Solar Powered Water Filtration System

ECE 445 - Design Review

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I. Introduction

Objective

This project was chosen because Dr. Gary Eden and Dr. Sung-Jin Park brought us their desire to develop a humanitarian application for their new technology, a simplified ozone reactor. The motivation to develop a new application arose from the technology's ability to produce clean water at low cost and high efficiency. Currently water purification systems use expensive, environmentally harmful chemicals to purify water. In contrast, our system will utilize low cost, treated foil, and sustainable energy to produce clean water. The simple aspects of our design will help it resist breakdown and limit maintenance costs. These are important aspects because we hope the system will be utilized in third world countries, where the lack of clean water is a growing issue.

Goal:

- Explore and develop a humanitarian use for new ozone reactor technology.
- Clean an adequate amount of water in reasonable time.
- EPA standards will be met.
- Set up and running in developing countries.

Benefits:

- Ozon is eco friendly
- Decomposes into oxygen immediately after usage
- Ozone decomposes bacteria and viruses chemically

Features:

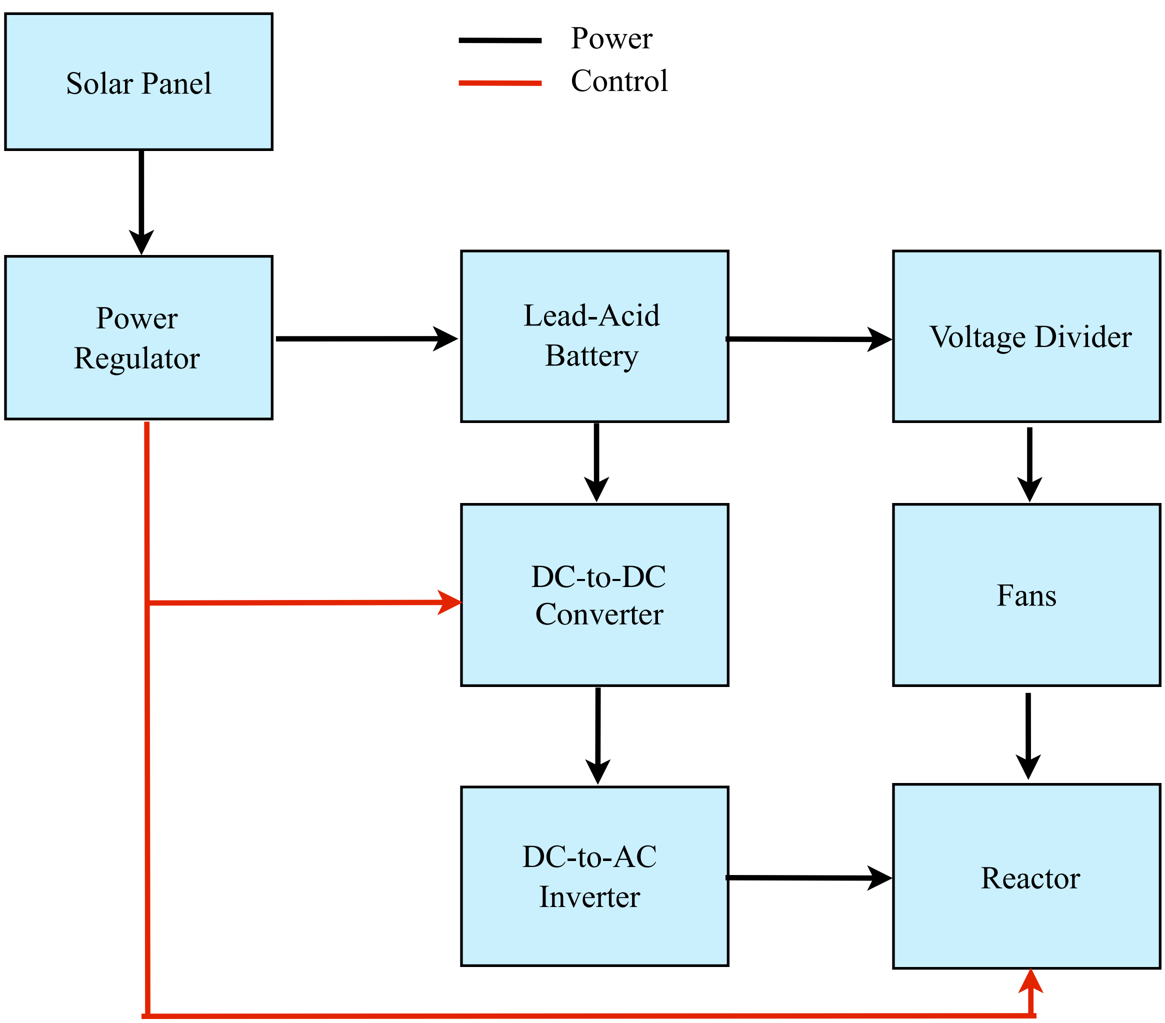
- Inexpensive
- Cheap Materials
- Compact Ozone Reactor
- Solar Powered
- Self-Sustating

Functions:

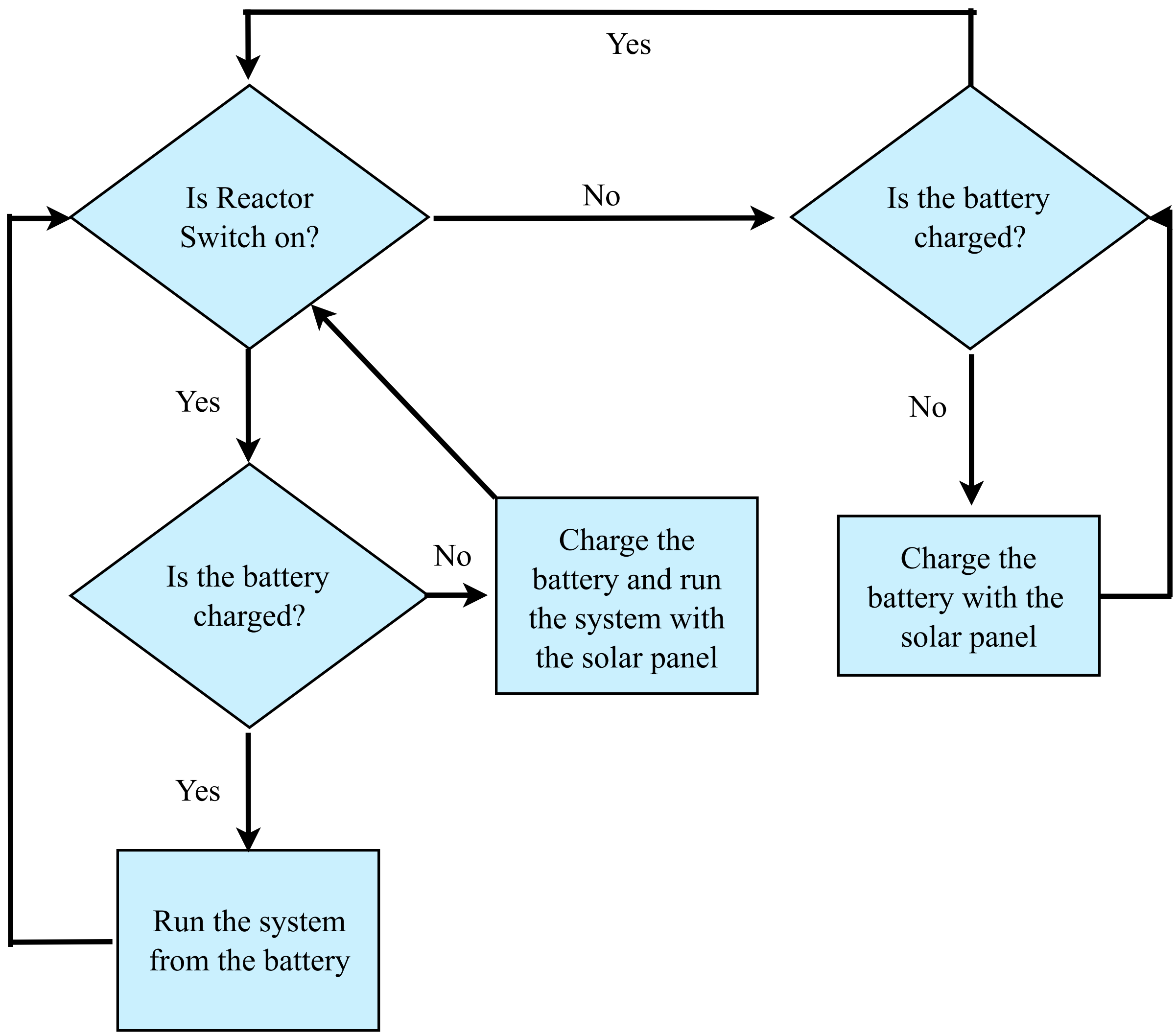
- Solar Panel produces 12 watts.
- Solar Panel produces 21.8 volts at Open-Circuit Voltage (Voc)
- Solar Panel produces 17.6 volts at Optimum Voltage (Vmp)
- Reactor's functionality is similar to a capacitor.
- Fans produce enough airflow to purify 1000 mL of water in 5 minutes.
- 12 volts Lead-Acid Battery will charge from solar panel and will provide power when the solar panel is not available.
- DC-to-AC Inverter will produce a pulse waveform input to the reactor from the output from the output of the DC solar panel.

II. Design

Block Diagram



Power Regulator Block Diagram in Detail:



Block Description

Regulator:

When the reactor is turned on a signal will be sent to the regulator to check the battery. If the battery is within the appropriate range to run the system then it will turn on the switch from the battery to the system and will turn off the switch connecting the battery to the solar panel. From there the regulator will continue to watch the battery and monitor the levels making sure that it has enough power to supply the rest of the system. If it does reach low levels, it will turn off the switch connecting the battery to the system and turns on the switch connecting the solar panel to the system and the battery so that it can be charged for later usage. When the reactor is not powered, it will turn off all the switches connecting any power source to the system. While the reactor is off the regulator will check the battery making sure that it is not low on power. If the battery is running low, then it will turn on the switch connecting the solar panel to the battery in order to charge the battery. The regulator will also play the role of battery protection, which will consist of a DC-to-DC buck converter that controls the upper bound of voltage supplied to the battery from the solar panel. We do not want the battery to receive more than 14 volts at any point, so the properties of the converter will be $D = V_{out}/V_{in} = 14/17.6 = 79.5\%$, where D is the duty cycle. Most batteries have a maximum charge current that is greater than the maximum output of the solar panel, so it should not pose a problem. However, the size of the inductor in the DC-to-DC converter can help limit the current to the battery. Finally, the regulator will include the “master” switch functionality in order to turn the reactor on when clean water is demanded.

DC-to-DC Converter:

The DC-to-DC converter will serve the purpose of stepping up the battery voltage. In the diagram, there is an arrow pointing from the battery to the DC-to-DC converter; because, the battery voltage is fed into the converter. However, the DC-to-DC converter will be connected to the battery via a switch that is controlled by the regulator. The DC-to-DC converter exists to step up the battery voltage before it enters the DC-to-AC inverter. A DC-to-DC converter is simple, cheap, compact, and efficient enough to aid in the stepping up of the battery voltage. The efficiency of DC-to-DC current converters reaches above 90%. The better the DC-to-DC converter, the smaller the transformer on the DC-to-AC inverter will need to be in order to reach our target voltage, which is between 1 kV and 2 kV. The DC-to-DC converter will play an important role in the overall project, because it works with the DC-to-AC inverter to supply the reactor with its necessary input. The DC-to-DC converter will have a duty cycle based on the desired V_{in} and V_{out}. $D = 1 - (V_{in}/V_{out})$. So for an input of 12 volts and output of 80 volts, we need a duty cycle of $D = 85\%$.

DC-to-AC Inverter:

The DC-to-AC inverter that will be utilized in this project will output a pulse wave to operate the reactor. In the circuit, DC is fed from either the battery or the solar panel depending on how much charge is left in the battery. Then, with the usage of 4 MOSFETS, it will alternate the signal to generate the pulse waveform. Both the positive and negative waveform is generated from the circuit. One pair of MOSFETS is used to create the positive waveform while the other pair is used to create the negative waveform. Once the DC passes through the inverter it will have a frequency of 20 kHz, with a peak equivalent to the peak input voltage from the DC-to-DC converter. From there, the output of the system will be boosted to a higher peak via a transformer. For this circuit the optimal peak for running this device should be about 20 times that of the input voltage. Lastly, the AC voltage is fed to the reactor to produce the ozone. The reason for going with a pulse wave instead of a sinusoidal wave is because a pulse wave has a higher efficiency than a sinusoidal wave. The pulse wave has a 90% power efficiency rate whereas the sinusoidal wave only has a 70% efficiency rate. This way the overall system will be much more efficient.

Solar Panel:

The solar panel is the main source of power for the entire system. It will be used to charge the battery and at times will be used to run the entire system. So an adequate solar panel is needed to provide both enough power to system as well as charging the battery. The system proposed requires at least 10 watts of power. This means that a solar power with a 30% efficiency needs to be rated for at least 34 watts of power. Furthermore, the amount of power that a solar panel can produce determines the size of the solar panel. The solar panel that was eventually decided was a solar panel rated for 40 watts of power. Even with a 30% efficiency, there will still be 12 watts of power produced leaving some extra power to work with. Another reason why the 40 watt solar panel was chosen was because this was the best bargain that we found. The 40 watt solar panel was priced at $75 while the 30 watt solar panel was priced at $60. This means that going with the 40 watt solar panel would be more economical when we are looking at watts/dollar. For comparisons, see Appendix.

Fans:

In order for the reactor to produce ozone, it needs oxygen. Since having a pure oxygen tank is impractical, the system will utilize the oxygen that is in the air. Since oxygen only makes up only 20% of air, it is not as efficient as pumping pure oxygen. However, by using fans to create air flow this would increase the efficiency rate of creating ozone. The fans that are being planned for usage are computer fans. They are cheap and would provide a sufficient amount of airflow.

Reactor:

The reactor is the main component that is in charge of cleaning the water. The reactor is made by firing particles through aluminum foil to create channels. By passing oxygen through the channels, it will produce something like a capacitor. Rather than having a dielectric in between the two conducting layers, oxygen will be its replacement. So to create the ozone, a plasma needs to be created within the channels. This means that a high level of voltage needs to be passed across the foil which comes from the DC-to-AC inverter in the form of a pulse wave that has been amplified by a transformer. Some of the best features about this device is that it is very compact and the material required to make it is very cheap. The material needed is aluminum foil which is readily available at a cheap price at most supermarket. Since the reactor is small and only requires a little amount of power to run, it is perfect for our use in third world countries.

Battery:

The battery is used as the main power source for the system when the solar panel is not used. The power level of the battery will be monitored by the regulator so that it will not be either overcharged or completely discharged. When the battery is fully charged or has enough energy to run the entire system, the regulator will flip the necessary switches so that the battery is the only thing that is running the system. However, if the battery is low in charge, it will be connected to the solar panel so that it can be charged. Again, the regulator will make sure the battery does not get overcharged. It will be disconnect from the solar panel once it has been fully charged. There are also benefits in utilizing a battery within the system. It provides a more stable current then the solar panel. This would be better for the DC-to-AC inverter. Another benefit is that it can provide as a backup system. For example, in case of poor weather conditions, a solar panel can not be used to its full extent. This means the battery can be used as the source and the reactor will still be able to run during poor weather conditions.

III. Block Level Requirements and Verifications

Component	Requirements	Verification
Regulator	• Checks whether reactor is on/off. • Determines the charge of the battery. • If battery is fully charged at 12 volts, system will run off the battery. • If battery is undercharged at 11.89 volts, the battery will be charged while the solar panel provides power to the system.	• A multimeter can be used to determine the charge of the battery. The test is successful when the battery outputs 12 volts when fully charged and 11.89 volts when undercharged. •
DC-to-DC Converter	• Steps up the voltage from battery before entering DC-to-AC Inverter. • Voltage of battery should be increased to between 50V and 70V. • Trigger wave of the convert should have a duty cycle of 80%	• A multimeter will be used to measure the voltage at the input and output to ensure its functionality. • A oscilloscope will be used to observe the trigger signal.
DC-to-AC Inverter	• Produce a pulse waveform. • Power efficiency of 90% • A frequency of 20 kHz once DC passes through the inverter. • Output voltage is 20 times the input voltage of 17.6V. • Uses 10 watts of power. • Provides current of 0.0284 Amps.	• A oscilloscope can be used to verify if the inverter does produce a pulse waveform. • A multimeter can be used to verify if the frequency, output voltage, and current give the correct values.

Component	Requirements	Verification
Solar Panel	• Single solar panel that produces 40 watts with 30% efficiency. • Produce at least 12 watts of power.	• A multimeter can be used to verify if the solar panel produces 12 watts of power.
Fans	• Provides necessary air flow through reactor. • Uses about 1.4 watts	• If the fan starts spinning, then it is working. • A multimeter can be used to verify the amount of power it uses.
Reactor	• Successfully converts oxygen to ozone.	• As a test, we will add methylene blue to a beaker of water. If the contaminate water starts to clear up, then it verifies the reactor is outputting ozone.
Battery	• Fully charged value = 12V • Discharged value = 11.89V	• A voltmeter/multimeter can be used to determine the voltage of the battery once it is fully charged or discharged.

Tolerance Analysis:

DC-to-AC Inverter:

This is the main component that is driving the reactor. Because the reactor requires AC and the solar panel and battery outputs in DC, that means that the converter is essential to the overall functionality of the design. If the DC-to-AC inverter is not functioning correctly that would mean that the reactor will not produce ozone, defeating the purpose of the device. So by running the solar panel through the DC-to-AC inverter, we will monitor the output. If it is to what we desire than it is functioning the way it should be.

Solar Panel has a power tolerance of +/- 3%
Battery - 11.89V to 12.65 V
DC-to-DC Boost Converter $V_{out} = V_{in}/(1-D)$ into the DC-to-AC Inverter

$V_{out} = V_{in}/(1\text{-}D)$, D = .85
V_{out} Swing = V_{in} swing of DC-to-AC inverter
$V_{out,low} = 11.89/(1-.85) = 79.22$
$V_{out,high} = 12.65/(1-.85) = 84.33$

With a corrective voltage of about 20V as seen in the transient analysis of the DC-to-DC converter. So for the DC-to-AC inverter 59.22V < V_{in} < 64.33V giving an output range of 1585.33V < V_{out} < 1686.66V which is peak voltage of the AC signal being provided to the reactor.

Noise only appears in the DC-to-DC converter. For the DC-to-AC Inverter, the peak for the input will be the peak for the output as well. Thus, noise obtained from the input will be reflected in the output. Possible noise that can come from the fan is when there is a decrease in power. Since the amount of power it draws is constant, noise from the fan should not be a problem because the fan is its own part of the system and would not disrupt the DC-to-AC inverter.

The point where noise destroys the efficiency of the reactor is when we can not get a peak voltage of 1 kV, which meas our DC-to-DC converter can not output a 50V DC.

By incorporating a zener diodes, it would prevent reverse current flow. This can prevent any noise induced by the system.

IV. Cost Analysis

Parts

Part	Quantity	Cost Per Part	Total Cost
40 Watt Solar Panel PV Mono-Crystalline	1	$72.00	$72.00
Blower-Digi Key Part Number:P12901-ND	1	$12.60	$12.60
Amstron 12V/5AH Sealed Lead Acid Battery w/ F1 Terminal	1	$15.99	$15.99

Part	Quantity	Cost Per Part	Total Cost
MOSFET N channel Digi Key Part Number:IRFB20N50 KPBF-ND	4	$5.26	$21.04
Estimate of DC - AC inverter Circuit not including the MOSFET	1	$20.00	$20.00
R1 33 Ohm	2	N/A	N/A
D2 1N4002	2	$0.10	$0.20
M2 IRFZ34PBF	1	$1.51	$1.51
M1 IRF840PBF	1	$1.55	$1.55
L2 M8405-ND 500uH	1	$1.56	$1.56
L3 542-70F105 10uH	1	$1.70	$1.70
C2, C3 WBR50-150 50uH	2	$2.51	$5.02
V2, V3 Timer LM555CN	2	$0.25	$0.50
Frame Grainger T-Slotted Aluminum Extrusion 2RCP9 97”x1”x1”	1	$34.55	$34.55
Electrical Box Automation Direct Nema Box B100806CH	1	$64.00	$64.00
Micro controller TEXAS INSTRUMENT MPS-EXP430G2	1	$5.35	$5.35

Part	Quantity	Cost Per Part	Total Cost
Zener Diodes 1N5359B	10	$0.17	$1.70
Total			$259.27

Labor

Name	Hourly Rate (HR)	Total Hours Invested (THI)	Total Cost = HR*THI*2.5
Matthew DuBois	$30.00	160	$12,000
Eric Liu	$30.00	160	$12,000
Albert Lo	$30.00	160	$12,000
Total		480	$36,000

V. Schedule

	Sept 23	Sept 24	Sept 25	Sept 26	Sept 28	Sept 29	Sept 30
DR Review Sign-Up							
DC-to-AC Design							
Design Encasement							
Power Regulator Design							
DC-to-DC Buck Converter Design							
DC-to-AC Simulation							

	Sept 23	Sept 24	Sept 25	Sept 26	Sept 28	Sept 29	Sept 30
DC-to-DC Buck Converter Simulation							
Reactor Calculation							
Fan Calculations							

	Sept 30	Oct 1	Oct 2	Oct 7	Oct 8	Oct 9	Oct 10
Order Parts							
Finish Design Review							
Assemble/Test							
	Oct 21	Oct 22	Oct 23	Oct 28	Oct 29	Oct 30	Oct 31
Individual Progress Report							
Final Assembly							
Final Report							

Legend

Name	Color
Eric Liu	
Matt Dubois	
Albert Lo	
Team	

VI. Ethical Considerations

Issues and Risks

We agree to uphold the IEEE Code of Ethics and will address any issues and concerns that may occur in our project.

In doing this project, our goal was to create a system purely for humanitarian purposes. When this project is finished, in no way will we try to exploit the abilities of this project. It will be used for only one purpose, to give the people in third world countries access to clean, affordable water. We will not take this chance to make profit off of this project since most of the main components were designed by other people. We were the ones that brought it all together. On that note, throughout the entirety of this project there have been many circuits and components that were not designed by us. The circuit design for the pulse generator as well as the reactor were designed and built by Professor Gary Eden, Professor Sung-Jin Park, and the graduate students at the optical lab. In no way will we take credit for coming up with the design for any of these components and they will be properly credited for their design.

Some inherent risks that come along with this project are that the amount of voltage needed to run this reactor runs very high and at a very high frequency. Special care should be taken when building and testing the circuit. Also, consideration of the enclosure will be taken into account, so that there will be no risk to the user in any way. Since this device runs off a solar panel, the amount of energy that can be produced can vary greatly depending on the day. So in order to avoid inefficiency, a battery is used. Nevertheless, there is always the possibility where the day is so bad that the solar panel can not charge the battery and therefore the entire system will not be able to run. But these are inherent problems that come up with trying to create a self-sustaining system and we hope to make it as efficient as possible when the opportunity presents itself.

More technical problems that arises in this project come from the fact that solar panels can not exactly be called efficient. That means we are left with a very limited amount of power, but most of our components require a good amount of power. As of now we are stretched thin but have just enough power to run everything. One thing that has come up is a problem of putting ozone into the system. If we use a fan, it needs to be powerful enough to push the ozone up through the water. The bigger the container the harder it becomes to push ozone through it. Thus, finding a balance between having an appropriate amount of airflow and using a minimum amount of power is crucial. Now there are other possibilities that we have in mind to get over this issue. One is to use a very low power fish tank pump rather than a fan. Another method that we are thinking of is using a system that does not even use electricity, but instead uses water flow to inject ozone into the water. By using Bernoulli's principle, a fast flowing liquid will produce a lower pressure. So by using that lower pressure differential, we can suck in the ozone without using an electrical system.

VII. Appendix

See Appendix Page.