

# System Design of a Solar Powered Water Pump in Haiti

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## **Abstract**

**A large number of institutions in Haiti are without reliable access to a source of clean drinking water. In particular, hospitals and schools that serve a sizable population experience strain in obtaining clean drinking water. Furthermore, the national electric grid of Haiti cannot always be relied on to provide consistent power, giving rise to the need for an alternate source of power. We provide a possible solution using a portable water filtration system powered by a photovoltaic array. A variety of implementations of such a system, custom tailored to the needs of its users, are outlined in this paper. These solar powered systems can supply institutions with clean water independent of the electric grid, providing reliable and economical access to drinking water.**

## I. Introduction

One World Environment (OWE), a non-profit organization, approached Engineers Without Borders (EWB), University of Washington chapter, with a project in the country of Haiti to design solar powered water filtration systems. John Peters presented the requirements to our group on behalf of Jahan Tevengar, CEO of OWE. These water purification systems will be installed in existing schools, hospitals and other community centers. In contrast to the current grid-powered systems, the new design will not rely on the electricity from the unreliable Haitian power grid; rather, the system be self sustainable from the power of batteries and solar panels to provide reliable water purification.

### Water Purification Project

Anis Zunuzi Baha'i School

Port-Au-Prince, Haiti

Water treatment capacity: 2,000 gallons per day

- 450 students currently benefit from this project. The school is planning to sell their excess purified water to the surrounding community, thus making this project economically self sustaining.



We designed the system to power two types of pumps: 12 V and 36 V DC pumps, which provide purification through UV lamps, filters and reverse osmosis membranes. Since we promote the purchasing of solar panels and other components in country, equipment specifications can vary between different implementations. Also, depending on the location and the model of the pump used, the power requirements and output capacity may also vary. Given these flexible constraints, our goal is to provide guidelines for creating such individual systems.

To bring focus to an initial design, we will concentrate primarily on a 12 V pump system that will consume 200 W, and operate for 4 to 6 hours per day.

## II. System Design

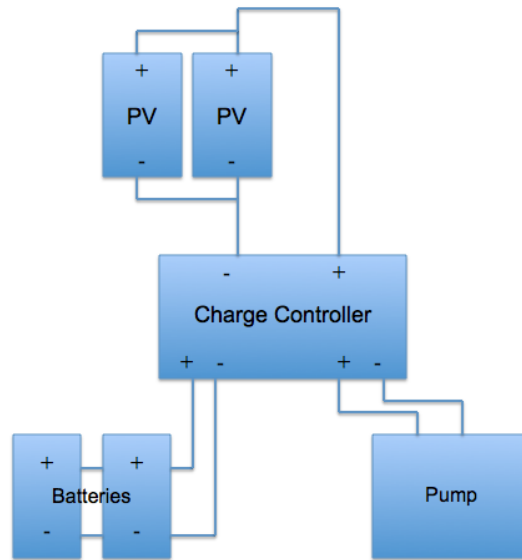


Fig. 1 (System Diagram)

### 12 V Pump System

#### 1. Solar Panels

The 12 Volt DC pump requires 12V solar panels and batteries to operate effectively. This particular pump draws 200 W, and we will also devote an extra 25% of that power to charging the batteries, and buffer the power requirements by an additional 10%. Furthermore, we must take into account the inefficiencies of our components: we assume that our charge controller will operate at 80% efficiency, and any inverters or DC-DC converters operate at 85% efficiency. Thus, the total power we require from the PV panels for this 200 W pump system is 330 W. The 12V solar panels should be connected in parallel fashion to produce an output reasonably close to that value.

#### 2. Batteries

Batteries will be included as a supplementary power source. They will contain sufficient energy to power the system for a maximum of two days without a recharge. With a target run time of 4 hours per day, we require a total capacity of 220 AH, either in one battery, or in multiple batteries connected in parallel.

### **3. Charge Controller**

A charge controller is necessary to maintain the proper charging voltage on the battery bank, and direct the necessary amount of power to operate the pump. The charge controller will be a Pulse Width Modulation (PWM) solar controller and must be rated to handle the currents in the system and the open circuit voltage of the solar panel. The charge controller should be rated above 21A. [2]

### **36 V pump**

The second type of pump system takes 36V DC input. However, we will leave the other components at 12V, since 36V components are difficult to procure. Instead, we will use a DC Boost converter to boost 12V to 36V before feeding it into the pump. The boost converter typically operates at 0.85 efficiency, and we will take that into account.

## **III. Design Process**

### **1. Weather**

It was important to gather as much information on the weather of Haiti in order to accurately estimate how much energy our PV panels would be able to harvest. We observed that even during the rainy seasons (May-July) and hurricane seasons (July-October) the peak sunlight changed by a only a slight amount, with the average number of sunlight hours per day during the year at around 6 hours. [4] Thus, we were able to use a conservative estimate of the average effective sunlight of 5-6 hrs per day. Moreover, the weather in Haiti is consistent enough to expect close to the average number of sunlight hours on most days. Since the number of sunlight hours exceeds the number of hours of pump run-time, we expect that the weather is adequate for the operation of our system.

### **2. Case scenarios**

There are 4 major scenarios our system can expect to encounter. The first possible scenario would be full sunlight with a full battery (1). Then, we could have situations in which we have a full battery charge with no sun (2), or full sunlight without battery charge (3). The worst case scenario would be a depleted battery with no sun (4).

Out of the 4 situations, we can do the most preparation against 2 and 3 (1 would be the optimal circumstance, and we couldn't do much for 4). The most common situation we face is if the sun stops shining for a period of time but battery is charged, as in case 2. Through some research, we concluded that for most time periods, 2 days will be the maximum amount of time that the sun will not shine in Haiti, and we decided to calculate our reserve power based on this estimate [1]. Thus, we size the batteries such that they will be able to sustain the system for 2 entire days without additional solar power.

Situation 3 becomes relevant when the system recovers from an extended period without sunlight, which will deplete the batteries. In this case, we would need additional power to

commit to charging the batteries. We calculated that if we provided an additional 25% of power needed to operate the pump to recharging the batteries in this circumstance, the system would fully recover a full battery charge in less than 3 days (provided the sun shines), and this was deemed the best tradeoff between buying extra solar panels to provide this energy, and having to wait longer for the battery charge to recover.

### 3. Solar Panels and Battery Bank Sizing

The output wattage of the solar panels must equal or exceed the power required by our pump system. Also, the maximum power voltage of the panels,  $V_{mp}$ , must exceed the charging voltage of the batteries, and be higher than, but as close as possible to, the full battery voltage. For 12V batteries, it is usually recommended that  $V_{mp} > 15V$  [2]. However, other factors will require the generation of more power: these include component inefficiencies, a buffer, and the extra power required to charge the battery bank. We determined that the PWM charge controller will generally operate at 75% efficiency, the batteries will require an extra 25% of the power consumed for charging purposes, and that it would be best to include a buffer of 10% of additional power above the calculated minimum [3]. Also, if a DC-DC boost converter is used for a 36V system, the boost converter will operate at 85% efficiency. Thus, to calculate the total required power from the solar panels, we use:

$$\begin{aligned} \text{without DC-DC:} & \quad W_{panel} = W_{pump} \times 1.25 \times 1.25 \times 1.1 \\ \text{with 36V DC-DC:} & \quad W_{panel} = W_{pump} \times 1.25 \times 1.25 \times 1.1 \times 1.15 \end{aligned}$$

As mentioned above, the batteries must contain enough energy to keep the pump running for 2 days, at 4 hours per day. Thus, the amp-hour of the battery array will be calculated by:

$$Ah_{battery} = (W_{pump} \times 4 \times 2) / V_{system}$$

### Other Considerations

To provide drinking water when sun is not available, we considered using a water tank placed on the roof of the building to store excess water for later usage. A 500 liter tank would provide enough water for about two days in a worse case scenario. However, we decided to abandon this method of storage for several reasons. First, the initial cost of installation, shipping, and the actual cost of the tanks would be equal to or possibly more expensive than buying extra batteries to store energy for days without sun. Secondly, we decided not to use a storage tank because of the maintenance costs and the possibility of contamination of the drinking water while it is being stored.

#### **4. Component limitation**

We decided to purchase most of our components in country, from a warehouse in Haiti. This will serve to minimize costs in equipment transportation, as well as provide components which will be easy to replace from local sources if necessary, and help them take control over their own system. However, this will limit our component selection, and this is the reason we do not recommend very specific models at the moment.

However, we have discovered on the most recent implementation trip that warehouses in Haiti do not provide a good selection of charge controllers. Thus, we recommend the purchase of a Xantrex C35 charge controller for use with our system, domestically.

#### **5. 36V DC-DC Boost**

36V components will be difficult to obtain for the 36V system, and it will be more cost effective and easier to implement a 12V system with a DC-DC boost conversion from 12V to 36V, connected directly to the pump. The boost converter will generally operate at a 85% efficiency.

#### **6. Charge Controllers**

We took two major types of charge controllers into consideration for this system: PWM and MPPT. PWM charge controllers will waste all additional power fed into the system above the battery charging voltage, while MPPT charge controllers are able to downconvert the voltage to make the power accessible. Thus, MPPT controllers will be able to operate at 85% efficiency, while the PWM controllers operate at about 75% efficiency. However, the difference in power savings amounts to only tens of watts for the power levels of our system, while the MPPT controllers are generally 5 times more expensive than the PWM controllers, so the MPPT controller does not amount to a cost effective decision [2].

The charge controller's current and voltage ratings must be adequate to operate in the system. The current rating is determined by the maximum current the solar panels are able to generate, or:

$$1.25 \times \text{total solar wattage} / \text{system voltage}$$

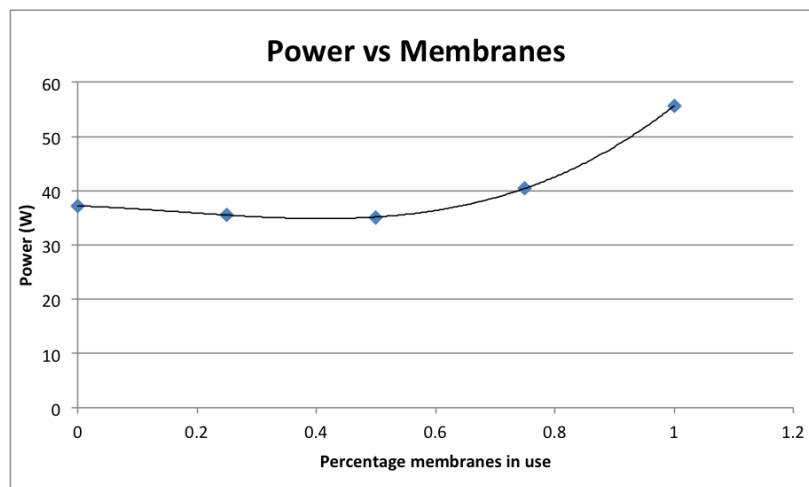
The 25% buffer is included in compliance with the National Electric Code which requires the current rating to be 25% percent higher than the maximum expected current. [2] The voltage rating of the charge controller must be greater than the open circuit voltage of the solar panels. For 12V panels, this is usually around 20-22V.



## 7. Pump Testing

The Harris Hydraulics Laboratory at the University of Washington provided the ability to test the 36V pump. Since this pump included Reverse Osmosis (RO) membranes, we anticipate that the power required will be the highest out of the various pump options. The three stages of purification on this pump include a carbon filter, three (optional) reverse osmosis membranes, and a UV lamp. Using this pump, we tested several aspects of our system. A conventional wall outlet powered the pump rather than solar panels due to a lack of available materials. We obtained measurements of the voltage, current, and power with a multimeter attached to the wiring of the pump. The reverse osmosis filters are not altogether necessary since the filters and UV will provide a fully purified product, and a valve on the machine allows the ability to bypass the RO membranes.

To gain an idea of the effect that the RO membranes have on power consumption, we attempted to control the amount of water diverted to the RO by turning the valve in various ways (closed,  $\frac{1}{4}$  turn,  $\frac{1}{2}$  turn,  $\frac{3}{4}$  turn, open). We also determined the pump's flow rate at each step by collecting and measuring the amount of purified water in a given time. In this way, we determined the optimum point at which flow rate could be fastest to best serve the users and at which power consumption could be lowest to best serve our system. Although the data is not infallible since the twisting of the valve to an approximate location is somewhat arbitrary and difficult to measure, we found the data to be interesting and informative. Predictably, the flow rate decreased sharply as we allowed additional water to pass through the RO membranes, beginning at about 108 L/hour with no membranes, and ending at about 18 L/hour with full membranes. According to our findings, the power required did not begin to increase until after the valve was half open. The power remained around 35 W from no membranes until one-half membranes, and increased up to 55 W with full membranes. In the end, when looking at the flow versus power graph, the minimum power requirement does occur at one-half membrane and with decent flow rate. Therefore, the best setting for the control valve is at the one-half location in order to maximize purification and flow rate.



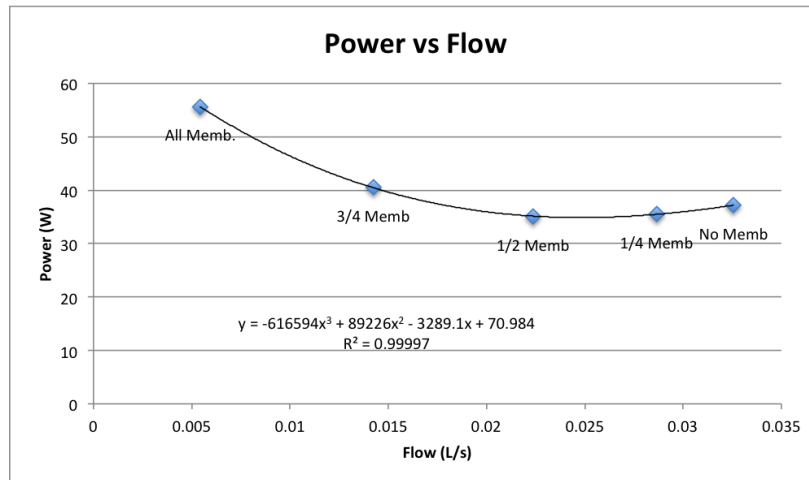


Fig. 2 (Pump Testing)

## IV. Conclusion

Our design will provide a reliable source of solar and battery power for filtration pump units. We have taken into account weather issues and considered inefficiencies in our equations for determining how much of each component is needed. From a recent implementation trip, we have concluded that in cases where the incoming water has a salinity of less than the taste threshold, 300 parts per million, we can use our design of a 12V pump without reverse osmosis. Using a system that consists of solar panels, a charge controller, and batteries in parallel, our design can produce the required volume of clean water, even on days without sunshine. Furthermore, the 36V pump system can be implemented in locations with high salinity by adding a DC-DC boost converter and adjusting calculations by using the equations that consider this additional component.

To facilitate future implementations of our system, we produced an Excel spreadsheet with the goal of allowing simple input of certain parameters to output all necessary components (e.g., number of solar panels, number of batteries, and required ratings of charge controllers). We focused on ease of use through the use of automated calculations and by creating distinct sections for inputting parameters. If a future designer inputs the required watt-hours, the wattage of the solar panels, and other such specifications, the spreadsheet will present the designer with recommendations for the system design. In this way, our single design may be easily broadened within the One World Environment projects and to any other similar project.

In the future, we hope our system design can be expanded and improved to work with a variety of different load requirements. We see possibility in exploring how a solar array system would work on a larger scale, in projects providing whole communities with a clean, reliable water source. Additionally, we believe our guidelines could be expanded to work loads other than a water filtration pump. With the flexibility of the Excel spreadsheet, our single design could be used to provide solar power for a variety of needs in Haitian communities and elsewhere.

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