Design of Solar PV Underground Water Pumping System for Household Water Consumption in Bilate Basin, Ethiopia

Mulugeta Tadesse[1*], Chernet Merkneh[2]

[1]Assistant professor, Department of Mechanical Engineering, College of Engineering, Wolaita Sodo University, Ethiopia; P.O. Box: 138

[2]Department of Mechanical Engineering, College of Engineering, Wolaita Sodo University, Ethiopia; P.O. Box: 138

Abstract: *The design of the solar PV underground water pumping system in the Bilate basin, Ethiopia based on the data of solar radiation, average surface atmospheric temperature, wind speed and other weather condition. It is designed to satisfy the total power demand of the hydraulic pump using solar PV modules. The system components are solar PV module, charge controller, battery and inverter.*

The system is configuration made to supply 15 m^3 water which is the maximum daily household water demand for the ten households from the 13 m deep underground water well. The hydraulic power of the pump calculated considering pipe friction and pump-set efficiency is 195.918 watts. Based this initial power demand, the number of PV modules, inverter and battery is determined. The number PV modules needed for this specific system is 6 modules, 6 inverters and 3 battery sets.

The comparison analysis made by using HOMER energy software, the total cost PV system is $2,927, diesel fuel generator pumping system is $3,194 while wind power water pumping system is $5, 300 ignoring common pump set, water storage tank construction and pipes cost. Wind and solar PV systems are environmental pollution free while diesel generator water pumping system releases 241 kg/year CO_2 and 0.483 kg/year SO_2 to the living environment.

In the case of total initial investment and total life time costs as well as the maintenance and operation costs and in case of pollution, solar PV underground water pumping system is more preferable.

Keywords*: Pump, Power, PV, Solar, Underground, Water*

I. INTRODUCTION AND BACKGROUND

Water is the most important thing for the existence life on the earth next to air. Plants need water to prepare their food using solar radiation through photosynthesis process and transporting minerals and also for the structure of the cells. An animal's cells need water for its proper functioning and transporting some minerals within the organs. Specifically, human body which is 60% water needs water to regulate body temperature and excretion, maintain the structure of cells as well as whole body and to assist digestion process. In addition to this, water needed daily for washing closes, living shelter, cooking utensils and also for cooking.

In Ethiopia, 85% of the populations live in rural areas while only 15% lives in urban. According to the Growth and Transformation Plan-I, the drinking water supply coverage is 65.8% (91.5% urban and 62% rural). While there has been significant progress in recent years, there are still close to 30 million people who lack access to safe and reliable sources of drinking water [1]. Because of this reason, in Ethiopia 46% of under-five-year's children are die related to waterborne diseases [2]. In some areas of the country the traditional water pumping systems powered by diesel or gasoline engines have been used for long time, but fuel cost, transportation problem, lack of skilled personnel makes the conventional water pumping system unreliable and expensive for rural communities. In developing countries like Ethiopia, generally composed of several villages sparsely located and with different topography, it is very difficult to extend the electric grid to every location where it is required. Also, the lack of safe drinking water is still an issue to be solved in many developing countries, especially in rural areas [3]. The trend of increasing fossil fuel price and its high contribution to environmental problems makes fossil energy sources unpromising. Different researches have been carried out and their results show that, renewable energies are the best alternative energy sources to replace the fossil energy to get energy demand for water pumping system. Among renewable energy sources, solar PV is the most preferable in the case construction and future maintenance simplicity, average total investment cost as well as energy density relation [4].

The solar PV underground water pumping system for the household water consumption works that the solar PV module is used to supply input electrical energy that derives the hydraulic pump motor. The components of solar PV under water pumping system to attain the pumping objectives, there is solar PV module, hydraulic pump with its motor, and accessories such as charge controllers, battery, inverter or DC-to DC inverter and cables and pipes and control valves as shown in figure 1 below.

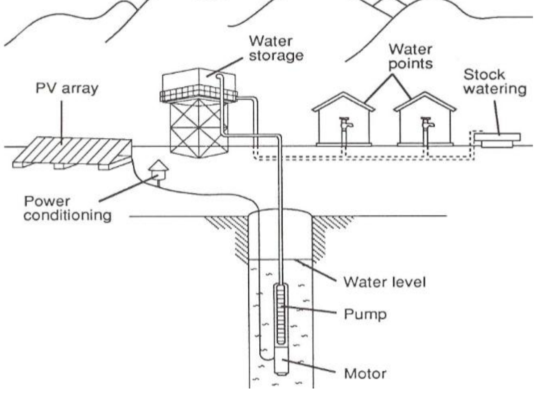


***Fig. 1*: Solar PV water pumping system**

Solar PV water pumps are cost-effective, environment-friendly and have good potential in places with high water table

Water pumping worldwide is generally dependent on conventional electricity or diesel generated electricity. Solar water pumping reduces the dependency on diesel; gas or coal and other fossil-fuels based electricity energy sources. The uses of fossil-fuels hydrocarbon based water pumping systems require not only the cost fuels, but it creates noise and air pollution to the living environment. The overall upfront cost, operation and maintenance cost, and replacement of parts of the diesel pump are 2–4 times higher than that of solar photovoltaic (PV) water pumping system. Solar pumping systems are environment friendly and require low maintenance with no fuel cost through its life time [4]. Keeping in view the shortage of grid electricity in rural and remote areas in most parts of world, PV pumping is one of the most capable applications of solar energy source. The technology is similar to any other conventional water pumping system except that the power source is solar energy. PV water pumping is gaining importance in recent years due to non-availability of electricity and increasing cost of diesel oil. The mass flow rate of pumped water is depends on the solar radiation incident and number of PV array interconnected. A properly designed solar PV system results in significant long-time relatively cost free as comparing to conventional water pumping systems [5].

Solar water pumping system may be classified as direct coupled solar water pumping system and battery coupled water pumping system [6]. Direct coupled water pumping system does not need battery to store electricity it to be used when sunshine is off. It uses directly DC motor to derive hydraulic pump. Battery coupled water pump system uses battery to store the electricity generated from solar PV panel and is reused for the time of sun is not shining as shown in figure 2 below.

The various types of components of PV system configurations of either direct coupled DC and/or AC solar water pumping systems being used worldwide.

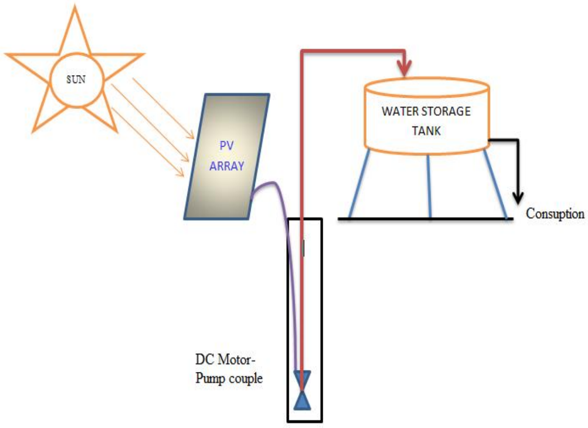


***Fig. 2*: Schematic of a direct coupled solar PV water pumping system**

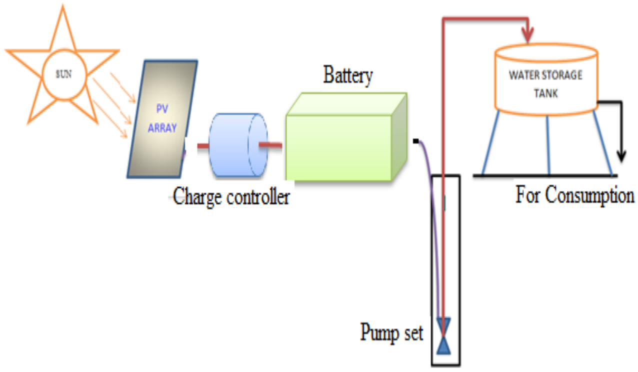


***Fig. 3*: Schematic of a battery coupled solar PV water pumping system**

Solar water pumping is a system based on solar PV technology that converts solar radiation into electricity to pump water. The solar PV module are connected to a motor (DC or AC) which converts electrical energy supplied from the PV module into mechanical energy which in turn derive hydraulic pump that is the conversion of mechanical energy to hydraulic energy in the pump. The capacity of a solar pumping system is a function of three main variables: pressure, flow, and power to the pump. For design purposes pressure can be regarded as the work done by a pump to lift a certain amount of water up to the storage tank. The elevation difference between the water source and storage tank determines the work, a pump has to do. The water pump will draw a certain power which a PV array needs to supply.

This research project aims to come up with the full design of the solar PV underground water pumping system for the area in the Wolaita zone, Ethiopia around Bilate basin between Humbo and Blate Charcho. The area has high underground water potential as same time it is high solar energy potential area.

II. MATERIALS AND METHODS

A. Water supply source

Water supply source of the solar PV water pumping system can be a pond, stream, and spring, deep drilled underground well or nearby Flow River. Water source must recharge faster than water pumping rate for its sustainable existence. 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 set. Main variables for system design are water reservoir volume, recharge rate and cost.

B. Study area

The selected site of this research project is Wolaita zone, Ethiopia around Bilate basin between Humbo and Blate Charcho. It is around the Bilate River which is a river of south-central Ethiopia. It rises on the southwestern slopes of Mount Gurage near 6°2′N 38°7′E, flowing south along the western side of the Great Rift Valley, to empty into Lake Abaya at 6°37′54″N 37°59′6″E. It is the longest river flowing into Lake Abaya and also the one with the highest discharge. The river is not navigable and it has no notable tributaries. The areal size of the basin is approximately 5,754 km^2. The areas has average monthly insolation incident on the horizontal surface of 5.70 KWh/m2/day with the average monthly temperature on the horizontal surface of 23.3 ^{O}C.

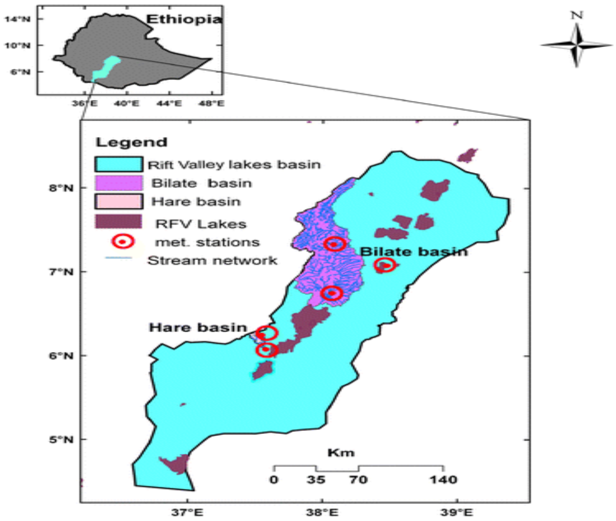


Fig. 4: **Map of the Bilate basin, Ethiopia**

Atmospheric data

The atmospheric data that critically needed for the system design which are solar insolation, average surface temperature and average wind speed data of the area that are collected by using site location latitude and longitude (6°37′54″N 37°59′6″E) from NASA using [https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?&num=218097&lat=6.37&hgt=100&submit=Submit&veg=17&sitelev=&email=&p=grid_id&p=swvdwncook&step=2&lon=37.59.6].

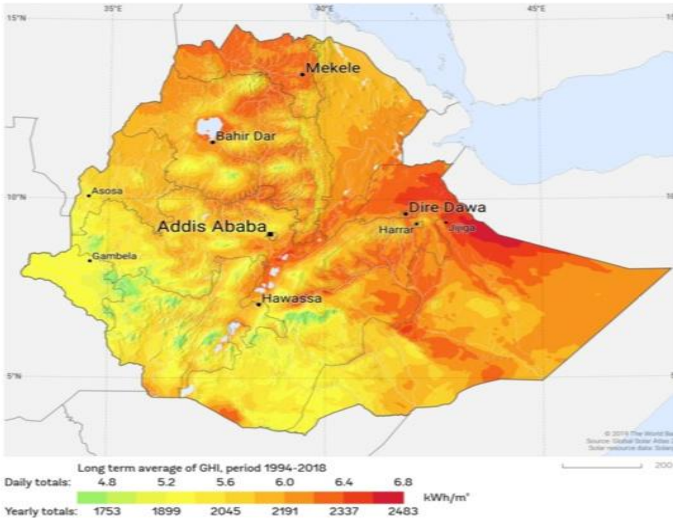


Fig. 5: **Global horizontal irradiation of Ethiopia**

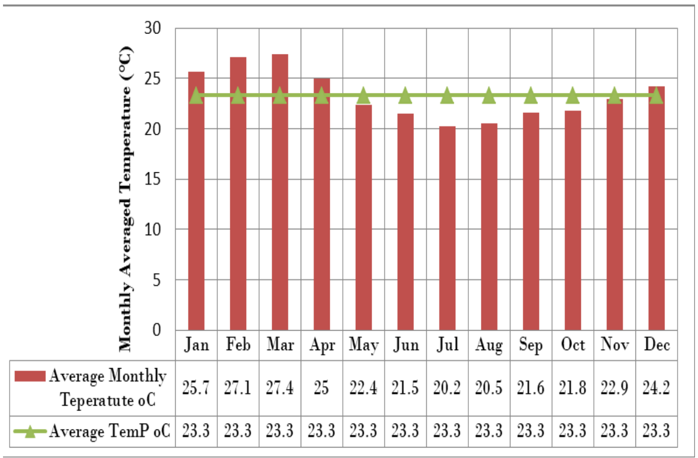


Fig. 6: **Monthly 22 years average surface temperature and its average value**

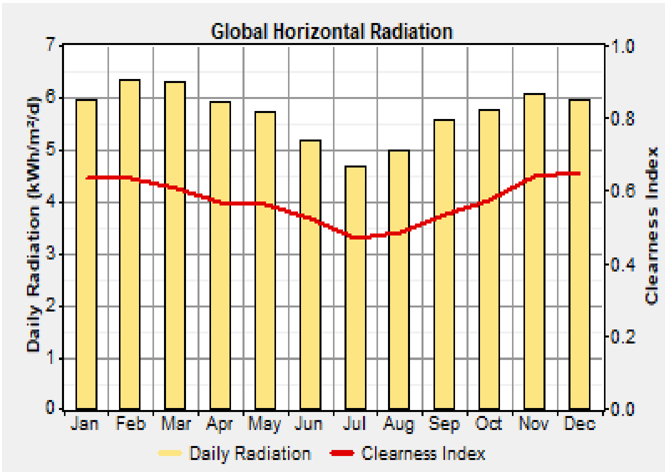
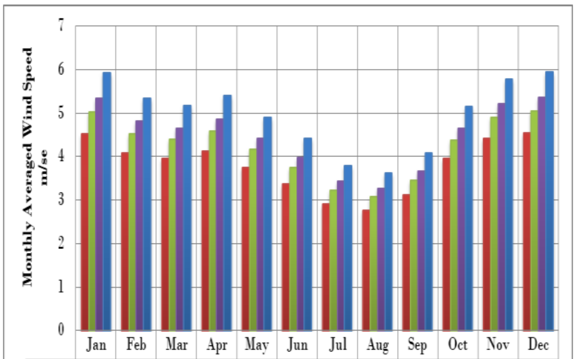


Fig. 7: **Monthly 22 years average insolation and clearness index**



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
50 m	4.53	4.09	3.96	4.13	3.75	3.38	2.91	2.77	3.12	3.95	4.42	4.55
100 m	5.02	4.53	4.39	4.58	4.16	3.75	3.22	3.07	3.46	4.38	4.9	5.04
150 m	5.34	4.82	4.66	4.86	4.42	3.98	3.43	3.26	3.67	4.65	5.21	5.36
300 m	5.92	5.35	5.18	5.4	4.9	4.42	3.8	3.62	4.08	5.16	5.78	5.95

***Fig. 8*: Monthly 22 years average wind speed (m/se) its average value in different heights**

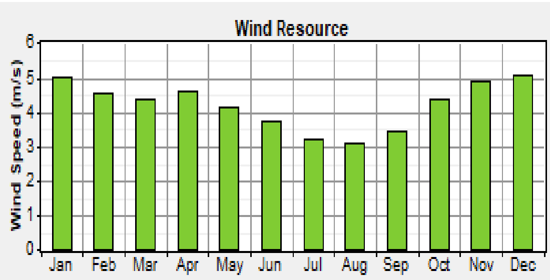


***Figure-9:* Monthly 22 years average wind speed (m/se) at 100 m**

III. DESIGN OF SYSTEM COMPONENTS

A. Water pumping power demand

In this paper it is estimated that to deliver underground water for ten houses in rural areas including all their daily water demands. This includes washing of closes, shower and cooking utensils, cooking, drinking, drinking of average number of cattle, cleaning of house, etc. average it needs 1.5m^3 per house and for total 10 households it is 15 m^3 per day. However the average daily household water consumption can not be greater than 900 liters [10].

The demand of power to supply 15 m^3 water from the maximum depth of 13 m underground water well to the 3 m height storage tank of total height of 16 m and with the consideration of its friction, material and bent power loss is estimated by using the formula; The water flow rate Q(l/sec) in the average sunny interval of a day, 8 hours, it will be;

Q = 15, 000/8*60*60
= 15000/28800
=0.52 l/sec= 5.2 *10^{-3} m^3/sec

The total head, h_T is the sum the well depth at which water is pumped out, h_w and h_s the height of storage tank at which water is temporarily stored for the night time use, and h_f is the head loss encounter due to friction and other losses.

$$h_T = h_w + h_s + h_f$$

Then hw is taken 13 m, hs is 3 m and hf is calculated by using the relation:

The head loss due to friction and other vents and from submerged exit losses is calculated using the relation [11];

$$hf = \left(f\frac{L}{Dh} + \sum k\right)\frac{V_{av}{}^2}{2g}$$

Where:
f=Darcy friction constant
L-the tolat length of pipe (estimated 16 m)
Dh-hydraulic diameter of pipe (is 2 cm)
K –friction loss constants of pipe parts (0.5 for sharp edge entrance, 1.06 for submerged exit)
Vav- average flow velocity
g- Gravity constant (g=9.81 m/se^2)
The average flow velocity;
$V_{av} = Q/A_C = 5.2*10^{-4}\ m^3/sec/\Pi D^2/4$
1.66 m/sec

Darcy friction constant for turbulent as well as transition flow with smooth or rough pipe is calculated by using Colebrook equation [11];

$$\frac{1}{\sqrt{f}} = -2.0log\left(\frac{\varepsilon/Dh}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

Where:
Re- Reynolds number, the ratio of inertia force to viscous force

$$Re = \frac{\rho VavDh}{\mu}$$

µ-dynamic viscosity (at normal temperature µ=8.90 × 10−4 Pa·s)

Material constants taken for the cast iron water pipe roughness, $\varepsilon = 0.26\ mm$

$$Re = \frac{1000*1.66*0.02}{8.90\ \times\ 10-4}$$
=37,214.6

From the above relation f=0.0712

Now the head loss;

$$hf = \left(f\frac{L}{Dh} + \sum k\right)\frac{V_{av}{}^2}{2g}$$

$$hf = \left(0.0712\frac{16}{D0.02} + 0.5 + 1.06\right)\frac{1.66^2}{2*9.81}$$

$$hf = 8.12\ m$$

The total head
h_T = 13+3+ 8.12
h_T = 24.196 m

The power demand P, of pump motor is the relation of hydraulic potential energy divided to to the efficiency of the pump motor coupling. The efficiency of submergible solar PV derived motor pump system is the product of the efficiency of the pump and motor. Efficiency of pump is taken 90% and efficiency of motor is 70% while efficiency of the system is 0.63.

$$P = \frac{\rho gQh_T}{\eta_p}$$

Where:

- ρ-density of water
- g-gravity constant
- Q-volumetric flow rate
- h_T-total head

$$P = \frac{1000 * 9.81 * 24.196 * 5.20 * 10^{-4}}{0.63}$$

=195.918 W

The total power demand for the eight hours work per day is

=195.918*8= 1567.344 Watts –hour

Design of solar PV module and its components

Solar photovoltaic system or solar power system is one way of renewable energy supply which uses PV modules to convert solar radiation into direct electricity. The electricity generated in this way can be stored or directly used or it may fed back into grid line or combined with one or more other electricity sources. Solar PV system is very reliable and clean source of electricity with zero carbon foot print that can suit a wide range of applications such as residence, industry, agriculture, livestock, etc. based on the number of PV module accordingly the system power demand.

Solar PV system comprises different accessory components that should be selected according to your system type, site location and applications, and type of output electricity. The major components for solar PV system are solar charge controller, inverter, battery bank, auxiliary energy sources and loads. Solar charge controller is applied to regulate the flow of voltage and current that generated by solar PV module to the storage battery. It also controls the overflow as well as discharging electric current to the storage battery and is sometimes called as solar battery charger. Inverter is also very important element of solar PV system. It is used to convert DC output electricity from PV module to AC. If the system uses directly need DC output it will be DC to DC converter. Battery bank used for the storage of energy for sunshine season. Based on this, solar PV system is classified as standalone direct coupled and standalone indirect system.

i. Design of Solar PV module of the system

The power demanded from solar PV module for this system is determined above. The output power of solar PV system is depends on the efficiency of the panels, the position at which determines solar shine, and the direction of solar panel faces to the solar. The area around your rooftop solar panel system can also change your efficiency numbers. The most common environmental factors that can affect the effectiveness of solar PV are: shading from nearby trees or other buildings, excessive cloud coverage, excessive dirt, dust, and pollution, thick layers of snow. Among them, shading is generally a fairly obvious efficiency blocker and should be avoided by continuous follow. Trimming trees and positioning solar panels to avoid shading from other nearby shades.

TABLE-I:

SPECIFICATIONS OF SOLAR PV PANEL

Specification	Values	Pv Panel
Maximum Power	100W	
Tolerance	± 3%	
Open Circuit Voltage	22V	
Short Circuit Current	6.06 A	
Maximum Power Voltage	18V	
Maximum Power Current	5.56A	
Module Efficiency	14.9%	
Series Fuse Rating	15A	
Terminal Box	IP65	
Maximum system voltage	1000V DC	
Operating Temperature	-40°C - 85°C	
Weight	8kg	
Unit Price	$137	

Different size of PV modules will produce different amount of power accordingly the provided specifications. To find out the required sizing of PV module to get the required power, the total peak watt produced needs. The peak watt (Wp) can be produced is depends on size of the PV module and climate conditions of the selected site location. We have to consider panel generation factor which is different in each site location. For the panel generation factor of the system having Corrections include:

- ✓ 15% loss for the environment temperature above 25 °C
- ✓ 5% losses due to sunlight not striking the panel straight on (caused by glass having increased reflection at the lower angles of incidence)
- ✓ 10% losses for not receiving energy at the maximum power point (if MPPT controller not attained)
- ✓ 5% allowance for dirt
- ✓ 10% allowance for the panel being below specification and for ageing

Total power = 0.85* 0 .95 * 0 .90 * 0.95 * 0 0.90 = 0.62 of the original, and for the average solar radiation, the PV panel generation factor will be 3.43.

Total peak Watts of PV panel capacity needed is;

= 1567.344 W-h / 3.43

= 456.95 W-h

For wire and other current flow losses, considering 30% losses

=456.95 W-h *(1.3)

= 594.04 W-h

Number of PV panels needed is for the system is

= 594.04 W / 100 Wp

= 5.94 modules ≈6 modules

So this system should be powered by six modules of having 100 peak Watts PV module.

ii. Design of Inverter

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of water pumping application power demand. The inverter must have the same nominal voltage of battery.
For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting.
For this specific application of underground water pumping system 100 Watt, 12V Luminous Solar Inverter is selected since its output power is 600 watts is preferable and its detail specification tabulated in table 2 below.

TABLE-II:

SPECIFICATIONS OF INVERTER

Specification	Values	Inverter
Operating Voltage	12 V	
Voltage at max power (Vmax)	18.2 V	
Open circuit voltage (Voc)	22.0V	
Current at max power (Imax)	5.5 Amps	
Short circuit current (I sc)	5.9 Amps	
No. of Cells	60	
Model Name	Solar Panel 100 W /12V	
Output power	100 Watts	
PV Panel Type	Poly Crystalline	
Performance Warranty	25 Years	
Unit Price	$280	

The total number of inverters need for this specific application will be 6 inverters in series

iii. Sizing of Battery

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days.

TABLE-III:

SPECIFICATIONS OF SOLAR ENERGY BATTERY

Specifications	Values	
Brand	MightyMax	
Capacity	150 Ah	
Load Type	AC	
Application	Solar System	
Voltage	24V	
Unit Price	$125.0	

The watts per hours to determine the size of battery for the system works for eight hours per day

=195.918 W*8 hrs/day

1,567.344 Watts- hour per day

To calculate the battery capacity (Ah):
Considering the battery losses (85%) and battery losses due to depth charge (60%) for the battery nominal battery voltage is 24 V with days of autonomy, 3 days:

=1,567.344 Watts- hour per day*3/(085*0.60*24 V)

=384.12 Ah

So the battery selected for this purpose is nominal voltage of 24 V, 150 Ah for 3 day autonomy using three units.

iv. Sizing of Solar charge controller

A solar charge controller is a solar components used to manage the power going into the battery storage bank from the solar PV module. It safeguards that the deep cycle batteries are not to overcharge during the day time and also it helps that the power doesn't run backwards to the solar panels during night time and drain the batteries. Some charge controllers are available with additional capabilities, like alarm lighting and load control, but managing the power is its primary requirement.

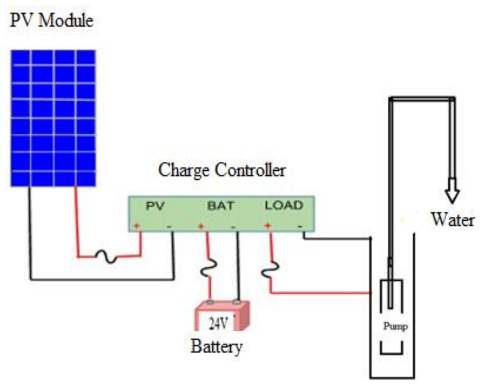


***Fig. 9:* Charge controller through the system**

The solar charge controller is typically rated against Amperage and Voltage capacities of the system. The solar charge controller is to be selected should match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. It needs to make sure that solar charge controller has enough capacity to handle the total current flow from PV module.
For the series charge controller type, the sizing of solar charge controller depends on the total PV module input current which is directly delivered to the solar charge controller and also depends on PV module configuration that is either series or parallel configuration of the PV modules.
According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV module array, and multiply it by 1.3.
The system will be powered by 18 V dc, 100 Wp, PV module.

Solar charge controller sizing

PV module specification
Pm = 100 Wp
Vm = 18 Vdc
Im = 5.56A
Voc = 22 A
Isc = 6.06 A
Solar charge controller rating = (6.06 A x 1.3 =7.878 A)
So the solar charge controller should be rated 10 A at 18 V or greater.

IV. RESULTS AND DISCUSSION

This project is designed for the underground water pumping for the household consumption in Bilate basin Ethiopia for the ten maximum demands. For the ten households it is estimated as 15 m^3 which is from underground of the average depth of 13 m and 3 m high temporarily storage tank. The power demand for the pump having hydraulic efficiency pump set of 63% is calculated as 195.918 W. The number of the PV modules needed to derive the hydraulic pump satisfying its power demand is calculated as 6 modules.
The comparative study made of the system to be run by diesel fuel generator and of the system of wind power derive using HOMER software. The comparison is based total investment, life time costs and maintenance costs and environmental emission rate. For the three systems of twent five years life time, solar PV underground water pumping system is more feasible in case of total costs and environmental pollution case.

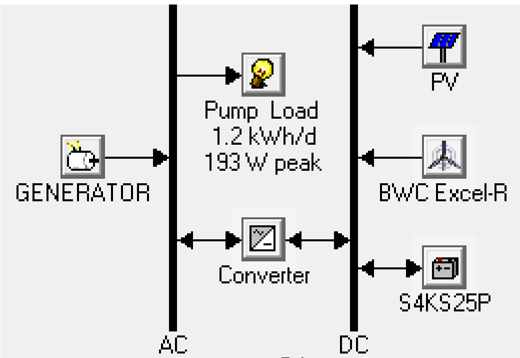


***Fig. 10:* HOMER system components configuration**

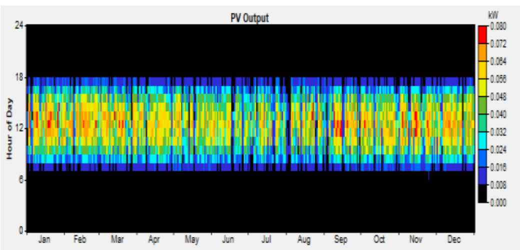


***Fig. 11:* Hourly PV KW output**

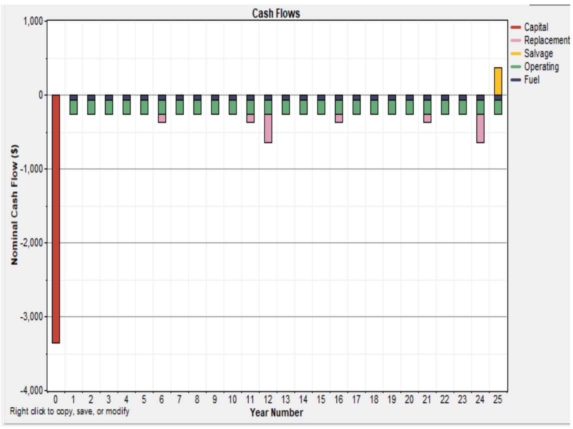


***Fig. 11:* System costs**

Pollutant	Emissions (kg/yr)
Carbon dioxide	241
Carbon monoxide	0.594
Unburned hydrocarbons	0.0658
Particulate matter	0.0448
Sulfur dioxide	0.483
Nitrogen oxides	5.3

***Fig. 12:* Emission Rate Diesel Generator**

V. CONCLUSSION AND RECOMMENDATIONS

The design of the solar PV underground water pumping system in the Bilate basin, Ethiopia based on the data of solar radiation, average surface environmental temperature, wind speed and other weather condition. It is designed to satisfy the total power demand of the hydraulic pump using solar PV modules. In solar module sizing, the PV panel generation factor factors of the weather condition dirt collection, temperature and reflection losses considered. This system uses temporarily electricity storage battery for the time of sun is not shining.
The system has preferably use inverter to convert the DC electricity from charge controller to the AC electricity for the AC hydraulic pump. The number of inverters and battery needed for this system is sized accordingly the input power demand.
The feasibility analysis conducted comparing the solar PV module system with other systems such as diesel fuel power generator and wind system having the specific wind speed of the area. The comparison made by using costs of the system such as total initial investment cost, maintenance and operation cost, fuel cost, and environmental pollution concern.
The system may be further improved using the actual measurements and anybody who interested can use this work. It is strongly recommend company/NGO or governmental body interested or engaged in the community based service can make this project practical and can hinder the water problems of these poor rural people.

REFERENCES

[1] UNICEF Report, Eastern and Southern Africa. Available from: https://www.unicef.org.

[2] Dessalegn R (1999) Water resource and irrigation development in Ethiopia, Forum for Social Studies. Available from: http://www.ethiopians.com/Main_FSS_Paper1.htm.

[3] Rosa J. Chilundo1,2*, Urânio S. Mahanjane2, Diana Neves: Design and Performance of Photovoltaic Water Pumping Systems: Comprehensive Review towards a Renewable Strategy for Mozambique. Journal of Power and Energy Engineering, 2018 pdf available http://www.scirp.org/journal/jpee

[4] A. Al-Badi and H. Yousef: Design of Photovoltaic Water Pumping System as an Alternative to Grid Network in Oman International Conference on Renewable Energies and Power Quality (ICREPQ'16), Madrid (Spain), 4th to 6th May, 2016 · May 2016

[5] Cabraal, R.A., Kennedy, T.G. and Hoelscher, J. (1991) Photovoltaic-Powered Water Pumping in Mali. European Photovoltaic Solar Energy Conference, Brussels and Luxembourg, 1158-1161. https://doi.org/10.1007/978-94-011-3622-8_296

[6] M.Abu-Aligah. Design of Photovoltaic Water Pumping System and Compare it with Diesel Powered Pump Jordan Petroleum Refinery Company (JPRC), Irbid LPG Filling Station Hall, PO Box 3396 Amman 11181, Jordan

[7] Funae (2009) Fundo de Energia, Plano Estratégico 2010 - 2014. Maputo.

[8] Van Koppen, B., Namara, R. and Safilios, R.C. (2005) Reducing Poverty through Investments in Agricultural Water Management. Part 1. Poverty and Gender Issues. Part 2. Synthesis of Sub-Saharan Africa Case Study Reports. International Water Management Institute, Colombo, 71 p.

[9] Campana, P.E., Li, H. and Yan, J. (2013) Dynamic Modelling of a PV Pumping System with Special Consideration on Water Demand. Applied Energy, 112, 635-645.

[10] JA Smith, How much water is enough? Domestic metered water consumption and free basic water volumes: The case of Eastwood, Pietermaritzburg. Oct 2010 Gauteng, South Africa

[11] Yunus A. Çengel, John M. Cimbala: Fluid Mechanics: Fundamentals and Applications, 1st Edition, Published by Mcgraw-Hill, A Business Unit of The Mcgraw-Hill Companies, Inc., New York, 2006

[12] Amy Beaudet. Solar Water Pumps – The Solution to Pumping without Electrical Lines; 2016 Online

[13] World map group, ESMAP: Solar resource and PV power potential maps and GIS data, 2019 Online