Smart Grid and Renewable Energy, 2015, 6, 27-39
Published Online February 2015 in SciRes. http://www.scirp.org/journal/sgre
http://dx.doi.org/10.4236/sgre.2015.62003

Solar Water Pumping System in Isolated Area to Electricity: The Case of Mibirizi Village (Rwanda)

Esdras Nshimyumuremyi

Alternative Energy Department, Tumba College of Technology (TCT), Kigali, Rwanda
Email: nshimesdas@yahoo.fr

Received 4 February 2015; accepted 22 February 2015; published 25 February 2015

Abstract

This paper made studies on the solar water pumping system in isolated area focusing on the case of Mibirizi village. The author made full interpretation of the construction of the solar pumping system and the general information of Rwanda, and then made full interpretation of the designing and calculating process of solar pumping system.

Keywords

Solar Energy, Pumping System, Mibirizi Village, Water Distribution System

1. Introduction

Solar water pumping system is an easy and affordable solution to solve the water shortage problem in Rwandan community, especially in Eastern province where the land is plane and then the low head solar pumps are needed for water supply.

Solar pumping system is a system of two main components: solar panel and solar pump. A solar panel is composed by a small electronic device called solar cells made in semiconductor materials which produce direct current (DC) when exposed to the solar radiation. The panel system collects the direct current and is then supplied to the pump directly or stored in the batteries for later use by the pump.

Actually there are two types of solar pumping systems: direct coupled and indirect coupled

Direct coupled: When there are no batteries in the system, this system is used when water is needed only during sun shine (day light) or when continuous water supply is not needed; in this case the storage tank is needed to ensure continuous water supply.

Battery coupled: When the system is having batteries to store DC currents, the direct current from solar panels during day light is stored in batteries then the batteries will supply the energy to the pump at any time when

How to cite this paper: Nshimyumuremyi, E. (2015) Solar Water Pumping System in Isolated Area to Electricity: The Case of Mibirizi Village (Rwanda). *Smart Grid and Renewable Energy*, **6**, 27-39.
http://dx.doi.org/10.4236/sgre.2015.62003

the water supply is needed.

1.1. Advantages of Using Solar Pumping System

Water pumping using solar energy presents the advantages since solar energy is available in most places in Rwanda; its investment cost is low and it requires a low maintenance cost. It has also added advantages of storing water to be used when the sun is not shining. In Rwanda, by comparing installation costs (including labor), fuel costs, and maintenance by using generators, you may find that solar is an economical choice and is a suitable solution for remote and isolated regions. A solar-powered pumping system is more reliable and required less maintenance compared to the other source used in pumping.

An existing way of water pumping system uses the fuel to power generators, while this system provides power for pumping at any time. It presents the following constraints: Transportation of fuel to the location of generator sometimes is in inaccessible roads and landscape; fuel costs is also a challenging issue for this existing way of pumping and the generator requires an important regular maintenance.

As it is stated by the title of this project work, generally the system of water pumping by using the solar energy as a source of electricity to run the water pump is applicable in developing countries where the place become inaccessible (in remote areas) for supplying the electrical energy generated from different plants like hydro or thermo power plants.

1.2. Main Equipments Required in Solar Powered Pumping System

1) Solar panels: Solar panel is one of the equipments required in solar systems; it has a role of collecting or generating direct current (DC). The system is made up by one or more than one solar panel according to the needed discharge, available head, and power required.

2) Pump: Different types of solar pumps are available for water delivering (DC and AC pumps). DC pumps are classified either displacement or centrifugal; they should be either submersible or surface pumps [1]. When the water source is dugout, the floating pump type will be used; if the water source is a well submersible centrifugal pump type will be used. For stream and shallow wells, surface centrifugal pump will be used. Whatever the type of pump to be used, the capacity of pump need to be matched to the available head and needed discharge (flow rate).

3) Charge controller: Charge controller is there to protect batteries for over charges and over discharges. Charge controller is required in the system when you need the pump to work even when the sun light is not available.

4) Inverter: For AC pumps, inverter is needed to convert DC electricity from solar panels to AC electricity to be used by AC solar pump.

5) Batteries: Batteries are used to store DC electricity to be used later by the solar pump when the sun is not shining.

The batteries are not recommended in solar power pumping system because of the following reasons:

- It reduces the overall efficiency of the system;
- It increases the cost of the system;
- It increases maintenance cost.

It is recommended in this case to use water storage tank to provide water when the pump is not working [1] Rwanda as one of developing countries presents the rural or isolated region to electricity, which becomes a great problem to the population where they suffer from the main infrastructures like easy accessibility to the potable water, hospitals, schools...etc.

From the statistics, about 90% of local populations are living in rural areas [2], and about 95% do not access to electricity [3].

The 59% of population does not access to potable water [4] and even they went about 3 km from tap stand. The solar water pumping system project will provide one of the solution to improve the above percentage of isolated population to accede the potable water.

2. Methods

2.1. Case Study

Rwanda is a country located in Southern sub Saharan region in Africa, in exactly East Africa region with a population of approximately 11.4 million (2011) on total size of 26,338 square kilometers. Rwanda is located at 2 degrees south and 30 degrees east. At 433 inhabitants per square kilometer, Rwanda's population density is amongst the highest in Africa. **Table 1** gives information about Rwandan population and access to portable water and electricity.

The most Rwandese people are subsistence farmers who rely on intermittent sources of water for their domestic needs (about 60% are suffering from lack of potable water). For this case, the feasibility study was conducted for mechanizing bore wells with solar powered pumps to provide water for the community in the Southern Regions of Rwanda in a village called Mibirizi, Kigese Cell, Rugarika Sector, Kamonyi District about 15 Km from Kigali City.

Mibirizi village is having 958 inhabitants and a primary school, a Youth Training Centre (boarding school of 120 students) and a Health Centre. And they are located on the top hill. The wells are located at great distance from the community or are located in a swamp area that cannot be easily accessed on foot. In this paper the technical data and calculations to determine the solar power and pump needed are included as well, according to the projected daily water capacity that will be pumped at the site, the financial cost was elaborated to provide to the communities with the pump, the solar power plant, the storage tanks, the faucets and necessary plumbing pipes and valves, as well as a fence to protect the equipment.

The solar water pumping project will provide 40 liters of water per day to each person in the communities from a tap stand located no more than 300 meters from their homes. The water capture system in the swamp, equilibrium reservoir on the top for supplying the communities is the system to use during the project. The water source has been tested to ensure enough flows rate during a dry season.

2.2. The Objectives of the Project

The main objectives of this project are:

- Design and supply the potable water to the isolated village called Mibirizi located at Kamonyi district, 15 km from Kigali City by using the solar pump.
- The water supply mechanism is using the water pump working under solar energy appropriate in rural or isolated area.
- Reduce the percentage of poor people do not accessed to the portable water.
- To demonstrate that the solar water pumping system is one of the solutions to improve the living standards of the population living to isolated region (remote areas).
- To conduct a cost benefit analysis between the water supply by solar pump and other source of electricity.

2.3. Methodology

In order to carry out the project, we referred on the collected data based on the questionnaires asked the MIBIRIZI village's Population; the site survey (engineering survey) results conducted in order to characterize the site and the theories of solar system.

During the site visits, most of the questions asked are related to know the daily needed water per family, location of water source used by Mibirizi's population, availability of water sources nearest the MIBIRIZI village and the identification of applications for actual water use in their households.

Three sites have been visited during site visits, we chose one whose the river in the swamp easy to capture the water and also should be pumped to the top of hill of MIBIRIZI and presents low cost during the channeling water through pipes to the capturing tank and construction cost appeared as may be small. The engineering survey conducted aims to identification of availability water source at the boring wells side to ensure that the located reservoir should satisfy the water demand for the community (Population of Mibirizi).

Table 1. Rwanda population information.

	Unit	Amount
Population	Number	11.4 millions
GDP (US$)	US$ million	4567
Population with electricity	Number	0.57 million (census 2002)
Population with portable water	Number	4674 millions

The survey indeed has identified the quite place to install the storage tank (distribution tank) of water to the population and the number of needed water tap to serve the population of Mibirizi's village. It has also determined the solar intensity and proposed the location to install the solar water pump and solar panels.

Some assumptions have been taken during the project as follows:

- Since the result of site survey shows that the founded water source was a small river, we decided that no need to bore the wells except to channel the water through the proposed reservoir to built.
- We only referred to the quantifying, sizing and determining the nature of the materials provided in this solar pumping project.
- We have conduced also the equivalent financial cost of the project (reasonable budget) based on actual local prices of the plumbing; electrical materials and water solar pump to use.

2.4. Description of the Site

The MIBIRIZI village is one of 317 villages (or Imidugudu in Kinyarwanda) that makes up the Kamonyi District in the Southern Province of Rwanda. It is located in the central region of the country in Kigese Cell of RUGARIKA Sector as shown in **Figure 1**. It is located at 2.055 degrees south the equator and 29.956 degrees East of Greenwich Meridian at altitude of 1490 m.

The Mibirizi village enjoys a moderate climate. The annual rainfall averages 1300 mm and the average temperature is 200˚C.

The monthly averaged global solar radiation varies between about 5.08 and 5.3 kWh/m^2 per day. We will use 5.08 peak sun hours for calculations which is the average day during the worst month of the year (*i.e.* November).

The village has a population of 958 inhabitants, a primary school, a Training Centre for Youth (boarding school of 120 students) and a Health Centre on a total surface area of 2.4 km^2.

2.5. Description of the Current Situation for Water in the Village

From the results of the visits conducted at Mibirizi village, the population walk about 2 to 4 Km from their homes to retrieve water for daily domestic needs from traditional tap located in the swap (river) of the village as shown in **Figure 2** They walk in the small and complex streets, climbed on the hills towards the swamp of the MIBIRIZI village by foots. The retrieved water is not potable.

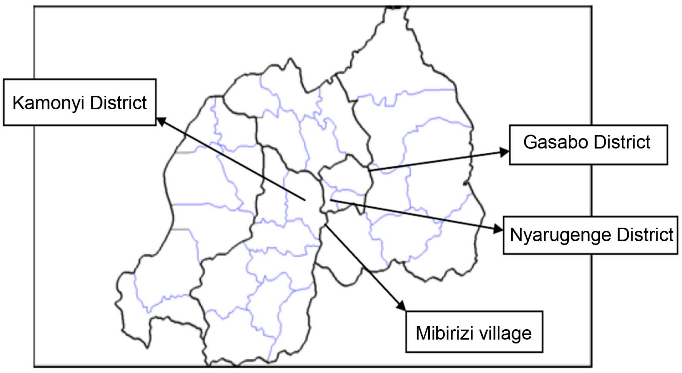

Figure 1. Rwanda administrative district.

Figure 2. The swamp retrieved water tap to Mibirizi population.

3. Results and Discussion

To design a solar-powered water pump system it is necessary to determine the size of the system needed, including the pump, PV panels, appropriate mounting structure, pipe length, tank size, etc.

In order to design the system correctly we are forced to know the following information:

- The quantity of water needed by the community
- The type of the water source, whether it is a stream, well or spring.
- When the water is needed
- Quantity of water available per unit of time
- The distance between source and user
- The elevation or head available
- The capacity of storage tank

3.1. The Community Water Needs

The average water required by person per day is 40 litters. MIBIRIZI village requires 38,320 litters (10,124 gallons) per day for 958 persons.

Primary school having 500 pupils and 11 staffs uses 230 liters (61 gallons) of water per day on average to clean the premises of classes and toilets. The Training Centre for Youth is a boarding school for 120 students.

Using the minimum water requirement of 45 liters per day per student, School's 120 students would need about 5400 liters (or 1427 gallons) per day. The Health Centre needs 600 liters (or 156 gallons) of water per day. The total water needed per day at Mibirizi village is **44,550 liters (or 44.55 m^3)** equivalent to **11,770 gallons**. The system would provide the required water for domestic needs: drinking, laundry, washing and cooking but not for crop irrigation or raising domestic animals.

3.2. Water Source

The visited swamp area provides sufficient water even in dry season and the water source will be a spring. Pumps will be submerged in a reservoir built close to the source. The water capturing system is done by digging a drained tranche at depth of 1m and 4m for underground water storage tank.

3.3. System Layout

The proposed system layout of the site is provided in **Figure 3** in which necessary distances and elevations for the water source, pump, PV panels, storage tanks, water t troughs and pipeline routes are shown.

3.4. Water Storage

A water storage tank is normally an essential element in an economically viable solar-powered water pump system. A tank can be used to store enough water during peak energy production to meet water demand in the event of cloudy weather or maintenance issues with the power system. Assume the tank should be sized to store for a minimum of two-day water use. This minimum storage capacity is calculated based on the water requirement.

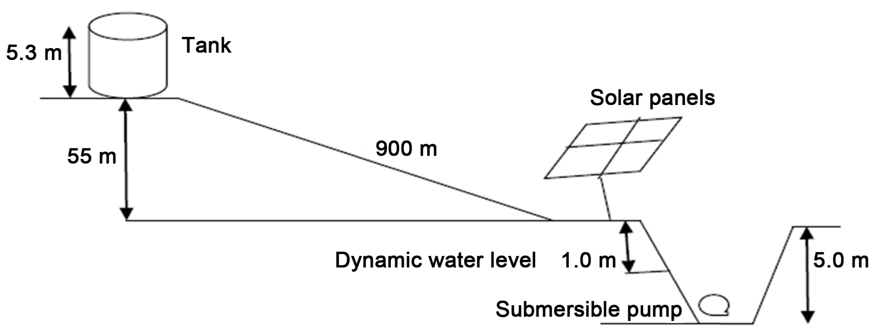

Figure 3. Mibirizi layout system.

$$\frac{44550l}{\text{day}} \times 2\ \text{days} = 89{,}100\ \text{litres} = 89.1\ \text{m}^3$$

$$\frac{11770\ \text{gallons}}{\text{day}} \times 2\ \text{days} = 23540\ \text{gallons}$$

Therefore, the storage tank must be sized to hold a minimum of 89.1 m^3. Thus, the tank is 4.63 m in diameter and 5.30 m tall. The available sizes are applicable on both water tank (underground storage water tank and distribution storage water tank).

3.5. Solar Insolation and PV Panel Location

The amount of solar insolation (peak sun hours) available at Mibirizi site can be taken as the same value like Kigali *i.e.* 5.08 hours per day [5]. In order to maximize the solar-powered system's energy production, the panels should be south facing with no significant shading in their vicinity in order to achieve full sun exposure.

3.6. Design Flow Rate for the Pump

The pump's design flow rate is based on the operation's estimated daily water needs divided by the number of peak sun hours per day, calculated as shown below:

$$\frac{44550l}{(5.08\ \text{peak sun hours} \times 60\ \text{minutes/hour})} = 146.16\ \text{lpm} = 0.1462\ \text{m}^3\text{pm} = 39\ \text{gpm}$$

We propose to install three pumps in parallel all dropped into the same source. All pumps will deliver the same volume flow rate of 13 gpm in order to make the total volume flow rate of 39 gpm while the total head is equal to the head of each pump (72.910 m). 6.7 Total dynamic head (H_T) for the pump

$$H_T = \text{vertical lift} + \text{pressure head} + \text{friction losses}$$

Vertical lift is the vertical distance between the water surface at the intake point (the well's water surface) and the water surface at the delivery point (the tank's water surface) [6]. For this case, *Vertical lift* = 1 m + 55 m + 5.30 m = 61.30 m.

Pressure head is the pressure at the delivery point in the tank. For this case let assume that there is no pressure at the delivery point (the tank's water surface), so: pressure head = 0.00 m.

Friction loss is the loss of pressure due to the friction of the water as it flows through the pipe and the pressure loss due to the valves and fittings. Friction loss due to the pipe run lengths is determined by four factors: the pipe size (inside diameter), the flow rate, the length of the pipe, and the pipe's roughness. We choose to use pipes in thermoplastics PVC (Polyvinyl Chloride) because they are light, flexible, and tough and provide exceptional corrosion resistance.

For the given system layout, approximately 900 m (or 2952 feet) of 1.5-inch diameter PVC pipe is needed to pipe water from the well to the storage tank. From table of friction loss in plastic pipe (**Appendix 3**), the friction loss for 13 gpm flowing in a 1.5-inch pipe is approximately 1.2 feet of head loss per 100 ft of pipe. Therefore, the total estimated friction loss for 2952 ft of pipe is 35.424 ft or 10.80 m (2952 ft ÷ 100 ft of pipe × 1.2 ft head loss = 35.4241 ft). In addition, a head loss of 0.20 ft or 0.6 m for the 5 m of pipe in the well must be added. Thus, the friction loss due to the pipe length is 10.80 m + 0.6 m= **11.40 m**.

Friction losses due to valves and fittings

The resistance through various valves and fittings will also contribute to the overall head loss. In a well designed system the resistance through valves and fittings will be of minor significance to the overall head loss, many designers choose to ignore the head loss for valves and fittings at least in the initial stages of a design. **Table 2** describes the fitting materials which will be needed for the whole piping system.

$$\text{The friction head due to fittings} = 57.30\ \text{ft} \div 100\ \text{ft of pipe} \times 1.2\ \text{ft head loss} = 0.6876\ \text{ft} = \mathbf{0.2096\ m}$$

Therefore, the total dynamic head for the system is

$$H_T = 61.30 + 0.00\ \text{m} + 11.40 + 0.2096 = 72.910\ \text{m}$$

Table 2. Fitting materials.

Fittings	Quantity	1.5-inches loss factor	Extension (in feet)
900 elbow	8	4.00	32.00
Insert coupling	0	1.25	0.00
Gate valve	0	0.80	0.00
Male-female adaptor	2	2.75	5.50
TEE flow through run	0	2.30	0.00
TEE flow through branch	1	7.00	7.00
Union fitting	4	2.00	8.00
Ball valve	3	0.80	2.40
Check valve	3	0.80	2.40
Other	0	1.00	0
	Total fittings (in feet)		57.30

3.7. Pump Selection

The hydraulic energy needed (E_H) is given by the following equation

$$E_H = \frac{\rho g H_T V}{3.6 \times 10^6}$$

where ρ = density of water **(1000 kg/m^3)**

g = gravitational acceleration **(9.81 m/s)**

H_T = Total dynamic head **(72.910 m)**

V = Volume of water required per day **(89.10 m^3/day)**

So, the hydraulic energy required is $\boldsymbol{E_H}$ **= 17.700 kWh/day**.

The total hydraulic energy is 17.700 kWh/day. Dividing this by the number of sun peak hours of 5.08, we find the pumps' total power required is **3484.7 W**. Assuming that three pumps will be installed in parallel; each pump's power required is **1160 W**.

The pump can be also selected by comparing the design flow rate and total dynamic head calculated above with the help of the information from the manufacturer's pump curves.

The pump curves in **Appendix 2** are used for this scenario. Based on a calculated flow rate of 13 gpm and a total dynamic head of about 240 ft (72.910 m), we find that a minimum input of 1160 Watts of peak power is required for each of the three centrifugal pumps.

Grundfos brand submersible pump (SQFlex) made with stainless steel can be selected for this purpose.

3.8. PV Panel Selection

The PV panels selected for this system must be able to provide the minimum energy requirement to run the pump. As calculated above, the minimum power needed is 1160 Watts.

However, the panels must also have additional capacity to account for any potential reduction in power due high heat, dust, age, etc. Many PV manufacturers recommend increasing the minimum peak power value by 25% to account for these environmental factors [6].

Therefore, the PV panels will be sized to provide a minimum output of 1450 Watts (1.25 × 1160 = 1450 W).

A PV panel is selected in order to have the electrical characteristics of peak power output of 240 W AT29.54 V and 8.13 A (**Appendix 1**). Therefore, 6 panels (1450 W ÷ 240 W per panel) are required to meet each pump's power requirement. They will be connected in series and parallel (two groups of three panels connected in series with the groups connected in parallel) to provide the necessary voltage for the pumps.

3.9. Design of Water Distribution System

We provide four water taps connected by PV pipes from the distribution water tank located at the Mibilizi centre. The population will retrieve the portable water nearest their homes at 300 m distance from the tap as it is shown on **Figure 4**. The water distribution is done by water gravity. The required pipes and plumbing accessories during the water distribution are described in **Table 3**.

3.10. Cost and Materials List for the Project

The **Table 4** shows the different activities and material details supposed to use in implementation of the project and the estimated cost in US Dollar.

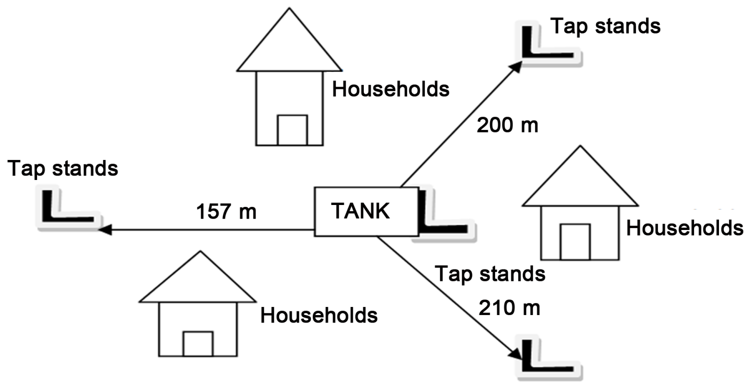

Figure 4. Proposed water distribution.

Table 3. Plumbing materials for water distribution.

Fittings	Estimated quantity per one water tap	Size	
		Diameter	Length
PVC pipes	50	1 inch	6 m
PVC pipes	2	3/4 inch	6 m
PVC TEE flow through run	1	3/4 inch	
PVC TEE flow through run	2	1 inch	
Union fitting	3	1inch	
Union fitting	2	3/4 inch	
Reduction	1	1 to 3/4 inch	
900 elbow	3	3/4 inch	
900 elbow	2	1 inch	
Insert coupling	98	1 inch	
Insert coupling	2	3/4 inch	
Gate valve	1	0.80	
Ball valve	1	3/4 inch	
Ball valve	1	1 inch	
PVC glue (500 ml)	3	500 ml	
Miscellaneous plumbing material			

Table 4. Cost of materials for the project.

The project materials	Quantity	Unit price (US$)	Total price (US$)
A. Water capturing system and water storage			
Construction of water tanks (1 reservoir build at the water source level and 1 water tower)	2	6550	13,100
Water capturing activities	1	750	750
Water pump	3	4375	13,125
Fencing 54 m^2	1	5212	5212
Sub total			**32,187**
B. Piping system **(*from pump to storage tank*)**			
PVC pipe 1.5 inch	150	5.2	780
PVC Pipes 1 inch	200	5	1000
PVC pipes 3/4 inch	6	3.7	22.2
PVC TEE flow through run	3	0.8	2.4
PVC TEE flow through run 1 inch	6	0.8	4.8
Union fitting 1 inch	9	1	9
Union fitting 3/4 inch	6	0.85	5.1
Reduction 1 to 3/4 inch	4	0.79	3.16
PVC 900 elbow 1.5 inch	0	0.5	0
900 elbow 3/4 inch	9	0.45	4.05
900 elbow 1 inch	6	0.5	3
Insert coupling 1 inch	294	0.65	191.1
Insert coupling 3/4 inch	6	0.58	3.48
Gate valve	3	2.8	8.4
Ball valve 3/4 inch	3	2.1	6.3
Ball valve 1 inch	3	2.5	7.5
Union fitting 1.5 inch	2	0.95	1.9
Ball valve 1.5 inch	2	2.89	5.78
Check valve 1.5 inch	2	3	6
Male-female adaptor	2	0.6	1.2
Miscellaneous plumbing material			206.53
Sub total			**2271.9**
C. PV solar system			
PV Solar arrays (240 W)	6 PV solar arrays per pump $x^3 = 18$	460	8280
PV solar accessories (controllers, racks, Steel election materials, floats switch, switches and fuses…..)	1	7830	7830
Sub total			**16,110**
D. Installation costs	1	830	**830**
E. Operation and maintenance			**1600**
F. Capacity building (training…..)			**1100**
Total investment cost (taxes) excluded)			**54098.9**

4. Conclusions

The choice of using solar electric panels to supply water to the population of Mibirizi village is motivated by several reasons. The Mibirizi population resides in rural areas and has no access to electricity. Wind pumps have a long service life, require no non-renewable fuel, require basic skills but are work-intensive to maintain, and have a well developed service infrastructure. Wind pump systems are however not simple to install and require larger water storage than for example a diesel or solar pumps to provide for periods of low wind. In addition, Rwanda reliable data of the wind are not yet available and the wind technology is not well known in Rwanda. Diesel pumps have the advantage of pumping water on demand, also in varying daily capacity, depending on the operating times and over high heads. Diesel engines have a fairly low capital cost. On the down side the diesel pumping system relies on oil fuel and all oil used in the country is imported and the fuel cost variations and exchange rate fluctuations cannot be controlled without neglecting its adverse consequences on the environment pollution. Furthermore diesel engines require regular maintenance, linked to the hours of operation and have a fairly short life expectancy (highly dependent on the level of maintenance, the operating conditions and the quality of the engine and the installation). Most diesel pumps require manual starting making remote pumping installations more costly to operate. Hand pumps are rugged devices which require renewable fuel and are easy to maintain and have low capital cost. They are however limited in terms of the pumping volumes and depth of installation (head).

The whole country has an excellent solar resource and the system designed uses proven and dependable technology to pump sufficient quantities of water without the use of expensive fuels or unreliable grid power. Unlike many conventional pumping systems, the solar pump can operate unattended. The design is simple; when the sun is shining, the pump is pumping water. There are very few moving parts which reduce the need for continued costly maintenance. The system designed essentially consists of three main components: the solar arrays, a controller and the pumps.

The array consists of 18 solar panels mounted on a pole (*i.e.* six panels for each pump). The electricity generated by the solar panels passes first through the control box where it is regulated before energizing the pump. The pumps that have been selected are Groundfos submersible pumps (SQFlex) that are made in stainless steel. These pumps are powered by DC motors using the Dc output from the PV panels directly but with also the capability to run off of A.C. power from a portable generator in the event the sun is not shining or the control has malfunctioned.

This gives the community the greatest flexibility. The designed PV system information can be summarized as follows:

Power required: 1160 Watts per pump;

Number of pumps: 3;

Solar panel rating: 240 Watts (29.54 Volts and 8.13 Amperes);

Number of panels: 18.

The panels come with more than 20 year performance warranty. This exceeds the warranties provided on other possible fuel sources, like diesel or propane, which power generators. Maintenance of solar panels is minimal and involves nothing more than washing the dust off occasionally. Also solar panels produce electricity without any noise or without any pollution.

Acknowledgements

The author wish to convey his sincere appreciation to Tumba College of Technology (TCT) for financial support towards the publication of this paper.

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Appendix

Appendix 1. Cost of solar panels.

Model	Watts	Minimum quantity	Price per watt	Total price
Kyocera 135	135	1	$2.30	$310
Kyocera 140	140	1	$2.50	$350
Astronergy 185	185	1	-	Negotiable
Sharp 235	235	1	$1.53	$360
Astronergy 240	240	1	$1.40	$335
SolarWorld 240 Mono	240	1	$1.92	$460
Astronergy 230 Mono	230	1	$1.52	$350
Astronergy 290	290	1	$1.41	$410

Appendix 2. Piping friction chart: Friction loss (per 100 ft) for SCH 40 PVC pipe, velocity = speed of water flowing through a pipe (typically 6 FPS or less).

	3/4" PIPE			1" PIPE			1 1/4" PIPE			1 1/2" PIPE		
gpm	*Vel*	*psi*	*FtHd*	*Vel*	*Psi*	*FtHd*	*Vel*	*Psi*	*FtHd*	*Vel*	*psi*	*FtHd*
1	0.67	0.14	0.32									
2	1.34	0.51	1.17	0.81	0.04	0.09	0.46	0.04	0.09			
5	3.36	2.81	6.49	2.03	0.21	0.48	1.15	0.21	0.48	0.84	0.10	0.23
7	4.70	5.24	12.1	2.84	0.38	0.87	1.60	0.38	0.87	1.17	0.18	0.41
10	6.71	10.1	23.3	4.05	0.74	1.70	2.29	0.74	1.70	1.67	0.34	0.78
15	10.1	21.5	49.6	6.08	1.57	3.62	3.44	1.57	3.62	2.51	0.73	1.68
20				8.11	2.68	6.19	4.58	2.68	6.19	3.34	1.24	2.86
25				10.1	4.05	9.35	5.73	4.05	9.35	4.18	1.87	4.32
30				12.2	5.68	13.1	6.88	5.68	13.1	5.01	2.63	6.07
35							8.02	7.55	17.4	5.85	3.50	8.08
40							9.17	9.67	22.3	6.68	4.48	10.3
45							10.3	12	27.7	7.52	5.57	12.8
50							11.5	14.6	33.7	8.35	6.77	15.6
60										10	9.49	21.9

Appendix 3

FRICTION HEAD LOSS
SCHEDULE 40 IPS
PVC PRESSURE PIPE OR FLEXIBLE PE PIPE

FRICTION HEAD LOSS IN FEET OF WATER PER 100 FT. OF PIPE

SIZE	1/2" PIPE 0.622" INSIDE DIA.		3/4" PIPE 0.824" INSIDE DIA.		1" PIPE 1.049" INSIDE DIA.		1 1/4" PIPE 1.380" INSIDE DIA.		1 1/2" PIPE 1.610" INSIDE DIA.		2" PIPE 2.067" INSIDE DIA.		2 1/2" PIPE 2.469" INSIDE DIA.		3" PIPE 3.068" INSIDE DIA.		SIZE
GALLONS PER MINUTE	VELOCITY FEET PER SECOND	HEAD LOSS FEET	VELOCITY FEET PER SECOND	HEAD LOSS FEET	VELOCITY FEET PER SECOND	HEAD LOSS FEET	VELOCITY FEET PER SECOND	HEAD LOSS FEET	VELOCITY FEET PER SECOND	HEAD LOSS FEET	VELOCITY FEET PER SECOND	HEAD LOSS FEET	VELOCITY FEET PER SECOND	HEAD LOSS FEET	VELOCITY FEET PER SECOND	HEAD LOSS FEET	GALLONS PER MINUTE
1	1.056	0.991	0.602	0.252	0.371	0.078											1
2	2.112	3.576	1.203	0.910	0.743	0.281	0.429	0.074									2
3	3.168	7.577	1.805	1.929	1.114	0.596	0.644	0.157	0.473	0.074							3
4	4.224	12.909	2.407	3.286	1.485	1.015	0.858	0.267	0.630	0.126							4
5	5.279	19.515	3.008	4.967	1.856	1.535	1.073	0.404	0.788	0.191							5
6	6.335	27.354	3.610	6.962	2.227	2.151	1.287	0.566	0.946	0.268	0.574	0.079					6
8	8.447	46.602	4.813	11.862	2.970	3.664	1.716	0.965	1.261	0.456	0.765	0.135	0.536	0.057			8
10	10.559	70.450	6.016	17.932	3.712	5.540	2.145	1.459	1.576	0.689	0.956	0.204	0.670	0.086			10
15			9.025	37.997	5.568	11.738	3.218	3.091	2.364	1.460	1.434	0.433	1.005	0.182	0.651	0.063	15
20					7.425	19.998	4.290	5.266	3.152	2.488	1.912	0.738	1.340	0.311	0.868	0.108	20
25					9.281	30.232	5.363	7.961	3.940	3.761	2.390	1.115	1.675	0.470	1.085	0.163	25
30					11.137	42.375	6.435	11.159	4.728	5.271	2.868	1.563	2.010	0.658	1.302	0.229	30
35							7.508	14.846	5.516	7.013	3.346	2.079	2.345	0.876	1.519	0.304	35
40							8.580	19.011	6.304	8.980	3.825	2.663	2.681	1.121	1.736	0.390	40
45							9.653	23.645	7.092	11.169	4.303	3.312	3.016	1.395	1.953	0.485	45
50							10.725	28.740	7.880	13.575	4.781	4.025	3.351	1.695	2.170	0.589	50
60									9.456	19.028	5.737	5.642	4.021	2.376	2.604	0.826	60
70									11.032	25.315	6.693	7.506	4.691	3.161	3.038	1.099	70
80											7.649	9.612	5.361	4.048	3.472	1.407	80
90											8.605	11.955	6.031	5.035	3.906	1.750	90
100											9.561	14.531	6.701	6.120	4.340	2.127	100
125											11.952	21.966	8.376	9.252	5.425	3.216	125
150													10.052	12.968	6.510	4.507	150
175															7.595	5.996	175
200															8.680	7.679	200
225															9.765	9.550	225
250															10.850	11.608	250

SIZE	4" PIPE 4.026" INSIDE DIA.	
GALLONS PER MINUTE	VELOCITY FEET PER SECOND	HEAD LOSS FEET
35	0.882	0.081
40	1.008	0.104
45	1.134	0.129
50	1.260	0.157
60	1.512	0.220
70	1.764	0.293
80	2.016	0.375
90	2.268	0.467
100	2.520	0.567
125	3.150	0.857
150	3.780	1.201
175	4.410	1.598
200	5.041	2.047
225	5.671	2.546
250	6.301	3.094
275	6.931	3.692
300	7.561	4.337
325	8.191	5.030
350	8.821	5.770
375	9.451	6.556
400	10.081	7.389

SIZE	6" PIPE 6.065" INSIDE DIA.	
GALLONS PER MINUTE	VELOCITY FEET PER SECOND	HEAD LOSS FEET
100	1.111	0.077
125	1.388	0.117
150	1.666	0.164
175	1.943	0.218
200	2.221	0.279
225	2.499	0.347
250	2.776	0.421
275	3.054	0.503
300	3.332	0.591
325	3.609	0.685
350	3.887	0.786
375	4.165	0.893
400	4.442	1.006
425	4.720	1.126
450	4.997	1.252
475	5.275	1.383
500	5.553	1.521
550	6.108	1.815
600	6.663	2.132
650	7.218	2.473
700	7.774	2.837
750	8.329	3.223
800	8.884	3.633

RECOMMENDED OPERATING CONDITIONS SHOWN ABOVE HEAVY LINES IN CHART

WATER HAMMER (shock waves) in pipe systems can result from sudden changes in flow, such as pumps starting and stopping, automatic control valves opening and closing, exhausting air from the system, or other flow restricting action. When a sudden change in flow occurs, the velocity energy of the flowing water is suddenly changed to pressure at that location. This excess pressure is called SURGE PRESSURE and is greater with larger changes in velocity. To help minimize SURGE PRESSURES, the maximum velocity of the water in the pipe line should be limited.

USE CAUTION IF VELOCITIES EXCEED 5 FEET PER SECOND, ESPECIALLY SUCTION VELOCITIES.

VELOCITIES SHOULD NOT EXCEED 8 FEET PER SECOND IN COLD WATER SYSTEMS.

Velocity calculated using the formula...

$$V = \frac{0.4085 \times Q}{D^2}$$

V = flow velocity in feet per second
Q = flow rate in gallons per minute
D = inside diameter of pipe in inches

Head loss calculated using Hazen-Williams formula with C=150...

$$F = \frac{0.2083\,(100/C)^{1.852} \times Q^{1.852}}{D^{4.8655}}$$

F = friction head loss in feet of water per 100 feet of pipe
C = coefficient for roughness of the interior pipe surface
Q = flow rate in gallons per minute
D = inside diameter of pipe in inches

AVERAGE FRICTION LOSS FOR PIPE FITTINGS IN EQUIVALENT FEET OF STRAIGHT RUN PIPE

ITEM	PIPE SIZE									
	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	6"
TEE (THRU FLOW)	1.0	1.4	1.7	2.3	2.7	4.0	4.9	6.1	7.9	12.3
TEE (BRANCH FLOW)	3.8	4.9	6.0	7.3	8.4	12.0	14.7	16.4	22.0	32.7
90° ELL	1.5	2.0	2.5	3.8	4.0	5.7	6.9	7.9	11.4	16.7
45° ELL	0.8	1.1	1.4	1.8	2.1	2.6	3.1	4.0	5.1	8.0