ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

CENTER OF RENEWABLE ENERGY

# DESIGN AND EXPERIMENTALLY INVESTIGATE MANUAL SOLAR TRACKING SYSTEM AND COMPARE THE RESULT WITH FIXED AXIS SOLAR TRACKING SYSTEM

BY:

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The thesis Submitted to the Center of Renewable Energy Technology Studies of Addis Ababa University in Partial Fulfillment of the Master of Science in Renewable Energy

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# CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for the acceptance by Addis Ababa University, Addis Ababa Institute of Technology, Energy Center a thesis entitled "Design and Experimental Investigation of new manual solar tracking for water pumping system". This certificate used as a partial fulfillment of the requirement for the degree of Master of Science in energy technology.

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Date ___________________

## DECLARATION

I, T/mariam Gochem, I declare that this thesis is the result of my own work and that all source and material used for this thesis have been acknowledged. This thesis is submitted in partial fulfillment of the requirement for master's degree in energy technology at Addis Ababa University and to be made available at university's library under the role of the library. I confidently declare that this thesis has not been submitted to any other Institutions anywhere for the award of any academic degree, diploma, or certificate.

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School of Multidisciplinary

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By T/mariam Gochem

Approved by board of examiners:

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## ACRONYMS

| **Symbols** | **Descriptions** |
|---|---|
| PV | Photovoltaic |
| WPS | Water Pumping System |
| SPWPS | Solar powered water pumping system |
| MPPT | Maximum power point tracking |
| DC | Direct current |
| W | Watt |
| h | Hour |
| l | Litter |
| s | Second |
| m | Meter |
| V | Voltage |
| I | Current |
| Vmp | Voltage at maximum power point |
| Imp | Current at maximum power point |
| Voc | open-circuit voltage |
| Isc | short-circuit current |
| KW | Kilowatt |
| GW | giga watt |
| kWh | kilowatt |
| MW | Megawatt |
| CWR | Crop water requirement |
| Q | Flow rate |
| P | Power |
| V | volume |
| H | Head |
| TDH | Total dynamic head |
| PH | Hydraulic power |
| Pm | Motor power |

| | |
|---|---|
| PPV | Photovoltaic Power |
| g | Gravity |
| L | Length |
| D | Diameter |
| V | Water Speed In A Pipe |
| A | Area |
| K | Loss Coefficient |
| STC | Standard Test Condition |
| CWR | Crop Water Requirement |
| P | Planting, |
| H | Harvesting, |
| PH | Planting And Harvesting |
| NMSTS | New Manual Solar Tracking System |
| FASTS | Fixed Axis Solar Tracking System |
| DMMT | Digital Multimeter |
| DCM | Digital Clamp Meter |
| SW | Stop Watch |
| RPR | Relative Pipe Roughness |
| ε | Roughness Coefficient Of Galvanized Pipe |
| RPR | Relative Pipe Roughness |
| Fx | Fixed Axis System |
| Tk | Tracking System |
| NSTs | New solar tracking system |

# ABSTRACT

*Ethiopia has abundant solar energy and irrigation potential which if exploited properly would contribute a great significance to the economic development of the country. Eventhough solar energy for water pumping is the most promising technology in Ethiopia, still less than 1% of 5.2 kWh/*$m^2$*has been exploited per day. Due to low system efficiency of conventional solar water pumping system, the initial cost of the system remained very high. Therefore, the main objective of this research is to design, manufacture and investigate an innovative solar tracking system for water pumping. The system designed by solid work software after sizing of solar water pumping system and determination of the different solar angles. Based on the design the new manual solar tracking system manufactured and assembled in Ethiopia Water Technology Institute. The new design has three solar panel (having voltage of 28.78 V, current 6.6A and power 190 W each) only the two panels move easily to track the sun manually. During experimental investigation, two solar tracking system (fixed and manual) were compared based on their efficiency. The result shows that the solar irradiance loss in the newly designed manual solar tracking system was reduced by 22% while the efficiency increased by 16% than the fixed axis solar collector. The result also revealed that, the manual tracking system took 7.5 hours to pump 30* $m^3$*of water whereas the fixed axis collector requires 8.3 hours to pump the same volume of water. This difference came due to making the two solar panel faced towards the direction of the sun especially in the early morning and late afternoon. Therefore, disseminating this new manual solar tracking system able to, maximize crop productivity; reduce initial cost used in conventional solar water pumping system. Hence, the novel manual tracking system developed in this study is cost effective and robust alternative to conventional solar water pumping system.*

**Keywords:** Current, efficiency**,** solar water pumping, solar radiation, water demand, voltage, current

# CHAPTER ONE

# 1. INTRODUCTION

In this chapter, background of the research, statement of the problem, objective of the research, significance of the research, delimitation of the research, scope of the study, organization of the research described.

## 1.1. Background

Now a days, the demand for energy in different parts of the world is increasing exponentially due to population and economic growth and the living standard of a country is determined by the energy consumption. According to World population review report, the population of Ethiopia estimated about 105 million of which 85% have been living in rural area with agricultural economic based development (Avtar et al. 2019). In Ethiopia, about 1.4 million farmers practiced small-scale irrigation (Otoo et al..2018.). Though agriculture is one of the leading sectors of economic development in rural areas, most of the agricultural practice is rain fed. Few of irrigated areas uses manually driven pump, which is inefficient to satisfy large farmlands. Other irrigation system uses petroleum to drive the pump that results high running cost and environmental pollution. Hence, it is important to find alternative sources of energy. Solar energy has been the main agenda for water industry especially in countries with high solar irradiance because the source of this energy is green and renewable.

Ethiopia has huge renewable energy potential throughout all regions and makes the country favorable for renewable energy power development (Hailu and Kumsa 2020). Moreover, the government of Ethiopia gives special attention and good working environment for developers to participate in the energy sector. The renewable energy potential of Ethiopia is estimated to be high i.e. hydropower (45 GW), wind,( 10 GW), geothermal (5 GW ) and 5.2 kWh/$m^2$/day of average solar irradiation (Mengistu et al. 2015). Solar energy has been used less than 1% from the average exploitable reserve. Solar energy is considered as a best alternative due to its abundant in nature, sustainability, renewability and accessibility to meet the energy demand (Sumathi et al. 2017). It is also approximated that daily 10000 TW of solar energy incident on earth's surface.(M. K. Sharma et al. 2020) (Raghuwanshi and Khare 2018a).

Researchers propose that the quantity of sunlight that reaches the Earth's surface within one and half hour is sufficient to satisfy the whole world's energy consumption for one year The amount of energy delivered by the sun to the earth's surface reaches $3 \text{ x}10^{24}$ joules/year which is almost equal to 10,000 times the global energy usage today (Singh* et al. 2020). Previous year's assessment and photovoltaic installations in 2014 showed 80% of the total globally installed PV found in five countries i.e. China, Japan, USA, Germany and UK. (Almarshoud 2016).

In the last few years worldwide total installed PV capacity has increased dramatically and reaching 591 GW in 2019 (Wilson et al. 2020). The article also discussed the positive driving policies, which encourage the expansion of the technologies, were funding and research and development activities:

As (Zegeye, Ramakrishnan, and Premalatha 2017) (Verma, Mishra, Chowdhury, Gaur, and Mohapatra 2020) also explained, solar energy available in large amounts which makes a good alternative to replace diesel powered water pumping system. One of the applications of Solar water pumping system to fulfill the need of water for irrigation fields, therefore, selection of appropriate design parameters and proper sizing of system design are important to achieve reliable and economic performance of the system(Shaik et al. 2020).

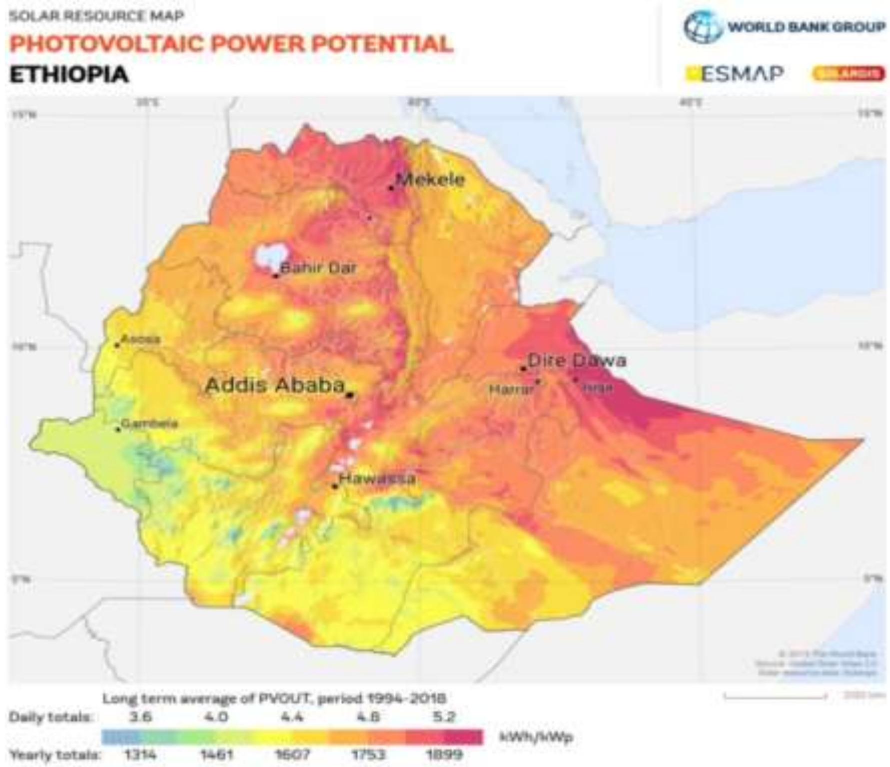



Figure 1 : Ethiopian solar resource map (Kebede et al. 2020)

Even though solar energy for water pumping is the most promising technology in Ethiopia, still only less than 1% of 5.2 kWh/m$^2$ has been exploited per day and therefore the system efficiency of solar water pumping system remained very low with high initial cost (A. K. Tiwari et al. 2020). Due to this reason improving the efficiency of harnessing solar energy and reducing the cost of production was one of the main concerns of this research.

In order to increase the system efficiency of solar water pumping, many researchers conducted researches in this area. The automatic sun tracking without human participation and manual trucking with three times angle changing per day had better efficiency around 15% more energy generation than non-tracking system (Moradi et al. 2016). One major disadvantage of automatic sun tracking system is that it consume external power source to actuate the motion (Krishnaraj et al. 2019). Therefore, the main aim of this research is to increase the efficiency of solar water pumping system by increasing the time of collecting solar energy especially in the early morning and late afternoon with relatively low cost as compared to the automatic sun tracking without human participation and high efficiency as compared to the fixed axis or none trucking system.

## 1.2. Statement of the Problem

Though, there have been various works conducted on the PV module, controller, inverter, storage, motor, pumps and environmental condition to study solar water pumping system for irrigation in many countries, the efficiency of the system is still not satisfactory. The generation of electricity used various types of PV solar panel mountings, such as fixed, tracked and adjustable were affected by a number of parameters. Some of the factors are sun intensity, relative humidity, cloud cover, orientation and heat accumulation. These possible factors affecting the efficiency and performance of solar water pumping systems have been reviewed by (Gouws and Lukhwareni 2012) (Mohammed Wazed et al. 2018).

The ability of solar PV system to produce electrical energy mainly depend up on the intensity of irradiance, orientation and duration of the sun ray's exposal on the PV panel. When the solar PV panel surface is at 90 degrees to the sun's radiation, the amount of solar radiation/intensity on the panel is greatest. To do this, a mechanism that allows the solar panel to move to follow the maximum amount of sunlight developed (automatic solar tracking system). However, this method has a disadvantage in that it consumes around 5-10% of the energy generated by the PV panels to rotate the system which causes in energy reduction, (D. P. Singh et al. 2020). It is also complex and expensive than fixed axis system.

In fixed axis solar system, all angles of the the systems are fixed while the incoming solar radiation move from east to west in a day. The angle between solar radiation and the PV panel surface gets near to $90^0$ only at noon so that more energy lost during early morning and late afternoon.

Even though many studies undertaken to improve solar energy efficiency for different applications, these studies have limitation of studying individual PV module orientation to harness the maximum possible solar energy. Because of this, the efficiency of the solar water pumping system is still very low. Therefore, the aim of this research is to design and experimentally investigate a new manual solar tracking system and compare the result with fixed axis solar tracking system

## 1.3. Objective of the Research

### 1.3.1. General Objective

The main objective of this research is to design, manufacture and experimentally investigate manual solar tracking system and compare the efficiency with fixed axis solar tracking for water pumping system.

### 1.3.2. Specific objectives

The specific objectives of the research are:

- To collect primary and secondary data
- To study and size the different design choice of water pumping system
- To design new manual solar tracking system.
- To manufacture new manual solar tracking system.
- To compare the efficiency of fixed and manual tracking system

## 1.4. Significance of the Research

The importance of this research is mainly to increase solar radiation energy harnessing time so that the maximum expected output energy would be collected by the system to satisfy the water requirement by the crop per day. Efficient and optimized design of solar pumping system would be suggested to specified area of land to be irrigated in a place where shallow ground water well exist. Practitioners and/or academia's can use it as a reference for the development study, research and application of solar water pumping systems. Reduce the increase in costs of energy by increasing the efficiency of the system (reduce size of solar panel and the area required to install) and provide long, pollution-free service and excellent return on investment

## 1.5. Delimitation

The purpose of this research is to design and investigate an innovative and efficient photovoltaic water pumping system with experimental testing analysis of the voltage, current and power with the collected information of the topographical and regional design data for the specified location. But it can be applied only in the place where shallow well ground water sources, rivers or lakes with limited head up to 30 m available. The system used small submersible pump directly coupled with the controller. Ground water level data and metrological data of the exact location are the main inputs to limit the size of the PV system to investigate hourly and daily performance of photovoltaic water pumping system. To implement this PV water pumping system for all location, the solar radiation, ground water data and the temperature data of that location should be the same, otherwise it would be the limitation of the system not to apply to all location to have the same output.

### 1.6. Scope of the Study

The scope of this research is to design, manufacture, investigate and evaluate the new PV module orientation with respect to fixed axis PV module orientation experimentally for collecting the maximum possible solar energy by changing the orientation three times a day. The output energy of the system has been used to supply irrigation water for Fogera woreda small scale irrigation specifically for onion crop. The study focused on solar water pumping system for small scale irrigation with shallow ground water sources.

### 1.7. Organization of the Research

The research's organizational structure is as follows: The first chapter describes the research's introduction, which includes the research's background, problem statement, and objectives. Many reviews of the study are covered in chapter two along with a detailed explanation of the research gap. Sizing the system, manufacturing processes, and assembling the new prototype are covered in chapter 3. In chapter four, the experimental testing is covered along with determination of different sun angles, applying governing equations and material selection are all covered in this chapter. Chapter 5 of this research discusses the results and discussion portion.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.1. Introduction

In this chapter, different literatures reviewed are discussed. Solar energy system designing of solar water pumping system, solar home system, efficiency improvement, effects of head and discharge, effects of different angles, environmental impacts, power conditioning, storages, solar panel configurations, different application of solar energy are discussed.

## 2.2. Energy and irrigation potential in Ethiopia

Agriculture is the most important sector in Ethiopia's economy, accounting for 47.7% of total GDP, compared to 13.3% for industry and 39% for services. Though agriculture is the dominant sector, most of Ethiopia's cultivated land is rainfed on the other hand solar radiation gives a massive amount of energy to the earth's surface, equivalent to almost 10,000 times the yearly global energy demand (Zegeye, Ramakrishnan, and Premalatha , 2017).

Sharma *et al.*, proved that agricultural productivity has been increased because of solar power assisted irrigation systems in the place where grid electric not reached (R. Sharma, Sharma, and Sharma, 2020). Solar water pumping is found to be economically viable in comparison to electricity or diesel-based systems for irrigation and water supplies in rural, urban and remote regions with payback period about four – six years (Zegeye, Tadiwos, and Aman 2014).

## 2.3. Solar tracking system

Tracking the sun reduces the size of PV module/array, area required for a given system, improves power output, extends the time for peak water output, overall system efficiency and reduce investment return. Even though DC solar pumps are still low cost, consistent and easy to handle for small head irrigation, it cannot work at maximum power tracking point (MPPT) of PV generator. Therefore, adding a (MPPT) and controls /protections can further improve the performance of such PV pumps (Chandel, Nagaraju Naik, and Chandel 2015). For a typical directly-connected solar water pumping system, the motor-pump efficiency did not greater than 30% yet and this type of system are convenient for low head irrigation system(Shaik et al. 2020).

Bakheet, pointed the reasons why PV module cost per watt reduce with mass manufacturing of PV modules as compared to other renewable energies (Bakheet 2019).

The sun travels not only east to west direction but also there is a changing of angle from south to north direction, therefore it should be necessary to consider both axis (the horizontal and vertical movment of the PV panel). As aresult the operating performance of the single axis trackers have less power output than dual axis trackers.(Shaik et al. 2020)

Automatic sun tracking solar panel not require optimization of panel direction, whereas fixed mounting solar panel requires optimal orientation and this type of orientation constantly being used because of free maintenance, free additional energy use and economic reasons. Laveyne *et al.* pointed that changing the orientation of the solar panels away from the optimal angle leads to more loss of energy. Different azimuth orientations of the PV panels have a profound effect on the time of day with eastward orientation - earlier hours and, conversely, southward orientation towards later hours (noon) and west ward in the late afternoon. He also proposed further possible research can be investigated in multiple orientations per PV system, e.g., when an installation is split in west facing side in the afternoon and an east-facing in the morning (Laveyne et al. 2020).

Zegeye *et al.*, performed proper designing of solar PV water pumping system and recommend to conduct research on efficiency improvement of solar PV water pumping system (Zegeye, Ramakrishnan, and Premalatha 2017). Almusaied *et al.*,pointed that one of the possibly solar water pumping system efficiency improvement could be studying in PV array structure , status of the PV panels (e.g., orientation, tilting), and PV modules configuration or development of distinct structures of any components [10,27].

According to *Li et al*, the SWPS is cost competitive than gasoline diesel, or electrical based pumps, with long life time approximately 20–30 years if it is designed properly. No need of maintenance, no pollution, no fuel consumption and it is said to be efficient and cost competitive. By considering the efficiency and the cost analysis comprehensively, use of tracking system is a good way to increase the efficiency of photovoltaic array with increase in cost of installation. They also explained that monthly and seasonal reorientation PV panel cause no difference, but hourly readjustment of tilt angle with manual tracking three times a day and found that 20% system efficiency improvement than the fixed one.

According to Almarshoud, automatic tracking consumed the energy produced by the system ranging from 5% to 10%, therefore, tracking the sun will not be practicable in countries with hot temperature. The system becomes more complex and expensive due to sensors and the frequent maintenance requirement (Almarshoud 2016). Even though automatic tracking improved the system efficiency, the cost is very high; hence two-way manual tracking systems proposed to be applied to increase the system efficiency by 20% and comparatively inexpensive (Wazed et al. 2018). With regardless of the demand and nature of use, it was found that PV system is suitable option for use in agriculture and domestic sectors. (Li et al. 2017).

Solar collection system has direct effect on the overall efficiency of the SWPS. These aspects involve the effect of PV configuration, use of tracking and concentrating collectors, and water spraying of the PV panels (Aliyu et al. 2018). The main factors affecting the performance and efficiency of the solar water pumping system are environmental conditions and PV configuration.

Mohammed Wazed *et al*, propose the best way to optimize the cost and design of the PV powered system recognize the crop water requirements and unlimited site investigation to analyze the working situations of the system(Mohammed Wazed et al. 2018). solar water pumping systems efficiency can be enhanced by appropriate sizing of PV array, optimal orientation and motor pump system and by introducing MPPT to prevent rapid shutting of the system at the time where low solar radiation to overcome the limitations and improve the system efficiency (Mohammed Wazed et al. 2018). According to the literature review held from 1995–2015 related to SWPS, the average system efficiency of solar water pumping system was around 3.4% and the average yearly water pumped by one kilo watt is around 6580.611 $m^3$ (Muhsen, Khatib, and Nagi 2017).

## 2.4. Possible factors affecting efficiency

Chilundo et al, investigated that the overall system efficiency not exceed 5% yet, because of the factors like variation of solar radiation intensity, total dynamic head, quantity of fluid extracted, PV and motor pump technology. For instance, with irradiance values fluctuating from 100 - 500 W/m2, discharge of 1000 to 3000 l/h of pumped water were found at a fixed head of 24 m, the system efficiencies reached 3.76%. (Chilundo, Mahanjane, and Neves 2018). Abdolzadeh et al, also investigated about the way how to improve the efficiency of a solar water pumping system by water spraying at head of 16m(Abdolzadeh and Ameri 2009). As they stated the efficiency increased from 1-3% in 1990 to 3.7-5% in 2015 and also using 11.2KW power with ahead of 100m the system efficiency reached to be 5.14%(Investigation et al. 2018). Raghuwanshi Khar et al, concluded that to pump 5.3 m3/h from 60 meter head, the overall solar-water-pump system efficiency as 3% (Raghuwanshi and Khare 2018b).

AS Verma et al,reviewed, with PV power 610W, the system efficiency were investigated and reaches 5% (Verma, Mishra, Chowdhury, Gaur, Mohapatra, et al. 2020). Gouws & Lukhwareni, reviewed about the possible factors which affects the efficiency and performance of solar water pumping systems are shown in Figure 2 below:

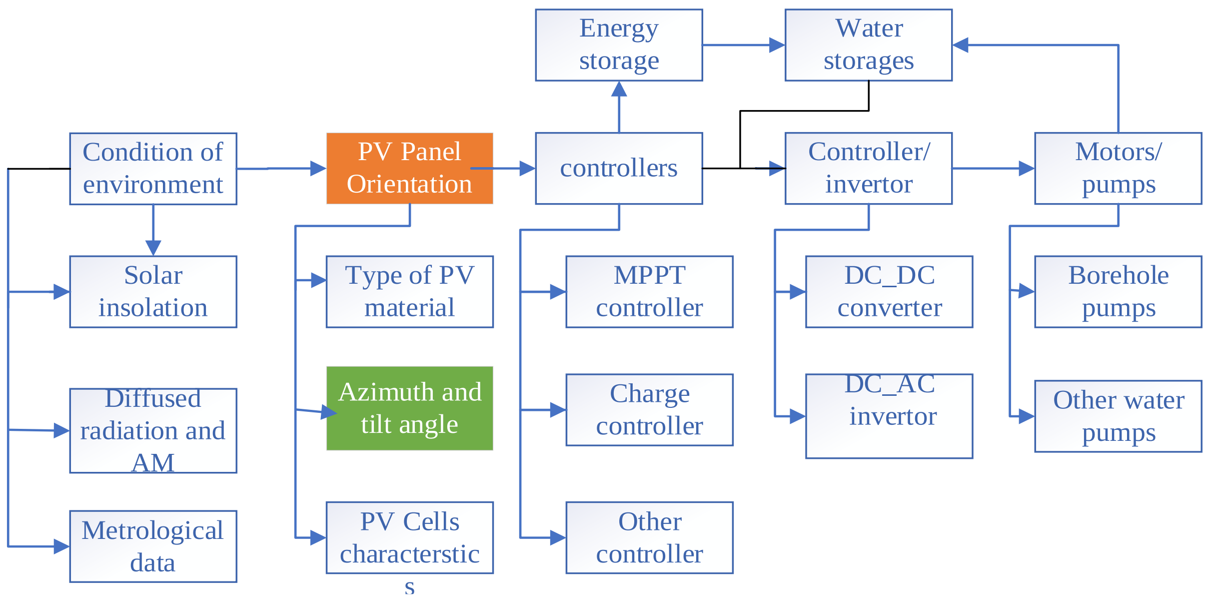



*Figure 2*: Factor affecting the efficiency of SWPs (Gouws and Lukhwareni 2012)

As a result, the researcher highly interested in studying azimuth and solar panel orientation of solar water pumping system in order to collect more solar energy which ultimately increases system efficiency than fixed axis collector.

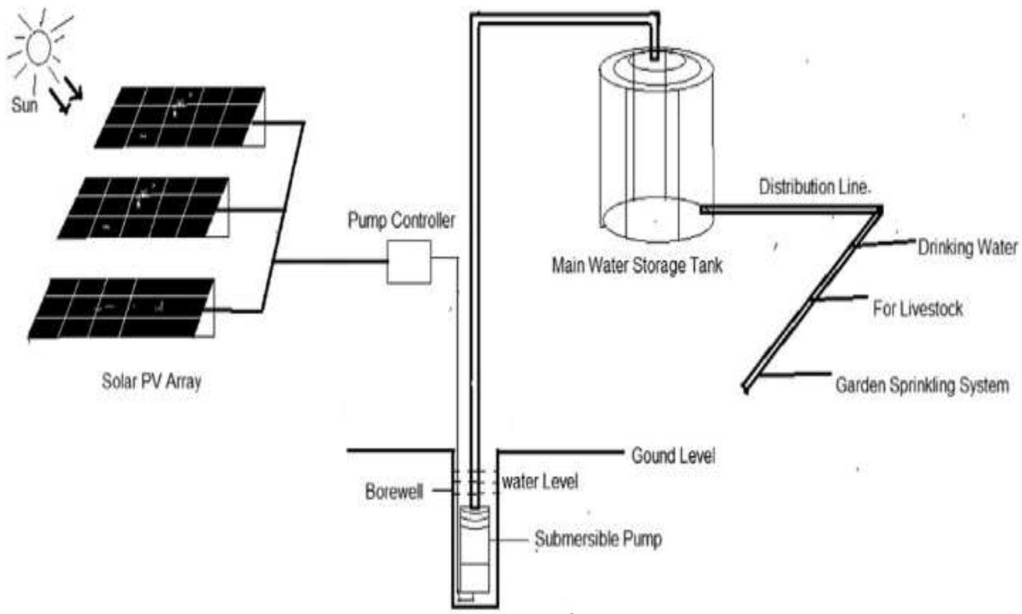



Figure 3: Coupled solar pumping system (Sontake and Kalamkar 2016)

Rawat *et al*, stated that The right choice of technology and sizing components is critical for stable, reliable, cost-effective and efficient operation of PV system (Rawat, Kaushik, and Lamba 2016). World Bankindicated that the best and proper solar pumping systems design performed mainly by investigating the demand of water , source of water , design flow rate, water tank or storage, total dynamic head , PV panels place or location of and solar resource (BankWorld 2018).

Agrawal & Jain, stated, Even though SWPS are affordable as compared to conventional pumps on life time basis, the capacity of farmers to invest on high initial capital costs would be a critical factor to use this technology (Agrawal and Jain 2019). Therefore, identify business models, which could enable access to solar powered irrigation in a sustainable way for a selected region would be indestructible action.

The output of a solar pumping system depends on system design, most PV pumping systems use reservoir tank instead of batteries for energy storage to make it cost effective (Abu-Aligah 2011). Basalike, stated about the determination of PV module used in irrigation system selected by considering the highest ratio between monthly water requirement and available solar irradiation in the worst month condition (Basalike 2015).The main factors that affects the economic viability of solar water pumping system is the mismatch between water demand and supply patterns. The proper design of PV array system is critical, because under sizing pumping system will not satisfy the water demand, over sizing of system contributes to more cost and automatic sun trucking system reduce the size of the system and increase the maintenance cost (Almarshoud 2016).

Table 1: Review Literatures Summary

| No | Topic | Finding | Recommendation | References |
|---|---|---|---|---|
| 1 | Optimal SWPS sizing | The cost of system reduced by<br>• Reducing the max power<br>• Finding the optimum tilt angle | • Improve system efficiency<br>• Loan access | Zegeye *et al.*, 2017 |
| 2 | Automatic sun trucking | • Increase system efficiency<br>• Reduce PV panel size, area<br>• Increase the cost<br>• Manual trucking=20% +fixed | • two-way manual tracking systems | Chandel *et al.*& Wazed *et al.*, 2018 |
| 3 | Economic Evaluation SWPS | • The cost of PV>conventional but reduced with time because of mass production | | Bakheet, 2019 |
| 4 | Renewable and Sustainable Energy Reviews | • Monthly and seasonal reorientation PV panel cause no difference<br>• Hourly readjustment of tilt angle with manual tracking three times a day and found that 20% system efficiency improved than the fixed one. | • PV array system adjustment | Li *et al.* 2017 |
| 5 | Sizing of PVWPS | • Automatic trucking consumes 5-10% power produced, no viable in hot country | • Manual trucking | A. Almarshoud, 2016 |
| 6 | Impact of Solar Panel Orientation on Solar Energy | • As the orientation moves away from the optimal angle energy loss increase and expected energy decreased.<br>Azimuth orientations have profound effect on Output energy production. | • multiple orientations system<br>split installation in an east-facing and west facing side | Laveyne et al. |

| | | | | |
|---|---|---|---|---|
| 7 | Optimization of Solar Energy Harvesting | • The main Factors that affect the output power of PV are Tilt angle, Azimuth angle and cleanness of PV | • studying in PV Array structure<br>• Status of the PV panels<br>PV modules configuration | Almusaied *et al.*, 2018 |
| 8 | A review of sustainable solar irrigation systems | • Unlimited site investigation<br>• Recognize the crop WR } best ways to optimize the cost<br>• Design the PV system properly | | Mohammed Wazed et al., 2018 |
| 9 | *Renew. Sustain. Energy Rev.*, | • From 1995–2015 related to SWPS, the average system efficiency of solar water pumping system is around 3.4%. | Yearly pumping 6580.611 m3 by one Kilo Watt is around | Muhsen *et al.*, 2017 |
| 10 | Design and Performance of SWPS | • With irradiance of 100 - 500 W/m2, at a fixed head of 24 m, the system efficiencies reached 3.76% | discharge of 1000 to 30 m3/h | Chilundo *et al.*, 2018 |
| 11 | Improving the effectiveness of SWPS by water spray: | • At 16m head the mean efficiency increased from 3.75% to 5.1% by spray.<br>$\eta_t = \frac{\rho * g * Q * h}{G * A}$, $\eta_{subsy} = \frac{\rho * g * Q * h}{Ppv}$ | | Abdolzadeh & Ameri, 2009 |
| | Sizing of SWPS for irrigation | The system efficiency is 3% | 5.3 m3/h from 60 m head | Raghuwanshi & Khare, 2018 |

## 2.5. Research Gap

Even though solar energy for water pumping is the most promising technology, in Ethiopia still only less than 1% of 5.2 kWh/ $m^2$has been exploited per day and therefore the system efficiency of solar water pumping is less than 5.2% with high initial cost (A. K. Tiwari et al. 2020). In Ethiopia, almost all installed solar systems are fixed axis type facing towards south and lacks to collect solar energy in early morning and late afternoon. In large system it is difficult to move solar collectors towards the sun because of its weight, area cover during rotation and complexity. Generally, the research gap from the previous works were lack of the individual PV module orientation by splitting the entire system configuration that has a critical effect on the performance of the system. Therefore, it is reliable to design, manufacture and experimentally investigate a new solar tracking system and compare the efficiency with fixed axis solar tracking for water pumping system.

### 2.6. Background of Research Site (Fogera)

Fogera is one of 151 districts of the south Gondar zone of the Amhara national regional state, with Woreta as its main town, 625 kilometers from Addis Ababa and 55 kilometers from Bahir Dar, the regional headquarters. It is located in south Gondar and bounded on the south by Deraa, on the west by Lake Tana, and on the north by the Reb River, which separates it from Kemkem. Woreta town is the administrative hub of this woreda. The area situated between latitudes $11.46^0$ and $11.59^0$ north and longitudes $37.33^0$ and $37.52^0$ east. It has a total land area of 117405 hectares, with 76 percent flat terrain, 11 percent mountainous hilly territory, and 13 percent bottom valleys (ILRI, 2009).

Fogera woreda is located between 1774 and 2415 meters above sea level. The Gomera and Reb rivers, both of which flow into Lake Tana, are found in the Fogera. According to a survey of the land in Fogera, 44.2 percent is arable or cultivable, with another 20% irrigated, 22.9 percent for grazing, 1.8 percent for forest or shrub land, 3.7 percent for water, and the remaining 7.4% is considered degraded or others. Teff, corn, sorghum, cotton, and sesame are among of the area's most important cash crops.

Fogera is also known for its cattle breed, which has a huge frame and is one of Ethiopia's best native milk cows; however, during the dry season, other breeds of cattle are introduced to the Fogera plains from Deraa and Kemekem woredas, putting the indigenous breed at risk of genetic dilution (ILRI., 2009). The region considered as a major source of onion seed for the entire Amhara region. From October to January and February to May, onion production takes place twice a year (Teshome et al. 2009).The experiment was done in Fogera woreda particularly in Shina kebele as shown in Figure 4, seven km away from the woreda where every farmer has their own shallow ground borehole source with ahead of about 12-30 meter dip.

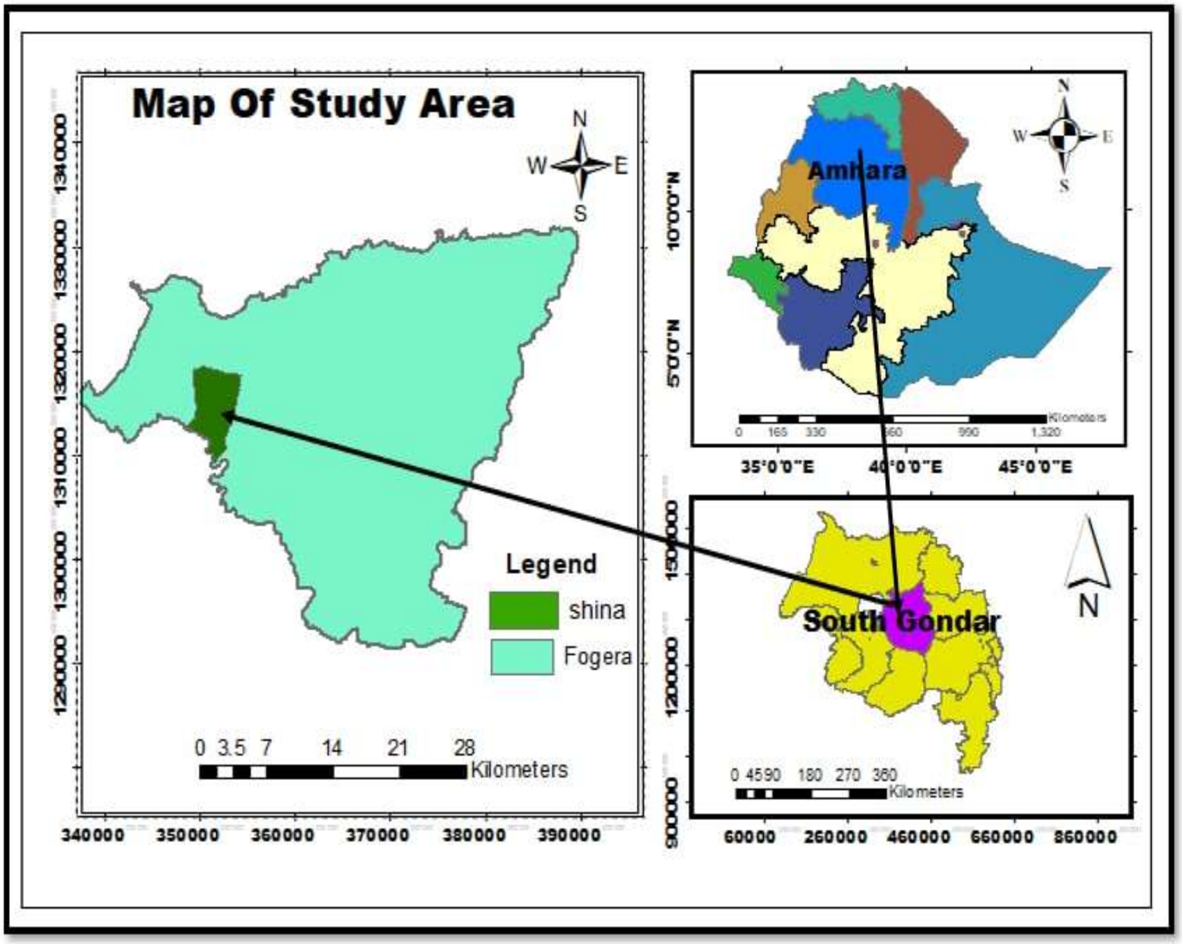



Figure 4: Maps of the study area

# CHAPTER THREE

# 3. MATERIALS AND METHODS

In this chapter, the materials used to manufacture the new manual solar tracking system and the method used to design experimental setup for the new manual solar tracking system discussed.

## 3.1. Materials

The solar water pumping system (SWPS) is one of the application areas of solar energy system which have solar panel, solar pump controller, 3 phase DC pump, PV stand, DC disconnect breakers, pipes, cables and storages. The following components used for the construction of the new manual solar water pumping system.

**The Solar panels:**

The solar panel is one of the components of SWPS that convert the sun light energy into electrical energy. The DC power obtained from the system is used for pumping of water for irrigation. The three solar panels are connected in parallel to obtain the maximum power output from the system. The solar panel have 190 Watt with maximum voltage and current of 28.8 V and 6.6 A respectively. The solar panels are prepared with sockets and plugs enabling easy connection in parallel and in series connection. The following PV module specification was used during the design and experiment of the study.

Table 2: Solar module Specification

| Solar module specification | | |
|---|---|---|
| Product name | Fixed axis system | Tracking system |
| | CSP-190 ECO SENSE | CSP-190 ECO SENSE |
| Electrical characteristics | 24 V | 24 V |
| Number of cells | 60 | 60 |
| Maximum power Pmax [$P_{max}$] | 190 Watts | 190 Watts |
| Current at maximum power [$I_{mp}$] | 6.6 A | 6.6 A |
| Open circuit voltage $V_{oc}$ [V] | 36.0 | 36.0 |
| Short circuit current $I_{sc}$ [A] | 7.22 | 7.22 |
| Maximum system voltage [V] | 600 | 600 |
| Maximum power voltage $V_{mp}$ [V] | 28.78 | 28.78 |
| Thermal parameters | | |
| Temp. coefficient: short-circuit current $I_{sc}$ | -0.006% / °C | -0.006% / °C |
| Temp. coefficient: open-circuit voltage $V_{oc}$ | - 0.035% V / °C | - 0.035% V / °C |
| Qualification test parameters | | |
| Temperature cycling range [°C] | -40 to +85 | -40 to +85 |
| Weight Pounds [kg] | 18.5 | 18.5 |
| Frame | Silver | Silver |

**Solar water pump:**

In rural areas without a grid connection, the LORENZ DC PS2-150 C-SJ5-8 submersible pump 300-Watt is a suitable and dependable option for irrigation using solar as an energy source. It is Centrifugal pump (3") fitted to 5 inch well with heads of 20 m and relatively large flow rates of 4.6$m^3$/h. The Dc motor supplied with only DC voltage input ranging from 17 V to 50 V and 50/60 Hz frequency. The solar powered submersible pump specification from the manufacturer manual used for this experimental analysis were as shown in Table 3 below:

Table 3: Pump specification

| LORENZ pump PS-2-150 C-SJ5-8 | | |
|---|---|---|
| 1 | Product name | PS-2-150 C-SJ5-8 |
| 2 | Maximum head (TDH) | 20 m |
| 3 | Water Temperature | 50 $0^c$ |
| 4 | Maximum flowrate (Q) | 4.6$m^3$/h |
| 5 | Power ($P_{max}$) | 300 W |
| 6 | Maximum input voltage (V) | 50 V |
| 7 | Optimum voltage ($V_{mp}$ ) | >17 |
| 8 | Maximum current ($I_{max}$) | 22 A |
| 9 | Efficiency (η) | 98% |
| 10 | Ambient temp | -40-$50^0$c |
| 10 | Enclosure class | IP 68 |
| 11 | Motor | ECDRIVE 150-C |
| 12 | Brushless DC motor | Maintenance free |
| 13 | Fluid | water |
| 14 | Premium material | Stainless steel ASI304/315 |
| 15 | Efficiency (η) | 92% |

**Controller:**

The MPPT controller that fit to the system is connected to the solar panels through electrical wires in order to control and maximize the power generated by the PV panels.

**Solar PV Stand:**

The new manual solar tracking system shown in Figure 4 has been developed in Ethiopia water technology institute (EWTI) Addis Ababa -Ethiopia. All the dimensions were based on available fixed axis solar panel dimension, selected solar panel dimension, landscape of the site, convenience for loading and unloading of the PV panels. The prototype has a vertical dimension of 1200 mm and 1600 mm for the short and long sides of the PV stand respectively. The module stand fabricated from galvanized stainless steel and designed in the way that it can move easily in order to track the sun manually. The panels moved up and down on this frame not only for tracking but also for loading and unloading of the panels as well as maintenance purpose. The PV modules stand easily assembled and disassembled when needed. The following table 4 shows the list of materials used to produce the new solar panel stand.

Table 4: List of materials used for PV stand manufacturing

| No | Material type | Specification | Part name | Quantity |
|---|---|---|---|---|
| 1 | Galvanized steel pipe | ½ inch × 1300 mm | 321 Stainless steels | 4 |
| 2 | Bolt &nut | Galvanized | M16 × 3 mm | 12 |
| 3 | Handle lock pin | pin | M10 × 3 mm | 6 |
| 4 | Handle | Seales tube R. H. S | 30 × 3160 mm | 2 |
| 5 | Handle connector | R. H. S Lockable pin | 30 ×3×100 mm | 2 |
| 6 | Long connector | R. H. SØ | 30 ×3×1600 mm | 2 |
| 7 | Middle support | R. H. S | 30 ×3×10 mm | 2 |
| 8 | Short connector | R. H. SØ | 30 ×3×100 mm | 2 |
| 9 | Solar panel holder | Angle iron | 30 ×3×1000 mm | 2 |
| 10 | Solar panel | CSAP190 ECOSENSE, | 1638×982×40 mm | 3 |
| 11 | Solar pump | 300 watt | 28.78V × 6.6A | 1 |
| 12 | Solar support table | R. H. S | 30*3*1000 mm | 1 |

## 3.2. Methods

The methodology shows the way how to achieve the objective of the research that has been presented in this section as shown in the diagram below. The overall methodology of the research is grouped into, data collection, optimum sizing of different solar water pumping system components, manufacturing & assembling of new manual tracking system based on the novel design, installing the system, experimental testing of the system, evaluating the efficiency.

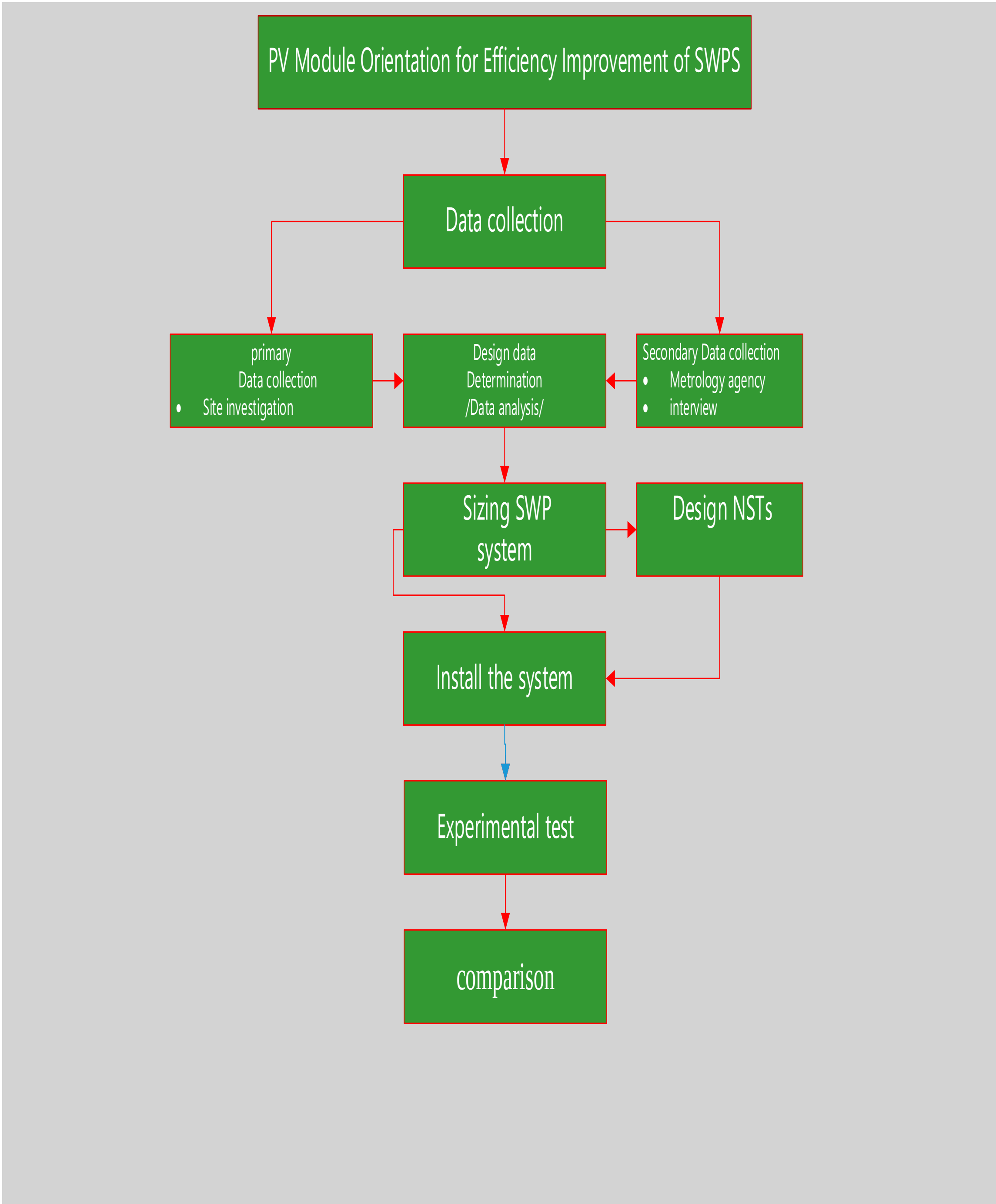



Figure 5: Schematic representation of methodology

### 3.2.1 Data collection

To design an efficient photovoltaic water pumping system, collecting local climate data of the area and system components were required. The first task was collecting necessary data from meteorology agency and minster of water, irrigation and energy for designing of solar pumping system for the specific selected site.

Type of soil, total area of irrigated land, time period for crop cultivation, and types of crops commonly cultivated, water requirement, crop root depth are obtained from direct interviews and agricultural office in Bahir Dar city. The monthly average solar radiation was determined from NASA satellite website based on the latitude, longitude and elevation of Fogera woreda due to unavailability of metrological stations in remote areas of region. Therefore, the sunshine hour data of Fogera woreda accessed from NASA website.

#### 3.2.1.1 Primary data

Shallow ground water depth (20-30 m) topography of the site (Flat land), amount of water production (1 l/s) Size of irrigation land 0.25-hectare.

Water source (borehole well and river), size of the bore hole (3-5 inch) type of pump currently used (diesel pump primarily) and solar pump, types of crops (onion, tomato, potato and green paper) latitude, longitude and altitude of the site (using kobo software), types of irrigation schemes they mostly used (furrow), source of energy (fuel and solar). These collected data used for the designing of the solar water pumping system.

#### 3.2.1.2 Secondary data

Average temperature, solar radiation, relative humidity, sunshine hours /shinning of the sun from morning to night/ collected from Ethiopian Meteorology Agency, Type of soil (GIS Software), onion planting period (Oct. and Nov.). The necessary data collected in the study area used for designing the solar water pumping system.

## 3.3. Study area

This research has been conducted in the north parts of Ethiopia specifically in irrigation fields of Fogera district, Shina kebele, which is, located around 680 km from Addis Ababa and 55 km from the town, Bahir Dar and lies at latitude of $11.889^0$ N and longitude of 37.636 E with the altitude of 1784.7 m. Therefore, all data collected from this area as much as possible primarily and from metrological agency secondary. The specific area of the study has been selected because of the following reasons. 1. The existence of shallow ground water table that can be accessed easily for experimental analysis. 2. The area is known for small-scale irrigation practices of horticulture throughout the year using irrigation water pumping system.3. Onion plant with emphasis on irrigation water was concern of the study, because roots of onion are so shallow. The study site has an onion plantation, which covers 0.25 hectare per each farmer land, which has dimension of 50 m length and 50 m width and planted in rows. Since the water source was shallow ground water with 20 m deep the total length of pipeline system was approximately 25 m considering the borehole at the center of the irrigation area. In Fogera areas, onion production (for both seed and bulb) gradually growing. Due to these reason the area considered as source of onion seed for the whole Amhara region. The Fogera boundary and irrigation potential map of onion are demonstrated as shown below in figure 6:

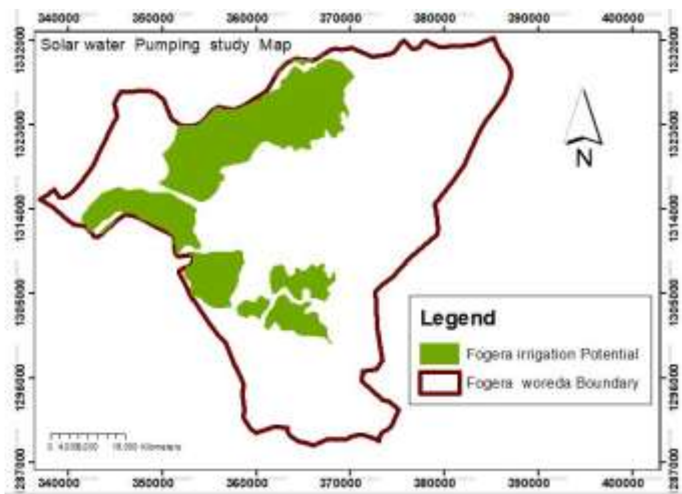



Figure 6: The irrigation potential map of Fogera

Figure 7 below showed the soil and landcover map of the study area


Figure 7: Landcover map of the study area

Even though the soil types of Fogera woreda consist of mainly chromic Luvisols, Eutric Fluvisols, Eutric Vertosols, Eutric Lepto sols, Haplic Luvisols etc.The specific area where the experiment conducted soil type was Eutric Fluvisols as shown below in figure 8.

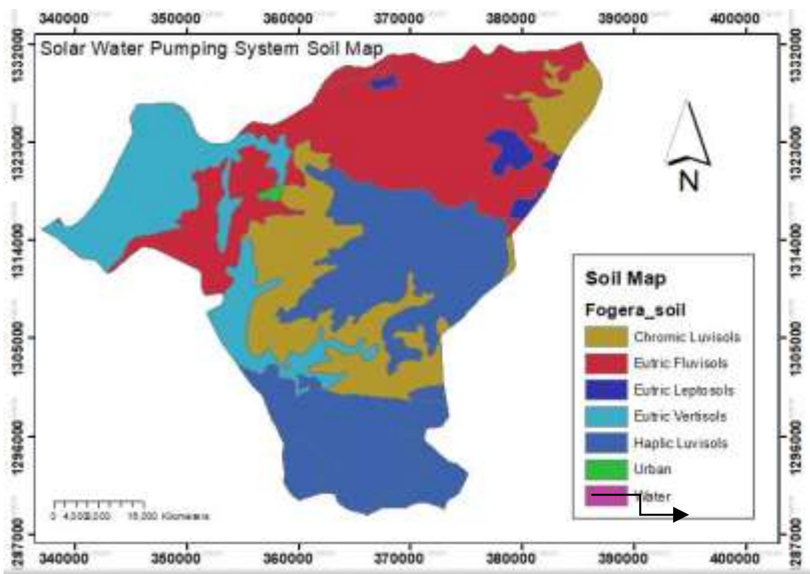



Figure 8: Soil and land cover map of Fogera

Knowing the cropping calendar of vegetables were essential to determine the design month based on the irrigation period as shown in table 5 below.

*Table 5*: Cropping calendar of vegetables (Otoo et al. n.d.).

| Vegetable/month | J | F | M | A | M | June | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shallot | H | H | H | H | H | P | P | - | H | PH | P | P |
| Onion | H | H | H | H | H | - | - | - | P | P | - | - |
| Garlic | H | H | H | H | H | - | - | - | - | P | P | P |
| Potato | P | H | PH | PH | PH | - | H | H | H | - | P | P |
| Sweet potato | - | H | H | H | H | - | - | - | - | - | P | P |
| Tomato | H | H | H | - | - | - | - | P | P | P | H | H |
| Cabbage | H | H | H | - | - | - | - | P | P | P | H | H |
| Lettuce | H | H | H | - | - | - | - | P | P | P | H | H |
| Swiss chard | H | H | H | - | - | - | - | P | P | P | H | H |
| Carrot | H | H | H | - | - | - | - | P | P | p | H | H |
| Hot paper | H | H | H | H | - | P | P | P | P | PH | PH | PH |

Legend: P=planting, H=harvesting, PH=planting and harvesting

Horticultural crops, particularly vegetables, are available all year due to varied production strategies that allow them to be grown for most of the year, indicating its potential to contribute to food and nutritional security. Rain fed vegetables are often planted in June, when the major rainy season begins. Most leftover, on the other hand, few types of vegetables planted at the end of the rainy season in September, while irrigated crops are delayed until January.

In Fogera, the practical onion planting began in October and November, with development taking place in December and January and harvesting taking place in February and March. For designing the system, November chosen. Similarly, during the onion irrigation season starting from planting to harvesting period, the sun is unfortunately in the southern hemisphere where most of the design orientation placed, that influenced to install the solar collector in the southern direction to collect more solar energy from the sun

Table 6: Annual sun position with suggested average days in a month

| Month | Sep | Oct | Nov | Dec | Jan | Feb | Mar | | | Apr | May | June | July | Aug |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sun Position | Eq | S | S | S | S | S | S | Eq | N | N | N | N | N | N |
| Recommended Average Days for Months | 15 | 15 | 14 | 10 | 17 | 16 | 16 | 16 | 16 | 15 | 15 | 11 | 17 | 16 |

Legend S= south, N= north, Eq= equator

## 3.4. Design new manual solar tracking system

Understand the position of the sun helps to design solar energy system throughout the year (Sari et al. 2021).Therefore, to determine the angle of new manual solar tracking for water pumping system, the following parameters (sun earth angles, irrigation seasons, day length) were studied.

### 3.4.1. Sun–earth angles

To estimate solar radiation intensity for any surface at any place throughout the year with a desired inclination and orientation, it is essential to understand the concept of Sun–Earth and hour angles.

**Latitude (ϕ)**

The latitude of an observer location on the Earth's surface is the angle made between the radial line joining the observer (location) with the center of the Earth, and its projection on the equatorial plane as shown in Figure 8. For an observer in the northern hemisphere, latitude is positive, whereas for the southern hemisphere is negative. The angular location in north or south of the equator, north positive; $-90^{\circ} \leq \phi \leq 90^{\circ}$, The latitude, longitude and altitude of Fogera Woreda, Shina kebele where the experiment had been taken are $11.889^0$ N, $37.636^0$ E and 1784.7 m respectively.

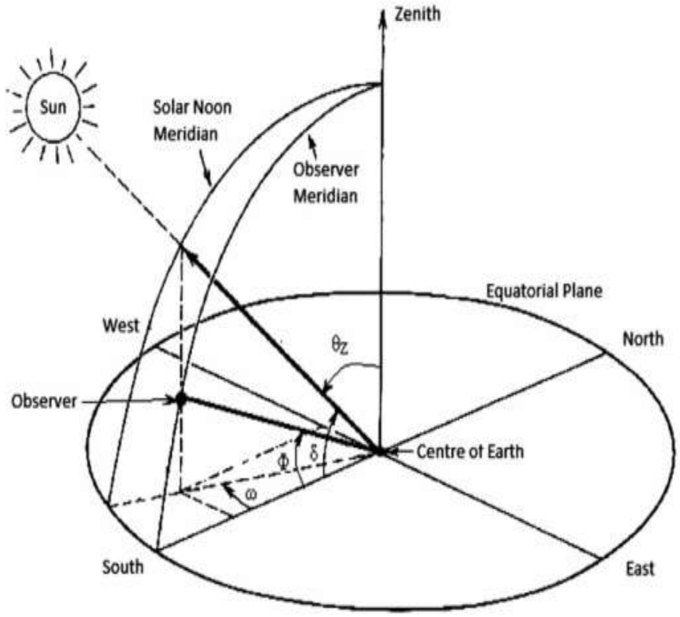



Figure 9: Different view of sun–earth angles (Duffie, Beckman, and McGowan 1985)

**Declination angle ($\delta$)**

Declination angle is the angle formed between the line joining from the centers of the Sun to the center of the Earth, that determines the direction of the incoming direct rays from the Sun and their projection on the equatorial plane as shown in figure 8 above. The angular position of the sun at solar noon when it is on local meridian with respect to the plane of the equator, north positive; -23.45˚ ≤ $\delta$≤ 23. 45˚. Therefore, it is suggested to select the values of declination δ and the number of days (N) by months as shown in Table below.

The date on which the value of the monthly average of the daily extra-terrestrial radiation that would fail on horizontal surface at the location under consideration is nearly equal to the mean value.

The angle of declination δ calculated as follows:

$$\delta \ = 23.5\, sin\left(\frac{360 * (284 + N)}{365}\right) \qquad 1$$

For January 1st (n=1) the declination angle was calculated as

$$\delta \ = 23.5 \sin\left(\frac{360 * (284 + 1)}{365}\right) = -23.011^0$$

Whereas for January 17 (n=17

$$\delta = 23.5 \sin\left(\frac{360 * (284 + 17)}{365}\right) = -20.90$$

The same procedure used to find the declination angle for all months of the year.

The declination angle variation in the n$^{th}$ day of year shown in Table 7. The highest value of (δ) as 23.1° in June 11 and the lowest value of (δ) was seen as -23.0° in December 10.

Table 7: Summary of suggested average days and declination angle(Deceased and Beckman n.d.)

| Month | Date | N for I the Day of the month | N | Declination angle (δ) |
|---|---|---|---|---|
| January | 17 | I | 17 | -20.9 |
| February | 16 | I+ 31 | 47 | -13.9 |
| March | 16 | I+ 59 | 75 | -2.4 |
| April | 15 | I+ 90 | 105 | 9.4 |
| May | 15 | I+ 120 | 135 | 18.8 |
| June | 11 | I+ 151 | 162 | 23.1 |
| July | 17 | I+ 181 | 198 | 21.2 |
| August | 16 | I+ 212 | 228 | 13.5 |
| September | 15 | I+ 243 | 258 | 2.2 |
| October | 15 | I+ 273 | 288 | -9.6 |
| November | 14 | I+ 304 | 318 | -18.9 |
| December | 10 | I+ 334 | 344 | -23.0 |

For the design, the suggested average days of November 14 and the declination angle of Fogera was -18.9 as calculated by equation 1 above.

The change in declination angle with n$^{th}$ day of the month shown in Figure 8 below.

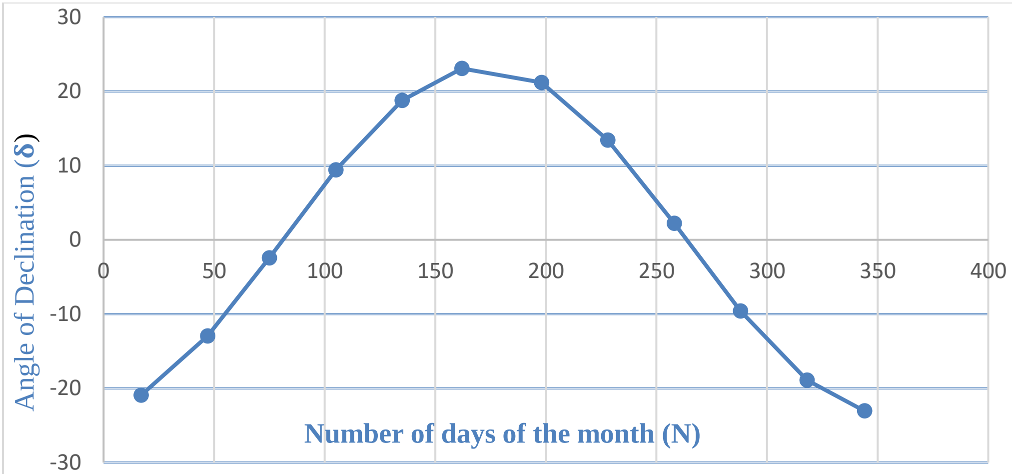



*Figure 10* : The change in declination angle with $n^{th}$ day of the month

Declination angle varied with days of the month throughout the year, therefore determining of this angle helps to the design optimal for specified month.

**Hour angle (ω)**

This is one of the determining angles for solar energy collection, away from solar noon which is negative in the early morning, positive in the afternoon and zero at local solar noon. It is the most determining factors that affect the intensity of the solar radiation. The hour angle formed because of the angular movement of the Sun from the local meridian and the Earth's rotation around its own axis. The relation between the hours to the angle is 1 h to 15°.

Hour angle expressed by:

$$\omega = (St - 12) * 15^0 \qquad 2$$

Where, St is local solar time.

The hour angle of the sun starting from sunrise to sunset (6:28 am to noon and 7:00 pm to 18:03 pm) calculated. (South of east or in the morning that is negative while south of west in the afternoon positive) as the result shown in the appendix C. Local solar time ($St$) taken as negative in the morning and positive in the afternoon for 24-hour time standard.

**Incidence angle (θ)**

The angle of incidence (θ) denotes the angle between the panel's orientation and the sun's orientation, as indicated in the figure 11 below. If (θ) = 0, the panel's position is optimal for maximum direct beam radiation capture. A is the sunbeam capturing surface of the panel. The panel on the right side of the image is directly facing the sun: The incidence angle is quite tiny and the proportion of direct beam sunlight recorded is nearly 100%.

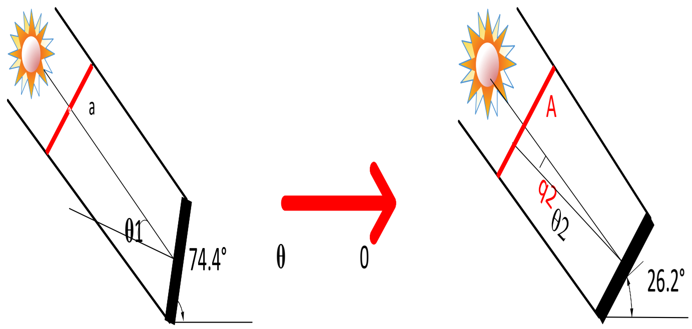



Figure 11: Effect of incident angle

As the Incidence angle (θ) is close to the normal to the surface, the probability to collect solar energy increase as the loss decrease. a/A is a function of θ’s cosinus: a/A= cos θ. As a result, the loss is (1 – cos θ) %. Because direct beam sunshine accounts for roughly 70% of total irradiance, the total irradiance loss will be (1 - cos θ) * 70% (B. Singh and Mishra 2015). The incidence angle on the left side is rather high and the irradiance that is not collected by the PV panel increasesed as the incidence angle increased as shown in the Figure11 above.

$$Irradiance\ loss = (1 - cos\,\theta) \times 0.7 \quad (3)$$

For tilted surface (northern hemisphere) the incident angle in November fourteen

$$\cos(\theta) = \sin(\phi)\sin(\delta)\cos(\beta) - \sin(\delta)\cos(\phi)\sin(\beta)\cos(\gamma) + \cos(\delta)\cos(\phi)\cos(\beta)\cos(\omega) + \cos(\delta)\sin(\phi)\sin(\beta)\cos(\gamma)\cos(\omega) + cos\,(\delta) sin\,(\beta) sin(\gamma) sin\,(\omega) \quad (4)$$

South-facing, tilted surface (northern hemisphere) in November 14 the incident angle

$$\cos\theta = \sin(L - \beta)\sin\delta + \cos(L - \beta)\cos\delta\cos\omega \qquad 5$$

For the special case of solar noon, for northern hemisphere with south-facing inclined surface, the incident angle is: *Calculated by*

$$\theta = |\varphi - \delta - \beta| \qquad 6$$

The total irradiance loss from the fixed and manual tracking system are shown in Table 8 below.

Table 8: Solar radiation loss in fixed and manual solar tracking system

| h | δ | ϕ | ω | β | γ | | (θ) | | Loss | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Fixed | Tracked | Tracked | Fixed |
| 6 | -18.9 | 11.889 | -90 | 15 | -71.48 | 0 | 88.99 | 78.83 | 0.56 | 0.69 |
| 7 | -18.9 | 11.889 | -75 | 15 | -68.1 | 0 | 74.81 | 65.04 | 0.40 | 0.52 |
| 8 | -18.9 | 11.889 | -60 | 15 | -63.17 | 0 | 60.66 | 51.66 | 0.27 | 0.36 |
| 9 | -18.9 | 11.889 | -45 | 15 | -55.79 | 0 | 46.72 | 38.99 | 0.16 | 0.22 |
| 10 | -18.9 | 11.889 | -30 | 15 | -44.24 | 0 | 33.31 | 27.69 | 0.08 | 0.12 |
| 11 | -18.9 | 11.889 | -15 | 15 | -25.86 | 0 | 21.55 | 19.16 | 0.04 | 0.05 |
| 12 | -18.9 | 11.889 | 0 | 15 | 0 | 0 | 15.79 | 15.79 | 0.03 | 0.03 |
| 13 | -18.9 | 11.889 | 15 | 15 | 25.86 | 0 | 21.55 | 19.16 | 0.04 | 0.05 |
| 14 | -18.9 | 11.889 | 30 | 15 | 44.24 | 0 | 33.31 | 27.69 | 0.08 | 0.12 |
| 15 | -18.9 | 11.889 | 45 | 15 | 55.79 | 0 | 46.72 | 38.99 | 0.16 | 0.22 |
| 16 | -18.9 | 11.889 | 60 | 15 | 63.17 | 0 | 60.66 | 51.66 | 0.27 | 0.36 |
| 17 | -18.9 | 11.889 | 75 | 15 | 68.1 | 0 | 74.81 | 65.04 | 0.40 | 0.52 |
| 18 | -18.9 | 11.889 | 90 | 15 | 71.48 | 0 | 88.99 | 78.83 | 0.56 | 0.69 |
| | | | | | | | | | | |

This shows that the incident angle of fixed axis solar tracking system is higher than the incident angle of the new manual solar tracking system. Solar water pumping system eficience hieghly dependant on the amount of solar radiation reached to solar collector (Krishnaraj et al. 2019).

The incoming solar radiation reached to the surface of solar collector converted to electricity based on the orientation of the panel. when incident angle close to the normal to the surface, near to zero, more energy would be produced. The change in incident angle for both (fixed and manual traking) system depends on the change in azimuth during sunshine. This variation of incident angle affect the capacity to collect solar energy from the sun. When incident angle gets $\theta$=78.8$^0$, 65.04$^0$, 51.6$^0$ 38.9$^0$ 27.7$^0$ ,19.16$^0$ and 15.79$^0$ the total irradiance loss was 0.56, 0.4, 0.27, 0.16, 0.08, 0.04 and 0.03 respectively. Solar adiation los is directly proportional to incident angle.

**Altitude angle (α)**

The angle formed between the solar ray and the horizon, complementary with the Zenith angle (θz) which is the angle between the solar beam and the vertical axis (the maximum value recorded at noon). Altitude angle is given by the following equation 6:

$$\sin\alpha = \cos z = \sin L \sin(\delta) + \cos L \cos(\delta) \cos\omega \qquad 7$$

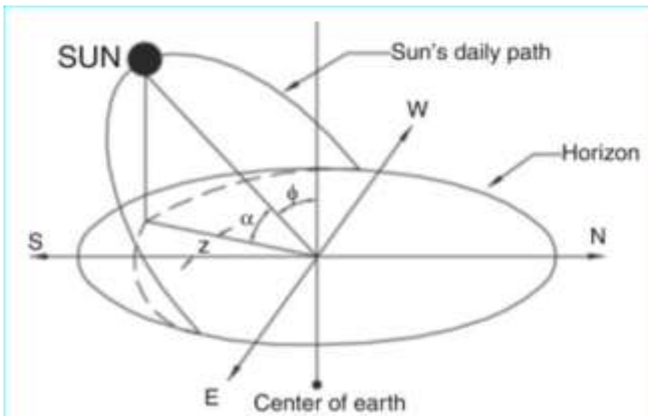



Figure 12: Path of the sun across the sky from sunrise to sunset

**Zenith ($\theta_z$)**

The angle formed between Sun's rays and the line perpendicular to a horizontal plane is known as the "zenith angle. It is also complimentary angle with altitude angle. The zenith angles for the design month calculated by equation 7 below:

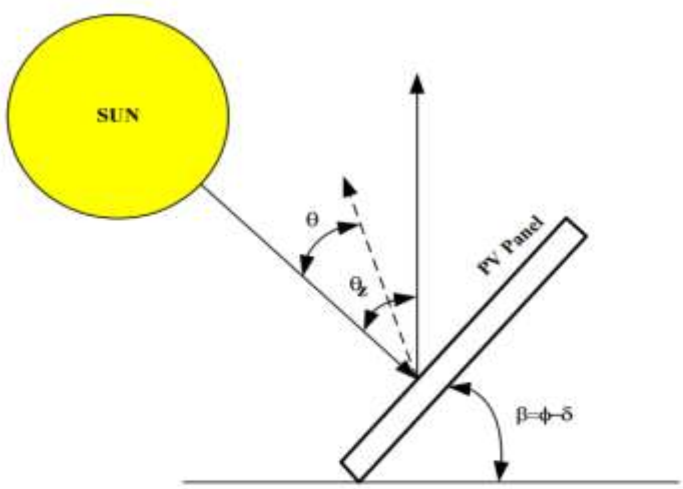


Figure 13 : Zenith and altitude angle representation

$$Zenith\ (\theta z) = 90^0\ -\ (\alpha) \tag{8}$$

Azimuth angle (γ)

The surface azimuth angle is one of the angles that affect the solar energy collection. In this thesis the surface azimuth angle changes in the direction of the east, west and south (negative, positive and zero) direction respectively. The two panel except the middle one changes its azimuth angle towards east and west with respect to the hour angle while the middle panel remains in the south direction. In the northern hemisphere, azimuth angle takes negative values before solar noon and positive value in afternoon hours. The azimuth angle calculated by the following formula.

$$cos\ (\gamma) = \frac{cos(\phi)\, sin\, \delta - \ cos(\delta) * sin(\phi)\, cos(h)\, sin\, \delta - \ \omega}{cos\ \alpha} \tag{9}$$

The sign of the azimuth angle may adjusted when using the above equation, depending on the zero azimuth. For the orientation due south 0 degree, it is subtracted from $180^0$($180^0$- cos $(\gamma)$)

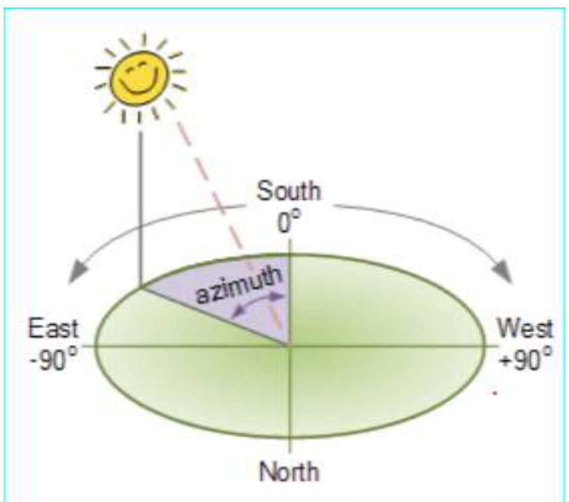



Figure 14: Azimuth angle orientation

**Tilt angle (β)**

This angle is one of the most determining angles that can affect the solar energy collection time and strength. It varies with season and follows the latitude of the place, therefore, knowing this angle helps to know the degrees between the PV module and horizontal surface; the ideal tilt angle of solar panel is approximately equal to the latitude of that location. Therefore, considering the latitude of the solar site location used to determine the tilt angle of solar array. In general, it is advised to tilt the panel towards the Equator at an angle equivalent to the local latitude for installations aiming at maximum yearly solar production in the intertropical region (Tsoukpoe 2022). Since the latitude of the location is $11.889^{0,}$ then the tilt angle most probably 12 to $15^0$. The optimal fixed tilt angles of all countries of the world including Ethiopia, Gondar with latitude angle of $12.53^0$ given as 18 degree (Jacobson and Jadhav 2018). The maximum tilt angle for fixed solar orientation in annual solar energy collecting system is about equal to the location of the latitude. However, maximum energy could be obtained by changing the tilt angle four times per year (G. N. Tiwari and Ahmad 2009).The tilt angle for places near to equator is sufficient to be between 10 to 15 degrees (*MWE, 2018*). It mainly useful to drain water or wash away dusts. Therefore, tilt angle for this study taken as 15 degrees.

**Day length, sunrise and sunset**

Day length

The solar noon, period in between sunrise and sunset. The daylight length is the whole time between sunrise and sunset.

Daytime length (DL) measured in hours and calculated by equation 10. Knowing the length of the day used for deciding the PV angle changing position with respect to incident angle and time.

$$DL = (\frac{2}{15}) \cos^{-1} (-\tan(\phi) \times \tan(\delta)) \qquad 10$$

Sunrise:

The time of sunrise calculated by equation 11:

$$Sunrise\ time = 12 - \left(\frac{DL}{2}\right) \qquad 11$$

Sunset:

The time of sunset calculated by equation 12

$$Sunset\ time\ 12 + \left(\frac{DL}{2}\right) \qquad 12$$

The following calculated result shown in Table 9 below used to determine the average PV adjustment angle with respect to time

Table 9: Relation of angles used to determine manual solar tracking system

| Time (Hr.) | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Incident angle | 78.8 | 65.0 | 51.7 | 39.0 | 27.7 | 19.2 | 15.8 | 19.2 | 15.8 | 19.2 | 27.7 | 38.9 | 51.7 | 65.0 | 78.8 |
| PV changing angle | 11.2 | 25.0 | 38.3 | 51.0 | 62.3 | 70.8 | 74.2 | 70.8 | 74.2 | 70.8 | 62.3 | 51. | 38.3 | 25.0 | 11.2 |
| Average angle 11 | | 35 | | | 60 | | | | 74 | 60 | | | 35 | | |
| Angle changing time | | 6:30-9:00 | | | 3:00-5:00 | | | | noon | 14:00-15:00 | | | 16:30-18:00 | | |

The average angle was determined by dividing the sunshine hour of the day throughout average irrigation period of the year (November 14), the day length (maximum sunshine hours of the day) of the month is 11.47 hours. To avoid the frequent changing of panels orientation, average angles were taken as $35^0$, $60^0$ before and after noon shown in Table 9. The sun rises at 6:28 and set 18:03 as shown in appendix D.

For the solar panel facing upward in the morning at 12:00 am, the solar radiation incident angle gets 78.8 degrees to the normal to the surface and 11.2 degree to the side of the panel. Therefore, to collect the maximum solar energy during sunrise, the solar panel angle faced 78.8 degrees from normal to horizontal to sun ray or faced near to east. i.e., the normal to solar panel surface positioned perpendicular to the normal to the horizontal surface.

### 3.5. Design Data Analysis

The raw data collected from primary and secondary source were very huge and needed further adjustment for the missing data using interpolation method. Once the required data collected, the next step was determining water requirement for the 0.25-hectare onion farm.

Submersible water pump, three parallel arrangement of PV module with Maximum Power Point tracker (MPPT controller) specified and used with its maximum performance. The data obtained from the user/manufacturer manual also used for sizing of solar water pumping system

The availability of solar energy received by the solar array installed have been assessed and estimated using theoretical and experimental analysis methods

The experimental analysis conducted with the integration of DC submersible pump, MPPT, Polycrystalline PV panel at different configuration and orientation. The experimental result focused on energy produced and water discharge from solar water pumping system. All factors like dimension of cable and water pipe properly considered. The water flow rate from the well mainly depends on the availability of solar radiation intensity that reach to the PV panel/PV array. Therefore, by varying the PV module towards the direction of the sun i.e., eastward in the early morning, upward at noon and westward in the late afternoon compared with the fixed axis orientation system by keeping all variables the same. PV module orientation, the effect of varying the hour angle, incident angle, azimuth angle and of the PV module stand to the direction of sun were investigated in this experiment

### 3.6. Solar Water Pumping System Sizing

For proper sizing of solar water pumping system, identification of each component specification, system configuration and orientation of the system considered. Selection of the most suitable components and installing them with the right configurations for each specific site application was critical to improve the economic viability, system efficiency and long-term performance of the system.

The designed schematic diagram of the solar water pumping system shown below in figure 16.

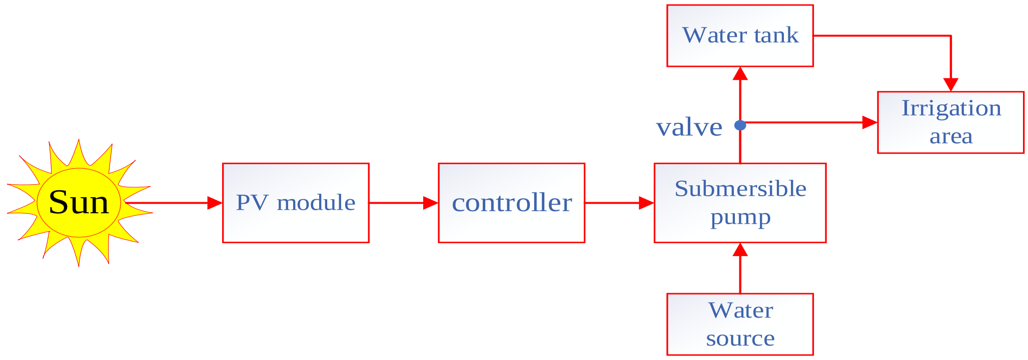



Figure 15: Schematic diagram of the solar water pumping system

During the solar powered water pumping system design, determining the water requirement and total dynamic head of the site and sizing of the system including the hydraulic power of pump, pump motor power, controller/inverter, PV panels, pipes, cables and water tank, irrigation area were done. The most important parameter that plays a great effect on the system efficiency were flow rate, total dynamic head, efficiency of all components, input/output power of the PV, controller, tilt angle, hour angle of the sun, temperature, pipe size, solar radiation, soil type, types of crops to be irrigated were considered for system design.

The hydraulic power $P_h$, Design flow rate$(Q_d)$ DC Motor power ( $p_m$), PV array power $pv_p$ number of modules, System efficiency, required to the system were calculated by equation 9:

$$P_h = (\rho \times g \times Q \times H) \qquad 13$$

The experiment considered the following parameter as input:

Table 10: Parameters used for design

| | |
|---|---|
| Water demand | $28m^3/day$ |
| Average sunshine hour | 6 hour/day |
| Static water level | 10 m |
| Height of the overhead to tank | 5 m |
| Draw down | 2 m |
| Pump level | 10 m |
| Area of irrigation field | 0.25 hectare |
| Average well water yield | 2/sec. |

**Water Requirement:**

Identifying the entire water requirement for the design is the first stage in designing a solar-powered water pump system. In this thesis the capacity of the solar water pumping system able to pump 27 $m^3/day$ which satisfies the water requirement for 0.25-hectare of onion crop, see in the appendix A.

Pérez Ortolá & Knox, reported vegetables, onion highly dependent on location, seasons and agro climatic condition with crop coefficient Kc value ranges 0.4 to 0.7, 0.85 to 1.05 and 0.6 to 0.75 for initial, middle and final stage respectively. Both excess and deficit water application highly affect the quality and productivity of the onion crops (Pérez Ortolá and Knox 2015). Other literature by Mitku et al, determined the onion coefficient value using Cropwat software shown in the table 26 below.

Table 11: Onion crop characteristics (Mitku, Kebede Kassa, and Tefera 2021)

| Crop characteristics | Growing stages | | | | Total |
|---|---|---|---|---|---|
| | Initial | Development | Mid | Late | |
| Kc | 0.5 | 0.7-0.8 | 1.15 | 0.99 | |
| Stages | 20 | 25 | 35 | 20 | 100 |
| Rooting depth | 0.25 | | 0.6 | | |
| Critical depletion (fraction) | 0.3 | 0.45 | | 0.5 | |
| Yield response factor | 0.8 | 0.4 | 1.2 | 1 | 1 |
| Crop height | | 0.4 (optional) | | | |

**Solar water pumping system diagram**

The solar water pumping system diagram shown in Figure 16 below consists of solar panel controller, pump with motor, water storage tank, electric cable and water pipe.

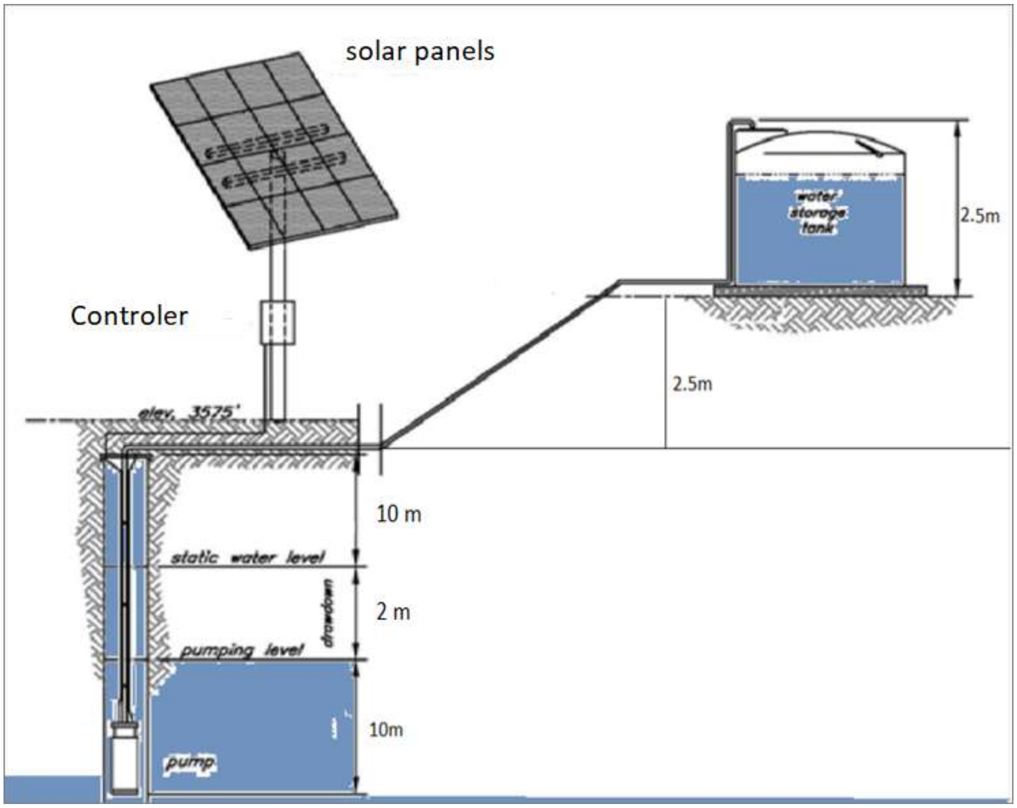



*Figure 16*: Schematic diagram of solar water pumping system(Zhu et al. 2019)

**Water Source:**

In Fogera every farmer has their own either tube well with a diameter of boreholes typically 75 mm (3 inch) 100 mm (4 inch) diameter or 150 mm (6 inch) diameter operated by diesel pump or hand dug well. Most of the time, the water fetched/pumped by bucket from the hand dug well under the consideration of static water level, dynamic water level and associated drawdown.

In order to make sure that the well has enough water production capacity to meet expected water needs, nobody did pump test. As a result, the diesel water pump work only for few hours to finish the water in the well before satisfying the water demand and cause the pump to run dry that result burn. During the experiment, series of drawdown measurements made for various flowrates and pumping heads until the draw down became stable since the higher the drawdown during the specified testing time, the less likely the well is to be able to supply the water demands of the crops.

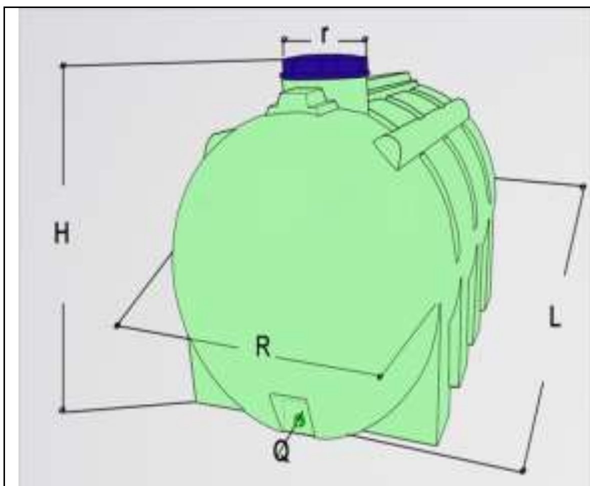
**Water Storage**

Typically, a water storage tank as shown in Figure 17 was required to make a solar-powered water pump system economically viable. The storage tank collects and store water during peak solar hours and provides water when solar panels are not producing electricity (early in the morning, late in the afternoon, cloudy and maintenance). To extend the life of an aboveground tank, it should be made of UV-resistant, structurally robust material.

The amount of water in the storage that the operation needs should be adequate to store water at least a for half-day's (three hours) of water consumption. The storage capacity calculated using equation 19.

$$Tank\ volume = \left(\frac{water\ requirement}{hour}\right) \times\ Irrigation\ hour \qquad 14$$

$(4.6m3/hr\ ))x\ 3hr\ =\ 13.8\ m3$




Storage tank volume

| Volume | Dimension |
|---|---|
| Radius (R) | 1.2 m |
| Length (H) | 3 m |
| Flow rate (Q) | 4.6 $m^3$/h |

Volume =A× L, where the Area A=$\pi r^2$

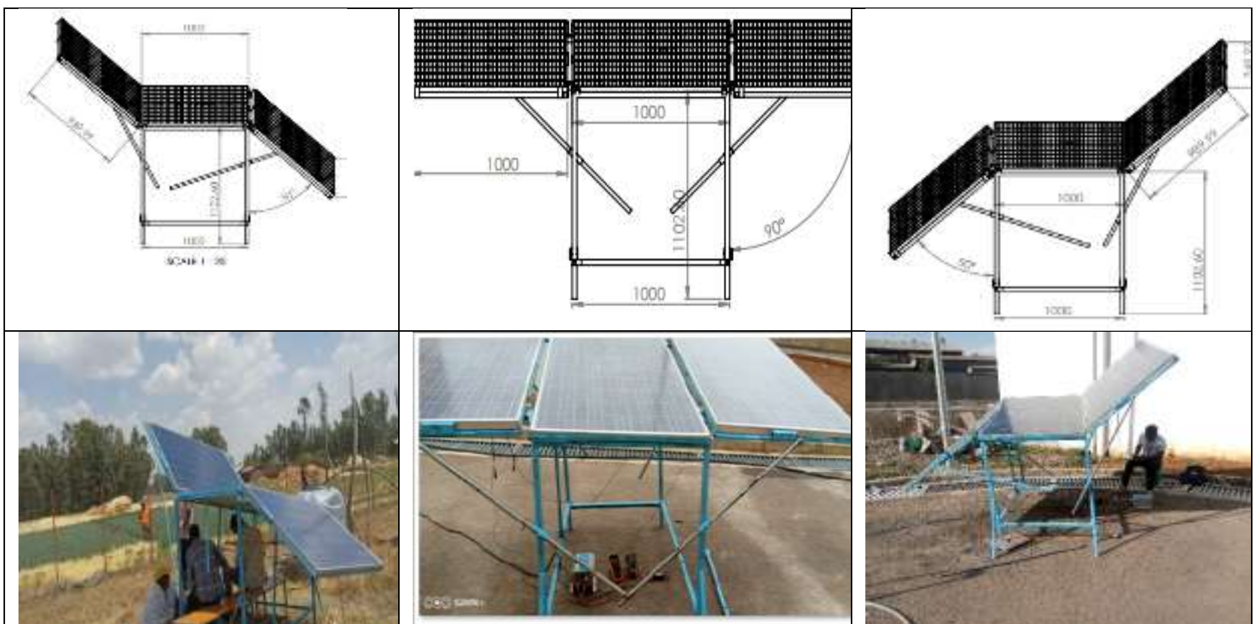
$V = \pi r^2 \times L = \pi \times 1.5^2 \times 3 = 13.8\ m^3$

Figure 17: Storage tank

**Solar panel orientation and insolation**

The amount of solar insolation (peak sun hours) available at the site was determined using solar insolation tool called PV WATTS Beta Viewer developed by the National Renewable Energy Laboratory and solar radiation calculator software that provide accurate statistics on solar insolation values for various locations.

For the selected sites with fixed solar panels pointed southward, an on-site investigation made to compare and validate the existing solar system energy collection capacity with the new solar panel orientation energy collection capacity per day. In order to maximize the solar-powered system's energy production, the two panels were directed eastward in the early morning southward in the midday and westward in the late afternoon while the middle panel remain southward all the day as shown in Figure 18 below with no major shade in their proximity.




| Morning orientation | Noon orientation | Afternoon orientation |
|---|---|---|

Figure 18: Possible solar panel orientations

The solar array placed close to the pump to minimize the electric wire length as well as installation costs and loss. The average solar insolation for the site obtained by using go solar software as 6.1

kWh/$m^2$/day and the solar irradiance was 1000 Wh/$m^2$/day at the STC. Then the peak sunshine hour obtained by equation 20.

$$Peak\ sun\ hour(Hr) = \frac{(Anual\ global\ radiation(kwh/m2/day)}{Iradiance\ at\ STC} \qquad 15$$

$$\text{Peak sun hour(Hr)} = \frac{(6.1\text{kwh/m2/day})}{(1000\text{w/m2/day})} = 6.1 \text{ hour}$$

**Design flow rate for the pump**

The design flow rate for the pump calculated by dividing the daily water needs of the operation by the number of peak sun hours per day. For the daily water requirement of $27.8\ m^3/day$ and a solar insolation value of 6.1 $kWh/m^2/day$)

$$Design\ flow\ rate\ (\ Q_d\ ) = \frac{(Daily\ Water\ requirement(m3/day)}{(peak\ sun\ hours(Hr)} \qquad 16$$

$$Flow\ rate\ (\ Q_d\ \ ) = \frac{27.8m^3/day}{\left(6.1\ \frac{hr}{day}\right)} = \left(\frac{4.6\ m^3}{hr}\right) = 1.23\ l/sec$$

**Sizing of the Pipe Diameter**

The diameter of pipe calculated by equation 24.

$$A\ = \frac{Q}{V} \qquad 17$$

$$A = \frac{\left(0.00123\ m^3/_s\right)}{1.2\ \frac{m}{s}} = 0.00102m^2$$

Assuming the recommended mean velocity of water in the pipe 1.2 m/s-2 m/s

Where:

Q is flow rate of water ($m^3$/s)

A is Area of the pipe ($m^2$)

V is the velocity of water in pipe (m/s)

$$A = \frac{(\pi\ D^\wedge 2)}{4} \qquad 18$$

Where D is the diameter of the pipe.

$$D^2 = \frac{4A}{\pi} \qquad 19$$

$$D = \frac{\sqrt{0.00102 * 4}}{3.14} = 0.037\ m$$

Therefore, the diameter of the pipe (D) should be 37 mm approximately, $1^{1/2}\ or\ 1.5\ inch\ (40mm)$ which is the theoretical internal diameter of pipe that can fit the system.

**Total Dynamic Head (TDH) for the Pump**

The size of solar water pumping system depends on the total dynamic head and flowrate. The system would be bigger when the total dynamic head increased. Therefore, it is important to carefully calculate and determine the TDH in the system.

The TDH for a pump is the sum of the vertical lift, pressure head, and friction loss. It can be calculated using equation 27.

$$TDH\ =\ Vertical\ Lift\ +\ Pressure\ Head\ +Friction\ Losse \qquad 20$$

Friction losses apply only to the piping and accessories between the point of intake (inlet) and the point of storage (i.e., the storage tank or pressure tank). Flow from the storage tank to the point of use is typically gravity fed. Therefore, friction losses between the storage tank and the point of use are independent from the pump sizing.

Vertical lift is the vertical distance between the water surface at the intake point (the well's water surface) and the water surface at the delivery point (the tank's water surface).

$$Vertical\ Lift\ = Height\ of\ tank + Drawdown + Static\ water\ level + Pump\ level$$

$$Vertical\ Lift = 5m + 2m\ + 10m = 17m$$

Pressure head is the pressure at the delivery point in the tank in this design there is no pressure at the delivery point (the tank's water surface). Friction loss is the loss of pressure due to the friction of the water as it flows through the pipe. Friction loss determined by four factors: the pipe size (inside diameter), the flow rate, the length of the pipe, and the pipe's roughness. Since this is the theoretical pipe size given the discharge and the guideline velocity of flow through the pipe, a practical or preliminary size of the pipe was to be made using the data of the pipe size that are available in the market. From the Darcy-Weisbach equation, the pipe size is inversely proportional to the frictional losses in the pipeline. Therefore, this implies that selecting a larger pipe that fit to the system would reduce the frictional losses and thus require a smaller pump that would reduce the overall cost.

**Head loss determination**

Properties of water and pipe material

The properties of water taken at a temperature of 25˚C. Under this condition; the density of water is 1000 $Kg/m^3$, kinematic viscosity of water is $8.9*10^4$ pa. Then, Darcy-Weisbeck friction factor is determined from moody chart by using Reynolds number and roughness of the pipe. While roughness and Reynolds number calculated by equation 28.

$$Re = \rho v D/\mu \qquad 21$$

Density of water $= 1000\frac{Kg}{m^3}$, $V = 1.2\ m/s$, (From recommended literature)

Diameter of pipe =40mm

Kinematic viscosity of water $\mu = 8.9 \times 10^{-4} N/m2$

$Re = \rho v D/\mu$,

$R_e = 53{,}932m$

For turbulent flow

RPR= D/ε

Where:

RPR is relative pipe roughness

ε roughness coefficient of galvanized pipe

$\text{RPR} = \text{D}/\varepsilon = 40\text{mm}/0.15\text{mm} = 266.6$ (Use the moody diagram to find frictional factor)

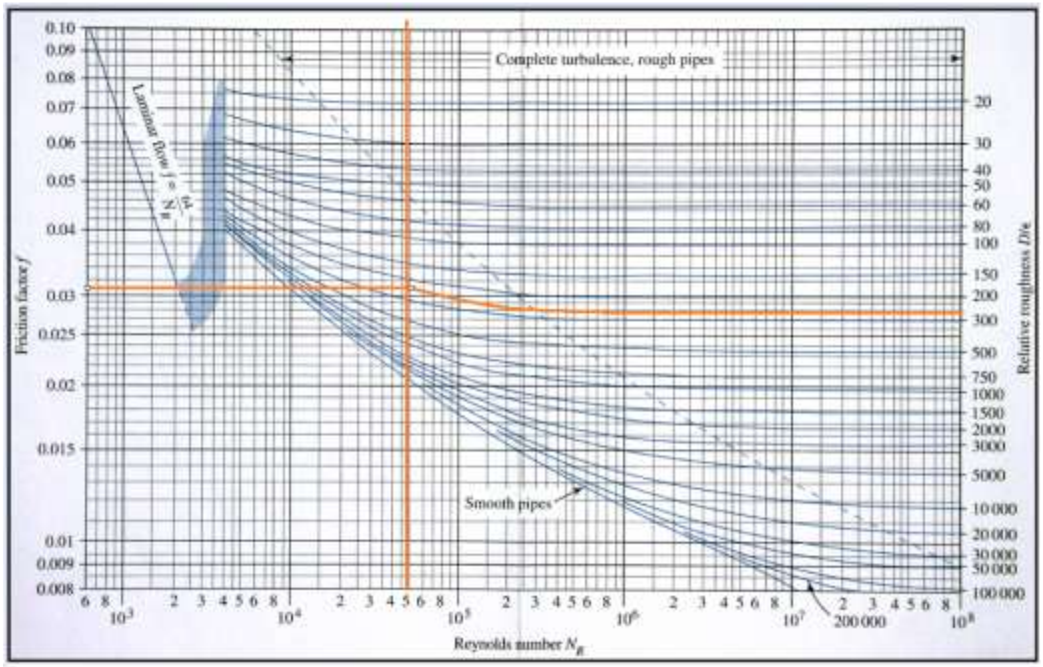



Figure 19: Frictional Factor determination

Therefore, the frictional factor obtained from the above graph figure 19 as 0.031, and the frictional loss of water in the pipe obtained by equation

$$f_h = \frac{f \times L \times V^2}{2 \times d \times g} \qquad 22$$

$$\text{f}_\text{h} = \frac{0.031 \times 20 \text{ m} \times 1.2^2}{2 \times 9.81 \times 0.04} = 1.13\text{m}$$

Therefore, total dynamic head of the was calculated by Equation 27 shown above

$$\text{TDH} = \text{Vertical Lift} + \text{Pressure Head} + \text{Friction Loss}$$

$$TDH = 17m + 0\ m + 1.13m = 18.13m \sim 20m$$

For the given system layout, approximately 20 m or 65.6 ft of $1^{1/2}$ inches diameter pipe needed to pump water from the well to the storage tank. From Appendix, the friction loss for 4.6 $m^3/h$ or 20 gallon/minute water flowing in a $1^{1/2}$ inches pipe has head loss of 1.13 m.

**Pump power Requirement**

The Empirical formula applied to calculate the pump hydraulic power

$$P_h = \rho \times g \times Q \times h \qquad 23$$

- Where:
- ρ is the density of water, kg/$m^2$
- g is gravitational acceleration, $(m/s^2)$
- Q is discharge, $(m^3/s)$
- h. is total dynamic head, (m)

$P_h = 255w$

$$Pump\ motor\ power = \frac{P}{\eta} = \frac{0.255kW}{0.85} = 0.3kW$$

*Where:*

P = Hydraulic Power (Watts)

η = Efficiency of pump, η =85%

**Controller sizing:**

$P_{controler} = \frac{P_m}{\eta_{cont}} = 310W$ (Efficiency of controller 98% from the manual)

The capacity of the pump needed to pump with 4.6 $m^3$/h from 20 m total dynamic head is about 0.3 kW

**$P_v array$**

$$P_v array = \frac{P_h}{Mf \times sys.eff} = 537W \text{ (mismatch factor 0.95, system efficiency 0.5).}$$

Then PV panels sized to provide a minimum output of 537 Watts or more to account losses of the system. PV panels having the following electrical characteristics are selected as shown in table 12

Table 12: PV panel specification

| Typical specification of 190 w solar panel | |
|---|---|
| Power max ($p_{mp}$) | 190 W |
| Short circuit current ($I_{oc}$) | 7.22 A |
| Max power current ($I_{mp}$) | 6.6 A |
| Maximum voltage ($V_{mp}$) | 28.78 V |
| Open circuit voltage ($V_{oc}$) | 36 V |
| Series fuse rating | 20 A |

$$Number\ of\ solar\ modules\ required\ = \frac{total\ PV\ output\ power}{indvidual\ Pv\ module\ power\ o/t} \qquad 24$$

$$= \frac{567w}{190w} = 2.98 \approx 3$$

Solar pump specification

Solar submersible pump system specifications attached in the appendix-B

The specification of the solar pump as shown in the appendix-B used to determine the best and optimized configuration of the solar water pumping system in which the solar panels are connected in parallel. The maximum input voltage and current to the pump, as indicated in table 3, should not be larger than 50 V and 22 A, respectively, while the minimum input voltage should not be less than 17 V. This makes a parallel connection to a solar PV system possible, whereas a series connection does not satisfy the requirements.

$$\text{Parallel PV string} = \frac{\text{pump current}}{\text{PV module(Isc)}} = \frac{22\text{A}}{7.2\text{A}} = 3.0 \text{ and,}$$

$$\text{Series string} = \frac{\text{no of panel}}{\text{parallel string}} = 3/3 = 1$$

**Parallel configuration of solar modules**

Panels wired in parallel by connecting positive-to-positive terminals and negative-to-negative terminals as shown in Figure 21, below.  In this case, the output voltage was the same as the individual panel voltage 28.78 V, while the total current is the sum of individual panels current that is 19.8 A. This shows that the current and the voltages are in the range of the required input voltage and current of the pump chosen.

The output power therefore, would be the product of the total voltage and current 570 W that is almost the same as the required PV panel power.

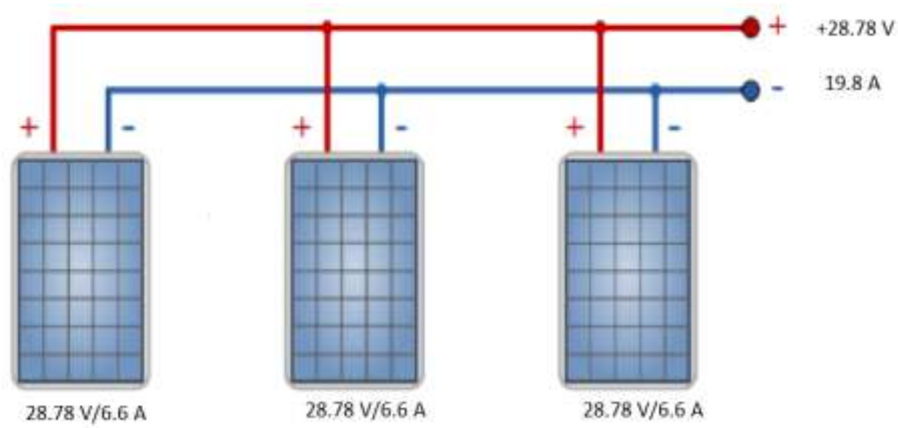



Figure 20: Parallel configuration of solar modules

**Series configuration of solar modules**

PV panels connected in series by connecting the negative terminal of one panel to the positive terminal of the next panel as shown in Figure 22. When panels wired in series, the total voltage is the sum of individual panel voltage that is 86.34 V while the total current of the three panel would be the smallest value of individual panel that is 6.6 A.

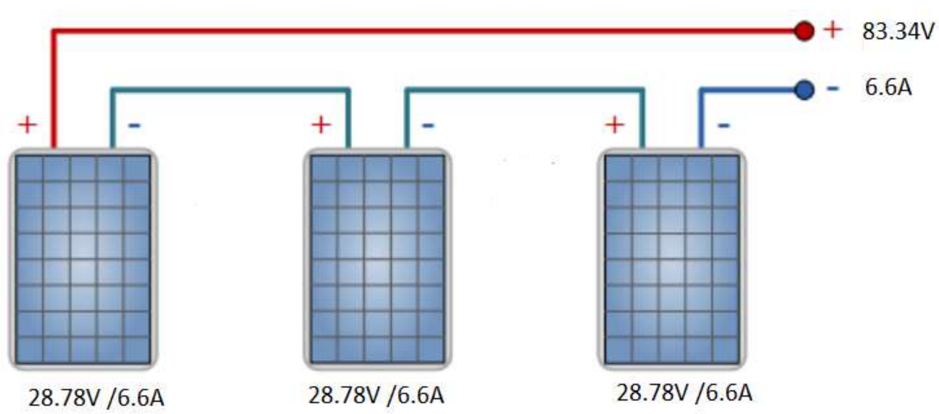


Figure 21: Series configuration of solar modules

The maximum allowable input voltage and current to the pump are 50 V and 22 A and series connection of panels voltage and current are 86.34 V and 6.6 A which is low input current and high input voltage respectively. Therefore, series connection resulted with high voltage and low current that is not possible both theoretically and experimentally with the selected pump to panel specification.

Table 13: Series and parallel configuration of PV module against Pump inputs required.

| Given the PV module specification | Pump specification (DC) | Series PV modules configuration | Parallel PV modules configuration |
|---|---|---|---|
| Peak power output of 190 W | 300 W | 570 W | 570 W |
| Rated voltage 28.78 V | >17 V-50 V | 86.34 V | 28.78 V |
| Rated current 6.8 A | <22 A | 6.6 A | 19.8 A |

**3.7. Manufacture and install the system:**

This research describes about design, construction and testing of the new manual solar tracker with an aim to bring the system at higher efficiency than the fixed axis solar collector with the same system size and cost does. The schematic diagram of PV stand shown below in Figure 24 and attached in the appendix, was manufactured in Ethiopia water technology institute and the experiment under taken in Amhara region Fogera woreda, Shina site. The dimension of all materials for new manual solar tracking system designed based on the fixed axis solar collector system. During the design, the area required by the solar array was considered as shown in equation below.

$A = l \times w = (0.95 \times 3) \times 1.80m = 5.13m^2$ That is equivalent area required with the fixed axis solar energy collector, while automatic tracking requires area of about $\pi r^2$ =3.14× $1.425^2$ =6.46.4 $m^2$.

The structure is designed and assembled in such a way that it can move eastward in the morning, upward in the noon, and westward in the afternoon using manual operation one panel at a time. This mechanism minimized the difficulty of moving many panels together at once. The structure designed using Solid Work software and performed several iterations before the final design obtained. The part drawing assembled drawing and manufactured collector orientation picture attached in appendix G

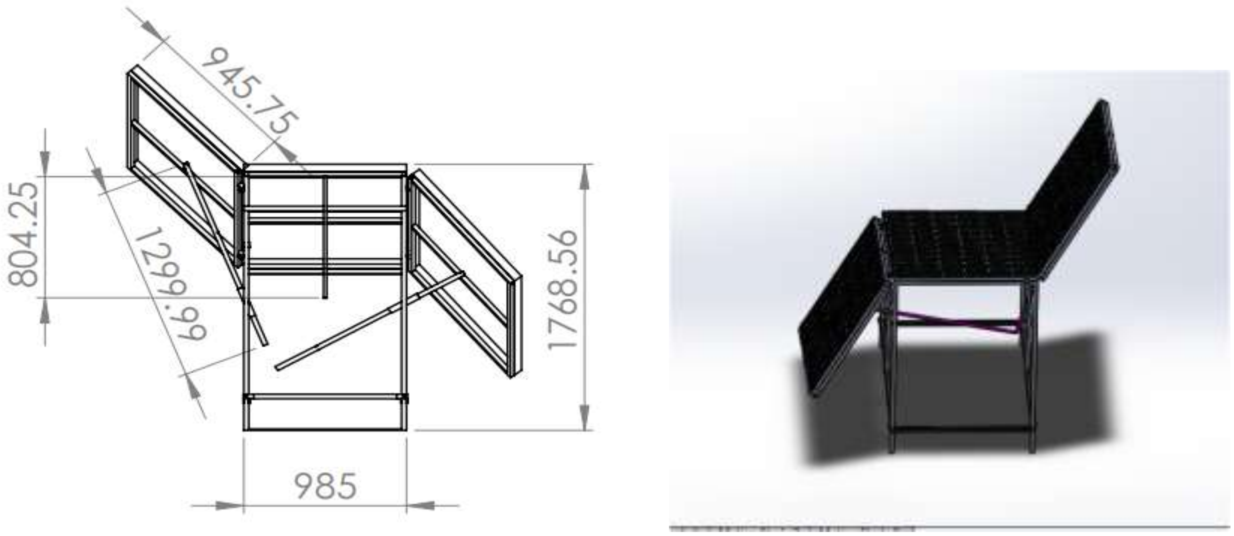



*Figure 22*: The schematic diagram of PV stand

After designed the system properly and efficiently with neither excess nor deficit power of the system, the new PV array stand that can hold the PV modules manufactured.  The three modules installed with the right configuration of parallel connection to get the maximum expected output power from the newly designed system by changing the direction of two modules from system eastward in the early morning; three modules southward in the midday and two module westwards in the late afternoon as shown in Figure 25 (a) and (b)

*Table 14: Summary of equations*

| No | Equation | Given | Result |
|---|---|---|---|
| 1 | $\delta = 23.5 \sin\left(\frac{360 * (284 + N)}{365}\right)$ | November 14 | -18.9 |
| 2 | $\omega = (St - 12) * 15^0$ | At noon | 0 |
| | $\text{Zenith } (\theta z) = 90^0 - (\alpha)$ | | 30.79 |
| 3 | $\cos(\theta) = \sin(\phi)\sin(\delta)\cos(\beta) - \sin(\delta)\cos(\phi)\sin(\beta)\cos(\gamma) + \cos(\delta)\cos(\phi)\cos(\beta)\cos(\omega) + \cos(\delta)\sin(\phi)\sin(\beta)\cos(\gamma)\cos(\omega) + \cos(\delta)\sin(\beta)\sin(\gamma)\sin(\omega)$ | At<br>δ= -14.9<br>ϕ= 11.89<br>β=15<br>γ =107<br>ω = 90 | 12.25 |
| 4 | $\cos\theta = \sin(L - \beta)\sin\delta + \cos(L - \beta)\cos\delta\cos\omega$ | θ | 17.75 |
| 5 | $\theta = \lvert\varphi - \delta - \beta\rvert$ | At noon | 15.1 |
| 6 | $\sin\alpha = \cos z = \sin L \sin(\delta) + \cos L \cos(\delta)\cos\omega$ | | 59.21 |
| 7 | $\text{Cos }(\gamma) = \frac{\cos(\phi)\sin\delta - \cos(\delta) * \sin(\phi)\cos(h)\sin\delta - \omega}{\cos\alpha}$ | At noon | 180 |
| 8 | $DL = \left(\frac{2}{15}\right)\cos^{-1}(-\tan(\phi) \times \tan(\delta))$ | Nov 14 | 11.45 |
| 9 | $\text{Sunrise time} = 12 - \left(\frac{DL}{2}\right)$ | Nov 14 | 12:28 |
| 9 | $\text{Sunset time } 12 + \left(\frac{DL}{2}\right)$ | Nov 14 | 12:03 |
| 10 | $Re = \rho vD/\mu$ | $\rho = 1000\frac{Kg}{m^3},$ | 48,539 m |
| 11 | RPR | $v = 1.2\ m/s$<br>d=37 mm<br>$\mu = 8.9 \times 10^{-4} N/m2$ | 247 |
| 12 | $TDH = \text{Vertical Lift} + \text{Pressure Head} + \text{Friction Losse}$ | | 20 |
| 12 | $f_h = \frac{f \times L \times V^2}{2 \times d \times g}$ | | 1.13m |
| 13 | $P_h = (\rho \times g \times Q \times H)$ | | 255W |

| | | | |
|---|---|---|---|
| 14 | $\text{Pump motor power} = \frac{P}{\eta}$ | η =85% | 0.3kW |
| 15 | $(Q_d) = \frac{\text{Volume}}{\text{Psh}}$ | V=27.8<br>Psh=6.1 | 1.23L/s |
| 16 | $A = \frac{Q}{V}$ , | V=1.2m/s | $0.00102m^2$ |
| 17 | $D^2 = \frac{4A}{\pi}$ | | 0.037m |
| 18 | $\text{TDH} = \text{Vertical Lift} + \text{Pressure Head} + \text{Friction Losse}$ | V L =17<br>P H = 0<br>F L =3 | 20m |
| 19 | $\text{Tank volume} = \left(\frac{\text{water req}}{\text{hour}}\right) \times \text{irig. hr/day}$ | $\text{no irig.} \frac{\text{hr}}{\text{day}} = 3$<br>Q=4.6 m3/hr | 13.8m3 |
| 20 | $P_v\text{array} = \frac{P_h}{\text{Mf} \times \text{sys. eff}}$ | Mf = 0.85<br>ηs = 85% | 537 |
| 21 | $PV\ mod\ equired = \frac{TPV\ output\ power}{indvidual\ Pv\ power\ o/t}$ | 190w | 3 |
| 22 | $\text{Parallel PV string} = \frac{\text{pump current}}{\text{PV module(Isc)}}$ | Ip=22 A, Ipv=7.2 A | = 3.0 and, |
| 23 | $\text{Series string} = \frac{\text{no of panel}}{\text{parallel string}}$ | | 1 |
| 24 | Area required by the solar, $A = l \times w$ | $(0.95 \times 3) \times 1.80\text{m}$ | $5.13m^2$ |
| 25 | Automatic tracking requires area $A=\pi r^2$ | $3.14\times\ 1.425^2$ | $6.46.4\ m^2$. |

### 3.8. Experimental testing of the system

The new manual solar tracking system prototype manufactured in Ethiopia water technology institute workshop. The operating current, operating voltage, water discharges recorded in 10-minute intervals in the selected site. The size of the land irrigated by this system were recorded. Measurements were made using a variety of devices. Energy collecting efficiency, time required to fill 1000 tank in a day were recorded.

#### 3.8.1. Devices used for the experiment.

The following devices used for the experimental Testing.

a) Digital Multi Meter ( DMMT)
b) Digital Clamp Meter (DCM).
c) Stop Watch (SW)

d) Discharge Measurement (water tank)

Discharge measurement using stop watch was a quick and accurate way to measure very small flows less than 5 l/s. (Division 2004). In the experiment, two 1000-liter water tanks used. One used for the fixed axis solar tracking system and the second used for the new manual solar tracking system. The stopwatch used to count the time until the tank filled with water.

e) Inclinometer

During installation of the system, inclinometer used to fix the tilt angle based on the design

f) Compass

This instrument used to identify the East-West and North-South direction in the site where installation made to fix the direction of solar panel based on the design.

## 3.9. Experimental test set-up description

The new manual solar tracking system and the fixed axis solar collector used for conducting the experimental study. The experimental work mainly studies the solar energy collection capacity of the two-system based on the available solar radiation.

A coted R.H.S. and angle iron were used for PV module holder stand construction with the area covered $5.13m^2$ for conducting the experiment of solar water pumping system. The digital mustimeters terminals connected to the end wire terminals of the PV modules after adjusting it to the right function to measure the total voltage of the system. It displays the voltage on its small screen on the top. The current carrying conductor passes through the clamp meters jaw and display the current value on its small screen. The experimental tests on the new manual solar energy collector and the fixed axis solar collector were carried out during the duration starting from November 11/08/2020-16/08/2020 between 6:30 am to 018:00 pm. The experimental site is located at Fogera woreda with longitude of $37.636^0$E and latitude of $12.889^0$ N. Figure 25 appendix E, shows the actual test set-up with measuring instruments used.

# CHAPTER FOUR

# 4. RESULT AND DISCUSSION

The experimental investigation conducted for six days for both the new manual solar tracking and fixed axis solar collector system. The results obtained from both the new manual solar tacking system and fixed axis solar collecting for water pumping were reported. The experiment focused on testing of conventional and new manual tracking based on energy collection efficiency per day for solar water pumping system. It specifically describes the solar energy collected by the PV modules and finally the overall efficiencies were tested. The voltage and current measurements were monitored while the water pumping systems operated. For measuring voltage and current two digital clamp meters and two digital voltmeters were used.

The new manual solar tracking system able to move up and down easily to track the solar energy in the early morning and late afternoon. The capability of moving up and down the individual PV panel with respect to the sun position enable the collector to start collecting solar energy earlier and stop collecting solar energy late in a day than the conventional collector which was stationary system. The new manual solar collector system was movable, It has irrigated five former's onion plant in a week during the experiment in different place where the conventional cannot do the same.

## 4.1. Experimental results

Designing of new manual solar tracking systems

The following calculated result shown in Figure 24, showed the irradiation loss of fixed and manual tracking system with respect to time.

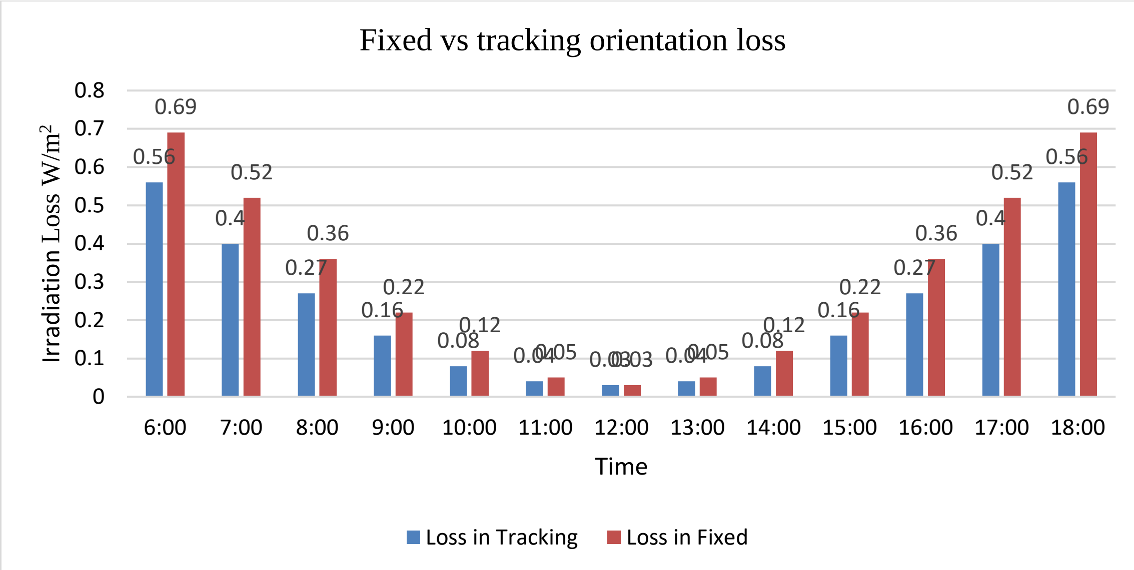



Figure 23: Irradiation loss of fixed versus manual tracking system

The new developed manual collector's solar irradiance loss was lower than that of the fixed axis solar collector, especially in the early morning and late afternoon, as illustrated in Figure 24 above.

In the fixed axis solar collector, the loss decreased from 0.52 to 0.03 $W/m^2$and increased from 0.03 to 0.52 $W/m^2$ (from 7:00am to 12:00 noon and from 12:00 to 18:00 pm, respectively). In manual tracking system, the loss decreased from 0.4 to 0.03 $W/m^2$ and increased from 0.03 to 0.4 $W/m^2$ (from 7:00am to 12:00 noon and 12:00 noon to 18:00 pm, respectively). The higher the solar irradiation loss the lower the efficiency of the PV system (Pervaiz and Khan 2015).

As shown in Figure 26 above, the solar irradiance loss in the new manual tracking system was lower than the fixed axis solar collector loss, particularly in the early morning and late after. The loss dropped from 0.52 to 0.03 $W/m^2$and grew from 0.03 to 0.52 $W/m^2$ (starting from 7:00 am to 12: 00 noon and from noon to 18:00 pm) respectively in fixed axis collector. However, the loss dropped from 0.4 to 0.03 $W/m^2$and grew from 0.03 to 0.4 $W/m^2$ (starting from 7:00 am to 12:00 noon and from noon to 18:00 pm) respectively in fixed axis collector At 7:00 am, the fixed axis collector had a loss of 0.69 $W/m^2$, but the new manual tracking loss was just 0.54 $W/m^2$which was 23% more effective. At noon, the loss of both collectors was just 0.03$W/m^2$.

The manual tracking having a total power of 570 W were designed, manufactured assembled and position where the sun can reach from sunrise to the sunset in October, November and December 2021/22 G.C. In the new manual solar tracking system, one of the three solar panels is fixed making a 15-degree angle with the earth's surface and facing south, while the other two panels could move east and west in addition to south.

In the conventional system, fixed axis collector system, where all three panels were stationary installed at a 15-degree angle with the earth's surface and facing to only south. For both systems open circuit voltage and short circuit current recorded using digital multimeter without introducing load. The recording of voltage and current were made for each PV module. During the experiment the operating voltage ($V_{mp}$), current ($I_{mp}$) and the discharge of the pump (Q) were measured (while the pump operated) morning 6:30 to afternoon 18:30 for six consecutive days. The Voltage readings from the experiment were plotted on a graph; as illustrated in Figure 26, below.

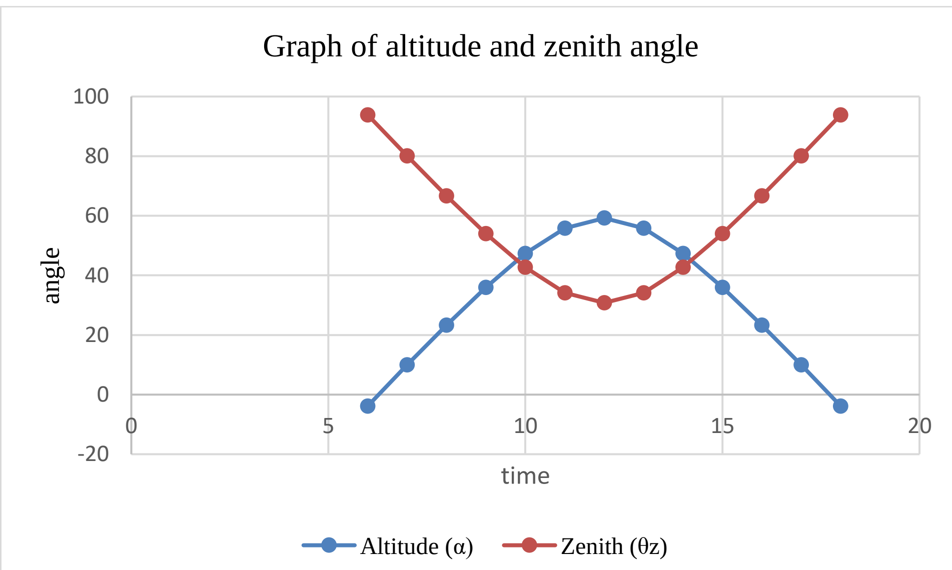



Figure 24: Graph of altitude and zenith angle

The graph in Figure 24 calculated by Equation 7&8 showed that in November 14 at solar time of 8:00 am and 16:00 pm, the altitude angle of the sun is 23.34 degree and the sun reaches its maximum altitude at solar noon, 12:00 that is $59.3^0$. The two angles (zenith and altitude) are complimentary angle each other.

### 4.1.1. Fixed axis solar collector system voltage with respect to time

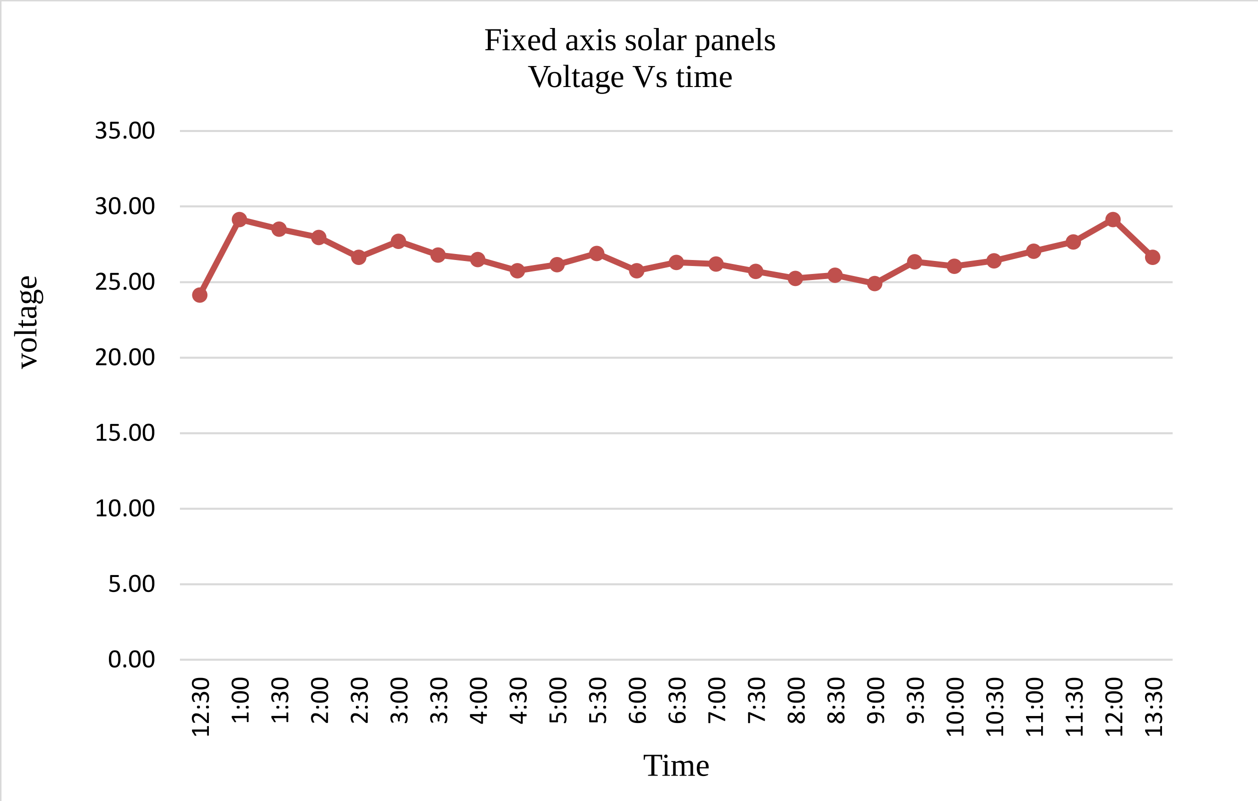



Figure 25: The voltage and time graph of fixed axis solar collector

In this orientation, in early morning at 6:30, 8:30, 10:30 and 12:30 noon, 14:30, 16:30 18:30 with two-hour interval, the voltage readings were 26 V, 28.15 V, 27.95 V, 26.65 V, 27.7 V, 26.8 V and 26.65 V respectively. The voltage increased in the early morning from sunrise 6:30 am until 7:30 am. It decreased after the sunrise to noon and gradually increased until the sunset 18:00 pm. In every instant, the voltage produced by fixed axis orientation solar collector system nearly the same throughout the day as shown in Figure 25 above. When solar radiation raise the current increased significantly while the voltage decreased slightly (Fesharaki et al. 2011).

### 4.1.2. New manual solar tracking system voltage with respect to time

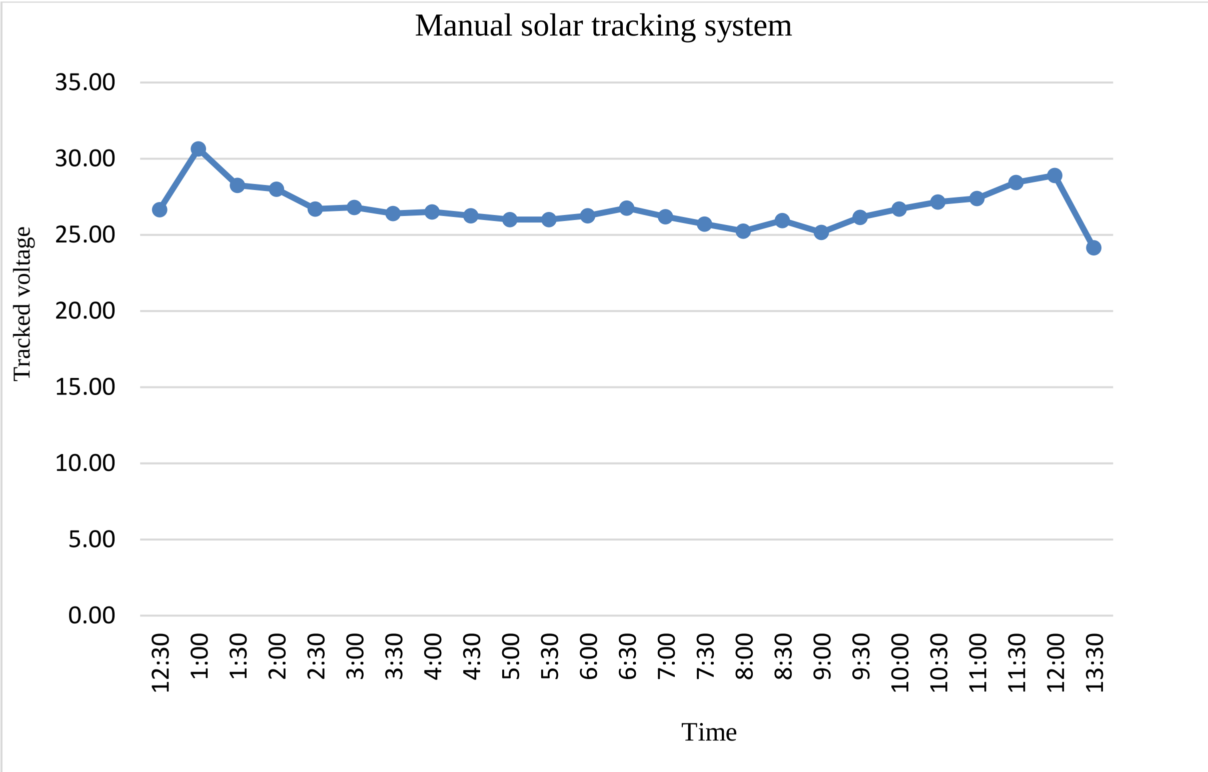



Figure 26: voltage and time graph of manual solar tracking system

According to Figure 2, the voltage reading in the manual solar tracking system at 6:30, 8:30, 10:30 and 12:30 noon, 14:30, 16:30 18:30 with two-hour intervals were 26.65 V, 28.8 V, 28.25 V, 28.0 V, 26.7 V, 26.8 V, and 26.4 V, respectively.

From the time, the sun raised at 6:30 am, until 7:30 in the morning, the voltage raised. It dropped slightly until mid-day and then gradually rose until sunset at 18:00 pm. The experiment shows that the fixed axis solar panels voltage increases in the early morning until the sunrise and operating output voltage decrease after the sunrise because of the incensement of temperature.

4.1.3. Fixed and new manual solar tracking system voltage with respect to time

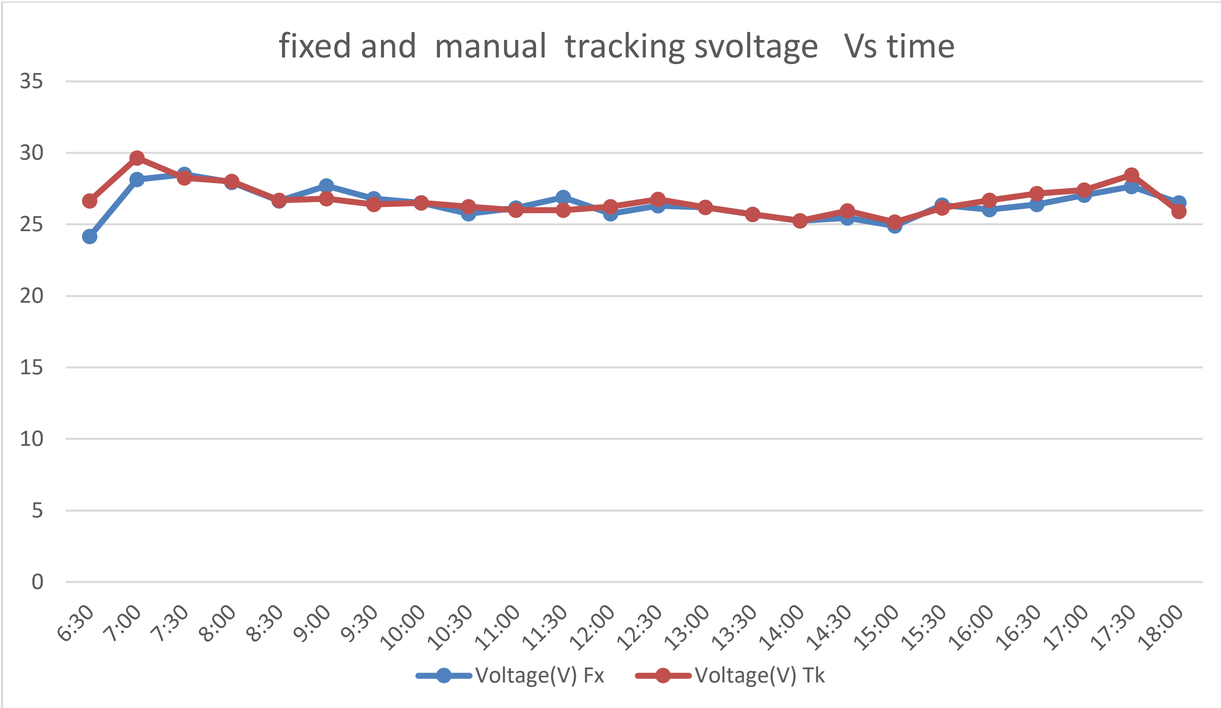



Figure 27: fixed and tracking voltage time graph

The graph in Figure 27 showed that for both solar collectors the voltage increased in the early morning up to near to 7:30 and decreased up to noon. The voltage again slightly increased starting from 7:30 am to late afternoon about 18:00 pm. Generally, the experimental result showed that, the voltage generated by a fixed axis orientation solar collector system was nearly constant (slightly decreased with temperature) throughout the sunshine hour in a day. In literature with other researchers stated the voltage marginally decreases while the current dramatically increases as sun radiation increases (Fesharaki et al. 2011).

### 4.1.4. New manual solar tracking system current with respect to time

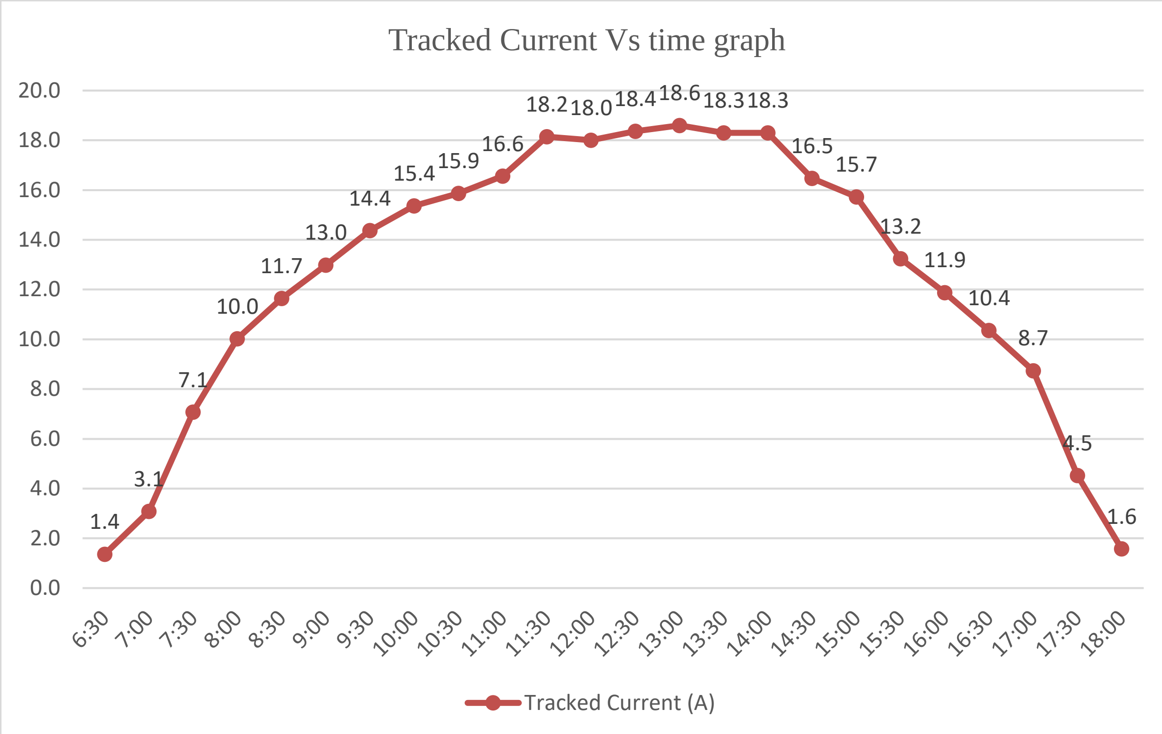



Figure 28: Tracked current versus time

As illustrated in the above Figure 28, the operating current varies with solar radiation and ambient temperature. From the experiment, operating current $I_{mp}$ of each single tracking solar module current recorded. The current increased remarkably with the increased in solar radiation, this shows that the current is highly dependent on solar radiation than the voltage. During the experiment the total current produced by the tracking system were at 6:30 am, 8:30 am, 10:30 am, 12:00 noon, 14:30 pm, 16:30 pm, 18:00 pm with a two-hour interval, the operating current obtained were 0A, 11.65A, , 15.37A, 18A 16.47A, 10.36A, 1.58 A respectively. It agreed with other reports who described that the solar radiation and temperature increased starting from the early morning to the noon and decrease from noon to sunset (Asahi, Hajjaj, and Alkoash 2022). The experimental result showed that the manual solar tracking system produced more current than the conventional solar collector did, especially in the early morning and late afternoon the detail shown in Figure 30 below.

4.1.5. Fixed solar collector system current with respect to time

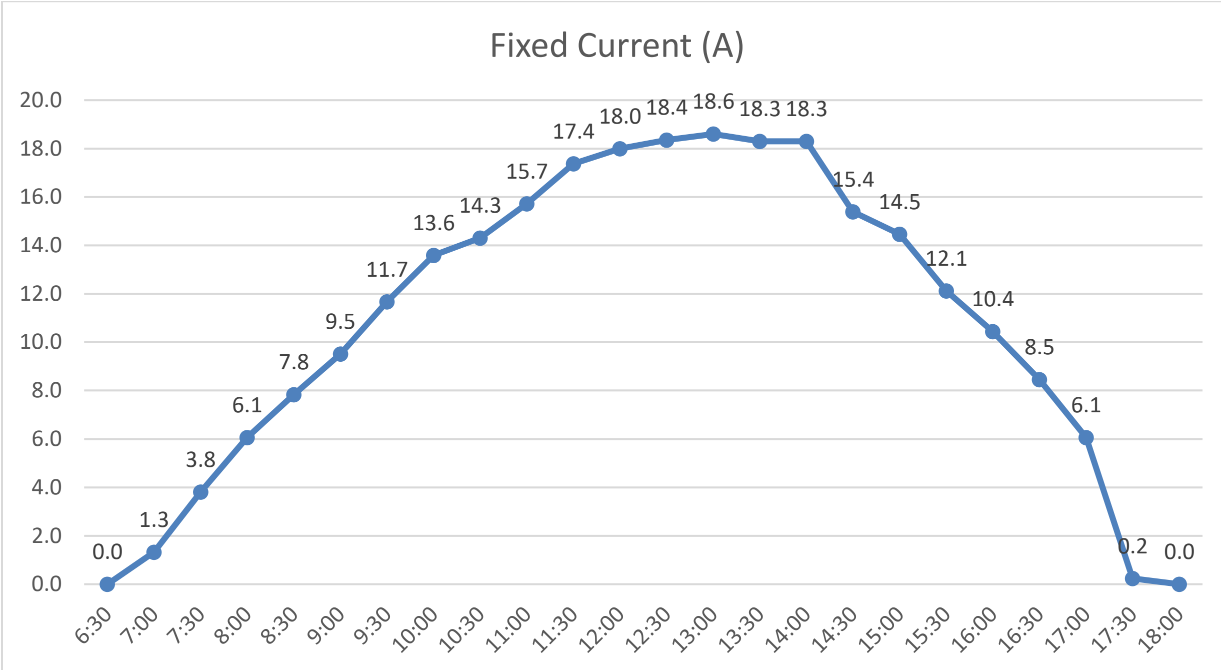



Figure 29: Fixed axis solar panel current Vs time

The current produced in each solar module of fixed axis solar collector system (at the same experimental time with tracking system) was the same, The total current was the sum of all three-module connected in parallel was (0A, 7.83A, , 13.59A, 18A 15.39A, 8.4A, 0 A) respectively as shown in Table13 below. The current produced in the early morning and late afternoon was less because of the sun radiation angle was near to parallel to the solar collector surface (the collecting performance of manual solar tracker is higher than fixed solar collector system before 11:00 am and after 15:00 pm).

Table 15: Current and voltage produced by the two system

| Time | Voltage(V) | | Current(A) | | Total Current (A) | | Power (W) | |
|---|---|---|---|---|---|---|---|---|
| Hr | Fx | Tk | Fx | Tk | Fx | Tk | Fx | Tk |
| 6:30 | 24.15 | 26.65 | 0 | 0.68 | 0 | 1.36 | 0.0 | 36.2 |
| 7:00 | 28.15 | 29.65 | 0.44 | 1.32 | 1.32 | 3.08 | 37.2 | 91.3 |
| 7:30 | 28.5 | 28.25 | 1.27 | 2.9 | 3.81 | 7.07 | 108.6 | 199.7 |
| 8:00 | 27.95 | 28 | 2.02 | 4 | 6.06 | 10.02 | 169.4 | 280.6 |
| 8:30 | 26.65 | 26.7 | 2.61 | 4.52 | 7.83 | 11.65 | 208.7 | 311.1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9:00 | 27.7 | 26.8 | 3.17 | 4.91 | 9.51 | 12.99 | 263.4 | 348.1 |
| 9:30 | 26.8 | 26.4 | 3.89 | 5.24 | 11.67 | 14.37 | 312.8 | 379.4 |
| 10:00 | 26.5 | 26.5 | 4.53 | 5.42 | 13.59 | 15.37 | 360.1 | 407.3 |
| 10:30 | 25.75 | 26.25 | 4.77 | 5.55 | 14.31 | 15.87 | 368.5 | 416.6 |
| 11:00 | 26.15 | 26 | 5.24 | 5.66 | 15.72 | 16.56 | 411.1 | 430.6 |
| 11:30 | 26.9 | 26 | 5.79 | 6.18 | 17.37 | 18.15 | 467.3 | 471.9 |
| 12:00 | 25.75 | 26.25 | 6 | 6 | 18 | 18 | 463.5 | 472.5 |
| 12:30 | 26.3 | 26.75 | 6.12 | 6.12 | 18.36 | 18.36 | 482.9 | 491.1 |
| 13:00 | 26.2 | 26.2 | 6.2 | 6.2 | 18.6 | 18.6 | 487.3 | 487.3 |
| 13:30 | 25.7 | 25.7 | 6.1 | 6.1 | 18.3 | 18.3 | 470.3 | 470.3 |
| 14:00 | 25.25 | 25.25 | 6.1 | 6.1 | 18.3 | 18.3 | 462.1 | 462.1 |
| 14:30 | 25.45 | 25.95 | 5.13 | 5.67 | 15.39 | 16.47 | 391.7 | 427.4 |
| 15:00 | 24.9 | 25.16 | 4.82 | 5.45 | 14.46 | 15.72 | 360.1 | 395.5 |
| 15:30 | 26.35 | 26.15 | 4.04 | 4.6 | 12.12 | 13.24 | 319.4 | 346.2 |
| 16:00 | 26.05 | 26.7 | 3.48 | 4.2 | 10.44 | 11.88 | 272.0 | 317.2 |
| 16:30 | 26.4 | 27.15 | 2.82 | 3.77 | 8.46 | 10.36 | 223.3 | 281.3 |
| 17:00 | 27.05 | 27.4 | 2.02 | 3.36 | 6.06 | 8.74 | 163.9 | 239.5 |
| 17:30 | 27.65 | 28.45 | 0.08 | 2.22 | 0.24 | 4.52 | 6.6 | 128.6 |
| 18:00 | 28.15 | 28.9 | 0 | 0.79 | 0 | 1.58 | 0.0 | 45.7 |
| Sum | 636.4 | 643.21 | 86.64 | 106.96 | 259.92 | 300.56 | 6809.95 | 7937.44 |
| Av. | 26.5167 | 26.8004 | 3.61 | 4.45667 | 10.83 | 12.5233 | 283.748 | 330.726 |

The solar water pump operational power generated in the tracking panel (orange line) vs fixed panel (blue line) on a bright day from 6:30 am to 18:30 pm is displayed in the aforementioned Table 14. It demonstrates that the manually tracked panel's daily average power output (7937.4W) was almost 16% higher than that of the fixed panel (6809.9W

$$\text{The efficiency increase} = \frac{7937.4\text{W} - 6809.9\text{W}}{6809.9\text{W}} \times 100 = 16\%$$

The efficiency measurement performed by recording the power delivered by the fixed PV module and manual tracking PV module with the same panel size. Hence. the purpose of improving the efficiency of the solar collector orientation through the new manual tracking system achieved.

4.1.5. Fixed and manual solar tracking system current with respect to time

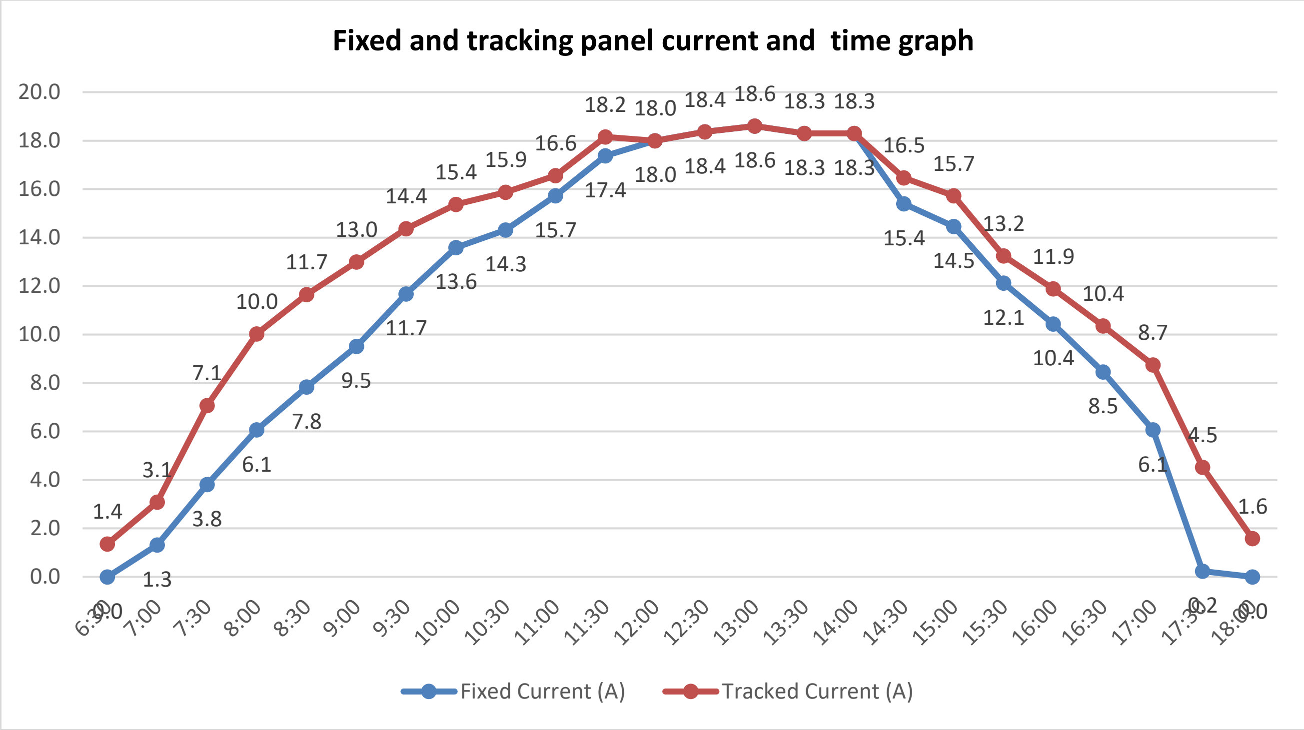



Figure 30: Fixed and tracking panel current and time graph

The above manual tracking system versus fixed axis panel current graph with respect to time shows the solar water pump operating current produced in the manual tracking system (yellow line) is greater than the current produced in fixed solar collector system (blue line) on a clear and sunny day from 12:30 am to 5:30 am. The two system nearly equal from 11:30 am to 14:30 pm and greater from 14:30 pm to 18:30 pm.

4.1.6. Fixed and manual solar tracking system power with respect to time

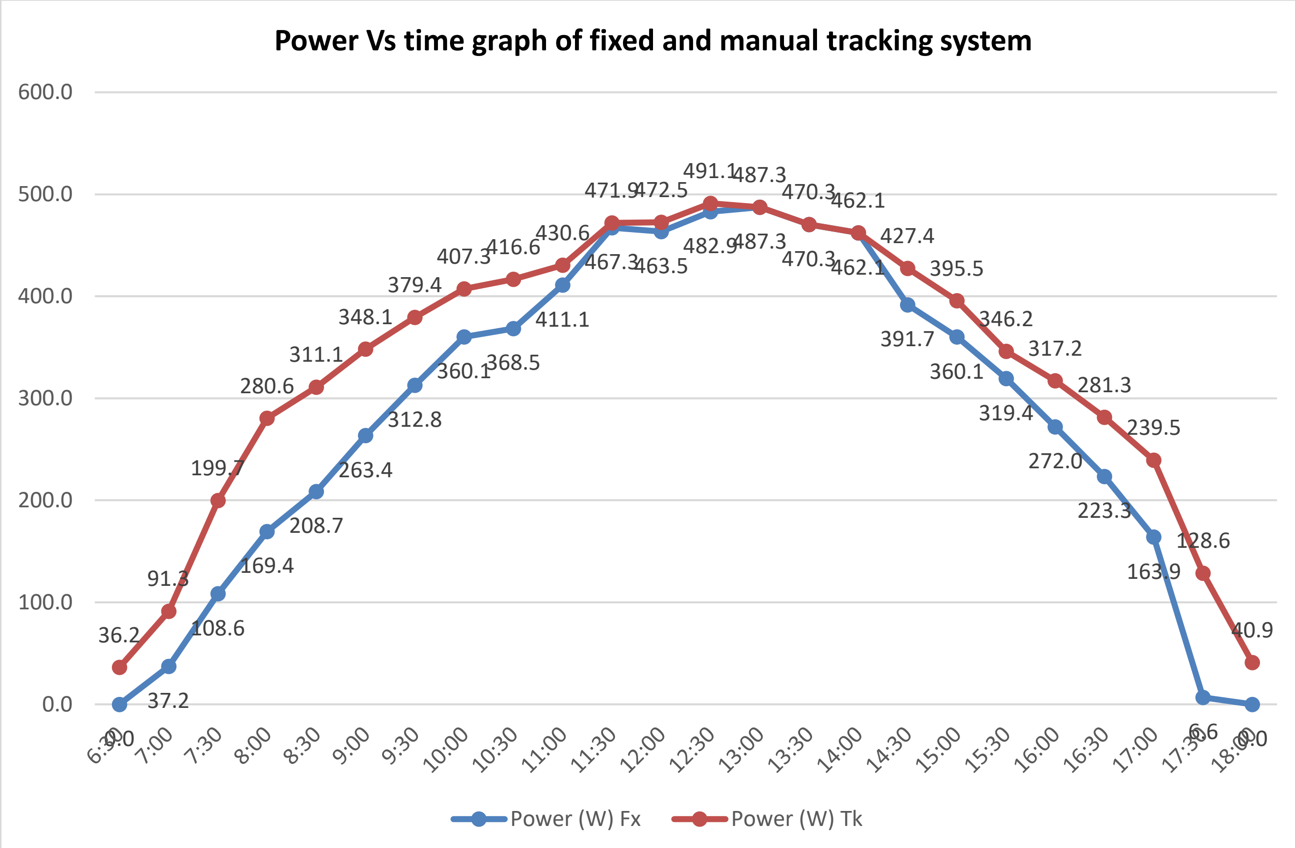



Figure 31: Fixed and manual solar tracking system power

In the experiment the performance of fixed axis solar energy collector & manual sun trucking with equal amount of system size also compared with respect to the daily power and water production as shown in appendix E Figure 36. . In manual sun tracking system (from 8:00 am-10:00 am) to fill 1000 liter it took 14 minutes or 1.1 liter per second while in fixed solar water pumping system, it took 16 minutes, 1 liter per second..

The other way of checking the performance of the collectors were measuring the current and voltage in every ten minutes of the day so that in manual sun tracking system the current started flowing earlier in the morning and stopped late in the afternoon as shown Table 13, than the fixed axis solar water pumping system. In general, on collecting of the solar power the efficiency of manual tracking much better than the conventional fixed axis collector. Hence by using the manual tracking developed in this study, better amount of water pumped out from the shallow ground water well and irrigate the onion with less cost than the conventional solar collector.system.

# CHAPTER FIVE:

# 5. CONCLUSION AND RECOMMENDATION

The required research information summarized in this chapter, along with recommendation for more study in future

## 5.1. Conclusion

This paper examines the performance of new manual solar tracking system through experimental investigation. The comparison between fixed and new manual solar tracking system for water pumping system was analyzed. The design and manufacturing of the new manual tracking system were successfully done in the way that it can collect more solar energy than the fixed axis system.

The manual solar tracking system was designed using a solid work and manufactured in Ethiopia water technology institute workshop. From the experimental investigation the effect of different angles, temperature, solar radiation, total dynamic head, flow rate were analyzed. As solar radiation increased the temperature and the current increased, while the voltage slightly decreased, however, the power increased.

The effect of solar radiation was more significant than the temperature effect in solar panel power collection. In this experimental investigation the two solar collector system (fixed and manual) were compared based on their efficiency. The result shows that the solar irradiance loss in manual tracking system reduced and the efficiency improved than the conventional solar collector. The efficiency measurement was performed by recording the power delivered by the fixed and manual tracking PV module having the same panel size.

Overall collecting of the solar power, the efficiency of manual tracking designed and used in this study much better than the conventional fixed axis collector. It is also easy to move from place to place for different purpose. Hence, by using manual tracking system tested in this study much amount of water pumped out from the shallow ground water well and used for irrigating the crops in Fogera site with less cost than the conventional solar collector. Hence the purpose of improving the efficiency of the solar collector orientation through the new manual tracking system is achieved.

## 5.2. Recommendation

The main objective of this research was achieved by the designed experimental investigation of this thesis. However, still there is a room to improve the efficiency of solar collector more and more.

- One of the three solar panel was stationary, cannot collect as the other two panels can. It is suggested to design all the panels moving in the way to track solar energy.
- During the experiment the combined system (fixed and tracking) was used due to financial constraint. It is recommended, to use two system separately to avoid errors.
- To use manual tracking for large system it may take time to move panels one by one and it could be heavy to adjust more than 35 kg. panel/s at a time. It is recommended to design simple mechanism using gear and pulley system to move many panels at a time.

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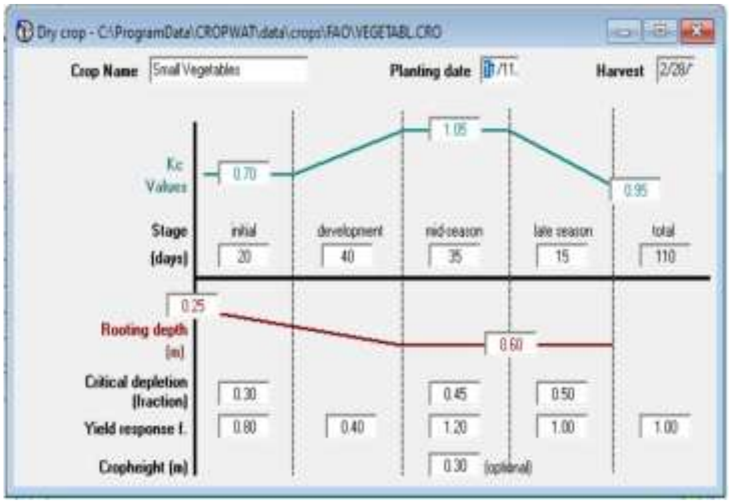
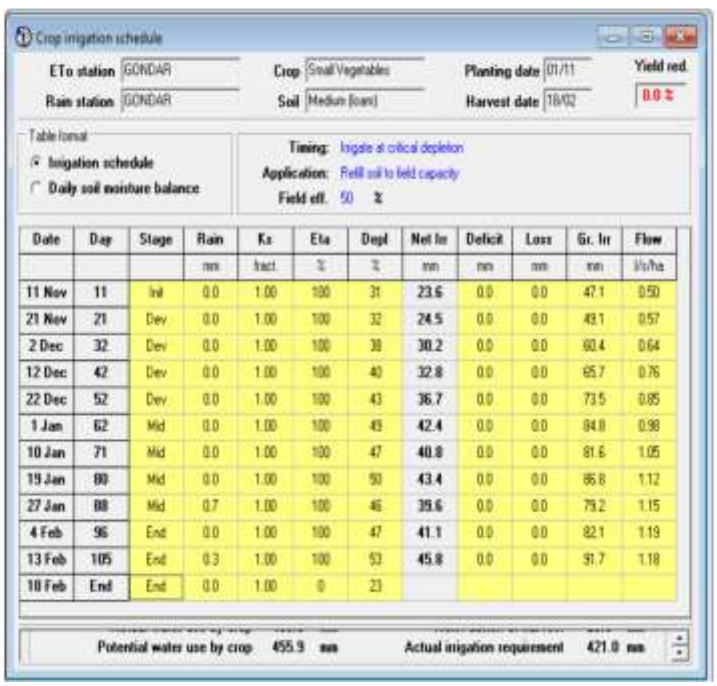
# APPENDIXES

## Appendix A




| Date | Day | Stage | Rain | Ks | Eta | Depl | Net Irr | Deficit | Loss | Gr. Irr | Flow |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mm | fract. | % | % | mm | mm | mm | mm | l/s/ha |
| 11 Nov | 11 | Init | 0.0 | 1.00 | 100 | 31 | 23.6 | 0.0 | 0.0 | 47.1 | 0.50 |
| 21 Nov | 21 | Dev | 0.0 | 1.00 | 100 | 32 | 24.5 | 0.0 | 0.0 | 49.1 | 0.57 |
| 2 Dec | 32 | Dev | 0.0 | 1.00 | 100 | 38 | 30.2 | 0.0 | 0.0 | 60.4 | 0.64 |
| 12 Dec | 42 | Dev | 0.0 | 1.00 | 100 | 40 | 32.8 | 0.0 | 0.0 | 65.7 | 0.76 |
| 22 Dec | 52 | Dev | 0.0 | 1.00 | 100 | 43 | 36.7 | 0.0 | 0.0 | 73.5 | 0.85 |
| 1 Jan | 62 | Mid | 0.0 | 1.00 | 100 | 49 | 42.4 | 0.0 | 0.0 | 84.8 | 0.98 |
| 10 Jan | 71 | Mid | 0.0 | 1.00 | 100 | 47 | 40.8 | 0.0 | 0.0 | 81.6 | 1.05 |
| 19 Jan | 80 | Mid | 0.0 | 1.00 | 100 | 50 | 43.4 | 0.0 | 0.0 | 86.8 | 1.12 |
| 27 Jan | 88 | Mid | 0.7 | 1.00 | 100 | 46 | 39.6 | 0.0 | 0.0 | 79.2 | 1.15 |
| 4 Feb | 96 | End | 0.0 | 1.00 | 100 | 47 | 41.1 | 0.0 | 0.0 | 82.1 | 1.19 |
| 13 Feb | 105 | End | 0.3 | 1.00 | 100 | 53 | 45.8 | 0.0 | 0.0 | 91.7 | 1.18 |
| 18 Feb | End | End | 0.0 | 1.00 | 0 | 23 | | | | | |

Potential water use by crop 455.9 mm    Actual irrigation requirement 421.0 mm

Figure 32: Crop water requirement by CROPWAT software

## Appendix B

# Solar Submersible Pump System for 4" wells

## System Overview

| | |
|---|---|
| Head | max. 20 m |
| Flow rate | max. 4,6 m³/h |

## Technical Data

### Controller PS2-150

- Controlling and monitoring
- Control inputs for dry running protection, remote control etc.
- Protected against reverse polarity, overload and overtemperature
- Integrated MPPT (Maximum Power Point Tracking)
- Battery operation: Integrated low voltage disconnect

| | |
|---|---|
| Power | max. 0,30 kW |
| Input voltage | max. 50 V |
| Optimum Vmp** | > 17 V |
| Motor current | max. 22 A |
| Efficiency | max. 98 % |
| Ambient temp. | -40...50 °C |
| Enclosure class | IP68 |

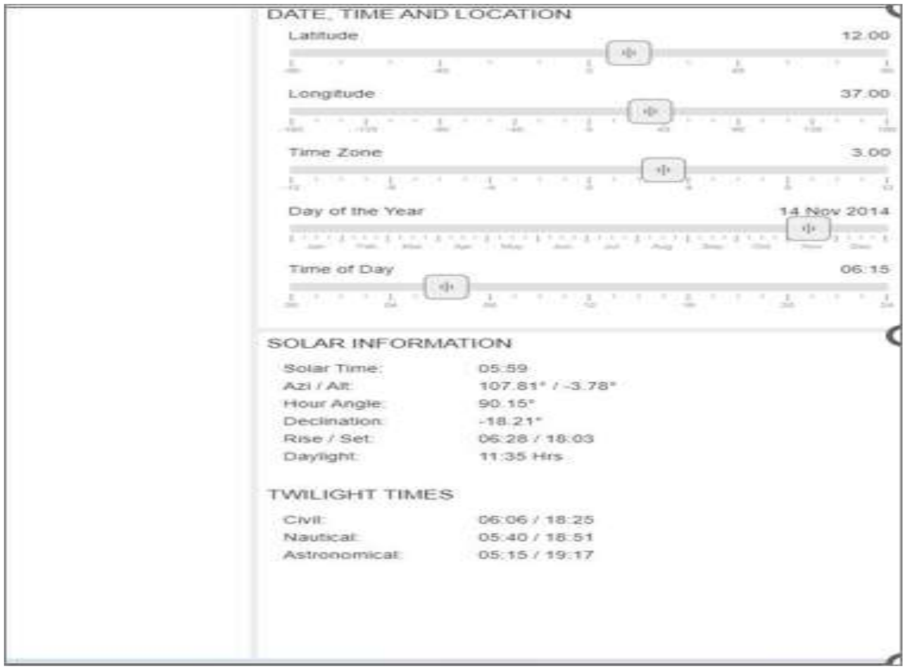
### Motor ECDRIVE 150-C

- Maintenance-free brushless DC motor
- Water filled
- Premium materials, stainless steel: AISI 304/316
- No electronics in the motor

| | |
|---|---|
| Rated power | 0,3 kW |
| Efficiency | max. 92 % |

Figure 33: Picture of the pump used

# Appendix C



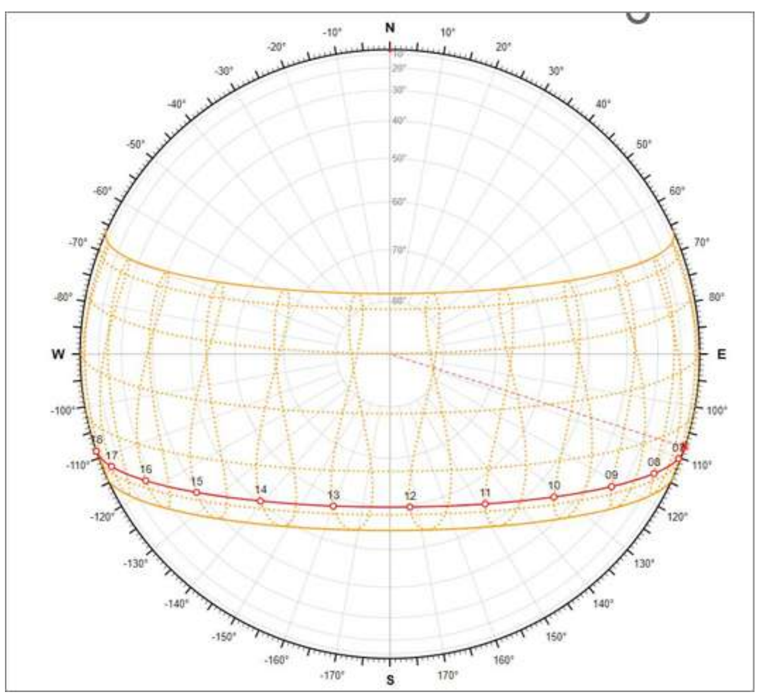




Figure 34: Actual sun path and position in line with calculation

## Apendix D

Layout of the system during the experiment

Figure 35: Photos during experiment for both systems

# Apendix E

Climate database

| | | | | |
|---|---|---|---|---|
| Country | | | Ethiopia | |
| Province/State | | | | |
| Climate data location | See map | | Gondar | |
| Latitude | | °N | 12.6 | |
| Longitude | | °E | 37.5 | Source |
| Climate zone | | 2A | Hot - Humid | NASA |
| Elevation | | m | 1,950 | NASA |
| Heating design temperature | | °C | 13 | NASA |
| Cooling design temperature | | °C | 28.8 | NASA |
| Earth temperature amplitude | | °C | 16.4 | NASA |

| Month | Air temperature | Relative humidity | Precipitation | Daily solar radiation - horizontal | Atmospheric pressure | Wind speed | Earth temperature | Heating degree-days 18 °C | Cooling degree-days 10 °C |
|---|---|---|---|---|---|---|---|---|---|
| | °C | % | mm | kWh/m²/d | kPa | m/s | °C | °C-d | °C-d |
| January | 21.1 | 37.3% | 5.39 | 6.23 | 82.7 | 3.3 | 24.6 | 0 | 345 |
| February | 22.6 | 34.2% | 4.93 | 6.61 | 82.6 | 3.4 | 27.0 | 0 | 352 |
| March | 23.4 | 40.5% | 19.64 | 6.74 | 82.5 | 3.3 | 28.0 | 0 | 415 |
| April | 22.5 | 51.5% | 38.85 | 6.86 | 82.5 | 3.2 | 26.2 | 0 | 376 |
| May | 21.3 | 63.7% | 59.86 | 6.43 | 82.7 | 3.2 | 24.1 | 0 | 351 |
| June | 19.0 | 79.2% | 97.69 | 5.91 | 82.7 | 4.0 | 20.9 | 0 | 270 |
| July | 17.9 | 81.1% | 246.54 | 5.27 | 82.7 | 3.9 | 19.1 | 3 | 246 |
| August | 17.9 | 81.3% | 225.10 | 5.28 | 82.7 | 3.3 | 19.0 | 3 | 245 |
| September | 18.8 | 71.1% | 74.46 | 5.82 | 82.7 | 2.8 | 19.8 | 0 | 264 |
| October | 20.3 | 47.4% | 62.52 | 5.99 | 82.7 | 2.4 | 21.7 | 0 | 319 |
| November | 20.6 | 39.7% | 16.06 | 6.24 | 82.7 | 3.0 | 22.6 | 0 | 317 |
| December | 20.6 | 38.0% | 5.29 | 6.02 | 82.7 | 3.2 | 23.1 | 0 | 328 |
| **Annual** | **20.5** | **55.5%** | **856.32** | **6.11** | **82.7** | **3.3** | **23.0** | **5** | **3,827** |

Figure 36: Solar radiation data from NASA

.

# Appendix F

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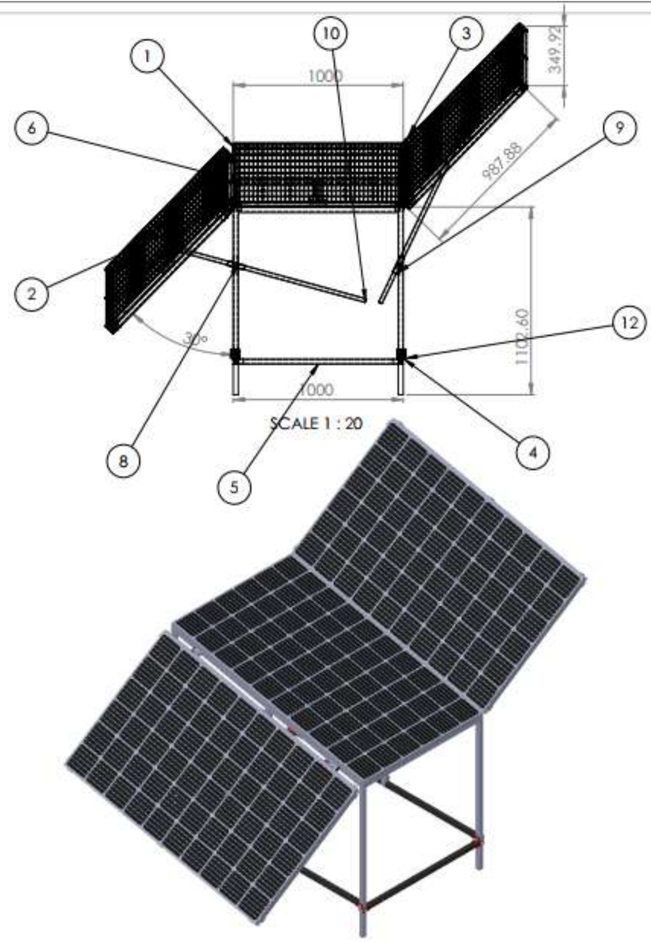
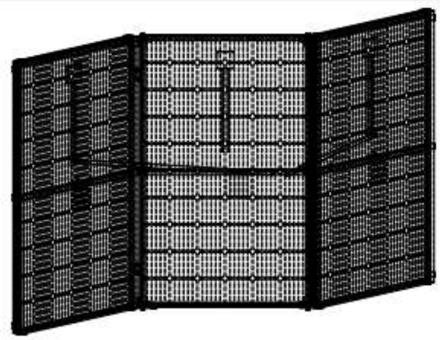
Figure 37: Waiting line to find fuel

# Apendix G




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | Solar support table | 30*3*10000 mm | 1 |
| 2 | Solar pannel | 1638*982*40 mm | 3 |
| 3 | Left solar pannel hoder | 30*3*5000 mm | 1 |
| 4 | Long conector | 30*3*1600 mm | 2 |
| 5 | Short conector | 30*3*1000 mm | 2 |
| 6 | Right solar pannel hoder | 30*3*5000 mm | 1 |
| 7 | Middle suppport | 30*3*1500 mm | 2 |
| 8 | Middle support connector | Ø30*3*100 mm | 2 |
| 9 | Handle connector | Ø30*3*100 mm | 2 |
| 10 | Handle | Ø30*3*1600 mm | 2 |
| 11 | Handle lock pin | M10*54 mm | 2 |
| 12 | Bolt M16 | M16*3 mm | 10 |

| | | | | | |
|---|---|---|---|---|---|
| AAIT<br>CENTER OF ENERGY TECHNOLOGY | | | ALL DIMENTION ARE IN MM | | |
| | | | PART NAME:<br>ASSEMBLY DRAWING | | |
| | NAME | DATE | MATERIAL: | | |
| DRAWN | T/MARYAM GOCHEM | OCTOBER,2022 | DWG NO. | | A3 |
| CHK'D | Dr. EBRAHIM TILAHUN | OCTOBER,2022 | SCALE 1:20 | SHEET 1/1 | |

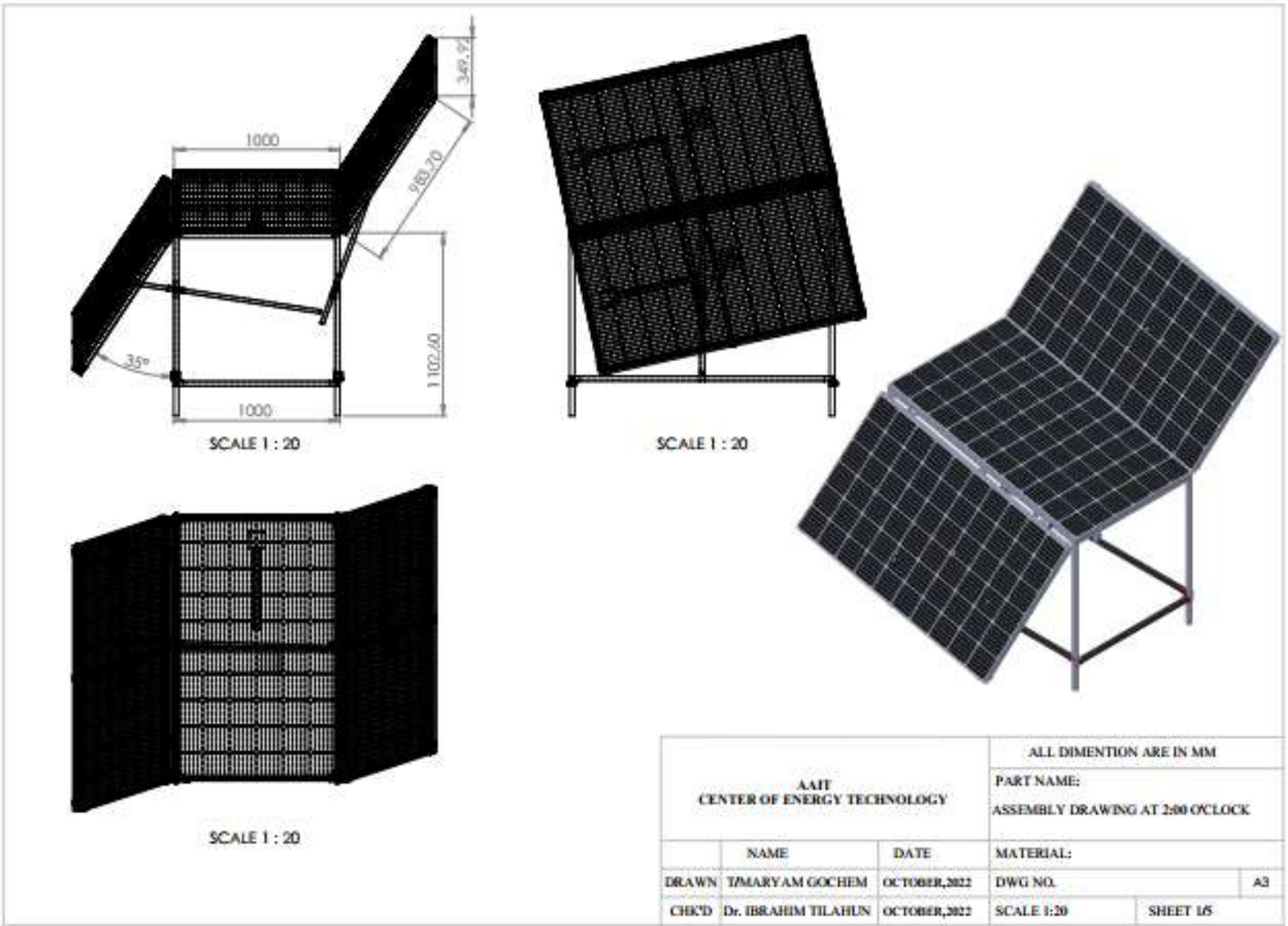



Figure 38: Assembly drawing of $35^0$ PV orientation

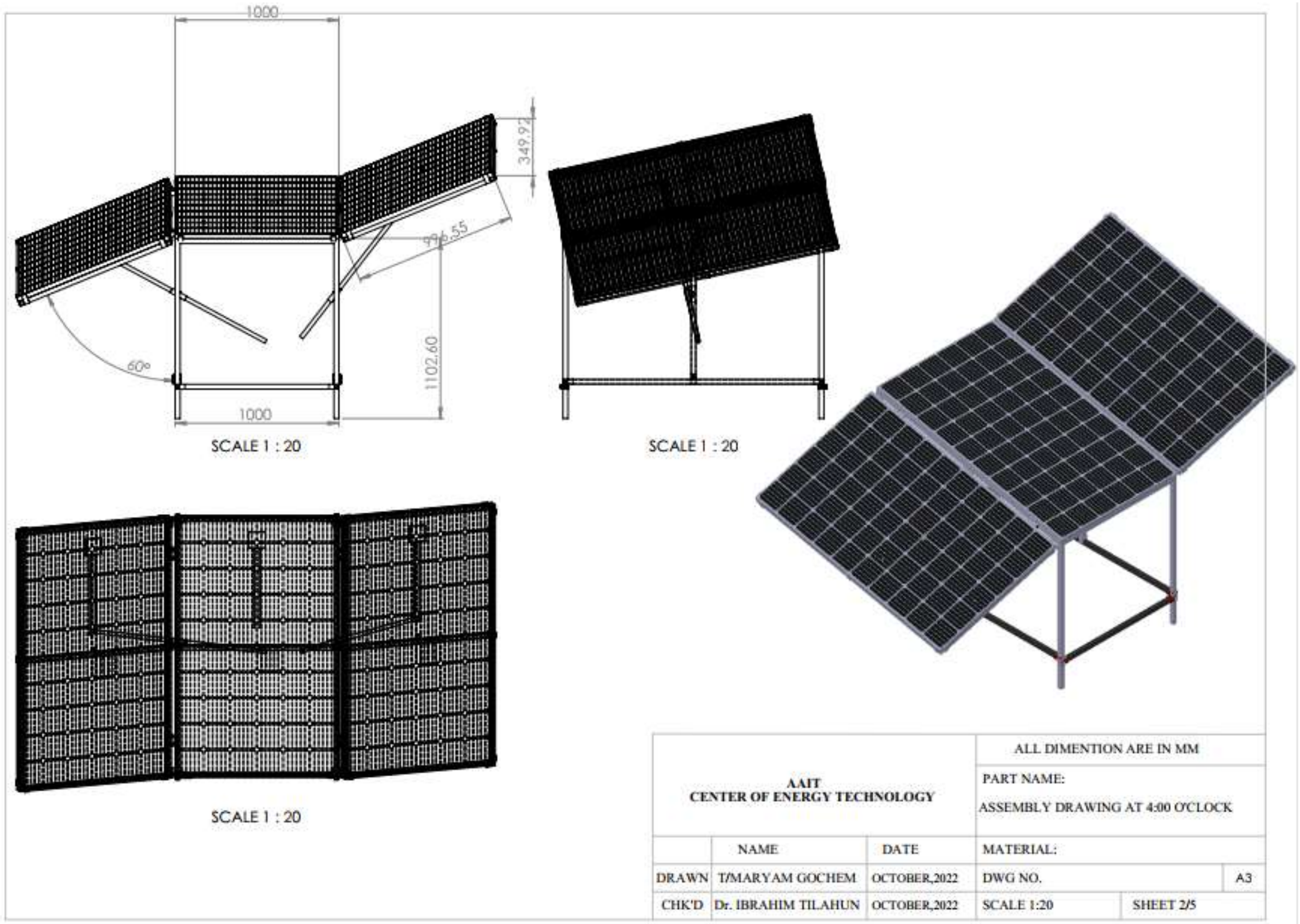



Figure 39: Assembly drawing of $60^0$ PV orientation

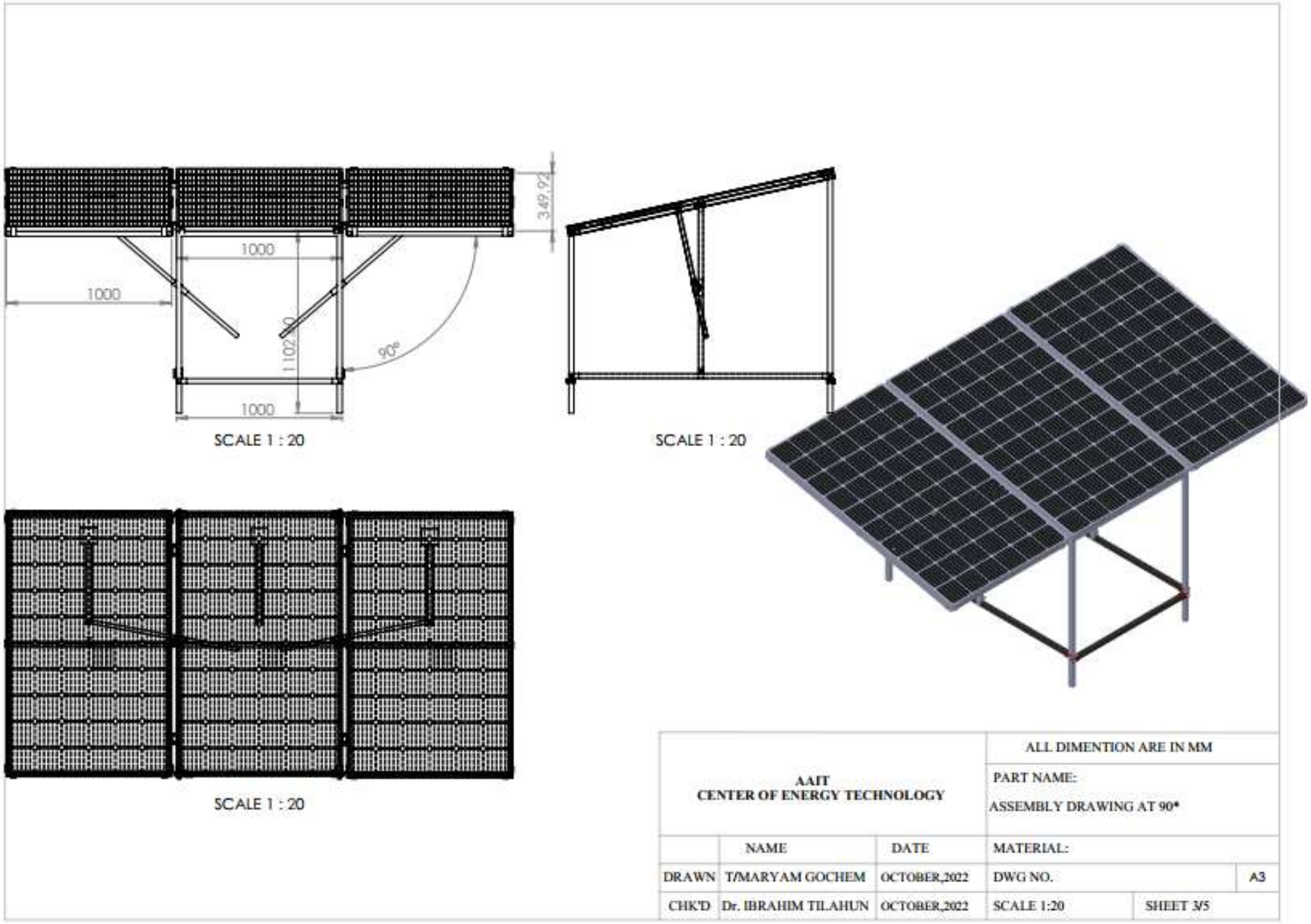
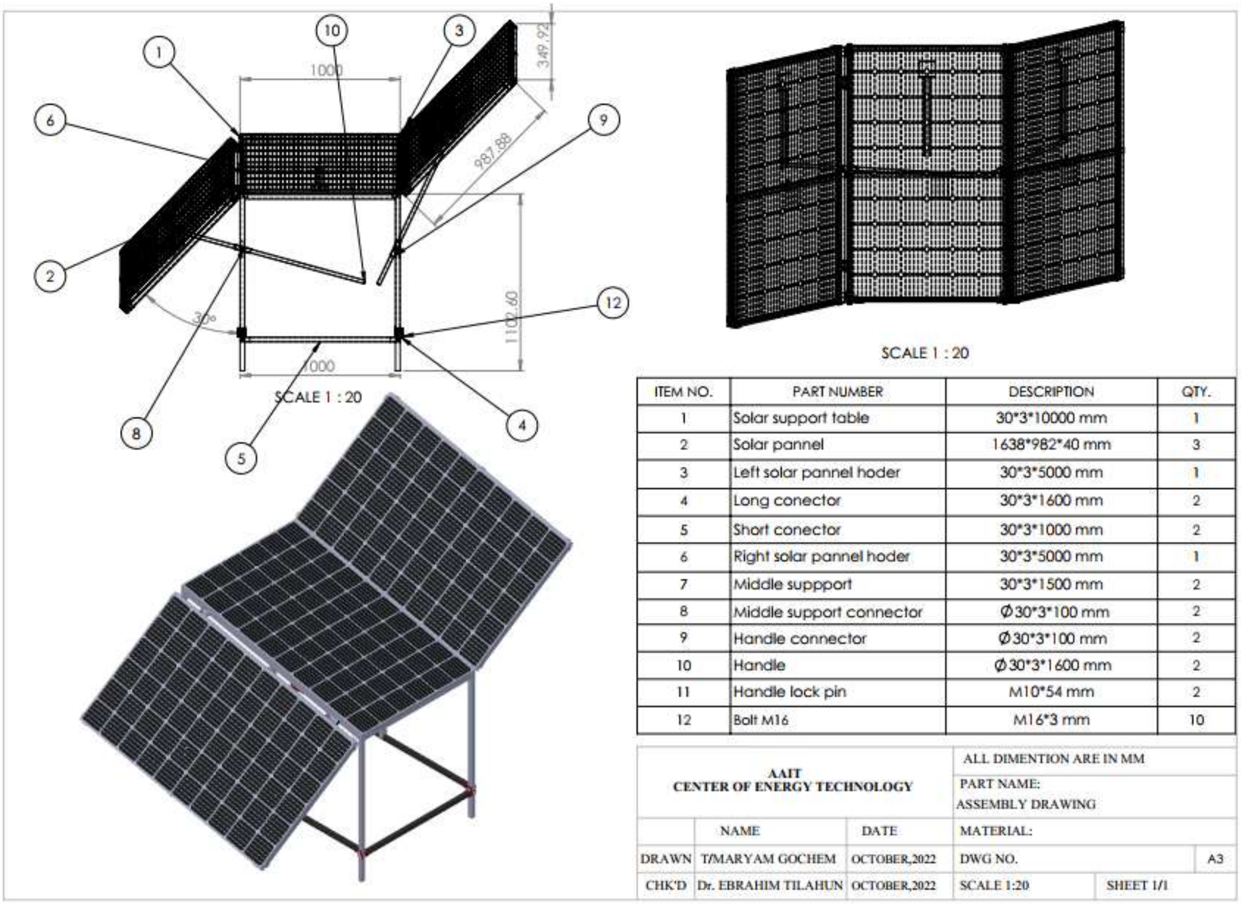



Figure 40: Assembly drawing of $90^0$ PV orientation




| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | Solar support table | 30*3*10000 mm | 1 |
| 2 | Solar pannel | 1638*982*40 mm | 3 |
| 3 | Left solar pannel hoder | 30*3*5000 mm | 1 |
| 4 | Long conector | 30*3*1600 mm | 2 |
| 5 | Short conector | 30*3*1000 mm | 2 |
| 6 | Right solar pannel hoder | 30*3*5000 mm | 1 |
| 7 | Middle suppport | 30*3*1500 mm | 2 |
| 8 | Middle support connector | Ø30*3*100 mm | 2 |
| 9 | Handle connector | Ø30*3*100 mm | 2 |
| 10 | Handle | Ø30*3*1600 mm | 2 |
| 11 | Handle lock pin | M10*54 mm | 2 |
| 12 | Bolt M16 | M16*3 mm | 10 |

| | | | | |
|---|---|---|---|---|
| AAIT<br>CENTER OF ENERGY TECHNOLOGY | | | ALL DIMENTION ARE IN MM<br>PART NAME:<br>ASSEMBLY DRAWING | |
| | NAME | DATE | MATERIAL: | |
| DRAWN | T/MARYAM GOCHEM | OCTOBER,2022 | DWG NO. | A3 |
| CHK'D | Dr. EBRAHIM TILAHUN | OCTOBER,2022 | SCALE 1:20 | SHEET 1/1 |

Figure 41: General assembly drawing