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March 08, 2012

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Design Specification for a Rain and Solar Power Generator

Dear Dr. Rawicz:

The attached document, *Design Specification for a Rain and Solar Power Generator*, outlines the Design specification for our project for ENSC 440 (Engineering Science Project). Our achievement is to design and implement a power generator which can create electricity for sunny and rainy weather conditions. Our project uses green energy which will cause no effect on nature.

Our design specification provides the detailed design requirements that need to be achieved at the end of the proof-of-concept phase for RSPG. In this document we will describe the detail in each of the functional requirements stated in the Function Specification and test plans for each module.

Green Power Innovation consists of five skilled, hard-working, and talented fourth-year engineering students: Frank Feng, Zhiyu Hu, Max Liu, Jeff Bian, and Xiao Dong. If you have any questions or concerns about our design, please feel free to contact me by phone at (778) 996-5591 or by e-mail at ffa5@sfu.ca.

Sincerely,

Frank Feng
President and CEO
Green Power Innovation

Enclosure: *Design Specification for a Rain and Solar Power Generator*

2012

Design Specification for a Rain & Solar Power Generation System

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Executive Summary

Our company is developing a renewable energy generator (RSPG). The device will collect the raindrops and sunlight to produce electrical power. The system will be highly effective in all space and climate.

It's clear from the name that the Solar & Rain Power Generation system (RSPG) has two major function parties: solar power generator and rain power generator. These two function parties will be both selected and coveted though a current & voltage regulation and then could be used to charge battery or providing power for local load.

This document gives detailed specifications for the designing and implementation of the prototype model of the electrical power generator. The SolidWork design model, operation flowcharts, test plans, testing parameters, and data analysis are all described in detail.

All the different components of our design will be tested thoroughly, by integration test plans we have discussed in this document. The design and implementation of these features and procedures will be accomplished and integrated into our product with an expected date of completion of April 20th.

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Glossary

GPI	Green Power Innovations
ISO	International Organization for Standardization
OSHA	Occupational Safety and Health Standards
RSPG	Rain and Solar Power Generator
SPG	Solar Power Generator
RPG	Rain Power Generator
ADJ	Adjustable Junction
AC	Alternating Current
DC	Direct Current
LCD	Liquid Crystal Display

1 Introduction

The Rain and Solar Power Generator (RSPG) system, which collects green energy, is a new style design. The system collects solar power and raindrops to create electrical power. The rain power generator part is our main design, and it works as follows: collecting the rain drops to a water tank, accelerating the water through a downpipe, and use the kinetic power of the water to drive the turbo on the power generator [1].

1.1 Scope

The SolidWork design model, operation flowcharts, test plans, testing parameters, and data analysis are all described in detail in this design specification document. The design specification includes all the requirements for a proof-of-concept system and a portion of the requirements for the final production model. There might be few changes between the conceptual and actual design layouts.

1.2 Intended Audience

This document is intended for use by the engineers at GPI and all others who may become involved in constructing the RSPG proof of concept product. This document will also include the necessary information on conduction through test cases on a RSGP proof of concept model. The testing engineers will test the proof-of-concept product under the regulations listed in this document.

2 System Specifications

Rain and Solar Power Generator (RSPG) system will harvest solar energy and the potential energy of rain drops to provide proper power. The RSPG system will continuously operate once when the user turns system on by open/close pushing button. The user will also have the option to override the power generation mode to either solar or rain mode under any situation.

For the solar power collection, solar cells would be mounted on the house roofs with removable mounting locks. Electricity generation should start within 10 minutes when solar radiations waves directly hit the solar cells.

If the rain mode is used, the system will automatically harvest rain drops thought the rainwater from the building downspout into the rain barrel and start electricity generation automatically once the water level in the rain barrel reached optima power generation level (carefully calculated and design to obtain maximum power output. Please refer to rain barrel section for detailed explanation). The user will also have the option to force electricity generation start at any time.

3 Overall System Design

This section demonstrated a system overview of the entire design. Design details of perspective parts of the Rain and Solar Power Generator (RSPG) will be discussed in next few subsections along with the design details and mechanism specification of individual parts correspondingly.

3.1 Mechanical Design

An overview figure and physical parts of rain power generation system are given as **Figure 3.1**. Please note the Rain Barrel and Minihydro Turbine blade enclosures have been made transparent to show the underlying mechanisms.

System was mounted on wall, right next to a downspout pipe. Input water was directly come from the downspout, part of which are intercepted and replaced with the Downspout Diverter as left top **Figure 3.1** shown (detailed mechanism will be described in Downspout Diverter section).

The DC power generator, whose rotor shaft is vertically attached on the center of the Minihydro Turbine blade, is not presented in the **Figure 3.1**. Other perspective mechanical overview pictures can be previewed in the Appendix A [2].

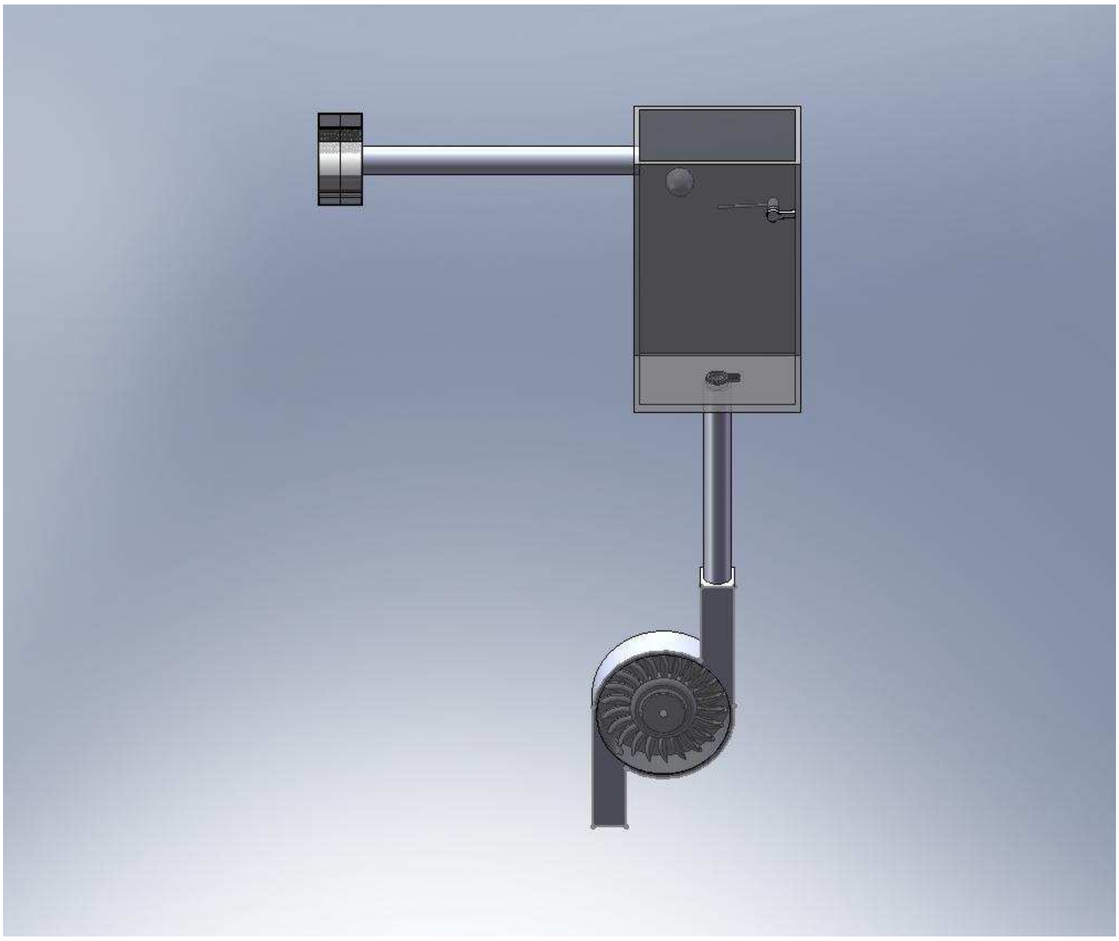

Figure 3.1 Overall System Design

Originally, a rain satellite dish was designed to harvest rain drops and solar panels are mounted on the satellite dish' conical as **Figure 3.2** [2] indicated.

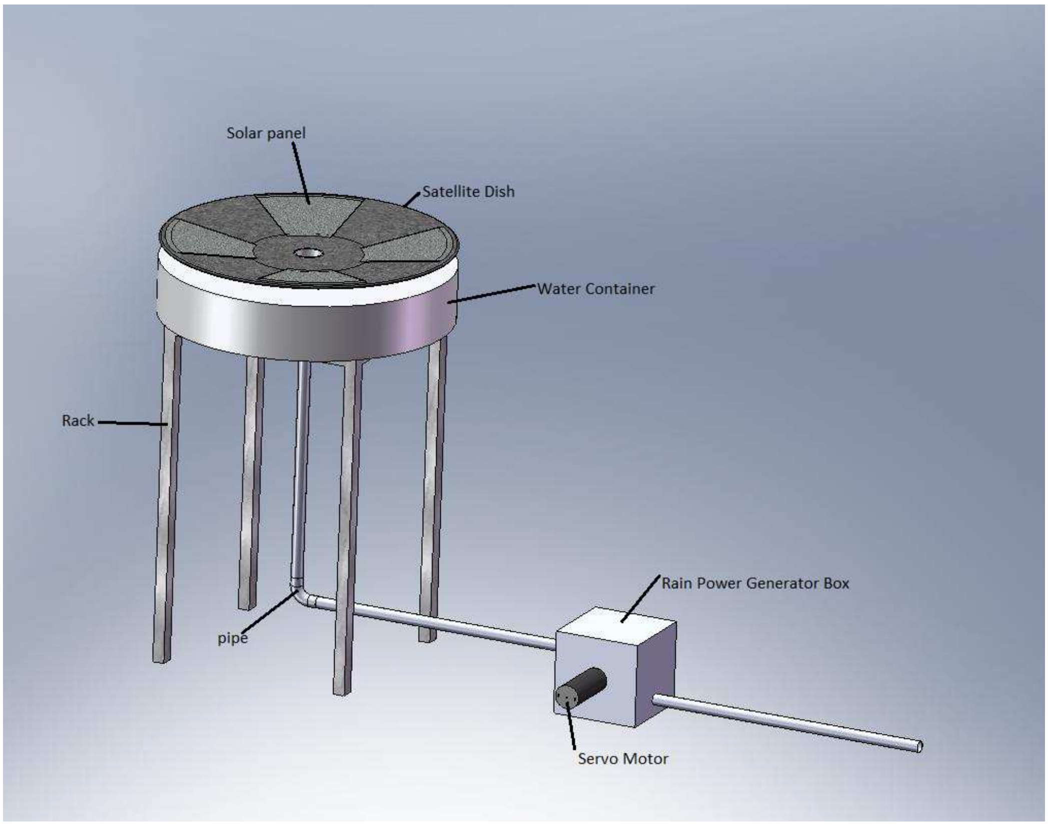

Figure 3.2 Original System Design

After longtime painstaking team research, we notice that the rain water volume is limited by the size of the satellite dish which may not harvest enough water to provide a continually flow in order to driven the turbine for a considerable rotation rate [3]. Moreover, the size and shape of the solar panels are also constrained by the curvature of the satellite dish. Such solar panels are rare in the current market and cost significantly over other normal solar panels. As a result, alternative solutions are used, since every building has its own rain downspout system, i.e. the building roof, and it is a native, costless and per-existed rain drop harvester in raining days. Developing a Downspout Diverter is relatively easy and a proper option to improve the system performance and adaptability.

The solar panels will be mounted on the roof of the house in order to maximize the sun light absorb. Please refer to specific design solutions in SPG section.

Table 3.1 provides theoretical power output for both Rain and Solar mode. Approximate rage of power generation rates for each mode is also listed in the table.

Table 3.1 System Power Output

Mode/Weather	Maximum Power	Minimum Power	Minimum production
Rain	5W	1W	0.167Wh
Solar	9W	5W	20Wh

Rain mode minimum power output value were calculated base on the minimum continues torque/RPM requirement from DC power generator's data sheets, whereas maximum power output was approximated by maximizing the flushing pressure on the turbine fan then used the DC power generator's data sheet (Torque/RPM) to calculate output level [2].

Solar mode values were obtained by the assumption that under ideal sun insulation conditions (i.e. full sun hours, one hour of sunlight at an irradiance level of 1000 watts per square meter) and calculated respected to corresponding values of the solar panels' data-sheet.

3.3 High-level System Design

This section provides a high-level design of the entire system and demonstrates the process of converting Rain & Solar energy to electrical energy.

Each block in **Figure 3.3** represents either a physical part or a sub-systerm of the entire design. The arrows between blocks indicate the co-operations between sub-systems.

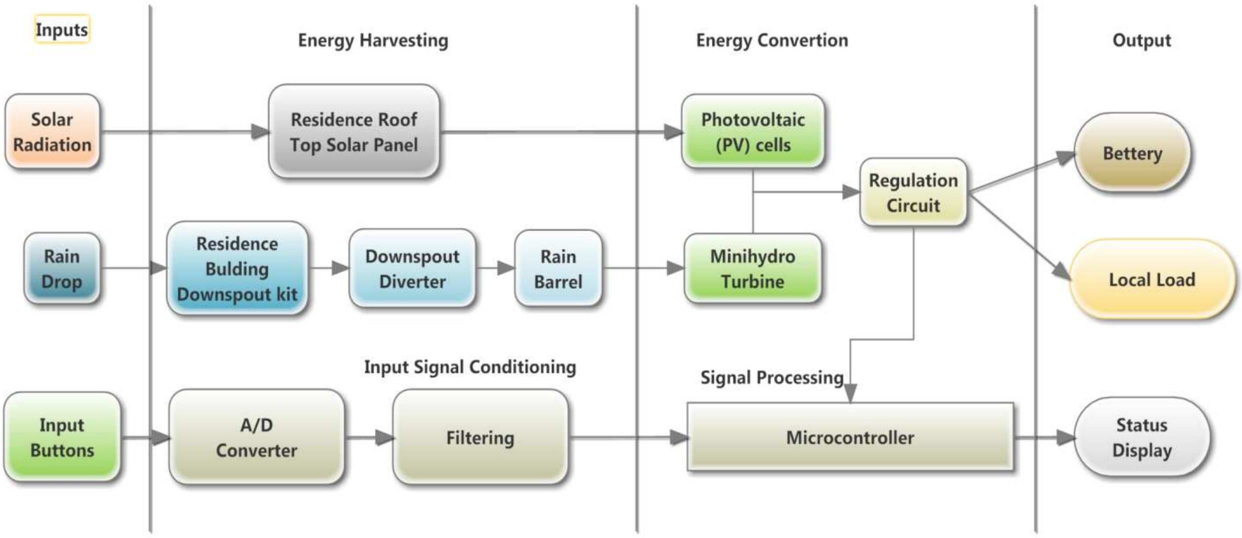

Figure 3.3 System Block Diagram

System inputs include user input buttons, solar radiation and rain drops.
The user input was designed as button pushes then sampled as electrical signals, and conditioned for use through amplification, filtering, and A/D conversion stages.

Signal will process through a microcontroller with operating software. However, the system may use analog circuits, which has a similar behave instead of microcontroller due to the limited time and cost.

Energy input is harvested and stored respect to their unique formation for next conversion stage. Energy conversion is the core operation of this project. The Minihydro subsystem is carefully designed and will be discussed later in the Minihydro Turbines System section.

Output electricity will be regulated and passed through a protection circuit then can be used directly on local load or charge the internal battery.

Operations mode and system status will be displayed as an output respect to user input.

3.4 Electrical System

The electrical system of Rain & Solar power generator consists of a LM family adjustable voltage regulator with over-current and short circuit protection. The main reasons why we choose this regulator are as follows [4]:

- Capable of supplying in excess of 1.5A over a 1.2V to 37V output range
  - As the rain power and solar power generators will generate different output voltage (the output generated by the rain power generator depends on the potential energy of water, i.e. the height of the water level), the regulator will ensure both output voltage will fall into this range
- Provided with full overload protection
- Used in a variety of applications
- Easily mounted and handled since it is packaged in standard transistor packages

As shown in **Figure 3.4**, the schematic drawing used a LM117 3-terminal adjustable regulator with two external resistors and noise-rejection capacitors.

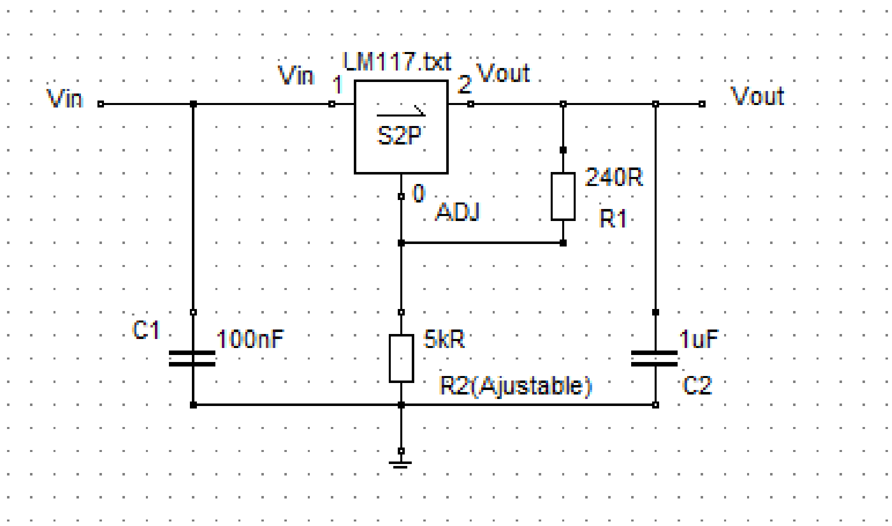

Figure 3.4 LM117 3-terminal adjustable regulator operating circuit

The terminal Vin will directly connect to DC-power generator, R2 is a variable resistor ranging from 0Ω to 5kΩ and R1 has a fixed value of 240Ω. To adjust the value of R2, we can get an output voltage which satisfies the following equation:

$$\mathrm{Vout} = 1.25\mathrm{V}\left(1 + \frac{\mathrm{R2}}{\mathrm{R1}}\right) + \mathrm{I_{ADJ}R2}$$

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Where I_{ADJ} is the current flow from the adjustment terminal (ADJ) and 1.25V is the typical voltage difference between Vout and V_{ADJ}. The two capacitors C1 and C2 are used to reject transient and improve output impedance so as to provide enough output current, a range from 1uF to 1000uF will do the job. The values shown on the **Figure 3.4** are just an example.

3.4.1 Over-current and short circuit Protection

Based on the above general system, another capacitor C3 was added to reject the transient response from the output terminal. An update schematic diagram is shown in **Figure 3.5**.

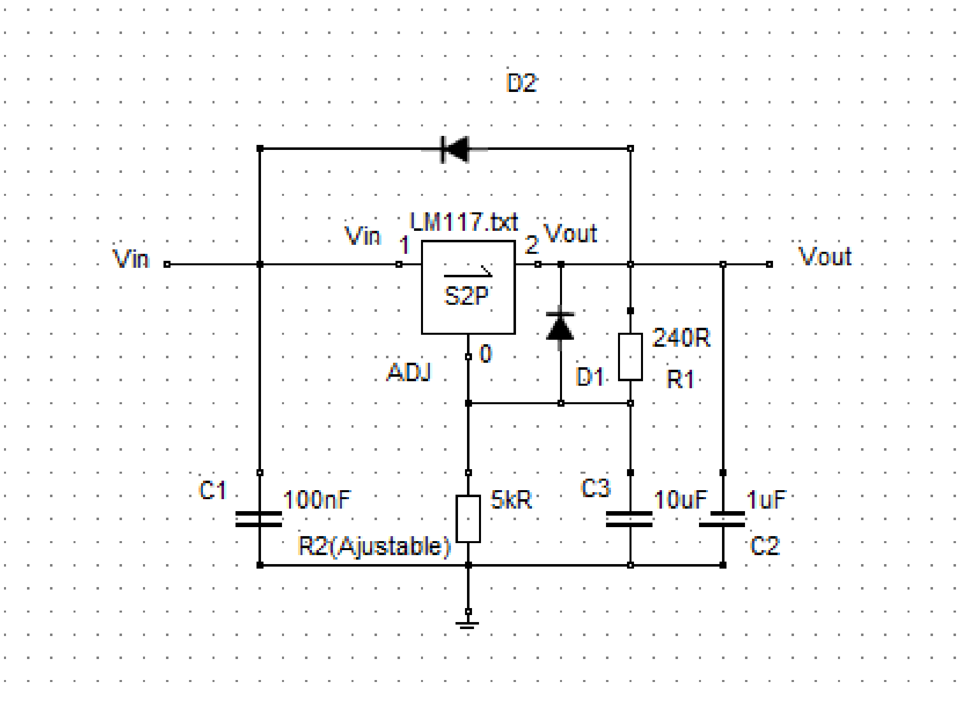

Figure 3.5: LM117 regulator with over-current and short circuit protection

When capacitors are used with the regulator, it is necessary to add diodes to prevent the current flow from low current limits into the regulator. When the input or output terminal is shorted, the current from discharging the capacitor will strike R1, resulting in affecting the nominal voltage between Vout and V_{ADJ}, therefore, a diode D1 is added parallel to R1 to against C3. Similarly, another diode D2 was added parallel to the regulator to prevent the C2 discharging current from flowing to the regulator.

3.5 Other Considerations

3.5.1 Noise Considerations

Our system will operate in 24/7 and embed as part of the resident building. Noise level reduction is an essential design requirement. The following procedures will be applied to ensure system noise level maintains in a reasonable range.
The protection cover of the DC generator will use acoustic absorbing material.
Minimize the twisting of system pipe in order to reduce unnecessary noise.
Rolling bearings are applied to reduce the frication noise. (i.e. motor shaft, turbine blade shaft)

3.5.2 Safety Considerations

In order to protect DC generator and other electric components from water leakage damage, the following system physical regulations are applied:

- All electrical components are isolated from water.
- The pipe joints are glued carefully.
- Joint washers are installed for both rain barrel injection and outflow valves

Following precautions are used to ensure the safety for the developers and users:

- Super screws are used to mount system on the building
- ABS-Plastic materials are used to build rain barrel to enforce anti-corrosion abilities.

4 Downspout Diverter

Downspout diverter kit automatically channels water from the gutter downspout to rain barrel when the rain barrel is full, the rainwater continues flow through the downspout where it will then drain away from the applied building, preventing it from seeping.

4.1 Physical and mechanical design of the Downspout Diverter

Downspout diverter kit replaces 30cm of the original building downspout and connects to the rain barrel. It is designed to work with the standard of 5.08cm x 7.62 (2''x3") or 7.62 x10.16 (3" x 4") gutter downspouts which are two common standards for most of the buildings in North American [5].

4.1.1 Automatically Water Channel Mechanism

The automatically water channel is shown in **Figure 4.1**. When rain water flows done along the downspout pipe into the diverter, rain water will be filtered and channeled into the barrel through the side hole whereas debris (i.e. leafs, tiny rocks) are not passed through the filter. As a result, they will slide along the filter surface and drain away.

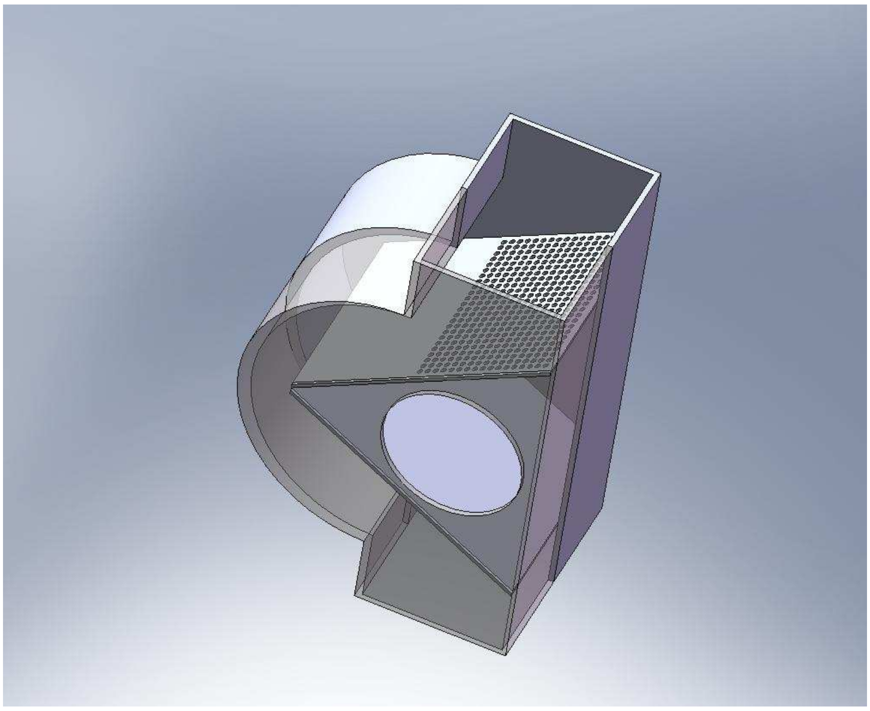

Figure 4.1: Downspout Diverter

4.1.2 Automatically Bypass Channel Mechanism

As **Figure 4.2** showed, once the barrel is full, the water level inside the diverter reaches its maximum level (blue line), then the water will be overflow then flow down along the remainder of the downspout

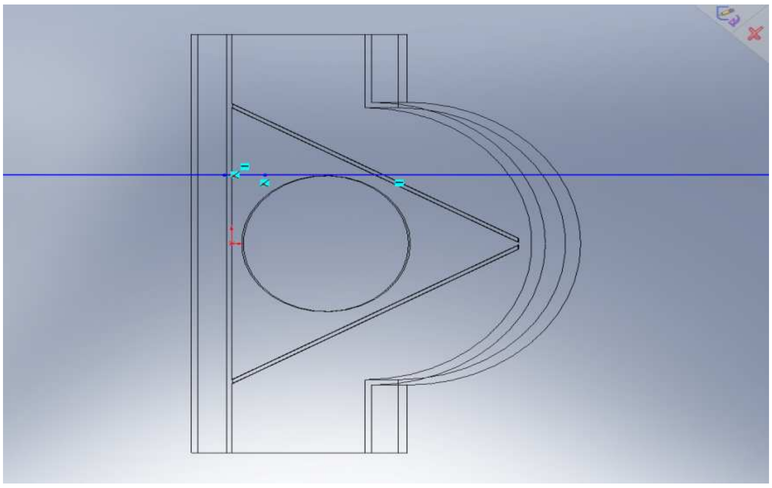

Figure 4.2: Downspout Diverter Max Water level

5 Rain Barrel

The purpose of the rain barrel is to store water collected from the water pipe. The user could choose to release the water for power generation in both manual and automatic manner, or the water will be released when the level of water reaches the maximum possible height.

5.1 Physical and mechanical design of the rain barrel

The design is based on the operation of toilet seat. The detailed design of rain barrel is shown in **Figure 5.1**. The basic components in the design are the handle with handle arm, the float ball, the flapper, the flapper chains, the flush valve seat and the tank.

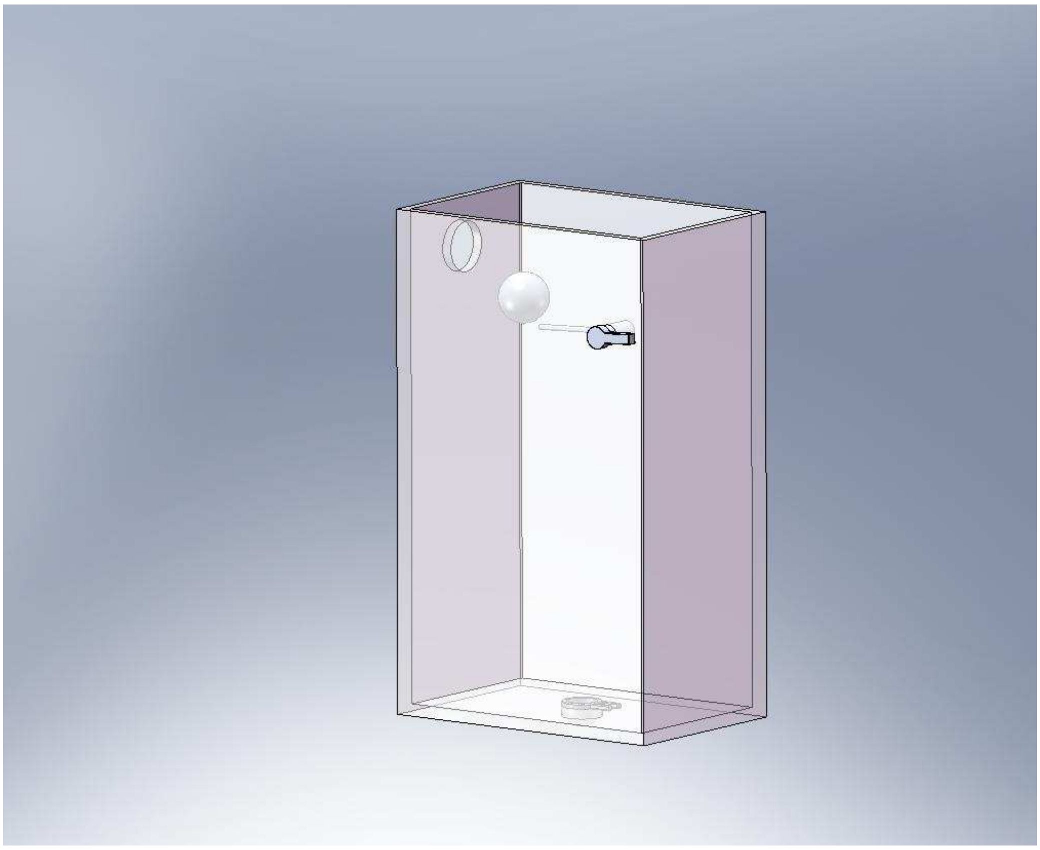

Figure 5.1: Rain barrel

5.1.1 Physical theory and mathematical calculation

The left top hole is located 40cm above the bottom of the tank. For the purpose of releasing water automatically, we need the buoyancy force acting on the float ball greater than the gravity force and the force acting on the flapper by water pressure. With the design of flapper having a shape of 2cm radius circle on the top, the force acting on it will be about 4.92N when the water level reaches a maximum height of 40cm. The gravity force in this case is about 0.99N. Thus, we conclude that a minimum of 5cm radius float ball is needed in order to open the flapper. Since the flapper chain will be fully stretched at that time, we also conclude that a length of 30cm will be a suitable length for flapper chain, so does the vertical distance from the bottom of the tank to the location of the handle.

Notice that the flapper will be empty inside, which means when flapper is lifted or open, it will have a buoyancy force acting on it and thus it will not close down during the process of water releasing.

5.1.2 Detail design with each component

There will be a pipe connected between the left top hole of the tank to the water pipe so that all water will be in the rain barrel. The flapper will sit on the top of the flush valve seat which placed on the bottom hole of the tank. The size of the bottom hole of the tank is slightly less than the flush valve seat. The purpose of having the extra flush valve seat is to ensure that flapper can be closed tightly and no water will be leaked.

The two legs of the flapper will then be stuck by screws. On the other side of the flapper, two flapper chains will be connected to the float ball and the handle arm, respectively. The lengths of the flapper chains will be the same as the vertical distance from the bottom of the tank to the location of the handle. The tank will also have a hole in the front allowing the handle to pass through it and thus connect to the handle arm. Lastly, a cord will be tied to the handle so that user can control the handle.

5.2 Material and size specification

5.2.1 Rain barrel

The rain barrel has a whole size of 30cm length, 20cm width and 50cm height. It will be made by ABS plastic.

5.2.2 Handle & handle arm

The handle will be made by ABS plastic with a size of 5cm length, 3cm width and 5cm depth. Detailed design for the handle is shown in **Figure 5.2**.
The handle arm will be made by zinc with a size of 10cm length and 1cm width.

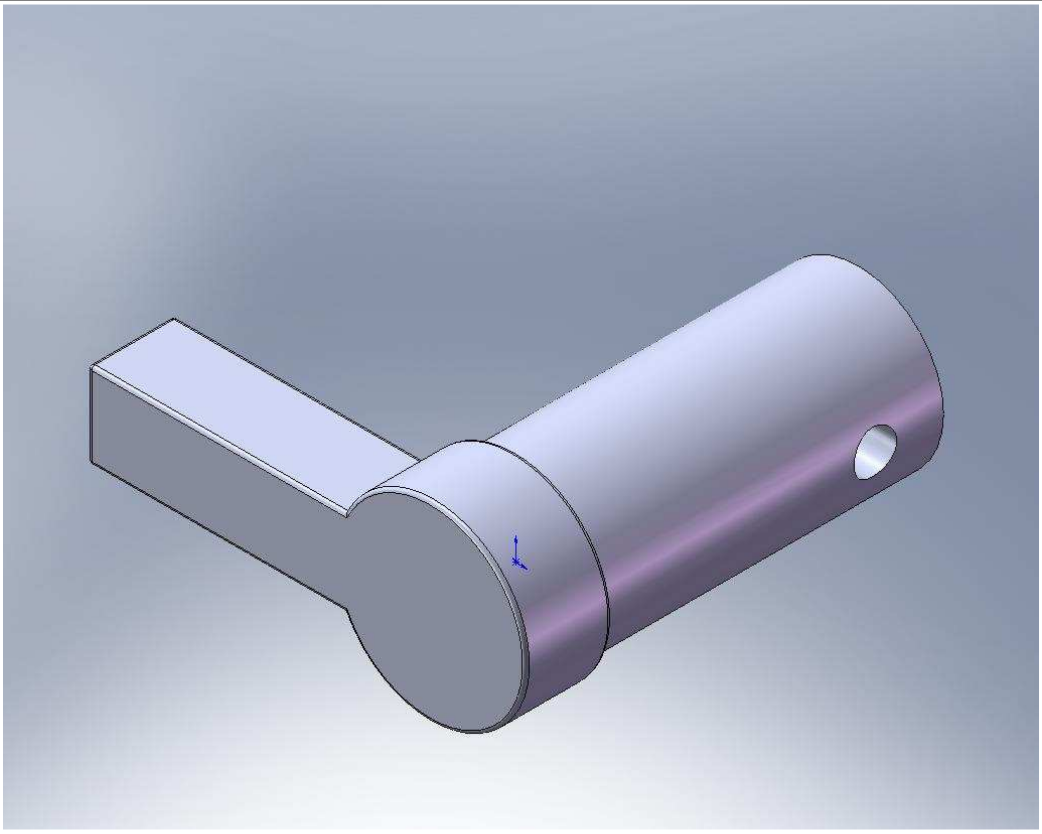

Figure 5.2: Rain Barrel Handle

6 Minihydro Turbine System

The Minihydro turbine system consists of two parts, one turbine blade and a DC power generator whose rotor shaft is vertically attached to the center of the Turbine blade. This subsystem is designed based on the same concept of the modern Hydroelectricity Dam systems [6]. When water running through the turbine blades, it rotates the turbine as well as the mechanical rotor which is attached to the turbine through a shaft. Therefore the rotor in the power generator will cut magnetic field thus covert the kinetic energy to electrical energy.

6.1 Physical and Mechanical Design

The Minihydro Turbine and DC power generator are locked together though a shaft, so the rotor of the power generator will rotate with turbine blades. A ball bearing will be mounted on the turbine blade cover.

6.2 Turbine Design

The physical and mechanical design of the turbine blade was shown in **Figure 6.1**. The front cover has been made transparent for better demonstration of the turbine blades' shape.

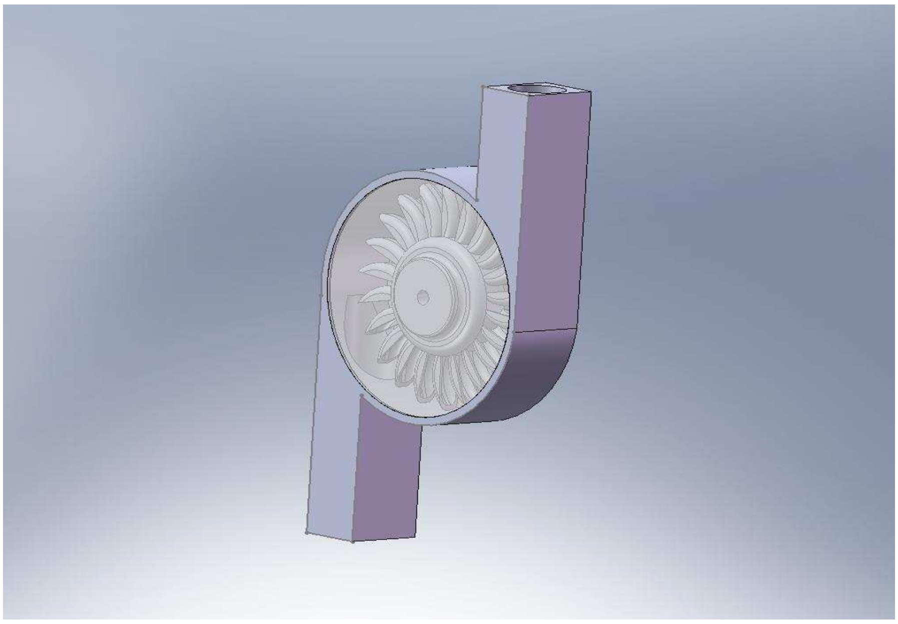

Figure 6.1 ： Minihydro Turbine Subsystem Design

6.2.1 Turbine Blade's Cover Design

The upper injection hole of the cover is connected with Rain Barrel's outflow pipe, and the injection line is tangent to the turbine blade. As **Figure 6.2** shown, the outflow hole of the cover locates at the lower bottom side with a relatively larger size then injection hole. Such design will allow the water flow to be free interrupt.

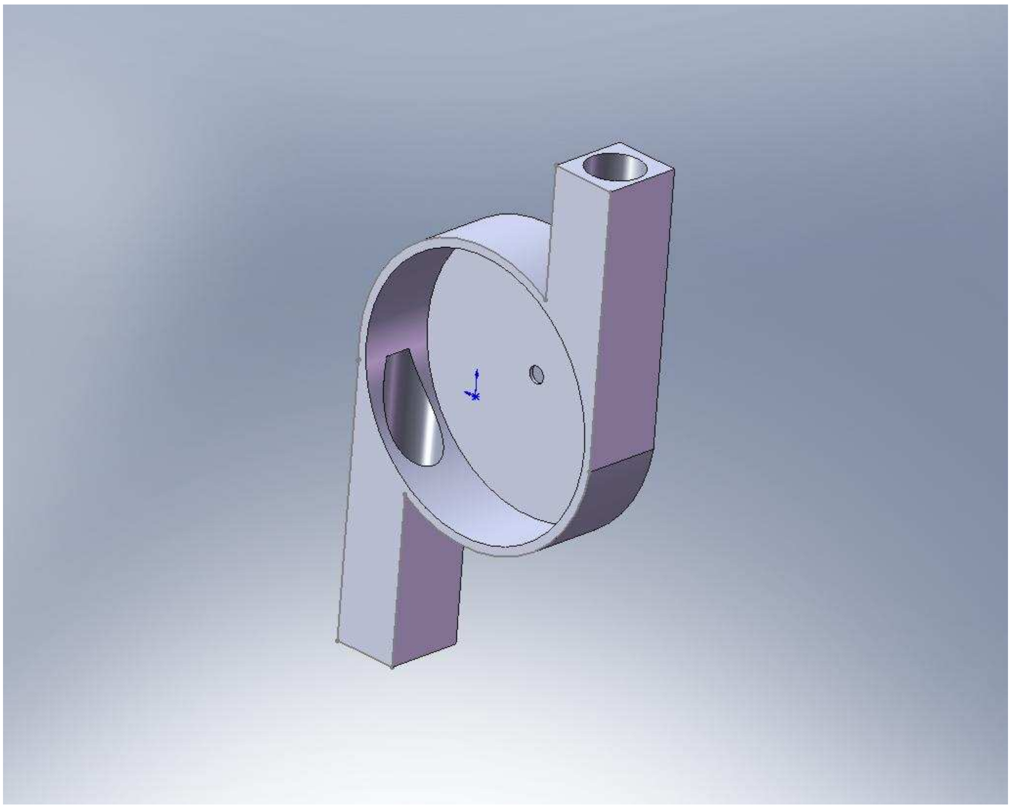

Figure 6.2 Turbine Blade's Cover Design

6.2.2 Turbine Blade design

Basically, turbine blade is just a series of spoon-shaped buckets mounted around the edge of a wheel as shown in **Figure 6.3**. The spoon-shaped buckets ensure efficient momentum transfer of the water flow to the turbine wheel [7]. As water flows into the bucket, the direction of the water velocity changes to follow the contour of the bucket. When the water-flow contacts the bucket, the water exerts pressure on the bucket and the water is decelerated as it does a "u-turn" and flows out the other side of the bucket at low velocity. Compared to Propeller shaped turbines, this design is more suitable for low flow rate water injection.

Figure 6.3 Turbine Blade Design

6.3 DC Power Generator

This system requires a precision balanced and extremely efficient power generator. The generator we chose has a good current output at low RMP, and output DC current directly (**Figure 6.4**).

Figure 6.4 DC Power Generator

The following tables cover the mechanical features and specifications of this power generator, and **Figure 6.5** pictured test values of output power in watts vs. motor RPM (For detailed values of open voltage and short circuit of this power Generator please refer to Appendix, **Table12.1**)

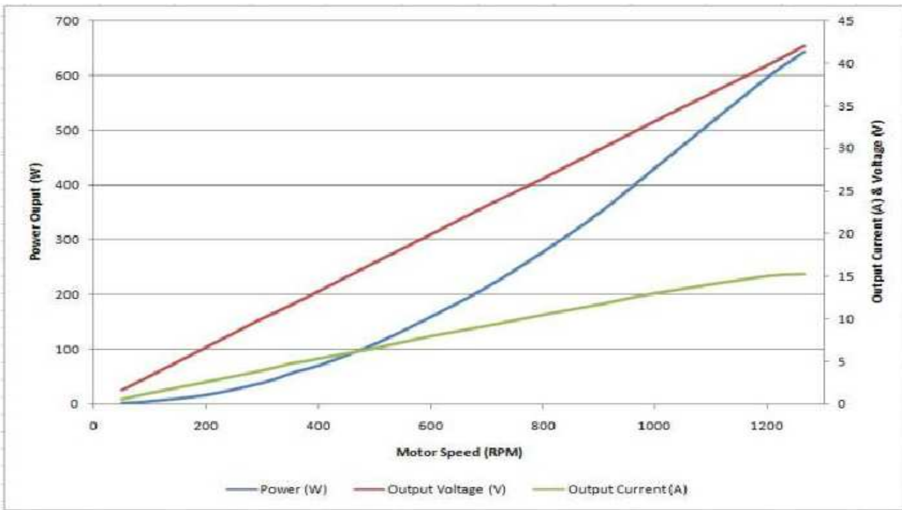

Figure 6.5: Output Power vs. Rotor RPM

7 Solar Power Generator

The solar panels will be mounted on the roof of the house in order to maximize the sun light absorb. The solar panel we chose can generate 12 volts output voltage which is commonly used for DC battery charger, LCD lamps and sign. As shown in **Figure 7.1** and **Figure 7.2** the solar panels have 36 cells and a switch attached at the back.

Figure 7.1: The solar panel with 36 (4×9) cells

Figure 7.2: The cable and switch attached at the back of the solar panel

7.1 Solar Panel Specification

The following **Table 7.1**, **Table 7.2** and **Table 7.3** summarize the specifications, characteristics and mechanical data.

Table 7.1: The physical data of the solar panel

PHYSICAL	DATA
Type	Monocrystalline Silicon
Dimension of module	12.2′′ × 11.2′′ × 0.98′′
Weight	3 lbs
Front Glass	3.2mm tempered
Frame	Anodize Aluminum Alloy Type 6063-T5
Maximum Load	5400 Pa
Cable Length	3 FT
Weather Proof	Rain, snow, hail

Table 7.2: The characteristics of the solar panel

ITEM CHARACTERISTICS	DATA
Power at STC (Pm)	10 Watt
Maximum Power Voltage	18.1 Volts
Maximum Power Current	0.49 Amp
Open Circuit Voltage	21.5 Volts
Open Circuit Current	0.52 Amp

Table 7.3: The limits of the solar panel

LIMTS	DATA
Operating Temperature	-40 – 85 Celsius
Maximum System Voltage	600V DC
Series Fuse Rating	10 Amp
Durability	25 years plus

7.2 Design Principle

The solar cells that we see on a small calculator or satellites are called photovoltaic (PV) cells, which convert sunlight directly into electricity. The solar panel was just packaged by a number of solar panels into a frame. The solar cells are made of semiconductors, such as silicon, which is widely used in analog design [8]. When light strikes the cell, the energy absorbed by the semiconductor will activate the electrons so as to allow them to flow freely, thus generating current. In our design, in order to make out system available 24/7, the solar mode will be activated in sunny weather. The following diagram shows how a solar panel converts sunlight to electricity.

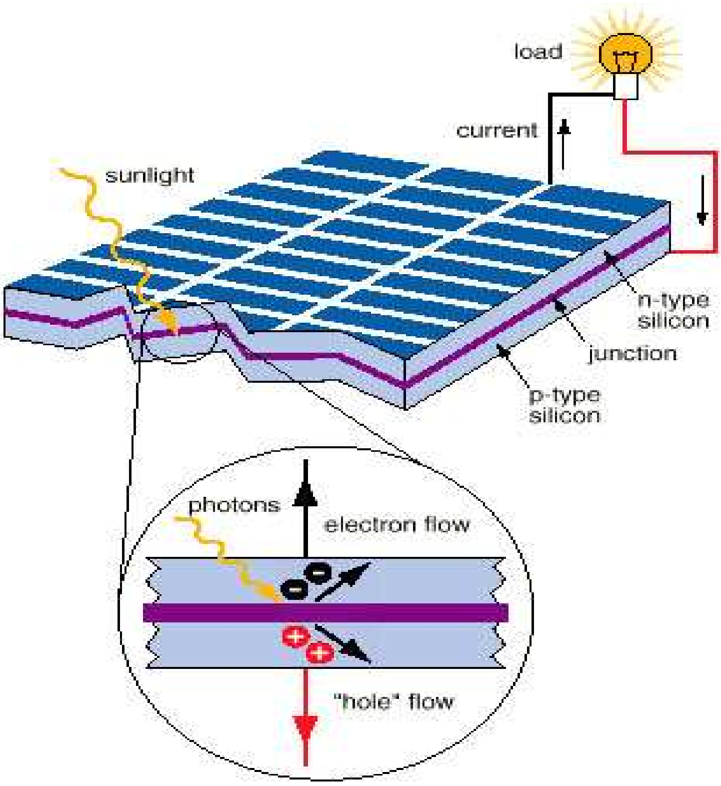

Figure 7.3: The principle of how a solar panel generates current

As mentioned above, the sunlight will knock the electrons and allow them to flow. The junction between the n-type silicon and p-type silicon is called pn junction which only allows electrons to flow from the p-type to the n-type. The solar panel acts as a DC power supply, and can directly connect to some loads, such as advertisement sign, LCD lamps and so on.

Due to the cost issue, we will connect the solar panel directly to our electrical system rather than having an inverter that converts DC to AC. However, we can extend our design to a more home-use basis if the budget allows.

8 User Interface

The user interface consists of a bunch of input buttons and an instrument monitor panel. There are four pairs of buttons for turn on and turn off the entire system, turn on or turn off water tank outflow valve, switch the power generation mode, and choose output applications. The user interface will also contain an instrument monitor panel to monitor instant output capacity and the battery storage capacity. The user interface will be placed near the DC power generator.

8.1 User Interface Hardware

The hardware will include instrument monitor panel and buttons.

8.1.1 Instrument monitor panel

The instrument monitor panel will display the instant output capacity, the battery storage capacity, current power generation mode, current used application, as well as error messages. The monitor panel will be used as a monitoring and controlling center.

The output data will be displayed on the monitor panel. The monitor panel will show the instant output capacity (time accurate into a second). It will also show the battery storage capacity by percentage. The monitor panel will display the error message for either the output power is not generated or the whole system is under unsafe mode. In addition, the current power generation mode and the current used application will also show on the monitor panel.

8.1.2 Buttons

Each adjustable part will consist of two buttons. **Table 8.1** below shows the number of buttons, as well as the input functions for each part.

Table 8.1: Button Specifications

Function	# of Buttons
Turn on and off the system	2
Turn on and off water tank outflow valve	2
Switch between solar and rain power generator mode	2
Switch use applications	2

8.2 User Interface Software

The input of software comes from the button configures and the software output will display on the monitor panel within 200 ms delay.

8.2.1 Monitor Panel Display

The monitor panel will exhibit the information for the current power generation mode, the current used applications, the water container on and off status, the instant output capacity, and the batter charge capacity. Any button be pressed (input change) will change the output. Meanwhile, the change information will display on the monitor panel with 200 ms delay. The error message will also be displayed on the monitor panel if the system is leakage or any other error occurs.

8.2.2 Button Identification

Each button will be initialized and programmed separately and performance the different usage. Hence, each button will treat as different input signal, and then directly show the relative output on the monitor panel. The delay time will be modified through testing.

8.3 User Interface Verification

The following tests will be done in order to test the user interface.

1. Pressing the buttons to get different information display on monitor panel.
2. Display the instant output capacity on monitor panel. (time accuracy into one second)
3. Display the batter charge capacity by percentage on monitor panel.
4. Display the correct on and off status for entire system.
5. Display the correct on and off status for water tank outflow valve.
6. Display the error message on monitor panel.

9 System Test plan

The solar and rain power generator will be tested first. Next, the individual buttons will be tested as well as the corresponding information shows on the monitor panel. The normal and extreme cases will also be examined.

9.1 Unit Testing

In order to guarantee each button works and the corresponding information on the monitor panel is correct, GPI plans to test each button separately. The rain and solar power generator will also be examined. The test procedures show as following:

1. Press the button which is going to be tested and once at a time. Do not press any other buttons.
2. Verify that the accuracy of changing information on the monitor panel is corresponding to related button when each time pressing it.
3. Verify that the monitor panel is on when the system is turned on
4. Verify that the output capacity is shown accurately when the electric power is generated.
5. Verify that the battery capacity is shown accurately when the battery is charging.
6. Verify that the water container plugging on and off status is correct.
7. Test the maximum power can be generated by solar power generator mode.
8. Test the maximum power can be generated by rain power generator mode.

9.2 Normal Case 1: Rain power Generator Mode

User Input: The user set system to rain power generator mode.

Conditions: The typical precipitation should be at least 9 mm. The typical temperature range should between 2°C to 8°C. The typical Pressure should around 100 KPa.

Expected Observation: The output capacity should have a minimum value respect to **Table 3.1**.

9.3 Normal Case 2: Solar Power Generator Mode

User Input: The user set system to solar power generator mode.

Conditions: The idea situation is that the solar panel will be placed as many as "full sun hours" (full sun hours = each hour of sunlight at an irradiance level of 1000 watts per square meter) per day. The typical condition is that the sunlight at a level of

120-160 watts per square meter. Hence, the solar power generator can generate at least 10W power.

Expected Observation: The solar panel placed in full sun will generate around 140-160 W per square meter of solar cells. The output capacity should have a minimum value respect to **Table 3.1**.

9.4 Normal case 3: Maximum level of water has been reached

User Input: None

Conditions: The user does not pull the handle of water tank and water is full in the water tank.

Expected Observation: Flapper is lifted automatically and water is being released. The control panel shows that the electrical power is being generated. After all water has been released, the control panel shows that electrical power has been generated and wait for user's instruction on how to use the electricity.

9.5 Extreme case 1: Handle of water tank was pushed when there was no water contained.

User Input: The user pulls the handle.

Conditions: The user pull the handle of water tank but no water available in the water tank.

Expected Observation: Flapper is lifted and no water being released. The control panel shows that there is no electrical power output and wait for user's instruction. If no instruction received, system switches to solar mode atomically.

9.6 Extreme case 2: Overcast weather, low solar radiation and no precipitation

User Input: The user set system on.

Conditions: No water reserved in water tank, solar irradiance not reached solar panel's minimum requirement

Expected Observation: The control panel shows that there is no electrical power output. System waits for user's further instruction. If no instruction received, system set to solar mode as default.

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10 Conclusions

This document explains the design specifications of the RSPG. These design specifications will be referred to and adhered to meet the functional specifications. Implementing the test plans included, through the design and testing as described in this document, the RSGP model should be able to demonstrate each of the previously stated functionality. The design specification provides clear goals for the development of the device prototype.

11 Reference

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12 Appendix

Table12.1: test values of both open voltage and short circuit current of motor

Motor RPM	Open Circuit Voltage (V)	Short Circuit Current (A)	Output Power (W)
50	1.65	0.6	0.99
100	3.31	1.3	4.303
200	6.62	2.6	17.212
300	9.96	3.9	38.844
350	11.63	4.7	54.661
360	11.96	4.9	58.604
375	12.46	5	62.3
400	13.28	5.3	70.384
500	16.6	6.6	109.56
600	19.92	8	159.36
700	23.23	9.2	213.716
800	26.53	10.5	278.565
900	29.84	11.7	349.128
1000	33.15	13	430.95
1200	39.77	15	596.55
1265	42	15.3	642.6