DESIGN OF SOLAR POWERED WATER PUMPING SYSTEM FOR IRRIGATION IN RURAL FARM DWELLINGS

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Abstract: Nigeria located in the tropical region of the world receives about 1680 – 2264 kWh/m^2 solar irradiation daily. Despite this enormous resource, the country citizenry is subjected to electricity blackout from the power generating companies due to different problems that entail in its generation and distribution. Rural farm settlements experience difficulties when it comes to irrigating farmlands since they are off-grid of national electricity supply. Solar radiations possess usable energy, therefore there lies potential in the use of solar energy to generate electrical power that can be used to power water pumps. This work looked at the possibility of utilizing solar energy for the generation of power through the use of photovoltaic cells. A system was designed for the generation of electrical power (direct current) from solar panels which can then be converted to alternating current to draw water from a water source for irrigation of farmlands.

Keywords: Irrigation, off-grid, photovoltaic cell, pump, solar energy, solar panel

Introduction

The incessant outage of electricity in the cities can lead to non-availability of electrical power in the rural area as preferential treatment with regular supply is given to the cities. Although this phenomenon mostly occurs in developing or underdeveloped countries, it can be as a result of rationing of generated power to consumers. This clearly shows the geometrical increasing need for electrical power by all populace, with increasing demand comes the burden of an enormous generation of power which has a direct effect on the sources of generation. These sources are dwindling as effort is being placed on the reduction of over-reliance on fossil fuel-based and other sources of power generation that create adverse effects on the earth through pollution. In the rural settings which are predominantly habited by farmers there exists little to no electrical power supply from the national grid as these rural areas are largely situated off-grid, therefore many works that need the use of power are done with human power or other means that can be sourced locally.

The unavailability of electrical power leaves the rural farmers to the mercy of other sources of water generation to irrigate their farmland and the use of human power to carry the water sourced to the field. To obtain optimum yield on such land efficient, sustainable water supply and management exerts a crucial role in supplemental irrigation of farmland (Kim and Evans, 2009). Irrigation agriculture being practiced in most rural dwellings depends on human and animal power for the supply of water but this method is not efficient on a medium to large scale agricultural land, therefore, the use of the electrically powered pump for the generation of water resources on the land but the epileptic nature of supply cannot be relied on, therefore the need to source for an alternative which should befrom renewable resources to generate electrical power.

Environmental friendly and renewable source of energy is the solar energy with little to no adverse effect on the environment when compared to fossil fuel-based source of fuel for energy generation and the energy can be utilized in the rural areas. Although solar energy is free, its availability depends on time, season, and geographical location (Prudhvitej *et al*., 2015). Nigeria receives a very high annual solar irradiation rate due to her being situated in the tropical region of the world measured in kW/m^2 as shown in Fig. 1. Solar energy can be harnessed to generate electrical energy which can then be used as a source of power to drive an electrical water pump for irrigation purposes (Odesola and Bright, 2019). This can be achieved using the solar-captured energy conversion of photovoltaic cell termed photo irrigation (Shinde and Wandre, 2015). Photoirrigation makes used of photovoltaic technology to generate electricity from solar irradiation. Abdelkerim *et al*. (2013) studied the photovoltaic module intending to improve its performance in the system while Achaibou *et al*. (2012) researched into the battery used in the system. This work aims to design a cost-effective, low capital intensive solar-powered water pumping system that can be utilized as an alternative source of drawing water either from well or rivers for irrigation.

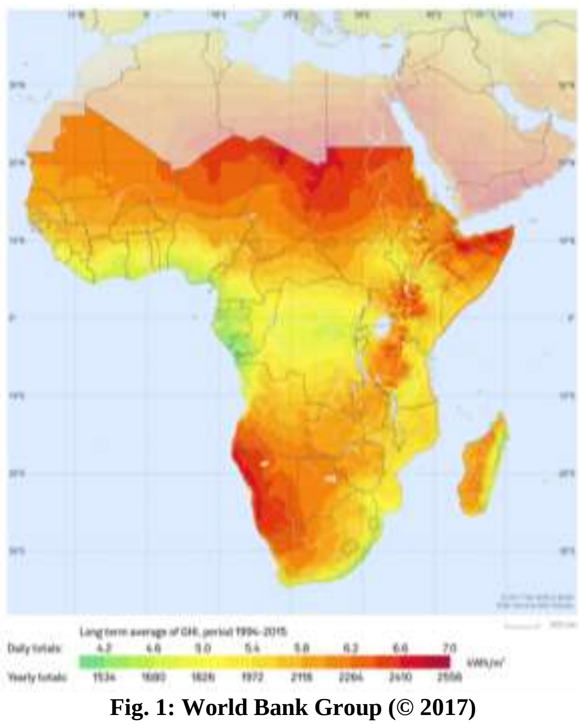

Fig. 1: World Bank Group (© 2017)

Materials and Methods

The main purpose of this research work is to develop a possible design that can be utilized to power a water pump through the use of an alternative source of power. DC is produced when solar radiation from the sun liberates electrons within the panel as it falls on it. The generated DC is stored into the battery as a backup which can be sourced anytime needed even at a period of no sunshine. Design considerations are listed below:

Design consideration of solar powered water pumping machine

The major considerations in the design of the solar-powered water pumping machine include;

- The site-specific solar energy available (referred to as "solar irradiance").
- The volume of water required in a given period for irrigation purposes
- The total dynamic head (TDH) for the pump.
- The quantity and quality of available water.
- The system's proposed layout and hydraulic criteria.
- Water depth

Equipment selection

The various components that make up the system are selected for the capital cost required to be at a minimum.Although the present solar energy technology is at the high side researchers continue looking at the possible means of reducing cost, therefore making this technology accessible to all interested.

Component description

It comprises three essential parts namely the solar panel, pump, and the power controller. Each of these components has a specific function it plays to ensure that the solar pumping machine functions appropriately;

- **Power controller:** These are safety devices incorporated into PV-powered water pump systems to control the electric power input to the pump and to provide necessary electrical protection and switching (Ret Screen, 2004).
- **Impeller:** This is the rotating part of the pump which transmits rotary motion in a device such as in a centrifugal pump or turbine. Rotating impeller sweeps the liquid out toward the ends of the impeller blades at high pressure. The impeller also gives the liquid a relatively high velocity that can be converted into pressure in a stationary part of the pump, known as the diffuser (Prakash *et al*., 2011).
- **Pump:** Pump generally is a device used to raise, transfer, or compress liquids and gases. The water pump is a device for moving water from one location to another, ranging from a fraction of a pound to more than 10,000 pounds per square inch. There are two main types of pumps used in the pumping of liquids, including water, namely; positive displacement pumps and rotor dynamic pumps (Kacira *et al.*, 2004).
- **Solar panel:** Thesolarpanels are made up of a series of solar cells. These cells produce electricity (Direct Current) as evidence of the movement of an electron from layers of semiconductor materials when solar radiations are set on them. A single, typical solar cell can generate approximately 0.7 watts of energy in full sunlight (Chiemeka, 2004).
- **Tank storage:** Serves as a means of a reservoir for water containment at a period of high energy production and at a period where direct irrigation is not needed.

Design analysis and calculation

PV module selection and sizing

Photovoltaic array size were calculated using the relation in accordance with Narale *et al*. (2013),

E = 0.002725HV (Kwh/day)

Where,

E = hydraulic energy required (Kwh/day)

H = Total Hydraulic Head (m)

V = Volume of water required (m^3/day)

Area of the solar panel

The area of the photovoltaic cell is calculated using the area of the rectangle and it is calculated;

$A_{pv} = L \times B$

Where: A_{pv} = Photovoltaic cell area, m^2; L = Length of Photovoltaic cell, m; B = Breadth of the photovoltaic cell, m;

$A_{pv} = 1.5 \times 0.9 = 1.35\ m^2$

Reynolds number

$$Re = \frac{\rho V D}{\mu}$$

Where: ρ = 1000 kg m^{-3} (density of water); V = velocity of fluid (ms^{-1}); D = diameter of the pipe (m); μ = 1.12 X 10^{-3} Nsm^{-2} (dynamic viscosity of water at 15.6°c)

Average flow velocity of 1 m s^{-1}

Pipe diameter = 0.08 m

$$Re = \frac{1000 \times 1 \times 0.08}{0.00112}$$

Re = 71428.57

Tilt angle

Cloudiness, latitude, orientation to the equator, etc are factors that affect the optimal angle of tilt of the solar arrays. In the Northern Hemisphere, the panels must face south to maximize the incident solar radiation due to the position of the sun in the sky. According to Yakup and Malik (2001), efficiency of solar arrays improves by 4% when panels are tilted towards solar insolation every month than stationary arrays. This assertion is corroborated by Vilela *et al.* (2003) and Al-Mohamad (2004) that stated that the use of a solar tracking system improves PV power output by 20 – 25%. Tilting of the solar arrays monthly was not feasible for this study neither was solar tracking device incorporated due to cost. Therefore, a compromise was made to change the panel tilt angle on every two years if need be. To determine the optimal angle in the raining and dry seasons, the declination or the angular position of the sun at solar noon, δ (in degrees), must be calculated (Vick and Clark, 1997);

$$\delta = 23.45 \sin (2\pi (284+n)/365)$$

Where: n = number day of the year (DOY); Sin ( ) is calculated in radians

$\delta = 23.45 \sin (2\pi (284+365)/365)$

$\delta = 4.46$rad

$\delta = 255.54$ degree = 360 – 255.54

$\delta = 104.46$ degree

Therefore, the optimal angle (δ) = 104.46degree.

Design flow rate for the pump

The design flow rate of the water pump is calculated using the formula as stated by Abu-Aligah (2011), which takes consideration of the total need for water and the sun intensity measured in hours per day. Solar insolation value of Enugu state as a case study is said to be in the range of 5.5 – 6.7 (kWh/m2/day or hr/day) (Osueke *et al*., 2013), that for Ibadan is put at 3.79 – 5.70 KWh/m^2/day (Odesola and Bright, 2019). Rate of flow of pump can be determined using the relationship below:

i. $\frac{Q(\frac{lits}{-day})}{T \times 3600}$, where Q = A * V -------(Odesola and Bright, 2019)

ii. $\frac{gal/day}{solar\ insolation}$ ------------(Hossain *et al.*, 2012)

Assuming an output of 900gal/day and average solar insolation of 5.5 h/day

$$Flow = \frac{900gal/day}{5.5hr/day} = \frac{164gal}{hr} = 2.73\ gal/min$$

Estimated pressure output

P_{out}= h x p x g

Where: h = equivalent head (m); μ = density of water (kgm^{-3}); g = acceleration due to gravity (m/s^2); P_{out} = outlet pressure (Pa)

Assuming

h = 5.25 m, p = 1000 kgm^{-3}, g = 9.81 m/s^2

P_{out} = 5.25 x 1000 x 9.81 = 51,502.5 Pa

= 51.5kPa

Power output and photovoltaic power output

Power requirement can be was calculated following Odesola and Bright (2019)

$$P\ (\text{watts}) = \frac{Q\rho gH}{eff}$$

Using the formula current was achieved to be = 3.5A

With each photovoltaic cell having a 0.7 watt

Therefore, total photovoltaic power = 0.7 x 84 = 59 watts

Result and Discussion

The need for water in the rural dwellings cannot be overemphasized enough as all biotic needs water for survival. This research set out to design a system that utilized the power of the sun through the effect of insolation on the solar panels to generate electricity which is then utilized to power a water pump. The set-out goals were achieved with the various design calculations taken into accounts the various aforementioned assumptions. The different major parts that made up the system are hereby showed as obtained after the design processes:

The panels and mount

The electrical system from solar is oftentimes termed as a photovoltaic system with acronym PV. Solar panels or modules help in the generation of direct current DC when solar irradiation falls on it. The solar array is the term used for the collection of modules (Fig 2).

The solar array can be placed on either fixed or tracking structure. The tracking type structure helps in the optimum attraction of solar irradiation and subsequent generation of current has this structure moves as the sun moves thereby facing the sun in every direction. The fixed type structure is the opposite of the tracking type structure has it cannot move in response to a change of direction of sunlight. Fig 3 shows the fixed type solar array mount.

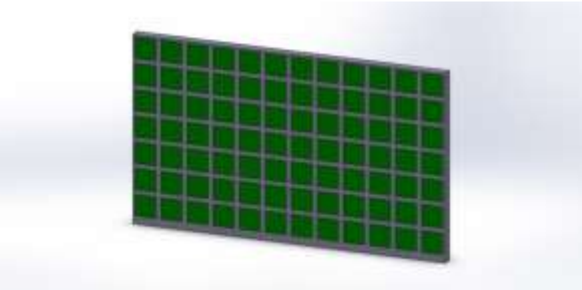

Fig. 2: Solar array

Fig. 3: Fixed solar array mount

The Flow pipes

Plastic pipes are used in the transfer of water from the source (well or river) to either the storage medium or directly onto the field of crops intended for irrigation. Fig 4 shows suction water pipe as this is connected to the pump from the well which helps with water uptake while Fig. 5 shows the water delivery pipe, which supplies water from the pump end to the storage.

Fig. 4: Inlet flow pipe

Fig. 5: Outlet flow pipe

The valves and flanges

These components are utilized to control the flow of water in the solar pumping system.

Fig. 6a: Connected pipes

Fig. 6b: Angle valve

Fig. 6c: Ball valve

The pumps

Researchers have confirmed that direct current (DC) water pumps make use of one-third toone-half of the energy that a conventional alternating current (AC) pumps will normally utilize (Eker, 2005). A direct current pump comes in varieties which include displacement and centrifugal, also it can either besubmersible or surface types. The working principle of the centrifugal pumps is the use of a spinning impeller which adds energy to the water and pushes into the system, similar towhat is obtained from a water wheel; this type is was incorporated into the design as shown in Figs. (7a – d).

Fig. 7a: Rotor Impeller

Fig. 7b: Pump

Fig. 7c: Side view of coupled pump

Fig. 7d: Elevation view of coupled pump

The inverter

The utilization of an alternating current pump can only be possible in this system by converting the direct current generated by the solar arrays into an alternating current and this is made possible by the use of an inverter that converts the generated electricity which is then used to power the pump (Fig 8).

Fig. 8: Inverter

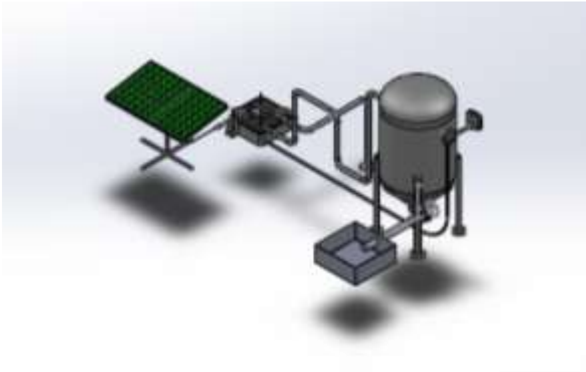

Fig. 9: Complete assembly of system

Assembled system

The complete assembled system is displayed in Fig. 9. The dimensions for the respective parts of the system are as presented in Appendixes.

Conclusion

From the foregoing, it can be concluded that the system design if properly installed can serve as the best alternative to the use of a fossil fuel-based drive pump which is prevalent in rural settings. This system is environmentally friendly as its usage has no adverse effect on the environment. Also, the maintenance of such a system in terms of comparison is infinitesimal small to that of other means of powering a water pump. This solar water pumping system can best serve farmers living at off-grid locations affording farmers the advantages of prompt and adequate irrigating of cultivated land which leads to a bumper harvest. Therefore this solar water pumping system can be made use of at farm settlements and remote areas that are off-grid of national electrical power providers.

Conflict of Interest

Authors have declared that there is no conflict of interest reported in this work.

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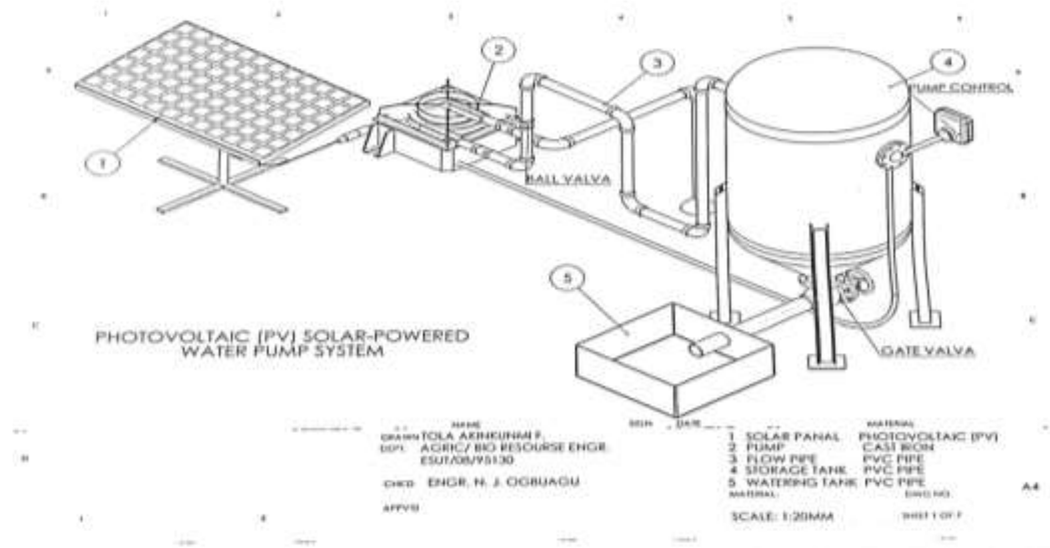
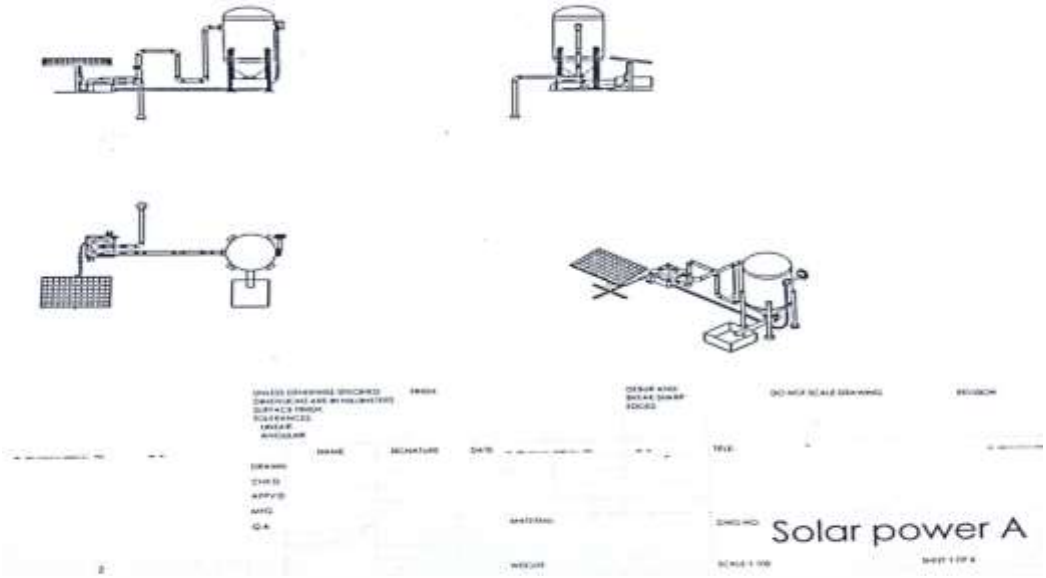
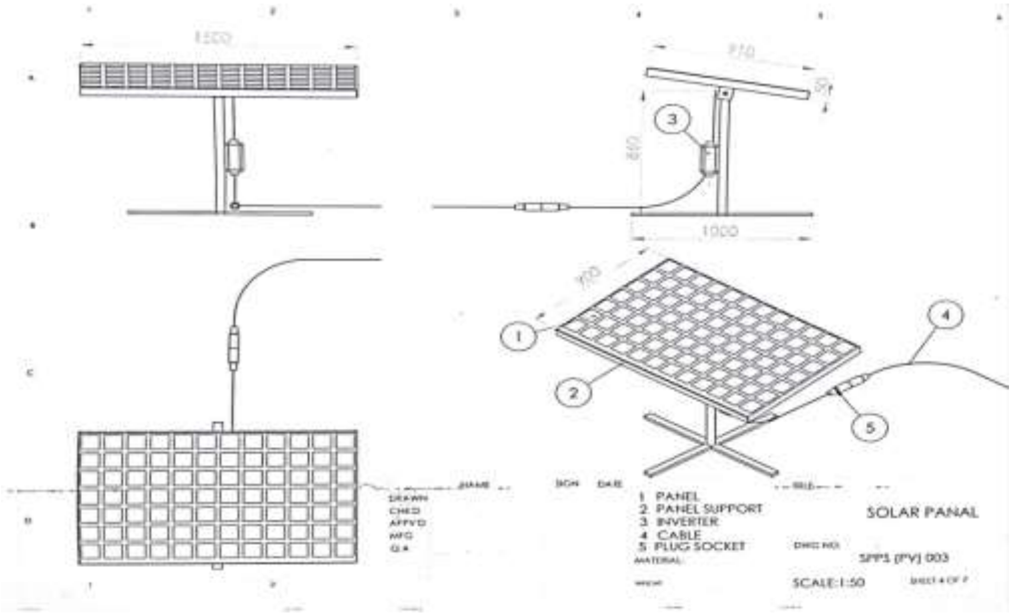
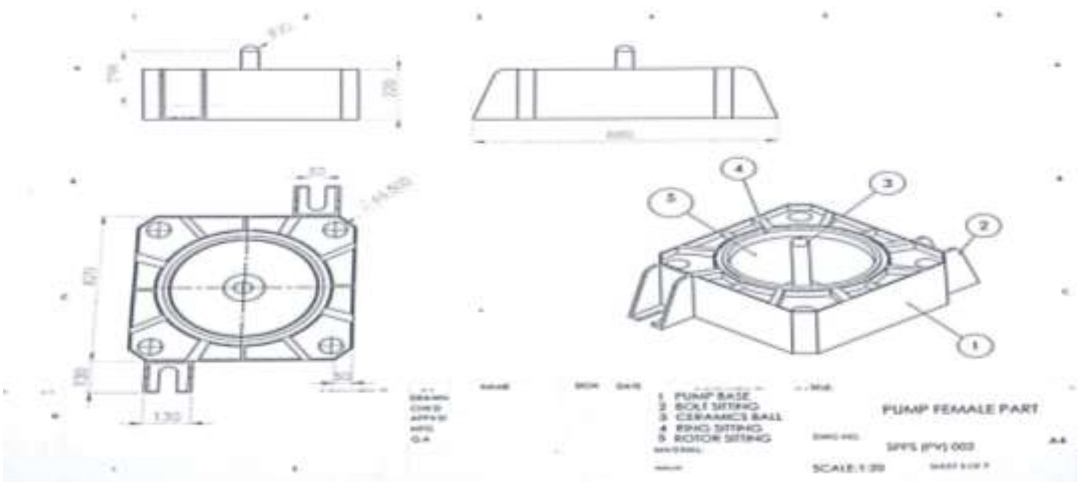
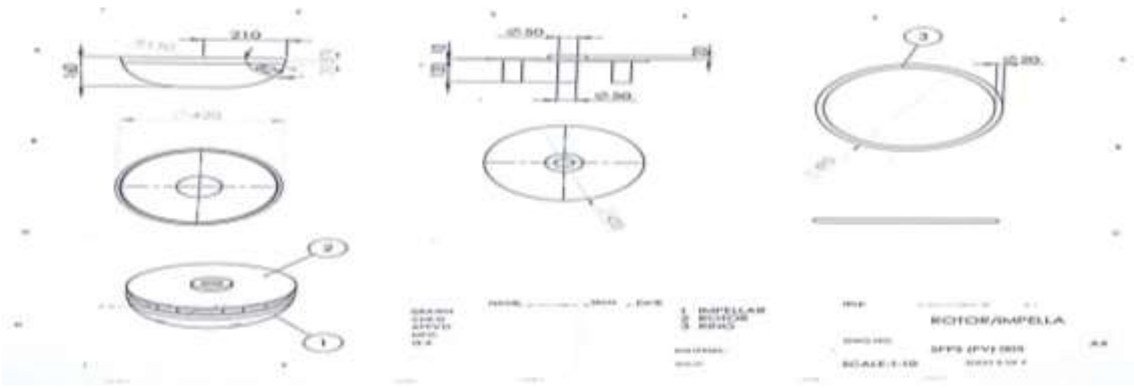
APPENDIXES

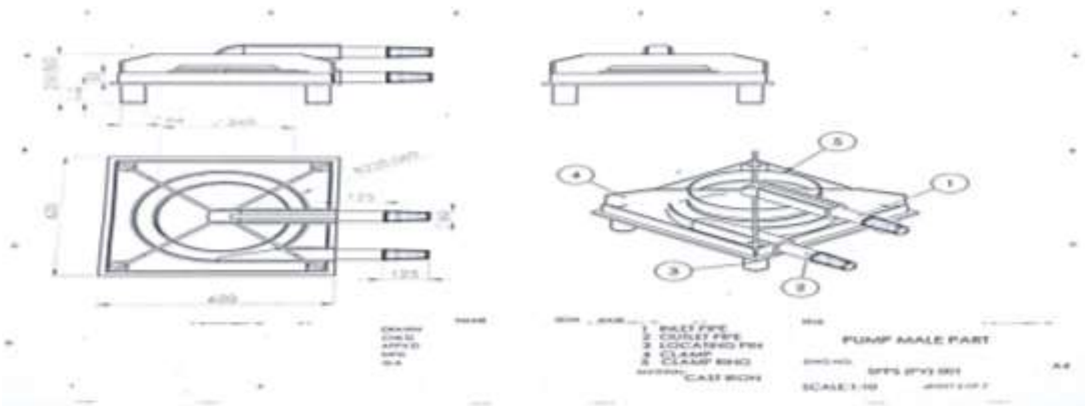


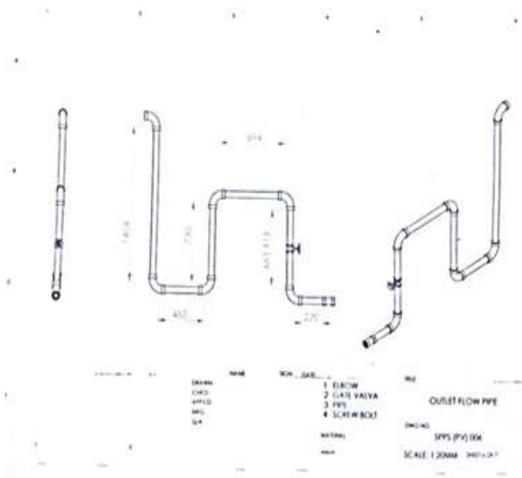

Solar power A

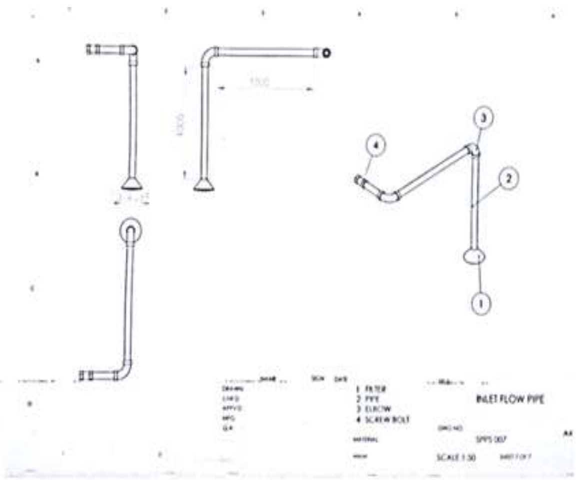

1500
1000
DRAWN
CHKD
APPV'D
MFG
Q.A
1 PANEL
2 PANEL SUPPORT
3 INVERTER
4 CABLE
5 PLUG SOCKET
SOLAR PANAL
SPPS (PV) 003
SCALE:1:50


130
1 PUMP BASE
2 BOLT SITTING
3 CERAMICS BALL
4 RING SITTING
5 ROTOR SITTING
PUMP FEMALE PART
SPPS (PV) 002
SCALE:1:20


ROTOR/IMPELLA


PUMP MALE PART


OUTLET FLOW PIPE


INLET FLOW PIPE