Panjamoorthy, (Ph.D.) at the Department of Electrical Power and Control Engineering, ASTU, Adama, Ethiopia. This thesis contains no material which has been accepted for the award of any other degree or diploma, except where due reference is made. To the best of my knowledge, this thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

________________________	______________________	_________________
Name Hamza Gadisa Megersa	Signature	Submission date

This M.S.c thesis has been submitted for examination with my approval as a thesis advisor.

________________________	______________________	_________________
Name	Signature	Submission date

Advisor Approval Sheet

To: Electrical Power and Control Engineering department.

Subject: M.Sc Thesis submission.

This is to certify that the thesis entitled "Design and Analysis of solar-powered water pumping system using DC-AC converter for Garbicha Kebele(Bishoftu)", submitted in partial fulfillment of the requirement for the degree of Master's Science in Electrical Power and Control Engineering department(Specialization in Power Electronics) the Graduate program of the Department of Electrical Power and Control Engineering and has been carried out by Hamza Gadisa Megersa Id. No. A/PR15497/10 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

____________________	____________________	____________________
Advisor Name	signature	date

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List of Acronyms and Abbreviations

AC	Alternate Current
BJT	Bipolar Junction Transistor
CFI	Current Fed Inverter
CGIAR	Consultative Group for International Agricultural Research
CSI	Current Source Inverter
DC	Direct Current
DI	Internal Diameter
DO	External Diameter
EMF	Induced Electromotive Force
FET	Field Effect Transistor
GTO	Gate Turn On Transistor
GTP	Growth and Transformation Plan
GW	Giga Watt
HDPE	High-Density Polyethylene
HP	Horse Power
HOMER	Hybrid Optimization Model of Energy Resources
IM	Induction Motor
IGBT	Insulated Gate Bipolar Transistor
KWH	KiloWatt Hour
LCC	Life Cycle Cost
MDG	Millennium Development Goal
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MPP	Maximum PowerPoint
MPPT	Maximum Power Point Tracking

MW	MegaWatt
NASA	National Aeronautics and Space Administration
NGOs	Non Governmental Organizations
NMA	National Meteorology Agency
NOCT	Nominal Operating Cell Temperature
NPV	Net Present Value
NPSH	Net Positive Suction Head
NPSH-A	Net Positive Suction Head Available
NPSH-R	Net Positive Suction Head Requirement
PD	Proportional Derivative
PI	Proportional Integral
PID	Proportional Integral Derivative
PV	Photovoltaic
PVC	Polyvinyl Chloride
RMF	Rotating Magnetic Field
RMSE	Root Mean Square Error
SMPS	Switch Mode Power Supplies
SPIM	Single Phase Induction Motor
SPWM	Sinusoidal Pulse Width Modulation
UAP	Universal Access Plan
UNICEF	United Nations International Child Emergency Fund
VDI	Voltage Drop Index
VFD	Variable Frequency Drive
VSI	Voltage Source Inverter

SYMBOLES

E_g	the bandgap energy (1.1 eV)
G	the irradiance (W/m^2)
Gref	reference irradiation (W/m^2)
h_f	friction losses in suction side pipework (m).
Is = Io	the saturation current (A)
I_{sc}	the short circuit current,
Irs	the cell reverse saturation current at a reference temperature
I_{ph}	the light generated current or photon current,
I_{pv}	PV output current, A
K	the Boltzmann constant ($1.3805*10^{-23}$ J/K),
K_i	a cell's short circuit temperature coefficient,
n	the ideality factor
Ns	the number of cells connected in series
N_p	the number of cells connected in parallel
P_e	absolute pressure in a pumped vessel (bar)
P_v	Vapor pressure of the fluid (bar)
Q	Electron charge ($1.6*10^{-19}$ C)
Rs	the series resistance
Rsh	the shunt resistance
T	the operating temperature in Kelvin
T_a	the reference temperature
V	fluid velocity in the pump flange
V_{pv}	PV output voltage, V
$\boldsymbol{\rho}$	density of the fluid (kg/m^3)

Abstract

As need of energy demand increseases, there will be diminishing of natural gasses, fossil fuels and coals. Using renewable energy beside those energy mentioned above reduces the problem related with energy sources and also it can reduce the global warming caused due to natural gassess.This work can be considered with the objective of supplying drinking water to the society living in the rural area of Ada Barga Wereda (Bishoftu). Garbicha kebele community is one of this wereda and has a serious problem in supplying drinking water. Their water pumping system includes a manually powered pump (most of them), a generator driven pump, all these mechanisms have many problems such as: (energy consumption), require high maintenance (fuel consumption) and diesel generator pump has environmental impacts.MATLABR2015a was used for modeling and simulation of Buck converter, Inverter, PV Cell, PV Array and HOMER software was used for PV water pumping economic cost analysis.IGBT device was used for switching of converters and PWM was used for controlling the output voltages of the converters. The designed system is capable of providing 85m^{3}per day for850 people in Garbicha Kebele with average daily water consumption of 100 liters per household at a total head of 76m.The outcome of the study will serve the community by supplying water and make the communities familiar with solar technologies.

Key Words: *HOMER Software, PV Cell, PV Array, MATLAB Software, Inverter (DC-AC Converter), Buck converter, Diesel, PWM, IGBT device.*

CHAPTER ONE

INTRODUCTION

1.1Background

Water is one of the most essential things for human beings. It is used for drinking, washing, food production and keeping the restoration of ecosystems. In the world, there are more than two billion people gained access to improved drinking water sources as reported by the wash watch and UNICEF on March 6, 2012[1]. Still now, over seven hundred eighty-three million people are still without access to safe drinking water [2].Comparing to developed countries like Latin America 90% gained access to clean water while Sub-Saharan African countries gained only 61%. Above forty percent of all people who lack access to drinking water live in sub-Saharan Africa. Historically, Ethiopia is known by water but still now, there is shortage of improved clean water for most of rural area communities. Ethiopia has the lowest clean water supply while comparing it with sub-Saharan African countries and the entire world. The government of Ethiopia planned to increase access of water supply funding with foreign aid to achieve the Millennium Development Goal(MDG) of halving the share of people without access to water by 2015 but still now the problem as it is, this is due to internal problems of the country politics, foreign organization fear to accomplish what they have been promised to improve sustainability and service quality. As the report of (2010) Ethiopian government presented, the equally ambitious Growth and Transformation Plan (GTP) which aims increasing water coverage from 68.5% to 98.5% between the years of (2011-2015) [3].

There are twelve river basins with an annual runoff volume of one hundred twenty-two billion cubic meters of water potential in Ethiopia, from these, two-point six up to six point five billion cubic meters of groundwater potential with an average of one thousand five hundred seventy-five cubic meters of physically available water. But as a result of the large spatial climatic change, the rainfall is reduced and water is not available where and when needed [4]. Only about three percent of water resources are used of which only about 11% (0.3% of the total) is used for domestic water supply. As the data indicated, the number of people lacking access to "improved" water in 2015 was 42 million [5].

Most of the rural community water source includes deep wells, springs, and shallow wells and rivers. Their source of water is from rivers, this may cause contamination and can cause waterborne diseases. Therefore, to overcome these problems, it is important to supply environmentally sound technology for the provision of drinking water. The pumping mechanism is hand-dug wells by using rope, shallow wells and boreholes are fitted with hand pumps or diesel and petrol-driven generators. These mechanisms of manpower water pumping system consume more time, require excess labor, failures of the system due to the frequent contact of the hand pump by human.Diesel and petrol-based pumps have many problems, such as fuel consumption, high running, and maintenance cost, and poor availability of spare parts to maintain it. PV energy systems will have to compete with small scale generator or set fuels by diesel which has been often used to supply electrical energy for water pumping [6]. PV water pumping system is the best option of energy source which plays a major role in fulfilling drinking water demand for remote areas community who far from grid electricity [7]. A solar cell generates electrical energy directly from solar energy through the solar photovoltaic module, made up of silicon cells. Each cell outputs relatively low voltage, But by connecting many cells in series, a solar photovoltaic module is formed. The solar module produces direct current(DC) power, to convert it to a rated DC chopper is used, to convert this DC PV power to AC power Inverter is used. At the given temperature and insulation level, PV cells supply maximum power at one particular operation point called maximum power point (MMP). It is desirable to operate the PV system at its MPP. The maximum power point locus varies depending on PV array temperature and insulation radiation [8]. A lifetime of PV cells and shading conditions can affect the locus of maximum powerpoint. So,to achieve operation at MPP, a time-varying matching network is required to interfaces varying sources and varying load in order to achieve optimum matching of PV array at MPPT. MPPT is a power electronic step up or step down dc-dc converter which is inserted between the PV module and its load to achieve the optimum matching[9].There are many intelligent algorithms, which ensure the PV module always to operates at its maximum power point regardless of temperature, insolation and load varying. There are many algorithms that are used for the Optimization of maximum power

point tracking(MPPT), due to its simplicity perturb and Observe(P&O) and an Incremental Conductance algorithm is commonly used[10]. In this research, An efficient Photovoltaic (PV) water pumping system installed on shallow wells proved to be promising technological innovation. An inverter fed_Induction Motor PV Water pump design and its analysis included with IGBT switches to regulate switching losses of DC to AC converter (inverter) and also presents MATLAB simulations of the system components.

1.2 Statement of the Problem

In developing countries, like Ethiopia which is composed of numerous rural villages and farmers, it is difficult to extend the electric grid to every location where it is needed and also lack of water is still a great issue to be solved in rural areas of the country. A case study on Garbicha Kebele (Bishoftu), Indicates, their water pumping system includes a manually powered pump, a generator driven pump, and using a rope.These mechanisms have many problems such as: (energy consumption), require high maintenance(i.e.it has many moving parts), (fuel consumption) and diesel generator pump has environmental impacts. Solar-powered water pumping system is one of the options, because it has less maintenance (no moving parts), easy to install, economically feasible after installation.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study is to design and analyze a solar-powered water pump system using a DC-AC converter which can be used by Ada Barga Wereda Water and Energy Burea as reference for installation of a water pump system in Garbicha Kebele.

1.3.2 Specific objective

The specific objective of the study includes the following;

- Assessment and analysis of solar radiation in the Garbicha Kebele.
- Assessment of the economic feasibility analysis by using HOMER software and reliability of solar photovoltaic water pumping system for Garbicha kebele.
- Analysis of the total depth requirement of the dynamic Head pump.
- Designing and simulation of solar PV water pump system components.

1.4 Significance of the study

- It will serve the community by supplying water and make the communities familiar with solar technologies.
- It will motivate the researcher to be familiar with the solar technologies and make initiation to do another research problem on another case study area and develop his/her knowledge.
- It will serve the government:-that means it helps the government by reducing the budget that will be assigned to the water supply to the societies with low cost.
- It will reduce the cost of motor maintenance, save energy, save time and ensure availability of water around the case study area.

1.5 Scope of the study

Solar-powered pumping is a big system that can pump a large amount of water for the irrigation purpose but this research is limited to drinking purpose for the communities.Wind energy is not easily designed with less cost and it made the system bulky. Due to its costs and complexity of wind energy, only Stand-alone PV Water Pump System is considered. Its simplicity and cost effectivity initiates the researcher to do A thesis on Analysis of Solar powered water pumping system using DC-AC Converter. The scope of this research is limited to designing, analysis and Simulation of each system components and modeling was conducted by using MATLAB software versionR2015a/Simulink. Preparation of the result documentation will be included for Bishoftu District Water Burea as a reference document for the installation of a water pump System for Garbicha Kebele.

1.6 Motivation of the research

Ada Barga wereda (Bishoftu) has 32 kebeles, among those 9 are under city administration and 23 are rural areas kebele. All the rural kebeles still now use hand pump water pumping systems, but the wereda water and Energy Burea understand the society's water-related problem and started to reduce the water shortage among the wereda's kebeles. The wereda installs one solar-based water pump for two kebeles around a place Akako 5 kilometer at the southeast of Bishoftu in 2010/2018. In the previously done PV based water pump system, there was a design and analysis problem which means system parameter sizing problem and operational failure occurs and faces for an additional cost. They need correctly designed and analyzed documents as a reference document for the installation of a solar-powered water pumping system for Gerbicha Kebele.

1.7 Description of the case study area

Bishoftu is a town which is located in the East Shewa Zone of the Oromia Regional State. It was formerly named as Debrezyit. It is located at 8^0 44'7" N and $39^0$0'30.7188'' E; it has an elevation above sea level of 1,920 meters and 47.9 Kilometers South East of Addis Ababa along its route 4 highway and, it has 9 cities Keble's and 23 rural. It is called as a resort town which is known for having seven crater lakes that are enclosed by steep escarpment which gives the lakes panoramic views: Lake Bishoftu , Lake Hora Arsedi (the largest lake of the town), It's close proximity to the capital city, Addis Ababa, and it's position on the road to Djibouti, makes it for industrial development. Its weather condition is sunny most of the time with mean daily temperature average of 32^0C.

1.8 Limitations of the study

This study is limited to investigating the design and analysis of a solar-powered water pumping system using DC to AC converter for the Ada Barga Wereda rural kebele (Garbicha kebele) area. There was a limitation of solar radiation data collector device (Pyranometer) failures and only sunshine data was used and converted to solar radiation.The value of solar radiation obtained by this conversion is not matched with the solar radiation data obtained from NASA.

1.9 Organization of the thesis

The thesis is organized into five chapters which are briefly summarized below. Chapter one, presents the introduction, background, problem statements, objectives, the significance of the study, the scope of the study, motivations of the research, limitations of the research. The second chapter discusses the theoretical background of Energy resources in Ethiopia, the basic theory of solar energy and review of the literature on design and analysis of solar-powered water pumping systems for the rural communities. In chapter three, load estimation, system parameter sizing, and component MATLAB modeling,economic anaylsis and result and discussion have been explained in detail. The fourth chapter presents Photovoltaic water pumping system theoretical background, the principle of operation, The fifth chapter discusses the conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Energy resources in Ethiopia

There are a lot of energy resources in Ethiopia:-among these, Hydro, Wind, Solar, and non-renewable resources. As the statistical data of 2017 energy consumption of the country shows that total energy consumed was 8.14 billion Kilo watt-hour per year, from this, 92% consumed by domestic appliances, 4% consumed by industries and 1% consumed by transportations others as losses. As the statistical data of 2017 energy report highlights, energy from hydropower, 45000MW, Geothermal,5000 to 10000MW, Annual solar energy average daily irradiation, 5.5KWper meter square per day, greater than1000GW average wind speed of 7m/s 50m above ground level[11].

2.2 Renewable Energy

2.2.1 Basic theory of Solar Energy

The energy that comes from the sun is called solar energy. The sun radiates an enormous amount of energy. Nuclear fusions cause the sun's extremely high pressure and hot temperature to cause hydrogen atoms to come apart and their nuclei (the central cores of the atoms) to fuse or combine. Solar radiation which is received at the earth's surface varies on hours, daily or monthly; this is due to sun-earth angle location concepts. The electromagnetic radiation emitted by the sun covers a very large range of wavelengths from radio waves through the infrared rays, visible and ultraviolet to X-rays and Gamma rays. However, 99% of the energy of solar radiation is confined in the wavelength band from 0.15 to 4 micrometers ($4*10^{-6}$ m) [12]. The variation actually observed in association with solar phenomena like sunspots, prominences and solar flares are mainly confined to radio waves. The axis of rotation of the earth is inclined at about 23 ½ degrees with respect to the plane of orbital revolution. As the consequences of this geo-meter of the earth and the sun, there may be large seasonal variations that occur in the amount of solar radiation received at a different latitude of the earth. Solar radiation variation occurs near the two poles and the smallest occurs near the equator.

The earth comes nearest to the sun each year on January 5(Perihelion) and farthest around July 5 (Aphelion). The sun-earth distance at perihelion is $1.471*10^8$km and at aphelion $1.521*10^8$km. The mean distance is $1.496*10^8$km, which is known as astronomical units. The solar energy reaches the earth's surface at a speed of one hundred eighty-six thousand miles per second, the speed of light. The Sun releases an estimated 384.6 Yotta watts (3.846×1026 watts) of energy in the form of light and other forms of radiation [12]. In one second; the sun emits about 3.86×10^{26} watts of energy. Most of the energy goes off into space, but about 1.74×10^{17} watts strikes the earth. Only fifteen percent of the sun's energy that hits the earth is reflected back into space. The rest could be used to supply our energy needs. According to the latest published papers, the surface of the earth receives about 124exa (10^{18}) Watts or 3,850Zetta (10^{24}) joules per year of solar energy [13].

2.2.2 Solar Energy Resources in Ethiopia

Ethiopia is a country that is endowed with a huge amount of water, wind, solar and geothermal energy potentials. However the country has enormous potentials of renewable energy but still, now the energy system highly depends on the conventional energy source, mostly on fossil fuels and biomass. Considering the diminishing of fossil fuel, the country has planned to achieve universal electrification systems as well as for the water pumping system by 2025[14]. Even though Ethiopia has abundant solar energy resources its annual average irradiance is estimated to be 5.2kwh/m^2. As in figure2.1 of now, only 14MW has been installed, still, it was a growing category of renewable year- to a year from 2016- 2017 compared to the growth of wind and hydro energy applications. The high degree of Solar PV potential in Ethiopia from figure 2.1 below shows that the development of solar PV projects presents an extremely lucrative opportunity for many of country investors. Solar capacity in Ethiopia is expected to soar in the near future with several large scale developments.

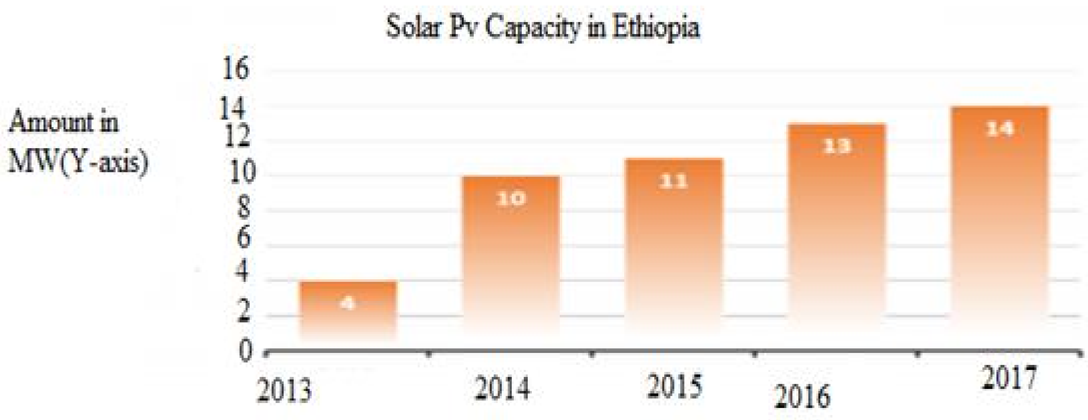


Figure 2.1 Ethiopia's PV Capacity From 2013- 2017

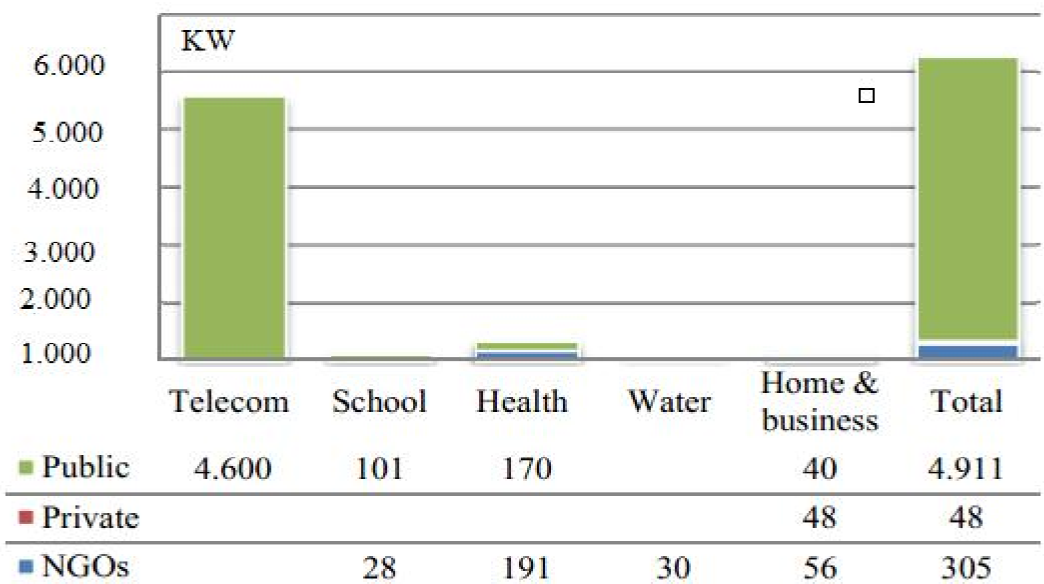


Figure 2.2 PV Capacity in the year 2011, in KW (ERG)

PV application for water Pump system is the lowest comparing to Telecom and Electricity as shown in figure(2.2). This indicates that concern may need to supply clean water for societies who have no opportunities to use gird electricity. Northern, Central and Western high-lands of the country receive lower solar radiation while the Western and Eastern low-lands and rift valley regions of the country receive higher annual average irradiance of 6kwh/m^2. The commercial market of solar technology was started early at a time its annual growth was under five percent, this is due to a lack of awareness about solar energy. Ethiopian government with the collaboration of the Chinese government prepared solar and wind energy resource utilization master plan for the country which can reduce the dependency of the country on hydropower. The analysis of this master plan indicates that the country wind energy potential has a capacity of 1,350 GW energy with wind speed potential of greater than 7m/s. The Ethiopian governments do not give major attention to renewable energy resources as an energy source of electricity while comparing with other African Countries. Some of the projects done on solar energy for providing water for rural communities of Ethiopia include the following.

Africa RISING project in Ethiopian high lands by CGIAR Fund donors aims to improve the household food security in the four sites. In a southern region in Lemo district, Jawe upper Gana, sinana district, salka and Ilu sanbitu in Oromia region, basona worena district, goshebado in Amhara region, and other organization East African Water and Sanitation program have done solar-based water pump for West Arsi Negele people. Off-grid solar applications play a great role in the development of rural areas of Ethiopia electricity, however, the relatively upfront financial associated with it constitute a hurdle that's hindering the progress of solar technology. Many organizations are participated to overcome this financial problem. Among these organizations development Bank of Ethiopia in partnership with the International Development Association by providing capital loans to the private sectors of household solar providers. As of 2017, 3.7% of the total renewable energy capacity in Ethiopia was off-grid. Considering this percentage 14MW of solar PV capacity essentially comprising all solar capacity in the country. Most of the solar technologies used in Ethiopia are imported from Asia countries with poor quality or sub-standard products. This led the government to approve a regulation that empowers the Ethiopian Energy Agency to set minimum and maximum energy efficiency performance standards for types of equipment and appliances. Recently held research, on March 27th, 2019 At Addis-Ababa on a title a new research on integration of variable renewable energy sources (VRES) in the National Electric system of Ethiopia developed by Enel Foundation and RES4 Africa, shows that the country can accommodate up to 3.6 GW of wind capacity and as much as 5.3 GW of solar PV capacity by 2030. With a strong dependency on the hydropower currently, the country could see its renewable mix improve by growing from the current 0.3 GW of wind capacity to 2.4 GW by 2025, before reaching 3.6 GW by 2030. In the same period, virtually inexistent solar PV capacity can reach an impressive 3.3 GW by 2025 ahead of the 5.3 GW project installed capacity in the year 2030.

Table 2.1 Solar PV projects installed in Ethiopia

No	project Name	capacity in(MW)	Estimated projectCost(USD million)	Region
1	Metehara Solar	100	120	Oromia
2	Gad solar scale	125	150	Somali
3	Dicheto Solar Scale	125	150	Afar
4	Mekele solar	100	120	Tigray
5	Humera Solar PV	100	120	Tigray
6	Welenchiti Solar PV	150	165	Oromia
7	Weranso solar PV	150	165	Afar
8	Metema Solar PV	125	150	Amhara
9	Hurso Solar PV	125	150	Dire Dawa

A report in this research indicates that more than 60 million habitants still without electricity. Ethiopia's growth in renewable capacity, through projects such as Enel Green power's 100MW Metehara Solar PV project in the region of Oromia, will strongly support the country's electricity access efforts. As CRLO PAPA, Director of Enel Foundation highlighted the importance of these results" This will allow achieving well balanced Energy Mix, reaching almost 25% of energy produced by wind and PV power plants, both in 2025 in 2030 increasing substantially the system resilience in case of extreme climatic conditions and diminishing the strong dependency of Ethiopia from Hydropower. However, most rural areas of the community do not get the opportunity to use grid electricity to drive the water pump and use surface water, wells, ponds, deep drilled well, and Pumping mechanism was based on man labor (most of them), generators or by using fuels. This pumping system has drawbacks such as poor availability of spare parts, unreliable supply of fuels, high running and high maintenance costs, consumes energy, wastage of time due to manually pumping system [15]. According to Foster RE,“ Renewable energy water pumping systems are now emerging on the market and are rapidly becoming more attractive than the traditional power sources”. He explains that technologies powered by renewable energy sources are especially used in remote locations where steady fuel supply is problematic and skilled maintenance manpower is scarce [16]. Another researcher Achour Bekta from University of Bisrak, has been studied on Photovoltaic water pumping development in the south without consideration of maximum power point tracking (MPPT). He was focus only on motor operations and optimization of PV pumping systems [17]. PV technology converts the sun’s energy into electricity through electromagnetic means when the PV module (array) is exposed to sunlight. The technology is similar to any other conventional water pumping system except that the power source is solar energy. According to B.Bouzidi, the PV system is more economical than other renewable energy. This paper mentioned that Using diesel or engine based water pumping system has economical and environmental impacts such as cost of fuel, air pollution due to smokes from the generator[6]. He use tanker to replace battery that store electricity and concludes that solar-powered water pumping is the best option to reduce maintenance cost and operational costs.Another researcher Misrak Girma from Ethiopia presents the viability of the Solar/ Wind and Hybrid Water Pumping System for off-Grid Rural Areas in Ethiopia. This can be achieved by studying Solar and Wind Potential at the selected site and design a water pumping system for both solar and wind and by combining the two energy source solar and wind, the Hybrid water pump has been designed. In this paper maximum power point, tracking and energy storage battery was not used. The paper concludes that the Hybrid water pumping system is more feasible than a standalone PV and Windmill [18]. H.M. Met Wally has been studied on,” Did on Directly coupled photovoltaic water pumping system by using DC Shunt Motor. Due to solar radiation fluctuation during the day from morning till evening, DC Motor pumps cannot operate at maximum power point [19]. To improve the problem of fluctuation of solar radiation on DC Motor pump performance, he added maximum power point tracking (MPPT). Power electronic converters increased the output power, performance of the system and overall efficiency of the system [20]. Using the controller by providing inputs, storage tank levels and pump speed can be controlled. Using DC-DC converter between the PV Array and the pump can reduce the physical size of the PV Panel area required for a given output, improve the power yield, overall efficiency of the systems [21]. Previously PV Pumping systems used Centrifugal pumps with DC Motors and the second generation of PV technology used Positive Displacement Pumps, progressing cavity pumps and Diaphragm pumps with AC motors are characterized by low PV input power requirement, high efficiency proven long-term reliability and efficiency varying from 25% to 35%.[22]. A researcher Mauray, V. Nhas did 'Numerical Simulations and design parameters in the solar PV water pumping system by using Simulink [22].The two Maximum Power Point Tracking (MPPT) Algorithm technique, Perturbation, and Observation algorithm and incremental conductance algorithm were performed by the two researchers below mentioned. Zainudin and Mekhilef explain the comparative study between the two MPPT algorithms techniques. The method was studied on different converters like a buck, boost and Cuk converters. In this paper, perturbation causes the power of the module to change. If power increase due to perturbation, perturbation continue in the same direction and the power at the next instant decreases after the peak power is reached and perturbation changed its direction. P&O method fails to track the power under highly varying atmospheric conditions and calculates the wrong MPP. Incremental Conductance algorithm technique does not go in the wrong direction when atmospheric condition changes rapidly but its design is complex that requires additional control circuit that increases cost [23]. Malla et al. 2011 [24] designed a stand-alone PV water pumping system without battery storage in MATLAB/Simulink. The system consists of Perturb and Observe (P&O) algorithm based MPPT (Maximum Power Point Tracker) for improving efficiency. He proposed the control strategy to monitor the water discharge speed for a single_ phase induction motor and for multiphase induction motor types. According to Chandel et al. [25], Motor Pumps which are suitable for solar water pumps can be DC or AC surface mounted or submersible pumps. According to Anis and Nour [26] increasing both array and battery size needs more cost, but using large size water tank is more economical. Abu-Aligah 2011 [27] did the Life Cycle Cost analysis between PVDC and diesel engine systems. He states that the PVDC system is a more reliable system than diesel even though its initial cost is high. Senol 2012 [12] is another researcher who did economic analysis for three different cases: (i) no subsidy, (ii) 50% subsidy (not including PV module cost), and (iii) a 50% subsidy (including PV module cost). His research outcome proved that PV powered pump is more preferable. In this research many limitations will have been addressed, such as previously directly coupled PV panel to DC motor Pump has been used but this has its own disadvantages; DC motor has high starting torque which is mismatch with variable load torque, this is due to variable solar irradiances this may cause damage of equipment or not operate properly. DC motor is not available everywhere easily, it is so expensive and also it needs high maintenance. Nowadays, AC motor is more appropriate for water pumping systems, because it has constant torque, less expensive than DC motor, simple, easily maintained, available everywhere and has less efficiency than DC motor pumping [28]. But by reducing switching losses of Inverter using (IGBT) and (SPWM) technique, its efficiency can be increased and Buck converter with P&O MPPT.Even if hybrid solar and wind is more feasible as done by Misrak Girma[18], due to its simplicity and cost effectivity stand-alone PV water pump system is considered.

2.3 Conduction Process in Semiconductors

Electrical current will flow in the material if there are charge carriers (usually electrons) in the material that are free to move in response to an applied electric field. The number of free carriers in various materials varies over an extraordinarily wide range. In metals, the free- electron density is in the order of $10^{23}cm^{-3}$ whereas in insulators such as quartz the free- electron density is less than $10^{3}cm^{-3}$. This difference in free-electron density indicates that the conductivity of the material in metal is in the order of 10^{6}mhos-cm^{-1}, 10-^{15}mhos-cm^{-1}in insulators. A material such as silicon or gallium arsenide which has free – carrier density intermediate between that of insulator and metal in the range of (10^{8}-$10^{19}cm^{-3}$) is termed as a semiconductor. This ability to manipulate the free-carrier density by large amounts is what makes the semiconductor unique and useful material for electrical application.Incident solar radiation which acts as a discrete energy unit called Photons. It the product of the Wavelength(λ) and the frequency V which results in the speed of light. The energy of a photon is the function of frequency V of the radiation and its wavelength and is given in terms of Planck's constant, h. The most energetic photons are those of high frequency, v, and short wavelengths. In 1883 Charles Fritts developed the Cell working principles by converging layers of the material selenium with a thin layer of gold. The first modern Silicon cell was developed in 1941 by Russel Ohl, with a yield of 4%. An atom of Silicon in the crystal lattice absorbs photons of the incident solar radiation. If the energy of the photon is high enough, an electron freed from the outer most shell of the atom. During this process, an electron _hole pair is formed and, where their hole lacks an electron. The free-electron disappeared spontaneously and again recombine with holes. The recombination process can be reduced by building a potential barrier into a cell, junction cross which a static charge exists. This barrier is created by doping(Adding impurity to the silicon) on one side of the barrier with very small amounts(of the order of one part in 10^6) of boron atom to form n_type silicon layer , which has a deficiency of electrons in its outer shell and on the other side with phosphorus tom to form p_type silicon layer, which has an excess electrons in its outer shell and the barrier inhibits the free migration of electrons leading to build of electrons in the n_type silicon and deficiency of electron in the p_type silicon. If both n_type silicon and p_type silicon layer are connected by an external circuit, electron(i.e, current will flow through that circuit). Electrical Contacts are taking place by using Metal bases on the bottom of the PV cell and Metal grids on the top layer of the PV cell. photons of light with higher energy can break free electrons in the PV material and create electron-hole pair and these electrons fall back into hole causes charge carriers to disappear. Providing electric field nearby free electrons can be continuously swept away from holes towards metallic contacts. Reflection losses are there at the top surface of the cell, which can be reduced by active coating. Contact grids are used to reduce active cell area as shown in figure 2.3 below.

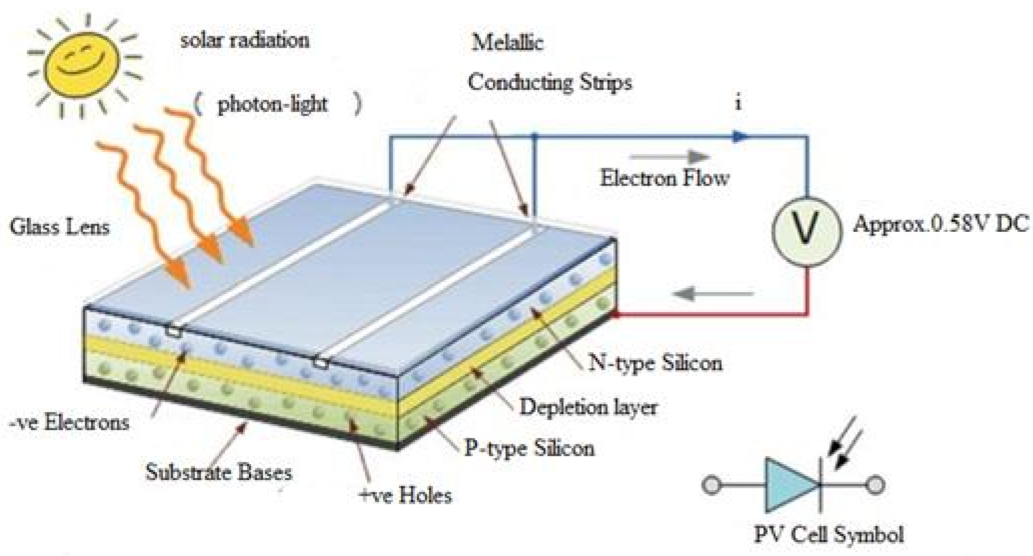


Figure 2.3 PN junction of PV cell showing Hole- Electron pairs created by photons[pinterest.com].

2.3.1 Photovoltaic Cell

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Individual solar cell devices can be combined to form modules, otherwise known as solar panels [29]. A solar cell is a device that converts the energy obtained from the sun, directly into electrical energy. It is also defined as a solid-state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. The photoelectric effect refers to the emission, or ejection, of electrons from the surface of, generally, a metal in response to incident light. In other words, it is the emission of electrons or other free carriers when light hits a material. This average energy carried by an ejected (photoelectric) electron should increase with the intensity of the incident light. Figure 2.4 below shows how electrons emit in response to incident light.

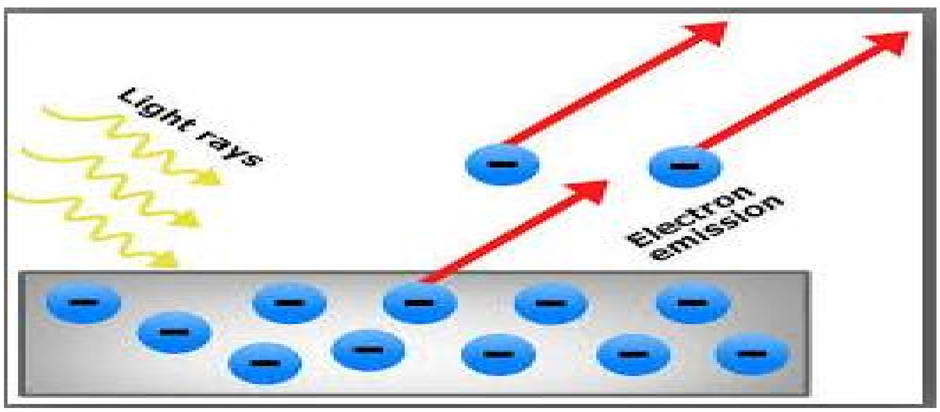


Figure2. 4 photovoltaic effect shown by the diagram[scienceabc.com]

In basic terms, a single-junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts[29]. Solar cells are described as being photovoltaic, irrespective of whether the source is sunlight or artificial light. They are used as a photo-detector, detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

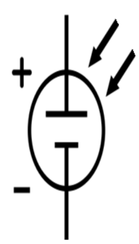


Figure2.5 symbol of photovoltaic cell[common.wikimedia.org]

Assemblies of solar cells are used to make solar modules that generate electrical power from sunlight, as distinguished from a "solar thermal module" or "solar hot water panel". A solar

array generates solar power using solar energy. Multiple solar cells in an integrated group, all oriented in one plane, constitute a solar photovoltaic panel or module. Photovoltaic modules often have a sheet of glass on the sun-facing side, allowing light to pass while protecting the semiconductor wafers. Solar cells are usually connected in series and parallel circuits or series in modules, creating an additive voltage. Connecting cells in parallel yields a higher current; however, problems such as shadow effects can shut down the weaker (less illuminated) parallel string (a number of series-connected cells) causing substantial power loss and possible damage because of the reverse bias applied to the shadowed cells by their illuminated partners.
Strings of series cells are usually handled independently and not connected in parallel, though as of 2014, individual power boxes are often supplied for each module, and are connected in parallel. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity, using independent MPPTs (maximum power point trackers) is preferable. Otherwise, shunt diodes can reduce shadowing power loss in arrays with series/parallel connected cells.

2.3.2 Construction of Solar cell

Solar cell construction consists of a silicon PN junction diode with a glass window on the top surface layer of P material extremely thin so, this may able the incident light photon's easier to reach the PN junction. When these photons collide valance electrons, they comfort them sufficient energy as to leave their parents atoms. During this interaction, the free electrons and holes are generated on both sides of the junction. The current produced due to these holes and electron is directly proportional to the illumination's (MW/cm2) and also depends on the size of the surface an illuminated. The operation of a photovoltaic (PV) cell requires three basic attributes, the absorption of light, generating either electron-hole pairs, the separation of charge carriers of opposite types, there is separate extraction of carriers to an external circuit. As shown in the figure (2.6) below, the solar cell is like an ordinary diode. It consists of germanium, Silicon PN junction with glass windows on the top surface of the layer of P-Type material is made with very thin and wide so this may able the incident light photon easily reach to PN Junction. The P nickel-plated ring around the Player acts as the positive output terminals (anode) and the metal contact at the bottom acts as a cathode. As soon as sunlight shines on the PV panel, electrons are detached from the top of the panel under the influence of solar radiation, as a result, there is a free electron with a corresponding hole.

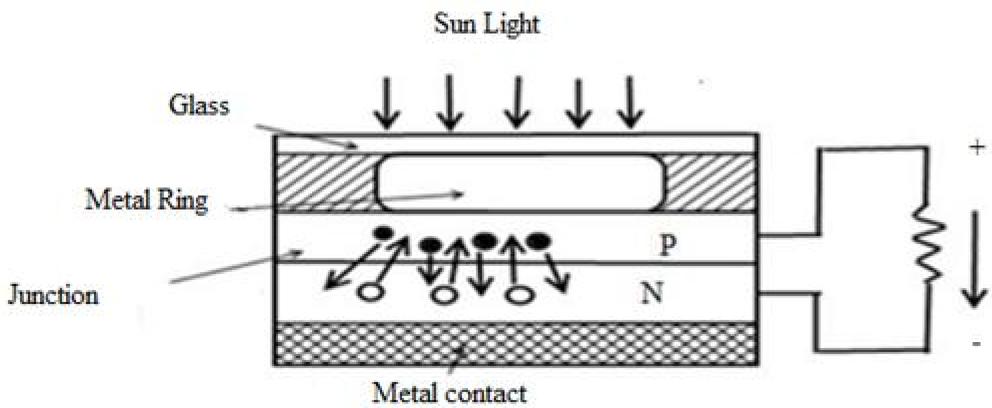


Figure 2.6 Simplified Solar Cell Construction[daenote.com]

Due to unequal charge distribution, an electric field arises at the interface, this leads an electron to go only one way. Every type of material has its own characteristics. One of these characteristics is the so-called bandgap. It is the energy difference that an electron has to bridge to jump from the valance band to the conduction band. It is the property that determines which pair of solar radiation is absorbed by the cell. Radiation has either insufficient energy to wake up the electrons or has much lower power than the atoms absorb it.The sun does not shine equally well in all wavelength, this leads the materials to have better maximum efficiency than the others. Figure 2.7 is a diagram shows the materials band gap plotted against the maximum achievable yield.

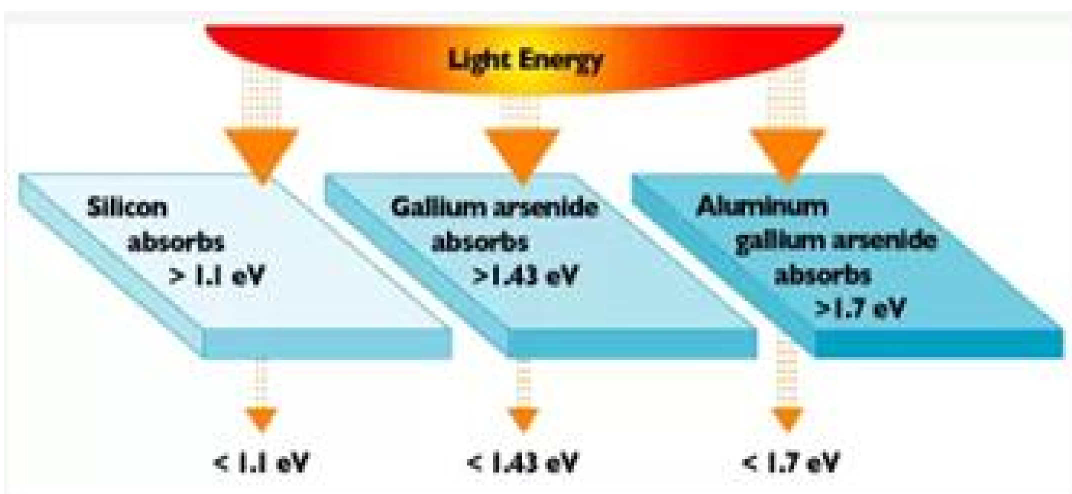


Figure 2.7 Bandgap Energy for different semiconductor Elements[horiba.com]

2.3.3 Working principles of Solar Cell

As soon as the solar cell is exposed to sunlight, the energy which is present in the form of a light photon is absorbed by semiconductor materials. As a result of this absorbed energy, the phenomena of photovoltaic occur and electrons are liberated and produce the external DC current. conversion of Photovoltaic depends on the number of photons striking the earth. On a clear day, about $4.4(10)^{17}$ photons strike the square centimeter of the earth's surface every second. Only some of these photons which have excess ban gap are convertible to the solar cell.

2.4 Types of PV Panel

There are 3 types of technology utilized in the solar panels available on the market today. These are mono-crystalline, polycrystalline, and thin-film amorphous. As the names suggest Mono-crystalline and Polycrystalline are both types of solar cells that are made from crystalline silicon. Both mono-crystalline and polycrystalline solar cells are very similar in performance. Thin-film is a totally different technology. It is much less efficient and therefore uses much more roof space. It's one advantage is that it performs better in low light conditions, when there is partial shading of the system or in extreme heat.

2.4.1 Mono-Crystalline Solar Cells

They are also known as single-crystalline silicon because they have a very even and uniform look, and this is mainly because only the purest silicon of the highest quality is used to make them. They are made from cylindrical silicon ingots that are cut into wafers and have higher efficiency. They can better exploit the sun irradiation Its efficiency is about 20–21 % [29] and it is higher as compared to polycrystalline solar panels. The panel occupies lesser space which is about 80 sqft and it is quite expensive.

2.4.2 Poly-Crystalline Solar Cells

Poly means many, so a polycrystalline solar panel is made up of more than one material. In a polycrystalline solar panel, fragments of silicon are melted to form a wafer of the panel. Its efficiency is around 16–17% and it occupies 100 sq ft. Moreover, it is less expensive as compared to mono-crystalline. Polycrystalline is also known as multi-crystalline solar panels. Advantages of this solar panel include, the manufacturing process is simpler and cheaper, there is no silicon waste, and they have a higher performance while increasing the operating temperature.

Its disadvantage includes Lower efficiency due to low silicon purity, require a higher installation area than a mono-crystalline solar panel, Lower architecture integration.

Table 2.2 Comparison of different Solar Panel

Parameters	**Mono-crystalline solar panels**	**Polycrystalline solar panel**	**Thin-Film solar panels**
Efficiency	high, 15-20%	less, 14-16%	7 -13%
space it covers	small space	large space	very large space
life span	longer than 25 years	because of its lower silicon purity, it lasts below 25 years	The shortest life span of the mono& poly solar panels.
Cost	High	less expensive	least expensive
heat tolerance	High	Less	Medium
high-temperature co-efficient and shading effects	its output decrease as temperature increase and shading effect increase	its output decrease as temperature increase and shading effect increase	less effect on the PV performance

By considering from the above table (2.2) the factors that have taken into consideration for the selection of PV panel must compromise with the country levels of Economical developments that means the initial cost plus the operational cost and maintenance cost for a mono-crystalline solar panel is very high regarding developing countries like Ethiopia. For achieving this goal, polycrystalline silicon solar panels have been selected. If all the solar cells in a module have identical electrical characteristics, and they all experience the same intensity and temperature, then all the cells will be operating at exactly the same current and voltage. In this case, the IV curve of the PV module has the same shape as that of the individual cells, except that the voltage and current are increased.

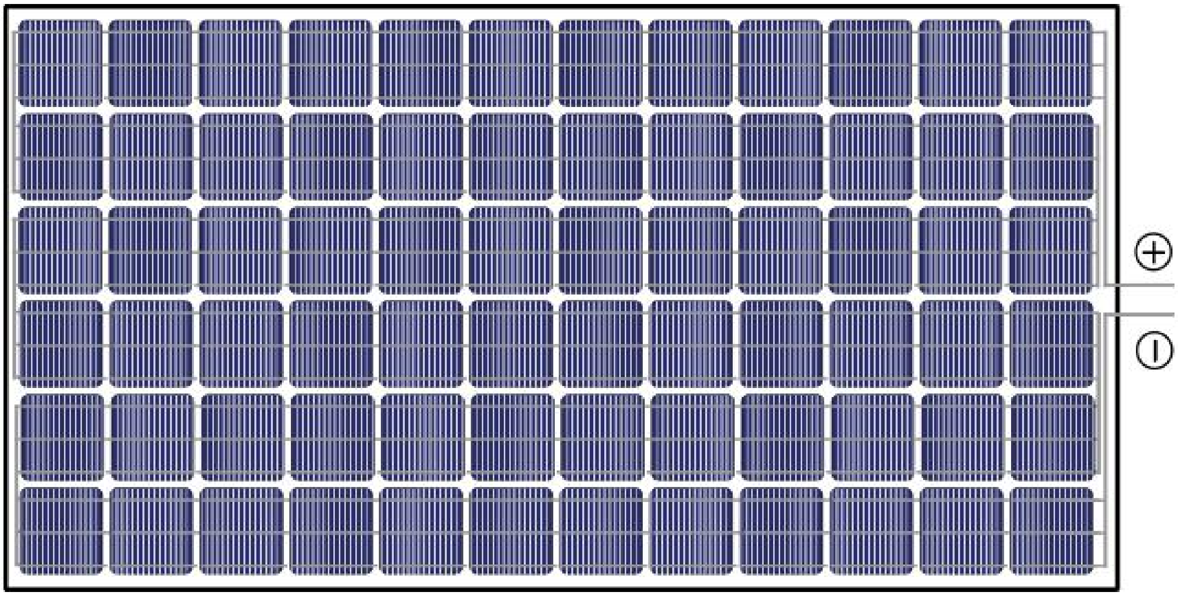


Figure2.8 Polycrystalline Silicon Solar Cell Series Connection[pveducation.org]

2.5 Types of solar PV System

Photovoltaic power systems are grouped under two type, these are off-grid (not-connected grid) and on-grid (grid-connected) PV systems. It can be designed to produce whether DC or AC voltage.

2.5.1 Grid-Connected PV systems

Since PV system produces less DC power, so for the need of AC system no need of bulky system like transformer that is so expensive, simply by using an electronic device called an Inverter the DC voltage produced by the PV system can be converted into AC power up to the need of grid by selecting an appropriate inverter.

2.5.2 Stand-Alone Photovoltaic System

Off-grid PV systems application is more applicable in the place where the power from the grid is far away, such as rural areas. It employs deep cycle rechargeable batteries and used for accumulating electricity for use when the seasonal weather condition varies. A stand-alone PV system is used to supply a certain DC or AC electrical loads.

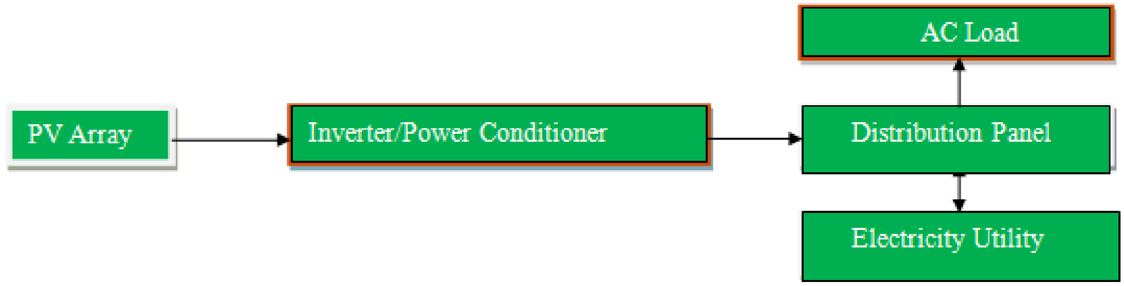


Figure 2.9 Grid-connected PV system diagram

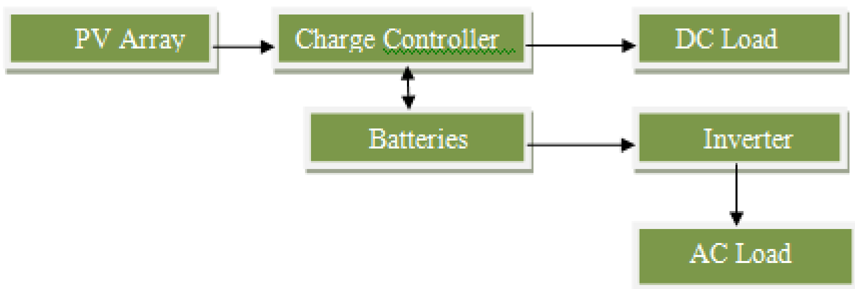


Figure 2.10 Stand-alone PV system diagram

In the above figure 2.9 Grid-connected PV system diagram shows that the power that comes from the solar energy is given to the inverter(DC-AC) converter and this power is stored in distribution panel and distributed to different AC loads and the remaining goes to electricity utility.

For stand-alone PV system diagram in the above figure 2.10 shows that the power which comes from the PV array is controlled by charge controller(DC-DC) converter is given to the DC load and the charge controller dc-dc may be step-down (buck converter) or step-up(boost converter) it is depend on the type of DC load required.Batteries are used for back up energy during low solar radiation to supply the energy for the required load of the inverter.

CHAPTER THREE
METHODOLOGY

The methodology to achieve the general objective of the study includes; Literature Review**:** From different journal papers, Articles, conference papers which have been done on solar-powered water pumping.

3.1 Data collection methods

Primary resource: Primary data has been collected by observation and field investigation of the selected site. Data for the Well types, well depth, water volume, and the number of residents, the storage size which fulfills the water demanded, total gallons of water used per day, all these data are obtained from the Water and Energy Office of Bishoftu.

Secondary source: The secondary source of data for the solar-powered water pumping system was obtained from a wide variety of sources, such as documents of off-grid rural water pump system components, specification of water access projects which has done previously and some other related sources, which includes, theoretical knowledge of solar energy technology, for solar PV water pumps available in the literature, data for solar radiation has been analyzed from sources such as National Meteorology Agency (Bishoftu Agricultural and Research Institute Office) and NASA.

3.2 Data Analysis Methods

Once the investigation of data would complete, expected to collect from the field and the data obtained from secondary sources and cross-checked, verified, analyzed and interpreted data theory on basis of the problem and generalizing principles using appropriate theories**.** Analysis of the solar water pumping system involves many constraints which are mentioned below. Analysis of environmental sustainability: Identifying the environmental sustainability of water pumping systems using solar PV energy requires an assessment of the available volume of water resources in terms of quality and quantity. Consider revising whether the water could be negatively impacted beyond an acceptable threshold, by getting a piece of advice from water quality experts. Identification of unsuitable areas: Those are factors that restrict the feasibility of solar pumps.This has been done by excluding areas where, low solar radiation is available, Excludes areas with no sufficient water volume exists. Analysis of photovoltaic system performance and reliability assessment developed by using mathematical modeling of each subsystem with its graphical demonstration. . To achieve all these tasks, the following designing steps are followed. first, identifying place where high volume of water is found around the site, second, calculating water requirement for the community in cubic meter(m^3) per person per day, third**,** calculating total load demand per day, and power requirement per day, then making decision to balance load demand and power requirement, forth**,** determining solar radiation of the site and identifying distances of storage tank will be placed, fifth**,** calculating total dynamic head of the pump and pump selection that meets daily flow. Sixth, determine the number of solar panels and selecting solar array size depending upon the power requirement of the pump, seventh, mathematical modeling of PV module and PV cell and drawing I-V characteristic curves.

3.3 Mathematical Modeling of PV Cell

The equivalent circuit diagram of the PV cell is shown below and includes Photon currents (I_{ph}) or Source current, a diode (D), and shunt resistance (R_{sh}), a series resistance (Rs)

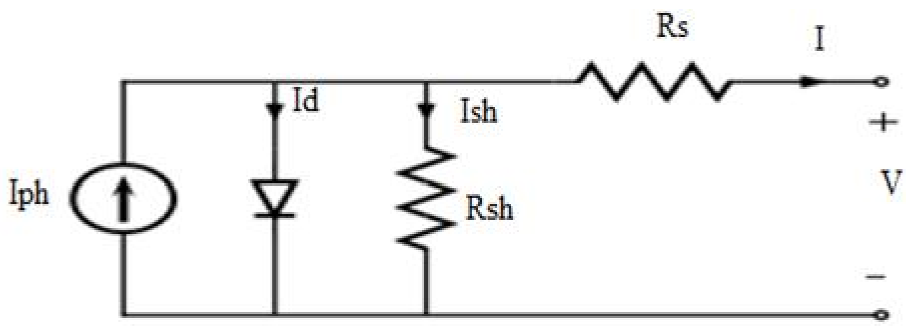


Figure 3.1 Circuit diagram of PV Cell[https://WWW.alaboutcircuit.com]

The PV cell circuit diagram modeled from two diodes parallelly connected to the source current or photon current represents the recombination effects of charge carriers. This configuration gives more accurate results but its computational time is much longer, so for its simplicity, a single diode-connected PV cell circuit model is used in this work [30]. Mathematical equations of PV cell/module can be calculated as follows: The voltage, current (V-I) characteristic equation of the PV cell is given by By applying KCL to the above PV circuit.

Iph – Id – Ish –I = 0, from this formula, each current value can be obtained as follow:

$$I = I_{ph} - I_0\left[e^{\frac{q(v+iRs)}{nKT}} - 1\right] - \frac{v+iRS}{Rsh} \tag{3.1}$$

Where $I_{ph} = I_{sc} + K_i(T - T_a)\frac{G}{Gref}$ (3.2)

The cell's saturation current equation becomes

$$I_{sc(T)} = I_s\left(\frac{T}{T_a}\right)^3 * e\left[^{\left(\frac{T}{Ta}-1\right)\frac{Eg}{Vt}}\right] \tag{3.3}$$

PV cell's saturation current varies as cell's temperature varies.

The cell's thermal voltage can be calculated as follows:

$$V_t = \frac{KT}{q} \tag{3.4}$$

The total output current, I_{pv} of the PV module is given:

$$I_{pv} = N_p * I_{ph} - N_p * I_0\left[e^{\{q*(\frac{V_{pv}+IRs}{n*N_S**KT}\}} - 1\right] \tag{3.5}$$

Voc = KT [exp(Iph-Is)] +1 (3.6)

Where, K, is Boltzmann constant, T, is the temperature, q is the electronic charge, Iph, is the photocurrent, and Is the diode saturation current.

$$Is = \frac{Isc(t)}{\exp(q*\frac{Voc}{n}*Ns*KT)) - 1]} \tag{3.7}$$

Where Ish = $\frac{(V + I*Rs)}{Rsh}$,Where the NOMENCLUTRES used here are, V_{pv} the output voltage(V), I_{pv} output current(A), T_a the reference temperature, T is the operating temperature in Kelvin, I_s= Io is the saturation current (A), I_{sc} the short circuit current, Irs is the cell reverse saturation current at a reference temperature, I_{ph} ,the light generated current or photon current,n is the ideality factor,K, the Boltzmann constant ($1.3805*10^{-23}$ J/K), Q ,electron charge ($1.6*10^{-19}$ C),Rs is the series resistance,Rsh is the shunt resistance,Ns is the number of cells connected in series, N_p is the number of cells connected in parallel, E_g is the bandgap energy (1.1 eV), K_i is a cell's short circuit temperature coefficient, G is the irradiance (W/m^2), G_{ref} is reference irradiation (W/m^2). Short Circuit Current,the short circuit current (Isc) is also temperature-dependent. It increases with temperature for a short period of time and tends to decrease from its saturation value at the temperature value that goes higher. Open Circuit Voltage**,** the open-circuit voltage (Voc) is the voltage across the internal diode when the total generated photocurrent flows through this diode. The open-circuit voltage is strongly dependent on temperature. The factor which represents how square has PV panel voltage/current characteristics are expressed by its fill factor. It is the ratio of the maximum power point divided by open-circuit voltage and short circuit current [31]. It determines the shape of the solar cell I-V characteristics. Its value is higher than 0.7 for good cells. The fill factor is useful parameters for the quality control test. It is obtained by dividing the peak power of the PV by its short circuit current.

$$FF = \frac{P_{max}}{V_{OC} * I_{sc}} \quad (3.8)$$

PV panel fill factor is usually between, 0.7 and 0.8 ideal PV panel has 1.0[31]. Designing and simulations of solar-powered water pumping system were conducted by MATLAB R2015a software and Simulations of the system was based on the maximum annual water demand and also pump and solar panels selection from the MATLAB data sheet should meet the maximum annual water demand.

3. 4 Modeling and Simulations of the PV Cell

PV Cell and Array Modeling is done Using MATLAB software and its I_V and P_V characteristics curves are obtained by adjusting its slope(fill factor).

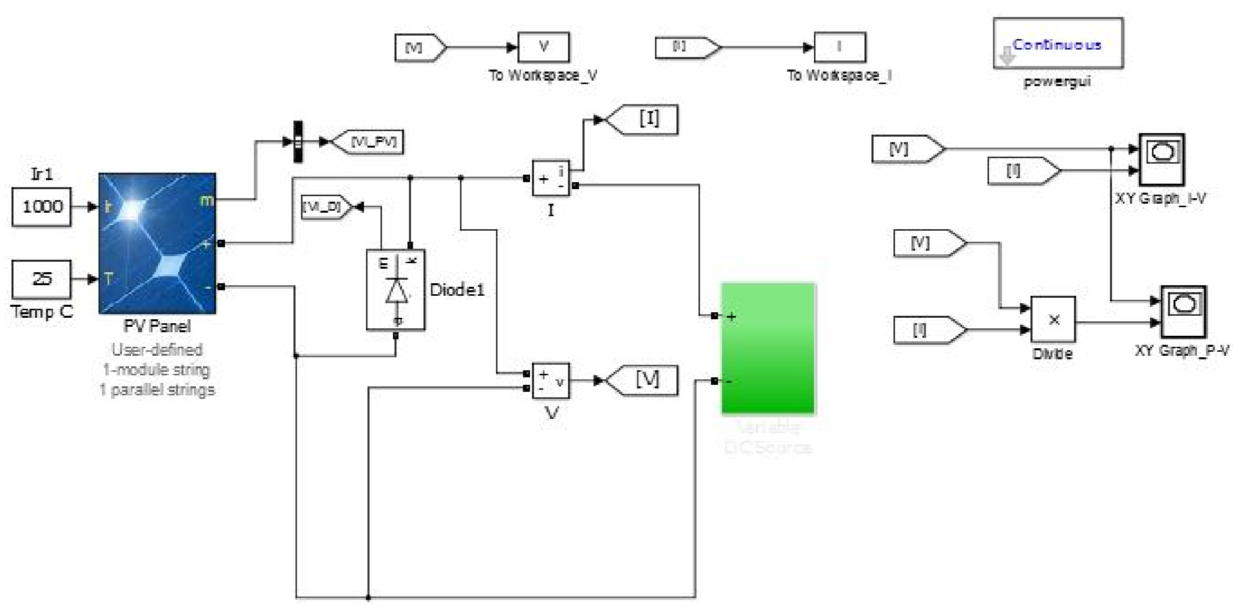


Figure 3.2 PV Module MATLAB Simulink Model

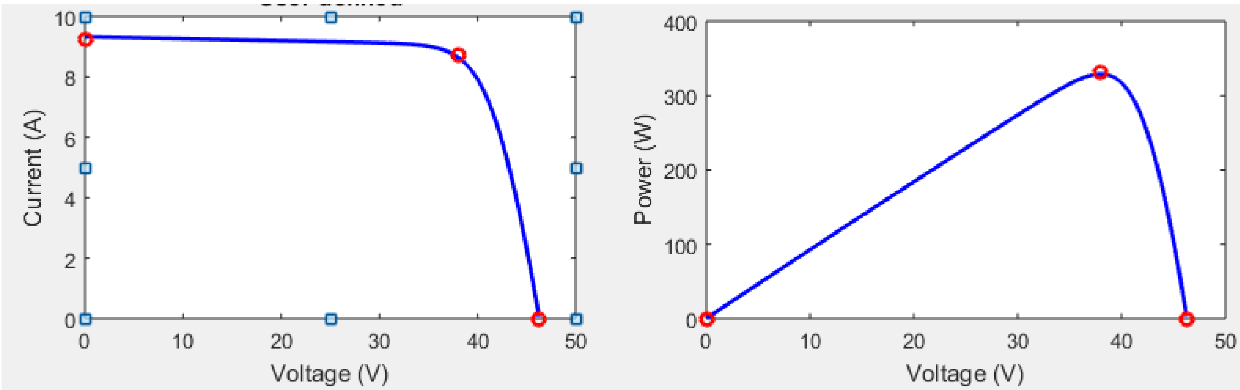


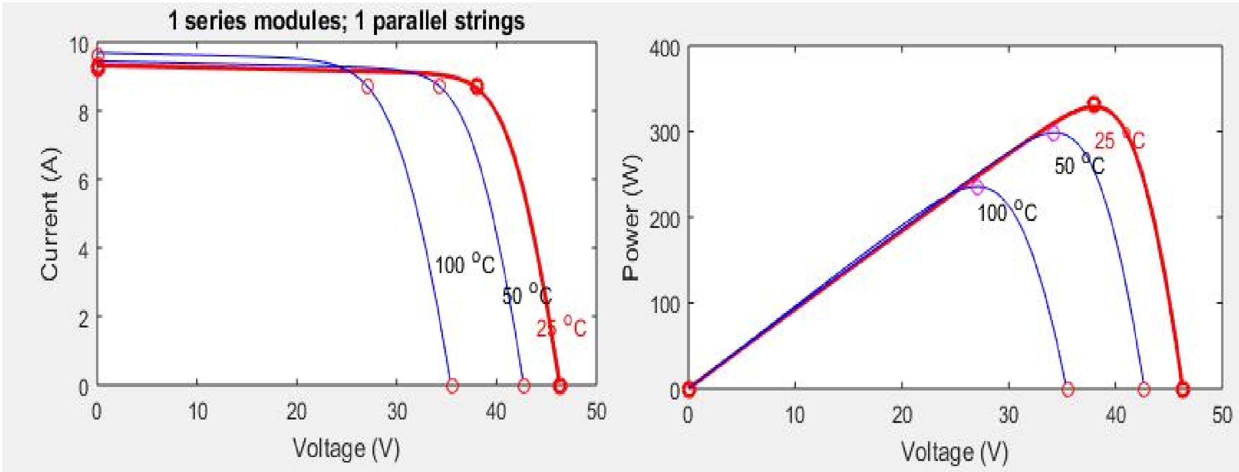
Figure 3.3 I-V and P-V Curve of the selected panel at the STC of irradiance and temperature(1000W/m^2, 25^{0}C)

3.5 Factors that affect the performance of PV Cell

Environmental conditions: Solar irradiation, Meteorological data, Air mass, temperature. PV panels: Types of PV materials, Tilt angle, Azimuth angle and characteristics of PV Cells. Controllers: MPPT, charge controllers. Converters: buck, boost, buck-boost and inverter performance. Energy storage**:** water storage, battery (energy storage) and pumps/Motors.

3.5.1 The Effect of Temperature on Solar Cell

Solar Cells are sensitive to temperature. Temperature and bandgap energy of semi-conductor materials have an inverse relationship, i.e. increase in temperature reduce the bandgap energy of semiconductors. The decrease in the bandgap of semi-conductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is needed to break the bond. In the solar cell, the parameter most affected by temperature is the Open circuit voltage. The impact of increasing temperature on the solar cells is shown in figure (3.4) below



(a) (b)

Figure 3.4 The effect of temperature on I-V and P_V curve of Vikram Solar at 50^0C, 100^0C $1000W/m^2$

From figure (3.4) above, the open-circuit voltage dependency is expressed in terms of intrinsic carrier concentration which depends on the bandgap energy. Lower bandgap energy gives higher intrinsic carrier concentration.

3.5.2 Effect of Light Intensity On the solar panel: Changing the light intensity incident on a solar cell change all solar parameters, like short circuit current, open-circuit voltage, FF, efficiency and series, and shunt resistances

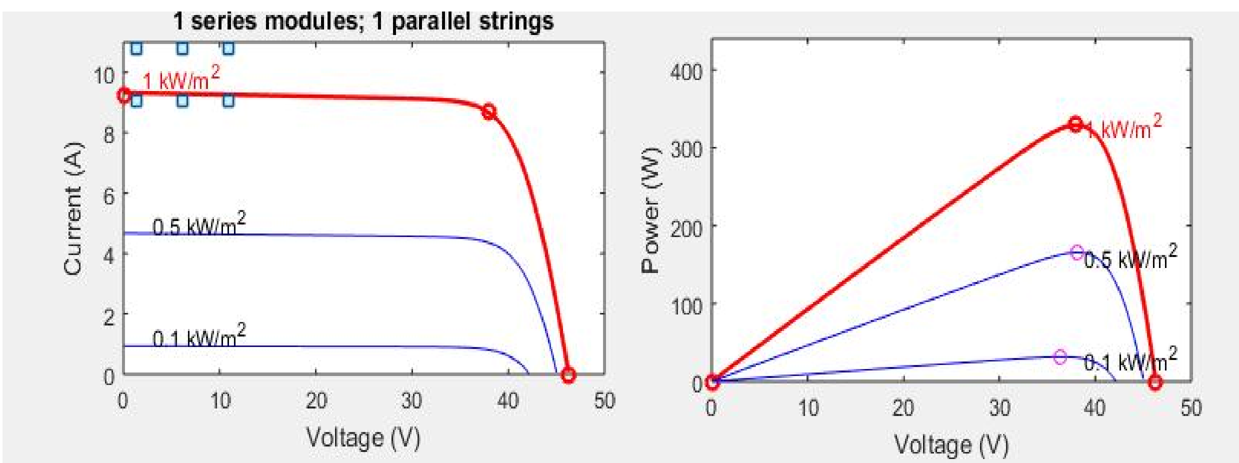


Figure 3.5 The Effect of Solar intensity on the I-V And P_V Curve of Vikram Solar at 25^0C

3.5.3 Effect of Series Resistance On Solar Cell

Series resistance in a solar cell has three major effects; first, it causes the movement of current through the emitter and base of the solar cell. Second, the contact between the metal contact and the silicon, and third, it may cause the resistance of the top and rear metal contacts. Its main impact is to reduce the fill factor, although excessively high values may reduce the short circuit current. It does not affect the solar cell at open-circuit voltage since the overall current flow through the solar cell and through the resistance is zero.

3.5.4 Effects of Shunt Resistance on Solar Cell :

Presences of power losses are caused because of shunt resistances, low shunt resistance in the solar cell causes power losses by providing an alternate current path for the light-generated current. This may reduce the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell. The shunt resistance effect is severe at low light levels since there will be less light-generated current. The loss of this current to the shunt, therefore, has a larger impact.

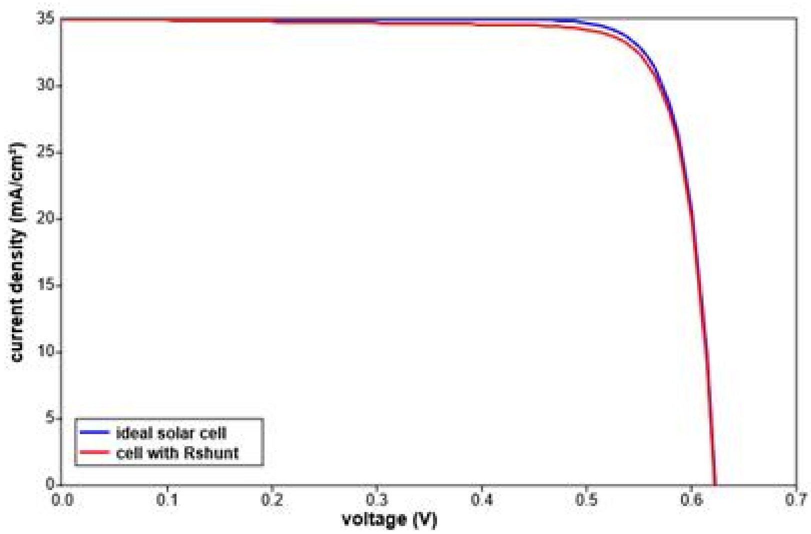


Figure 3.6 Effect of Shunt Resistance on Solar Cell I-V characteristics curve.

3.6Tilt angle and PV Module Orientation

The module orientation with respect to the direction of the sun determines the amount of solar intensity that falls on the module surface. The tilt angle and Azimuth angle determine the path of the sun.Tilt angle is the angle between the plane of the module and the horizontal surface. It is equal with a site latitude degree plus 15 degrees in winter and minus 15 degrees in summer. Azimuth angle is the angle between the plane of the module and due south. The optimum array orientation will depend on the site latitude angle and shadow effect has been taken into considerations.

3.8 PV Module and Array Formation

A single solar cell cannot provide the required useful output. So to increase the output power level of a PV system, it is required to connect the number of such PV solar cells**.** A solar module is normally a series-connected number of solar cells to provide the required standard output voltage and power. The output from a solar module depends upon some conditions such as ambient temperature and intensity of incidence light. Hence the rating of a solar module must be specified under such conditions. To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV Array as shown in figure(3.7) below.

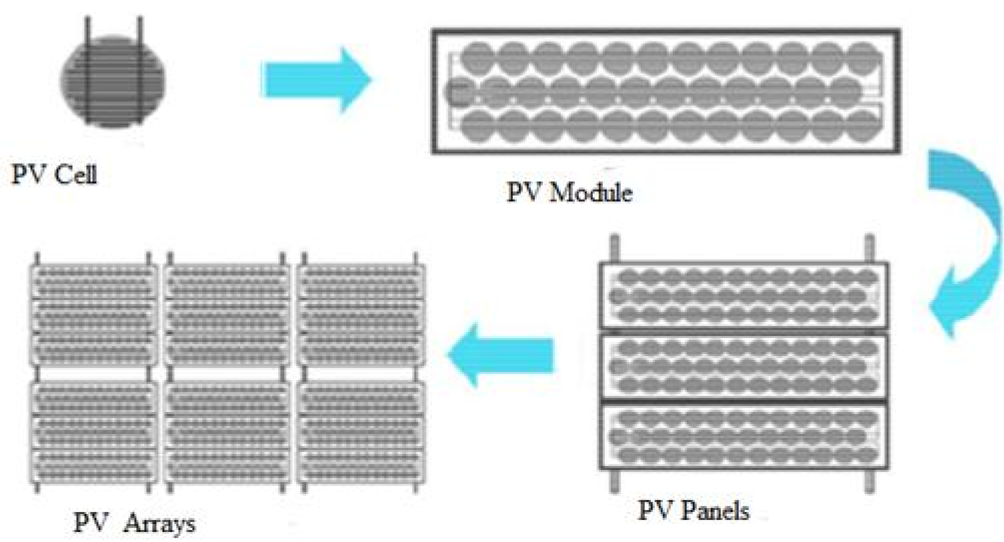


Figure 3.7 PV Cell, Module, Panels, and Array[Wafers, Modules & Arrays solardirect.com]

The efficiency of the PV module can determine the module performance. The efficiency of a PV module can be calculated as follows:

η_{pv}=$\boldsymbol{\eta}_r$[1- β_{pv} (T_d-T_r)] (3.9)

Where, T_d is the average temperature of the PV module, T_r is reference temperature of the module, $\boldsymbol{\beta}_z$ is the temperature coefficient for the module efficiency, $\boldsymbol{\eta}_r$ is module efficiency at the reference temperature, T_r. The array's PV module is characterized by its average efficiency (η_{pv}), which is a function of modules average temperature (T_d).The average module temperature (T_d) is calculated from the mean monthly ambient temperature (T_a) using Evan's formula as follows:

$$T_d\text{-}T_a= [219\text{-}832K_T]\ \frac{\text{NOCT}-2}{800} \quad (3.10)$$

The above equation(3.10) can be valid if the tilt angle is at the optimum condition, the tilt angle differs from the optimum value means the right side of equation(3.10) must be multiplied by the correction factor K which is defined by ;

$$K=1\text{-}1.17*10\text{^-}4(\boldsymbol{\beta}_z\text{-}\boldsymbol{\beta}) \quad (3.11)$$

$$\boldsymbol{\beta}_{z,=}\boldsymbol{\Phi}\text{-}\boldsymbol{\delta} \quad (3.12)$$

Where NOCT is nominal operating cell temperature, $\boldsymbol{\delta}$ is declination angle, $\boldsymbol{\Phi}$ is latitude angle

K_T is a monthly clearance index.

3.8.1 Module Selection:

The PV panels selected for this system must be able to provide the minimum energy required to run the pump.

The minimum power needed is 42000 Watts. However, the panels must also have additional capacity to account for any potential reduction in power due to high heat, dust, age, etc. Many PV manufacturers recommend increasing the minimum peak power value by 25% to account for these environmental factors. Comparing Vikram Solar Panel which have 330W with those solar panel having the maximum rating of 250W and Vikram Solar Panel is selected.This module is selected because of its better efficiency, and its high-temperature coefficient.

Table 3.1 ELDORA VSP.72.330.03.04 Vikram Solar Data Specification

I. Electrical Data	
Parameters	Values
Rated maximum power(Pmax)	330W
Open Circuit Voltage(Voc)	46.3 volts
Maximum Power Voltage(Vmax)	38 volts
Short Circuit Current(Isc)	9.24Amps
Maximum Power Current(Imp)	8.7 Amps
Module efficiency:	17.01%
Maximum System Voltage	1000DC
Maximum Series Fuse:	15 Amps
II. Mechanical Data	
Technology:	Polycrystalline(poly, 5BB
Dimensions	1956x992x36mm(±1mm)
Weight:	45.63 lbs
Number of cells	72(6x12)
Glass	3.2mm high transmission low iron tempered glass.
Junction Box	IP68/IP67, 3 Bypass diodes
Connector and cables	47.24 inch length cable, MC4 Compatible

Table 3.2 Temperature Coefficient (Tc) Vikram Solar

T_c of Open Circuit Voltage(ß)	-0.31%/^{0}c
T_c of short circuit current(ɣ)	0.052%/^{0}c
T_c of power(ɸ)	-0.41%/^{0}c
Maximum System Voltage	1000v
NOCT	44^{0}c ±2^{0}c
Temperature Range	-40^{0}c to +85^{0}c

3.8.2 Simulations of PV Array Using MATLABR2015a

MATLAB Simulation for the designed Array can be shown as in figure (3.8) below:

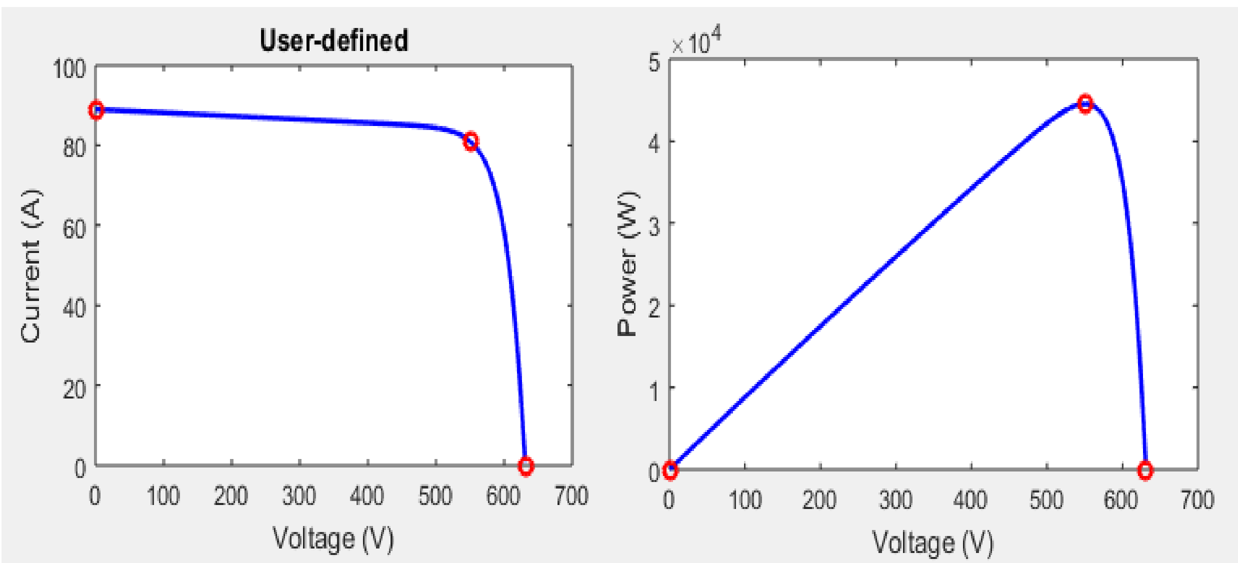


Figure 3.8 The I-V and P-V characteristics of PV Array at 1000W/m^2 and a 25^{0}C.

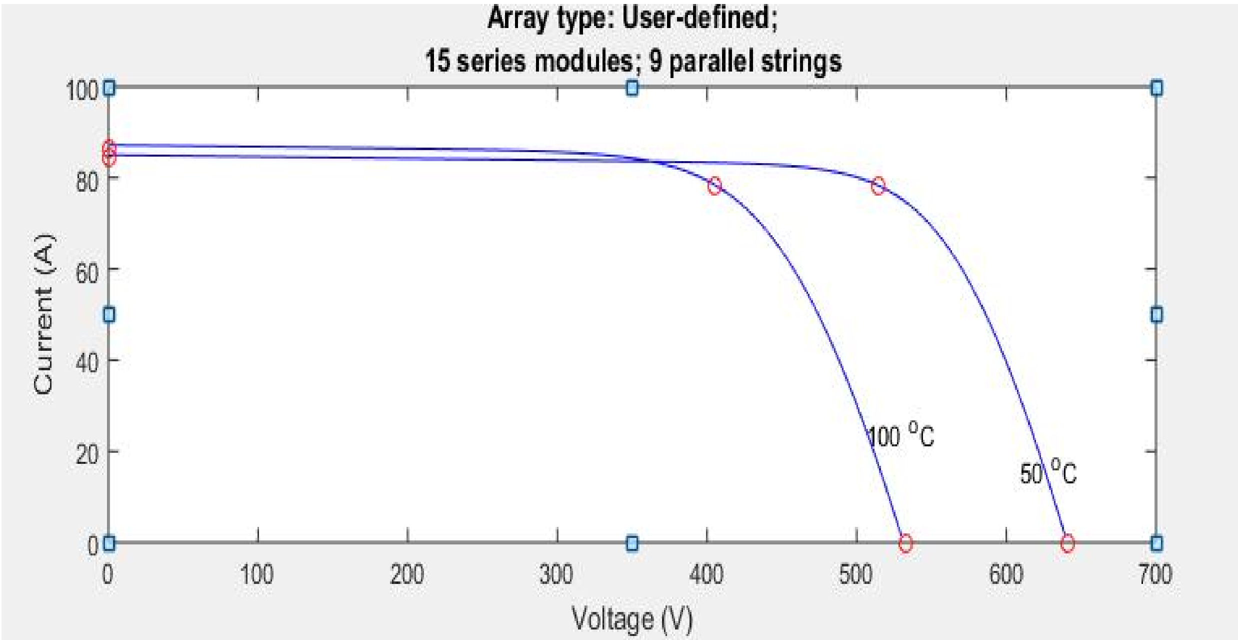


Figure 3.9 the I-V Curve of the PV Array at a different temperature of 50^0C, 100^0C 1000W/m^2

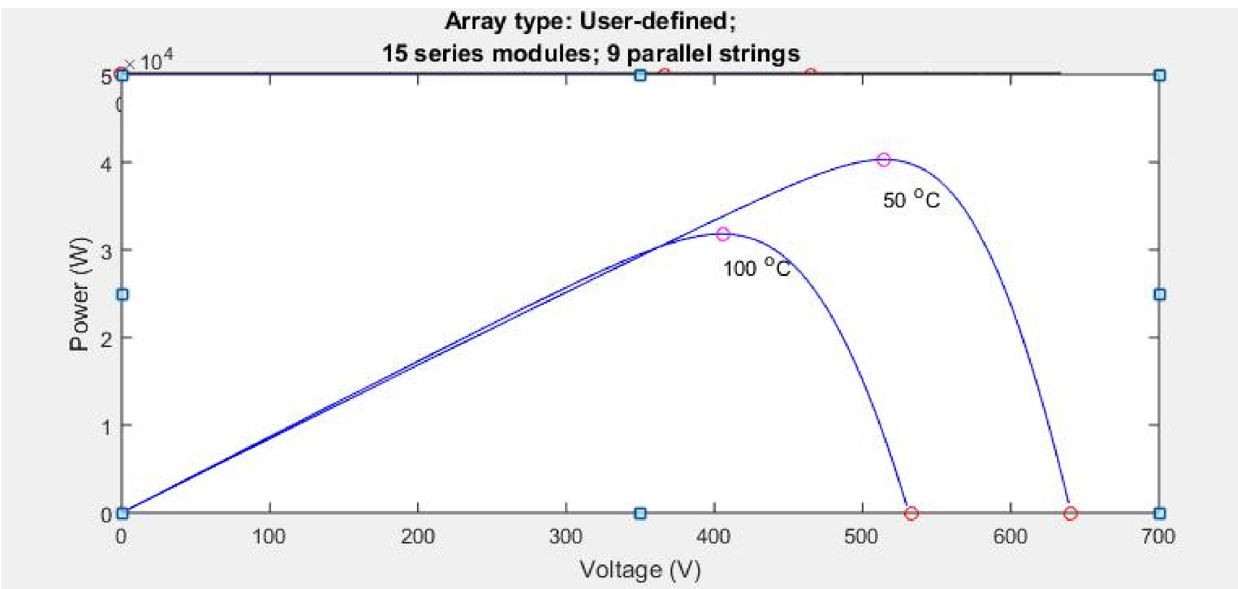


Figure 3.10The P-V Curve of the PV Array at a different temperature of 50^0C, 100^0C 1000W/m^2

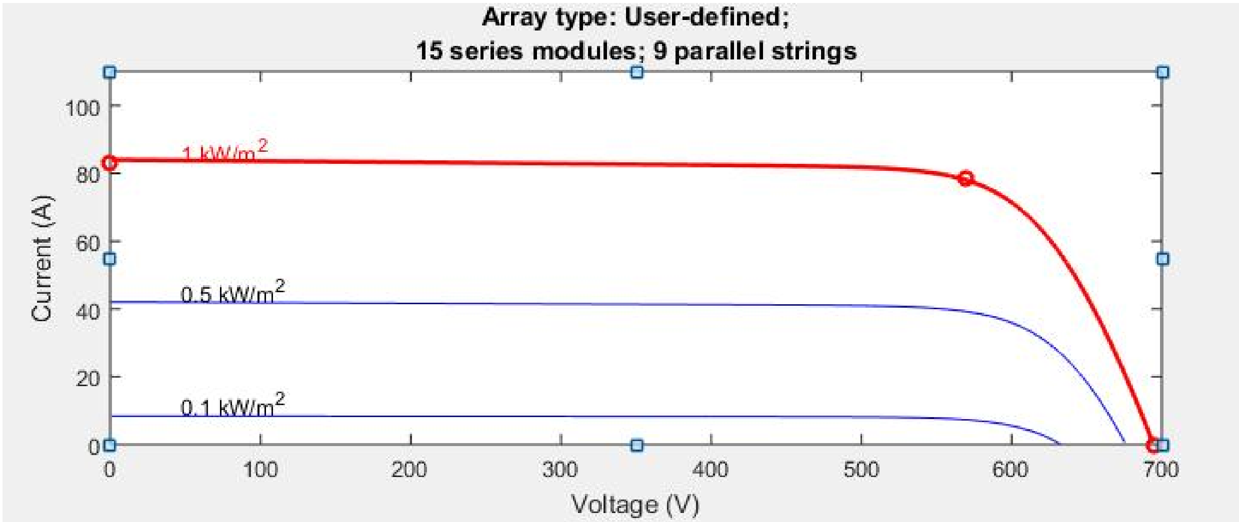


Figure 3.11 The I-V Curve of PV Array at different values of irradiance at 25^0C.

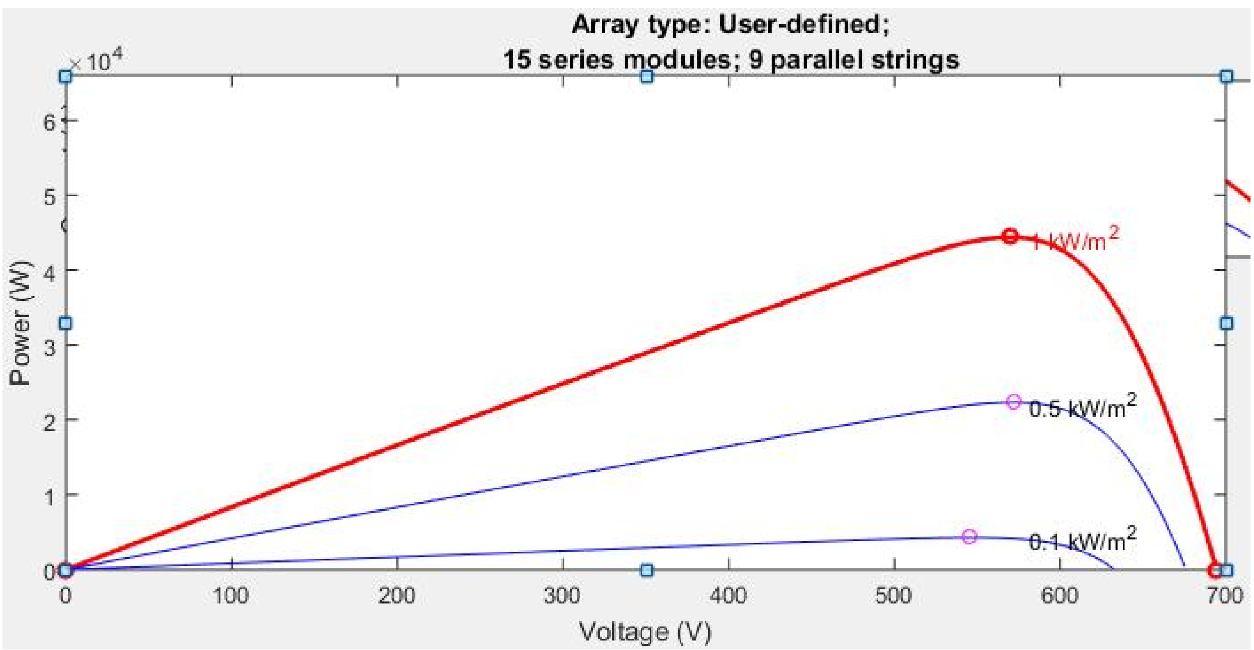


Figure 3.12 The P-V Curve of PV Array at different values of irradiance and at 25^0C.

3. 9 Solar Radiation analysis of Garbicha Kebele (Bishoftu)

Table 3.3 average sunshine hours for garbicha kebele (Bishoftu) from (2008-2015)

Year and Month												
Year	J	F	M	A	M	J	J	A	S	O	N	D
2008	6.0	5.3	7.4	7.1	6.5	7.1	5.0	5.4	7.2	7.2	6.9	5.5
2009	7.2	6.2	7.2	6.4	7.5	6.2	4.6	5.3	6.5	6.7	8.7	7.0
2010	6.3	5.4	6.2	6.0	6.1	5.0	4.7	5.0	6.4	6.2	6.8	7.3
2011	5.9	4.5	5.5	6.1	7.3	5.5	4.6	4.3	4.5	7.3	7.8	7.3
2012	7.3	6.4	6.1	6.0	6.4	5.1	5.0	5.1	5.0	6.4	8.4	7.5
2013	5.6	5.3	5.5	6.4	7.4	5.2	4.3	4.2	6.3	6.4	8.4	7.6
2014	6.5	6.0	4.6	6.2	7.4	5.0	5.2	4.3	6.3	5.5	7.3	8.3
2015	6.1	5.3	5.3	5.2	6.4	4.4	5.3	4.4	7.0	5.0	7.1	7.8
Avg.	**6.4**	**6.5**	**5.8**	**6.0**	**6.8**	**5.5**	**5.2**	**4.7**	**6.1**	**6.3**	**7.2**	**7.3**

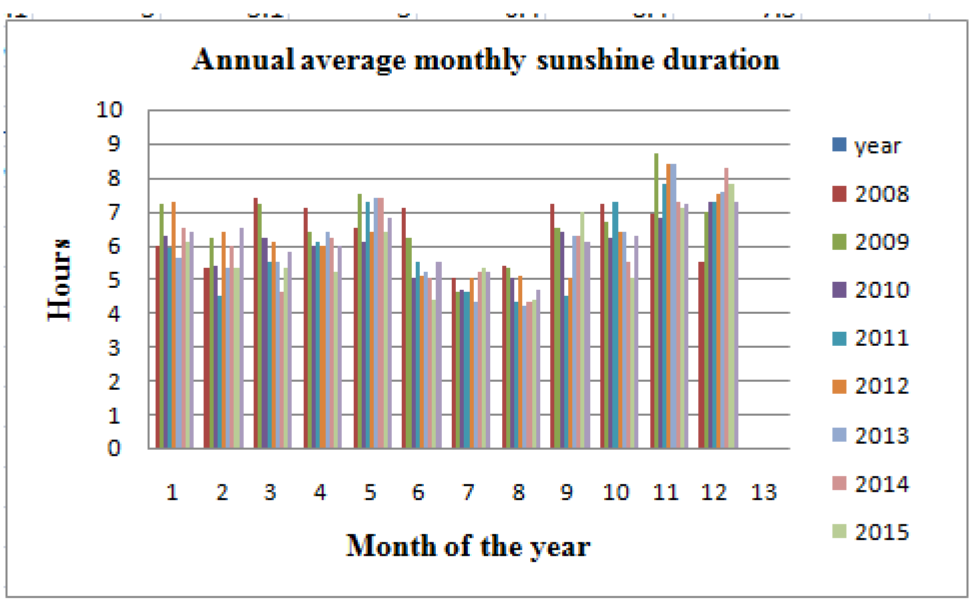


Figure 3.13 Graphical Representation of Annual average monthly sunshine duration

Table 3.4 recommended average days for months and values of n by months

Month	n for i^{th} Days of Months	Date	n, days of the year	**δ**, declination angle
January	I	17	17	-20.9
February	31+i	16	47	-13.0
March	59+i	16	75	-2.4
April	90+i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1
July	181+i	17	198	21.2
August	212+i	16	228	13.5
September	243+i	15	258	2.2
October	273+i	15	288	-9.6
November	304+i	14	318	-18.9
December	334+i	10	344	-23.0

Source: Klein (1977)

3.9.1 Global Irradiation on Horizontal Surface

Estimation of monthly average daily global solar radiation on the horizontal surface can be obtained by calculating the sunshine hour of each month and substituting the obtained result into the Angstrom equation [Duffie,e and Beck Man 1991]. This equation can be described as follows:

$$H = H0\left(a + b\frac{n}{N}\right) \qquad (3.13)$$

Where H = the monthly average daily radiation on a horizontal surface (MJ/m^2)

n = the monthly average daily number of hours of bright sunshine

N = the monthly average of the maximum daily hours of bright sunshine (i.e. the day length of the average day of the month.

H_0=the monthly average daily extraterrestrial radiation on a horizontal surface (MJ/m^2).

The constant a and b are the regression coefficient for X number of data points.

H_0, which is extraterrestrial radiation on a horizontal plane outside the atmosphere, is given by

$$H_0 = \left(\frac{24*3600*Hsc}{\pi(1+0.003*\cos(360nd/365)}\right) * \left(\cos\Phi \cos\delta \sin ws + \frac{\pi ws}{180\sin\Phi\sin\delta}\right) \quad (3.14)$$

Where n_d= the day number, H_{sc}= 1367W/m^2, which is the solar constant, Φ = the latitude of the location,
δ is the declination angle, which is given by the equation of [Duffie and Beck Man, 1991]

$$\delta = 23.45 \sin\left(360 * \frac{(284+nd)}{365}\right) \quad (3.15)$$

W_s is the sunset hour angle, which given by the equation of [Duffie, E and Beck Man, 1991].

$$Ws = cos - 1(-tan\Phi tan\delta) \quad (3.16)$$

The monthly average day length N can be calculated as follows:

$$N = \frac{2}{15Ws} \quad (3.17)$$

The regression coefficient constants a' and b' can be calculated as following [12]

$$a = \frac{\sum\frac{H0}{H}(\frac{n}{N})^2 - \sum\frac{n}{N}\sum\frac{n}{N}*\frac{H0}{H}}{X\sum(\frac{n}{N})2 - (\sum\frac{n}{N})2} \quad 3.18)$$

$$b = \frac{X\sum\frac{n}{N}*\frac{H0}{H} - \sum(\frac{n}{N}\sum\frac{H}{H0})}{X\sum(\frac{n}{N})2 - (\sum\frac{n}{N})2} \quad (3.19)$$

The value of the constants 'a' and 'b' taken as randomly are 0.3 and 0.5 respectively and the daily solar intensity is calculated by using these values. Table 3.5 below can be filled using the equation(3.13 &3.14).

The below table 3.6 horizontal solar irradiation data is obtained from NASA for the selected site with a latitudinal degree of 8.7346 and a longitudinal degree of 39.085. It is compared with the calculated solar radiation of the site which is done by converting sunshine hours into solar radiation by using Empirical Equation [Duffle. and Beckman,1991].

Table 3.5 annual average monthly daily solar radiation of Garbicha kebele(2008_2015)

Month	H_0 (MJ/m^2)	H (MJ/m^2)	H ($Kwh/m^2/day$)
January	32	22.40	6.22
February	38	27.09	7.52
March	37	25.17	6.99
April	38	25.57	6.83
May	38	24.24	6.73
June	38	23.05	6.40
July	33	19.15	5.32
August	38	23.11	5.93
September	37	22.97	6.05
October	35	23.04	6.40
November	32	21.94	6.37
December	31	17.84	6.48
Annual Average	**35.58**	**23.2975**	**6.43**

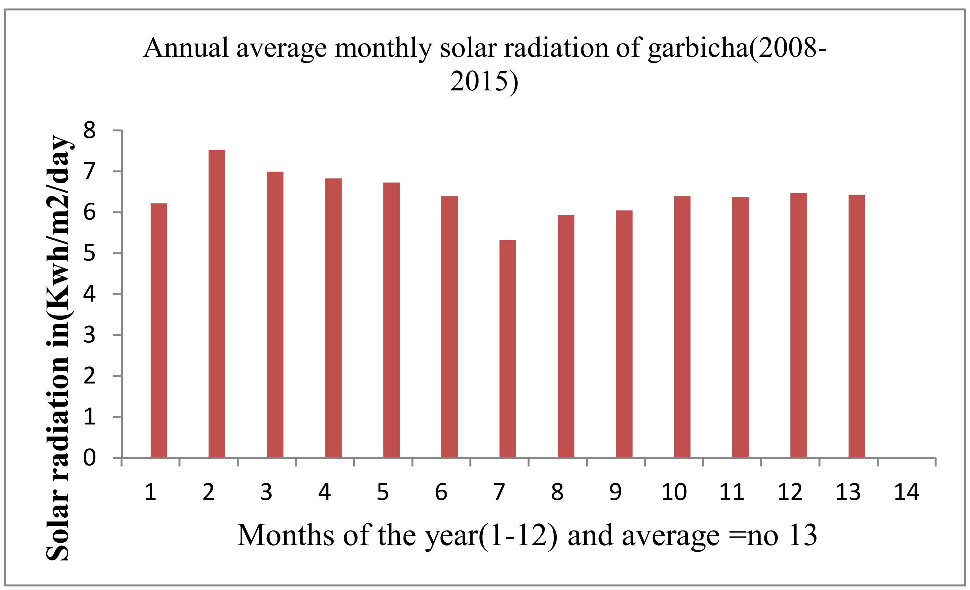


Figure 3.14 graphical plot of annual average monthly solar radiation of the site.

Table 3.6 Allsky Insolation Incident On Horizontal Surface Of Bishoftu (Kwh/m^2/Day)

J	F	M	A	M	J	J	A	S	O	N	D	Ava.
6.1	6.6	6.5	6.31	6.36	5.57	5.23	5.36	5.84	6.3	6.2	6.08	6.06

Source: **NASA@Latitude8.7346 degree and Longitude 39.085.**

For the comparison, the root means square error (RMSE) formula can be applied to the equation below.

$$RMSE\% = 100\left(\frac{1}{H_{ob}}\right)\left(\sum\frac{S_i^2}{u}\right)^{1/2} \tag{3.20}$$

where, $S_i = \mathbf{H_{estimated}} - \mathbf{H_{obtained}}$ (3.21)

For x= 1, 2, 3,…,u, U is the total number of observation point, $\mathbf{H_{ob}}$ =the arithmetic mean value of the obtained data (data from NASA [NASA,2008]. The correlation coefficient, r by which the depth of the correlation of the two radiation levels is compared is given by the following statistical formula [Nguyen and Pryor, 1997].

$$R, \quad = \quad \frac{\sum(\mathrm{H_{estimated}} - \mathrm{He})^2(\mathrm{H_{obtained}} - H_{ob})}{\sqrt{\sum(\mathrm{H_{obtained}} - H_{ob})^2}\sum(\mathrm{H_{estimated}} - \mathrm{He})^2} \tag{3.22}$$

Where H_e is the arithmetic mean value of the estimated value of the solar radiation and Hob, is the arithmetic mean value of u obtained a value of the solar radiation. The solar radiation, calculated from the daily sunshine hour is greater than the solar radiation obtained from NASA. For better reliability of the solar radiation for the given purpose: the worst condition is taken, i.e. the data obtained from NASA is taken for the input of the Photovoltaic water pump. This data is considered because of fluctuation of solar radiation from hour to hour. The optimum designing array size is determined on this data.

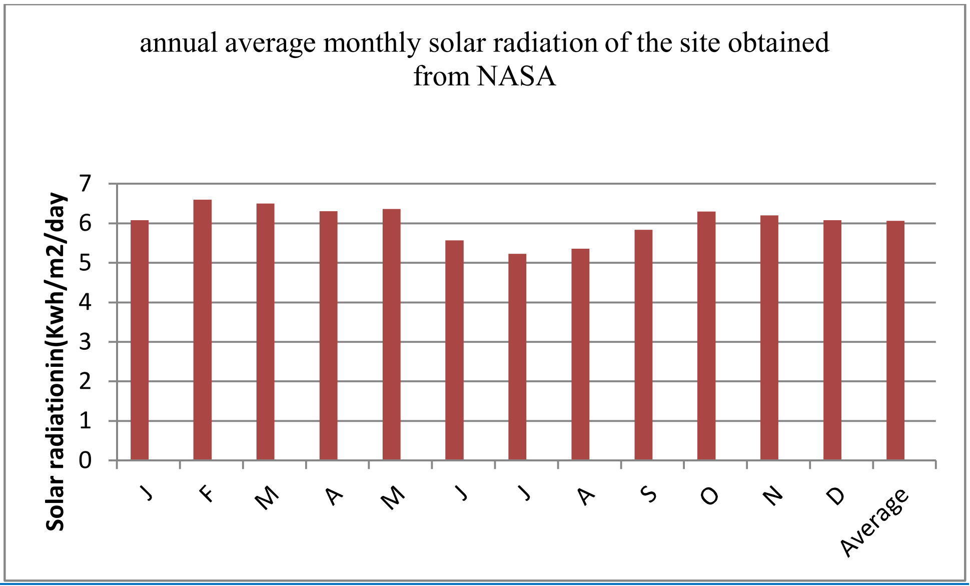


Figure3.15 graphical representation of average monthly solar radiation of the site (NASA).

3.9.2 Ratio of Water requirement to solar radiation

The calculation is done by considering the worst operation condition. From table 2.9, it was cleared that for July the ratio of water requirement to solar radiations was largest therefore daily solar radiation of 5.23kWh/m^2 and water requirement of 15977.44 liters/July was considered for optimum PV Array sizing (i.e.) 20 liter per day per each household, this is enough for drinking only but for washing purpose Rain can be used, because of the month is winter in Ethiopia.

Table 3.7 Ratio of Water Requirement to Solar Radiation

Water required(m^3)	Month	Solar R in (kwh/m^2)	Ratio Wr/Sr in L
85	J	6.08	13980.26
85	F	6.6	12878.78
85	M	6.5	13076.92
85	A	6.31	13470.68
85	M	6.36	13364.78
85	J	5.57	15260.32
85	J	5.23	15977.44
85	A	5.36	15858.2

3.9.3 Determination of a well location

Knowing the location of a well for a specific purpose is very important. To meet the pumping requirements of the wells, a large volume of groundwater must be available. For small and medium-sized community water systems may depend on water wells that produce 100 to 500 gallons per minute but for individual home's domestic well's may meet their needs with as few as 1 to 5 gallons per minute. Good water well location for drinking and irrigation purpose can be determined by a professional consultant.

3.9.4 Water well design

The overall objective of the design is to create a structurally stable, long-lasting efficient well that has enough space to house a pump. A well consists of a bottom sump, well screen, well casing (pipe) surrounded by a gravel pack and appropriate surface and boreholes. Components of a well can be shown in figure(3.16). Water enters the well through openings in the well screen. Wells can be screened continuosly along the bore specific depth intervals. The alluvial aquifier which commonly contain alternating sequence of coarse material (sand and grave) and fine material, the latter construction method clean sediment-free water and is more energy efficient than the installation of a continuous screen. Hard rock wells on the other hand, are constructed very differently. The purpose of the screen is to keep sand and gravel from the gravel pack. At the surface of the well, a surface casing is commonly installed to facilitated the installation of the well seal. The well seal and surface casing protects the well against contamination caving into the well .Correct water well design is the most important task in order to get pure water which is free of any sands or dust particles. Water which is pumped from the well must be filtered and chemicals like chlorine added in the water storage to avoid germs which causes water borne diseases if the water is stored for long period of time in the storage.

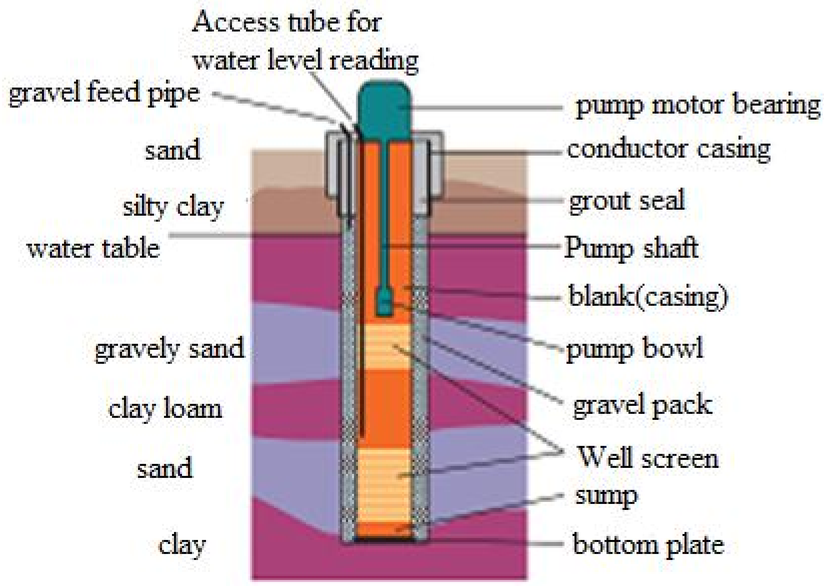


Figure 3.16 components of a well(http://waterquality.ucanr.org and http://groundwater.ucdavis.edu.)

3.9.5 Selection of water sources

Configuration of the watering system means to identify the type of water source, depth of the water and its relative location to the place where the water is to be provided. There are two types of water sources such as surface water like a pond, spring or stream, and subsurface water like well. From all of these water sources, well is more preferable due to its consistency and quality. However, wells are more expensive to drill it up where it's water table is deep than surface water sources which are affected by seasonal variations. The amount and quality of the water are low during summer when it is needed most. The factors that have taken into consideration for the subsystem water source are the following:

- Static water level
- Seasonal depth variation of the wells.
- Recovery Rate
- Water quality

For the surface water source the following factors need to be determined:

- Water quality
- Seasonal variation on the volume of the water and flow rate.

3.9.6 Daily Water Demands

It is difficult to estimate the acceptable daily rate of water consumption. Many countries have different figures for minimum daily water consumption per person per day. The heaviest user of daily water consumption of 78 gallons per person per day takes place in the United State of America. The average daily water consumption in the Netherlands reduced to 27 gallons per person per day in comparing to the US. Due to lack of economic, limited supply of water availability and conservation problems most countries of the World use significantly less water per person per day. In 2006 the government of Ethiopia adopted a universal access plan (UAP) to achieve 98% access for rural water supply and 100% access for urban water supply and sanitation by 2012. Its cost was estimated at US$2.5 billion. During the first phase until 2012, the focus is on affordable and appropriate technologies with the following standards. Setting per capita consumption for rural 15liter/cap/day,Urban 20liter/cap/day.

3.9.7 Water Schedule for the Communities

The watering schedule for the community is estimated based on three sections: - Early morning, Afternoon and Evening. In the morning, more people wake up, so water consumption steadily increases for the purposes of many tasks like breakfast preparation, Hygiene, and drinking. In the evening time, people might want to perform their hygienic needs after a long day of work. Based on this estimation, daily and hourly load for the pump and storage or tank can be selected.Solar PV water pump gets sufficient solar irradiance at midday because of this the time interval starts from 7 O'clock and the remaining four hours lefts used for maintenance and its time schedule is described in table 3.1. Estimation of the daily water requirement for 850 household families can be done as the following: The total daily water demands, Q_v is the product of the number of household (N_h) by the daily water demanded by each household (q_v).

Mathematically it can be done as follows:

$$Q_v = N_h * qv \quad (3.23)$$

Where Q_v is the total daily water demanded by the residents, q_v is the daily water demanded by individual household, N_h is the total number of households.

Given that N_h =850 households, q_v =100 liter per individual household. Daily water demanded by each household having an average of five members becomes 100 liters per day (i.e. using 20 liters per capita). Therefore, Q_v =850*100 liter/day=85,000 liter/day= 85m^3/day by following 20 liters per capit

Table 3.8 Water Schedule of the Communities

Time of day	Water used in (%)	Reason for water use
7	8	-breakfast-making -drinking - miscellaneous(washing) -toilet -shower
8	7	
9	4	
10	2	
11	**3**	
12	10	-lunch preparation -drinking(human) -Laundry -Cattle drinking
13	14	
14	5	
15	15	
16	10	**-**dinner preparation -drinking -shower -miscellaneous
17	7	
18	9	
19	7	

3.9.8 Design flow rate of the system

Estimation of the pump flow rate is based on daily water demanded and daily peak sun hours or the daily solar radiation of the site.Mathematically,

$$\text{pump flow rate, } Q = \frac{\text{daily gallons needed}}{\text{Peak sun hours per day}}, \qquad (3.24)$$

The daily water requirement is 85000 liters for 850 households with average family members of five by following 20 liters per capita.

$$\text{Therefore, } Q = \frac{85000\text{L}}{6.06 \text{ peak sun hour} * 60\text{min/hour}} = 208.33\text{L/min} \quad \cong 208 \text{ L/min}$$

3.9.9 Total dynamic head of the pump

It is the sum of static head loss and frictional losses. During pump system sizing, the variables that are taken into consideration are the following;

Static head: It refers to the vertical height from the dynamic water level to the height point of water delivery.

Suction head: It refers to the vertical height from the water level to the pumping inlet where the water level is below the pump inlet.

Pressure loss: It refers to the loss of pressure due to pipe length and friction caused by pipe material and additional pipeline elements like elbow, valve, in this system no need of distribution pumps because the storage tank is hanged at a high elevation in order push downward the distribution storage using pressure force.

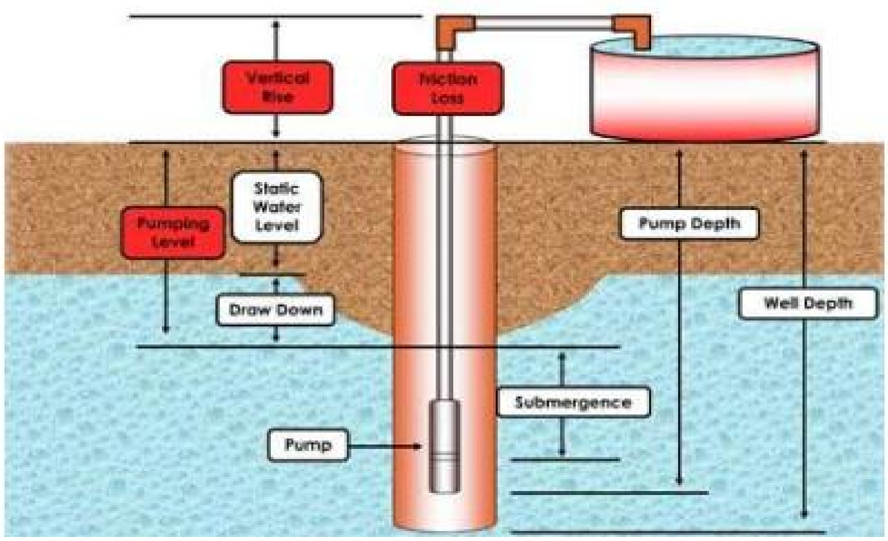


Figure 3.17 total dynamic head for the pump(courtesy:http://www.siliconsolar.com)

Draw down refers to the vertical height from pumping level to upper surface from which the liquid is pumped to the storage.

Static water level refers to the vertical height from upper surface to the water is pumped storage.

Structural Layout of the static head pump can be shown in figure 3.3 below

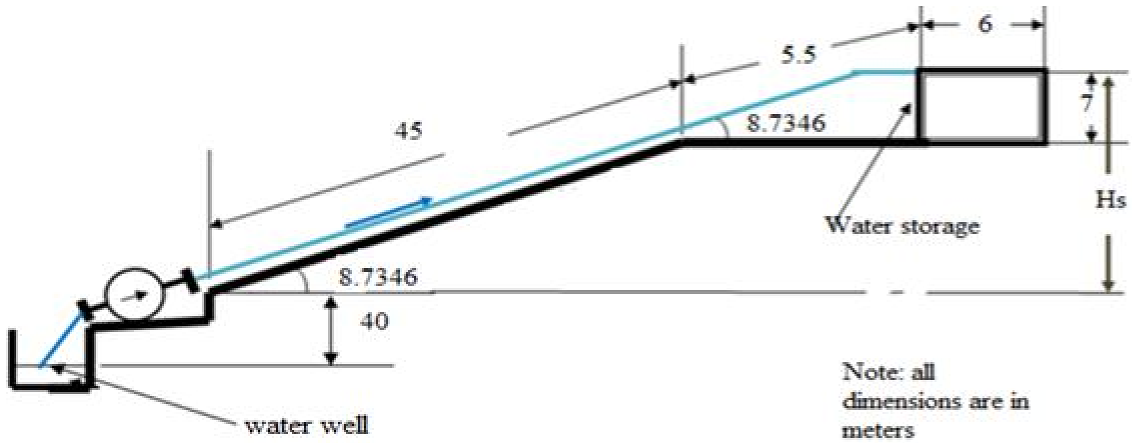


Figure 3. 18 structural layout of static head

Where the latitudinal location or tilt angle of the site is 8.7346 degrees. By applying trigonometric sin law, the static head of the pump can be calculated as follow

$$\frac{\sin 90}{50.5} = \frac{\sin 8.7346}{\text{Hs}} \tag{3.25}$$

from this, Hs= $\text{Hs} = \frac{\sin 8.7346 \text{ x } 50.5}{\sin 90} = 7.67\text{m}$

Total static head, $\text{Hs} = 7.67\text{m} + 40\text{m} = 47.67\text{m}$

The systems fitting components like, elbows, valves can be calculated as follows. Total head loss of the system is the sum of loss due to pipe component, loss due to elbows, loss due to foot valve, check valve. (please refer-AppendixB_1),Mathematically, the head loss can be calculated as follows:

$$H_f = H_{\text{pipe}} + H_{\text{elbows}} + H_{\text{valve}} + \text{velocity losses} \tag{3.26}$$

The average velocity of the fluid can be calculated as follows:

$$V = \frac{Q}{A} \tag{3.27}$$

Where Q is fluid flow (m^3/gallons/liters/), A is area of the pipe, The flow rate of the system is 208LPM, in cubic meter per second Q =0.0036m^3/s

$$V = \frac{0.0036 m^3/\text{s x } 4}{\pi(0.040894)^2} = 2.7\text{m/s.}$$

Table 3.9 Common pipe materials roughness value

pipe material	**roughness,ε (in feet)**
drawn brass or copper	0.000005
PVC pipe	0.000005
commercial steel	0.000150
galvanized iron	0.000500
Concrete	0.001-0.01

Relative, roughness for PVC pipe, $\boldsymbol{\varepsilon} \triangleq 5(10)^{-6}$m,

$$\boldsymbol{\varepsilon}/d = \frac{5(10)^{-6}m}{0.040894} = 0.0001222673 = 1.222673(10)^{-4}$$

Reynolds number is the ratio of inertial force to the kinematic viscosity of the fluid.

Re for the water at 15^0 C, $Re = \frac{Vd}{v}$, (3.28)

Where V is the average velocity of the fluid, d is the internal diameter of the selected pipe (PVC Pipe), small letter v is the relative roughness of the PVC pipe.

$$Re = \frac{2.7 m/s x 0.040894 m}{0.5(10^{-5}) m^2/s} = 22082.76$$

Friction factor (μ) is defined as the ratio between the force required to move a section of pipe and the vertical contact force applied by the pipe on the seal bed.

$$f = \frac{0.316}{Re^{0.25}} \tag{3.29}$$

By substituting the Calculated Re number into equation (3.28)

$f = \frac{0.316}{22082.76^{0.25}} = 0.026$. Now, all possible system losses can be calculated as follows:

Using Darcy Weisbach equation head loss can be calculated as follow,

The Darcy Equation is a theoretical equation that predicts the frictional energy loss in a pipe based on the velocity of the fluid and the resistance due to friction: Fittings such as elbows, tees, valves, and reducers represent a significant component of the pressure loss in most pipe systems.

$$H_{pipe} = f\frac{v^2}{2g} \tag{3.30}$$

$$Hp= f\frac{L}{D}*\frac{V^2}{2g}$$

Where, L= length of the pipe, f = Darcy friction factor, V = velocity of the fluid, D = internal diameter of the pipe, g = acceleration of gravity (9.81m/s2). Therefore, using the equation for head loss in the pipe, we can calculate the loss through the straight piping:

$$H_{pipe} = 0.026x \frac{(\frac{2.7m}{s})^2}{2x9.81\frac{m}{s^2}x\ 0.040894m} x93.5m = 22.0878m \approx 22m.$$

Loss coefficient for the pipe component, $h_l = kl\frac{v^2}{2g}$

$$H_{elbow} = KL\frac{V^2}{2g} \tag{3.31}$$

From Appendix-C for long radius 45-degree flanged elbow, the K_r value is 0.2

$H_{elbow} = 0.2*\frac{(2.7m/s)^2}{2x9.81m/s2} = 0.0743mx3$ (because, there are three elbows)

$H_{elbow} = 0.22m$

$$H_{valve} = KL\frac{v^2}{2g} \tag{3.32}$$

For piston foot valve, the K_L value is 15 from the appendix C

$$H_{fv} = 15*\frac{(2.7m/s)^2}{2x\ 9.81m/s2} = 5.57m$$

$$\text{Velocity loss} = \frac{V^2}{2g} \tag{3.33}$$

$$\text{Velocity loss} = \frac{(2.7m/s)^2}{2x\ 9.81m/s2} = 0.37m$$

Therefore,

T_{DH} =static head loss + frictional loss (3.34)

T_{DH} = 47.67m+0.37m+5.57m+0.22m+22m=**76m.**

3.9.10 Water Pump Selection

A pump is a mechanical device that raises, transfers, delivers, and compresses fluids by using suction pressure or both. Sizing of a pump for the water pump involves matching the fluid flow rate and pressure rating of a pump required for a specific process. Mass flow rate requires a pump that can generate a pressure high enough to overcome the hydraulic resistance of the systems, like pipes, valves. This hydraulic resistance is known as the system head. It is defined as the amount of pressure which is required to achieve a given flow rate in the system downstream of the pump. To provide an interrupted supply of water that would satisfy the water demand of the communities using PV panels combined with a bank of batteries to store energy for night pumping as back-up was used earlier but in this research back up batteries avoided in order to reduce the cost of maintenance and replacement of batteries every two years. Instead of backup batteries, it is possible using a larger tank for low flow rate water pumping systems. Not only the cost of maintenance but also it reduces the efficiencies of the system.

3.9.11 Types of Water Pumps

There are two types of pumps that are commonly used for PV water pumping applications. These are positive displacement pumps and centrifugal pumps. A positive displacement pump is used in low-volume pumps [32]. Centrifugal pumps have relatively high efficiency and are capable of pumping a high volume of water.The most basic difference between a reciprocating pump and a centrifugal pump is that centrifugal uses the kinetic energy of its impeller such that it continuously supplies fluid [33]. Centrifugal pumps provide a continuous discharge of fluid. In this system, a centrifugal pump is selected because of its ability to pump fluids with high viscosity. The type of centrifugal pump used in this work is Brand/Model: Viking 1-1540 series, RPM 1750 TO 3500, GPM 55, TDH 110m, Canadian products. Capacities: to 1500 USGPM (5678 L/M) Heads: to 250 feet (76 m), Temperatures: to 250°F (121°C). These pump types are selected due to their highest tolerance of the environmental temperature.

Figure 3.19 Image of Viking Centrifugal Pump[SG Series | Spur Gear Pump]

3.9.12 Working principle of a Centrifugal Pump

Centrifugal Pumps can be categorized into three based on the type of fluid flow; these are radial flow, mixed flow, and axial flow. Axial flow is selected among the rest, because of its high flow at low pressure. It converts rotational energy from the motor to energy in a moving fluid. It sucks (drives) liquid from a low level to a high level and works on a very simple mechanism. Centrifugal Pumps has two main parts which play a major role in energy conversion. Those are the impeller and Casing. (i) An impeller is the rotating part of the pump. (ii) The casing is the airtight passage that surrounds the impeller and its main function is collecting the liquid discharged by the impeller and converts the kinetic energy into pressure energy. The fluid can be entering into the casing through the impeller blades. The velocity and pressure of the fluid increases while passing through the Impeller. With the flow rate requirements determined, When two (more) pumps are arranged in serial their resulting pump performance curve is obtained by **a**dding their heads at the same flow rate. To overcome larger system head loss Centrifugal pumps should be connected in series.

Pumps in Parallel - Flow Rate Added**:** When two or more pumps are arranged in parallel their resulting performance curve is obtained by adding the pump flow rates at the same head. Centrifugal pumps in parallel are used to overcome larger volume flows than one pump can handle alone. The pump is selected based on its performance curve. For the designed system, the pump performance curve has a motor with pressure at 100(Psi) with a capacity of US GPM between 42-60(please refer- Appendix d).

3.9.13 Pipe Selection and its size determination:

Pipe materials are devices in which the fluid can passes through it. There are many types of pipes are there among these Concrete pipe, PVC pipe, HD pipe are some of them, but the best pipe designed for drinking water supply must be free from any chemical composition, corrosion and also be cost-effective, and also its selection based on the fluid property of the materials.

Table 3.10 Comparison of PVC and HDPE pipes

No	PVC	HDPE80
1	It is a cheap and durable vinyl polymer	more expensive
2	It has a lightweight and high strength	It has higher strength, is harder,
3	Very popular in piping applications both above ground and underground.	can withstand high temperatures
4	heavier and stronger while	they are found to dampen and absorb shock waves minimizing surges that can affect the system
5		They also have the best joint pressure resistance.
6		Harder and more abrasion and heat resistant.

There are many factors are there for the selection of Pipe types. The main criterion is its life expectancy relation with cost-effectiveness. Based upon the above table 3.10 comparison of pipe types, the PVC pipe type is selected because of its cost-effectiveness and lightweight and high strength. It is locally fabricated by Oromia Pipe factory with a joint venture between Oromia Water Works Construction Enterprise (Government-owned enterprise) and Golden Trade Company (American/Egyptian Company).

Figure 3.20 Oromia Pipe Factory[2merkato.com]

Schedule 40 PVC: is the typically used PVC type for water drinking application. Because it is corrosion resistant and the chemical composition is not that much dangerous comparing to other PVC pipe types and it is cost-effective. The relationship between the pipe size and the fluid flow rate has an inverse relationship, i.e. the smaller pipe size restricts the flow of water. This reduction in the flow of the water reduces the pressure losses in the pipe, resulting in more pressure. Maximum operating pressure for Schedule 40 PVC Pipe is around 270(PSI) and has bursting pressure (rapid discharge) at a pressure of 1100(PSI), this may causes, the overflow of the fluid and the system may damage(please refer-appendix E). For water pressure, there are different Abs Schedule 40 PVC Pipe types. For the designed system, the nominal pipe diameter is 11/2 inch, so at this point, the corresponding water pressure below pipe pressure is Abs 1210 with 175(PSI),(Please refer- Appendix H)Flow rate increase as the pipe diameter increase but results decrease in pressure. The suction pipe is always less than the delivery pipe, this is due to the net positive suction head (NPSH) requirements for centrifugal pumps because NPSH has different values for different pump types. The ratio of fluid to the pipe at any moment determines the pressure inside the pump. So schedule 40 PVC has a strength of $\boldsymbol{\lambda}$ys =5757,223.3 N/m^2 and with a roughness factor of $\boldsymbol{\gamma}$. PVC =0.00015± 0.0009mm and for11/2 inch diameter with a conversion factor of 25.4mm, it will be 19.05mm, the nominal wall thickness of 0.145 inchx25.4mm/inch it become , t= 3.68, internal diameter, di = 1.610 inchx25.4mm/inch = 40.894mm ≅ 41mm, Outer diameter do =1.9inchx 25.4mm/inch = 48.26mm.

Suction pipeline design: The root cause of many pump problems and failures can be traced to the poor upstream, suction side, and pipeline design. The following problems which to be avoided while suction pipeline design include

- Insufficient fluid pressure leading to cavitations within the pump.
- Narrow pipes and poor construction produce noise, friction loss
- Air or vapor entrainment causes noise, friction, and loss of performance.
- Suspended solids resulting in increased erosion.
- Poor installation of pipework and other components should be under consideration.

Cavitations: are defined as the liquid boiling point corresponding to the temperature at which its vapor pressure is the same as the pressure of its environment. To avoid cavitations, the pressure of the fluid must be maintained above its vapor temperature at all points as it passes through the pump. Manufacturers specify a property referred to as Net positive suction head requirement (NPSH-R),it is the suction side pressure at which cavitations reduces the discharge pressure by 3% so while designing the suction-side pipework for any system, ensure that the designed suction –side pipe exceeds the manufacturer's NPSH-R rating for the operating condition. NPSH-R is the minimum recommended fluid inlet pressure, expressed in meters (m). The calculated value is termed as NPSH-Available (NPSH-A)

$$\text{Calculating NPSH-A)} = \frac{(P_e - P_v}{10}) *2+ h_z - h_f + \frac{v2}{2} \quad (3.35)$$

Where P_e= absolute pressure in a pumped vessel (bar), P_v= Vapor pressure of the fluid (bar)

$\boldsymbol{\rho}$= the density of the fluid (kg/m^3), h_f=friction losses in suction side pipework (m).

h_z= minimum fluid level above pump (m), negative term if below the pump.

V= is the fluid velocity in the pump flange. Ensure that NPSH-A>NPSH-R+0.5m (safety margin).

3.9.14 Friction and Turbulence

The efficiency of the pump is affected by friction and turbulence. Because turbulence can increases wear and tear on the pump bearing. To avoid wear and tear on the pump bearing, there should be at least more diameters of pipe worth of straight piping connecting to the pump [34]. and also cannot be connected to an elbow, reducer, and valve within this run of pipework. If a valve or an elbow is directly connected to the pump flange, the fluid may be centrifuged towards the outer curve of the elbow without directly into the center of the impeller. During this, stress on the pump's bearings happens and Pump failure may occur. In standard practice, suction-side piping should be one or two sizes bigger than the pump inlet. Small pipe results in larger friction losses, which means it costs more to run the pumping system. Mathematically pipe velocity can be calculated as follows:

$$\text{Pipe velocity (m/s)} = 1.274q/d^2 \tag{3.36}$$

Where q=volume of flow rate (m^3), d= pipe inside diameter. Problems in suction-side pipework can be avoided by the following guidelines:

- Ensure that conditions do not favor cavitations
- Position the feed pipe to minimize entrainment of air/vapors
- Minimize friction and turbulence by choosing the appropriate pipe.
- Use pipe with a diameter twice that of the pump suction side flange.

From the equation (3.2) the flow rate of the water is 208LPM equals to 52GPM, by looking the best pipe size comparable to the desired flow rate, the bolded pipe size could be selected from the table 3.11 below.

Laminar and Turbulent Flow in Pipe: Determining the type of pipe flow as laminar or turbulent is very important. Laminar flow is recommended for flow situations with low fluid velocity and high fluid viscosity. Turbulent flow occurs when flow situations with high fluid velocity and low fluid viscosity and mixing occur in the flow [34]. Its point of velocity vectors are all directions but its overall flow is in one direction (please refer-AppendixB_2).

Table 3.11 Standard (Std) Weight Schedule 40 PVC Pipe

Nominal size(lps)	External diameter(Inches)	Internal diameter(Inches)	Wall thickness(Inches)	Weight/foot (pound)	Internal area()	GPM 10fts
1/8”	0.405	0.269	0.068	0.244	0.057	1.8
¼”	0.540	0.364	0.088	0.424	0.104	3.2
1/8”	0.675	0.493	0.091	0.567	0.191	6.05
½”	0.840	0.622	0.109	0.852	0.304	9.5
¾”	1.050	0.824	0.113	1.130	0.533	16.6
1”	1.315	1.049	0.133	1.678	0.864	26.9
1-1/4”	1.660	1.380	0.140	2.272	1.495	46.6
1-1/2”	**1.900**	**1.610**	**0.145**	**2.717**	**2.035**	**63.5**
2”	2.375	2.067	0.154	3.652	3.355	105

Source :(pvc40.com/2-pvc-schedule-40/-pvc-schedule-40-pipe)

Calculations of temperature rise in the pump: No pump is perfect with 100%efficiency, energy lost in friction and hydraulic losses transforms to heat –heating up the fluid transported through the pump. This temperature rise can be calculated as follows:

$$d_t = \frac{Ps(1-\mu)}{C_{pq\rho}} \tag{3.37}$$

Where, $\mathbf{P_t}$ = temperature rise in the pump (c^0), q = volume flow through the pump (m^3/s), P_s= brake power (Kw), μ = pump efficiency, $\boldsymbol{\rho}$ = fluid density (kg/m^3, c_p = specific heat of the fluid (kj/kg c^0)

3.9.15 Method for Friction Loss reduction in the pipe

Methods for reduction of friction loss in the pipe includes the following

- Reduce interior surface roughness of the piping system.
- Increase the pipe diameter of the piping system.
- Minimize the length of the piping system.
- Minimize the number of elbows, tees, valves, fittings, and other obstructions in the piping system; replace 90 degree turns with gentle bends.

3.9.16 Water storage , It is used to store water which is pumped by solar photovoltaic energy. Use of large water storage can reduce the extra cost paid for electric battery which is

used as backup energy when solar intensity becomes low during cloudy weather condition but large water storage stores enough water during peak energy production and it meet the water requirement in case of cloudy weather condition,(i.e. while intensity of solar power is lower than pump rated, the pump will not start but the operation of delivering water to the community will continue due to use of large water storage rather than using battery to store electricity.) The proposed tank must store the water at least for a minimum of three days(6m*6m*6m) by considering the storage neatness in order to prevent water-borne diseases.

3.9.17 sizing of the water storage:

In the estimated water demand, the pump will work for 8 hours each day pumping at the specified GPM below and it needs 4.2kwx8hoursx3days =100.8kwh energy is required for the storage capacity of the tank. The storage tank need controller (float switch) which is used when the water volume is above the tank level limit then the pressure switch controls the pump operation.

3.9.18 Sizing of Systems Parameter

It is the process of evaluating and selecting the adequate voltage and current ratings for each component of the photovoltaic system in order to meet the water demand in the area under study.

3.9.19 Sizing of the solar array: to avoid under-sizing of the system component, first calculate daily average energy needed and divide it by the product of all system component's efficiencies.Shaft power (hydraulic energy): is the power transferred from the motor to the shaft of the pump. It depends on the efficiency of the pump motor and can be calculated as follows: This hydraulic Energy needed by the pump can be calculated as below.

$$P_{hyd} = \frac{Q * g * T_{DH}}{\eta} \tag{3.38}$$

Where Q is the flow rate of the water in liter per second, g is the acceleration of gravity [9.81m/s^2], T_{DH} is the total dynamic head for the pump in meters, η is the efficiency of the pump typically (80-90) [25]. Assumed the pump efficiency to be 85%

$$P_{hyd} = \frac{3.6 \text{ liter/sec} \times 9.81 \text{m/s}^2 \times 75.83 \text{m}}{0.85} = 3150.6 \text{ W}$$

3.9.20 Sizing of induction Motor

The power needed by the induction motor can be calculated as follows:

$$P_{IM} = \frac{P_{hyd}}{\eta_{im}} \tag{3.39}$$

Where, H_{hyd} is the hydraulic power, η_{im} is the efficiency of induction motor, Efficiency of induction motor is assumed 75%.[45]

$$P_{IM} = \frac{3150.6\ W}{0.75} = 4200.8W$$

Daily Pump used power is equal to the product of power needed by induction motor and PV panel time durations per day. Mathematically, Pump used = P_{IM} *day hours =4200.8W *8 (pumping hours) = 33600Wh/day.

Daily PV energy needed = pump used energy (33600Wh)* 1.25(system loss factor) (3.40)

To determine how many modules can satisfy the daily energy demanded, the designer should care for serial or parallel connections to obtain the desired power, which is required for the specific work. The total current can be calculated by dividing the peak power of the PV by the systems DC Voltage.

$$I_{DC} = \frac{\text{peak power (W)}}{\text{System DC Voltage}} = \frac{Pp}{VDC} \tag{3.41}$$

$$= \frac{4200\ W}{48\ VDC} = 87.5 \text{ Amps.}$$

Modules connection serially or parallel can be determined based on these ratings to meet the desired voltage and current in accordance with.

$$\text{Total number of modules} = \frac{\text{PV Array Size (Wp)}}{\text{Rating power per Module}} \tag{3.42}$$

$$= \frac{42000Wp}{330Wp} = 127.27 \approx 127 \text{ modules.}$$

The number of serially connected modules can be found by dividing the system DC Voltage to modules rated voltage.

$$Ns = \frac{VDC}{V_r} \tag{3.43}$$

$$\text{Number of modules in series: } N_s = \frac{\text{the desired VDC voltage}}{\text{Nominal voltage of the module}} \tag{3.44}$$

$$N_s = \frac{350\ \mathrm{VDC}}{24\ \mathrm{VDC}} = 15 \text{ modules.}$$

In a series connection, individual current and total equivalent current is the same, but total voltage is the sum of each individual, so the total voltage for this system in series connection is, the sum of all 15 modules with 38V each gives 507, Number of modules in parallel:

$$N_p = \frac{\text{total number of Modules}}{\text{Series connected strings}} \quad (3.45)$$

$$N_p = \frac{127}{15} = 9 \text{ modules.}$$

In a parallel connection, total voltage and individual voltage are the same but current is the summation of all individual nodes. The product of both parallel and serial connected PV modules is equal to the total number of modules used for the system.

$$N_t = N_p * Ns \quad (3.46)$$

Where: N_t is the total number of Modules

$$N_t = 9 * 15 = 135$$

135 Modules needed for the Proposed system.in order to meet the desired target successfully.

135*330Wp = 44550Wp is more than 42000Wp daily required power (WP), It is not beyond the capacity of dc current and if it is, it may damage the device so it is better to take parallel-connected modules 9. To check whether it satisfies the dc current calculated above, since the current in parallel is the sum of each module having 8.7Amps, so 9*8.7Amps+ 8.7 Amps (series current) gives 87Amps. it is below dc current rating Value (87Amps ≤ 87.5Amps) so the design can work.

3.9.21 Sizing of the voltage controller: It controls or protects the devices from over current**.** It is obtained by multiplying the short circuit current of the selected modules connected in parallel by the safety factor. This gives the rated current for the voltage controller.

$$I = I_{sc} * N_p * F_{safety} \quad (3.47)$$

$$I = 9.24\text{Amps} * 9 * 1.25 = 103.95 \approx 104 \text{ Amps}$$

A safety factor is used to handle the maximum current produced by the PV array. The number of controllers used can be obtained by dividing the array short current Amps by the Amps of a single controller.

$$N_c = \frac{Isc}{Amps} \tag{3.47}$$

For a single controller, where Nc is a number of the controller I is the rated current for the voltage regulator. N_c = 104Amps/9.24Amps = 12 charge controllers are needed, but in this work, the battery is not needed, so the charge controller is not required.

3.9.22 Sizing of the Inverter:

Before sizing the inverter the actual power drawn from the appliances that will work at the same time first determined. The maximum peak power of AC load is 7.0 KW so that the inverter size is determined by using the peak power and safety factor as follows:

The rate of inverter = peak power of the PV * 1.25(de-rating factor) (3.48)

Inverter size in kilowatt = 7.0kw*1.25 = 8.75kw, an available inverter size approach to this rating is 10KW.For a DC input voltage of 350 VDC serially connected inverter output is 220 VAC.

Figure 3.21 Must Inverter Model[www.mustpower.com]

The selected inverter specification is mentioned in table(please refer-appendix G)

Table 3.12 selection of an inverter with suitable input voltage

For a DC Voltage of 350V	For inverter input Voltage of	Number of Inverters required
	24 V	15
	48V	8
	72	5

Since the pump motor used is AC, it is a must convert the dc voltage obtained from the Photovoltaic cell by using DC –AC converter called an Inverter. As mentioned above in the table, all input voltage for an inverter is less than the required dc voltage 220V AC to run the pump motor of a single-phase induction motor. Using one huge inverter is possible but if it may damage, the operation will stop, it is also not easily available in the market, so using small inverter is advisable. 350Vdc input voltage for the inverter can be used in order to yield 220VAC, many inverters must be connected serially, so using many inverters leads to more expense, So by looking from the above table, the least number of the inverter is selected to minimize the cost expense for the inverters. Based upon this, an inverter with an input voltage of 48V and 72V is compared to each other in relation to cost and efficiency then the best one can be selected. For its availability reason and less number of the inverter, 48VDC inverter is selected. As shown in figure (3.22), below, the 8 inverter proposed for the system were configured.

This is for three phase but for the proposed system changing the switching to 4 and selecting single-phase induction motor. Variable DC voltage is obtained using chopper in between PV and inverter. The proposed system configuration looks like the figure below and one phase and one switch is removed.The factors like MPPT is used to optimize the Power obtained from the PV module and Voltage –frequency ratio(V/f) is used to control the speed of the motor. SPWM is used to control the switching sequence of the inverter.

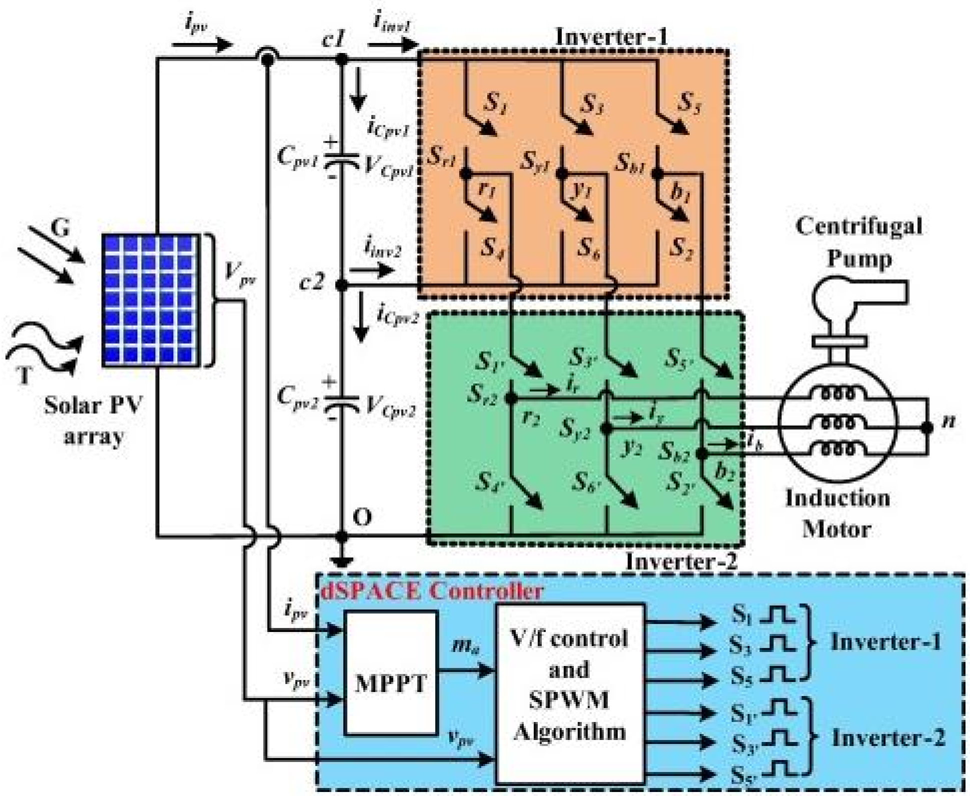


Figure 3.22 Cascaded Inverter with induction motor pump for two inverters.[sciencedirect.com].

3.9.23 Basic Switching Converter:

Dc-dc converters are power electronic circuits that convert a dc voltage to a different dc voltage level, often providing a regulated output. An efficient alternative to the linear regulator is the switching converters. In a switching converter circuit, the transistor operates as an electronic switch by being completely on or completely off (saturation or cutoff for BJT). Assuming the switch is ideal in Figure 3.7 below the output is the same as the input when the switch is closed, and the output is zero when the switch is open.

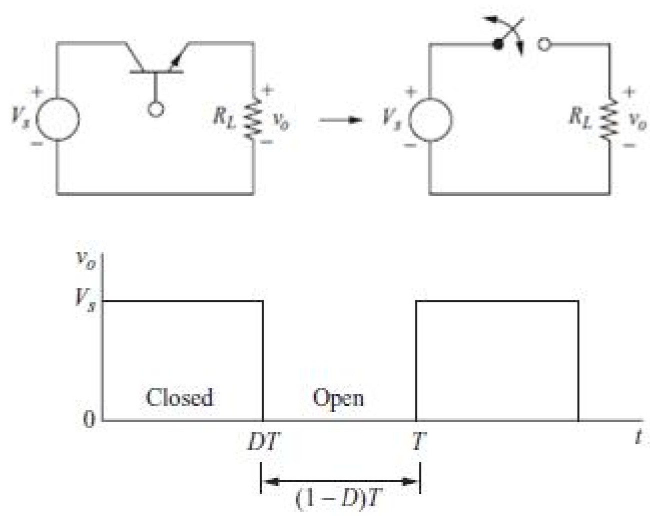


Figure 3.23 Basic DC – DC Converter Converter (a)

(b) Switching Equivalent :(c) output voltage

The average or dc component of the output voltage is calculated as follows;

$$\int_0^T Vo\ (t) = \frac{1}{T}\int_0^{DT} Vs\ (t)\ = V_s\text{D} \tag{3.52}$$

The dc component of the output voltage is controlled by adjusting the duty ratio D, which is the fraction of the switching period that the switch is closed.

$$\text{D} = \frac{\text{t}_{\text{on}}}{\text{t}_{\text{on}} + \text{t}_{\text{off}}} = \frac{\text{t}_{\text{on}}}{\text{T}} = \text{t}_{\text{on}}\text{f} \tag{3.53}$$

Where: f is the switching frequency.

The dc component of the output voltage will be less than or equal to the input voltage for this circuit. The power absorbed by the ideal switch is zero. When the switchis open there is no current in it; when the switch is closed; there is no voltage across it

3.9.24 The Buck (Step-Down) Converter:

The objective of the buck converter is to produce an output that is purely dc. Figure 3.24 below shows an LC low-pass filter added to the basic converter. The diode provides a path for the inductor current when the switch is opened and is reverse-biased when the switch is closed. This circuit is called a buck converter or a step-down converter because the output voltage is less than the input. This analysis assumes that the diode remains forward-biased for the entire time when the switch is open, implying that the inductor current remains positive. An inductor current that remains positive throughout the switching period is known as continuous current. Conversely, the discontinuous current is characterized by the inductor currents returning to zero during each period.

Buck Converters have the following properties when operating in the steady-state:

The inductor current is periodic.

$$i_L(t+T) = i_L(t) \tag{3.54}$$

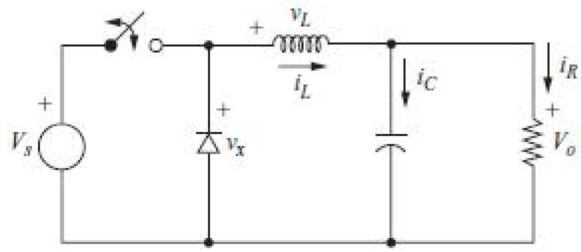
The average inductor Voltage is zero.

$$VL = \frac{1}{T}\int_{t}^{t+T} VL\,(\gamma)\,d\gamma = 0 \tag{3.55}$$

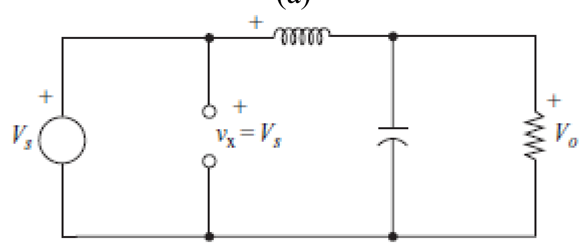
The average capacitor current is zero.

$$I_C = \frac{1}{T}\int_{t}^{t+T} Ic(\gamma)\,d\gamma = 0 \tag{3.56}$$

The power supplied by the source is the same as the power delivered to the load. For the non-ideal components, the source also supplies the losses



(a)



(b)

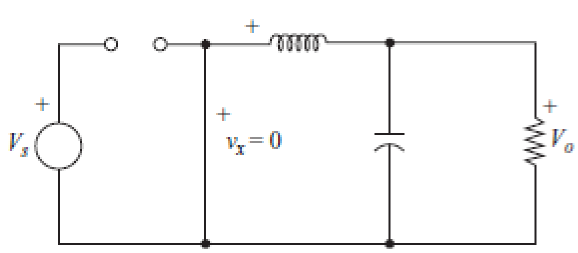


Figure 3.24 Buck dc- dc converter (a)
(b) Equivalent circuit for the closed circuit; (c) Equivalent circuit for the open circuit.

Analysis for the switch closed: when the switch is closed in the buck converter, the voltage across the inductor is calculated as follows.

$$VL = Vs - Vo = \frac{LdiL}{dt} \tag{3.57}$$

Analysis for the switch open:

when the switch is open, the diode becomes forward-biased bai to carry the inductor current.

The voltage across the inductor when the switch is open is calculated as follows;

$$VL = -Vo = \frac{LdiL}{dt} \tag{3.58}$$

$$(\Delta il)open = -(\frac{Vo}{L})(1 - D)T \tag{3.59}$$

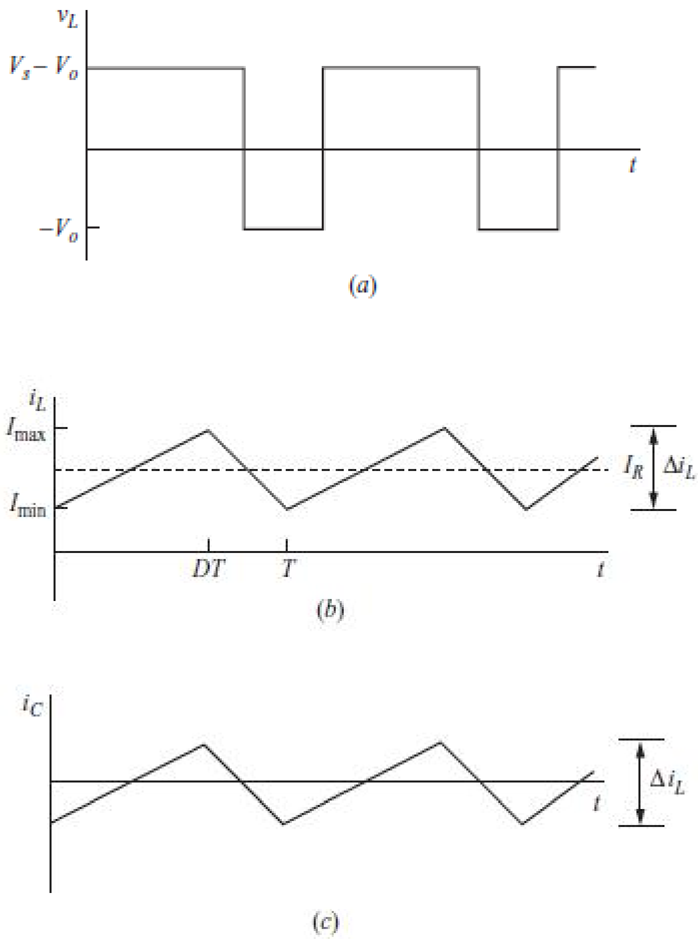


Figure 3.25 Buck converter waveforms (a) inductor voltage, (b) inductor current (c) capacitor current.

Steady-state operation requires that the inductor current at the end of the switching cycle be the same as that at the beginning, meaning that the net change in inductor current over one period is zero. This requires

$$\Delta IL\ (t)\ closed + \Delta IL\ (t)\ open = 0 \tag{3.60}$$

$$(\frac{Vs - Vo)}{L(DT)} - (\frac{Vo}{L})(1 - D)T = 0 \tag{3.61}$$

Solving for Vo,

$$Vo = Vs\,D. \tag{3.62}$$

The output voltage depends on only the input and the duty ratio D. If the input voltage fluctuates, the output voltage can be regulated by adjusting the duty ratio appropriately.

The average inductor current must be the same as the average current in the load resistor since the average capacitor current must be zero for steady-state operation.

$$I_L = I_R = \frac{Vo}{R} \tag{3.63}$$

The maximum and minimum values of the inductor current are computed as:

$$I_{max} = i_L + \frac{\Delta iL}{2} \tag{3.64}$$

$$\frac{Vo}{R} + \frac{1}{2}\left[\frac{Vo}{L}(1-D)\,T\right] = Vo\left(\frac{1}{R} + \frac{1-D}{2Lf}\right) \tag{3.65}$$

$$I_{min} = I_L - \frac{\Delta I_L}{2} \tag{3.66}$$

$$= \frac{Vo}{R} - \frac{1}{2}\left[\frac{Vo}{L}(1-D)T\right] = Vo\left(\frac{1}{R} - \frac{1-D}{2Lf}\right)$$

Where $f = \frac{1}{T}$ is the switching frequency.

To be valid the above equation (3.45), continuous current in the inductor must be verified. Since the minimum value of inductor current must be positive for continuous current. $I_{min} = 0$ is the boundary between the continuous and discontinuous current

$$I_{min} = 0 = Vo\left(\frac{1}{R} - \frac{1-D}{2Lf}\right) \tag{3.67}$$

$$L_{min} = \left(\frac{1-D}{2f}\right) R, \text{ for continuous current} \tag{3.68}$$

Where: L_{min} is the minimum inductance required for continuous current.
In practice, a value of inductance greater than L_{min} is desirable to ensure continuous current.

To determine the value of inductance for a specified peak – to –peak inductor current for continuous current operation: $L = \left(\frac{Vs-Vo}{\Delta I_L f}\right)D = Vo\left(\frac{1-D)}{\Delta I_L f}\right.$ (3.69)

$$\Delta I_L = \left(\frac{Vs - Vo}{L}\right) DT = \left(\frac{Vs - Vo}{Lf}\right) D = Vo\left(\frac{1-D}{Lf}\right) \tag{3.70}$$

The buck converter produces an output voltage that is less than or equal to the input.

Output Voltage Ripple: In this analysis, the capacitor was assumed to be very large to keep the output voltage constant. The variation in output voltage or ripple is computed from the voltage-current relationship of the capacitor.

The current in the capacitor is $I_c = I_L - I_r$ (3.71)

While the capacitor current is positive, the capacitor is changing.

From the definition of capacitance,

$$Q = CVo \tag{3.72}$$

$$\Delta Q = C\Delta Vo, \tag{3.73}$$

$$\Delta Vo = \frac{\Delta Q}{C}$$

The change in charge ΔQ is the area of the triangle

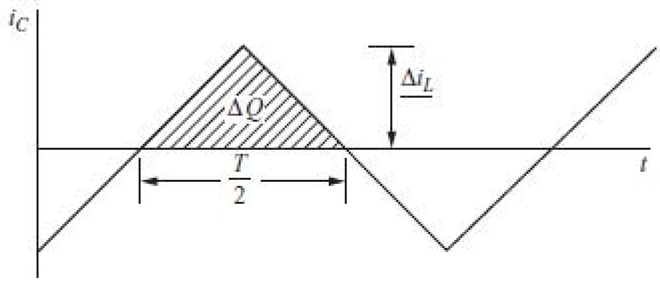


Figure 3.26 buck converter waveform: capacitor current

$$\Delta Vo = \frac{1}{2}\left(\frac{T}{2}\right)\left(\frac{\Delta I_L}{2}\right) = T\Delta I_L \frac{1}{8C} \tag{3.74}$$

$$\Delta V_o = \frac{TV_o}{8C\,L(1-D)T} = \frac{Vo(1-D)}{8LC\,f^2} \tag{3.75}$$

The capacitance required is obtained in terms of the specified ripple voltage.

$$C = \frac{1-D}{8L\left(\frac{\Delta Vo}{Vo}\right)f^2} \tag{3.76}$$

Where:, $\frac{\Delta Vo}{Vo}$ is equal to $\frac{1-D}{8LC\,f^2}$, T is the period. The input voltage for the buck converter is 608V which is obtained from the photovoltaic PV and the required inverter input is buck converter output, which is 350VDC.

The designed Buck converter calculation is computed as follows: Input voltage 608V, output Voltage, 350V, and ripple voltage is 2-5% of input voltage and Ripple current is 20-40% of the input current [49]. For ripple voltage 0.05x608V = 30.4V, and ripple current 0.3x87Amps =26.1Amps. Input power 135 solar panel x330W of each panel gives 44550W, Output power 42000W, which is the required power to generate the pump.

$$I_R = I_L = \frac{Vo}{R} = \frac{P_{in}}{V_{in}} \tag{3.77}$$

$$I_R = \frac{44550W}{608V} = 73.27Amps.$$

From this, R = $\frac{Vo}{I_L} = \frac{350V}{73.27Amps}$ = 4.7Ω. For the IGBT, the switching frequency taken is 4KHz. Its period becomes $\frac{1}{fs}$ = 1/4 KHz, T = 2.5x10^{-4}s. By comparing equating (3.47) with the calculated output ripple voltage value, 30.4V= $T\Delta I_L \frac{1}{8C}$, from this, the capacitor value can be calculated, c = 75µF, L = 0.51mH.

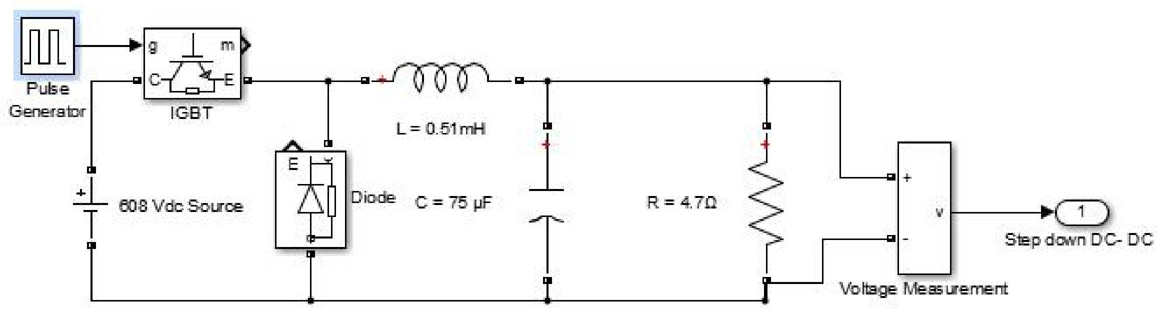


Figure 3.27 MATLAB Simulink Model for Step-down DC- DC Converter

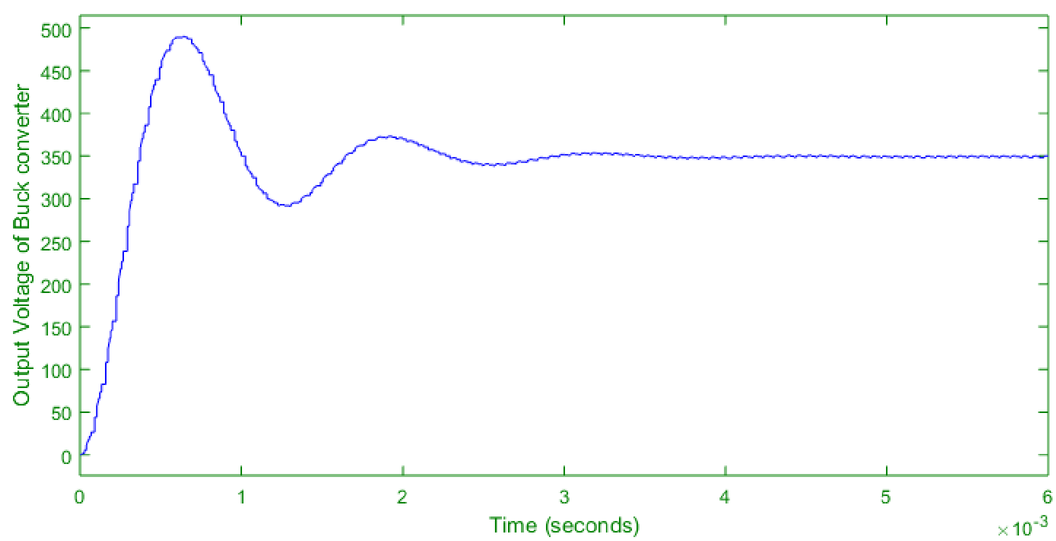


Figure 3.28 Buck Converter output Voltage simulation result.

From figure 3.28, there is stability problem(i.e. high rise time and overshoot time which has high fluctuations in voltage but after one second, it becomes to saturation point.

3.9.25 Switching Devices In Power Electronics:

A power electronic switching device is a combination of active switchable power semiconductor drivers which are integrated into one. The major distinctiveness of the switch will be determined by the inner association of functions and interactions of its integrated system.

3.9.26 IGBT switching device in Power electronics

IGBT is an insulated gate bipolar transistor semiconductor device which has three terminals and can be used as an electronic switch. It combines the characteristics of BJTs and MOSFETs for getting high current and low saturation voltage capacity correspondingly. IGBT switch has fast switched and highly effective, due to this it can be used in modern appliances like lamp ballasts, electric cars, and variable frequency drives (VFDs).

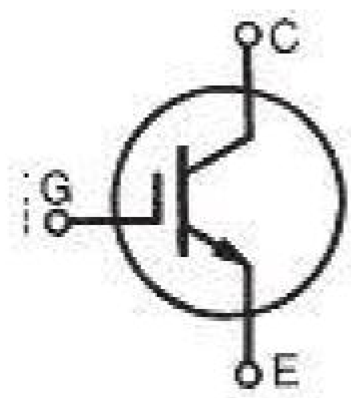


Figure 3.29 IGBT Switch Symbol[https://www.electronics.ws]

MOSFET has a high value of ON-state resistance when compared to IGBT. This means that the voltage drop (I^2R) across the bipolar for a specific switching operation is very high in MOSFET. IGBT will be switched ON or OFF depending on its gate signal whether its gate terminal is activated or deactivated.The positive potential difference across the gate and the emitter will maintain the IGBT ON state but it will be turned OFF after removing the input signal.

3.9.27 IGBT Principle of Operation:

Less voltage is required for maintaining conduction in the IGBT device. Because of its unidirectional, it switches ON in the forward direction,(i.e. the current flow direction is from the collector to the emitter while compared to MOSFETs which are bi-directional. It is more preferable due to its higher voltage and current carrying capability than a MOSFET switch. There are no MOSFETs Listed with Voltage handling Capabilities above 4500V and Current at high Voltage, While IGBT Modules go up to 6300Vwith current up to 600A for a power rating of 3.78MW[26].

Table 3.13 Advantage and disadvantage of IGBT switching device

Advantage	**Disadvantage**
Low on-resistance	It has to latch-up a problem
High voltage capability	It cannot block high reverse Voltage
Fast Switching speed	It takes a high turn off time
Low Switching Loss	Its cost is high
Low gate drive requirement	
It has excellent forward and reverses blocking	
It is easy to turn ON and OFF	
Smaller Snubber circuit requirement	

As table 3.13 shows, the IGBT switch gives a better output signal, because of its fast switching speed without any switching loss.

3.9.28 Maximum Power Point Tracking:

MPPT is an algorithm that in charge-controllers used for extracting maximum available power from the PV module under Certain Condition. The voltage at which the PV module can produce maximum power is called Maximum Power Point (peak power voltage). The typical PV module produces power with a maximum power voltage of around 17V when measured at a cell temperature of 25^{0}C. It can drop to around 15V on a very hot day and it can rise to 18V on a very cold day.

3.9.29 Operational Principle of MPPT

The major principle of maximum power point tracking is to extract the maximum available power from PV module by making them operate at the most efficient Voltage, that means, it checks output of PV module and compares it with battery voltage and then fix what is the best power that PV module can produce to charge the battery and convert it to the best voltage to get maximum current into battery. MPPT is most effective under the following conditions:

(i) Cold Weather cloudy or hazy days: Normally PV module works better at cold temperature and MPPT is utilized to extract the maximum power available from them.

(ii)When the battery is deeply discharged: MPPT starts extracting more current and starts charging a battery if the state of charge in the battery is lower.

3.9.30 Inverter:

Inverter is the power electronic circuit, which converts the DC voltage into AC voltage. A solar inverter or PV inverter is a type of electrical converter which converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network [26]. A solar inverter converts the low voltage DC electricity produced by the solar panels to the 120 volts or more AC electricity used by household appliances. The output voltage waveform of the inverter can be a square wave, quasi-square wave or low distorted sine wave. The output voltage can be controlled with the help of drives of the switches. The pulse width modulation techniques are most commonly used to control the output voltage of inverters. Such inverters are called as PWM inverters. The output voltage of the inverter contains harmonics whenever it is not sinusoidal. These harmonics can be reduced by using proper control schemes.

3.9.31 Types of Inverters

Basically, Inverters can be broadly classified into two types. They are

- Voltage Source Inverter (VSI)
- Current Source Inverter (CSI)

Voltage source inverter is a type of inverter which has input constant input DC Voltage, and then it is called Voltage Source Inverter (VSI) or Voltage Fed Inverter (VFI). Current Source Inverter is a type of inverter having constant input current and then it is called Current Source Inverter (CSI) or Current Fed Inverter (CFI). The difference between the two inverter types can be explained in table(3.14) below.

Table 3.14 comparative study between VSI and CSI

VSI	CSI
DC voltage source of VSI has a small impedance.	It is fed with adjustable current from a DC voltage source of high impedance.
Its Input voltage is maintained constant	Its input current is adjustable and maintained constant
The output voltage is independent of the load	Its amplitude of output current is independent of the load.
The waveform of the load current, as well as its magnitude, depends on the load impedance.	Its magnitude of output voltage and waveform depends upon the nature of the load impedance.
It requires feedback diodes	It does not require feedback diodes.
It has complicated commutation circuit	Its Commutation circuit is simple because, it contains only capacitors.
Power MOSFET, IGBT, GTO, Power BJT, with self commutation can be used in the circuit.	It does not withstand reverse voltage.

Current source inverter is used in only in high Power AC motor drives. Because of its limited application,current source of inverter is rarely used. For this system, Voltage Source Inverter is selected.

Sizing solar inverter: it is an important part of any solar installations, whether big or small. For an inverter to be right for any system, its watts rating must be approximately equal to the system's watts rating. This is the correct way to size an inverter. Surge Watts is the amount of

power the inverter can support for a short time, usually momentary. The inverter surge watts rating must be approximately equal to or greater than the potential surge watts of each appliance. For correct solar system sizing, solar panels, inverter and battery bank all needs to the same voltage. The input voltage of the inverter will depend on the inverter's power or watts rating. For inverters with a relatively small amount of power like 100Watts, the voltage will be 12V, 24V and 48V. For higher powered inverters, the input voltage will likely be more. If two compatible inverters are wired together in series, the output voltage (volts) of the system can be doubled. If two compatible inverters are wired in parallel, the power (watts) of the system can be doubled. When the sun is not at its brightest and the system is not producing at close to full capacity the inverter operating at partial load and its efficiency will drop. Energy loss occurs when an inverter is too small to operate in the condition of overload. By utilizing MPPT (maximum power point tracking), solar pumping inverters regulate output frequency to control the speed of the pumps in order to save the pump motor from damage. Solar pumping inverters usually have multiple ports to allow the input of DC current generated by PV arrays, one port to allow the output of AC voltage and a further port for input from a water-level sensor. The power output rating of the inverter you choose (in VA or in watts) is directly dependant on the load you will be powering. It is absolutely critical that you select an inverter that is powerful enough to operate your specific loads.

Step 1: The first step in inverter selection is to calculate the total (Watts or Amps) of all appliances.

Step 2: The second step is to determine the characteristics of the load. AC loads generally fall into two categories: Electronic loads, such as switching power supplies (or SMPS, as found in computers), and motors, such as the compressor in a refrigerator. Both of these types of loads require different levels of the initial surge of power required to start up, often called a Peak Surge for electronic loads or Locked Rotor Current for motor loads. The Peak Surge or Locked Rotor Current is almost always considerably higher than the Continuous Load (which is the power needed to run the load after initial start-up) and must be considered when sizing the inverter, the battery, and the cables that connect the two. The following formulas should, therefore, be strictly observed selecting a high-frequency topology inverter with a power output rating equal to or only slightly greater than the power rating of the load will result in an overloaded inverter, with a distorted wave shape at the output. The formula to use for all inverters which are to power motor loads is inverter's output AC voltage multiplied by Locked Rotor Current of motor load equals a minimum rating of inverter in VA**.** The selected motor size is 4.2Kw (7.5hp single phase), so the size of the inverter suitable for this motor be 40% more than motor size equal to 6kw. The type of inverter selected here is MUST inverter with a rating of 10KVA. Fundamental voltage V = modulation index times V peak Voltage.By taking modulation index, m = 0.8, output voltage for the inverter is Vo = 0.8 x 350V = 280V.

Single Phase Full Bridge Inverter: Inverter is DC to AC converter which converts dc power to ac power at desired output voltage and frequency. The output voltage of an inverter has a periodic waveform that is not sinusoidal but can be made to closely approximate this desire waveform. The full-bridge single phase inverter is made from two half bridges connected to form what is known as a full bridge or H-bridge inverter. Its arrangement is shown in figure 3.30 below. It comprises of DC voltage source, 4 power switches (usually bipolar junction transistors- BJTs, metal-oxide-semiconductor field-effect transistors- MOSFETs, insulated gate bipolar transistors- IGBTs or gate turned on transistors-GTOs) and the load.

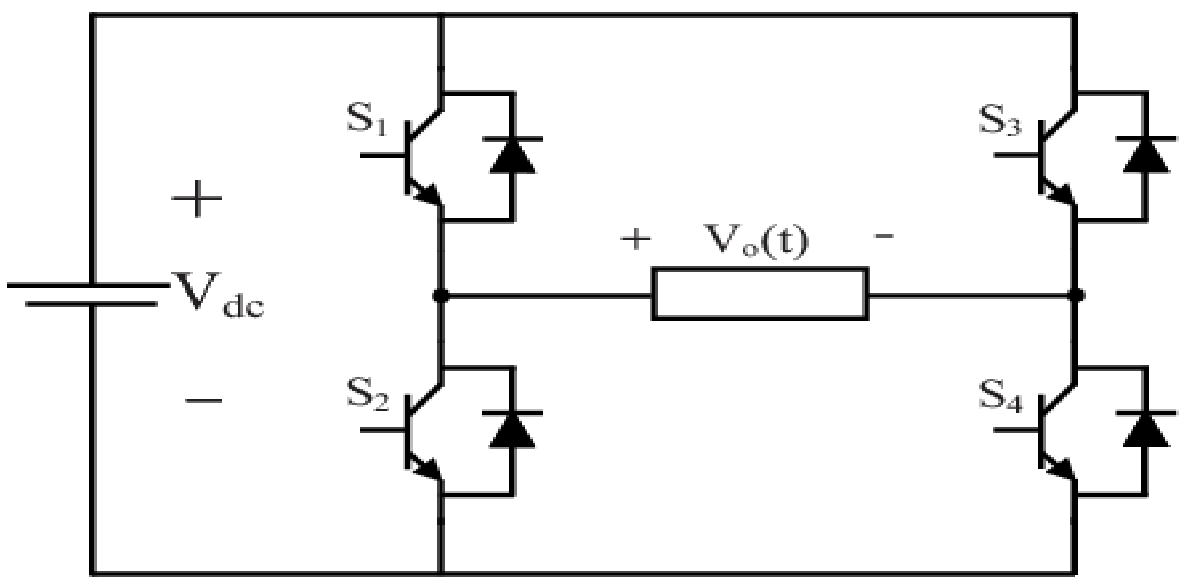


Figure 3.30 Full bridge single phase inverte[https://www.myelectrical2015.com › Full Bridge inverter › Inverter]

3.9.32Operation and switching sequences of Full-Bridge Single phase inverter

In order to create a square-wave output voltage, the device pairs Q1Q3 and Q2Q4 are switched alternatively at a delay of 180 degrees. When Q1 and Q3 are ON with Q2Q4 OFF for a duration t, also with Q2Q4 ON and Q1Q3 OFF at t. By assuming there is a sinusoidal load current, the load will absorb power when Q1Q3 and Q2Q4 pairs are conducting alternatively whereas feedbacking occurs when the diode pairs are conducting. A method for controlling the output voltage of the inverter in figure 3.31 called Phase shift control or phase shift pulse width Modulation.

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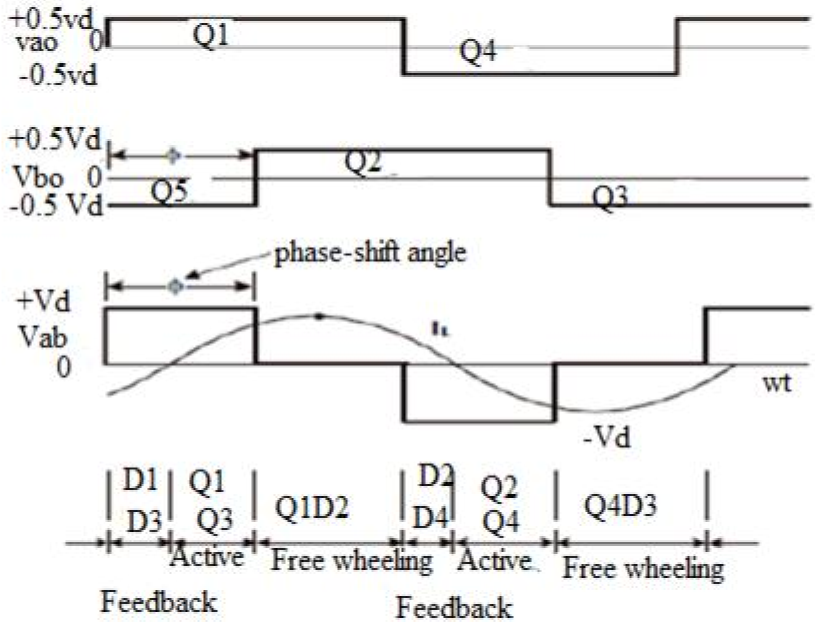


Figure 3.31 phase shift voltage control [Curled from Bose B. K. 2006]

3.9.33 Pulse Width Modulation (PWM)

Pulse width modulation (PWM) is a way of digitally encoding analog signal levels. The technique combines both frequency and voltage control. To obtain the necessary specific waveform on the constant pulsing period, the PWM circuit should give a chain of constant amplitude pulses in which the pulse duration is modulated. In PWM, the controlled output voltage is easily obtained by switching the transistors ON and OFF many times within a cycle to generate a variable voltage output which is normally low in harmonic content. The performance of a PWM converter significantly depends on the control method and the type of modulation control circuit for the single-phase bridge inverter.

The designed inverter Model is simulated as shown below by using MATLAB software R2015a.

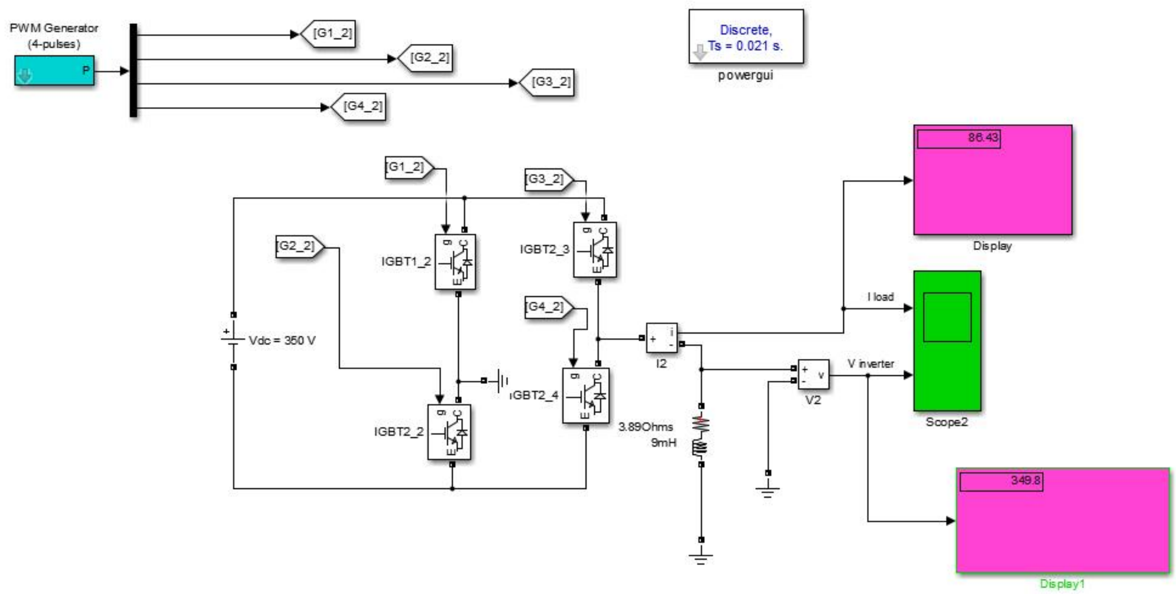


Figure 3.32 Single-Phase Inverter Model in MATLAB Simulink

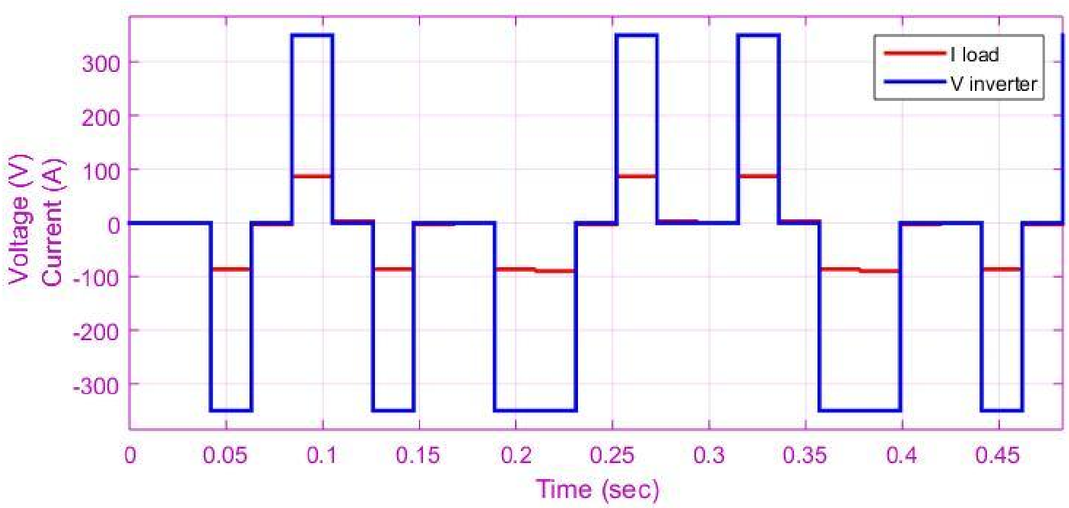


Figure 3.33 the output voltage and output current of the designed Inverter

From figure 3.33 the output voltage result obtained from the inverter is around 349V with square waveforms and the output current is around 86Amps, by adjusting the switching frequency of the inverter sinusoidal output current is obtained in figure3.34 below but the output voltage of the inverter obtained in figure below approaches to sinusoidal but not pure sinusoidal waveforms.

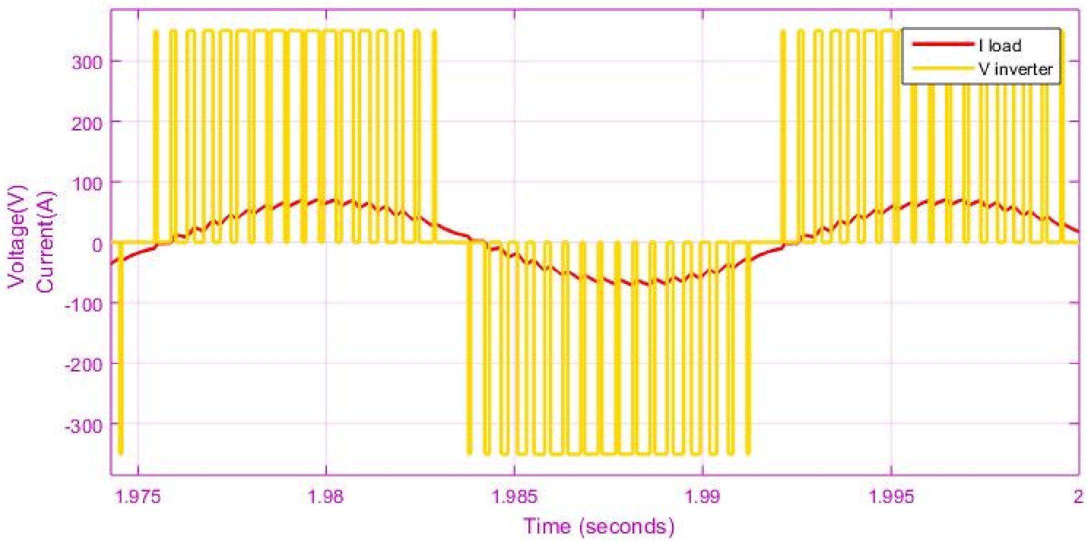


Figure 3.34 the modified output current and output voltage result of the Inverter.

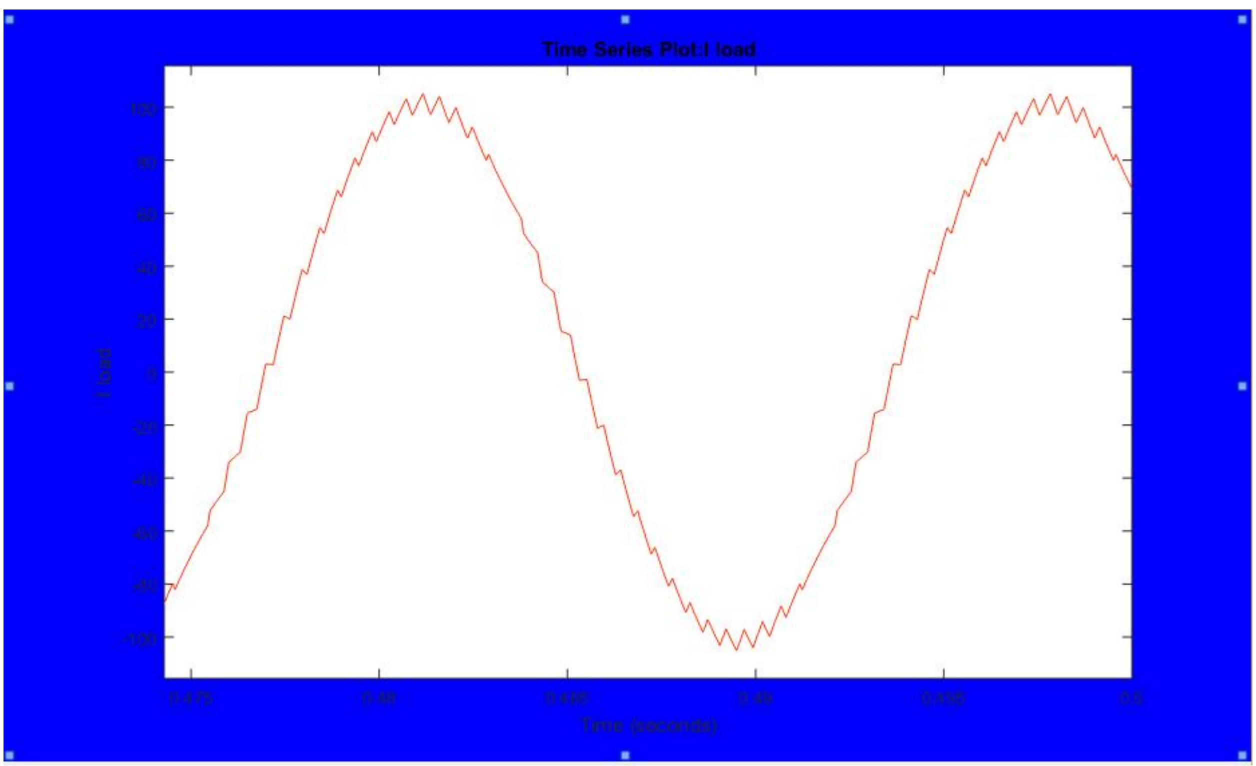


Figure 3.35 Output current of the inverter simulation result

3.9.34 L-C-L Filter design:

A filter is an important part of every semiconductor converter. This filter reduces the effects caused by switching semiconductor devices on other devices. The generation of the harmonics around switching frequency can be filtered by large inductance connected to the output of the converter. But large inductance decreases the dynamics of the system and operation range of the converter. The L-C –L filter has good current ripple attenuation even with small inductance values. However, it can bring also resonances and unstable states in the system. Therefore, the filter must be designed precisely according to the parameters of the specific converter**.** First, the base values need to be calculated

The filter components, $Z_b = \frac{U^2{}_n}{S_n}$ (3.78)

Where: $U^2{}_n$ is the nominal voltage of the converter, S_n is the apparent power of the converter.

$$C_b = \frac{1}{Z_{bw_n}} \quad (3.79)$$

The first step in calculating the filter components is the design of the inverter side inductanceL_i, which can limit the output current ripple by up to 10% of the nominal amplitude. It can be calculated as follows:

$$L_i = \frac{U_{DC}}{16 f s \Delta I_{L-Max}} \quad (3.80)$$

Where ΔI_{L-Max} is the 10% current ripple specified by

$$\Delta I_{L-Max} = 0.01 \frac{P_n\sqrt{2}}{U_n} \quad (3.81)$$

The filter capacity can be calculated as a multiplication of system base capacitance and maximal Power factor variation. In order to reduce oscillations and unstable states of the filter, the capacitor should be added with an in-series connected resistor. It can increase the heat losses in the system and decreases the efficiency of the filter, so it is rejected due to its drawback.

The selected Inverter specification: Model EP30-30KW (please refer-Appendix g).

- Nominal power (Pn) 10000W.
- Power factor full load (1)
- Nominal Voltage 240V+10%RMS

- Nominal Battery Voltage, 48VDC
- Fs, 50Hz

Using these converter specifications, the filter component value can be determined as follow:

Z_b = 5.9Ω as in equation (3.57), C_b = 169mF as equation (3.58), L_i= 1.29mH in equ(3.59)

These filters limits ripple output current and output voltage. Filter component value is depends on the converter specification.

3.9. 35 Induction Motor:

Induction Motors are the most commonly used motors in many applications, this is because of simplicity, low starting torque and it availability unlike DC Motors.These induction motors are also called as Asynchronous Motors because an induction motor always runs at a speed lower than synchronous speed.It is also defined as is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. Synchronous speed means the speed of the rotating magnetic field in the stator.

Basically, there are 2 types of induction motor depending upon the type of input supply - (i) Single phase induction motor and (ii) Three-phase induction motor.

Table 3.15 comparative study between Single Phase and Three Phase Induction Motor

Basics	**1-Φ IM**	**3- Φ IM**
Supply	Single-phase	Three-phase
Starting Torque	Starting torque is low	Starting torque is high
Maintenance	Easily maintain	Difficult to maintain
Features	Simple construction, reliable	More complex
Efficiency	Low	High
Power factor	Low	High
Application	Domestic appliances	Mostly used in industries

Single-phase motors are typically 1 to 10 hp, fixed or multispeed, ranging from 900 to 3600 rpm in 115 and 230 V, and 60 Hz. They are available in the same horsepower rating at 50 Hz with fixed speeds ranging from 3000 rpm down to 750 rpm [35].

According to type of rotor: - (i) Squirrel cage motor and (ii) Slip ring motor or wound type. Squirrel-cage Induction motors are cheaper in cost due to the absence of brushes, commentators, and slip rings. They are maintenance-free motors, unlike dc motors due to the absence of brushes, commentators and slip.

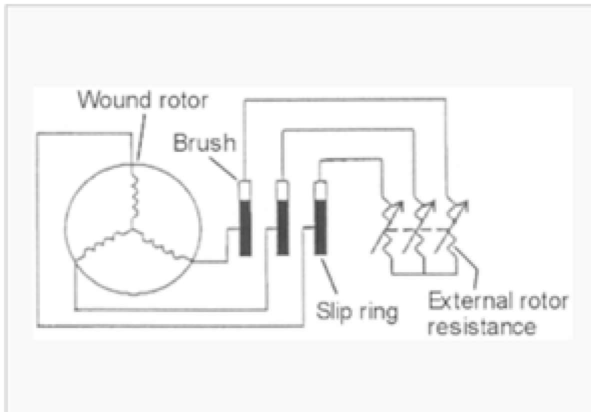


Figure 3.36 Wound-rotor-motor diagram [courtesy of Houston Armature Works Inc.]

Wound-rotor induction motors are used in applications of certain types of pumps, in mine hoists, mills, and applications where speed reduction is required in the drive application. Because of its simplicity, low starting torque in a single-phase induction motor is used to protect surge current that can damage the electronic device and due to the above-mentioned cases listed in the table, single-phase squirrel-cage induction motor is selected for the purpose of this work.

3.9.36 Basic Working Principle of an Induction Motor:

In a DC motor, supply is needed to be given for the stator winding as well as the rotor winding. But in an induction motor only the stator winding is fed with an AC supply. Alternating flux is produced around the stator winding due to AC supply. This alternating flux revolves with synchronous speed. The revolving flux is called as "Rotating Magnetic Field" (RMF). The relative speed between stator RMF and rotor conductors causes an induced emf in the rotor conductors, according to the Faraday's law of electromagnetic induction.

Figure 3.37 induction motor diagram[enquiries@mawdsleysber.com]

The rotor conductors are short-circuited, and hence rotor current is produced due to induced emf. That is why such motors are called as induction motors.

Hence induction motors can be called as rotating transformers. Now, the induced current in the rotor will also produce alternating flux around it. This rotor flux lags behind the stator flux. The direction of induced rotor current, according to Lenz's law, is such that it will tend to oppose the cause of its production. As the cause of the production of the rotor current is the relative velocity between rotating stator flux and the rotor, the rotor will try to catch up with the stator RMF. Thus the rotor rotates in the same direction as that of stator flux to minimize the relative velocity. However, the rotor never succeeds in catching up with the synchronous speed. This is the basic working principle of an induction motor of either type, single phase of three Phases.

3.9.37 Types of Single phase Induction Motor:

- Capacitor Start Capacitor Run Motor:
- Permanent Split-Capacitor Motor: its starting torque is very low, perhaps only 75% of rated torque.

Capacitor Start Capacitor Run Motor: The capacitor-start motor uses a capacitor to produce a phase shift. It is sized to provide high starting torque, as much as 300% of rated torque. The capacitor is not designed for continuous operation, so there is a centrifugal switch in this motor to remove the auxiliary winding after the start-up. To obtain good starting torque and good running performance, two capacitors could be used. One capacitor provides high starting torque and is switched out when the motor reaches rated speed.The Capacitor Start Capacitor Run Motor has a cage rotor, and its stator has two windings known as Main and Auxiliary Windings. The two windings are displaced 90 degrees in space. There are two capacitors in this method one is used at the time of the starting and is known as the starting capacitor. The other one is used for the continuous running of the motor and is known as the RUN capacitor. This motor is also known as Two Value Capacitor Motor. Connection diagram of the two valve capacitor motor is shown below.

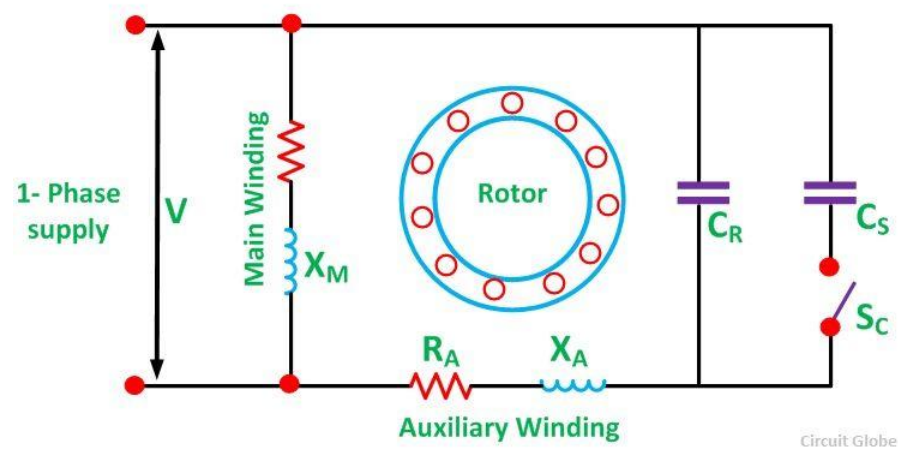


Figure 3.38 Single-phase capacitance start capacitance run induction motor[enquiries@mawdsleysber.com]

There two capacitors in this motor represented by C_S and C_R are connected in parallel.The Capacitor Cs is the Starting capacitor is short time rated. A large amount of current id required to obtain the starting torque. Therefore, the value of the capacitive reactance X should be low in the starting winding. Since, $X_A = 1/2\pi fC_A$, the value of the starting capacitor should be large. Rated line current is smaller than the starting current at the normal operating condition (i.e.) the value of the capacitive reactance should be large. Since, $X_R = 1/2\pi fC_{R,}$ the value of the run capacitor should be small. The starting capacitor Cs is disconnected from the circuit by a centrifugal switch Sc as the motor reaches the synchronous speed. The capacitor C_R is connected permanently in the circuit, thus it called RUN Capacitor. The Torque Speed Characteristic of a two-value capacitor motor is shown below.

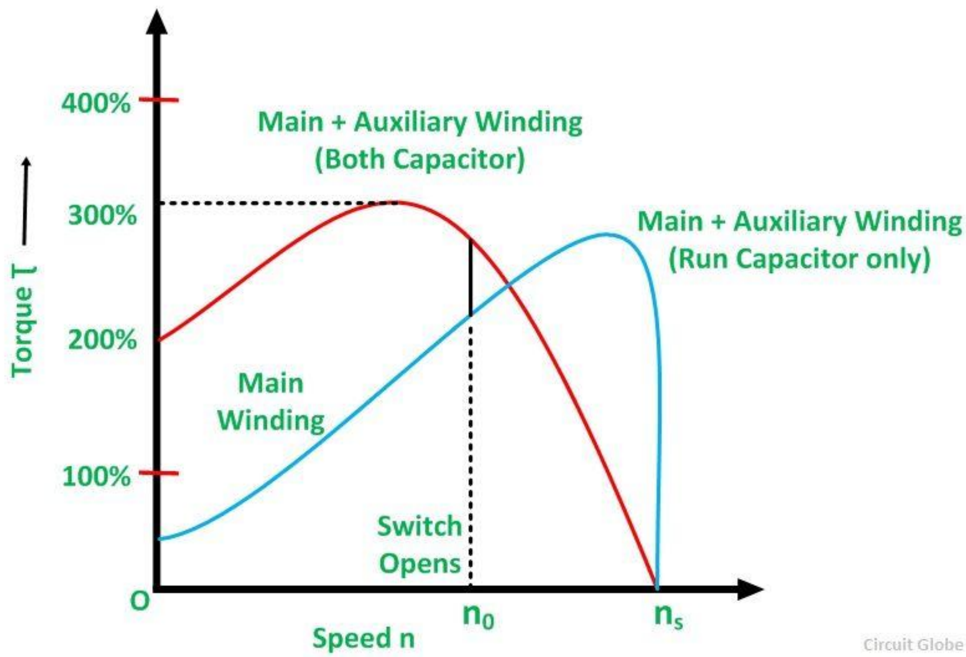


Figure 3.39 Torque Speed Characteristic of Capacitor Start Capacitor Run Motor[circuitGlobe]

This type of Motor has quite and Smooth running. They are used for loads of higher inertia requiring frequent starts where the maximum pull-out torque and efficiency required are higher. They have higher efficiency than the motors that run on the main windings only and are used in Pumping applications, Refrigeration, and air compressors, etc.

3.9.38 Mathematical modeling of induction motor

The torque and voltage equations that describe the dynamic behavior of an induction motor are time-varying. A change of variables can reduce the complexity of differential equations by eliminating all time-varying inductances, due to electric circuits in relative motion, from the voltage equation of the machine (Batool & Ahmad 2013). By following this approach, a poly-phase winding can be reduced to a two-phase winding (d-q) with their magnetic axes formed in quadrature. Matlab/Simulink implementation of an induction machine using dq0 axis transformations of the rotor and stator variables in the arbitrary reference frame was formulated by Ratnani & Thosar (2014). The voltages, currents and flux linkages of an induction machine are transferred to a reference frame, which rotates at any angular velocity or may remain stationary. Such a generalized machine analysis called an arbitrary reference frame.The mathematical model of the single-phase induction motor (SPIM) in the d-q axis is given by the equation below.

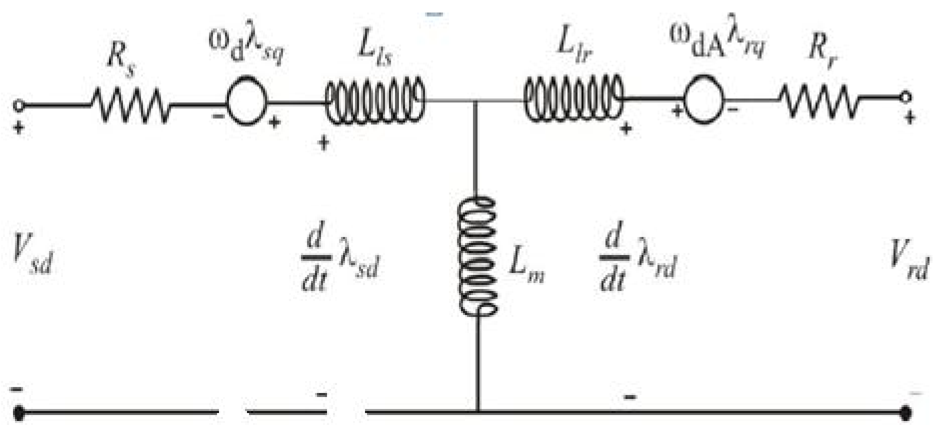


Figure 3.40 IM Equivalent Circuit in the d-axis frame

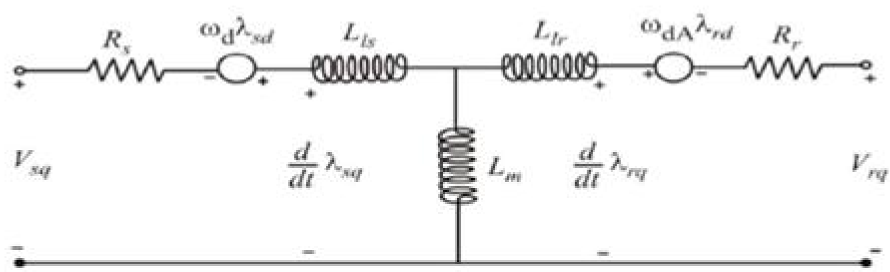


Figure 3.41 IM Equivalent Circuit in the q-axis

$$\begin{pmatrix} Vsq \\ Vsd \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} (Rsq+PLsq) & 0 & PLod & 0 \\ 0 & (Rsd+PLsd)Isd & 0 & PLod \\ PLoq & -(Nq/NdwrLod) & (Rrd+ PIrd) & (Nq/NdWrIrd) \\ PLod & -(Nd/NqWr.Loq) & (Nd/NqWrIrq) & (Rsq+PLsq) \end{pmatrix} \begin{pmatrix} Isq \\ Isd \\ Irq \\ Ird \end{pmatrix} \quad (3.82)$$

Where the parameters refer to; Rsq and Rsd are the q and d axis stator resistances, Lsq and Lsd are the q and d axis stator inductances, Vsq and Vsd are the q and d axis stator voltages, and ,

Nq and Nd are the d and q axis effective turns, p is the differential operator (d/dt), Isq and Isd are the q and d axis stator currents, Loq and Lod are the q and d axis mutual inductances, i'rq and i'rd are the q and d axis rotor currents, R'rq and R' rd are the q and d axis rotor resistances, L'rq and L'rd are the d-q axis rotor inductances and the angular speed Wr.

Using the d-q axis, the stator Ls and rotor Lr inductances can be given by the equation below:

$$L_{sd} = L1_{sd} + L_{od} \tag{3.83}$$

$$L_{sq} = L1_{sd} + L_{od} \tag{3.84}$$

$$L'_{rd} = L'1_{sd} + L_{od} \tag{3.85}$$

$$L'_{rq} = L1_{sq} + L_{od} \tag{3.86}$$

Where, L1sd and L1sq refer to the d-q axis stator leakage inductances and L'1rd and L'1rq are the d-q axis rotor leakage inductances. The electromagnetic torque can be calculated as follows:

$$Te = \frac{P}{2} * \frac{Nd}{Nq} * Lod\,(Isq * Ird - Isd * I'rq) \tag{3.87}$$

Where, P is the number of poles. For the single − phase induction motor, the electromechanical equation can be given as follow:

$$P.Wr = \frac{1}{J_M}\,(Te - T_L) \tag{3.89}$$

Where, J_M is the motor inertia constant and T_L is external load torque, Te is the motor torque. in the above equation(3.89), the auxiliary winding and the main winding represented by the d-axis,and q-axis respectively. Therefore Vsq voltage is equal to the Vs source voltage.

The auxiliary winding Vsd is expressed as :

$$Vsd = Vs - \frac{1}{C}\int Isd.dt \tag{3.90}$$

Optimal capacitor value calculation**:** From the equivalent circuit of single phase induction motor, its motor toque is expressed as:

$$Te = \frac{1}{we}.\frac{2}{P}[\{(Rsq + Rb + Rd)Vsq + RdVsq\}2 + \{(X1sq + Xb + Xd)Vsq + XdVsq\}2] * (Ra/(M12 + N12)) - \frac{1}{we}.\frac{2}{P}[\{(Rsq + Ra + Rd)Vsq + RdVsq+\}2 + \{(X1sq + Xa + Xd)Vsq + XdVsq+\}]2 * (Rb/(M12 + N12)) \quad ((3.91)$$

Where, Rb, Ra, M1, N1, Xa, Xb and Xd are dummy variables. All these variables can be expressed as below equations.

$$Ra = \frac{\{\frac{X^2 osR'rq}{S}\}}{\{(\frac{R'rq}{S})^2 + (Xos + X1rq)2\}} \tag{3.92}$$

$$Xa = \frac{\{Xos((\frac{R'rq}{S})^{\mathbf{2}} + (Xos + X1rq)XosX1rq\}}{\{(\frac{R'rq}{S})\mathbf{2} + (Xos + X1rq)2\}} \tag{3.93}$$

$$Rb = \frac{\{\frac{Xos2\ R'rq}{(2-S)}\}}{\{\left(\frac{R'rq}{(2-S)}\right)^2 + (Xos + X1rq)\mathbf{2}\}} \tag{3.94}$$

$$Xb = \frac{\{Xos\left(\frac{(R'rq}{(2-S)}\right)^2 + (Xos + X1rq)XosX1rq\}}{\{\left(\frac{(R'rq}{(2-S)}\right)^2\}} \tag{3.95}$$

$$Rd = ½\{Rsd(\frac{Nq}{Nd})2 - Rsq\} \tag{3.96}$$

$$Xd = 0.5Xlsd(\frac{Nq}{Nd})2 - 0.5Xlsq - Xc \tag{3.97}$$

$$M1 = (Rsq + Ra + Rd)(Rsq + Rb + Rd) - (Xlsq + Xa + Xd)(X1sq + Xb + Xd) - (Rd2 + Xd2) \tag{3.98}$$

$$N1 = (Rsq + Ra + Rd)(Xlsq + Xb + Xd) + (Rsq + Rb + Rd)(Xlsq + Xa + Xd) - 2RdXd \tag{3.99}$$

Maximum torque at various speeds can be achieved by letting

$$dTe/dXc = 0 \tag{3.100}$$

3.9.39 Speed Control of Induction Motor

The speed of an Induction Motor can be controlled in many methods. The following block diagram shows the different speed control method of induction motors.Those are stator voltage control, supply frequency control, pole changing, rotor resistance control and the latest mechanisms which is called slip- energy recovery.

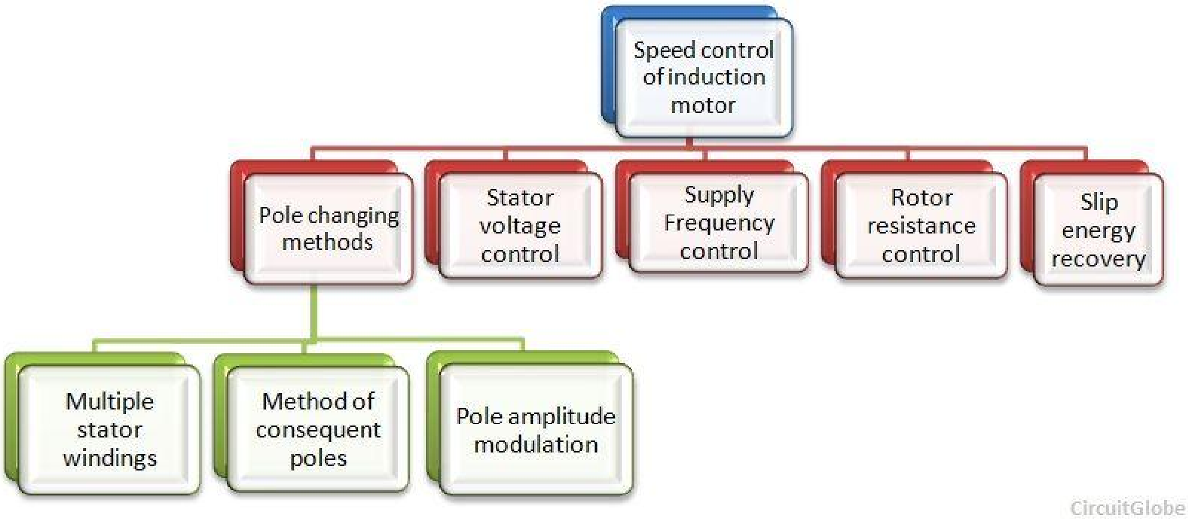


Figure 3.42 types of Speed control for induction motor[https://www.electrical4u.com]

The most commonly used speed controls of the induction motor are:

Rotor resistance control: it is used for slip ring Wound rotor induction motor. It is possible to have high starting torque and low starting torque by connecting an external resistor to the rotor circuit. Maximum torque is independent of the rotor resistor but it depends on the value of the slip rings. Increasing the motor resistance will decrease pull out the speed of the motor but its maximum torque remains constant. It is used in cranes, pump drive fans The main disadvantage of this control method is the connection of external resistance in the rotor circuit through slip rings, I^2R power losses exist.

Variable Frequency Control: The speed of an Induction motor can be controlled by varying the supply frequency. The synchronous speed of an induction motor is given by the relation.

$$N_s = \frac{120f}{P} \tag{3.101}$$

The EMF induced in the stator of the induction motor is given by the equation shown below.

$$E_1 = 4.44fw\Phi T_1 \tag{3.102}$$

If the supply frequency is changed, induced EMF will also change to maintain the same air gap flux. An induced EMF E_1 is equal to the terminal voltage V_1 if the stator voltage drop is neglected. To minimize the power losses, the motor is operated at rated air gap flux. This condition is obtained by varying the terminal voltage with frequency so as to maintain (V/f) ratio constant at the rated value. The rotor speed of an induction motor is given by the equation below;

$$\mathrm{Nr} = (1 - \mathrm{s})\mathrm{Ns} \quad (3.103)$$

$$\mathrm{Nr} = \frac{120\,\mathrm{f}}{\mathrm{P}}(1 - \mathrm{s}) \quad (3.104)$$

From equation (3.104) rotor speeds of an induction motor are controlled by varying frequency, slip and pole. In this system, a variable frequency control method is selected due to the commutation problem in the wound rotor induction motor, so the squirrel cage induction motor is recommended.

3.9.40 Economic Feasibility Analysis of Solar PV Water Pump

There are many factors that need to be known before carrying out the economic assessment of PV water pumps. Those factors include the system lifetime, discount and interest rate each item. The life cycle of the entire system is decided considering the component system with the longest replacement interval.

Major assumptions made in economic assessment for PVWPs

- The discount rate was assumed to be 10%
- No parts of the system are stolen
- Salvage value of the PV system is assumed 15% of the total initial purchasing cost.
- Salvage value of diesel engine was assumed to be 20% of the capital cost of the engine
- The operating life of the PV panels was assumed to be 20 years.
- The life of the solar pump was assumed to be 10 years.
- The maintenance of the PV system assumed to be 0.1% of the total capital cost per year.

3.9.41 Economic Assessment for Diesel Water Pumps, For diesel water pumps, many assumptions have been made. It was assumed that the pump operates 6 hours per day [29]. The pump efficiency is 60% and Pump replaced every 10 years [36]. The discount rate is the same for PV water pumps has been assumed to be 10%. The maintenance cost was 10% of the capital cost per year. Salvage value of diesel engines was assumed to be 20% of the capital cost of the engine. The fuel consumption of a generator with a capacity of 10 cubic meters per hour can be calculated as below. Annual Fuel cost = specific fuel consumption * total operating hours in a year * fuel rate [18](4.2). Since the daily water demand is 85 cubic meters, so the pump can stay on operation for 9 hours to fulfill the daily water demand.

1.5 liter/hr *(9hr/day*365day/year) *0.69$/liter = 1.5L/hr*9hr/24hr*365*24hr/year*0.69$/L = $3400 per year. Fuel cost of diesel generator for the duration of 20 years is the product of annual cost times its life span assumption of 20 years, which = 20 years*$2266.65 = $45333(only for fuels). (Generator fuel consumption depends on specific objective). Replacement cost for diesel generator and pump $2000, twice within 20 years and$2000 per year for maintenance. By considering the pump cost with its accessories (motor, controller box, $10,000) generator cost($2500), annual fuel cost $3400 and minor cost for cable wire, pipe, and breaker the initial investment for the diesel water pumping system is $15900+ $300) = $16200 at the first year. But after installation completed, total yearly cost will be $5400 per year. Even though the capital cost of a PV water pump in the first year is high, it dramatically reduced to a minimum value after all its installation is finished and it is a better option of a water pumping system, because it is free energy and always reliable.

Revenue Assumption: under the current system, the villagers must either use water collected throughout the week or find other sources of water. Both options cause **a** decrease in productivity due to the related opportunity. If water is stored for long periods of time without purification, then it is likely that parasites and bacteria will inhabit the water and causes illness, therefore care must be taken.

Cost Assumption: the cost assumptions primarily consist of initial investment costs in the power and hydraulic system. The power system major components includes Panel modules, inverter, combiner boxes, a $/Watt estimation for Gerbicha Kebele was calculated given that the economic scales of EEPCO cost of 1260KWh maximum power Energy used by the system per month determined based on scales 0-500Kwh with service charge 0.95 Cents ($0.032) per Kwh and above 500Kwh the service charge is multiplied by ($0.046) or 1.35 ETB . The combiner Box is estimated to cost $200 from Beijing Multifit Electrical Technology Co. Ltd, AC Breaker panel is estimated to cost $160 from Indian. The warranty on the entire system Provided by five years but for the individual solar panel, it is 20 years. Replacement for the Breaker panel, the combiner box is negligible but for the inverter, it can need replacement every ten years. Considering cables price, installation and other labor costs for implementing the system must be considered. The US department of energy, energy efficiency and renewable energy division estimates for the installation costs at \$0.17/W of the system and indirect costs of \$0.76/W [49]. The indirect cost includes site-related costs, permitting, design, Engineering, and profit costs. But as the task of design and Engineering is completed, this Cost was down to half of the original cost which is \$0.38/W [50] The total investment of the project will be \$52673.36 with annual operation and maintenance costs of \$4300(please refer-appendix A1). The financial benefits of implementing this design will determine the savings afforded to the people in the village. All materials and labor costs are estimated based on local costs. The cost of a Cubic meter of water pumped is obtained by dividing the annualized life cycle cost of the system by the total pumped water. Using this formula, the cost of pumped water becomes \$0.16/m^3. Comparing this cost of water per cubic meter with that of grid-connected water pumping at \$0.34/m^3, this is too much cheap. The hydraulic system included investment cost for the 21250-gallon tank (\$5000), the Pump cost (\$4,000), replacement of the pump also a significant factor as they must be replaced every eight years. Cost of inverters for each \$1,446.67x8which is 335627.44 ETB (\$11573.36.) The minimum capital cost for this research is simulated by HOMER Software as below.

3.9.42 Introduction of HOMER SoftWare

HOMER (Hybrid Optimization of Multiple Energy Resources) is a free software application developed by the National Renewable Energy Laboratory in the United States. This software application is used to design and evaluate technically and financially the options for off-grid and on-grid power systems for remote, stand-alone and distributed generation applications. Models of HOMER greatly simplify the task of designing hybrid renewable micro-grids, whether remote or attached to a larger grid. HOMER's optimization and sensitivity analysis algorithms allow to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs, electric load, and energy resource availability. It was originally designed at the National Renewable Energy Laboratory for the village power program. HOMER can model both the technical and economic factors involved in the project. It can provide an important overview that compares the cost and feasibility of different configurations so that designers can use more specialized software to model technical performance. Its sensitivity analysis helps determine the potential impact of uncertain factors such as fuel prices or wind speed on a given system. It models both conventional and renewable energy technologies, either as a microgrid or as distributed generation within a larger grid: Inputs for HOMER Software are daily load demand, daily peak load, and converter rating load

Table 3.16 Simulation results of economic feasibility by HOMER software.

Detailed Optimization Results

#	PV kW	Converter kW	Total Capital Cost $	Total NPC $	Tot. Ann. Cap. Cost $/yr	Tot. Ann. Repl. Cost $/yr
1	35	7.50	36,088	39,798	2,823	283
2	35	8.00	36,160	39,895	2,829	284
3	35	8.75	36,269	40,039	2,837	286
4	35	10.00	36,450	40,279	2,851	290
5	35	12.00	36,740	40,663	2,874	295
6	42	7.50	43,088	47,470	3,371	335
7	42	8.00	43,160	47,566	3,376	337
8	42	8.75	43,269	47,710	3,385	339
9	42	10.00	43,450	47,950	3,399	342
10	42	12.00	43,740	48,334	3,422	347
11	50	7.50	51,088	56,238	3,996	395
12	50	8.00	51,160	56,334	4,002	397
13	50	8.75	51,269	56,478	4,011	399
14	50	10.00	51,450	56,718	4,025	402
15	50	12.00	51,740	57,102	4,047	407

3.9.43 Result and Discussion:

Generally, the PV cell output power was shown to be increased with the radiation intensity as shown in figure(3.3). An increase in the output power is primarily caused by a rise in the Voc and Rs decreases continuously with increasing the intensity of illumination. The efficiency of the solar cells falls when temperature increases, as shown in figure (3.4), this is due to the decrease of the open-circuit voltage. It is shown that the output power is a direct function of the cell temperature; it is mainly due to an increase in temperature results the bandgap energy of the intrinsic semiconductor shrinks. With Fill Factor calculation a reduction in Voc results in a smaller theoretical maximum power (Pmax) is the product of short circuit current and open-circuit voltage (Isc x Voc**).** The presence of the series resistance limits the output current and causes a drop in voltage at a specific current which lowers the fill factor of the curve. Increasing the series resistance results in the I-V characteristic becoming flattened at the knee. The shunt resistance (Rsh) must be higher to avoid current loss at the junction reducing the Photocurrent and solar cell performance. It is known for any PV cell its shunt resistance should be large enough for higher output power and Fill Factor. For small Rsh values, the power losses in the cells are due to an alternate current path for the light- generated current. Such a diversion reduces the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell.

As shown in figure (3.8) the maximum rated current for the system is obtained at maximum voltage 570VDC and the required power 42Kw is at 570VDC from the MATLAB simulation result as STC of $1000W/m^2$,25^0 C, but at different temperature of 50^0C and 100^0C with irradiance of $1000W/m^2$, there is slightly change in the output current but open-circuit voltage decreases as temperature increase as shown in figure (3.9 and 3.10) as temperature increase open-circuit voltage goes to zero, this implies that the maximum power point is shifting to zero and it leads to reduction of power. So by using the latest optimization technique, the effect of temperature may reduce. The effect of solar intensity on PV array is shown in figure(3.11) at temperature of 25^0 C , increase in solar intensity causes increase in PV array current(i.e. for $0.1Kw/m^2$, the system current is 10Amps, for $1Kw/m^2$, system current is 83Amps, this approaches to the systems current rating and also as solar intensity/radiation increases, the maximum power point operating area also increases as shown in figure(3.12), this implies that

increase in solar intensity causes increase in system power. Here is, the result obtained is almost approaching the rated value but not the exact value, this due to the materials resistance, Cell temperature, and Switching losses. From the Simulink model of a step down dc-dc converter shown in figure (3.27), the diode connected to the IGBT Switch is used for freewheeling during the IGBT Switch is open and closed and it is forward biased. Since there is fluctuation in solar radiations so single phase induction motor is selected for the system designed, this due simplicity of single phase induction motor in comparison with a three-phase motor and also the power it needs to start. Considering the switching losses in the inverter, 350VDC is selected as the designed inverter inputs. Using this inverter input, the step down buck converter output voltage is determined to be 350VDC because, the output voltage of PV Array is the input voltage of buck converter and buck converter output voltage is inverter input voltage, so, as the simulation result in figure (3.27) shows, its output voltage is 350VDC and its output voltage waveform is shown in figure(3.28), which has stability problem at start(i.e. rise time and overshoot time is up to 490VDC but drops to its saturation point after one second and becomes smooth signal after three seconds without put of 350VDC.

For the implementation of the system, controllers like proportional-integral (PI), Proportional-Derivative (PD) or Proportional, integral derivative (PID) controllers may avoid stability problems in the system. The main criteria for selecting a power electronics switching device are, to reduce power losses due to switching devices. Due to its current carrying capability, fast switching, and easy turn ON and turn OFF, IGBT Switch is selected for Inverter switch, so the result obtained from the figure (3.32) of Single phase PWM inverter model is 349.8VAC and current is 86.4Amps. The result indicates that it is sufficient to run a single-phase induction motor. As shown in figure(3.33) both the output voltage and output current of inverter simulation result waveform is a square wave, by adjusting the switching frequency of the inverter sinusoidal output current waveform is obtained as shown in figure(3.34) and its output voltage approaches to sinusoidal waveforms but not pure sinusoidal waveforms and also pure sinusoidal current waveform obtained as shown in figure(3.35qq).

The simulation result obtained from table(3.16) indicates that the feasibility of the PV water pumping system is economically feasible from $36,088 to $51,743 without including the cost of pump and storage and its accessories and also simple to install than Wind and Hybrid of both. The Optimization Result obtained from the simulation is $36,088, this is, the minimum requirement to yield the main objective of the research in case of energy. But for this system daily load required is 42KW and inverter with 10Kw rating, so as shown in table 4.2 simulation result, the capital investment for the designed system will be $43450 and Net present value will be $47950 with annual maintenance and replacement cost $3399 and $342 respectively. The detail descriptions of the HOMER simulation result are shown in(appendix A_2).

CHAPTER FOUR

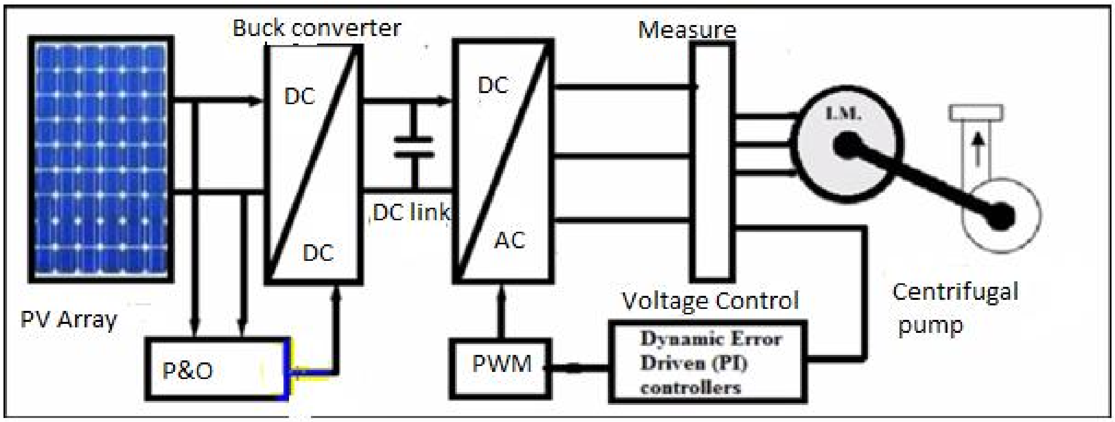
PHOTOVOLTAIC WATER PUMPING SYSTEM

4.1 Background

Water pump system is a system which drives the water from the lower level to the high level or upper surfaces of the earth. Photovoltaic water pumping system is an application of solar energy that converts solar energy into electrical energy in order to run the motor of the pump[37]. Many people around the world live with limited access to water. In many communities, water from the ground is extracted through electric water pumps, which use diesel to fuel their systems. However, these systems need or require many costs, regular servicing and the purchasing of fuel, they emit carbon dioxide polluting the atmosphere. photovoltaic water pumping (PVP), is an alternative one comparing to diesel fueled water pump because of its cost effectivity and free energy[51]. After years of technological advances and researches, this solar water pumping has been proved operationally, financially, and environmentally sustainable. The cost of solar technology has dropped tremendously and also Prices for the solar panels used have dropped as a number of demand increases. In addition, these panels last around 25 years, requiring little maintenance throughout this time. These factors have made Solar Water Pumping an extremely viable way to expand energy access across developing countries and communities while creating a strong resistance to shifts in rainfall caused by climate change or unreliable seasonable patterns.Some governments have opted to subsidize the cost of solar pumping, increasing the pool of shared learning for this emerging technology. Even though solar water pumping is ready for mainstreaming and has started to take off in some parts of the world, its benefits remain largely unknown to communities, governments, and development institutions.

4.2 Operational principle of Solar Water Pump

The photovoltaic cells in solar modules can convert the sunlight into direct current (DC) Electrical energy. This energy is given to the pump through a pump controller in case of DC Pump Via variable frequency drive (VFD) in case of AC pump variable frequency drive can convert DC into AC**.** Pump system operation is the combination of the impeller and the motor. The main function of an impeller is propelling the water movements and that of the motor is driving the pump. During this, the water is propelled out of the bore wells/river/lakes/ through the pipe; the water then stored for a limited day and distributed to the community by using gravitational force. This gravitational force is due to the storage of the water is placed at a high elevation in order to reduce the cost of pumps for distributer pumps.



.Figure 4.1 PV Powered Water Pumping System[researchgate.net]

System Description: The configuration of stand-alone PV-powered IM-based water pumping system is shown in Figure(4.1)comprises two main schemes; the first scheme is the power scheme and includes: photovoltaic power source, DC/DC buck converter, Dc link capacitor, 3-leg 4-switch IGBT inverter, and Single-phase induction motor mechanically coupled with water pump. In the second scheme known as the control scheme using dynamic error driven (PI). MATLAB computing environment is used for system simulation[50].

4.3 Annual water demand Assumption: Yearly energy used and water pumped assumption for the months January to June, the water consumption is more, because these months are summer month in Ethiopia, so more water consumption is there and as calculated above in the daily water requirement of 85 cubic meter per day, which gives 2550 cubic meters per month with 1260Kwh of energy. July up to November, the season is winter in Ethiopia, so no more water is used and the assumption is made to be 50% of daily water demanded used in July, 60% in August, 70% in September, 80% in October, 90% in November and 100% in December, because in winter for washing purpose and for cattle drinking the community can use rain.

The annual average of water pumped is 26775 cubic meters and 13230Kwh of energy is used and 1890Kwh of energy is excess.

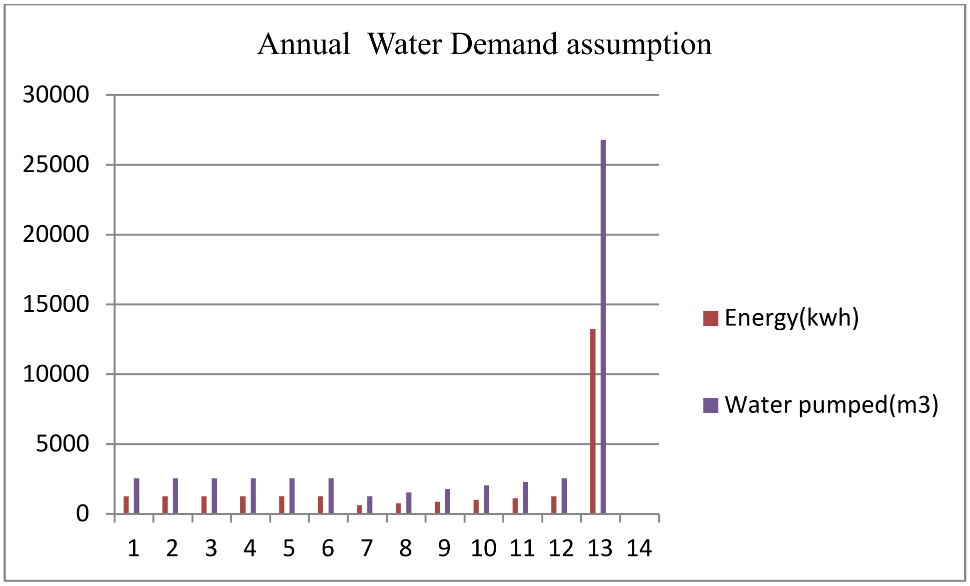


Figure 4.2 graphical representation of water pumped (No 1-13 represents months &average)

From figure 4.2 graph of annually water pumped, it indicates that annual water demand assumption is correctly shown by the graph and the output result of water pumped has direct relationship with solar intensity and as assumption for the months of July and August, the water pumped is very low compared with others as shown in figure 4.2.

4.4 Factors that influence PV Water Pumping Systems:

Environmental Conditions and PV Panel includes the following: Meteorological data, Solar irradiation, Air mass, PV Material Types, Tilt angle and Azimuth, Characteristics of PV Cell, Energy Storage, controllers, converters and pump types all are the main factors that determine PV water pump efficiency.The overall solar-powered water pump efficiency is obtained by the following formula

. $\dot{\eta}_{total} = \dot{\eta}_{pv} * \dot{\eta}_{mp}$, where $\dot{\eta}_{pv}$ is the efficiency of PV and $\dot{\eta}_{mp}$ is the efficiency of the pump.

$$\dot{\boldsymbol{\eta}}_{pv} = \frac{\mathrm{P_{PV}(W)}}{G\left(\frac{w}{m^2}\right) * \mathrm{Acm}^2}, \dot{\eta}_{mp} = \frac{\text{Hydraulic Energy(Eh)}}{\text{input energy of the pump(Ei)}} \tag{4.1}$$

4.5 Pump Control Valves, For pumping systems where surge control is critical and energy savings is important, a pump control valve is typically used. The valve is wired to the pump controls and provides adjustable opening and closing times in excess of the system-critical surge period. Unlike check valves, the pump control valve's speed of operation is not affected by line flow or pressure conditions. Stable operating times are essential in controlling surges in pumping systems. A Val-Matic Ener•G™ Ball Valve is the ideal pump control valve for pumping systems. Its equal percentage flow characteristics, rugged AWWA construction, and virtually zero head loss make it the preferred choice. AWWA Butterfly Valves can also be used for clean water applications and AWWA Eccentric Plug Valves for wastewater applications. Its control signal port and the internal circuit are expressed as the figure below.

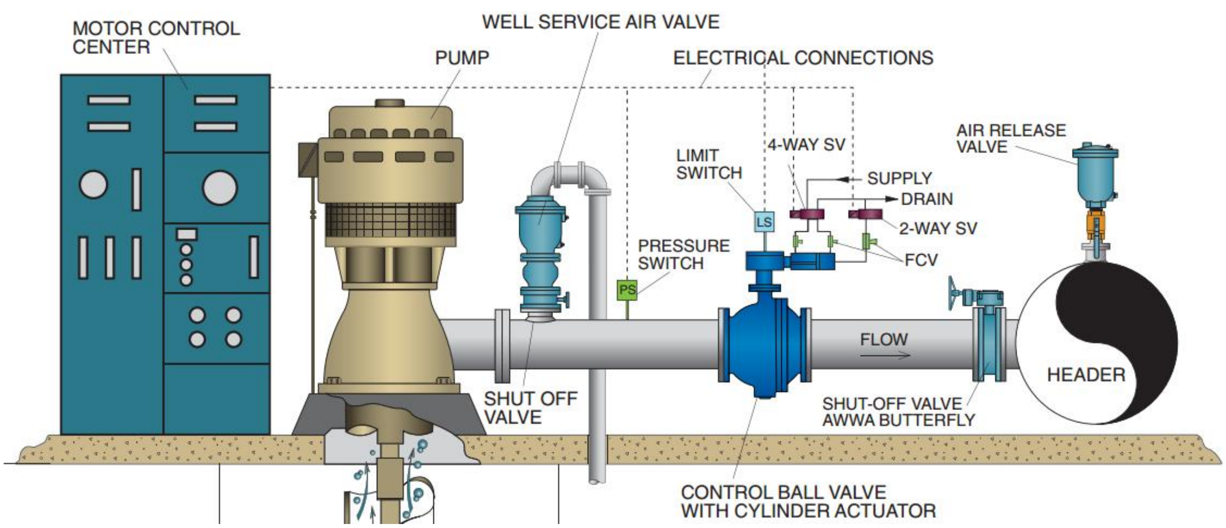
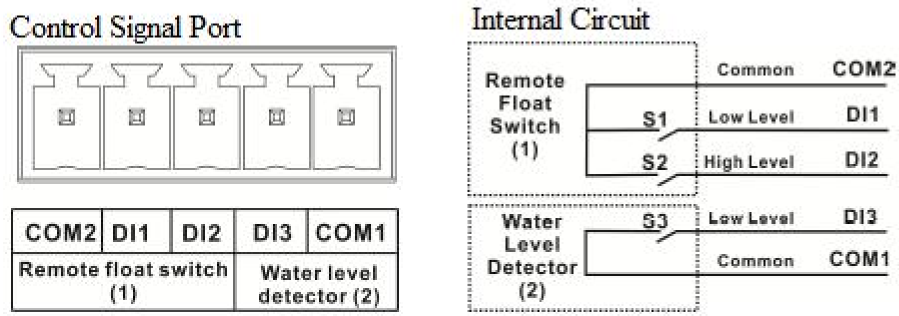


Figure 4.3 Pump Control System Diagram:



Signal Port Status

signal / water level status	remot float switch(1)		low water level (1)
	S1	S2	S3
Normal level	open	open	close
low level	close	open	open
High level	open	close	n/a

Figure 4.4 Control Signal internal circuit of the pump

Sequence of Operation: When the pump is started and pressure builds, a pressure switch (PS) located on the pump discharge signals the control valve to open. During the shutdown, the valve is signaled to close while the pump continues to run. When the valve nears the closed position, a limit switch (LS) located on the valve will stop the pump. After a power outage or pump trip, the flow will rapidly reverse. The valve must close rapidly to prevent back spinning the pump and rapid depletion of a hydropneumatic surge tank when utilized.

Water level detector: For the safety of the water pump dry running, the water level detector is connected to the water level probe. Lengths of connecting wire-no exceed more than 50m. If the water level is normal in the Well, $COM_{1,}$ and DI3 (S3) are in close status and if the water level is low in the Well, COM1 and DI3 (S3) will be in open status.

Remote Float Switch: it is used to prevent water tank overflow or underflow by sensing a remote float switch in the water tank. It is done as follows; when the water level is normal, it will keep DI_1 and COM2 and DI2 and COM2 in open status. When water level is high in water tank, it will reverse high –level signal (open status on DI1 andCOM2 and closed status on DI2 and COM2) from float switch and stop the inverter, when the water tank is in low level, it will receive low-level signal (closed status on DI1 and COM2 and open status on DI2) from float switch and start up the inverter. This action is only if the system is automatically turn-on function is enabled. If the water level is normal.DI1 and COM2 are normally in open status.

4.6 Hydraulic Panel: The Val-Matic hydraulic control panel is designed to reliably operate the pump control ball valve with water or oil supply. Unlike a motor-operated control valve, the control panel allows field adjustment of the valve operating times so that the valve can be set to match the surge characteristics of the piping system. The controls are panel mounted and pre-wired to a terminal strip in a NEMA 4X junction box for easy installation. There are four pressure connections to the cabinet: Supply, Drain, Open, and Close. The supply connection is equipped with an isolation valve and pressure gauge for ease of troubleshooting the control system. The supply and drain headers are controlled by brass two-way normally-open solenoid valves piped with rigid brass pipe to provide rapid valve closure on electrical power failure to minimize the backs pinning of the pump. The emergency closure rate is adjustable in the 10-30 second range by the balancing valve in the bottom header.

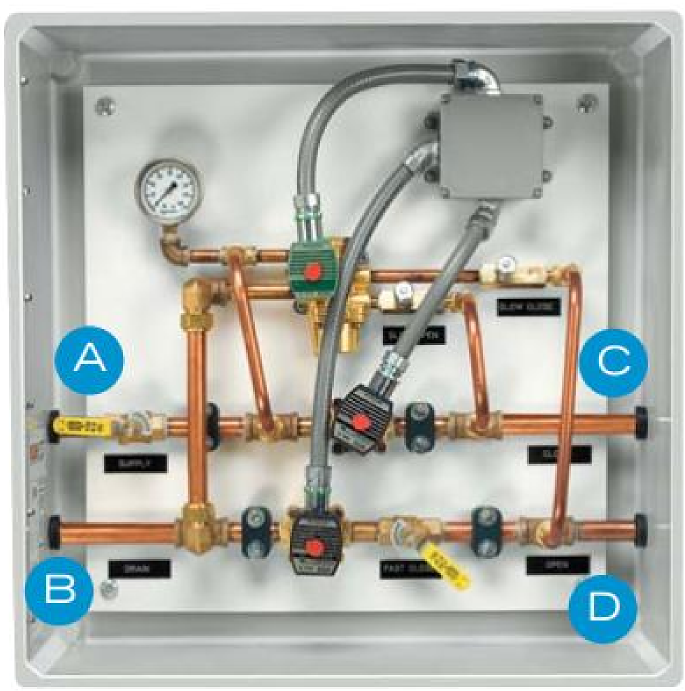


Figure 4.5 Hydraulic Panel control switch

A. Supply Pressure B. Drain

C. The pressure to Close D. Pressure to Open

4.7Electric Panel: TheVal-Matic electrical control panel is designed to work with the hydraulic panel in controlling and monitoring the operation of the pump control valve.The relays and timers are panel mounted and pre-wired to a terminal strip in a hinged NEMA 4X enclosure for easy installation and to protect the equipment in the harshest of environments. The control panel includes internal plug-in type Run and Stop Relays to control the operation of the pump. An adjustable Timing Relay monitors the operation of the system and automatically shuts down the pump if the pump does not build pressure or the valve fails to open. Transformer-type Pilot Lights are used to provide a safe indication. The RUN, OPEN, and CLOSE pilot lights indicate valve and pump operation. The STOP light indicates that an alarm condition exists and the pump is locked out. Once the alarm condition is resolved, the RESET button is pressed to activate the system. An emergency stop button is provided to stop the pump at the valve location.

Figure 4.6 Electric Panel

Table 4.1The Comparative study between PV and Diesel Powered Water pump

PV-powered Water Pumping system	Advantage	Disadvantage
	Low maintenance	Its output is low during a cloudy day
	Reliable long- life	Its initial cost is high
	No Noise	
	No Fuel&Fumes	
	Easy to install, move	
	System is modular	
Diesel-powered	Easy to install	Noise, Fumes, dirt problems
	Can be portable	
	Do not depend on weather condition	Its fuel is often expensive
	Moderate capital cost	It needs frequent maintenance & replacement

As shown above in Table 4.1, without its initial cost, PV powered system is more advantageous than diesel-powered water pumping with a reliable long life and its suitability environmentally.

4.8 Environmental Analysis of the PV system:

Global warming is the result of high usage of diesel or engine for electricity, those causes the emission of more carbon dioxide and it produce noise but using PV for electricity and also for pumping has no effect of noise and it cannot emit carbon-dioxide that increase global warming.

4.9 Equipment Grounding

The main purpose of grounding is the metal drop pipe or metal casing in an installation is safety. It is done to limit the voltage between non electrical parts of the system and thus minimizes the dangerous shock hazards. By using wire at least the size of the motor cable wires to provide an adequate current-carrying Capability for any ground faults thatmay occur. Not only this but it also provides a low resistance path to the ground, ensuring that the current to the ground will be large enough to trip any overcurrent devices designed to detect faults.

4.9.1 Grounding Control Boxes and Panels:

The United States National Electric Code requires that the control box or panel grounding terminal always be connected to the supply ground. If the circuit has no grounding conductors and no metal conduit from the box to the supply panel, use a wire at least as large as line conductors and connect as required by the National Electric Code from the grounding terminal to the electric supply ground. The operation of a motor without control boxes or with incorrect boxes can result in motor failure. Control boxes contain starting capacitors, a starting relay, overload protector.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The scope of this study was to provide a sustainable source of power for the water pump in Garbicha Keble with a low-cost. After considering several power source options for the water pump Photovoltaic Cell System is selected. The maintenance cost of the PV system was determined to be more affordable than the current electric source and it achieved its goal of providing low- cost power to the village. This study solves the problem existed previously in PV water pump system in device rating size and also appropriate device is selected for the proposed system.The initial investment in the case study area was determined to be \$52673.36 which includes tank, PV modules, Pump and related parts (motor, control box), Inverters (please refer-Appendix A1). Although the initial investment in this system is high, it was determined that using PV power provides the villages with low- cost monthly maintenance, with reduced monthly electric bills. Whereas the residents now pay as much as \$2266.65 for annual electricity needs from diesel (for water pump) as calculated in equation (4.2) and \$9103.5/m^3 of the annual cost of water pumped from grid-connected electricity. Having a PV system will reduce the cost to approximately \$4284 annually. Moreover, Water has a very strong correlation with the economic development of the community. a lack of access to clean drinking water increases the chance of affecting by water-borne related diseases in both adults and children. Giving no attention to the impact of water will have on a developing country community has prevented many investors in allocating much-needed funds towards water-related projects. The atypical investor requires a return on his own bank account.The problem with a water development project is that they benefit the individuals receiving the water and adding the individual's productivity. The investors hardly get financial returns (except if charges may has been taken from the villagers monthly until the debt is repaid. Thus all the net present value (NPV) numbers calculated seem irrelevant (please refer-Appendix A2), since getting any hard cash flow or the money they have invested. So the government of Ethiopia must do this latest technology in collaboration with the country investors from inside or outside of the country in order to enhance the shortage of water throughout the country.

5.2 Recommendation

This thesis presents, the design and analysis of a solar-powered water pumping system using DC-AC Converter for Garbicha Kebele (Bishoftu), and it is analyzed from economical and environmental points of Views. The study provides a good awareness and inspiration for using PVWP technology for drinking and also for irrigation center. To achieve accurate results from the software simulation, it needs correct input value, so it is better if a solar radiation collector device (Pyranometer) exists, hence it yields exact solar radiation of the site rather than solar radiation obtained from sunshine hour conversion. In this study, design, analysis, and simulations of individual PV water pumping system components are done as a document reference for Bishoftu Water and Energy Bureau. For future work, the overall system simulation will be done with a complete design for Bishoftu and other areas with a feasible cost. Finally, all investors in the country should participate in order to reduce the shortage of electricity and water for the rural community of the country and also the government should give major attention to this latest technology, because of its simplicity and cost-effective source of energy.

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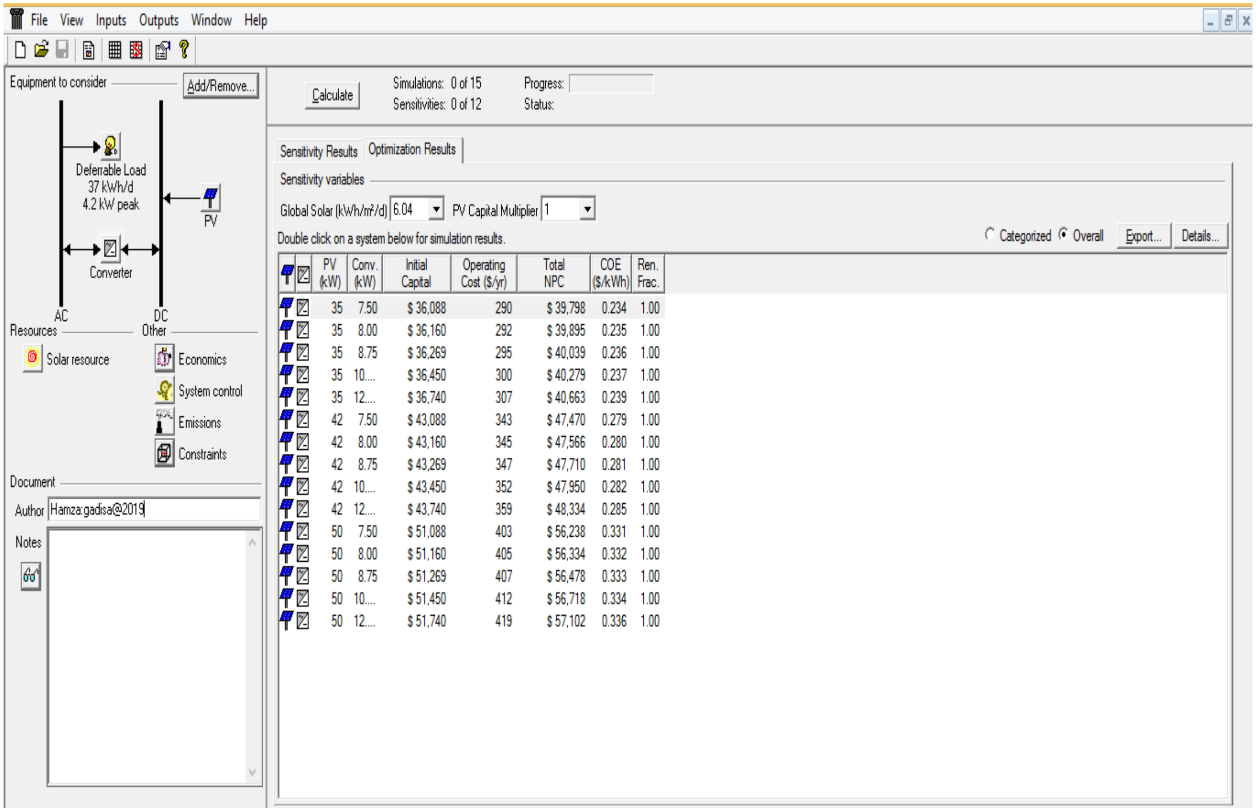
APPENDIXES

AppendixA_1: Component Cost:

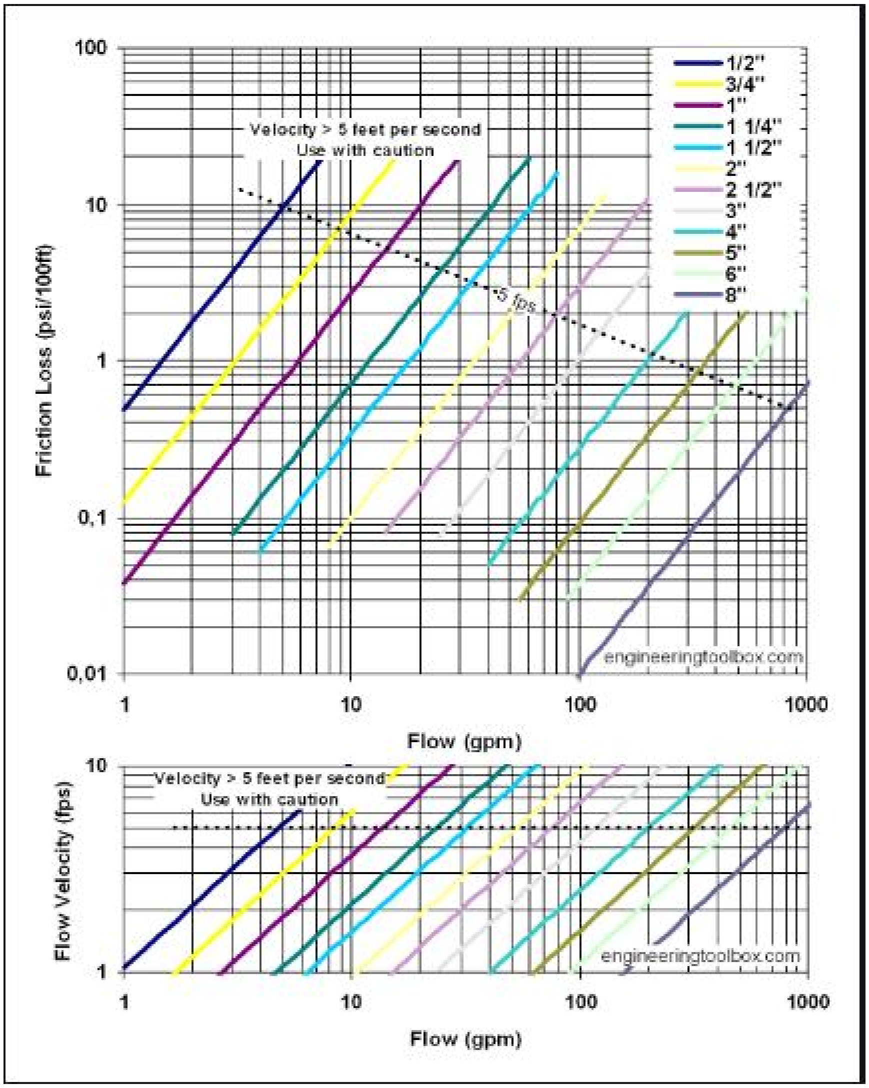
Table 3.17 Component Cost

Costs	pieces	Prices in ($)	Prices (ETB)
Module Cost	135	135x 150 =20250	587250
Pump &Accessories	1,	4000	116000
Inverters	8	1446.67x8 =11573.36	335627.44
Storage tank	1	5000	72500
Chopper	1	300	8700
Engineering	-	10000	14500
Setting & Wiring	-	1000	8700
Pump controller	1	250	7250
AC Breaker	1	300	4350
Total investment		**52673.36**	**1527527.44**
Maintenance cost			$3800/year
Provision for pump replacement(life time 10 years)			$500/year
Cost of water pumped			$0.16/m^3
Total yearly cost		**$4300/year = 124700 ETB/year**	
Water and Energy cost			
Energy used for pumping			13230kwh/year
Excess energy			1890kwh/year
Water Pumped			26775m^3/year

Appendix A2: Economic Evaluation of PV Water pumping System Using HOMER software



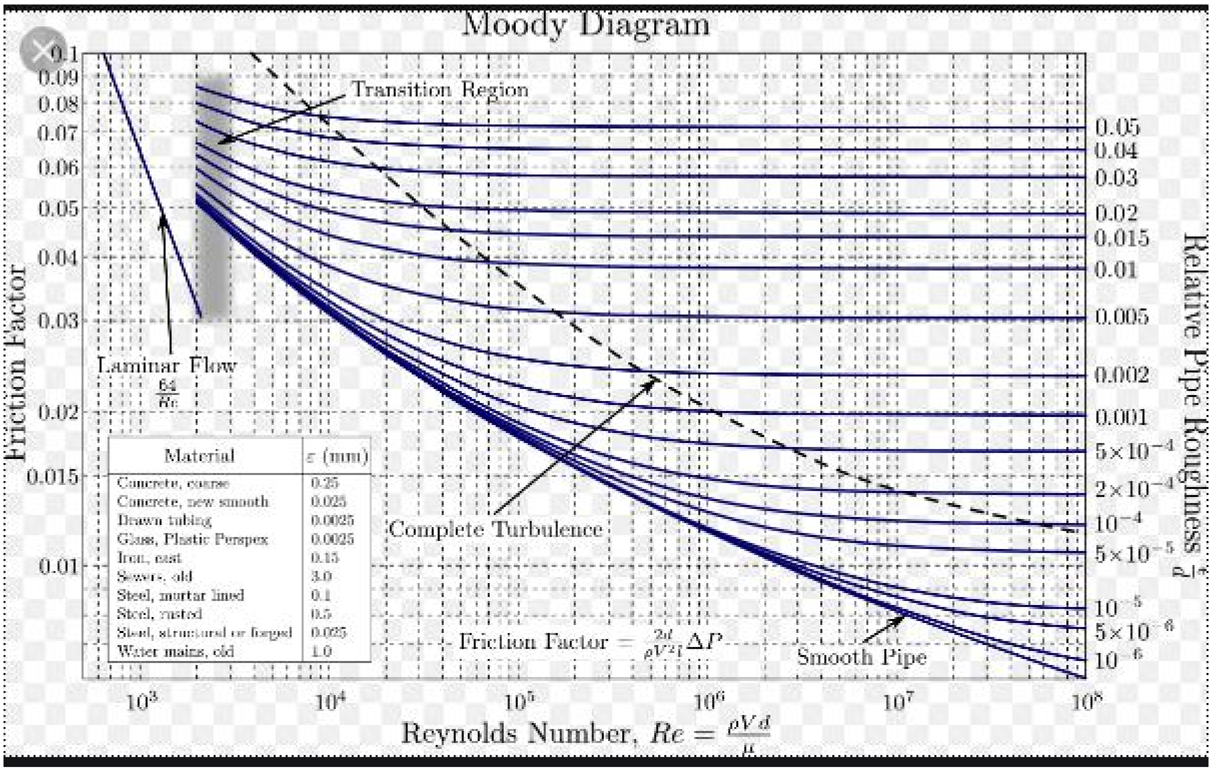
Appendix B_1: Friction Head Loss for Schedule 40 PVC Pipe



TYPE OF FITTING	NOMINAL PIPE DIAMETER												
	½"	¾"	1"	1¼"	1½"	2"	2½"	3"	4"	5"	6"	8"	10"
Gate Valve (open)	.35	.50	.60	.80	1.2	1.2	1.4	1.7	2.3	2.8	3.5	4.5	5.7
Globe Valve (open)	17	22	27	38	44	53	68	80	120	140	170	220	280
Angle Valve (open)	8	12	14	18	22	28	33	42	53	70	84	120	140
Standard Elbow	1.5	2.2	2.7	3.6	4.5	5.2	6.5	8.0	11.0	14	16	21	26
Medium Sweep Elbow	1.3	1.8	2.3	3.0	3.6	4.6	5.5	7.0	9.0	12.0	14.0	18.0	22.0
Long Sweep Elbow	1.0	1.3	1.7	2.3	2.8	3.5	4.3	5.2	7.0	9.0	11.0	14.0	17.0
Tee (straight thru)	1.0	1.3	1.7	2.3	2.8	3.5	4.3	5.2	7.0	9.0	11.0	14.0	17.0
Tee (right angle flow)	3.2	4.5	5.7	7.5	9.0	12.0	14.0	16.0	22.0	27.0	33.0	43.0	53.0
Return Bend	3.5	5.0	6.0	8.5	10.0	13.0	15.0	18.0	24.0	30.0	37.0	50.0	63.0

AppendixB$_2$: Friction Factor as of Reynolds Number and Relative Roughness for Round

Moody Chart

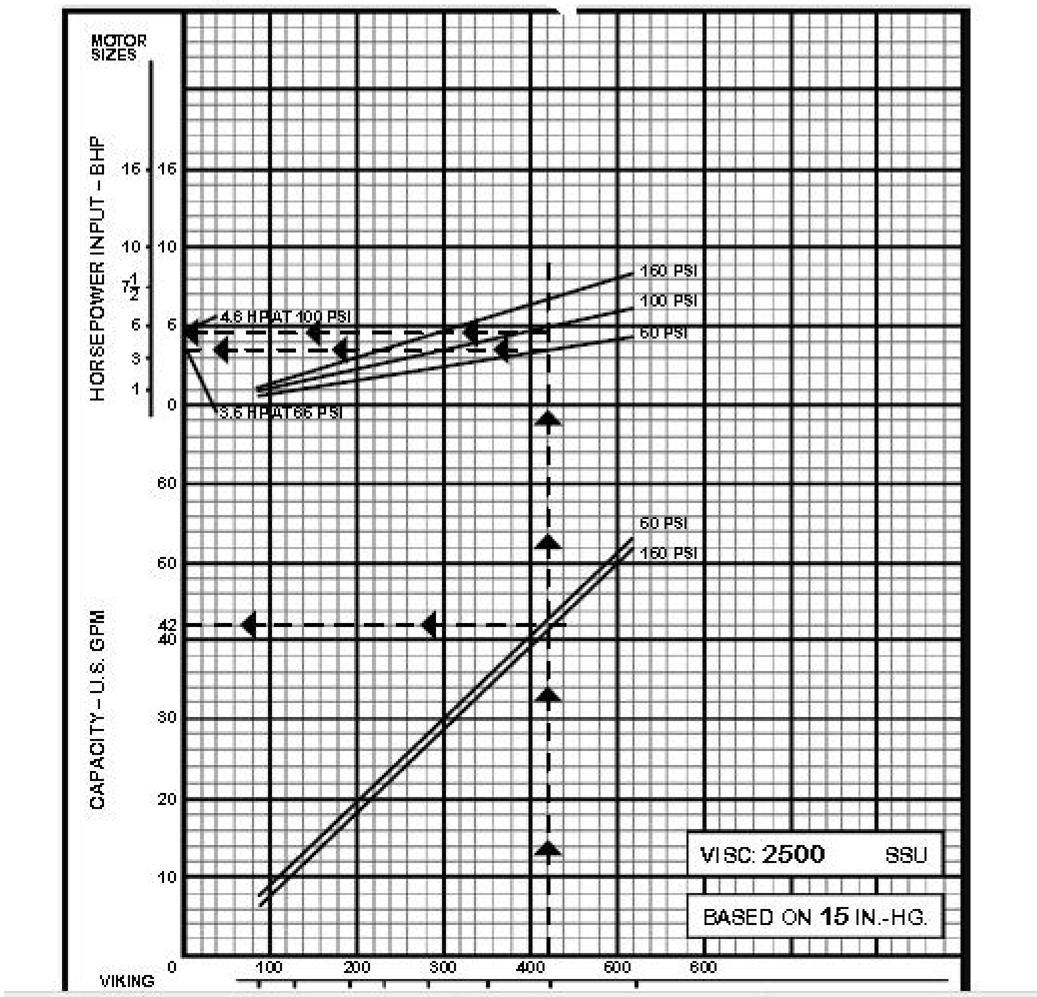


Appendix C: KL value of different fittings

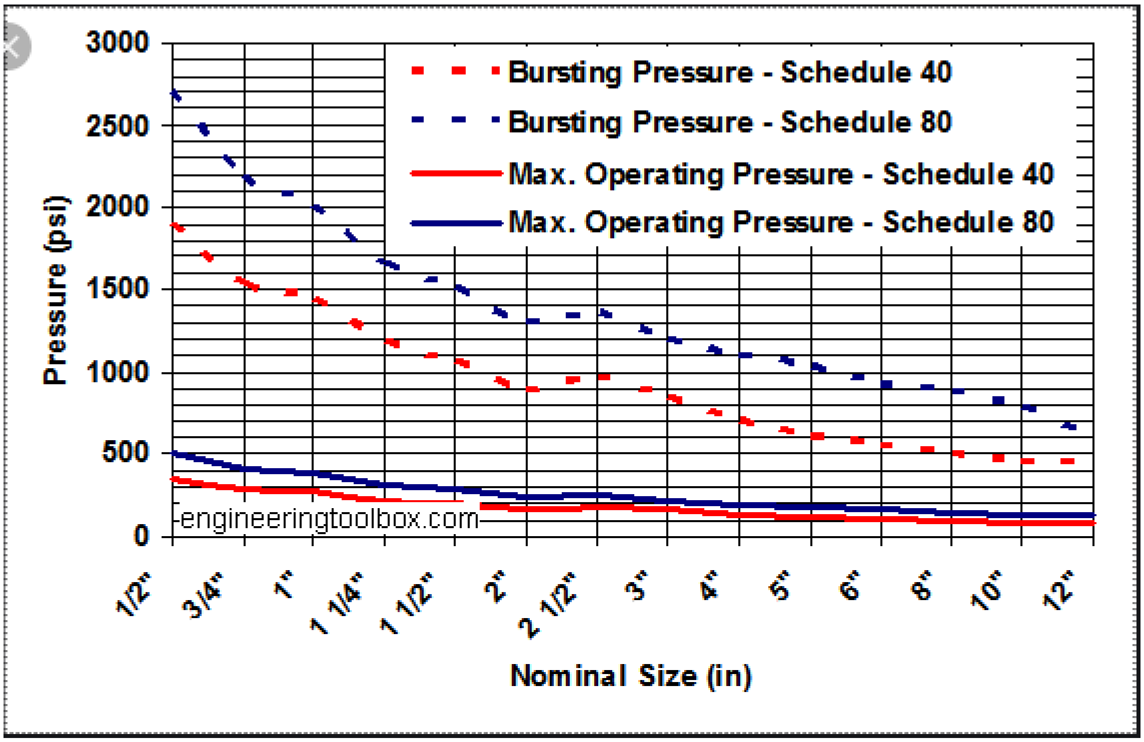
Component	KL value
Elbow	-
Regular 90^0 flanged	0.3
Regular 90^0 threaded	1.3
Long radius 90^0, flanged	0.2
Long radius 90^0, threaded	0.7
Valve	
Valve	KL value
Glob, fully Open	10
Gate, fully Open	0.15
Check, disk	10
Foot, Piston	15
Foot, disk	7

Appendix D: Pump Performance Curve:

K124 Viking Pump Performance Curve



Appendix E: Schedule 40 PVC Pipe Dimensions and Pressure Rating



Appendix F: Stranded Wire Chart (AWG)

TABLE 6A Single-Phase Motor Maximum Length of Copper Cable (feet)

Motor Rating			American Wire Guage, 75° C Insulation - AWG Cable in Feet										
Volts	KW	HP	14	12	10	8	6	4	3	2	1	0	00
220 Volt 50 Hz.	.25	1/3	900	1450	2310	3530	5480	8460					
	.37	1/2	580	940	1500	2310	3600	5580	6830	8470			
	.55	3/4	400	660	1050	1610	2510	3890	4750	5880	7150	8670	
	.75	1.0	310	500	800	1240	1940	3010	3690	4580	5610	6840	8350
	1.1	1.5	210	350	560	870	1360	2130	2620	3270	4020	4930	6060
	1.5	2.0	170	280	450	710	1120	1770	2180	2730	3390	4180	5160
	2.2	3.0	**110**	190	300	470	750	1170	1440	1800	2220	2730	3360
	3.7	5.0	0	**120**	190	300	480	760	940	1180	1480	1830	2280

Cable Temp. Rating (°C)	Motor Nameplate Rated Amps Full Load	$6mm^2$		$10mm^2$		$16mm^2$		$25mm^2$		$35mm^2$	
		#10 AWG		#8 AWG		#6 AWG		#4 AWG		#2 AWG	
		In Air	In Conduit	In Air	In Conduit	In Air	In Conduit	In Air	In Conduit	In Air	In Conduit
75	3-LEAD (DOL)	40A	28A	56A	40A	76A	52A	100A	68A	136A	92A
	6-LEAD (Y-Δ)	69A	48A	97A	69A	132A	90A	173A	118A	236A	159A
90	3-LEAD (DOL)	44A	32A	64A	44A	84A	60A	112A	76A	152A	104A
	6-LEAD (Y-Δ)	76A	55A	111A	76A	145A	104A	194A	132A	263A	180A
125	3-LEAD (DOL)	66A	46A	77A	53A	109A	75A	153A	105A	195A	134A
	6-LEAD (Y-Δ)	114A	80A	133A	91A	188A	130A	265A	181A	337A	232A

Based on 30 °C maximum ambient with cable length of 100 feet or less.

Appendix G: Off-grid Must Solar Inverter Specification

Power(kw)	10
AC Power System	Single-Phase
Inverter Type	Off-grid
Standard Warranty(Years)	1
Length (cm)	67
Width (cm)	41
Depth/Height (cm)	21.5
Weight (Kg)	74
Brand	Must
Origin	Asia
Model	EP30-10KW
AC Nominal Power	10000W
Surge Power	30Kw
Nominal AC Voltage; Range	220/230/240;(+/- 10%RMS)
AC Grid Frequency Range	50Hz/60Hz; +0.3Hz
Power Factor Full load	1
Over-current protection	yes
Overvoltage protection	yes
Maximum. Efficiency	88%
Nominal Battery Voltage	48
Operating Temperature	$0^0C \sim 40^0C$
Max. charge Power(W)	1/3 Rating power
Storage Temperature(^0C)	-15 ~ +60
Noise Emission	<60dB
Installation	Wall Mounting
Communication Interface	RS485
Display	LED + LCD

Appendix H: Water Pressure Rating