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EVALUATING THE PERFORMANCE AND EFFICIENCY OF SOLAR POWER WATER PUMPING SYSTEM

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BAHIR DAR UNIVERSITY

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BAHIR DAR ENERGY CENTER

GRADUATE PROGRAM IN SUSTAINABLE ENERGY ENGINEERING

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Bahir Dar, Ethiopia

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A thesis submitted to the School of Research and Graduate Studies of Bahir Dar Institute of Technology, Bahir Dar University in partial fulfillment of the requirements for the degree of Master of Science in Sustainable Energy Engineering.

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September, 2017

DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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Date of submission: 03/01/2010 E.C.

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ABSTRACT

This research work describes the performance evaluation and design of solar pv water pumping system by taking a case study at kolella kebele having 0.9 kW motor with 1000W (4 panels of each 250W) have been used for discharge up to 59 m water head. The system efficiency is evaluated by measuring and calculating different factors of solar pump performance and comparing the result with the designed capacity of the solar pumping system. The efficiency of the solar panel due to the variation of irradiation is reduced by 2.035% from the designed working capacity at 1000 W/m^2 radiation level. The efficiency of the solar panel due to the generated panel temperature is reduced by 0.755% at 1000 $W/m^2$and 60 ^{0}c from the recommended design temperature of 25 ^{0}c. The fill factor value was calculated to be 0.7906, 0.7888, 0.784 and 0.7806 at 1000 w/m^2, 800 W/m^2, 500 W/m^2 and 200 W/m^2 radiation levels respectively. The submersible pump efficiency is loosed by 3.14 % from its designed capacity, totally the solar water pumping system installed at kolella kebele is reduced its efficiency by 5.96%.

The effects of dust also has a great influence on the performance of solar PV water pumping system and by comparing the efficiency of panel at dust were available and after removing dust from panel, the efficiency is reduced by 1.496%. The calculated value of total water demand of the community is 157,200 liter per day, but the measured value that the community still uses from this system is about 16,528 liter/day. The performance of the solar pumping system is good and enough sufficient for the current users of the community but for the whole society of kolella kebele it does not efficient so, due to this reason there were the new design of solar pv water pumping system.

The results of the design for the whole community are total hydraulic water requirement is 10,538.8 watt (10.5388 kW), Required electrical energy is 55.8 kwh (11.13 kW), Most much module size to require system is 170 Watt, Number of modules connected in series is 10 modules, Number of modules string in parallel is 8 modules, Total cost of the system is 2,529,950.00 ETB, Cost of pumping by solar pv system is 12.59 ETB/m^3, Percent of cost saving compared to diesel pump is 67%. From the result pumping water by using solar PV system is much feasible than the diesel consume pumps.

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Nomenclature

I	Output current.
I_{ph}	Photo current.
I_{sat}	Diode reverses saturation voltage.
V_o	Output Voltage.
R_s	Series resistance (Representing voltage loss on the way to external connectors).
R_p	Parallel resistance (Representing leakage currents).
k	Boltzmann‘s constant.
q	Charge on electron.
N_s	Number of cells in series.
N	Ideality factor.
T_{cell}	Solar panel temperature.
B_h	Beam solar radiation components on horizontal surface.
D_h	Diffuse solar radiation components on horizontal surface.
β	PV array tilt angle.
R_b	Beam radiation tilt factor.
L	Latitude angle of Toshka.
h	Solar hour angle.
t	Local time, hours.
δ	Solar declination angle.
N	Day number starting from January first.
G_{oh}	Extraterrestrial irradiance on a horizontal surface.
G_{sc}	Solar constant (1367 W/m2).
r_d	Ratio of diffuse irradiance on a horizontal surface.

D_h	Daily diffuse irradiation.
G_{oh}^{-}	Daily extraterrestrial solar radiation on a horizontal surface.
FF	Fill Factor.
V_{mpp}	Maximum power point voltage.
I_{mpp}	Maximum power point current.
V_{oc}	Open circuit voltage.
I_{sc}	Short circuit current.
η	Efficiency.
P_{in}	Input power.
$\eta_{designed}$	Designed pump efficiency.
ρ	Density of water.
H	Total Head.
Q	Flow rate.
g	Gravity.

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CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Energy is a critical foundation for economic growth and social progress. As economy advances and human society requires more energy, the lack of fossil energy and its influence effect on the environment has given rise to the ever-serious contradiction among energy providing, environmental protection and economic development. Renewable energy with the availability of its renewability and minimum pollution will grow to be an effective and practical choice to guarantee the future development of the world. As Ethiopia is one of the developing countries in the world.

The photovoltaic energy has been employed around the whole world in most recent years as the power source for pumping water during the day, making water available for domestic and irrigation uses. In addition the advantage of using water pumps which powered by PV system including low maintenance, ease of installation, reliability and matching the powers generated and the water usage needs. Disadvantages of solar water pumping systems are low performance and low energy efficiency [2].

There is a solar powered water pumping system installed at Amhara region, Mecha woreda, Kollella kebele used to delivering water from the ground for household and school, the entire project is done by Bahir Dar University. This proposal also provides the factors that influence the performance and efficiency of this solar water pumping systems, with a specific focus to Kollella kebele. A solar water pumping system is typically constructed of photovoltaic (PV) module(s), controller(s), water and/or energy storage, and motor/-pump combination [9].

When analyzing the performance and efficiency of a solar water pumping system, the environmental conditions must be considered. For this project, a selection of the factors with the largest impact on the performance and efficiency of the system will be investigated. The most important environmental factors are solar irradiation, meteorological data, air mass and indirect radiation. The factors influencing the performance and efficiency of the PV panel are the type of PV material used, the tilt angle and azimuth, the characteristics of the PV cell, and PV array arrangement (for example, how many modules in the panel are in series and how many panels in the array are in parallel).[5]

The performance of solar pump depends on the water requirement, size of water storage tank, head (m) by which water has to be lifted, water to be pumped (m^3), PV array virtual energy (kWh), Energy at pump (kWh), unused PV energy (kWh), pump efficiency (%), and system efficiency (%) and diurnal variation in pump pressure due to change in irradiance and pressure compensation [1]. Besides the degradation of PV panels is one of the important parameters which affect the performance of a solar pump.

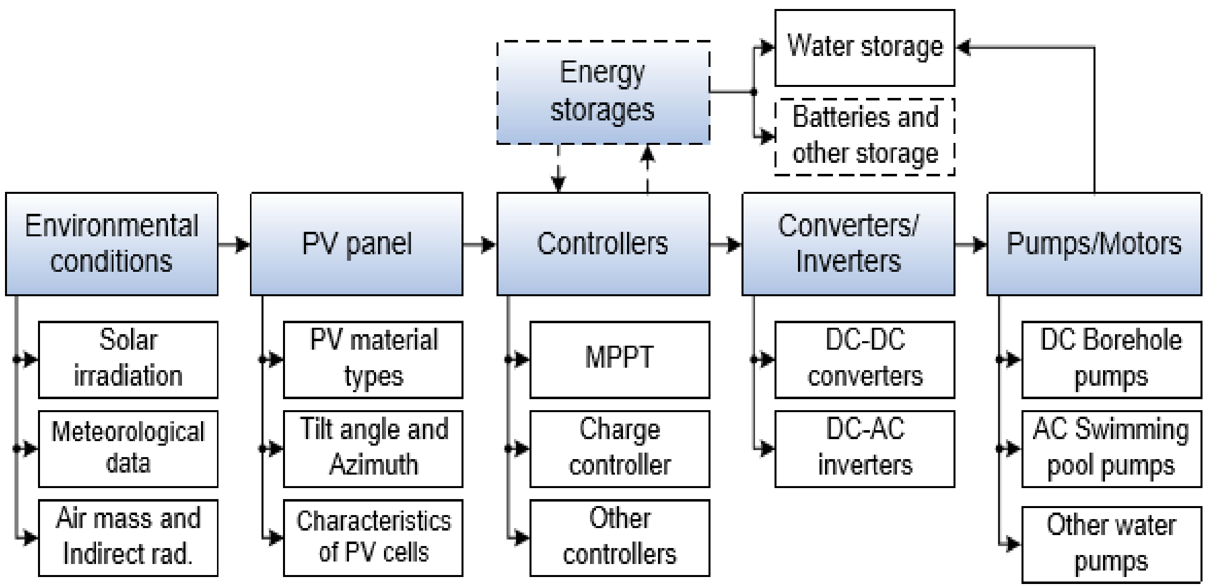


Figure 1.1: Factors influencing the performance and efficiency of solar powered water pump

1.1.1. History of the case study

The performance of a photovoltaic (PV) array based water pumping system situated at Kollella kebele, amhara region, Ethiopia will be studied. Kollela keblele is located at south west part of amhara region. A 0.9kw motor with 1000W (4 panels of each 250W) have been used for discharge up to 59 m water head. The maximum discharge logged 0.8 liter/second between 11AM to 2PM at PV power output between 0.6kw to 0.8kw and the system is operating approximately 8 hours in the winter season.

The water source of the solar water pumping system is spring water and it is located at 11^{0}28'33.69'' N; 37^{0}08'45.80'' E and its elevation is 1897 meter (6224 ft). first there is a dam formed by a concrete having a capacity to hold 15 m^3 of water the recovery rate of the water is 3.5 m^3/s, and after it fully charged water will move to the collection chamber having a capacity of 2 m^3 of water and the pump is install inclined at this collection chamber and the over flow of water is allowed to mix with the bypass river water. The full day discharge has found around 20,000 liter and it is used for public school and domestic consumption for four villages. But currently the two villages are used water from the system. It is revealed that PV array based water pumping system is suitable and feasible option for off-grid and drip irrigation system like the interior area of Kollella, where clear sky days are around more than 250 in a year.

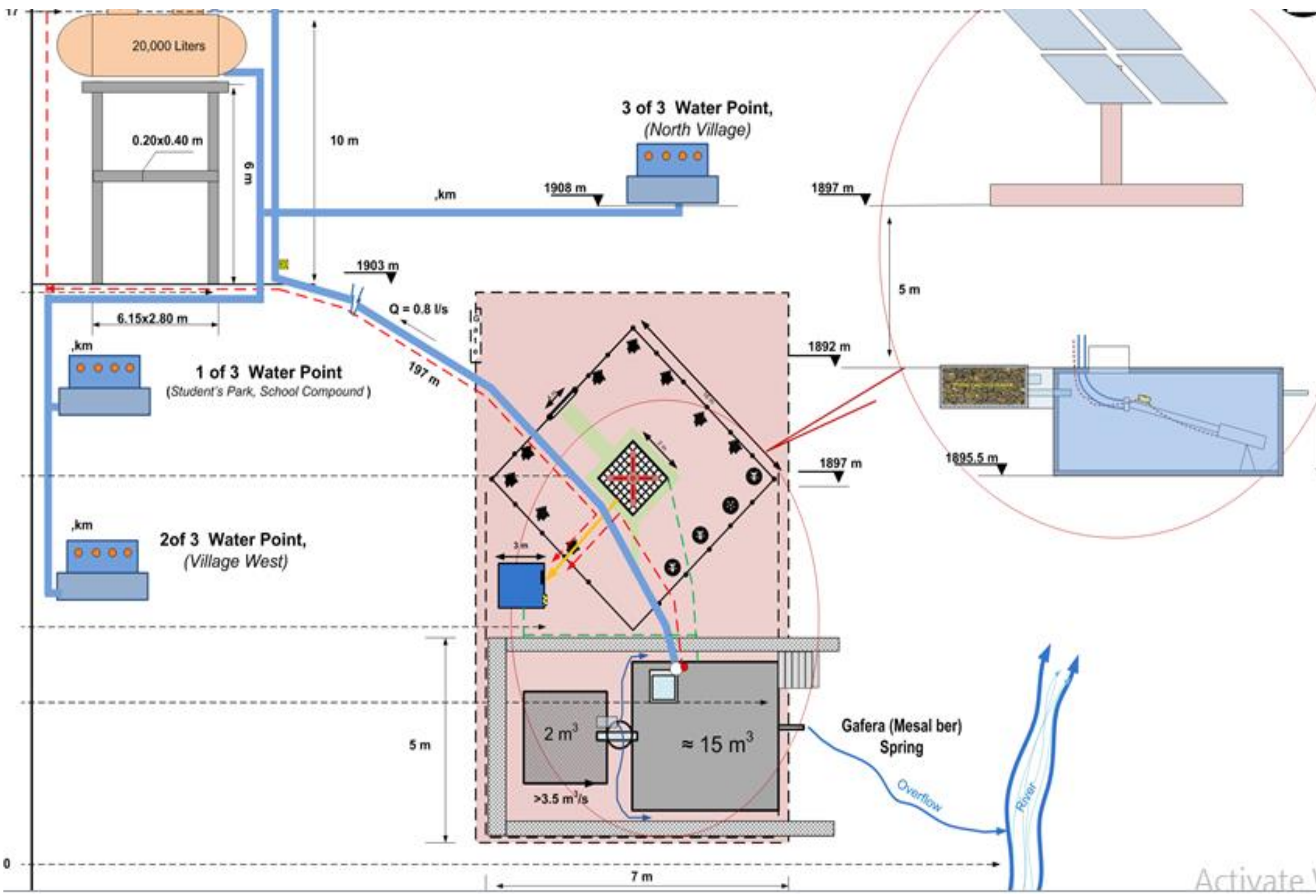


Figure 1.2: Schmaic diagram of solar powerd pv pumping system

Source: Dr.Tassew Tadiwos (Ass. Professor) presentation document of Collaboration in Wind and Solar- powered Pumping system for drinkable and irrigable water delivery at rural areas to the benefit of both partners and local communities.

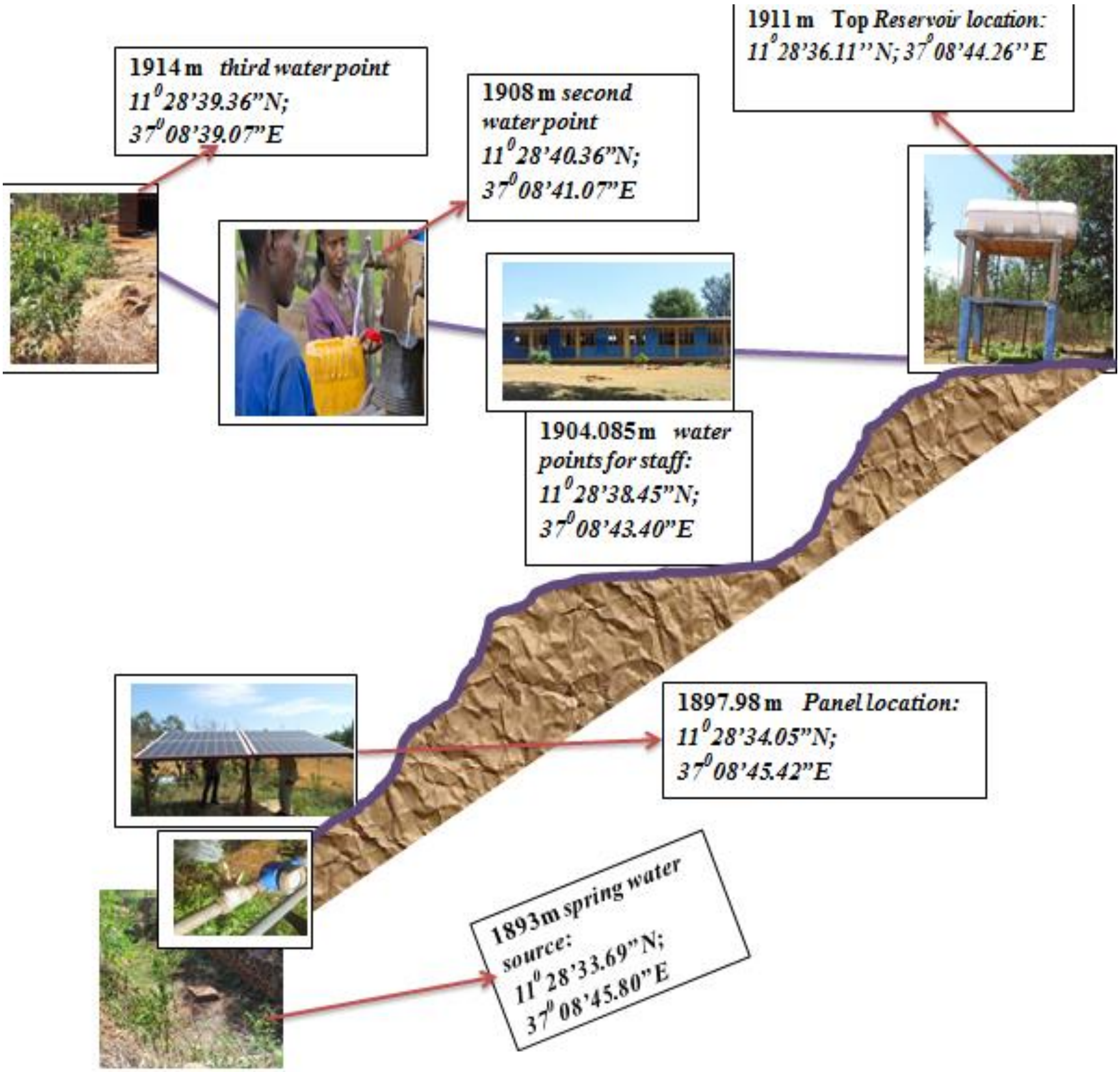


Figure 1.3: Schmaic diagram of solar powerd pv pumping system with its location

1.2. Statement of problem

There are some solar water pumping systems are installed in Ethiopia, but there is limitation of detail study conducted on the performance and efficiency of such systems after installation.

About 15 solar powered water pumping system were installed at different parts of amhara region, Ethiopia, but 5 out of those systems are non-functional because of the following causes;

- Sheading of the pv panels,
- Lack of communication between the community and the technology.
- Operators are not capable on the motor control system and operating the entire system.
- Reducing the pump efficiency because of unbalancing of the recovered water and the pump discharge rate.
- Using water label guard out of the system.
- Installed the panel without considering the wind direction.
- Peoples are broking the panels by throwing stone.

By taking a solar powered water pumping system installed at Amhara region, Mecha woreda, Kollella kebele, which is intended for public school and domestic consumption, this project, will evaluate the detail performance and efficiency of such type of solar powered water pumping system.

Those problems are allowing me to think, evaluating the performance and efficiency the installed solar powered domestic water pumping system effectively.

Research Questions

1. How does the performance of a solar PV pump system at different radiation and panel temperature level since installation?
2. Does the system delivering amount fits the water demand of the community?
3. How does the efficiency of the system with and without removing of the dust from the photovoltaic panel.

Hypothesis

This research work intends to evaluate the performance of the solar pv pump system after installation and develop a new designing of solar photovoltaic pump system as per the water demand of the community.

1.3. Objectives

1.3.1 General objective

The main objective of this thesis is to evaluating the performance and efficiency of solar power water pumping system installed in amhara region by taking a case study at kollella kebele.

1.3.2. Specific objective

- Determining the total water demand of the community.
- Determining the performance factor parameters.
    - ✓ To measure the available solar radiation energy,
    - ✓ To measure PV array power output, d.c.-voltage and current,
    - ✓ To measure the water flow rate at different variation of solar radiation.
    - ✓ To measure the temperature of solar panel.
- Evaluating the current performance and efficiency comparing with the pre designed capacity.

1.5. Significance of the Research

The need for evaluating the performance and efficiency of utilization of water and energy resources has become a vital issue during the last decade, and will become even more essential in the future. For this reason, it is relevant to study these types of systems that can improve life quality of many communities, and encouraging different studys to construct this system at different places of the country.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

A similar system for irrigation was addressed in Bangladesh. [10]. In this case, a DC solar water pump is built and experimented to observe the results with a direct connection from a solar array. The use of batteries and inverter is avoided in this study, which allows a lower cost and maintenance. The system used twelve 75W solar panels to provide DC power supply for the water pumping system. In overall and according to the test results, the system provide satisfactory performance on water pumping, being mentioned as a good alternative considering the energy problems in Bangladesh.

Also in India, and for the same purpose [12] reported that SPWPSs are more suitable for low and medium depth water pumping in areas where grid connection is not available. Moreover, it was concluded that SPWPSs are economical in operation only during peak sunshine hours. However, this study was made in 1994, and since that time, solar technology evolved significantly.

In a similar investigation, in Egypt [13] investigated the performance of SPWPSs using batteries for sprinkling and dripping irrigation systems. It has been concluded that SPWPSs can be used efficiently for water pumping in agriculture sectors. The cost of the water pumped by photovoltaic systems is much less than the cost of water pumped using conventional grid connection and diesel generators. They also concluded that SPWPSs also improve the quality of life and promote socio-economic development in rural areas.

For domestic water pumping, [19] assessed the performance of SPWPSs both theoretically and experimentally. The system consists of a photovoltaic generator, a DC-DC converter, a DC-AC inverter, s submersed type motor-pump and a storage tank. It has been reported that the values of solar radiation will affect the global efficiency of the pump. The maximum performance of the pump was reached during the middle of the day. However, the performance of the system was degraded due to meteorological parameters such as the solar intensity, the ambient temperature, the wind velocity and the relative humidity. They also confirmed that the theoretical simulation results are close to the experimentally predicted results with acceptable errors.

A performance investigation of SPWPSs for remote locations of the United States has been conducted [20]. The conclusion was that SPWPSs have a good performance in terms of productivity, reliability, and cost effectiveness. SPWPSs could considerably reduce CO2 emissions over their 25-year life compared to conventional grid connected or diesel powered systems. Additionally, [21] presented the opportunities and challenges of SPWPSs. They suggested that the economy and the reliability of these systems make them more feasible and economical in rural locations facing a shortage of electricity. SPWPSs have been proven to be a technically and economically feasible option also in developed nations such as the USA, Germany and Australia.

In another work, [22] experimentally studied the performance of a1.14kW SPWPS using an 860W centrifugal pump, together with a simulation model for validating the experimental results. They suggest that the overall efficiency of the SPWPS can be improved by good system design and load matching. The storage tank was introduced to improve the stability of SPWPS. In related work, a time dependent SPWPS model consisting of a photovoltaic array, a battery, a storage water tank, a DC motor and a centrifugal pump was developed [23]. It has been reported that a storage water tank improves the stability of the pumping operation. The fraction of power supplied by the battery is stored in the form of the gravitational energy of water, which proves that both the battery and the water storage tank increase the operation stability of SPWPSs.

This project will be done by measuring the whole factors of influencing the performance of the system at the same time interval, when the radiation varies the rest factors also varied due to this method it is possible to know the detail performance of the system after some years later but the above related works are done during installation for commissioning purpose.

2.2. Solar Energy

The source of all solar energy is the sun and all life on the earth depends on solar energy. Knowledge of the quantity and quality of solar energy available at a specific location is of prime importance for the design of any solar energy system. Although the solar radiation (insolation) is relatively constant outside the earth's atmosphere, local climate influences can cause wide variations in available insolation on the earth's surface from site to site. In addition, the relative motion of the sun with respect to the earth will allow surfaces with different orientations to intercept different amounts of solar energy [23].

The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9m and is 1.5×10^{11}m from the earth, on the average. The earth revolves around the sun every 365.25 days in an elliptical orbit, with a mean earth-sun distance of 1.496×10^{11}m (92.9×10^6miles) defined as one astronomical unit (1 AU). This plane of orbit is called the ecliptic plane. The earth's orbit reaches a maximum distance from the sun, or aphelion, of 1.52×10^{11}m (94.4×10^6miles) on about the 3rd of July. The minimum earth-sun distance, the perihelion, occurs on about January 2nd, when the earth is 1.47×10^{11}m (91.3×10^6miles) from the sun [34].

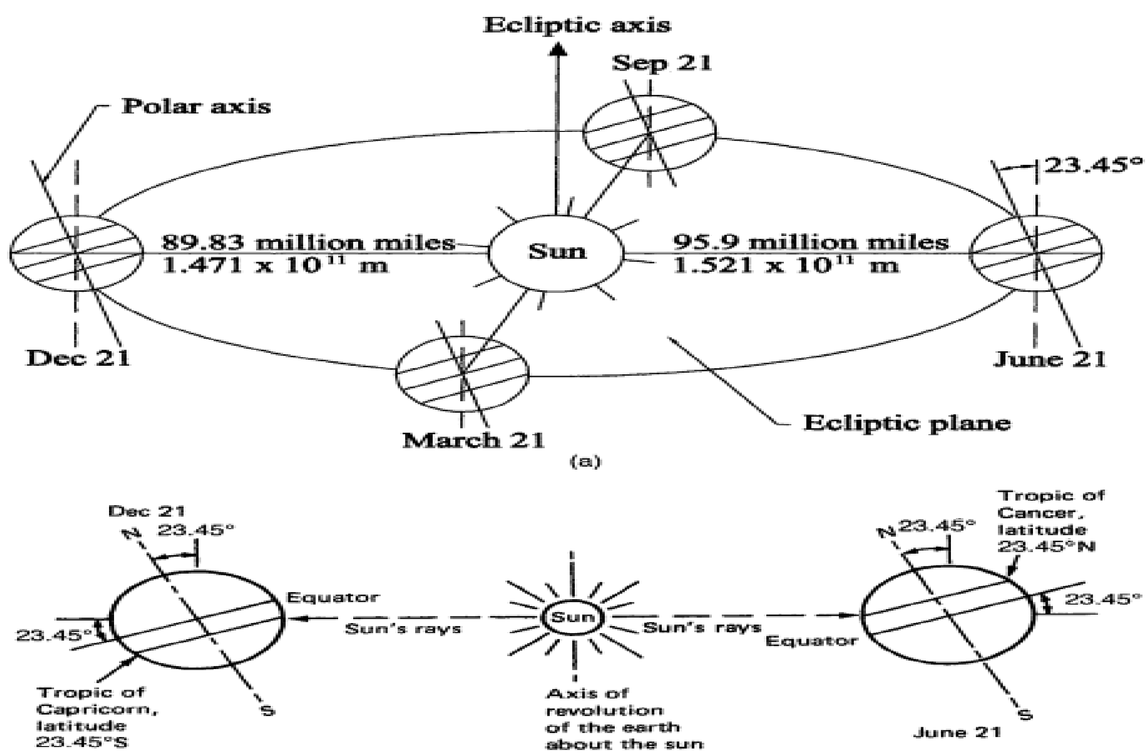


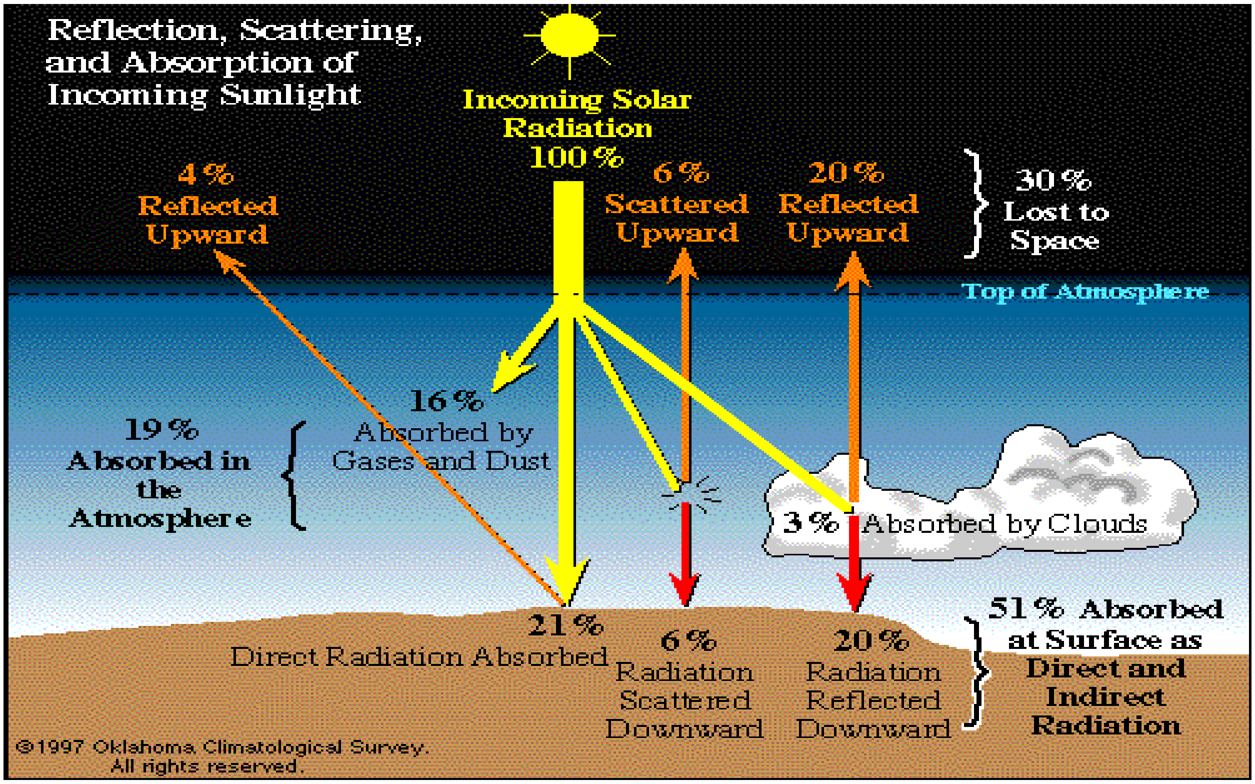
Figure 2.1: (a) Motion of earth about the sun. (b) Location of tropics. Note that the sun is so far from the earth that all the rays of the sun may be considered as parallel to one another when they reach the earth. (40)

Solar energy will provide an ever-increasing fraction of our future energy requirement. Although sunlight or solar radiation is abundant and renewable, it is diffuse. The temperature from this diffuse source is sufficient to provide domestic hot water or home heating, but much higher temperature is necessary to replace fossil fuels for production of electricity or other industrial applications. Thus solar radiation must be collected entreated to produce this elevated temperature; it must also be collected and moved to the point of use. The use of solar energy to cook food presents a viable alternative to the use of fuel wood, kerosene, and other fuels [34] [35].

2.3. Potential of Solar Energy and Its Range of Applications

Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy is used, it will be one of the most important supplies of energy. Energy comes to the earth from the sun. Solar energy keeps the temperature of the earth above that in colder space, and causes current in the atmosphere and in the ocean, and the rain-cycle, and generates photosynthesis in plants [33] [34].

The solar power at the earth's atmosphere is 10^{17} watts, whereas the solar power on earth's surface is 10^{16}watts. The total world-wide power demand of all needs of human activities is 10^{13}watts. Therefore, the sun can give 1000 times more power than what we need. If we can use 5% of this energy, it will be 50 times what the world will require. Attempts have been made to utilize energy in raising steam which may be used in driving the prime movers for the purpose of generation of electrical energy. However on account of large space required, uncertainty of availability of energy at constant rate due to clouds, winds, mist etc. there is limited application of this source in the generation of power.



Solar Radiation Budget (to Earth)

Now a days the drawbacks as pointed out that the energy cannot be stored and it is a dilute form of energy etc. are out dated arguments, since the energy can be stored by producing hydrogen, or by storing in other mechanical or electrical thermal storage devices, or it can be stored in containers of chemicals called phase changing solutions. These solutions store large quantities of heat in a relatively small volume [34].

The facts speak in favor of solar energy, that world's reserves of coal, oil and gas will be exhausted within a few decades. Nuclear energy involves considerable hazards and nuclear fusion has not yet overcome all the problems of even fundamental research, compared with these technologies, the feasibility of which is still uncertain and contested [37].

2.4. Solar Radiation

The design and sizing of the PV pumping system depend mainly on the solar radiation since the produced power depends on its value. The global solar radiation intensity on the PV array tilted surface, *Gc* can be calculated. [34] (Neglecting the reflection component) as,

$$Gc = R_b\ B_h + \cos^2\left(\frac{\beta}{2}\right) D_h \text{ --------------------------- } (2.1)$$

R_b is the beam radiation tilt factor given by,

$$R_b = \frac{\cos(L-\beta)\cos\delta\cos h + \sin(L-\beta)\sin\delta}{\cos L\cos\delta\sin h + \sin L\sin\delta} \text{ ---------------- } (2.2)$$

Where, L is the latitude angle of Toshka, L = 23.45^0 N.

h is the solar hour angle,

$$h = (12-t) * 15^0 \text{ ------------------------------- } (2.3)$$

δ is the solar declination angle defined by,

$$\delta = 23.5 \sin [360/365 *(N + 2840) \text{ ------------------- } (2.4)$$

And   N is the day number starting from January first.

The total solar radiation intensity on a horizontal surface G_h is obtained from the clear sky model as,

$$G_h = k_{td}\ G_{oh} \text{ -------------------------------- } (2.5)$$

Where, G_{oh} is the extraterrestrial irradiance on a horizontal surface given by as,

$$G_{oh} = G_{sc}\,\varepsilon\,(\cos L \cos\delta \cos h + \sin L \sin\delta) \text{ ---------------- } (2.6)$$

Where $\varepsilon = [1+0.033 \cos\left(\frac{2\pi N}{365}\right)]$ ---------------------- (2.7)

And *Gsc* is the solar constant (1367 W/m2).

The daily average clearness index obtained from as a function of N by the polynomial,

$$k_{td} = 4.5753^{-9}\ N^3 - 4.2009^{-6}\ N^2 + 0.0009185\ N + 0.66893 \ ----------(2.8)$$

The ratio, r_d of diffuse irradiance on a horizontal surface, D_h to the daily diffuse irradiation, D_h $^-$can be estimated as follows. [41]

$$r_d = \frac{Dh}{Dh\,.} = \frac{Goh}{Goh}.\ -------------------------(2.9)$$

G_{oh}^- is the daily extraterrestrial solar radiation on a horizontal surface, obtained by integrating equation over the day. D_h can be obtained in terms k_{td} as,

$$\overline{D}_h = F_d\,\overline{G}_h$$

Where,

$$F_d = 1.88 - 2.272\,k_{td} + 9.473\,k_{td}^2 + 21.856\,k_{td}^3 + 14.648\,k_{td}^4 \qquad = 0.99 \quad if \quad k_{td} \leq 0.17 \quad -(2.10)$$

2.5. Solar PV overall system

The overall solar PV pump system is constructed from solar photovoltaic pv panel, motor control, submersible dc pump and water storage tank.

2.5.1. Photovoltaic Array

Photovoltaic Arrays essentially consist of a number of internal silicon based photovoltaic cells combined in series and in parallel, depending on the voltage or current requirements. These cells are used to convert solar energy into electricity. [3] This occurs when the photovoltaic cells are exposed to solar energy causing the cells electrons to drift which, in turn, produces an electric current. This current varies with the size of individual cells and the light intensity [2]. Photovoltaic cells, or solar cells as they are more commonly referred to, are available commercially in a number of different semiconductor materials. The most common materials are mono-crystalline silicon, polycrystalline silicon, amorphous silicon and copper-indium selenide (CIS). These technologies consist of p-n junction diodes capable of generating electricity from light sources and usually have efficiencies of 6% - 20% in commercial use. [3]

A photovoltaic array is comprised of one or more PV modules made of PV cells wired together in series and/or in parallel to produce a specific voltage and current respectively under a given level of irradiance. Each cell of the module has two or more layers of semiconductor material which produces direct current upon exposure to sunlight. These layers are either made of the crystalline or thin film [4]. Crystalline is generally made of silicon whereas thin film is made of metal and several metals are used for the purpose.

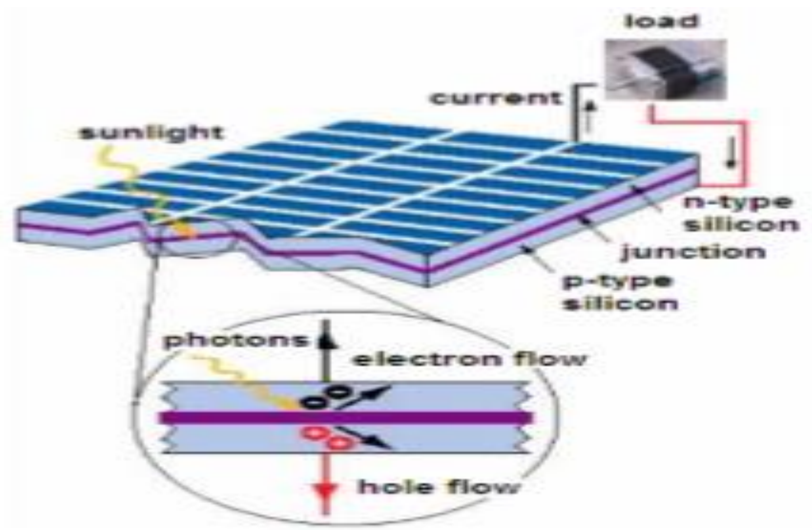


Figure 2.2: A schematic of the layers of a typical PV cell. [29]

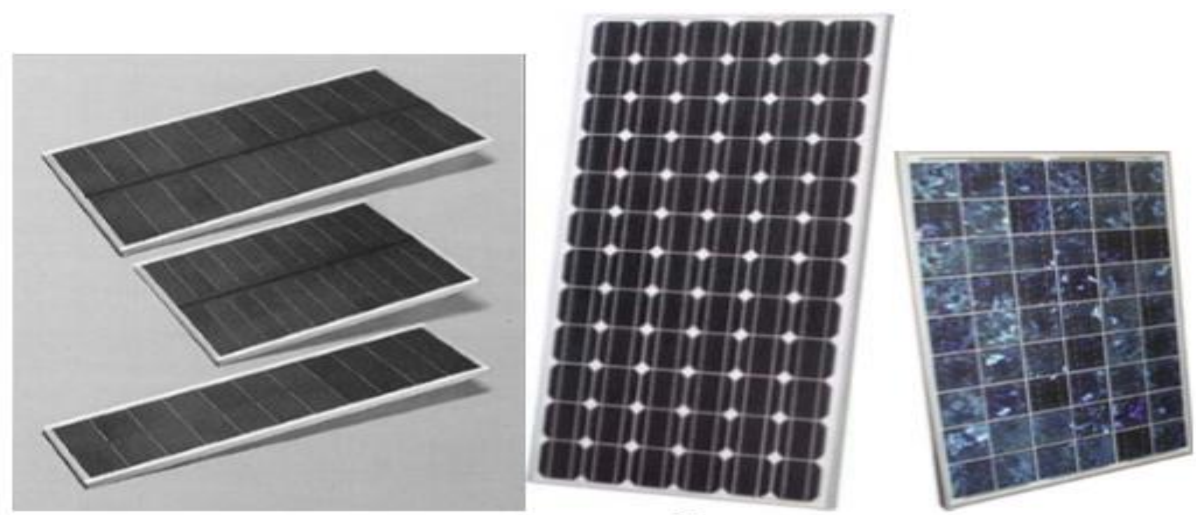


Figure 2.3: diagram of solar modules.

Crystalline modules are more efficient (12% to 15%) as compared to the thin film (3% to 9%) in terms of power production. Furthermore, there are three types of crystalline modules: amorphous, polycrystalline and mono-crystalline. Mono crystalline panels are the most efficient and amorphous silicon type is the least efficient. [4]

The performance of a solar cell is usually evaluated by representing it as an electrical equivalent one diode model shown (figure 2.3), in which the diode current is the current generated by an inactive solar cell (at dark times) and series resistance represents the resistance inside as well as in between the cells. The voltage and current produced by a PV array depends upon the connection pattern of the cells and modules respectively. Power produced by the PV array is a product of voltage and current. [6]

2.5.2. Equivalent Circuit of PV Cell

The equivalent circuit of a PV cell is demonstrated below and Derived from Kirchhoff‘s first law (also referred to as Kirchhoff‘s current law), the output current is given by

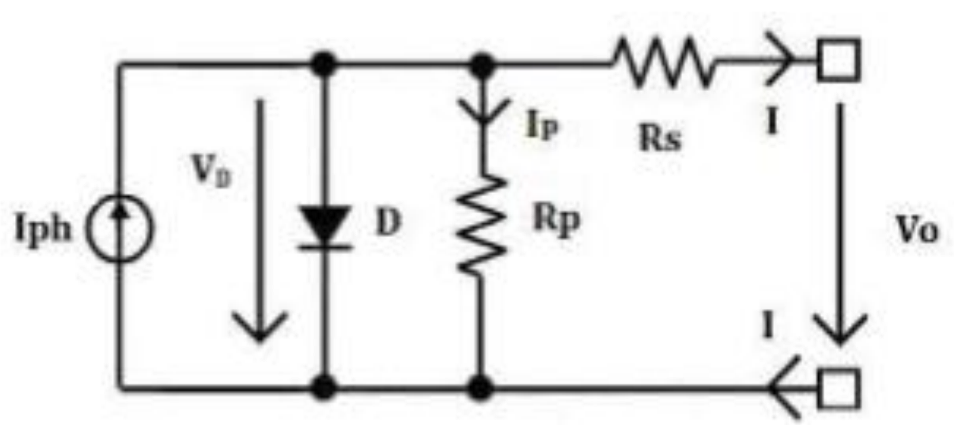


Figure 2.4: Equivalent circuit of a PV cell

$$I = I_{ph} - I_D - I_p \text{ -------------------------- } (2.11)$$

$$I = I_{ph} - I_{sat} . (exp \frac{(q .(V0+I.Rs))}{(n .K .Tcell .Ns)} - 1) - \frac{V0+I .Rs}{Rp} \text{ ------------- } (2.12)$$

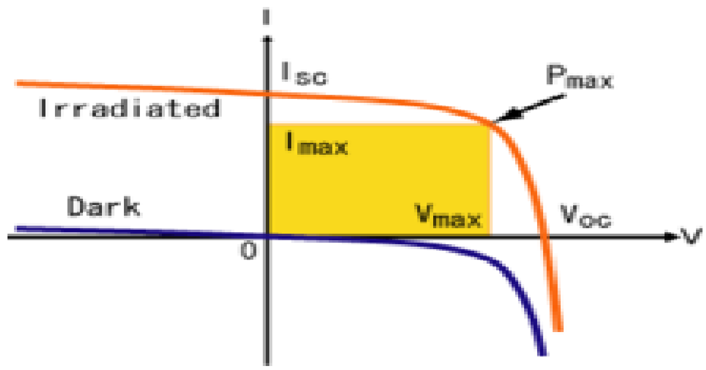


Figure 2.5: Shows the IV-curve of a solar cell both under irradiated and dark conditions. The shaded area shows the maximum power operating region.

2.5.3. Parameters of Solar Cell

2.5.3.1. Short Circuit Current (Isc): The current is maximum when the two terminals are directly connected with each other and the voltage is zero. The current in this case is called short circuit current. The short-circuit current is due to the generation and collection of light generated carriers. [5]

2.5.3.2. Open Circuit Voltage (Voc): When the cell is not connected to any load there is no current flowing and the voltage across the PV cell reaches its maximum. This is called open circuit voltage. When load is connected to the PV cell current flows through the circuit and the voltage goes down.

$$V_{oc} = \frac{K\,T}{q}\,ln\,(\frac{I}{I0} + 1) \sim \frac{K\,T}{q}\;ln\,(\frac{I}{I0}) ------------------ (2.13)$$

2.5.3.3. Fill Factor (FF): The FF is defined as the maximum power from actual solar cell to the maximum power from ideal solar cell. As time goes the PV curve degrades. It is essential to check quality of cell periodically. Quality of cell is determined by fill factor. For a good panel FF is in between 0.7 to 0.8 while for bad panel it may be 0.4.[5]

$$FF = \frac{Vmpp\;Impp}{Voc\;Isc} ---------------------------- (2.14)$$

2.5.3.4. Efficiency (η): Efficiency is defined as ratio of energy output from solar cell to input energy from sun.

$\eta = Max\ cell\ power / \ Incident\ light\ intensity$

$$\eta = \frac{Vm\ Im}{Pin} ------------------------ \quad (2.15)$$

2.5.4. Factors affecting on PV cell generation

2.5.4.1. Effects of PV technology types

Many types of PV cells are available today. This section gives details on the types of the PV cells that are currently in the manufacturing, research and development stage.

Monocrystalline silicon cells:

These cells are made from pure monocrystalline silicon. In these cells, the silicon has a single continuous crystal lattice structure with almost no defects or impurities. The main advantage of monocrystalline cells is their high efficiency, which is typically around 15%. The disadvantage of these cells is that a complicated manufacturing process is required to produce monocrystalline silicon, which results in slightly higher costs than those of other technologies [25]. Crystalline silicon cell technology is well established and the PV modules have long lifetimes (20 years or more).

Multicrystalline silicon cells:

A less expensive material, multicrystalline silicon, by passes the expensive and energy-intensive crystal growth process. Multicrystalline cells are produced using numerous grains of monocrystalline silicon. In the manufacturing process, molten multicrystalline silicon is cast into ingots, which are subsequently cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones because of the simpler manufacturing process required. They are, however, slightly less efficient, with average efficiencies being around 12% [27, 25].

Amorphous silicon cells:

Generally, the main difference between these cells and the previous ones mentioned above is that, instead of the crystalline structure, amorphous silicon cells are composed of silicon atoms in a thin homogenous layer. Additionally, amorphous silicon absorbs light more effectively than crystalline silicon, which leads to thinner cells, also known as a thin film PV technology. Thin film solar has approximately 15% market share; the other 85%

is crystalline silicon [25]. The greatest advantage of these cells is that amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible. Their disadvantage is the low efficiency, which is on the order of 6%.

Other types of cells:

In addition to the above types, a number of other promising materials, such as CdTe and copper-indium selenide (CuInSe), are used today for PV cells. The main trends today concern the use of polymer and organic PV cells. The attraction of these technologies is that they potentially offer fast production at low cost in comparison to crystalline silicon technologies, yet they typically have lower efficiencies (around 4%), and despite the demonstration of operational lifetimes and dark stabilities under inert conditions for thousands of hours, they suffer from stability and degradation problems [27]. Each semiconducting material has its own properties which make it more or less suitable for use in a PV cell. One of these properties is the so-called band gap, which is the energy gap an electron must cross in order to be promoted from the valence band to the conduction band [25]. In the literature studies, it has been shown that silicon, with its band gap of 1.12 ev, is not optimal. Materials with band gaps nearer to 1.5 ev, such as GaAs and CdTe, have higher theoretical efficiencies. As mentioned above, a single-material PV cell can convert only about 15% of the available energy to useful electrical power. To improve this performance, multiple cells with different band gaps, which are more complex and therefore more expensive, can be used. These are called multi-junction PVs. particularly; a triple-junction PV produced recently achieved a remarkable 40% efficiency. This PV consists of three layers of PV material placed one atop the other. Each of the three materials captures a separate portion of the solar spectrum and the objective is to capture as much of the solar spectrum as possible. These are much more expensive than other silicon PV cells, but their efficiency offsets their high cost, and in concentrating systems, a small area of these cells is required. Another way to increase the effectiveness of PVs according to their technology is to concentrate sunlight on small, highly efficient PV cells using inexpensive reflective material, lenses, or mirrors. These are known as concentrating photovoltaic (CPVs). Today, the technology takes up a very small portion of the solar industry; however, it is expected that the CPV industry will soon take up a larger share of the solar market as technology improves and cost comes down [27].

2.5.4.2. Effects of Ambient Conditions

The term photovoltaic refers to the phenomenon involving the conversion of sunlight into electrical energy via a solar cell. In Photovoltaic power generation there are two major problems which are less conversion efficiency of PV modules & amount of power generation depends on weather conditions. And also, the PV cell I-V characteristic be non-linear due to complex relationship between voltage and current and vary with change in temperature or insolation. There is single point on I-V or P-V characteristics curve knows as Maximum Power Point where PV system gives highest efficiency and produces highest output power. [2] The main source of the power loss is the failure to track MPP. So, Maximum Power Point Tracking is essential to operate PV system at MPP. The most important parameters of the solar cell that describe the operating conditions are the irradiance and the temperature. Designer of solar cell asses their devices by evaluating the efficiency at standard test conditions (STC: illumination =1000 W/m2, temperature=25°C and AM1.5 reference spectrum). [14] However, these conditions practically never occur during normal outdoor operation as they do not take into consideration the actual geographical and meteorological conditions at the installation site. There are various ambient conditions that affect the output of a PV power system. These factors should be taken into consideration so that the customer has realistic expectations of overall system output. In this paper, we discussed the temperature and irradiance variations effect on the parameters of the solar cells. This will be explained.

Effect of Irradiance

The term Irradiance is defined as the measure of power density of sunlight received at a location on the earth and is measured in watt per meter square. Whereas irradiation is the measure of energy density of sunlight .The term Irradiance and Irradiation are related to solar component.

The short circuit current is a linear function of ambient irradiation whereas the voltage varies slightly with it. [6] Therefore, solar panels with irradiation tracking mechanisms may be adopted to improve the PV system performance. A practical alternative for improving performance is to tilt the PV panel at some fixed angle, which is plus or minus 15 degrees from the latitude of the location for winter and summer months respectively. Performance of non-tracking (fixed angle) solar panels have evaluated and it has been realized that the additional cost associated with a tracking system can be avoided by fixing the panels at some tilt angle, with only a minor loss in efficiency. [3]

Effect of panel temperature

An increase in cell temperature causes a linear decrease in open circuit voltage of a PV module resulting in reduction of module efficiency. Higher power output is achieved at colder module temperatures. The cell temperature of a PV module is largely influenced by the ambient temperature and irradiance. It also depends upon the PV panel material because different materials have variable dependence on temperature [10].

Module temperature is a parameter that has great influence in the behavior of a PV system, as it modifies system efficiency and output energy. In addition to this, the atmospheric parameters such as irradiance level, ambient temperature, dirt/dust and the particular installing conditions have influence, too. Temperature effects are the result of a connatural characteristic of crystalline silicon cell-based modules. They tend to produce higher voltage as the temperature drops and, conversely, to lose voltage in high temperatures. Any PV module or system derating calculation must include adjustment for the temperature effect [26].

As temperature increases, the band gap of the semiconductor shrinks, and the open circuit voltage Voc decreases following the p–n junction voltage temperature dependency of seen in the diode factor q/kT. PV cells therefore have a negative temperature coefficient of Voc. Moreover, a lower output power results given the same photocurrent I_{ph} because the charge carriers are liberated at a lower potential [25, 28]. As temperature increases, again the band gap of the intrinsic semiconductor shrinks meaning more incident energy is absorbed because a greater percentage of the incident light has enough energy to raise charge carriers from the valence band to the conduction band. A larger photocurrent results; therefore, Isc increases for a given insulation, and PV cells have a positive temperature coefficient of Isc. This effect would raise the theoretical maximum power by the relationship below,

$$\text{Pmax} = I_{SC} \times V_{OC} ---------------------------- (2.16)$$

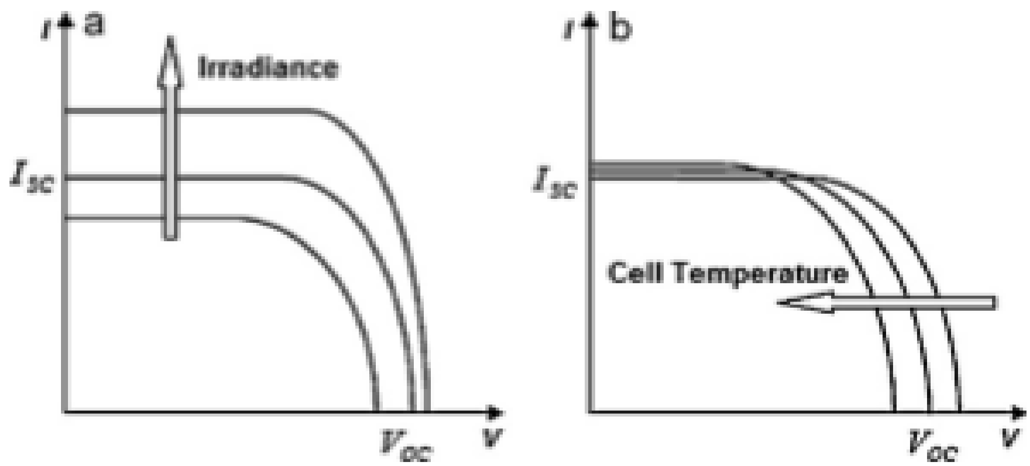


Figure 2.6: Effects of irradiation and cell temperature on PV cell characteristic (a) effect of increased irradiance and (b) effect of increased cell temperature [30]

3.5.4. Effect of dust

Dirty solar panels produce less electricity. The term "soiling" sounds fancier than it is. All it refers to is dust, dirt, and other debris settling on the surface of the solar panels. This blocks sunlight from reaching the solar cells and reduces solar system performance. In areas with frequent rain, soiling is not usually significant [16]. Areas that experience long periods of dry weather, such as amhara region, experience more soiling during the winter, rapid soiling can also occur on systems located near construction sites and other places that produce dust. Cleaning the system may be undertaken to keep things looking nice, but it shouldn't be necessary to maintain the expected energy cost-savings from a properly-designed system.

2.5.5. Controller and/or Inverter

A controller is very useful component of a PV water pumping system. It can perform multiple tasks such as limiting the power supply to the battery charger, adjusting voltage and current to improve pumping performance, allowing switches to disconnect automatically to perform different jobs such as disconnecting PV modules with pump, protecting the motor from running dry when water level in the well or tank is below the pumping intake and can shut off the pump when the tank is full. It is considered the most vulnerable component of the PV system since it contains sophisticated electronics and it has to operate in varying environmental conditions. Three types of controllers may be used in PV pumping for controlling the power input: maximum power point (MPP), constant voltage tracking and voltage/frequency modulation (. In maximum power point mode, the voltage and current produced by the PV panel is adjusted in order to produce the maximum power at given conditions [22]. In constant voltage mode, PV array is operated at a fixed voltage without considering MPP. In voltage/frequency modulation mode, the voltage of the PV array is adjusted by the controller based on output frequency value in order to maintain a constant voltage/frequency. Direct current (DC) is produced by the PV array.

Figure 2.7: motor control board and breaker switch

2.5.6. Motors for PV based pumps

PV modules produce direct current so DC motors are most commonly used in a low power solar water pumping system. Solar pump systems below 5 kW generally use DC motors. These motors are of two types: DC motor with brushes and without brushes. DC motor with brushes requires frequent maintenance due to commutator and sliding brush contacts especially in submersible applications where the pump has to be removed frequently from the water well for replacing brushes. A permanent magnet synchronous (PMSM) brushless DC motor coupled to a centrifugal pump is found to be a better alternative than a DC motor for low power direct coupled PV water pumping systems. This type of motor is small in size and rugged as compared to an AC motor. The cost and maintenance problems of DC motors have resulted in the use of induction motors (IM) which require an inverter to be used between PV array and the motor. PV pumping system based on induction motor is rugged, reliable and maintenance-free with increased efficiency and provides more possibilities for control strategies in comparison to DC motors [9].

2.5.7. Solar pumps

Solar water pumps are rated as per voltage supplied and require accessories like filters, float valves, switches, etc to function optimally. Solar pumps are constructed from high quality low lead marine grade bronze and stainless steel and are designed for corrosion-free and maintenance-free service even in harsh environment with long term performance and reliability. Solar pumps are classified into three types according to their applications: submersible, surface, and floating water pumps. A submersible pump draws water from deep wells, and a surface pump draws water from shallow wells, springs, ponds, rivers or tanks, and a floating water pump draws water from reservoirs with adjusting height ability [24]. The motor and pump are built in together in submersible and floating systems. In the surface system, pump and motor can be selected separately to study the performance of system along with controller and PV panel. A pump produces a unique combination of flow and pressure i.e. high-flow/low-head to low-flow/high-head for a given power input. Broadly, pumps can be classified under two categories based on operating principle: dynamic pumps and positive displacement pumps. Dynamic pumps operate by developing a high liquid velocity and pressure in a diffusing flow passage. The efficiency of dynamic pumps is lower as compared to positive displacement pumps but have comparatively lower maintenance requirements. Positive-displacement pumps operate by forcing a fixed volume of fluid from the inlet pressure section of the pump into the discharge zone of the pump. These pumps generally tend to be larger than equal-capacity dynamic pumps. Centrifugal pumps and axial flow pumps are dynamic pumps [23].

Figure 2.8: submersible pump and its Dc motor

2.5.8. Water supply source

Water supply source can be a pond, stream, spring, deep drilled well or a river. Water source must recharge faster than water pumping rate. In case pumping rate is faster than recharging rate of water source, the reservoir can dry which should be avoided to prevent damage to the pump. Main variables for system design are water reservoir volume, recharge rate and cost.

2.5.9. Tank Storage

All solar water pumping systems use some type of water storage. The idea is to store water rather than store electricity in batteries, thereby reducing the cost and complexity of the system. A general rule of thumb is to size the tank to hold at least one days' worth of water [8].

The most common method of water storage is a food-grade plastic tank which is often placed at a high point on the property for gravity feed to different fields or paddocks used in seasonal grazing or drip irrigation applications [12]. A float switch is installed inside the tank to control the pump according to water level. A wire is run along with the distribution pipe from the switch to the pump controller.

Figure 2.9: water storage tank

2.5.10. Energy Conversion Efficiency

In order to study the energy conversion from solar radiation to water flow, the following six equations will be used.

The incident solar radiation to the PV array gives the input power (Pi) to the system:

$$P_i = G \, x \, A \, (W) \quad ------------------------(2.17)$$

Where G = solar radiation (W/m 2) and A = effective module cell area (m2).

The D.C. output power (Po) from the PV array is given by:

$$Po = VxI\ (W) \text{ ------------------------ } (2.18)$$

Where V = d.c. operating voltage (V) ; I = d.c. operating current (A).

The hydraulic power output of the pump (P_h) is the power required to lift a volume of water through a given head:

$$Ph = dxgxQxH\ (W) \text{ ------------------- } (2.19)$$

Where d = water density (kg/m 3) ; g = specific gravity (m/s2); Q = water discharge (m3/s) and H = total pumping head (m).

Array efficiency (Ea) is the measure of how efficient the PV array is in converting sunlight to electricity:

$$Ea = \frac{Po}{Pi}\ x\ 100\%. \text{ --------------------- } (2.20)$$

Subsystem efficiency (*Es)* is the efficiency of the entire system components (inverter, motor and

Pump):

$$Es = \frac{Ph}{Po} \times 100\%. \text{ -------------------- } (2.21)$$

Overall efficiency (Eo) indicates how efficiently the overall system converts solar radiation into water delivery at a given head:

$$Eo = Ph/Pi \times 100\% \text{ ------------------ } (2.22)$$

Or

$$Eo = Ea\ x\ Es \text{ ---------------- ------ } (2.23)$$

CHAPTER THREE

METHODOLOGY

3.1. Description of the solar power water pumping system

Figure 3.1: shows the working flow diagram of a solar power water pumping system , solar energy is striking the solar panel and the panel converts this energy in to electrical energy it employed four mono-crystalline type 250 watt of solar panels to produce the operating power input of the pump.

The electrical power from the solar panel is controlled by the electrical control board to sustain the constant DC voltage output and this board also sensing the water level of the tank by using water floater switch which means when tank becomes full the switch makes a short circuit and the board disconnects the pump from the input electrical power.

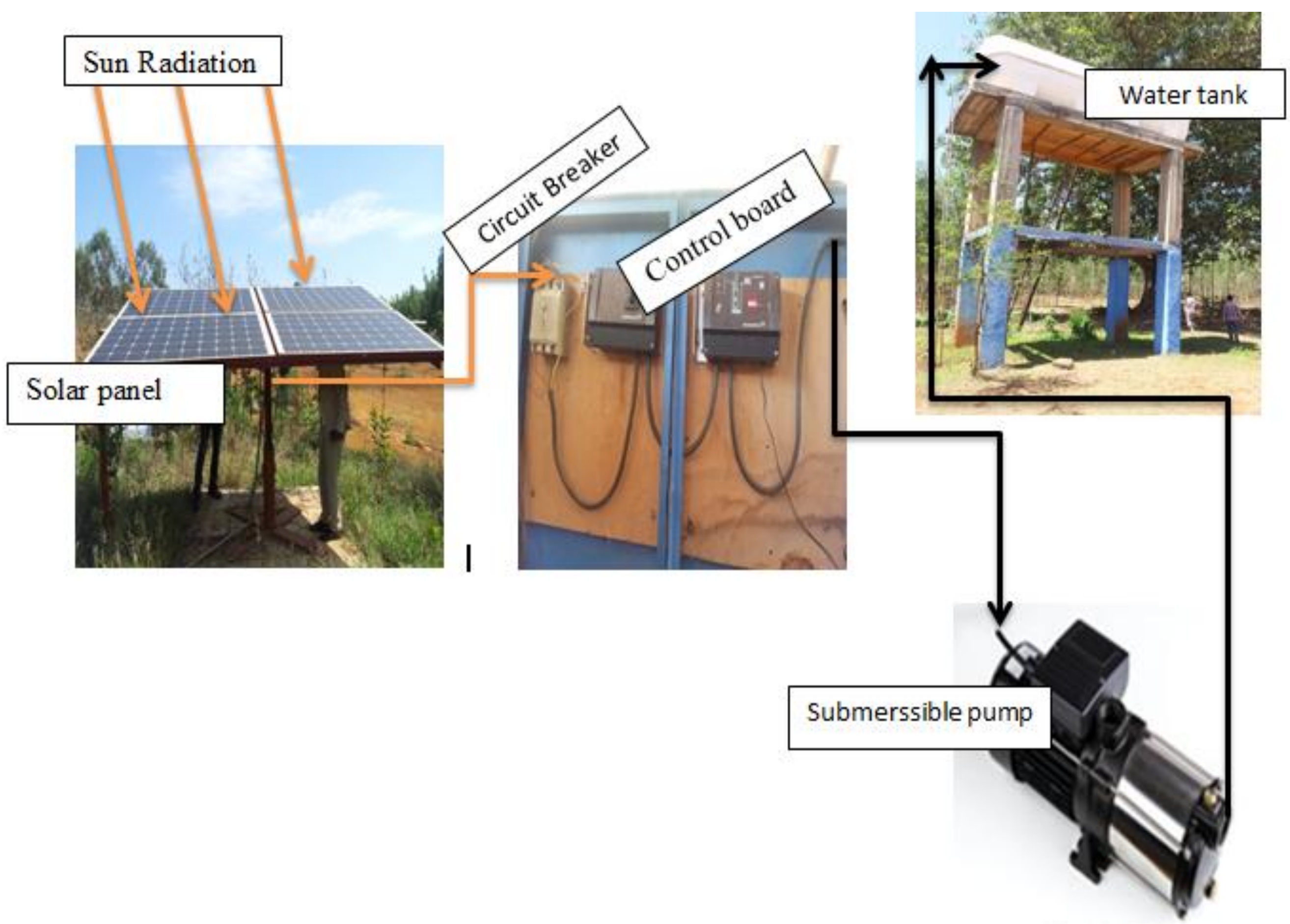


Figure 3.1: working flow diagram of solar powered water pumping system (before).

3.2. Determining water need

The first step is to determine the total amount of water that will need for households and animals. If the water needs vary during the season, be conservative and use the highest amount that we expect to use. In kolella kebele the whole people are not used from this project but this project is functional for some peoples and the school. Based on this for the whole community water demand there must be a new design. To know the water demand of the community the following things must be assessed.

- The total number of houses in kollela Keble.
- Average households per a house.
- The average festivity days and Sunday with in a month.
- The average number of animals per house.
- The daily water consumption per animals.

And the actual consumption of the water by the people per day can be evaluated by adjusting and constructing the water flow meter and measuring the flow of water at the outlet of the storage tank.

3.3. Solar panel

The solar array which installed in kollela kebele is connected four panels in series to produce 123.2 volt and 8.12 ampere DC power output and a single panel has the following specification,

1	Manufactured by	Helios USA LLL
2	Photovoltaic module	6T
3	Monocrystaline familly	6T
4	Normal power PMPP(W)	250
5	Tolerance	+3%
6	Voltage MPP/Vmpp (v)	30.8
7	Current mpp/Impp(A)	8.12
8	Voltage OC	37.4
9	Current SC	8.67

Table 3.1: Manufacturing specification of solar panel installed at kolella kebele

Figure 3.2: constructed solar panels installed at kolella keblel

3.4. Effect of Irradiance

The short circuit current is a linear function of ambient irradiation whereas the voltage varies slightly with it (Hansen et al., 2000). Therefore, solar panels with irradiation tracking mechanisms may be adopted to improve the PV system performance. A practical alternative for improving performance is to tilt the PV panel at some fixed angle, which is plus or minus 15 degrees from the latitude of the location for winter and summer months respectively (Morales, 2010). And measure all electrical dc power, voltage and current at different values of radiation then calculate the efficiency of the panel at its designed value and current values.

The performance of the solar panel can be evaluating by computing the current electrical power output from the panel from the designed power output of the new panel at the same radiation label.

$$\text{Efficiency} = \frac{current\ power\ out\ put}{designed\ power\ output}$$

$$= \frac{\mathrm{Impp(A)}}{\mathrm{Vmpp\ (v)}} ----------------------------(3.1)$$

The lose power generation of the panel is calculated by the following equation

Power loss = designed power – current power

3.5. Effect of panel temperature

An increase in cell temperature causes a linear decrease in open circuit voltage of a PV module resulting in reduction of module efficiency (Hansen et al., 2000). Higher power output is achieved at colder module temperatures. The cell temperature of a PV module is largely influenced by the ambient temperature and irradiance (Garcia and Balenzategui, 2004). It also depends upon the PV panel material because different materials have variable dependence on temperature (Lasnier and Tony, 1990).

The efficiency of the solar panel can be calculated by taking the current electrical power output at maximum panel temperature (60 ^{0}c)from the panel and the designed power output of the new panel at the operating temperature (25 ^{0}c) label, but this reduced energy loss is also the degradation of solar panel due to radiation.

$$Efficiency = \frac{current\ power\ out\ put}{designed\ power\ output}$$

$$= \frac{Impp(A)}{Vmpp\ (v)} ----------------------------(3.2)$$

3.6. Fill factor

The fill factor is denoted as FF, is a parameter that helps in characterizing the non-linear electrical nature of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of Voc and Isc, and it gives an idea about the power that a cell can produce with an optimal load under given conditions,

$$P=FF*Voc*Isc. ----------------------------(3.3)$$

$$FF = \frac{p}{Voc*Isc} ----------------------------(3.4)$$

The panel will have better performance if the computed fill factor is in between 0.6 to 0.8.

Fill factor is also an indicator of quality of cell. With FF approaching towards unity the quality of cell gets better.

3.7. Effect of dust

Dirty solar panels produce less electricity. The term "soiling" sounds fancier than it is. All it refers to is dust, dirt, and other debris settling on the surface of the solar panels.

The efficiency of the solar panel with dust and without dust at the panel can be calculated by taking the current electrical power output by considering dust from the panel and the current power output of the panel with removing the dust from panel at the maximum and minimum radiation label respectively.

$$Efficiency = \frac{power\ out\ put\ with\ dust}{power\ output\ without\ dust}$$

3.8. Solar DC Pump

The pump type which is installed inside the collection chamber is a dc type helical rotor submersible pump and its characteristic curve looks in the following graph.

Pump description

- The motor is a sealed construction made of stainless steel. It is a brushless, electronically commutated DC-motor with a permanent-magnet rotor.
- The motor can be supplied with either DC or AC voltage:

Its operating Voltage, V_{DC}: 30-300 V

V_{AC}: 1 x 90-240 V

Power factor = 1.

Maximum input current [A], = 7 A

Rated speed, 500 - 3600 rpm;

Maximum input power [kW], = 0.9 kW

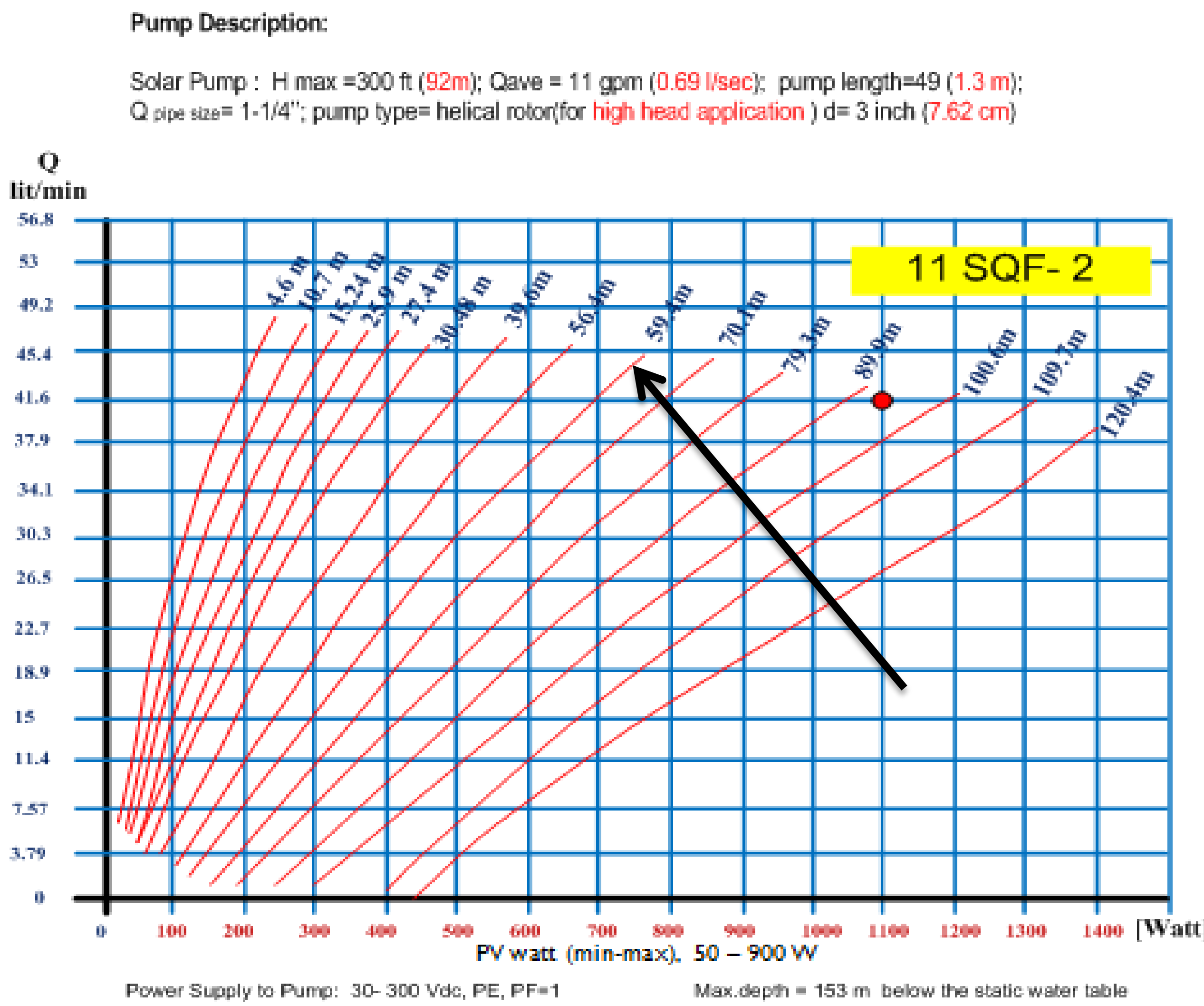


Figure 3.3: submersible DC pump characteristic curve

The performance of the pump is evaluated by calculating the designed pump efficiency and the actual working efficiency of the pump.

The designed pump efficiency can be calculating by selecting the designed curve of the pump from above figure 3.4.

$$\text{Efficiency} = \eta_{\text{designed}} = \frac{hydraulic\ power}{electrical\ power} = \frac{\rho * g * H * Q}{pin} \quad -- \; ------- (3.5)$$

And the actual pump efficiency can be calculating at a given head.

$$\text{Efficiency} = \eta_{\text{actual}} = \frac{hydraulic\ power}{electrical\ power} = \frac{\rho * g * Hac * Q}{pin} \quad -- \; ------- (3.6)$$

3.9. Overall efficiency

The overall efficiency of the solar water pumping system is the sum of the efficiency of the whole components from the designed capacity, by using equation 2.23.

3.10. Experimentation

This project is located in the Mecha woreda, situated in West Gojam Zone belonging to the Amhara Region, Ethiopia. The city is located approximately 542 km north-northwest of Addis Ababa, and 36 km from Bahir-dar city having a latitude and longitude 12°69′N 37°02′E and an elevation of about 1895 meters (5,906 feet) above sea level.

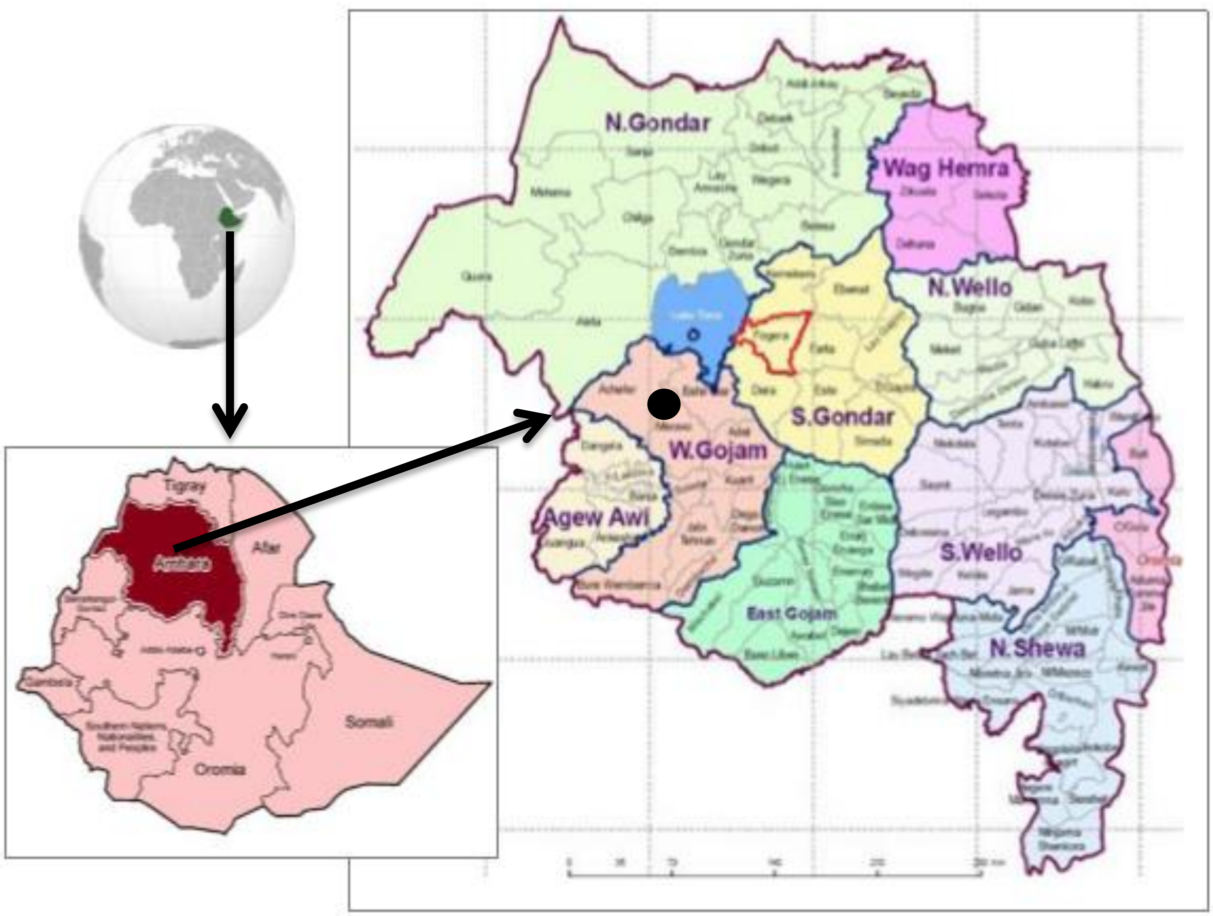


Figure 3.4: Map with Regions of Ethiopía, emphasizing Amhara (left). Map of Zones and woredas which are part of Amhara Region, emphasizing Mecha woreda (right).

Source: Wikipedia (2015) y IDP (2012)

The methodology used for the research work was as shown below

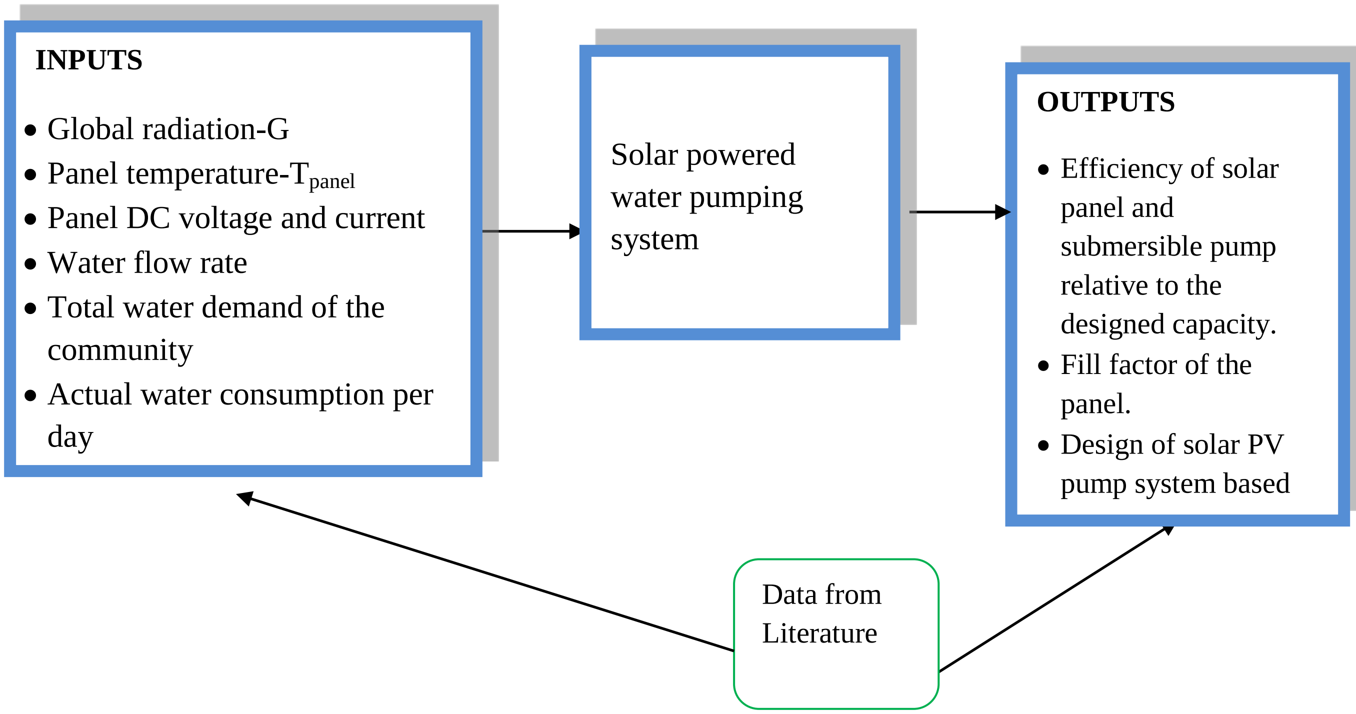


Figure 3.5: Flow chart which shows inputs, process and the output of the methodology.

3.11. Experimental Setup

The experimental setup consists of four PV modules (4 series), a dc PM motor coupled with centrifugal pump, control board, water flow meters, phyranometer, thermo-couple, multi-meter, elevation Gps measuring device, foset valve and water reservoir tank. In the system, the performance evaluation of the system has been done by keeping the PV array at a fixed tilt of 15^0 to face the sun. At the operating point of the system, the relationship among solar radiation, panel temperature, water flow rate, open circuit voltage, short circuit current, maximum power point current and voltage can be obtained by considering energy balance of the whole system.

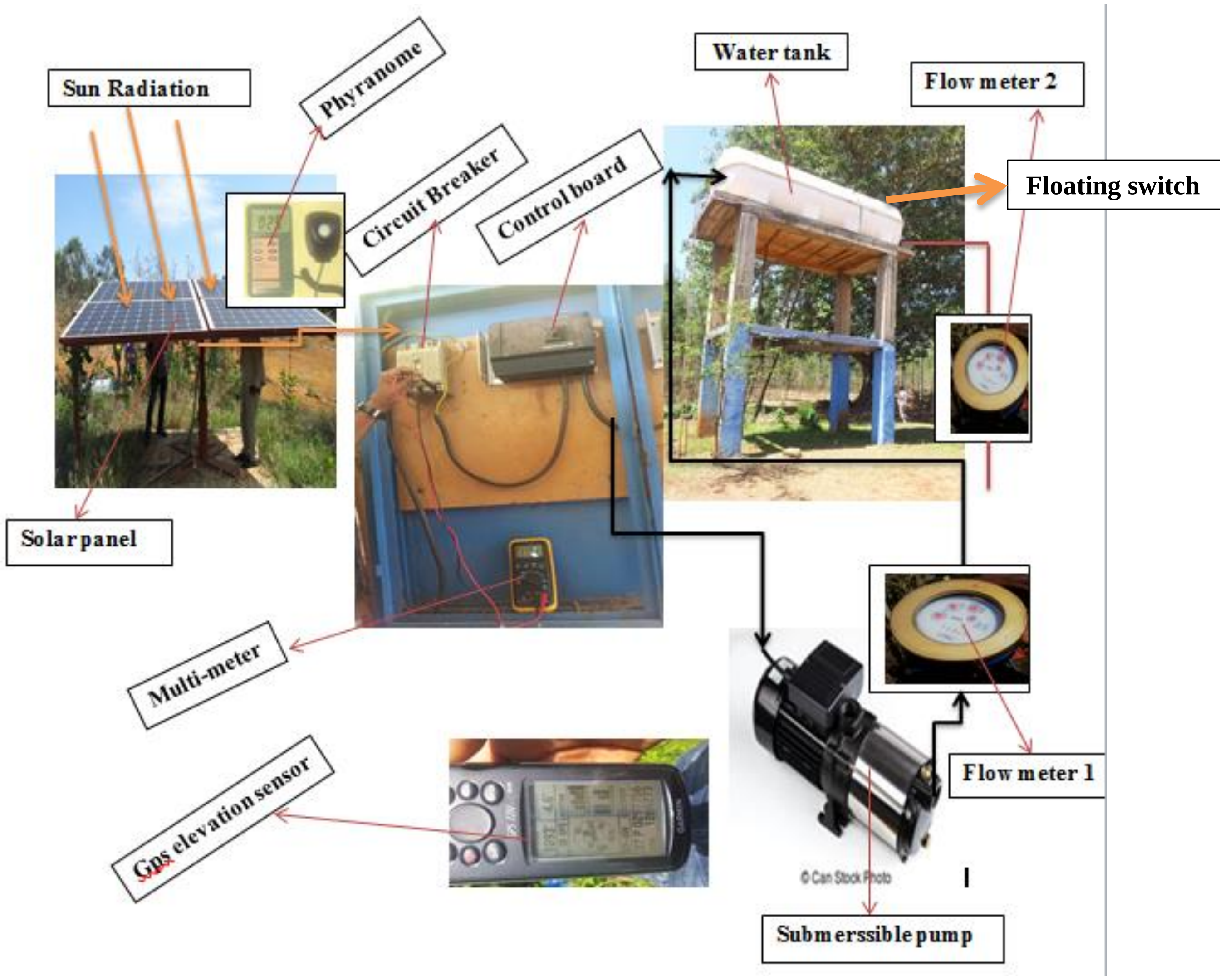


Figure 3.6: Experimental setup of the solar water pumping system with measuring instruments

3.12. Experimental Test

The system of pumping water comprised of a 900 W electric motor and four PV modules; each having 250 Wp (Watt-peak) and a DC-DC converter. DC current operated the electric motor used in this system and the electronic controller used was a fixed DC-DC type. The output generated by PV array and electronic controller monitors input provided to motor in a well. The energy output from PV panels varied with the solar irradiance level. Output of the PV panels was used as input for pump. The flow rates from pump were measured at different solar irradiance intensities for performance evaluation of solar powered water pumping system. A number of tests load, with removing dusts, with dusts on panel were conducted on the whole solar PV pumping system to determine its solar radiation at a fixed tilt angle. Pyranometer was used to measure solar irradiance of PV array during experiments. The flow rates of pumping unit were measured at various irradiances, at a fixed head and inclination angle of PV array for the performance evaluation of PV submersible pumping unit. Water flow rates were measured at different solar radiation intensities by fixing 1.5 inch water flow meter at the outlet pipe of the pump. Pyranometer was used to measure solar irradiance in $W.m^2$ on a surface of PV array. The Pyranometer was adjusted on the same angle as that of modules. An Apogee Pyranometer with a silicon cell yields in milli-volts of output with conversion factor of 5. The data of solar irradiance were collected on hourly basis from 7:00 AM to 6:00 PM, from the month of March 2017 to May 2017. The data of solar irradiance falling on PV array tilted surface were measured from sunrise to sunset. The hourly discharge from pump was measured along with solar radiation data and the relationship between these two variables was determined using statistical techniques. The effect of panel temperatures on the pump discharge was measured by using 1.6mm diameter thermocouple with Eli digital thermometer (LX-6500) capable of reading temperature between -50°C and 750°C on hourly basis. The experimental system was deep well pump and discharge directly into storage tank. Vertical elevation was measured by GPS sensor device.

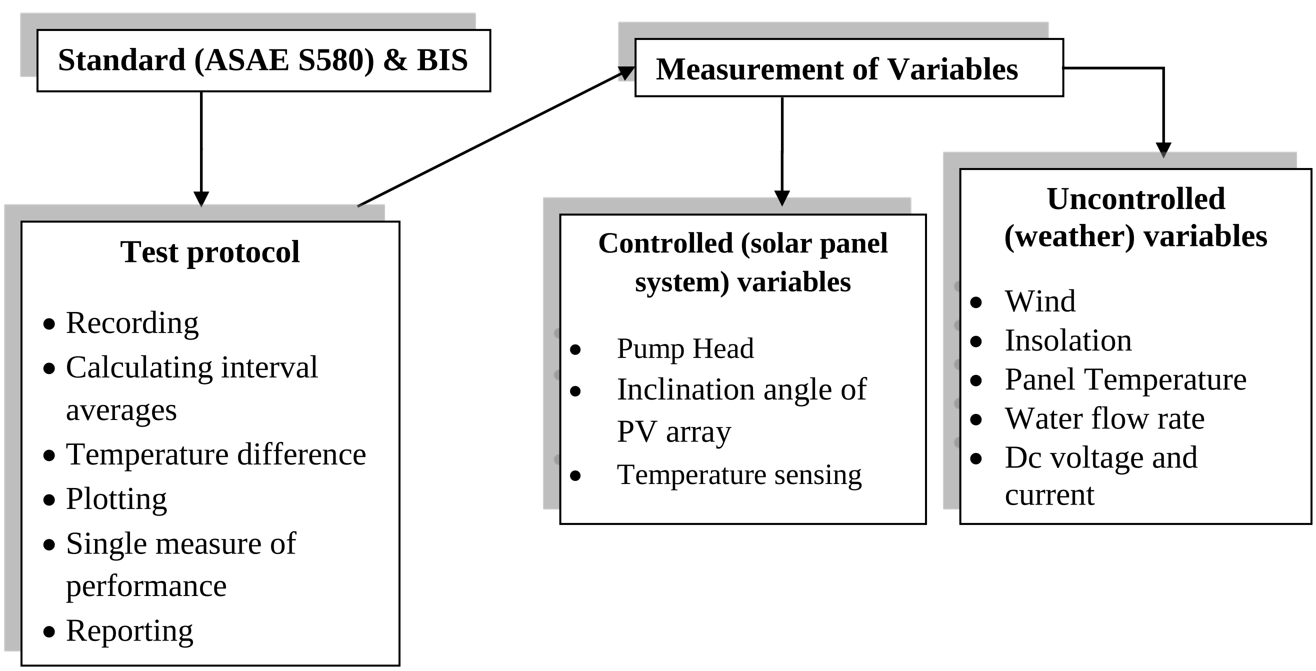


Figure 3.7: Flow chart for list of activities and variable measurements in SAE S580.

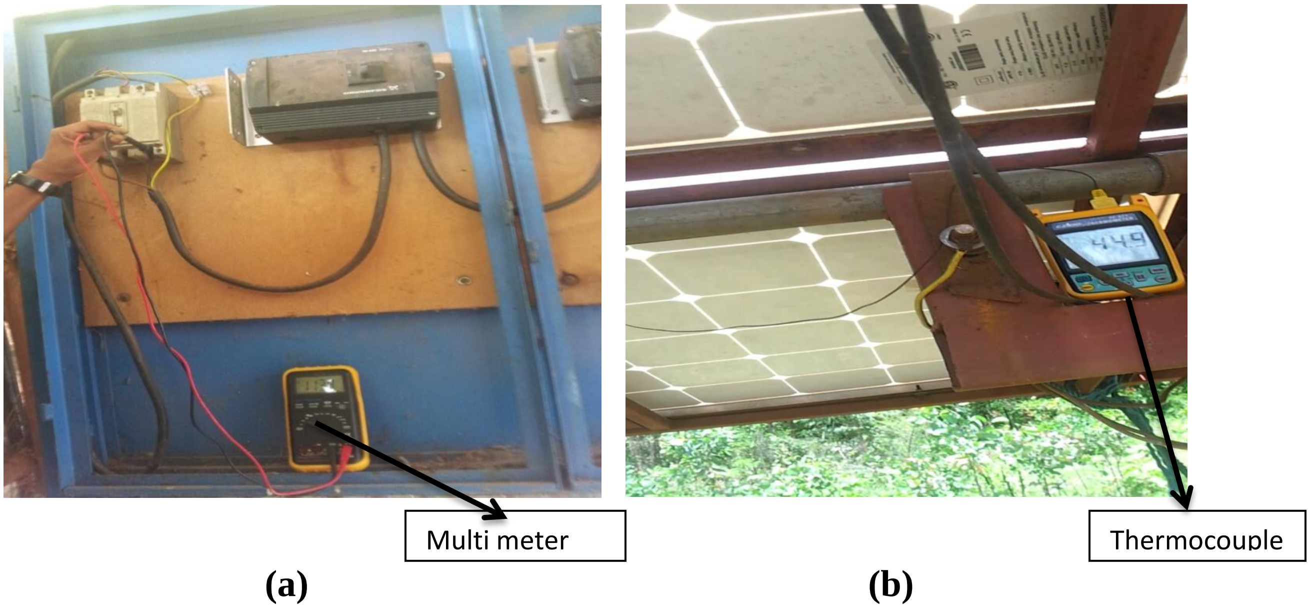


Figure 3.8: (a) shows the voltage and current measurement, (b) shows cell temperature measurement

3.13. Design of solar PV water pumping system methods

The designing methods of solar water pumping system starts to know from daily water requirement of the community, the method how to calculate the water demand is mentioned before in section 3.4.

3.14. Hydraulic Power Requirement

3.14.1. Determination of the head

The total dynamic head is the sum of the vertical lift, friction losses through pipes, and the reservior height. Therefore the total head for kollela kebele is determined by the elevation difference between the pump position and the highest place for storage tank.

TDH = Total vertical lift + Friction loss + booster height

3.14.2. Determination of Hydraulic energy

The hydraulic energy requirement is the energy required to lift the daily water demand through the total dynamic head. The relation used to calculate the hydraulic energy demand is as follows:

$$E_h = (\rho \times g \times Q \times TDH) \quad \text{--} 3.7$$

3.14.3. Determination of pump capacity /Sizing of pump Motor/

The capacity of the pump motor is calculated by using the converting efficiency of electrical power to hydraulic power.

$$\text{Motor power} = P/\eta$$

Where:

P = Hydraulic Power (Watts)

η = Efficiency of pump.

3.14.4. Sizing of the total solar array power

To design solar array first Design month must be selected which means, design month is the month for which the solar PV system is sized to ensure sufficient water supply when the solar resource is the minimum.

The solar array power required (kWp) =

$$\frac{Hydraulic\ energy\ required\ Eh\ (kWh/day)}{Average\ minimum\ \ of\ daily\ solar\ irradiation\ for\ month\ (kWh/m^2/day\ x\ F\ x\ E}$$

Where:

F = array mismatch factor = 0.85 on average (a safety factor for real panel performance in hot sun and after 10-20 years).

E = daily subsystem efficiency.

3.14.5. Pumping Controller/Inverter sizing

The size of the inverter can be calculated as follow,

Inverter size = 25% to 30% higher than Total pump motor power

= (1.25 to 1.30) * Motor power

The solar water pumping system is designed by using an excel software and the software is programed by the Federal Democratic Republic of Ethiopia, Ministry of Water, Irrigation and Energy. The design process has input parameters and output required designed parameters, generally it has six steps and briefly shown in the next block diagram.

Step One; Determine Daily Water Requirement.

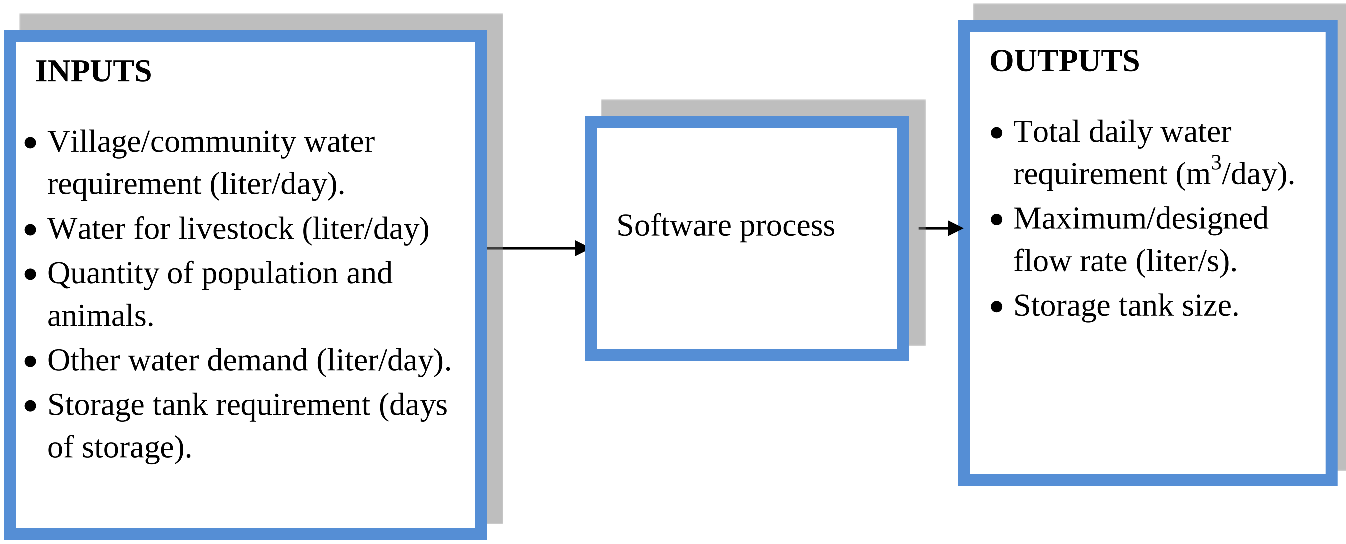


Figure 3.9: Flow chart shows inputs, process and output of determine daily water requirement methodology.

Step Two; Determine Hydraulic Power Requirement.

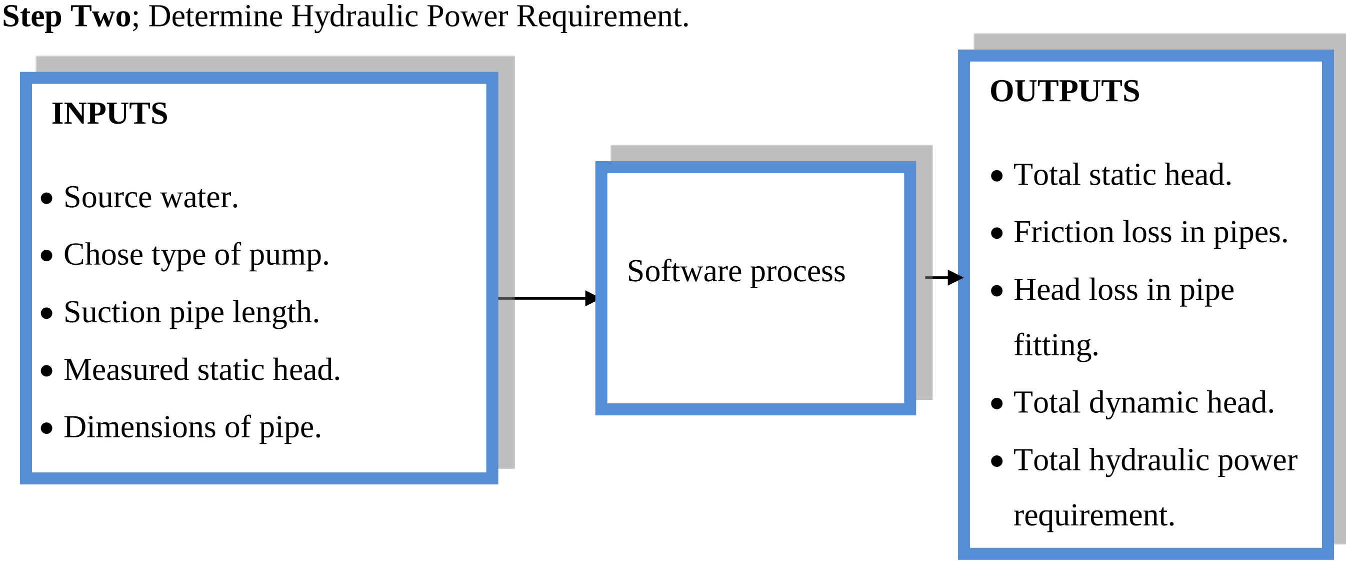


Figure 3.10: Flow chart shows inputs, process and output of determine hydraulic power requirement methodology.

Step Three; Estimate the Solar Resource in the site.

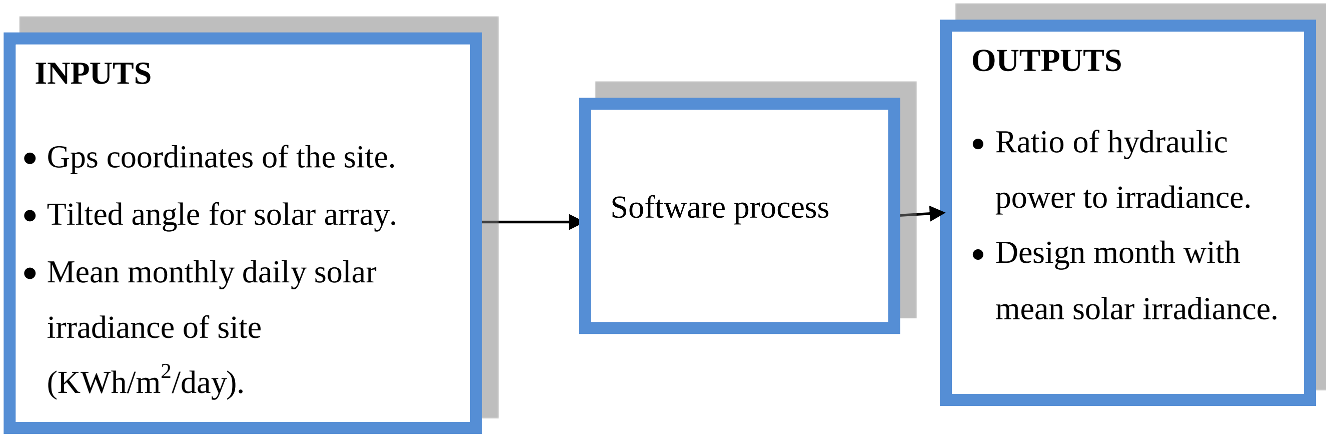


Figure 3.11: Flow chart shows inputs, process and output of estimate the solar resource in the site methodology.

Step Four; Determine PV Array Size.

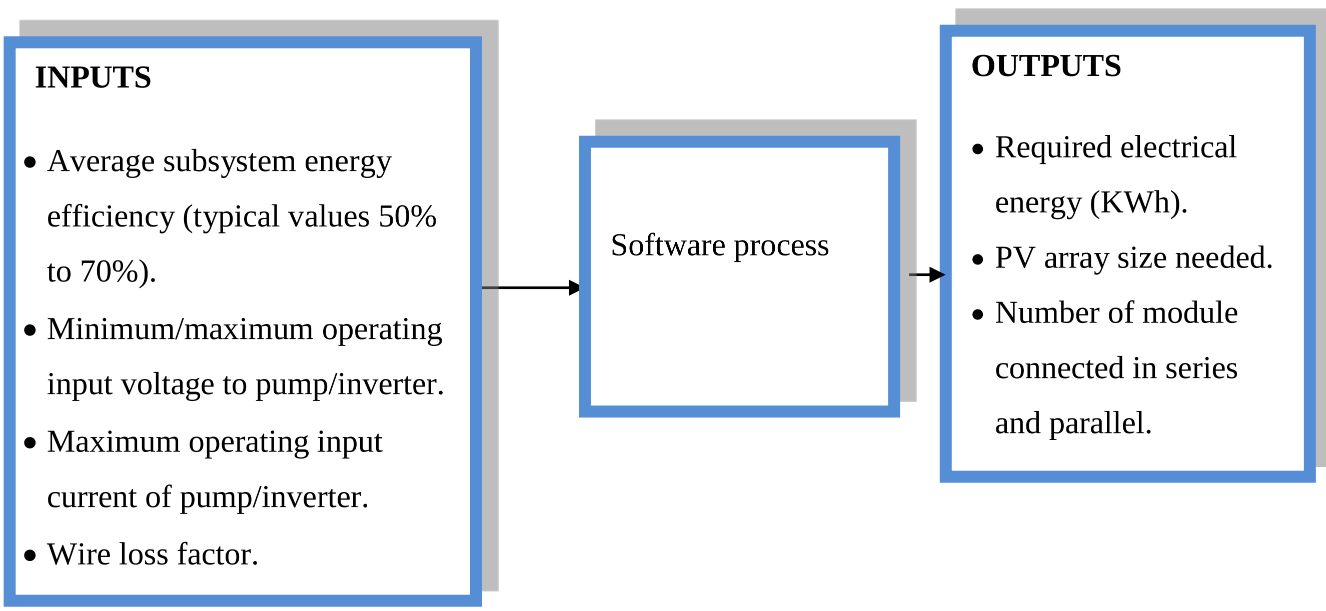


Figure 3.12: Flow chart shows inputs, process and output of determine pv array size methodology.

Step Five; Determine Bill of Quantity and Bill of Costs.

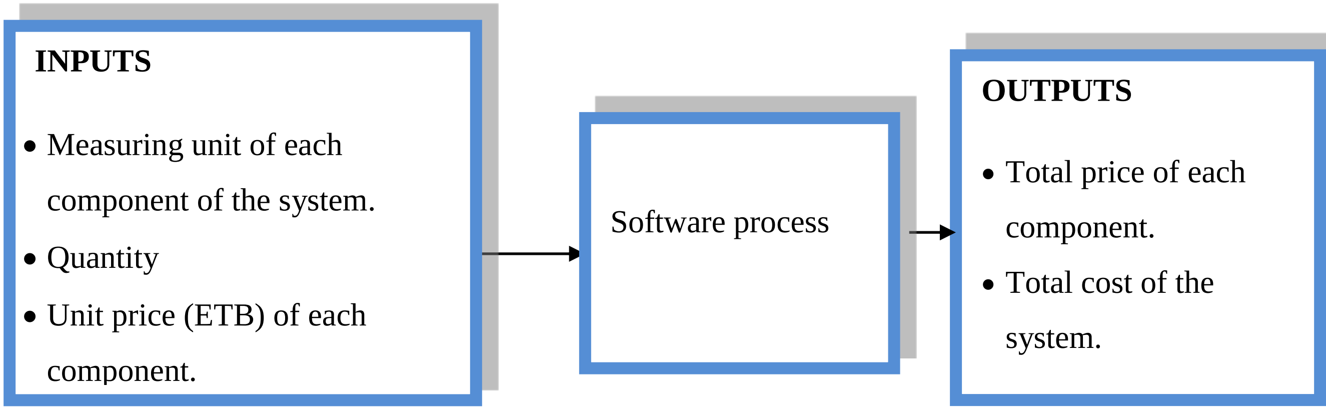


Figure 3.13: Flow chart shows inputs, process and output of determine bill of quantity and bill of costs methodology.

Step Six; Determine financial feasibility of the system.

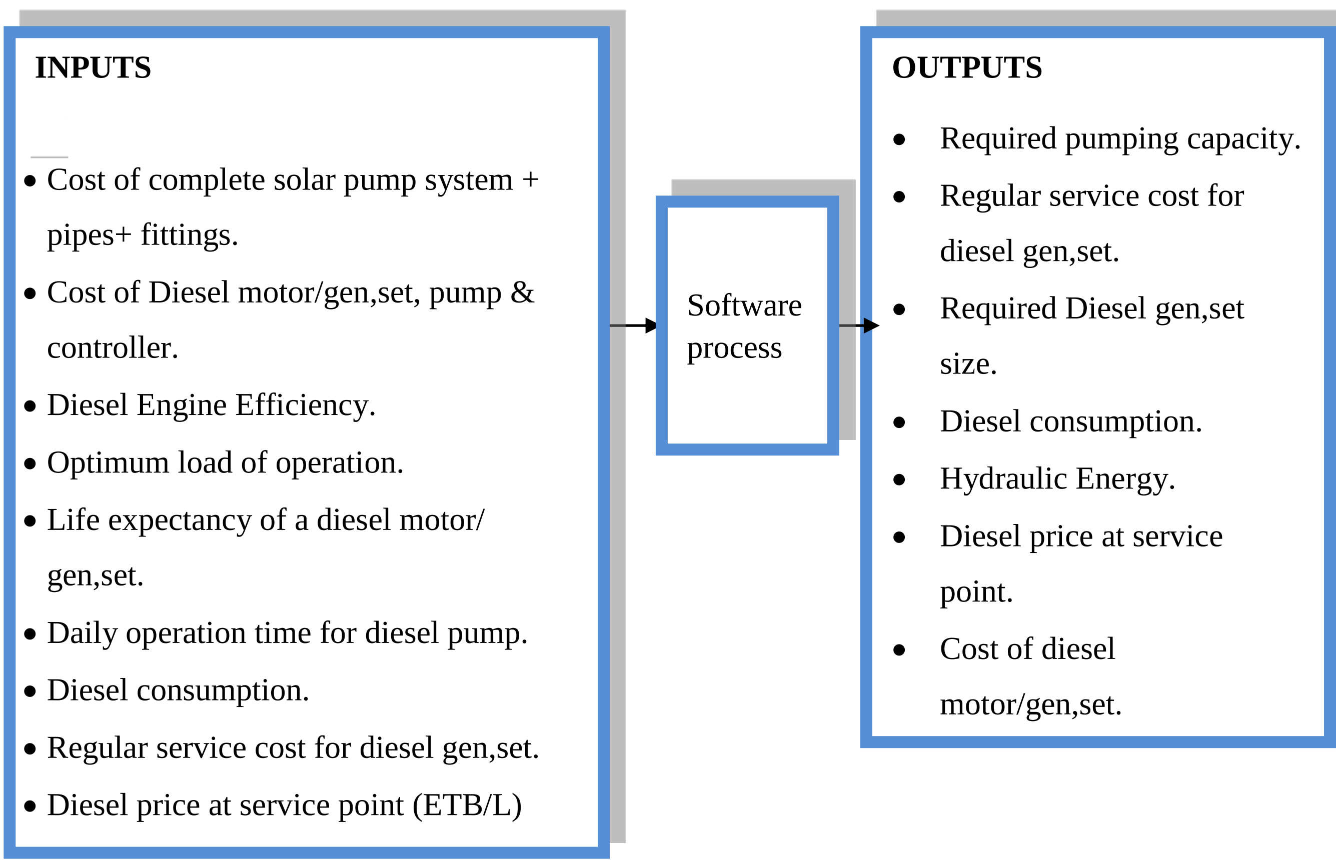


Figure 3.14: Flow chart shows inputs, process and output of determine financial feasibility of the system methodology.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Water requirement of the community

- The total number of houses in kollela Keble =900 houses.
- Average households per a house =5.

The average festivity days and Sunday with in a month= 4 Sundays and 3 festivity days.

Animals	Average number of animals
Cattle	6
Horse or Mule	1
Sheep and Goat	4
Cat and Dog	2

Table 4.1; Average number of animals per household.

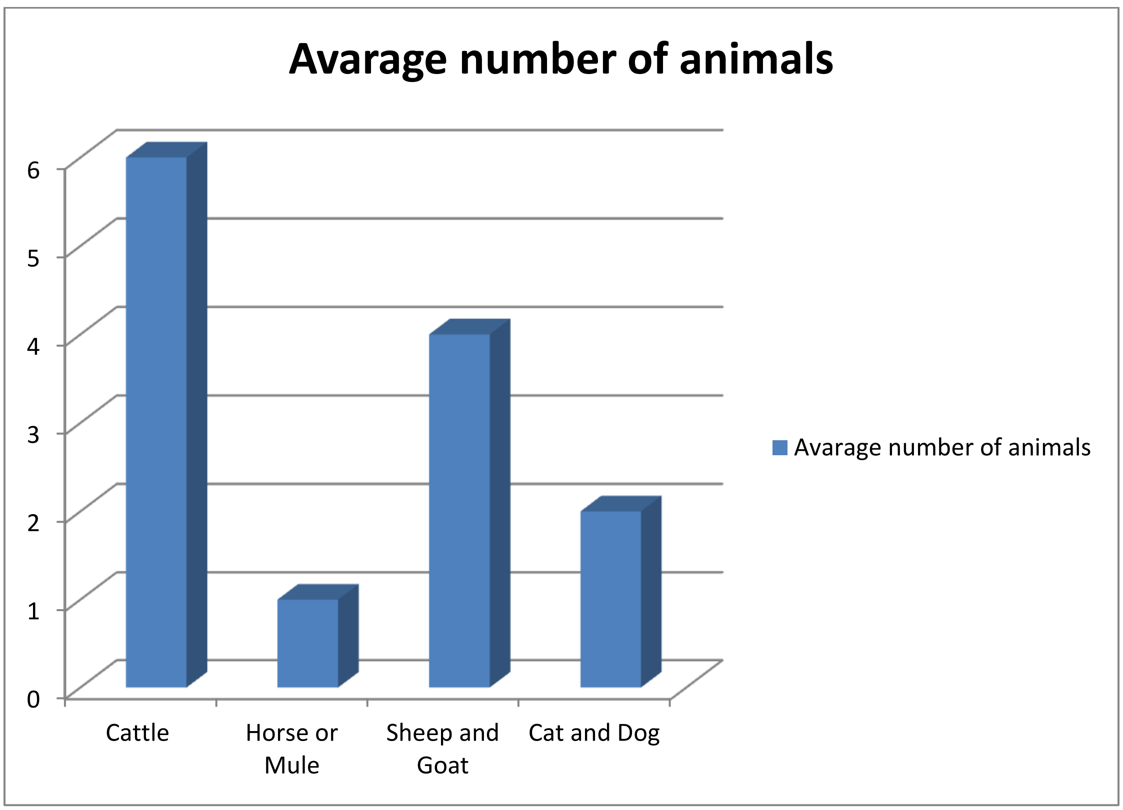


Figure 4.1; graph shows average number of animals per household.

Based on the assessment the water demand of household and animals are estimated as follow

Number	Water consumer	Water demand in liter per day
1	household	20
2	cattle	8
3	Horse or mule	8
4	Sheep and goat	4
5	Small animals	1

Table 4.2; Water demand for animals in liter per day.

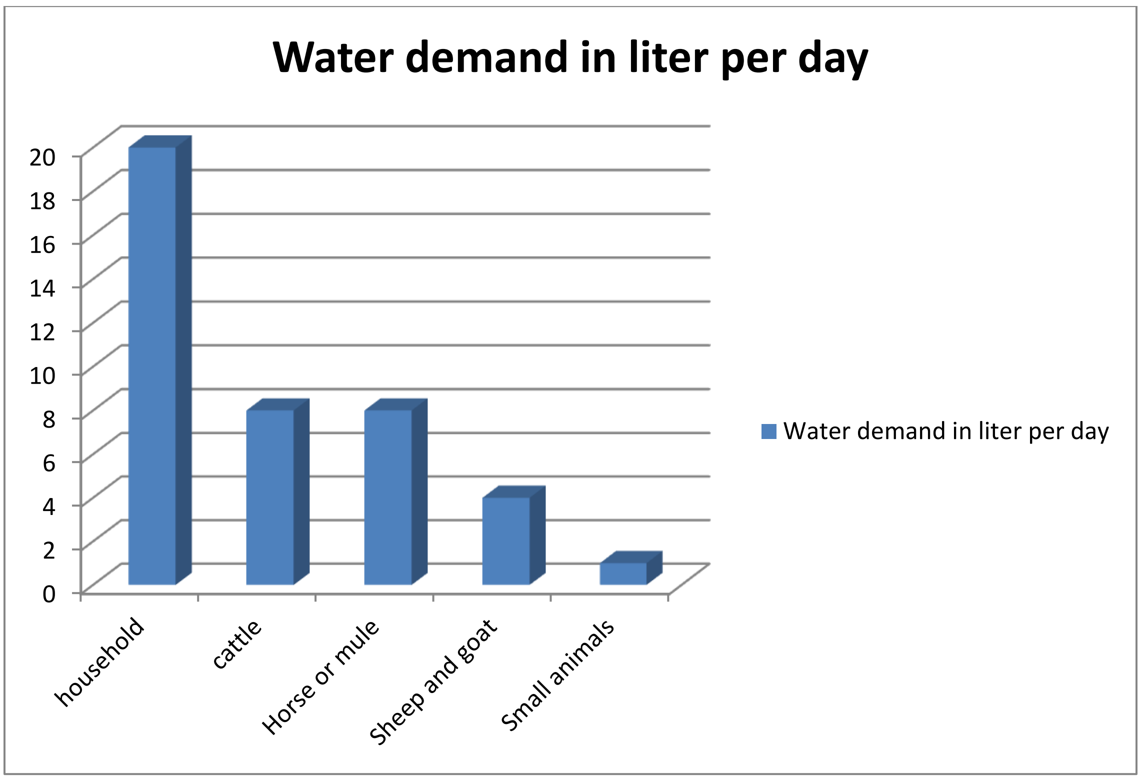


Figure 4.2; Water demand for animals in liter per day.

The total water demand of the households without considering the festivity day is calculated 90,000 liter/day, the festivity day and Sunday water demand per month will be 756,000 liter/ month, the normal day water demand within a month 2,070,000 liter/ month and the total water demand of the households per day is calculated 94,200 liter/day.

The total water demand of the animals,

number	animals	Number of animals per house	Water demand per day	Total water demand
1	Cattle	6 =5400	8 liter/day	48 liter
2	Horse or mule	1=900	8 liter/day	8 liter/day
3	Sheep and goat	4=3600	3 liter/day	12 liter/day
4	Cat and dog	2=1800	1 liter/day	2 liter/day
5	Total			70 liter/day

Table 4.3; Number of animals per house, Water demand in liter per day and total water demand by animals.

The total water demand of the animals is calculated 63,000 liter/day and total daily water requirement of the community is 157,200 liter/day (157.2 m^3/day).

4.1.2. The actual water consumption of the community

The current actual water users of the community are only the households and school students.

- ✓ The number of water distribution point =4 (but one cannot be functional and the other one is for school)
- ✓ The average household user in a single water distribution point =50
- ✓ Average households per a house =5.
- ✓ The average festivity days and Sunday with in a month= 4 Sundays and 3 festivity days.

The amount of water consumption for school can be evaluated as follows;

- ✓ The total number of students and staffs in a school =1157
- ✓ The student and staff water consumption per day per person =1.5 liter

The water consumption amount by the school is calculated 1735.5 liter/day, the total water demand of the households without considering the festivity day will be 15,000 liter/day. The water consumption of the households per day is 15,700 liter/day and the total actual water consumption of the community (households and school students) is 17,435.5 liter/day. But in actual case the water demand of community, those are users from three water point based on the above calculation must be 25,500 liter/day and the average measured water consumption at different day from the water flow meter at the outlet of the storage tank is 16,528 liter/day.

4.2. Relation between Irradiance and Flow rate

From measured data of time and irradiance, irradiance and discharge; the flow rate at various irradiance intensities were recorded. This data represented three months average flow at various irradiance intensities and the relationship between irradiance and flow rate is given in Figure 4.3. The flow rate analysis with respect to solar irradiance showed that flow rate increases as irradiance increases and becomes constant at certain value of irradiance. When this specific irradiance level is reached, then there is no effect of water on flow rate. Solar irradiance shows a parabola curve like trend throughout the day starting from low values to maximum at noon and then decreasing in the evening. It was also observed that the solar pumping unit started at irradiation level of above 200 W/m2, below this level pump cannot contribute to flow as the available solar radiations are not strong enough to provide the required starting power to run the pumping system. At early morning minimum radiation level of 217 W/m2, the discharge from pump was 0.228 liter/ second. When medium irradiation level is at 511 W/m2, the discharge from pump was recorded to be 0.348 liter/ second and at noon, maximum irradiance level of 1050 W/m2, the discharge was recorded as 1.087 liter/ second.

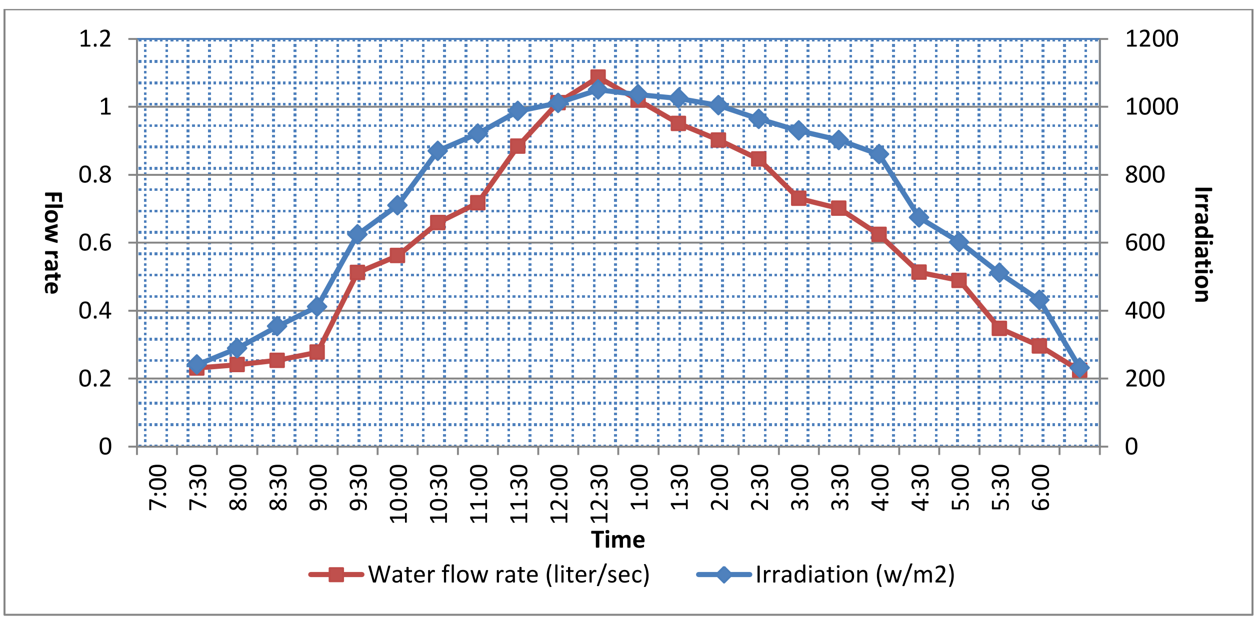


Figure 4.3: the relation of radiation and water flow rate under test measurement.

4.3. Relation between Irradiance and panel Temperature

From measured data of time and irradiance, irradiance and generated panel temperature; the panel temperature at various irradiance intensities were recorded. This data represented three months average temperature at various irradiance intensities and the relationship between irradiance and temperature is given in Figure 4.4. The panel temperature analysis with respect to solar irradiance showed that panel temperature increases as irradiance increases. Solar irradiance shows a parabola curve like trend throughout the day starting from low values to maximum at noon and then decreasing in the evening. At early morning minimum radiation level of 250 W/m2, the panel temperature generate equal with the atmospheric temperature of 25 ^{0}c.When medium irradiation level of 500 W/m2, the temperature was recorded to be 30 ^{0}c and at noon, maximum irradiance level of 1050 W/m2, the temperature was recorded as 60 ^{0}c.

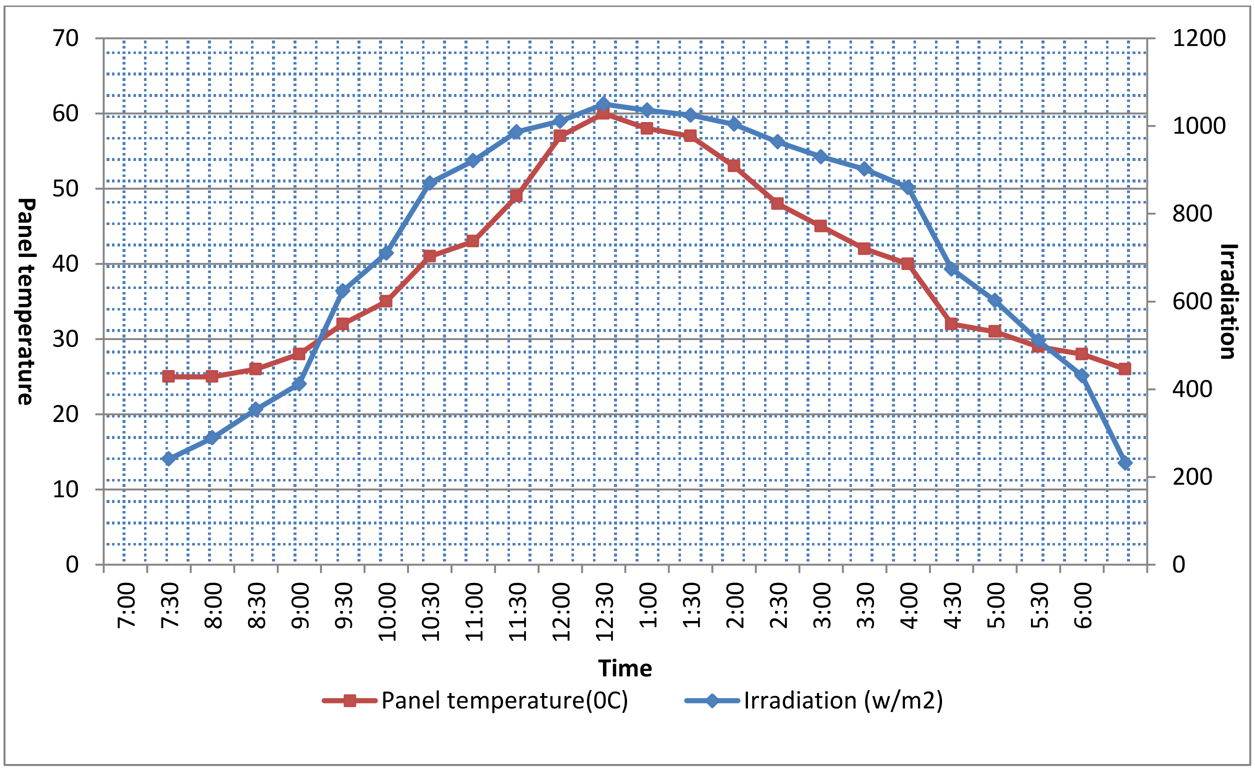


Figure 4.4: The relation of radiation and generated panel temperature under test measurement.

4.4. Effect of solar radiation on the solar PV performance

From measured data by taking minimum, medium and maximum radiation level, different electric dc voltage and current were recorded. The experiment takes one factor with 24 run totally 28 observations were takes place. At the solar radiation of 1050 W/m^2, the open circuit voltage, short circuit current and operating power are 138 volt, 8.6 ampere and 973.65 watt respectively, when solar radiation of 800 W/m^2, the open circuit voltage, short circuit current and operating power are 131 volt, 4.8 ampere and 491.48 watt respectively, when solar radiation of 500 W/m^2, the open circuit voltage, short circuit current and operating power are 128.3 volt, 3.1 ampere and 303.94 watt respectively, When solar radiation of 200 W/m^2, the open circuit voltage, short circuit current and operating power are 125 volt, 1.45 ampere and 137.76 watt respectively.

Figure 4.5 shows that with the decreasing of solar radiation, results small changes in voltage but major changes in reduction of current. So, by using equation 3.1, The efficiency of the solar panel is evaluated which means, by taking the current measured electrical power output at maximum solar radiation and the designed power output of the new panel at the same radiation and the lose efficiency of the panel due to the effect of radiation is about 2.035% or 20.35 watt of power.

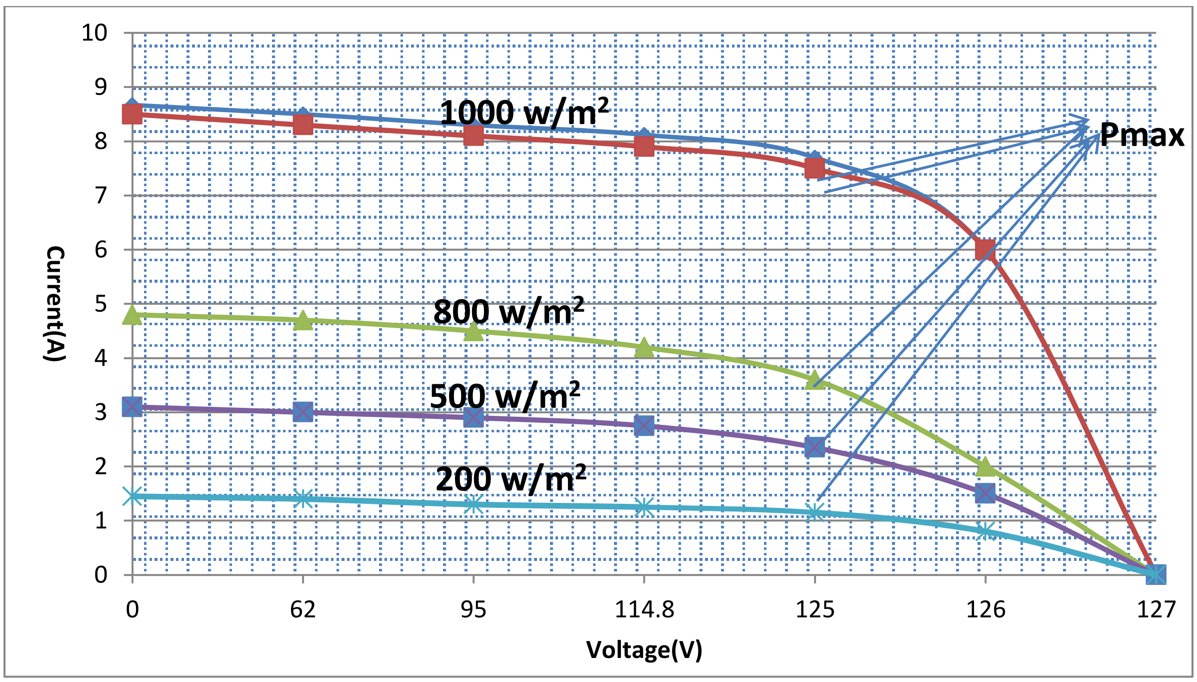


Figure 4.5: The I-V solar PV panel characteristic at different radiation level.

4.5. Effect of panel temperature on the solar PV performance

From measured data by taking maximum radiation of 1000 W/m^2, different electric dc voltage and current at different panel temperature were recorded. The experiment takes one factor with 24 run totally 28 observations were takes place. At the panel temperature of 60 ^{0}c the open circuit voltage, short circuit current and operating power are 138 volt, 8.6 ampere and 974.01 watt respectively, when panel temperature of 56 ^{0}c the open circuit voltage, short circuit current and operating power are 142.6 volt, 8.61 ampere and 976.02 watt respectively, when panel temperature is 54 ^{0}c the open circuit voltage, short circuit current and operating power are 144.1 volt, 8.63 ampere and 984.54 watt respectively. When panel temperature of 52 ^{0}c the open circuit voltage, short circuit current and operating power are 146.8 volt, 8.65 ampere and 991.01 watt respectively.

Figure 4.6 shows that with the increase in panel temperature, results marginal changes in current but major changes in voltage reduction, because the rate of photon generation increases thus reverse saturation current increases rapidly and these results on reduction in band gap. Hence this leads to voltage reduced. So, by using equation 3.2, The efficiency of the solar panel is evaluated which means by taking the current measured electrical power output at maximum panel temperature (60 ^{0}c) and the designed power output of the new panel at the operating temperature (25 ^{0}c) and the lose efficiency of the panel due to the effect of temperature is about 0.755% or 7.44 watt of power.

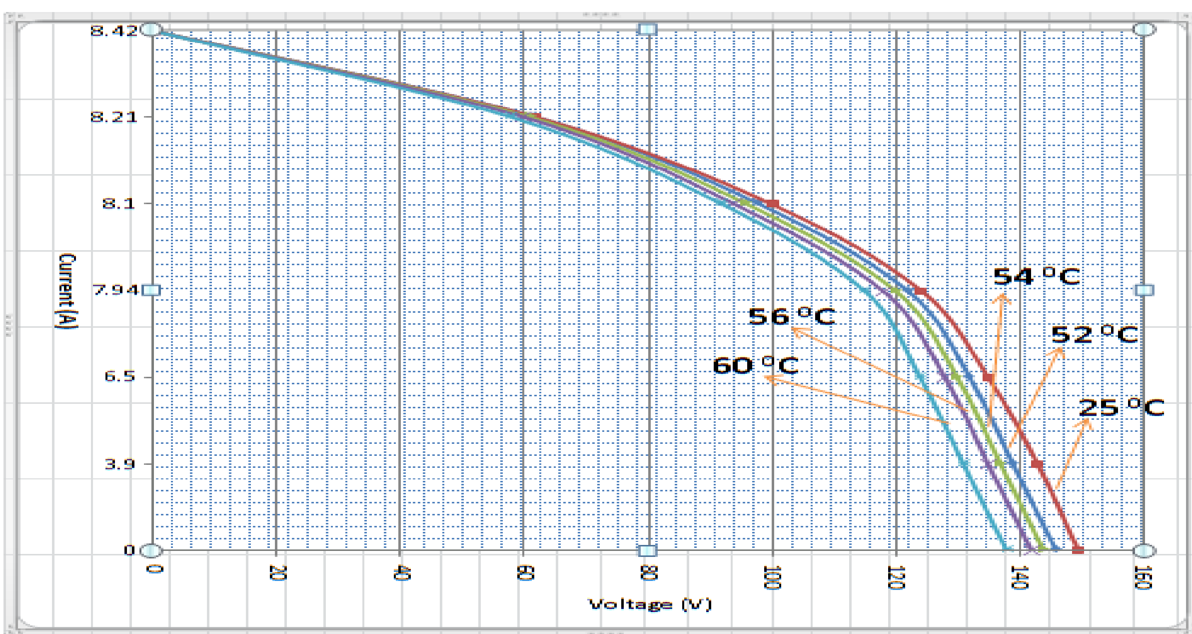


Figure 4.6: The I-V solar pv panel characteristic at different panel temperature.

4.6. Fill factor

As stated in the methodology, to evaluate the performance of the solar panel the fill factor value is used to conclude the panel is safe or not and Fill factor is also an indicator of quality of cell. The panel will have better performance if the computed fill factor is in between 0.6 to 0.8[42].

Figure 4.7 shows that the fill factor value at different radiation, when radiation is 1000 W/m^2, fill factor is 0.7906. At radiation is 800 W/m^2, fill factor is 0.7888. At radiation is 500 W/m^2, fill factor is 0.784. At radiation is 200 W/m^2, fill factor is 0.7806. The above fill factor result is in between 0.6 to 0.8, so the solar panel has a better performance.

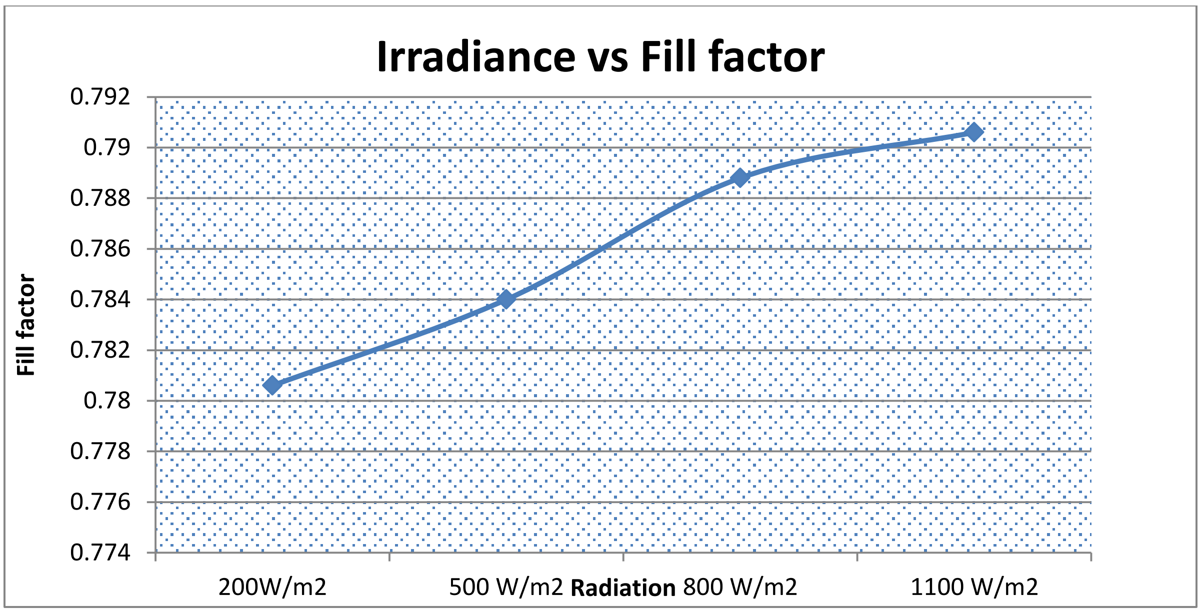


Figure 4.7: Shows the variation of Fill factor with changing Irradiance.

4.7. Effect of dust

From measured data by taking minimum, medium and maximum radiation level, different electric dc voltage and current were recorded with dust and after removing dust from panel. With dust, At the solar radiation of 1050 W/m^2, the open circuit voltage, short circuit current and operating power are 134.3 volt, 7.9 ampere and 959.06 watt respectively, when solar radiation of 800 W/m^2, the open circuit voltage, short circuit current and operating power are 130 volt, 3.8 ampere and 449.36 watt respectively, when solar radiation of 500 W/m^2, the open circuit voltage, short circuit current and operating power are 126.8 volt, 2.28 ampere and 262.6 watt respectively, When solar radiation of 200 W/m^2, the open circuit voltage, short circuit current and operating power are 123.6 volt, 1.02 ampere and 114.5 watt respectively. After removing dust from panel, At the solar radiation of 1050 W/m^2, the open circuit voltage, short circuit current and operating power are 135 volt, 7.97 ampere and 973.65 watt respectively, when solar radiation of 800 W/m^2, the open circuit voltage, short circuit current and operating power are 131 volt, 4.1 ampere and 491.48 watt respectively, when solar radiation of 500 W/m^2, the open circuit voltage, short circuit current and operating power are 128.3 volt, 2.6 ampere and 303.94 watt respectively, When solar radiation of 200 W/m^2, the open circuit voltage, short circuit current and operating power are 125 volt, 1.2 ampere and 137.76 watt respectively.

Figure 4.8 shows that the IV characteristic curve of the solar panel at maximum radiation with dust and removing dust from panel, and the graph shows the decreasing of the electrical current from without dust to dust on panel. So, the efficiency of the solar panel with dust and without dust at the panel is evaluated by taking the current electrical power output by considering dust from the panel and the current power output of the panel with removing the dust from panel at the maximum radiation label, and the lose efficiency of the panel due to the effect of dust is about 1.496% or 14.59 watt of power.

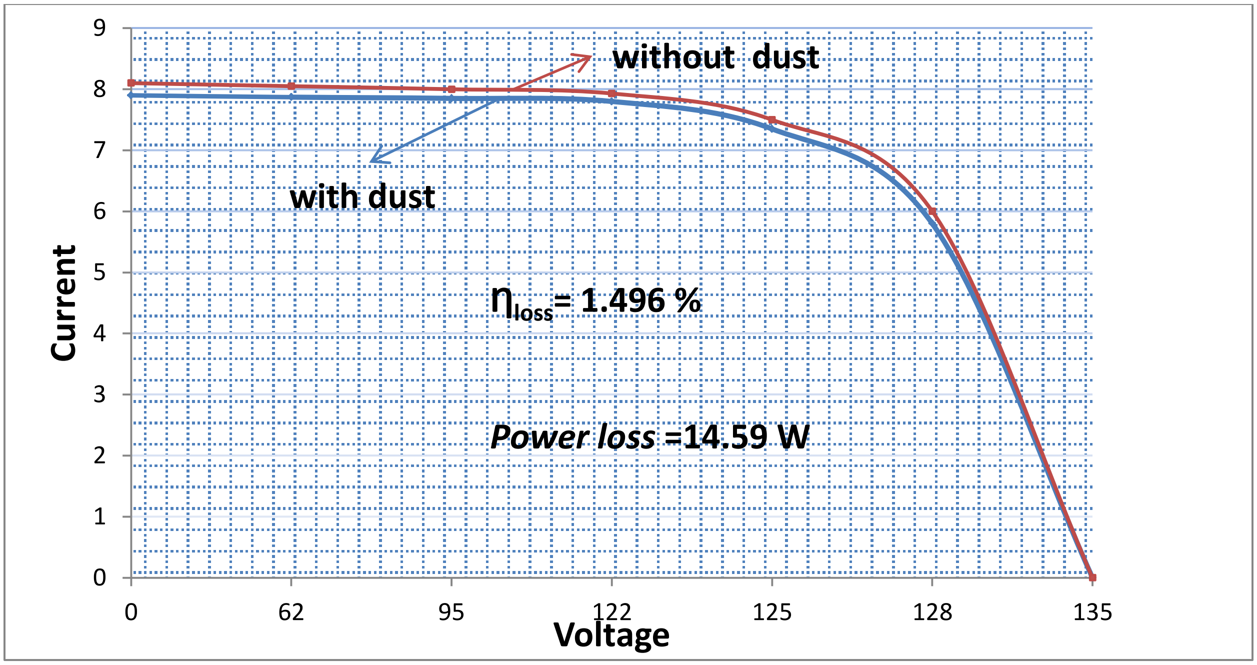


Figure 4.8: The I-V characteristic curve of solar panel with and without dust.

4.8. Solar DC Pump

The performance of the pump is evaluated by calculating the designed pump efficiency and the actual working efficiency of the pump. The designed maximum water flow rate of the pump at a given head and power is 0.8 liter/second (48 liter/min) and the power of the pump motor is 0.9 kW. The designed pump efficiency is 51.4% and the actual pump efficiency at maximum radiation and actual total dynamic head which is 40 meter at this level it yields 1.087 liter/second, then actual pump efficiency is 48.26%, Thus the performance of the pump is reduced by 3.14% from it is being to start working.

4.9. Overall efficiency

The solar PV panel efficiency is loosed by 2.79% and the submersible pump efficiency also loosed by 3.19%. By using equation 2.23, the total solar PV water pumping system efficiency is loosed by 5.96%.

4.10. Design of solar water pumping system

The solar PV water pumping system designed result is found by using the excel software, as mentioned in the methodology to design the solar water pumping system by using this software, it has different steps. And the results are explain as follows,

- The total daily water requirement is 159.9 m^3/day,
- Maximum design flow rate is 8.9 liter/second (31.9 m^3/hr),
- Storage tank size is 159.9 m^3,
- Total static head is 103.3 meter,
- Total friction loss in pipes and fittings is 16.4 meter,
- Total dynamic head is 121.4 meter,
- Total hydraulic water requirement is 10,538.8 watt (10.5388 kW),
- Required electrical energy is 55.8 kwh (11.13 kW),
- Most much module size to require system is 170 watt,
- Number of modules connected in series is 10 modules,
- Number of modules string in parallel is 8 modules.
- Total cost of the system is 2,529,950.00 ETB,
- Cost of pumping by solar pv system is 12.59 ETB/m^3,

- Cost of pumping by diesel pump is 37.60 ETB/ m^3,
- Percent of cost saving compared to diesel pump is 67%.

4.10.1. Step one; total daily water requirement.

1. Village/community water supply

Community water supply can be estimated from population size and from the daily per capita water consumption. Water demand estimation also considers the future demand from the growing population. Usually water demand estimation considers the life time of the water lifting system or the major cost item of the system components.

2. Water for livestock

Livestock water supply is estimated from the number of animals using the system multiplied by the per capita water consumption. It also considers livestock population growth rate.

Please enter daily water demands for the predicted period in gray shaded cells:

3. Location Name: Region	Amhera	Zone	W/gojam	Woreda	Mecha
Kebele	kolella	Site Name	mesal		

4. Community water suppy

Per capita water demand 20 liters/day (ranges from 15 to 50 liters/day)

5. Water for livestock

Livestock Type	Water demand (L/day)	Typical values (L/day)
Cattle	8	25 - 60
Camel	0	40 - 70
Equine	8	30 - 45
Sheep/goat	4	4 - 15
Pigs	0	10 - 20
Chicken	0	0.1

Values in __Green Shaded Cells__ are typical values for livestock water requirement. These values may vary depending on livestock breed and also seasonally. Users are required to enter appropriate values in __Gray shaded cells__.

Note: Water demand for humans and livestock may vary depending on local climatic conditions.

Daily Water Requirements: *Enter population valuse for the predicted period.*

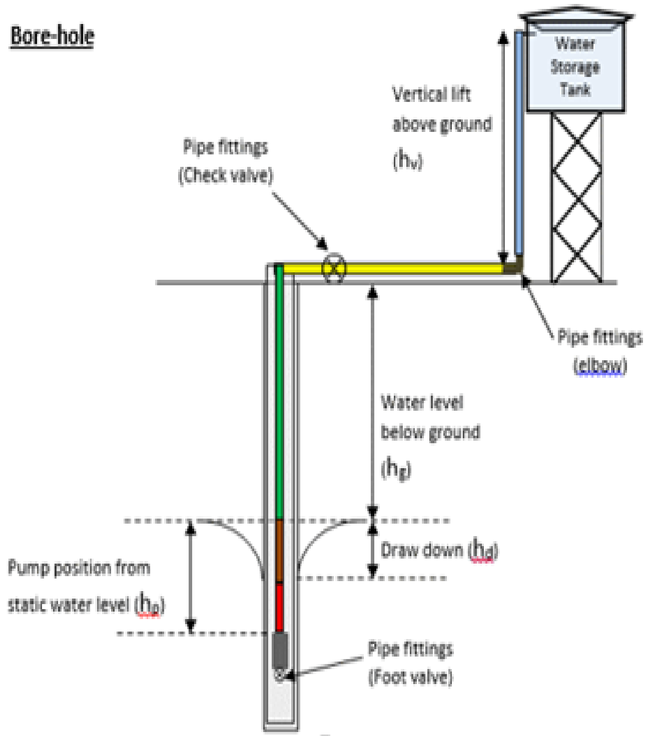
		Quantity	L/day
6	Population size	4,500	90,000
7	Cattle	5400	43,200
	Camel	20	0
	Equine	900	7,200
	Sheep/goat	3600	14,400
	Pigs	0	0
	Chicken	4500	450
8	Other water demand (L/day)	0	-
9	Enter additional percentage of daily water supply that you want to account for storage or compensate for losses	3.0%	
10	Storage Tank Required - days of storage	1.0	days
11	**Total Daily Water Requirement**	159.9	m^3/day
12	**Maximum/Design flow rate**	8.9	L/s
		31.9	m^3/h
13	**Storage Tank size**	159.9	m^3

4.10.2. Step two; hydraulic water requirement.

STEP 2 - Determine Hydraulic Power Requirement

To determine the hydraulic power requirement, the total daily water demand and the total dynamic head should be known.

Enter values only in Gray shaded cells. Refer the diagrams.



1	Source of water	Bore-hole	
2	Choose the type of pump:	Submersible pump	
3	Enter suction pipe length (For Suction pumps only) (Enter 0 for other types of pumps)	2.0	m
4	**Total Hydraulic Workload**	1.075	m^4/s

Static Head

5	Static water level below ground (hg)			30.0	m
6	Draw down (h_d)			3.0	m
7	Pump position from static water level (hp)			5.0	m
8	Vertical lift above ground (hv)			70.0	m
9	**Total Static Head**			**103.0**	**m**
	Head loss in pipe				
10	Riser pipe diameter			2.5	inch
11	Riser pipe type			Galvanized Steel	
12	Delivery pipe length			500	m
13	Delivery pipe diameter			3.5	inch
14	Delivery pipe type			PVC	
15	Adustment of friction loss for pipe aging			5	% (0- 15)
	Friction loss in the pipe			**15.31**	**m**
	Head losses in pipe fittings				
	Enter fitting sizes in inch	**Quantity**		**Size**	
16	Gate Valves	1		3.5	inch
17	Globe Valves	0		3.5	inch
18	Check Valve	1		3.5	inch
19	Foot valve with strainer	0		3.5	inch
20	90 Degree Elbows	5		3.5	inch
	Enter values in inch	**Quantity**		**From (inch)**	**To (inch)**
21	Reducers	0		3.5	2
22	Diffusers/Expansion	0		2.5	3.5
23	**Friction losses in pipe fittings**			1.06	m
24	**Total Friction losses in pipes and fittings**			**16.4**	m
25	Residual pressure at reservoir exit			**2.0**	m
26	**Total Dynamic Head**			**121.4**	m
27	**Percentage of friction losses**			**13%**	
28	**Total Hydraulic Power Requirement**			**10,538.8**	Watt

4.10.3. Step three; solar resource determination

Step 3 - Estimate the Solar Resource in the site

Determine the mean mothly global solar irradiance in $kWh/m^2/day$ for every month of the year. This can be obtained from sveral sources. Solar irradiance data can be obtained from the nearest meteorology station, national solar resource maps or own data for the site.

1 Enter the GPS coordinates of the site in Decimal Degrees

(Eg. 7.9549999 E, 34.31399917N)

Latitude: 12.69 °N Longitude: 37.02 °E

Altitude: 1897.98 m

2 Enter the tilt angel for the solar array 15 °

(Tilt angele between 10° to 15° for site in Ethiopia)

3 Populate the table with the mean mothly daily solar irradiance data for the site ($kWh/m^2/day$)

Month	Global Irradiance on Horizontal	Tilt	Irradiance on Array
January	5.54	15	5.4
February	6.22	15	6.0
March	6.82	15	6.6
April	7.01	15	6.8
May	6.86	15	6.6
June	6.37	15	6.2
July	6.72	15	6.5
August	6.67	15	6.4
September	6.19	15	6.0
October	5.72	15	5.5
Novemebr	5.19	15	5.0
December	5.26	15	5.1

(**Note**: For inhabited areas, the solar radiation flux varies from about 3 to 30MJ per m^2 per day (0.8 to 8.3 kWh per m^2 per day), depending on the place, time and weather conditions).

4 Design month is the month for which the solar pumping system is sized to ensure sufficient water supply when the solar irradiance is the minimum while the corresponding hyraulic power is the maximum. This is the month where the Reference Area is the maximum.

Month	Average hydraulic power (kWh/day)	Solar Irradiance on Array ($kWh/m^2/day$)	Ratio P_{hy}/Irrad
January	52.8	5.4	9.87
February	52.8	6.0	8.79
March	52.8	6.6	8.02
April	52.8	6.8	7.80
May	52.8	6.6	7.97
June	52.8	6.2	8.59
July	52.8	6.5	8.14
August	52.8	6.4	8.20
September	52.8	6.0	8.84
October	52.8	5.5	9.56
Novemebr	52.8	5.0	10.54
December	52.8	5.1	10.40

Design month is the month for which the solar PV system is sized to ensure sufficient water supply when the solar resource is the minimum.

5 Design month is the month of ***Novemebr***

with mean solar irradiance of ***5.0*** $kWh/m^2/d$

4.10.4. Step four; determining of PV array size

Step 4 - Determine PV Array Size

When determining the PV array size, derate factors for the array performance due to power mismatch and cell temperaturing increase are considered. In this worksheet a derate factor of 20% is considred.

Required electrical energy and the corresponding solar PV power

1 Average subsystem energy efficiency 60% *(Typical values 50% to 70%)*
(Older electrical pump sets may have lower sub system efficiency)

2 Required electrical energy: 55.8 kWh 11.13 kW

3 PV Array Size Needed: 13,576 Wp

Note: Use manufacturers manual for pumps to determine the appropriate type and size of motor-pump unit at the *Maximum Flow Rate* (shown in '**Daily Water Requirement**' sheet) and at the *Total Dynamic Head* (shown in '**Hydraulic Power Requirement**' sheet). Read the pump efficiency from the manufacturers' manual at the system's operating head and discharge. Also determine the minimum and maximum input voltage, and maximum input current to the motor-pump unit directly or to the inverter. Enter these values in the gray shaded

Selection of module size and PV array arrangement

(Selection of modules is made from size that range from 50 Wp to 250Wp)

4 Minimum operating input voltage to pump/inve 420 Volt

5 Maximum input voltage of pump/ inverter 500 Volt

6 Maximum input current of pump/ inverter 40.0 A

7 Wire loss factor 0.95 *(Typi*

8 Most matched module size to required system 170 Wp

9 Number of modules connected in sieries 10

10 Number of module strings in parallel 8

11 Actual Size of PV Array 13,600 Wp

Warning: System voltage and current must not exceed the maximum Voltage and maximum Current of the pump or inverter.

In such cases, user may need to look for a different array configuration or another motor-pump unit or inverter with higher maximum input voltage and current.

4.10.5. Step five; bill of quantities and costs.

Step 5 - Determine bill of quantities and bill of costs

Bill of Quantities and cost of main solar pumping components

#	Cost Item	Description	Measuring Unit	Quantity	Unit Price (ETB)	Total Price (ETB)
1	Solar Module	170	Wp	80	8,000.00	640,000.00
2	Inverter/Controller/Switch		Number	1	100,000.00	100,000.00
	Min. operating voltage (V)	*420*				
	Maximum input voltage (V)	*500*				
	Maximum input current (I)	*40*				
3	Pump (solar pump)	11.1	kW	1	120,000.00	120,000.00
	Type of pump	Submersible pump				
4	Water pipes					
	Suction/riser pipe type and size	*Galvanized Steel*	meter	110	300.00	33,000.00
	Suction/riser pipe diameter (inch)	*2.5*				
	Delivery pipe type size	*PVC*	m	2320	300.00	696,000.00
	Deliver pipe diamber (inch)	*3.5*				
5	Pipe fittings (inches)					
	Gate Valves	3.5	Number	1	400.00	400.0
	Globe Valves	3.5	Number	0	540.00	0.0
	Foot valve with strainer	3.5	Number	0		
	90 Degree Elbows	3.5	Number	5	400.00	2,000.0
	Check valve	3.5	Number	1	600.00	600.0
	Reducers	3.5	Number	0	200.00	0.0
	Diffusers/Expansion	3.5	Number	0	340.00	0.0
6	Conductors and accessaries		meter	165	230.00	37,950.0
	Conductor material	copper				
	Wire diameter @ < 10% loss (mm^2)	8.37				
7	Array support structure	Metal				100,000.0
8	Water storage tank					800,000.0
	Material	RC Concrete				
	Capacity	71				
9	Water tank support structure	**Masonry**				0.0
Total cost of system						**2,529,950.00**

4.10.6. Step six; financial feasibility of the system.

Step 6 - Determine financail feasibiilty of the system

Cost factors

Cost of complete solar pump sytem+ pipes+fittin	2,529,950.00	ETB	Discounting rate	10%	
Life time of a PV pump system	20	years	Required pumping capacity	8.93	m^3/hour (For a diesel pump)
Cost of Diesel motor/genset, pump & controller	30,000	ETB/kW	Required pumping capacity	7.0	kW
Diesel Engine Efficiency	40%	(35% to 50%)	Hydraulic Energy	33.48	kWh per day
Average Diesel Pump Efficiency	70%	(50% to 70%)	Required Diesel genset size	37.8	kW
Derate factor due to Altitude	93%		Diesle consumption	0.22	liter/kWh *(at about a 1/3 of full l*
Drive Factor	Electrical		Regular service cost for diesel genset	850	ETB (Filter+oil+technician)
Optimum load of operation	50%		Diesel price at service point	19	ETB/L
Life expectancy of a diesel motor/ genset	15,000	hours	Cost of diesel motor/genset	1,134,594	ETB
Daily operation time for diesel pump	8	hours	Pumping days with a diesel pump	365	days
Life time of a diesel motor/genset	5.1	years	Annual operation/management costs	6,000.00	ETB/year
Regular service time at	250	hours			

4.10.7. Step seven; financial comparison between solar PV and diesel pumping system.

Financial Comparison between solar PV and diesel water pumping system based on major cost items

Water pumping system	Annualized Cost of system	Annual Maintenance/ service cost	Cost of fuel	Annual costs for water pumping (ETB/year)	Cost of pumping (ETB/m^3)	Percent of cost saving
Solar PV pump	297,166.98	31,300	-	328,466	12.59	67%
Diesel Pump	503,322.91	15,928	461,613.22	980,864	37.60	

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The performance and efficiency of solar powered water pumping system is evaluated in accordance to the details available in journals and previous works. The system efficiency is evaluated by measuring and calculating different factors of solar pump performance and comparing the result with the designed capacity of the solar pumping system.

From the study the following results were obtained: The irradiance has a significant effect on the average discharge of the pump from morning to noon time as the irradiance increased, the discharge of the pump also increased and its measured value at morning 0.231 liter/second and at noon 1.087 liter/second. The efficiency of the solar panel due to the variation of irradiation is reduced by 2.035% from the designed working capacity at 1000 W/m^2 radiation level. The efficiency of the solar panel due to the generated panel temperature is reduced by 0.755% at 1000 W/m^2 and 60 ^{0}c from the recommended design temperature of 25 ^{0}c. The fill factor value was calculated to be 0.7906, 0.7888, 0.784 and 0.7806 at 1000 W/m^2, 800 W/m^2 500 W/m^2 and 200 W/m^2 radiation level respectively and this result shows in a recommended region of the safe quality of the solar pane so, the panel still has a good quality and performance to convert solar energy to electrical energy. The submersible pump efficiency is loosed by 3.14 % from its designed capacity, totally the solar water pumping system installed at kolella kebele is reduced its efficiency by 5.96%.

The effects of dust also has a great influence on the performance of solar PV water pumping system and by comparing the efficiency of panel at dust were available and after removing dust from panel, the efficiency is reduced by 1.496%. The calculated value of total water demand of the community is 157,200 liter per day, but the measured value that the community still uses from this system is about 16,528 liter/day and the pumping hour of pump is 8:24 hour per day because of adjusting the floating swich. The performance of the solar pumping system is good and enough sufficient for the current users of the community but for the whole society of kolella kebele it does not efficient so, due to this reason there were the new design of solar pv water pumping system. The result of the design is as follows; Total hydraulic water requirement is 10,538.8 watt (10.5388 kW), Required electrical energy is 55.8 kwh (11.13 kW), Most much module size to require system is 170 watt, Number of modules connected in series is 10 modules, Number of modules string in parallel is 8 modules, Total cost of the system is 2,529,950.00 ETB, Cost of pumping by solar pv system is 12.59 ETB/m^3, Percent of cost saving compared to diesel pump is 67%.

5.2. Recommendations for further work

The total actual water consumption of the community (households and school students) is 17,435.5 liter/day. But in actual case the water demand of community those are users from three water point based on the calculation must be 25,500 liter/day and the average measured water consumption at different days by water flow meter at the outlet of the storage tank is 16,528 liter/day. Based on the result, the community does not use the water resource properly because of the following reasons;

- The community does not have a habit to use safe water for their animals.
- They are not able to use water for washing purpose.
- The water point from their house is a little far and difficult for transporting the water, unless water is distributed safely to each household.
- The elevation difference between the top storage tank and the water point must be known perfectly. (as shown in figure 1.3 the third water pint elevation is higher than the storage tank elevation)

To achieve the water demand of the whole community either installing a new solar powered water pumping system based on the design or installing a new pump having higher capacity, increase a recovery water volume amount, constructing a new concrete base water storage tank and put it at higher elevation mountain to get enough power to distribute water to each households in the community.

To increase the performance and efficiency of the solar water pumping system, the following technical works must be taking place;

- Remove any trees around which may a cause for shading.

- Adjusting the water floating switch at the storage tank and motor control board and this results reducing the working hour of the pump with in day and sustained its efficiency as well.
- Tap water outlet from the main delivery pipe and adjust the gate valve for cleaning the dust from the panel.

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APPENDIXES

Appendix A

Table 7.1: average monthly daily radiation and other factors test measurement

Time	Irradiation (w/m2)	Electrical power(kw)	Water flow rate (liter/sec)	Panel temperature(^{0}C)
07:00	241	0.15	0.231	25
07:30	289	0.17	0.241	25
08:00	354	0.189	0.254	26
08:30	412	0.2	0.278	28
09:00	624	0.32	0.512	32
09:30	710	0.39	0.562	35
10:00	870	0.42	0.659	41
10:30	921	0.5	0.717	43
11:00	987	0.54	0.884	49
11:30	1011	0.609	1.012	57
12:00	1050	0.63	1.087	60
12:30	1036	0.618	1.019	58
01:00	1025	0.6	0.951	57
01:30	1004	0.58	0.902	53
02:00	964	0.53	0.846	48
02:30	930	0.51	0.7303	45
03:00	902	0.49	0.701	42
03:30	860	0.41	0.624	40
04:00	674	0.34	0.513	32
04:30	602	0.31	0.489	31
05:00	511	0.26	0.348	29
05:30	431	0.21	0.296	28
06:00	232	0.14	0.224	26

Table 7.2: The test measured and designed value of voltage and current at different radiation

Run	Set	Voltage(V)	Current(A)	Power (W)
1	Irradiance 1000 w/m^2	149.6 (V_{oc})	0	0
2		123.2	8.12	1000 (Mpp power)
3		0	8.67 (I_{sc})	0
1	Irradiance 1000 w/m^2	138	0	0
2		122	8	973.65(Mpp power)
3		0	8.6	0
1	Irradiance 800 w/m^2	131	0	0
2		119.8	4.1	491.48 (Mpp power)
3		0	4.8	0
1	Irradiance 500 w/m^2	128.3	0	0
2		116.9	2.6	303.94 (Mpp power)
3		0	3.1	0
1	Irradiance 200 w/m^2	125	0	0
2		114.8	1.2	137.76 (Mpp power)
3		0	1.45	0

Table 7.3: The test measured and designed value of voltage and current at different temperature and same radiation.

Run	Set	Voltage(V)	Current(A)	Power (W)
1	At T=25 ^{0}C	149.6	0	0
2	Irradiance	123.2	8.12	1000 (Mpp power)
3	1000 w/m^2	0	8.67	0
1	At T=60 ^{0}C	138	0	0
2	Irradiance	121.4	8.01	972.41 (Mpp power)
3	1000 w/m^2	0	8.6	0
1	At T=56 ^{0}C	142.6	0	0
2	Irradiance	121.6	8.05	974.2 (Mpp power)
3	1000 w/m^2	0	8.61	0
1	At T=54 ^{0}C	144.1	0	0
2	Irradiance	122	8.07	984.54(Mpp power)
3	1000 w/m^2	0	8.63	0
1	At T=52 ^{0}C	146.8	0	0
2	Irradiance	122.5	8.09	991.01 (Mpp power)
3	1000 w/m^2	0	8.65	0

Table 7.4: The fill factor at different radiation level

NUMBER	IRRADIANCE	FILL FACTOR
1	1000 W/m^2	0.7906
2	800 W/m^2	0.7888
3	500 W/m^2	0.784
4	200 W/m^2	0.7806

Table 7.5: the outdoor test measured value of panel power and flow rate at different value of radiation without removing dust from panel.

Run	Irradiance	Voltage(V)	Current(A)	Power(W)	Flow rate(l/s)
1	1000 w/m^2	134.3	0	0	0
2		121.4	7.9	959.06	1
3		0	7.95	0	0
1	800 w/m^2	130	0	0	0
2		118.4	3.8	449.36	0.59
3		0	4.61	0	0
1	500 w/m^2	126.8	0	0	0
2		115.2	2.28	262.6	0.31
3		0	2.91	0	0
1	200 w/m^2	123.6	0	0	0
2		112.3	1.02	114.5	0.199
3		0	1.26	0	0

Table 7.6 the outdoor test measured value of panel power and flow rate at different value of radiation with removing dust from panel.

Run	Irradiance	Voltage(V)	Current(A)	Power(W)	Flow rate(l/s)
1	1000 w/m^2	135	0	0	0
2		122	7.97	973.65 (Mpp power)	1.087
3		0	7.99	0	0
1	800 w/m^2	131	0	0	0
2		119.8	4.1	491.48 (Mpp power)	0.615
3		0	4.8	0	0

1	**500 w/m^2**	**128.3**	**0**	**0**	**0**
2		**116.9**	**2.6**	**303.94 (Mpp power)**	**0.346**
3		**0**	**3.1**	**0**	**0**
1	**200 w/m^2**	**125**	**0**	**0**	**0**
2		**114.8**	**1.2**	**137.76 (Mpp power)**	**0.22**
3		**0**	**1.45**	**0**	**0**

Table 7.7 Number of animals per house, Water demand in liter per day and total water consumption by animals

number	**animals**	**Number of animals per house**	**Water demand per day**	**Total water demand**
1	**Cattle**	**6**	**8 liter/day**	**48 liter**
2	**Horse or mule**	**1**	**8 liter/day**	**8 liter/day**
3	**Sheep and goat**	**4**	**3 liter/day**	**12 liter/day**
4	**Cat and dog**	**2**	**1 liter/day**	**2 liter/day**
5	**Total**			**70 liter/day**

.

Table 7.8 measured value of pumped water, pump hour per day and consumed water at different days.

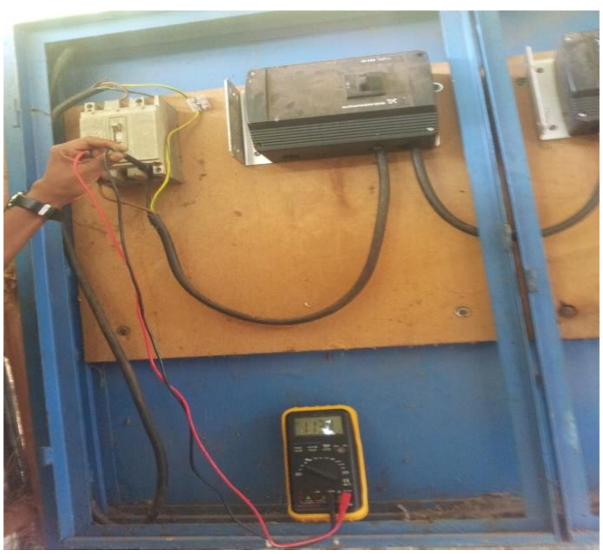
Day	**Pumped water(liter/day)**	**Pumped hour to fill storage tank**	**Consumed water (liter/day)**
1	**19,564**	**8:40**	**15,090**
2	**18,050**	**8:55**	**17,681**
3	**17,678**	**9:00**	**18,560**
4	**19,800**	**8:20**	**16,480**
5	**21,056**	**8:02**	**17,254**
6	**20,965**	**8:15**	**14,500**
7	**21,650**	**8:00**	**15,360**

8	**19,245**	**8:10**	**16,250**
9	**20,156**	**7:55**	**17,600**
10	**17,689**	**8:50**	**16,500**
Average	**19,585**	**8:24**	**16,528**

Appendix B

Photos of the project

Photo of solar panel



Electrical power test by multi meter constructed water flow meter

Photo of motor control board

Panel temperature test by thermocouple

photo of gate valve after constructing

During assembly of flow meter

Installing of water level switch on the tank

Appendix C

Numerical Analysis

Total Watering Needs

The total water demand of the households without considering the festivity day will be

= (the number of houses) * (average household per house) * (water demand per person per day)

= 900 * 5 *20 liter/day

= 90,000 liter/day

Within one month there are seven (7) days are festivity and Sunday and the water demand is increased by 20% so,

The festivity and Sunday water demand = 90,000 + (0.2 * 90,000)

=108,000 liter/day

The festivity day and Sunday water demand per month will be

=108,000 L/day *7 days

=756,000 liter/ month

The normal day water demand within a month = 90,000 liter/day *(30-7) days.

= 2,070,000 liter/ month

The cumulative water demand per month by considering the festivity days and normal days will be = (*2,070,000 +756,000)* liter per month

=*2,826,000* liter/ month

The water demand of the households per day

$$=\frac{2,826,000}{30} = \textbf{\textit{94,200 liter/day}}$$

The total water demand of the animals will be

= number of house * water demand per day

= *900 * 70 liter/day*

=*63,000 liter/day*

Total daily water demand of the community = volume of households + volume of animals

= 94,200 liter/day + 63,000 liter day

=157,200 liter/day

The efficiency of the solar panel can be calculated by taking the current electrical power output from the panel and the designed power output of the new panel at the same radiation label.

$$\text{Efficiency} = \frac{\text{current power out put}}{designed\ power\ output} = \frac{973.65W}{1000W} = 0.97965$$

$$= 97.965\%$$

Effect of radiation

The power generation by the panel is loosed by the following amount

Power loss = designed power – current power

=1000W- 979.65W

=20.35 W

$$\eta_{loss} = \frac{20.35\ w}{1000\ w} = 0.02035$$

$$= 2.035\%$$

Effect of temperature

The efficiency of the solar panel can be calculated by taking the current electrical power output at maximum panel temperature (60 ^{0}c)from the panel and the designed power output of the new panel at the operating temperature (25 ^{0}c) label.

$$\text{Efficiency} = \frac{\text{current power out put}}{designed\ power\ output} = \frac{972.41W}{1000W} = 0.97241$$

$$= 97.2\%$$

The power generation by the panel by considering effect of temperature at a given irradiance is loosed by the following amount;

Power loss = designed power – current power

$$=1000W - 972.21W$$

$$=27.79\ W$$

$$\eta_{loss} = \frac{27.79\ w}{1000\ w} = 0.0279$$

$$= 2.79\ \%$$

But it includes currently performance loss of panel at different radiation

$$\text{Net efficiency loss} = 2.79\% - 2.035\%$$

$$= 0.755\%$$

Fill factor

The fill factor at different radiation can be obtained as follows;

- ✓ At irradiance 1050 W/m^2,

$$\text{Fill factor} = \text{FF} = \frac{power}{Voc*Isc} = \frac{964.71W}{135\ V*7.91\ A} = 0.7906$$

- ✓ At irradiance of 800 W/m^2

$$\text{Fill factor} = \frac{power}{Voc*Isc} = \frac{491.48\ W}{131\ V*4.8\ A} = 0.7888$$

- ✓ At irradiance of 500 W/m^2

$$\text{Fill factor} = \frac{power}{\text{Voc}*\text{Isc}} = \frac{303.94W}{123.3\ V*3.1\ A} = 0.784$$

- ✓ At irradiance of 200 W/m^2

$$\text{Fill factor} = \frac{power}{\text{Voc}*\text{Isc}} = \frac{137.76\ W}{125\ V*1.45\ A} = 0.7806$$

Effect of dust

- At maximum radiation label (1100 w/m^2)

$$\text{Efficiency} = \frac{\text{power out put with dust}}{power\ output\ without\ dust} = \frac{959.06W}{973.65W} = 0.9846$$

$$= 98.46\ \%$$

The power generation difference of the panel with dust and without dust at a given irradiance will be;

$$Power\ loss = power\ output\ without\ dust - power\ out\ put\ with\ dust$$

$$=973.65W - 959.06W$$

$$=14.59\ W$$

$$\eta_{loss} = \frac{14.59\ w}{973.65\ w} = 0.01537$$

$$= 1.496\ \%$$

Solar Dc pump efficiency

The designed pump efficiency will be,

$$\text{Efficiency} = \eta_{designed} = \frac{hydraulic\ power}{electrical\ power}$$

$$= \frac{\rho * g * H * Q}{Pin}$$

$$= \frac{1000\frac{\text{kg}}{\text{m3}} * 9.81\frac{m}{s2}\ 59\ m * 0.8\ l/s}{900\ w}$$

$$=51.4\%$$

The actual pump efficiency at maximum radiation and actual total dynamic head which is 40 meter at this level it yields 1.087 liter/second.

$$\text{Efficiency} = \eta_{actual} = \frac{hydraulic\ power}{electrical\ power}$$

$$= \frac{\rho * g * H * Q}{Pin}$$

$$= \frac{1000\frac{kg}{m3} * 9.81\frac{m}{s2}\ 40\ m * 1.087\ l/s}{900\ w}$$

= 48.26%

The performance loss of the pump since it installed will be ;

= designed efficiency of the pump – actual efficiency of the pump

= 51.4 % – 48.26 %

= 3.14 %

Thus the performance of the pump is reduced by 3.14% from it is being to start working.