

# DC House Distribution Panel

A Senior Project

Presented to

The Faculty of the

**ELECTRICAL ENGINEERING DEPARTMENT**

California Polytechnic State University, San Luis Obispo

2013

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science

By

Khanh Ho

2013

## Table of Contents

List of Figures .....	3
List of Tables .....	4
Acknowledgements.....	5
Abstract.....	6
I. Introduction .....	7
II. Background .....	8
III. Design .....	10
IV. Testing and Results.....	20
V. Conclusion .....	23
Appendix A.....	24
References.....	25

## List of Figures

Figure 2-1: System Block Diagram of DC House .....	8
Figure 3-1: Circuit Schematic of the Distribution Panel with a Main Voltage Bus.....	12
Figure 3-2: 2A, C-Curve Circuit Breaker, Model: WMZS1C02 .....	13
Figure 3-3: Model WMZS Circuit Breaker's Tripping Curve from Eaton Corporation Datasheet.....	14
Figure 3-4: Fast-Acting, AGC Fuse; Rated at 8A, 250V .....	15
Figure 3-5: Component's Layout with Dimensions.....	18
Figure 3-6: Final Layout in Distribution Panel with Components.....	19
Figure 4-1: Testing Set-Up for Circuit Breaker and Fuse.....	20

## **List of Tables**

Table 3-1: List of Appliances and Respective Ratings .....	11
Table 3-2: Current Distribution through Each Branch.....	11
Table 4-1: Effects of Circuit Breaker Tripping Time due to Rest .....	21
Table 4-2: Influence of Ambient Temperature on Thermal Tripping Behavior [3].....	22
Table A-1: Parts List for Distribution Panel Design.....	24

## **Acknowledgements**

I want to acknowledge the Electrical Engineering Department staff of Cal Poly for all they have taught me. More importantly, I want to thank Dr. Taufik for his efforts in helping me as an advisor through the senior project. I would also like to thank my parents for all their support and sacrifices they made during my time at Cal Poly. If it wasn't for them, then I will not be where I am today.

## **Abstract**

This paper details the process in designing the distribution panel, or circuit breaker box for a DC house. The main purpose of the project is to design a distribution panel that will provide electrical power to the DC house while also providing an electrical system protection through the use of circuit breakers, or fuses. An actual hardware design for the distribution panel was built and tested. The results demonstrate the functionality of the breaker box to supply power to the DC House ensuring safe operation of the DC House.

## I. Introduction

The use of a distribution panel, or breaker box, is extremely important in households everywhere as they provide distribution of electrical power and protection of appliances within the household. With each distribution panel, the circuit breakers allow for control and limits the current being distributed in circuits inside a house. In addition, circuit breakers are important in protecting the system from inrush (input surge) current that can damage the appliances and circuit systems within a home. The main function of the circuit breaker is to sense a short circuit or an overload in current flowing through the branch. If any is detected then the circuit breaker will trip and thus cut off any power going through that branch. This will prevent any damage to the appliance and the home.

The goal for the project is to design a distribution box, equipped with circuit breakers and several other components, to protect the loads inside the DC House. The DC House will have a total a total of three branches where appliances will be connected in shunt form to each branch, thus the current coming to each load is independent from one another [1]. However, the total current in each branch is the summation of the applied current. The goal is to design an effective and safe distribution of power through each branch in order for common typical household appliances to be used. To do this, proper sizing of the circuit breaker is needed to limit the current going through each branch.

## II. Background

The DC House design project started in order to allow improvements in lifestyle for small, unfortunate villages that do not have access to electricity [2]. The DC House aims to supply these villages with electrical power through the use of renewable energy sources which are commonly found in these places.

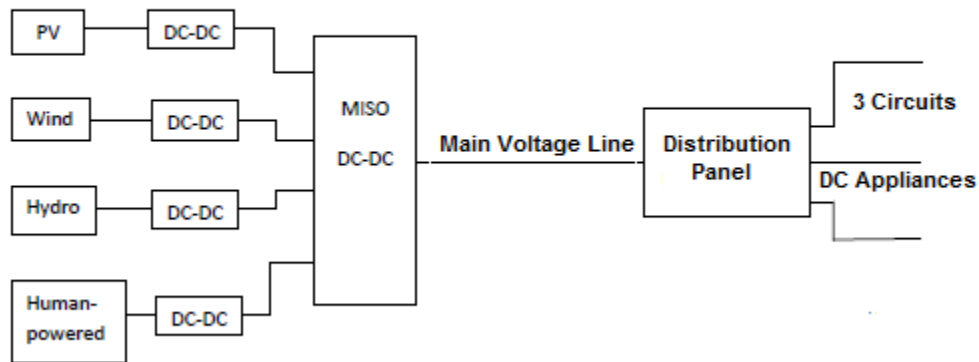


Figure 2-1: System Block Diagram of DC House

Figure 2-1 shows the system block diagram of a DC House consisting of many different component working together to make the home functional. At Cal Poly, each component is worked on by different students, currently and in the past few years, to make the DC House operational. The DC House starts with at most four renewable energy sources connected to their respective boost DC-DC converters. The boost DC-DC converter steps the voltage from a 12V input, from the renewable sources, to a 24V output. Each converter is connected to the Multi-Input-Single-Output (MISO) DC-DC converter, which sums the total power produced and steps the voltage further to 48V. The overall system produces around 600W for the DC House to supply its appliances [2].



With 600W in the main voltage line, there needs to be a way to properly distribute the power within the DC House as well as to protect the DC House from overloading its current. To do so, a distribution panel is required. The DC House will have three branches, which is the optimal number of circuits based on a previous study, used for powering the appliances in the home. However, just like in any other circuits in a house, faults may occur due to the improper operation of a load as well as some inrush current that may occur due to some inductive loading. Therefore, the circuit breakers and fuse are needed in a distribution panel to safely supply power in each branch of the DC House. In addition, the appliances used in the house must carefully be selected for power consumption in each of the branches for optimum operation of the DC House [2].

### III. Design

The allowable power through each branch is based off the maximum power generated by the renewable energy sources connected to the DC House. For the DC House, the renewable energy source generates a maximum of 600W. Taking into consideration the design in Figure 2-1; the renewable energy steps through a DC to DC converter in order for a 48V main bus line to be accessible in each branch.

#### Distribution of Power

The distribution panel is in charge of distributing the main bus voltage into three branches within the DC House. There are many different ways to carry out the distribution of the power; and depending on the appliances being used, the splitting of current is crucial. With a 48V main bus and a total of 600W, there exists a maximum of 12.5A supplying the DC House. Certain appliances require a heavier current to operate and hence should be treated carefully when placing them in the house. Table 3-1 lists several appliances and their respective ratings. As we can see, the personal refrigerator and the laptop require the most power to operate. On the other hand, the other components do not need as much power, thus there is no need for the lower power appliance to be in the same branch as the laptop or the refrigerator.

**Table 3-1: List of Appliances and Respective Ratings**

<b>Appliance</b>	<b>Voltage Input</b>	<b>Current Rating</b>	<b>Maximum Power Input</b>
<b>Personal Refrigerator</b>	12 V	4.2A	50.4W
<b>Laptop</b>	18.5V – 19V	3.5A	64.75W – 76W
<b>Fan</b>	12V – 24V	0.5A	6W – 12W
<b>3 LEDs</b>	12V each	355mA each	12.78W each
<b>Smoke Detector</b>	12V	60mA	0.72W

For the design of this project, one branch will be dedicated to handling the heavier loads while the other branches will be used for consumption of lower power appliances. This way voltage stability on the lower power branch can be maintained and be less affected by the higher power branch. In order to do this, the use of circuit breakers will limit the allowable current that can flow through each branch. Since the personal refrigerator and the laptop consume the most energy, we will need enough reserved power to accommodate for these loads and so forth. Table 3-2 shows the breakdown of each circuit branch and the appliances that will be theoretically used.

**Table 3-2: Current Distribution through Each Branch**

<b>Circuit Branch</b>	<b>Appliance List</b>	<b>Total Current</b>	<b>Circuit Breaker's / Fuse's Current Limit</b>
<b>1</b>	Refrigerator, Personal Laptop	7.7A	8.5A
<b>2</b>	3 LEDs	1.065	2A
<b>3</b>	Fan, Smoke Detector	560mA	2A

Keep in mind, additional DC appliances may be added in the DC House, but they would have to be within the current rating of each branch. The circuit breaker in Figure 3-3 will be supplied by Eaton Corporation with the following model number: WMZS1C02 for a 2A, C-curve circuit breaker. The circuit breaker was selected due to the 2A current rating as well as the tripping current of the device. As for the 8A branch, a fuse will be required. Explanation on why a fuse is used, instead of a circuit breaker, will be described in a later section.

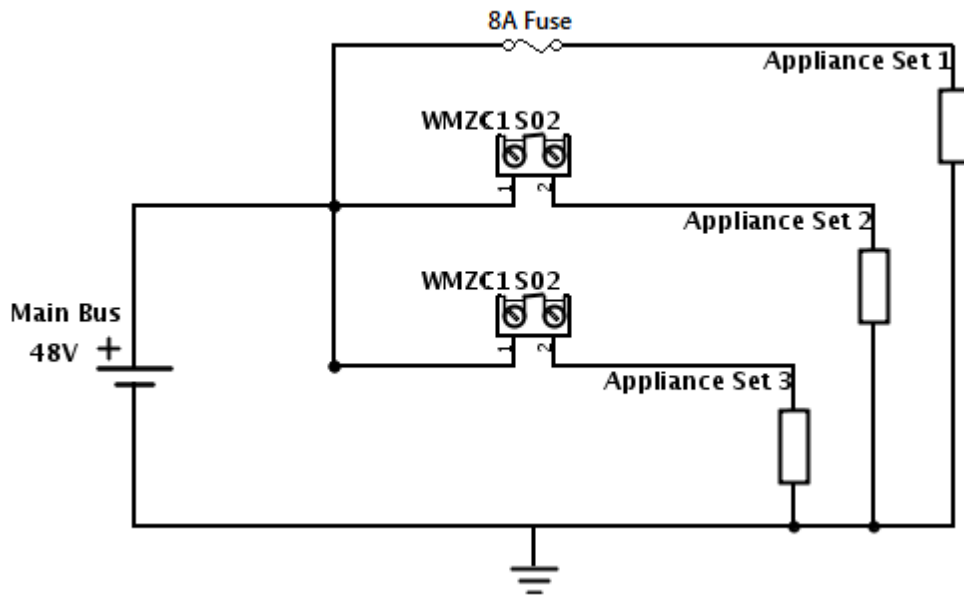


Figure 3-1: Circuit Schematic of the Distribution Panel with a Main Voltage Bus

## Circuit Breaker



**Figure 3-2: 2A, C-Curve Circuit Breaker, Model: WMZS1C02**

There are many different types of circuit breakers and each is dependent on the application it is used for. Each type of circuit breakers has different types of time curve that designates the instantaneous tripping current range. Figure 3-3 illustrated the time curve for the WMZS models of circuit breakers created from Eaton Corporation.

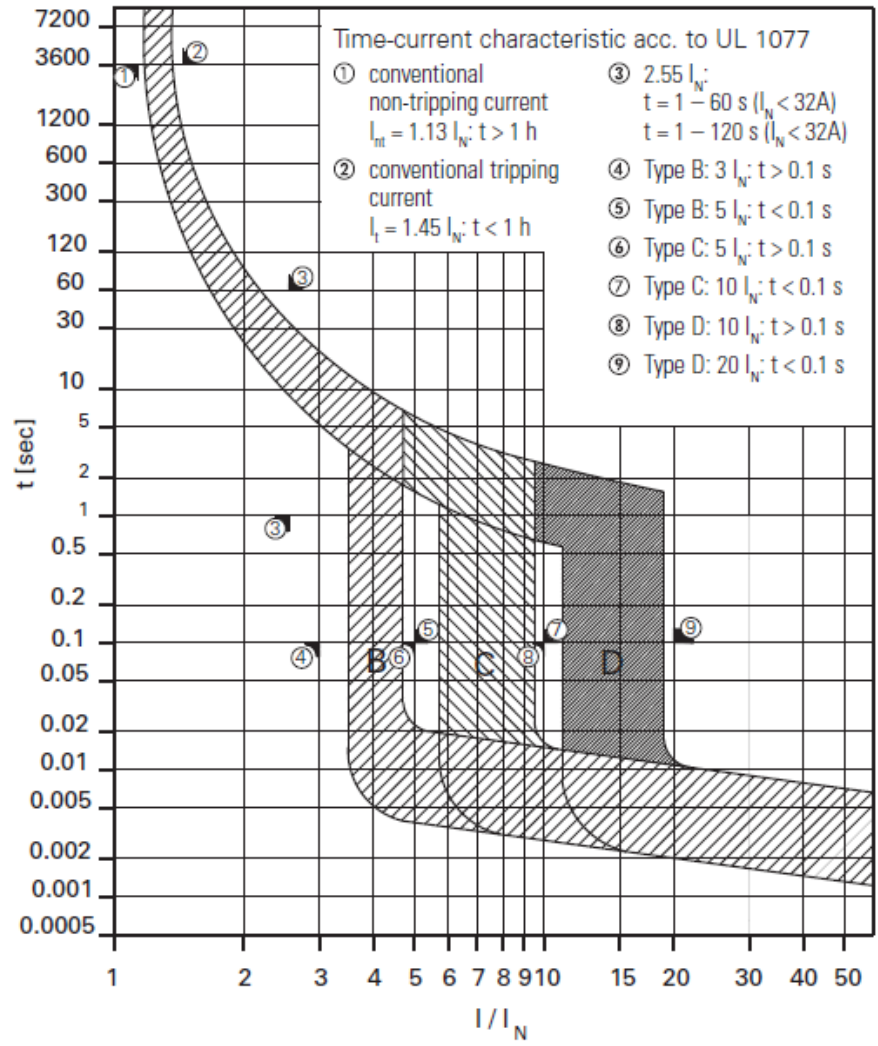


Figure 3-3: Model WMZS Circuit Breaker's Tripping Curve from Eaton Corporation Datasheet

The most common circuit breakers curves are: B, C, and D; but there are several more types as well. Type B circuit breakers are generally used for domestic applications. Type C breakers are used more in the commercial and industrial companies, and type D is used in industry where high inrush current is expected. Considering the DC House only uses DC power, we were limited in the selection type of DC circuit breakers. For the project, a C curve breaker will be used for the 2A current rated branch due to its ability to instantaneously trip if a short was to occur.

The characteristic “ $I_n$ ” is used to define the current rating of the circuit breaker. For the B curve, the breaker will have an instantaneous trip from three times  $I_n$ , up to five times  $I_n$ . The C curve is five times  $I_n$  to ten times  $I_n$  and the D curve is ten times  $I_n$  to twenty times  $I_n$ .

For simplicity, the WMZS1C02 model will be used as reference for the explanation of the tripping curve. The WMZS1C02 model is a C curve breaker with a 2A current rating, thus  $I_n$  will be two. As previously mentioned, the C curve will have an instantaneous trip anywhere from five to ten times  $I_n$ . From Figure 3-3, if a current of 5A is introduced to the branch, the circuit breaker will take anywhere from 10-30 seconds to trip. The tripping of the circuit breaker is dependent on the amount of excess current that is introduced to the branch. If there is a short in the system, the circuit breaker will draw all the current, which is 12.5A, thus tripping instantly.



**Figure 3-4: Fast-Acting, AGC Fuse; Rated at 8A, 250V**

Due to heavy load branch, an 8A current rating protection is required. Since an 8A rated circuit breaker will trip anywhere from 120-600 seconds, if a short was to occur, it is dangerous to have use a circuit breaker for this branch. Instead, an 8A, AGC, fast-acting fuse will be used to

accommodate for the circuit protection of the branch because a fuse has the ability to quickly blow, thus create an opening, in the circuit. The fast acting fuse can be seen in Figure 3-4. Considering the laptop and personal refrigerator is an inductive load, there will be a small inrush current introduced when these appliances are turned on as well. Because of the inrush current, it is important to have only one appliance turned on at a time.

### Differences between Fuses and Circuit Breakers

Fuses and circuit breakers act in the same manner, they both protect the circuit from overload in current. However, the properties between the two are entirely different.

A fuse is a one-time use component, where it will blow when excessive amounts of current is introduced into the circuit. In many cases, using a fuse is not ideal, due to the constant replacement of the fuse. The task of replacing a fuse is dangerous especially since it is still connected to the live wire. On another note, a fuse will protect a circuit system better since it will react and isolate fault quicker to the overload current. Compared to a fuse, a circuit breaker has an instantaneous trip current much higher than the rated current. In short term, fuses will be much cheaper to use than a circuit breaker.

As for the circuit breakers, at currents slightly above the rated current, there will be a delay in the tripping of the breakers. On the other hand, circuit breakers will prove to be cheaper in the long run due to the switching properties of the breaker. When a circuit breaker trips, the switch on the breaker will create an open thus no current can flow through the circuit. To re-introduce the current, the switch can be reset to reactivate the component.

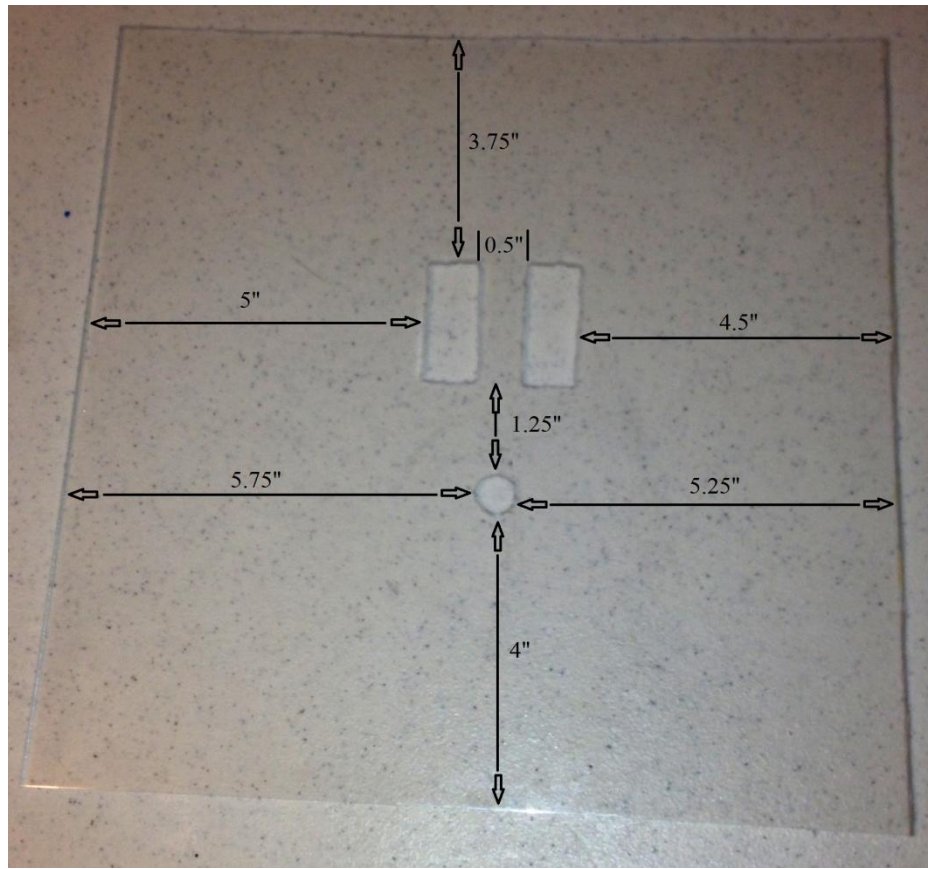


### AC Circuit Breakers vs. DC Circuit Breakers

The main difference between AC circuit breakers and DC circuit breakers lies within the arc of the components. The arcing of the device is the dielectric strength build up as the breaker contacts start to open. Until the contact has open sufficiently, conduction will re-establish after the zero crossings of the current. When there is enough dielectric strength and the arc contacts open completely, the arc will extinguish. DC circuit breakers handle ac current that does not alternate; therefore there is no zero crossing. Because of this, the opening of the beaker will operate quicker to extinguish the arc [4].

### Construction of Distribution Panel

The construction of the distribution panel started with an acrylic top for protection from live wires that will be connected to the circuit breakers and fuse underneath. In order for the acrylic sheet to fit within the metal casing of the distribution panel, it must be cut down to 11½” x 11½” square. In addition, four 2” x 0.5” strip of acrylic are needed inside at each corner of the metal casing to support and hold the 11½” x 11½” sheet. The strip is visible in Figure 3-6 where the complete layout of the components is within the metal casing.



**Figure 3-5: Component's Layout with Dimensions**

The next step is to create a layout for placement of the components. Figure 3-5 illustrates the layout and dimensions of each cut on the  $11\frac{1}{2}$ " x  $11\frac{1}{2}$ " acrylic sheet. In addition, the dimensions for the circuit breakers' cut are  $2$ " x  $\frac{3}{4}$ " and the diameter of the fuse's cut is  $\frac{1}{2}$ ".



**Figure 3-6: Final Layout in Distribution Panel with Components**

Figure 3-6 illustrates the final layout of the distribution panel minus the wire connections. The additional space on the acrylic sheet will be used for future design on the distribution panel. Each of the components will have one end connected to the “hot” wire of the DC bus, and the other end transfer the power into the DC House. The ground wire will also be connected, but not to the distributional panel. Instead, the ground wire will be connected to the outlets inside the DC House, as shown in the circuit schematic in Figure 3-1.

## IV. Testing and Results

Since the DC House will be using a main voltage bus of 48V, we will need to have a power supply that will supply the same amount of voltage. In addition, we also need the power supply to have a current limit of higher than 8A in order to test the behavior of the circuit breakers and fuse. Figure 4-1 below shows the ideal set up of the testing.

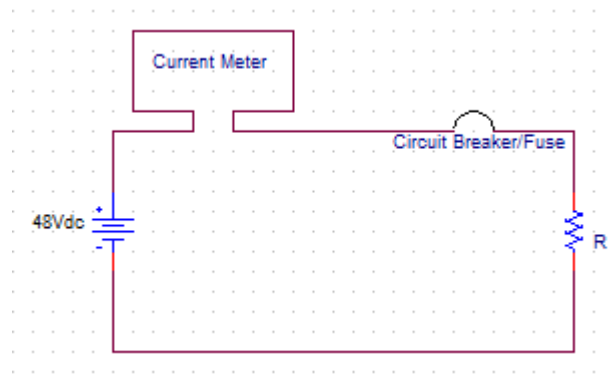


Figure 4-1: Testing Set-Up for Circuit Breaker and Fuse

With the limitations of the equipments at hand, we were not able to get hold of a power supply above 3A rated current. Therefore, the following tests done are based off the effects of the current through the circuit breaker at a higher current than the rated current on the circuit breaker and not on demonstration of the instantaneous trip of the breaker. Also, precise data for the testing was hard to obtain due to the limitations of data acquisition instruments. Instead, data on the effects of the tripping time for the circuit breaker is recorded through a stopwatch. For the most part, the power supply supplied a consistent 48.06V while producing current between 2.92A-2.94A. The resistor we used was a variable power resistor, rated at 3A, and it was set at 15.63 $\Omega$ . From basic Ohm's Law, there should be 3.2A flowing through the system. Table 4-1 illustrates the effects of the circuit breaker through various rest time.

**Table 4-1: Effects of Circuit Breaker Tripping Time due to Rest**

<b>Rest Time Between Each Tests</b>	<b>Current Through Load (Amperes)</b>	<b>Time Before Breaker Trips (seconds)</b>
<b>0 minutes</b>	2.95	132
<b>1 minutes</b>	2.93	83
<b>2 minutes</b>	2.92	98
<b>30 minutes</b>	2.94	124
<b>2 minutes</b>	2.92	105
<b>15 minutes</b>	2.94	144
<b>2 minutes</b>	2.92	96

The effects of the circuit breaker proved to be similar to Figure 3-4, Model WMZS Circuit Breaker's Tripping Curve from Eaton Corporation Datasheet. Figure 3-4 predicts a tripping time of 120-1200 seconds with an average of 3A transferring through the circuit breaker. With the circuit breaker rested at 15 minutes or more, the experimental data holds true. However, at 1-2 minutes rest, the circuit breaker trips sooner than 120 seconds. This phenomenon is due to the thermal properties of the circuit breakers, which can be seen in Table 4-2. Without a thermocouple to measure the ambient temperature inside the circuit breaker, we cannot predict the exact time in which the circuit breaker will trip.

**Table 4-2: Influence of Ambient Temperature on Thermal Tripping Behavior [3]**

$I_n$ (A)	-25°C	-20°C	-10°C	0°C	10°C	20°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C
0.16	0.2	0.19	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.15	0.14	0.14
0.25	0.31	0.3	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22
0.5	0.61	0.6	0.58	0.56	0.54	0.52	0.5	0.49	0.48	0.47	0.46	0.45	0.44
0.75	0.92	0.9	0.87	0.84	0.81	0.78	0.75	0.74	0.73	0.71	0.69	0.68	0.66
1	1.2	1.2	1.2	1.1	1.1	1	1	0.99	0.97	0.95	0.93	0.9	0.89
1.5	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.3
1.6	2	1.9	1.9	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4
2	2.4	2.4	2.3	2.2	2.2	2.1	2	2	1.9	1.9	1.9	1.8	1.8
2.5	3.1	3	2.9	2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.3	2.3	2.2
3	3.7	3.6	3.5	3.4	3.3	3.1	3	3	2.9	2.8	2.8	2.7	2.7
3.5	4.3	4.2	4.1	3.9	3.8	3.7	3.5	3.4	3.4	3.3	3.2	3.2	3.1
4	4.9	4.8	4.7	4.5	4.3	4.2	4	3.9	3.9	3.8	3.7	3.6	3.5
5	6.1	6	5.8	5.6	5.4	5.2	5	4.9	4.8	4.7	4.6	4.5	4.4
6	7.3	7.2	7	6.7	6.5	6.3	6	5.9	5.8	5.7	5.6	5.4	5.3
7	8.6	8.4	8.1	7.9	7.6	7.4	7	6.9	6.8	6.7	6.6	6.4	6.3
8	9.8	9.6	9.3	9	8.7	8.4	8	7.9	7.7	7.6	7.4	7.2	7.1

## V. Conclusion

Since many applications use AC power devices, DC circuit breakers were difficult to find. Since DC circuit breakers were so limited, the project required the use of a fuse for the 8.5A rated current branch. A circuit breaker will not be ideal in the heavy load branch since it requires 120-600 seconds to trip in the occurrence of a short circuit. Within that time, many damages may occur to the appliances and the home. Thus, a fuse was needed to accommodate for the circuit breaker.

In addition, the power supply used for the project had many limitations as well. A proper oscilloscope graph cannot be measured to display the tripping time of the circuit breaker due to the amount of time required for the circuit breaker to trip. Therefore, we had to resort to a stopwatch to measure and estimate the time for the circuit breaker to trip.

As the project nears its end, there are many other features that can be added in order for this distribution panel to be fully user friendly. For instance, an LED display readout can be equipped in the panel in order for the total current being used to be read out in each branch. This can be helpful because if more appliances were to be added within the DC House, there is a display showing how much power is left for distribution throughout the home.

Another addition to the distribution panels are two LED lights, one red and one green. The LEDs can be used to show if a circuit breaker has been tripped or if it is active. Since the LEDs are connected directly to the 48V line, we will need a DC-DC converter, or a regulator, that will not affect the current distribution.

Overall, the project did what it was meant to do, and that is provide a distribution of power for the DC House while protecting the appliances within the DC House from any current overload.

## Appendix A

**Table A-1: Parts List for Distribution Panel Design**

<b>Components</b>	<b>Purchase Store/Part Number</b>	<b>Cost</b>
<b>2Amp Circuit Breaker</b>	Platt.com/WMZS1C02	\$41.20ea
<b>8 Amp Fuse</b>	Radioshack/270-1014	\$2.19
<b>Acrylic Sheet</b>	Home Depot/241610	\$9.78
<b>Fuse Holder</b>	Radioshack/270-0364	\$2.19
<b>Distribution Box Metal Frame</b>	Supplied	---

Total Cost: \$96.56



## References

- [1] Jessica E. Chaidez, DC House Modeling and System Design. Senior Project, Cal Poly, SLO June 2011
- [2] Mark Cabaj, DC House Model Design and Construction. Senior Project, Cal Poly, SLO June 2012
- [3] Eaton Corporation, “UL 1077 DIN Rail Supplementary Protectors,” Web. Nov. 2010  
<<http://www.eaton.com/ecm/groups/public/@pub/@electrical/documents/content/pg01101006e.pdf>>