Malawi Solar Powered Water Pump System

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Abstract - This project will consist of a water pumping system to supply potable water to an orphanage located in the Chuluchosema community of Malawi, Africa. The water will be pumped from a nearby well up to a water tower located in the orphanage center. The pump will be powered by a solar panel that will capture the solar energy from the sun. This project is in association with Mercer's University's Master's Program for Environmental Engineering and Mercer on a Mission. The water pump system will be built on Mercer's campus and will then be sent to the orphanage in Malawi to be assembled permanently. The water pumping system will be built by materials that are sustainable enough to allow the system to function properly long after the student has installed the system and has left. The intent of this project is to provide a hands-on experience for the graduate student by working with various professors and manufacturers as well as different contacts from the developing country. The goal of this project is to supply potable water to an orphanage without the residents retrieving it from a well.

Keywords: Malawi
Solar Water Pump

Introduction

Water is the world's most precious commodity. Every living thing on earth needs water in order to survive. For developing countries, this resource is difficult to obtain on a regular basis and some people must walk for miles every day in order to get a regular supply. Africa has the most water deprived countries in the world and many efforts have been made by the World Health Organization, the Peace Corps, and other smaller organizations to help these countries bring clean drinking water to the people. Locally, many student and college organizations travel to these countries and help the people there supply water to their villages. One particular student group will travel to Malawi and install a water pump that is powered by a solar panel. This paper describes a solar powered water pumping system that will be installed in an orphanage located in Malawi, Africa. The project is in association with the Mercer University's Master's of Engineering Program as well as the Mercer on Mission study abroad program. This paper includes some background information on the Mercer on Mission study abroad program as well as literature review of solar powered water pumping systems and how they are used in irrigation and the global water shortage issue. Specific information on the orphanage in Malawi is also presented and a preliminary design of the solar powered water pump system. In addition, key project challenges will also be discussed along with how they will be overcome.

Mercer On Mission

Mercer on Mission is a unique study abroad program at Mercer University in which a group of 9 to 15 students travel with two Mercer Faculty staff members to different locations around the world [Mercer University, 1]. The students and faculty members go to a certain part of a developing country and help the local villages and communities with special projects to improve the residents' overall quality of life. Mercer on Mission provides students with "hands-on" learning experiences while helping people in developing countries in need. These study abroad programs occur during the summer months and last approximately five weeks. Three weeks are spent in the

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developing country while the first week and the last week of the trip are spent on Mercer's campus in a class session led by the faculty members going with the students. Multiple groups of students and faculty travel simultaneously to different parts of the world throughout the summer. The first Mercer on Mission trip occurred in 2007 when a group traveled to Brazil. Since that time, many Mercer on Mission groups have traveled to Greece, Guatemala, Kenya, Liberia, Thailand, Vietnam and many other countries.

Global Water Crisis and the Solar Water Pump

The water supply in all parts of the developing world is scarce. Over 1.1 billion people in the world do not have access to potable drinking water and 5000 children die of water-borne diseases annually [Meah, 4]. People are fighting over control of the water supply and children are dying of diseases and dehydration. Most of the people in the villages must walk for miles in order to get drinking water. Unfortunately, these people usually get the water from a surface source such as a river, lake, or stream, which are polluted by animal and human wastes. Many of the resultant diseases contracted are fatal.

Cleaner sources of water, such as groundwater, are more difficult to obtain and are therefore rarely utilized. Once a well has been drilled, however, this water can be used. The use of an automatic pump is an excellent way to access the water without the constant operational demand of the residents living there. The economic problem now comes into view because most of the countries cannot afford the fuel supply, such as electricity or gasoline, to run the pump. This is why the use of the solar energy has become an increasingly popular strategy in the delivery of water to the people. Many countries have adopted this idea in isolated villages where water resources are limited. Countries such as India, Mexico and others have built successful solar powered pumps and are able to supply villages the potable water [Ramos, 5]. The number of solar pumps in India has increased dramatically which can be seen in Figure 1 below.

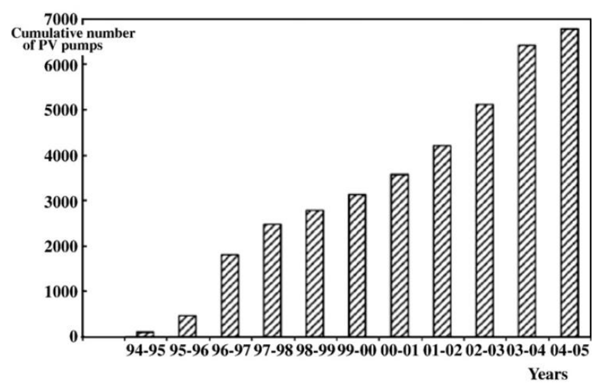

Figure 1. Rise in Solar pumps in India (C).

Half of the water supplies used for irrigation and drinking in India come from groundwater while 80% of the rural areas use the groundwater as well. This groundwater supply is recharged at approximately 45.2 million hectare meters per year. 13 million pumps in India are powered by electricity, which is very costly to operate. Farmers have begun to use the solar powered float pump to irrigate their crops and feed their livestock. India has planned to install 50,000 solar water pump systems by the end of 2012 [Ramos, 5]. Mexico has also implemented 206 solar water pump systems as a response of the Mexico Renewable Energy Program. Many of these pumps were installed in areas where water supply is very limited. When a survey was conducted in 2000 regarding the solar pumps, only 6% of the surveyors thought the pump did not reduce the cost of the operational charges required to obtain the water, 2% said the pumps were not reliable and the same 2% said they were not satisfied with the amount of water that was produced by the pump. The rest of those surveyed considered the pumps to be cost effective, reliable, and productive.

Another case study conducted at the University of Florida tested the effectiveness of solar panel cells in pumping water [Helikson, 8]. Six solar panel modules were used to test the system efficiency of pumping water. In a span of seven hours with an estimated power rating of 900 W/m^2, the water system was able to pump 20,180 gallons up a vertical height of 8 feet. While the costs of the parts are still relatively high, the price of the solar panels has dropped considerably since 1970's. The estimated capital cost of a solar powered system is $6.80 per watt of power produced [Meah, 6]. This is relatively inexpensive compared to electricity which is $22 per watt of power. The cheapest capital cost is the gasoline generator at only $2.50 per watt. The major disadvantages to the generators are the high maintenance requirement and a short typical life span of 5-10 years. The solar panel system requires low maintenance and can last between 10 to 15 years before parts may need to be replaced [Helikson, 8]. Figure 2 presents a chart of the decrease in the cost of solar panels, how much power the solar panel can produce, and the proportion of the countries that have been using the solar panel system in 2005 [Meah, 4].

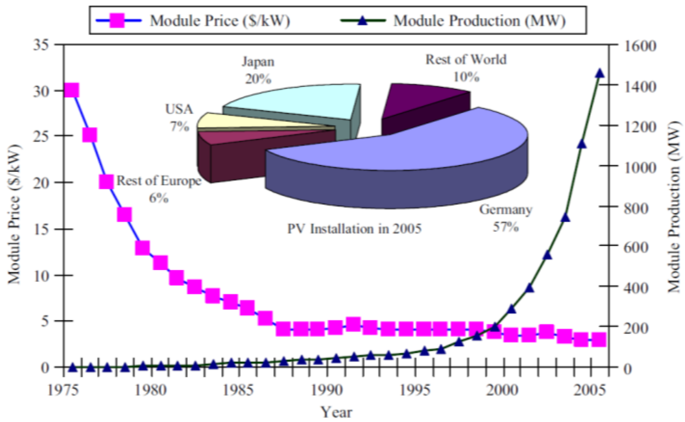

Figure 2. Solar panel production, cost, and proportions(D).

Malawi, Africa

The Chuluchosema Orphanage in Zomba, Malawi will be served by the pumping system. This orphanage is mainly used as a small hospital for children and nearby villagers in need of medical assistance. The hospital is assumed that between 40-50 people utilize it. It is also assumed that there are no hostile neighboring villages or tribes to threaten the water supply system. Figure 3 shows the relative location of Zomba in Malawi. The location of Zomba is circled.

Figure 3. Zomba, Malawi (A).

Currently, there is a pump connected to the well that has ceased to function and a hand pump has replaced it. Every day, the people that live and work at the orphanage must manually pump the water from the well and carry the heavy containers to a storage tank located approximately 160 feet away. This is done multiple times per day. During the summer of 2010, a Mercer on Mission student group was able to record measurement data on the site. They determined the well to be approximately 147 feet deep, with the water level 22 feet below the surface of the ground. The storage tank is placed on top of a tower that is 13 feet high. The added height of the tank on top of the tower is 18 feet. There is currently a 1,000 L (264 gallons) tank in place, but an additional 10,000 L (2641 gallons) tank will be added for more storage. The pump system will be designed to supply enough water to fill both storage tanks. The combined height of the water tower and the static water level in the well is the approximate total head that the pump will have to accommodate. Therefore, the total head will vary between 40 and 50 vertical feet. The amount of horizontal friction losses in the pipe is assumed to be minimal. There is a 4.5-inch diameter flexible pipe inside the well that travels 41 feet down from the ground. This pipe will be used to house the water pump. It is assumed that each resident uses approximately 10 L (2.7 gallons) of water per day. The total estimated amount of water used in the orphanage is between 400-500 L (110-140 gallons) per day. The amount of solar radiation is estimated to be 5-6 kilowatt-hours per square meter per day (kWh/m^2/d). This information was obtained from a solar map, which is shown below in Figure 4.

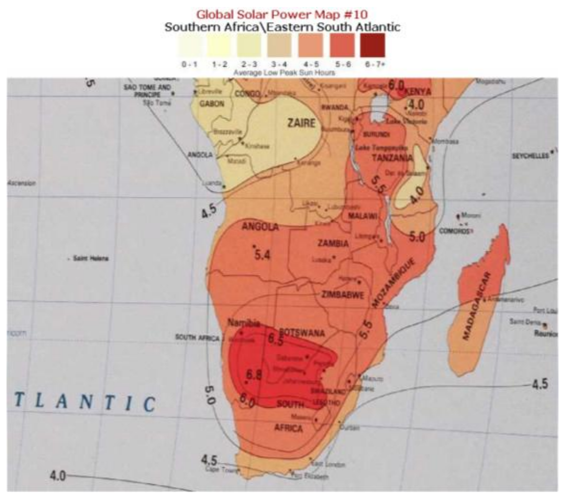

Figure 4. Solar Map (B).

Solar Pump Design

The solar panel design was chosen because of the limited energy resources surrounding the orphanage. Fuel is very difficult to obtain on a daily basis at the orphanage and the tree cover will not allow any wind turbines to be installed to produce any sustainable wind power. The solar panels will be able to power the pump which will allow the villagers to conserve their fuel supply. The system is broken down into four parts: the pump, the solar panels, the switches and controller, and the water piping. These components must be simple to use and durable enough to withstand the environment. The system will first be built at Mercer University and then it will be disassembled and shipped to Malawi where the student group will reconnect the parts for permanent installation. While at Mercer, the system will be tested on the varying flow rates it produces from the power supplied by the solar panels and determine if any adjustments need to be made before delivery to the orphanage.

Pump

The pump chosen is the 11 sqf 2 Grundfos Submersible Pump. It is a positive displacement helical pump. This means the water is sucked in through a rotating vacuum and pushed through the pump by a rotating helix out the other end. At 300 W, this pump is capable of providing a maximum of 11 gallons of water per minute (gpm). The pump must be placed at least 3 feet under the level of the water and to compensate for the possible water depth fluctuations, it will be placed 30-40 feet down from the surface of the ground inside the 4.5” diameter pipe. This pump is 3 inches in diameter and approximately 4 feet long, which is small enough to fit in the well pipe. Some maintenance to the pump will have to be administered periodically. Before the pump is put into use, lubrication oil must be applied to the pump. This oil will protect the pump against rust, lubricate the ball bearings, and cool the motor. Sand may also have accumulated at the bottom of the well and might be sucked up through the pump. If this occurs, the pump’s ball bearings will have to be cleaned of sand and grit to avoid any further damages to the pump.

Solar Panel Module

The solar panel chosen to power the system is the 180W Trina Solar Panel. Two panels will be required in order to obtain the maximum flow rate from the pump as well as the minimum voltage requirement to run the pump. The panels will be positioned on the roof of a near-by building adjacent to the well to be able to keep the panels in full exposure to the sun. They will be mounted on a support structure, attached in series with one another, and will be tilted toward the sun at an angle between 15° and 45°. The amount of solar radiation captured by the solar panels will vary throughout the day. As a result, the flow rate will also vary. Table 1 shows some of these variations. Periodic cleaning of the panels will have to be done to wipe off any dust that might have accumulated on the photovoltaic cells. This will ensure that the panels will receive as much sunlight as possible at all times. Another maintenance issue that needs to be checked is that the bolts holding the panels need to be tightly in place at all times. Over time, the bolts holding the panels may loosen which will cause the panels to angle downward and away from the sun. This will decrease the amount of solar energy to the pump and slow the volumetric flow rate.

Table 1. Power to flow rate ratio.

Power output from panels (W)	Flow rate achieved (GPM)
300	11
250	9
200	7
150	5.5

Controller and Float Switch

The controller is used to monitor the power delivered to the pump from the panels and also to turn the pump on and off. The controller used for this system is the CU 200 Grundfos controller. Using this controller, an inverter will not be needed to convert the DC power generated from the solar panel to AC power required by the pump. The CU 200 is capable of monitoring the voltage and power delivered by the panels to the pump and automatically alarms the residents if an electrical overload occurs. It is also able to monitor the level of water in the storage tank and notifies the residents if the pump is not pumping any water. A float switch will be connected to the controller to monitor the level of the water in the tank. The float switch is used to communicate with the controller to tell the pump to turn off once the water has reached full capacity in the tank. If the water level falls below a certain level in the tank, the float switch will notify the controller and it will turn the pump back on. The float switch chosen is the Grundfos low level float switch. The electrical wiring used in the system is a combination of AWG #12 and AWG #10 size wiring. The AWG #12 wire will be used to connect the solar panels together in series and the AWG #10 wire will be used to connect the solar panels to the pump and controller as well as from the controller to the float switch. At longer distances, the power transported decreases due to electrical resistance in the wire. By using a larger diameter wire, the AWG #10, this decreases the power consumption from the wire and increases power delivery to the pump.

Black Polyethylene Pipe

Polyethylene pipe will be used to transport the water from the well to the storage tank. This material is durable enough to be able to withstand a wide range of water pressures and environmental factors for an extended period of time. Another advantage to polyethylene is the flexibility of the pipe to be able to bend into the well and also up to the storage tank. The pipe diameter will be 1.25” to be able to fit the exit of the pump, which is also 1.25”. The pipe will be placed underground approximately 6-8 inches deep to avoid any physical damage and UV exposure from the sun.

Budget

Table 2 shows the approximate cost of each part as well as the total approximate cost for the whole system.

Table 2. Total cost of system.

Part	Quantity	Price (each), $	Total, $
11 sqf 2 Grundfos pump	1	1699	1699
180 W Trina solar panel	2	450	900
CU 200 controller	1	320	320
Float Switch	1	28.50	28.50
Black polyethylene pipe (1 ¼ " @ 100')	2	100	200
AWG #12 wire @ 25'	1	20	20
AWG #10 wire @ 100'	2	100	200
		Total:	$3367.5

Obviously, the majority of the cost is from the submersible pump and the solar panels. However, this total price does not include the shipping charges required to send the parts to Malawi. Figure 5 is a computer graphic of the solar powered water pump system that will be installed at the orphanage where "FS" is the flow switch and "CU 200" is the controller.

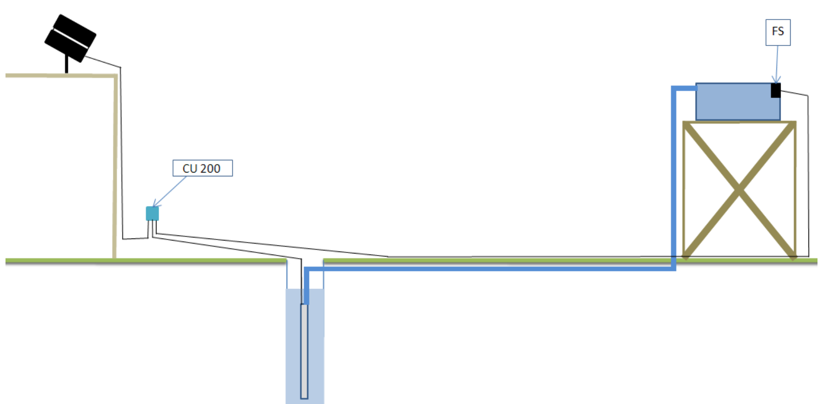

Figure 5. Solar Water Pump Schematic.

Challenges

In order for this project to be completed, a few key challenges need to be solved. One major challenge is to figure out how to deliver all the parts and materials to a remote location in Malawi. Approximately 200 feet of piping, 300 feet of electric wire, and two solar panels that are approximately 5'x3' will all have to be delivered to the orphanage safely and in a timely manner. The pump will be brought separately with the students to ensure it does not get damaged during transport. These materials will have to be brought either by plane or by ship through a freight shipping company. Since the materials are being sent on the other side of the world, they will also have to be sent a few weeks before the students and teachers arrive to the orphanage to give the shipping company enough time to deliver the materials. This will have to be timed perfectly to make sure the students do not have to wait on the materials to arrive and lose time building the system. It will also be extremely difficult to obtain any extra materials at the remote location if a mistake or miscalculation is made. Extra materials will be brought with the shipment to make sure a supply shortage does not occur. This includes a few extra feet of piping, wiring, building materials and piping couplings.

Before the system is even built at the orphanage in Malawi, it will first be built at Mercer with the site characteristics of Malawi to test performance of the pump. These site characteristics must be as close to the measurements of the orphanage as possible in order to accurately determine how the pump and the solar panels will perform at its permanent location. One idea is to place the solar panels and an empty water tank on the roof of the Mercer University School of Engineering building and another water tank will be placed on the ground next to the building. The pump will be wired to the solar panels and placed inside the water tank on the ground. The tank on the ground will be filled with water and the pump will send the water up the side of the building and into the tank on the roof. This will give the best real case scenario of the total hydraulic head that the pump will push up from. Another option is to simulate the total head through a series of valves in a lab that the pump will push through.

Another challenge that may be encountered is training a few people there to operate the pump once the Mercer on Mission group leave. The Mercer on Mission group will not be able to return to the orphanage until the next year when the summer classes are back in session. Two or three residents that live and work at the orphanage must be with the students in charge of the system at all times to learn how the system works. Important maintenance issues and troubleshooting solutions will have to be addressed with the residents to allow them to run the system once the students and teachers leave. A challenge with this is that if the residents do not understand how the system works, then they will not be able to fix it if anything happens. A maintenance/troubleshooting guide may have to be made for the residents if any problems due occur. Before the students and teachers leave the orphanage, they must be certain that the residents know how to operate the controller, pump, and solar panels and that the understand how to read the guide.

Conclusion

This paper described a solar powered water pump system that will be installed in an orphanage in Malawi, Africa. The system will first be built and tested at Mercer University and then will be shipped to Malawi where the student group attending the study abroad program will build the system at its permanent location at the Chuluchosema orphanage. This project is in association with the Mercer on Mission study abroad program and the Mercer University's Master's of Engineering Program. Mercer on Mission will help fund some of the expenses for the parts and shipping charges required to send them to the orphanage. The pump chosen for the project is the Grundfos 11 sqf 2 submersible pump. This pump is capable of pumping a maximum flow rate of 11 gpm at approximately 300 watts of power. It will be placed in the well and will pump the water up to a water storage tank approximately 160 feet away. The other components required for the system is the solar panels, controller, float switch, polyethylene pipe, and electrical wire. The total cost (not including the shipping charges) is approximately $3367.50. Some challenges addressed with the project is shipping the materials over to Malawi, having extra material s to avoid supply shortage, duplicating the orphanage site characteristics at Mercer University, and finally training the residents there how to operate the water pump system.

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Biographical Information

Hunter King
Hunter King is a graduate student At Mercer University majoring in Environmental Engineering. He completed a senior design project involving a design for a recycling system at Mercer and was also involved in a gray water reuse system for a Habitat for Humanity home as an independent study. This solar powered pump system is part of his thesis project/research and plans to graduate in the Fall Semester of 2011 with a Master’s in Environmental Engineering.

Dr. Andre Butler
André J. Butler is an associate professor of environmental and mechanical engineering at Mercer University. His research interests include pollutant measurement of the ambient atmosphere (ozone and particulate matter), air quality health effects, and design and development of particulate matter measurement instruments. He teaches a wide variety of undergraduate and graduate courses in environmental and mechanical engineering.