Project Design Document

Project: PV Emergency Back-up System

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Contents

Abstract

Malawi, Africa, is the poorest country in the world. At the Embangweni Mission Hospital in northern Malawi, brownouts and power outages lasting days at a time are frequent occurrences. Without consistent and reliable power for necessary medical equipment such as suction machines and lights, human lives are endangered and lost. An emergency backup power device has been requested for the hospital that can provide two days of autonomous power for a suction machine, lighting, as well as recharge consumer electronic devices such as phones or tablets. The device is to be used during times when standard wall power is unavailable. This device is referred to as the Solar Surgery Suction System, or the S4. The S4 is recharged via a solar panel or wall power over no more than two days. It is approximately the size of a suitcase and can be moved from its charging location to a room for use as necessary. Included with the S4 are two lights to provide lighting during medical procedures. The developed S4 is paired with an included suction machine and solar panel. Ultimately, the S4 and its associated parts will be delivered to and installed at the Embangweni Mission Hospital in Malawi to provide emergency backup power during critical medical operations.

1.0 Introduction and Design Background

In Malawi reliable power is not a reality. Those living there are faced with inconsistent power; brownouts and blackouts last for days at a time. For many this is merely an inconvenience, but in some situations it can be dangerous. This is especially true in hospitals where an unexpected power outage can happen in the middle of a surgery. Because of this, emergency power supplies that do not rely on the grid are needed. The purpose of this project is to build a solar powered emergency power solution for use in a hospital. There are several objectives for this project. The system is to store solar or grid power in a lead-acid battery. Over a period of two days, it is to supply power to two LED lights for 12 hours each per day, a suction machine for four hours per day, and two additional 12 VDC car sockets (up to 2.1A) for three hours per day. The system is monitored through the use of a status display. The system is compliant with international travel check-in luggage size requirements. The system consists of the following parts: solar panel, charge storage, power output receptacles, and a charge controller with a status display. Ultimately, students from the class will hand deliver and install the developed backup power system to the Embangweni Mission Hospital in Malawi, Africa.

In order to design the system the load requirements for the above components were calculated. The size of the battery (110 Ah) was selected based on the ability to sustain power to the system's loads for two days. The panel was selected (100 W) based on the worst case solar irradiance of the region of use as well as the daily power requirements.

2.0 Requirements and Functional Specifications

The S4's have the option to be powered and charged using solar energy or through the use of an electrical outlet. During power outages the system will provide power to a portable suction machine (provided with the system), two lights (provided with the system), and up to two tablets or phones. Table 2.1 shows details on the requirements and specifications of the system.

Table 2.1: S4 Requirements and Specifications

#	Requirement name	Requirement Statement
1.00	**Mechanical Requirement**	
1.10	Weight	The device shall weigh ≤ 100 lbs*
1.11	Dimensions	The device's linear dimensions (L+H+W) shall be ≤ 62 in*
2.00	**Component Requirement**	
2.10	Solar panel	The system shall include a solar panel
2.20	Suction machine	The system shall include a suction machine
2.30	Portable power box	The system shall include a box containing all components except solar panel, suction device, and external cables
2.31	Battery	The system shall include a lead-acid AGM battery.
2.32	LED lights	The system shall include two LED rechargeable flashlights
2.40	Light mount	The system shall include a mounting device for the LED flashlights
2.50	Cables	The system shall include: panel to power box cables, flashlight and suction machine charging cable (DC and AC), power box charging cable (AC to DC)
3.00	**Electrical Requirement**	
3.10	Solar Panel Power	A solar panel will be provided that is able to fully charge the battery within 2 days
3.11	AC Input Power	The AC input power shall be converted to DC and be able to charge the battery within 2 days
3.20	Input charging	The device shall be charged using either a solar panel or a wall outlet (220V/50Hz)
3.21	Input connectors	Input power shall be supplied to the charge controller using MC4 connectors
3.22	Battery charge	The charge controller shall output power to charge a lead-acid AGM battery and shall have LDO capabilities
3.23	Battery discharge	The battery shall be able to power the suction machine and 2 tablets 3h/day and two LED lights 12h/day for 2 days
3.30	Output Ports	The device shall have five charge ports (max 60 W) (auxiliary power socket part number: 39048-8)
3.31	Output Port Volts	The output ports shall output 12V
3.40	Battery charge indicator	The device shall have a display indicating charging levels of the lead-acid battery

*Measurement does not include the solar panel, suction machine, light fixtures, and external cables.

3.0 System Architecture

3.1 Hardware Specifications

A high level block diagram (Figure 3.1) was designed to ensure the necessary components are included in the system.

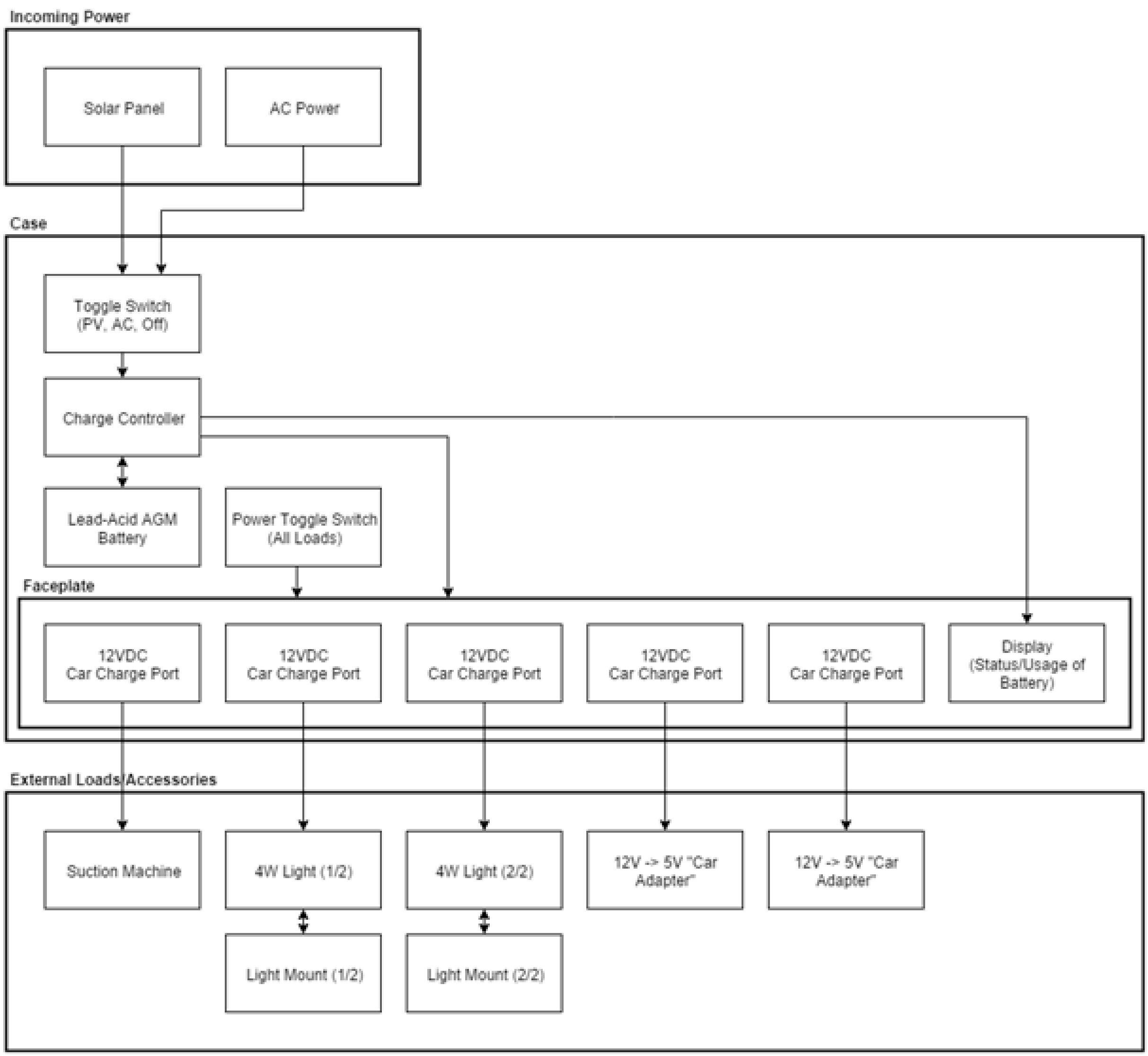

Figure 3.1: High Level Block Diagram of the S4

3.1.1 Incoming Power

Power is supplied using either a solar panel or AC power from a wall outlet. The solar panel must be able to supply at least 100W in order to charge the battery within the allotted time of two days.

3.1.2 Case

The case contains the main system for supplying power to the load. The input power from the AC wall outlet will connect to a battery charger inside the case which will connect to a 110 Ah AGM battery. The input power from the solar panel is regulated by a charge controller which is used to charge the battery or provide power to the load directly. Load power is supplied from the charge controller to five 12 VDC car charge ports. One of the charge ports is designated for the suction machine. Two of the charge ports are designated for the lights. The remaining two EW for charging either phones or tablets. The charge controller has a display that shows the battery charge level and other relevant status information.

3.1.3 External Loads and Accessories

A connector from the suction machine charge port to the suction machine is provided. Connectors from the light charge ports to the lights are provided as well. Any external load requiring a voltage up to 12 VDC and 2.1 A maximum may be connected to phone/tablet charge ports. Two car charge port to USB connectors are provided as well as two car charge port to micro USB connectors.

4.0 System Design

4.1 Energy Requirement of Loads

The S4 has five loads: The suction machine, two lights, and two consumer electronic devices such as cell phones or tablets. As all five loads can be operated with 12V DC power, the system is designed for five outputs in the form of 12V DC auxiliary car sockets. These loads are to be powered for two days at the requested number of hours per day as outlined in Table 4.1.

Table 4.1: Daily hour usage of each output device

Output Device	Hours of Usage per Day
Suction Machine	3 Hours
Light #1	12 Hours
Light #2	12 Hours
Phone/Tablet #1	3 Hours
Phone/Tablet #2	3 Hours

4.1.1 Suction Machine

The power specifications for the selected suction machine that can be powered by a 12V DC car socket. Its maximum power consumption is 48 W making the current draw 4 A. The suction machine is requested to run for 3 hours per day, for a total of 6 hours. The daily energy consumption of the suction machine is 144 Wh.

4.1.2 Lights

The two lights are to be approximately 5W each. At 12V this is approximately 0.417 amps. Each light is to run for 12 hours per day, or 24 hours total per light. The daily energy consumption of both lights is 120 Wh.

4.1.3 Consumer Devices

The system is to be capable of charging two consumer electronic devices such as cell phones or tablets. Many chargers that fit into a car socket and use 12V DC are available nearly worldwide. Though these chargers plug into 12V DC, most output 5V DC as they charge a USB device. A common “quick charger” (high amperage charger) for phones charges at 5V and 2.1A. However, most chargers draw less than one ampere. Due to the voltage drop from 12V to 5V there is a significant efficiency loss. This efficiency loss is difficult to predict as the end user may plug in a variety of chargers. To account for the unpredictability and efficiency loss, the devices are considered to be operating at 12V. Each charger is to be used to charge a 2.1 A device for 3 hours per day, or 6 hours total each. The daily energy consumption if both chargers are connected is 151.2 Wh.

4.1.4 Total Energy Requirements

Table 4.2 shows the total energy requirements based on each load.

Table 4.2: Load Energy Requirements

Device	Voltage [V]	Amperage [A]	Wattage [W]	Daily Hours of Operation	Necessary Amp Hours [Ah]	Necessary Watt Hours per Day [Wh]
Suction Machine	12	4	48	3	12	144
Light 1	12	0.417	5	12	10	60
Light 2	12	0.417	5	12	10	60
Consumer Device 1	12	2.1	25.2	3	6.3	75.6
Consumer Device 2	12	2.1	25.2	3	6.3	75.6
Total		**9.03**				**415.2**

From Table 4.2, the total daily energy consumption from the loads is 379.2 Wh. The maximum current draw at any time is 8.03 A.

4.2 Sizing of Batteries

The S4's power loads are summarized in Table 4.3.

Table 4.3: Load Energy consumption for battery sizing

Device	Voltage [V]	Amperage [A]	Wattage [W]	Total Hours of Operation	Necessary Amp Hours [Ah]
Suction Machine	12	4	48	6	24
Light 1	12	0.417	5	24	10
Light 2	12	0.417	5	24	10
Consumer Device 1	12	2.1	25.2	6	12.6
Consumer Device 2	12	2.1	25.2	6	12.6
Total					**69.2**
Total with 80% DOD and 85% overall efficiency					**101.76**

The total necessary amp hours to power the S4's loads for two days is 69.2 Ah. Accounting for a maximum 80% battery discharge the battery needs to be able to provide 86.5 Ah. However, a reasonable assumption of power loss within the system is an efficiency of around 85%. This indicates that the battery powering the S4's loads should provide approximately 101.76 Ah. It is safe to state that the battery powering the S4's load may be a 110 Ah battery that provides 12 V DC as a 102 Ah battery is not commonly found for purchase.

4.3 Sizing of Solar Panels

In order to size the panel the Global Horizontal Irradiance (GHI) was researched for various regions of Malawi. Data was available for the regions shown in Table 4.4.

Table 4.4: GHI Data for cities in Malawi

Month	Global Horizontal Irradiation [kWh/m^2]													
	Karonga		Mzuzu		Mzimba		Chitedze		Mangochi		Blantyre		Nsanje	
	Average	Min / Max	Average	Min / Max	Average	Min / Max	Average	Min / Max	Average	Min / Max	Average	Min / Max	Average	Min / Max
January	5.58	4.48 / 6.37	5.16	4.51 / 5.59	5.25	4.76 / 5.71	5.26	4.56 / 6.12	5.57	4.85 / 6.38	5.44	4.76 / 6.11	5.85	4.81 / 6.86
February	5.60	4.57 / 6.42	5.07	4.30 / 5.83	5.20	4.58 / 5.96	5.41	4.21 / 6.72	5.82	4.37 / 7.16	5.73	4.17 / 6.77	5.90	4.05 / 6.97
March	5.82	4.97 / 6.38	5.24	4.30 / 5.82	5.30	4.27 / 6.11	5.56	4.86 / 6.46	6.01	5.20 / 7.18	5.57	4.99 / 6.61	5.86	4.77 / 6.36
April	5.65	5.14 / 6.27	4.79	4.04 / 5.28	5.50	5.01 / 6.00	5.51	4.70 / 6.08	5.76	4.83 / 6.33	5.22	4.28 / 5.79	5.32	4.67 / 5.88
May	5.50	5.16 / 5.91	4.77	3.99 / 5.50	5.45	4.48 / 5.87	5.27	4.16 / 5.83	5.37	4.43 / 5.78	4.84	3.71 / 5.30	4.75	4.24 / 5.17
June	5.31	4.91 / 5.55	4.47	4.00 / 5.11	5.17	4.83 / 5.55	4.81	4.11 / 5.28	4.78	4.32 / 5.07	4.24	3.67 / 4.62	4.21	3.77 / 4.69
July	5.51	5.01 / 5.85	4.55	3.97 / 5.35	5.28	4.83 / 5.81	4.80	3.92 / 5.45	4.83	4.38 / 5.26	4.24	3.46 / 4.92	4.27	3.70 / 4.92
August	6.20	5.72 / 6.55	5.51	4.61 / 6.23	5.95	5.30 / 6.56	5.56	4.63 / 6.10	5.56	4.85 / 6.09	5.13	4.40 / 5.60	5.22	4.67 / 5.58
September	6.93	6.41 / 7.15	6.60	5.81 / 7.13	6.90	6.48 / 7.27	6.56	6.02 / 6.99	6.41	5.82 / 6.91	6.16	5.42 / 6.62	6.07	5.37 / 6.33
October	7.36	6.88 / 7.68	7.01	6.16 / 7.65	7.22	6.44 / 7.62	6.81	6.06 / 7.49	6.79	6.19 / 7.38	6.41	5.64 / 7.10	6.55	5.61 / 7.08
November	7.08	5.59 / 7.81	6.83	4.94 / 7.89	6.80	5.01 / 7.94	6.50	5.00 / 7.55	6.74	5.24 / 7.36	6.35	5.16 / 6.80	6.62	5.57 / 7.07
December	6.20	5.28 / 7.12	5.71	4.76 / 6.83	5.78	4.91 / 6.77	5.67	4.53 / 6.59	6.18	4.91 / 6.92	5.91	4.86 / 6.66	6.17	5.63 / 6.81
YEAR	6.06	5.93 / 6.30	5.48	5.17 / 5.80	5.82	5.65 / 6.10	5.64	5.27 / 5.98	5.82	5.32 / 6.15	5.43	5.00 / 5.77	5.56	5.21 / 5.84

The closest city to Embangweni is Mizmba. Thus, the GHI data of Mzimba was considered for sizing the solar panel. The worst case scenario GHI was found to be the minimum value of GHI during the month of March (4.27 kWh/m^2). Thus, the peak sun hours are 4.27 hours per day. Table 4.5 shows the panel sizing calculations based on the required load and GHI.

Table 4.5: Solar Panel Sizing Calculations

Total Wh per day required by the load [Wh]	415.2
Worst case GHI [kWh/m^2]	4.27
Worst case peak sun hours for Malawi near the Hospital (Mzimba) [Hours]	4.27
Minimum Panel Size [W]	97.24
Account for possible shading effects, reduce efficiency to 98%:	**~100 W**

The minimum solar panel size was found to be approximately 97.24 W. However, accounting for shading effects and overall system efficiency losses the solar panel efficiency is adjusted to 98%. Thus, a 100 W solar panel will be used to supply sufficient power to the system.

4.4 Sizing of the Charge Controller

The charge controller should be able to supply at least 9 A to the load. Additionally, it should be able to handle up to 21.6 V and 6.1 A from the solar panel since the selected solar panel has an open circuit voltage of approximately 21.6 V and a maximum short circuit current of approximately 6.1 A. If the battery is to charge within the allotted time of two days the current to the battery has to be approximately 2.3 A on average for the full 48 hour period.

4.5 Cables and Wires

The maximum load current is 9 A. Therefore, a 16 AWG wire is sufficient in handling the maximum load current. The cables connecting the solar panel to the charge controller will need to support up to 10 A. Thus, a 14 AWG wire can be used. However, the standard solar cable is 12 AWG and includes the necessary connectors to and from the solar panel. Therefore, the standard 12 AWG will be used to connect the solar panel to the charge controller. The cable will need to be at least 30 ft. to account for the location of the panel. Additional cables will be purchased in accordance with the devices used. Table 4.6 shows the necessary cables that are included in the system.

Table 4.6: Cable and wire description and sizing

Cable/Wire	Gauge [AWG]	Description/Comments
Solar Panel to Charge Controller	12	50’, includes MC4 connectors
Battery to charge controller	14	
Internal wiring	16	
Socket to Suction Machine	-	Included with suction machine purchase
Socket to lights #1 and #2	-	Included with flashlight purchase
Socket to aux device #1 (phone)	-	Universal phone charging cable
Socket to aux device #2 (tablet)	-	USB to mini USB cable

5.0 Validation

#	Requirement Name	Test	Pass/Fail	Comments
1.00	**Mechanical**			
1.10	Weight	Scale	Pass	Weight is 90 lbs
1.11	Dimensions	Tape	Pass	24.83”+11.88”+ 19.56” = 53.67”
2.00	**Component**			
2.10	Solar panel	Inspection	Pass	
2.20	Suction machine	Inspection	Pass	
2.30	Portable power box	Inspection	Pass	
2.31	Battery	Inspection	Pass	
2.32	LED lights	Inspection	Pass	
2.40	Light mount	Inspection	Fail	Light mounts are not necessary due to current design
2.50	Cables	Inspection	Pass	
3.00	**Electrical**			
3.10	Solar Panel Power	Test 5.1.1	Pass	
3.11	AC Input Power	Test 5.1.2	Pass	
3.20	Input charging	Inspection	Pass	
3.21	Input connectors	Inspection	Pass	
3.22	Battery charge	Test 5.1.3	Pass	Battery charges within allotted time
3.23	Battery discharge	Test 5.1.3	Pass	
3.30	Output Ports	Inspection	Pass	
3.31	Output Port Voltage	Test 5.1.4	Pass	Voltages depend on battery voltage can reach to 14.4V
3.40	Battery Charge Indicator	Test 5.1.5	Pass	

5.1.1 Solar Panel Power Test

The solar panel were set up outside on a sunny day. Open circuit voltage, short circuit current, and voltage and current under different loads were measured. The measurement values were compared to the requirements. Relevant charge data is located in Appendix D.

5.1.2 AC Input Power Test

Voltage and current drawn under load were measured at the charging side of the battery charger. The measurement values were compared to the requirements.

5.1.3 Battery Charge and Discharge Test

The battery was charged and charge time, open circuit voltage, short circuit current, and voltage and current under load (as per load requirements) were measured. The battery was discharged and discharge time, open circuit voltage, short circuit current, and voltage and current under load (as per load requirements) were measured. The measurement values were compared to the requirements. Relevant discharge and charge data are located in Appendix D and E, respectively.

5.1.4 Output Ports Voltages Test

The voltages at the output ports were measured. The measurement values were compared to the requirements.

5.1.5 Battery Charge Indicator Test

With the system fully assembled, the battery was charged and the charge indicator was observed. The system was discharged and the charge indicator was observed. Relevant discharge and charge data are located in Appendix D and E.

6.0 Conclusions

This design meets the requirements laid out by the Embangweni Mission Hospital staff. The battery was specified to be able to provide sufficient power to run the requested equipment for two days. Two rechargeable LED lights are able to supply 12 hours of light per day each. A suction machine powered by a 12VDC supply is able to operate for 3 hours per day. Consumer electronics can be powered by 12VDC, and two 12VDC to 5VDC adapters are included with the system. The system is capable of powering two such devices at 5VDC and 2.1A for 3 hours per day each. The solar panel is specified to recharge the system in two days under expected solar conditions at the hospital. The AC powered battery charger is to be used to charge the battery during the rainy season, and can fully recharge the system in two days. Collectively, the system and its peripherals meet the requirements laid out by the Embangweni Mission Hospital staff, and at present will be implemented on-site in August of 2016.

7.0 Project Budget and Schedule

7.1 Budget

A detailed Bill of Materials and final costs showing all items can be found in Appendix B.

Component	Allocated Price
Solar Panel + extension cable	$160.00
Solar Panel Mounting brackets	$10.00
Charge Controller	$60.00
110Ah AGM Battery	$160.00
Battery Charger	$50.00
Suction Machine	$250
Lights	$80
Light Mounts	$20
Wiring (16 AWG, 14 AWG)	$0 (lab support)
Fuse Box	$10
Receptacles, and Switches	$15
Auxiliary Accessories	$50
Case	$135
Total	**$1000**

7.2 Schedule

Project Component	Tentative Completion Dates
Functional Requirements Document	February 12, 2016
Design Document Rough Draft	February 26,2016
Design Review	March 18, 2016
Ordering of Parts within Budget Requirements	March 23, 2016
Constructed System	April 21, 2016
Presentation	April 21, 2016
System Testing	April 22-27, 2016
Final Design Document	April 28, 2016

8.0 Revision History

Revision Number	Date	Author	Changes
0.0	3/18/16	SF, WB, PM	Draft Design Document
1.0	4/28/16	SF, WB, PM	Final Design Document

Appendix A – System Schematics

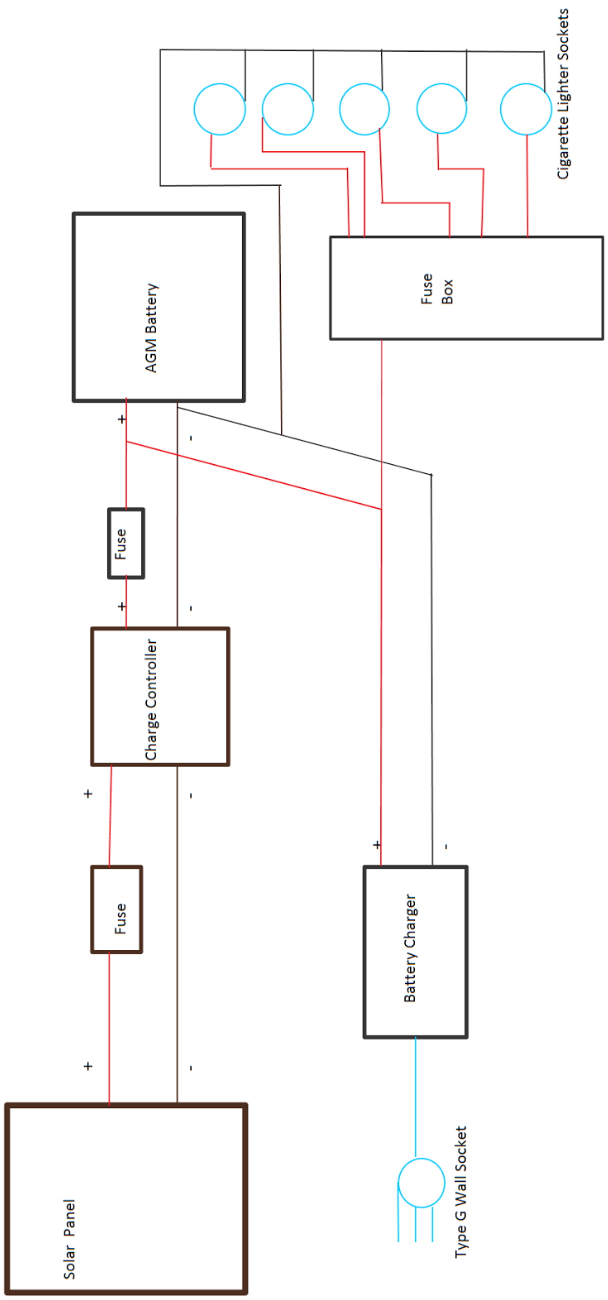

Figure A-1: High Level schematic

Appendix B – Bill of Materials

Table B-1: Detailed BOM

Item	Vendor	Price
Pelican Case	Adorama	175.00
Solar Panel*	Amazon	131.00
Solar Cable (200ft)*	Amazon	49.99
Mounting Brackets	Amazon	7.00
MC4 connectors	Amazon	6.67
Fuses (5x5A, 3x15A)	Amazon	7.33
Charge Controller	Amazon	60.00
AGM Battery	Cabelas	160.00
Battery Charger	Battery Space	39.95
Suction Machine	Amazon	227.32
Headlight	Amazon	21.99
Sticklight	Amazon	30.00
Fuse Box	Amazon	9.18
Car socket (x5), 12V	Amazon	16.99
Car Charger (x2), USB, 2.1A	Amazon	9.99
Bus Bar (x2)	Amazon	9.90
ABS 1/4" Black	Grainger Industrial Supply	35.73
Terminal Connectors	Meijer	2.30
Velcro	Meijer	2.99
Cable 14 AWG	Self-provided	0.00
Cable 16 AWG	Self-provided	0.00
Total		**1003.35**

*A package of 2 panels + 50 ft. cable, a package of 1 panel + 50 ft. cable, and a package of 200 ft. of cable were ordered for three groups.

Table B-2: BOM Summary Table

Item	Vendor	Price
Pelican Case	Adorama	175.00
Solar Panel	Amazon	131.00
Mounting Brackets	Amazon	7.00
Charge Controller	Amazon	60.00
AGM Battery	Cabelas	160.00
Battery Charger	Battery Space	39.95
Suction Machine	Amazon	227.32
ABS 1/4" Black	Grainger Industrial Supply	35.73
Lights	Amazon	51.99
Sockets and chargers	Amazon	26.98
Cables, Connectors, Organizational Units, and System Protection	Various	88.36

Appendix C – Mechanical Drawings

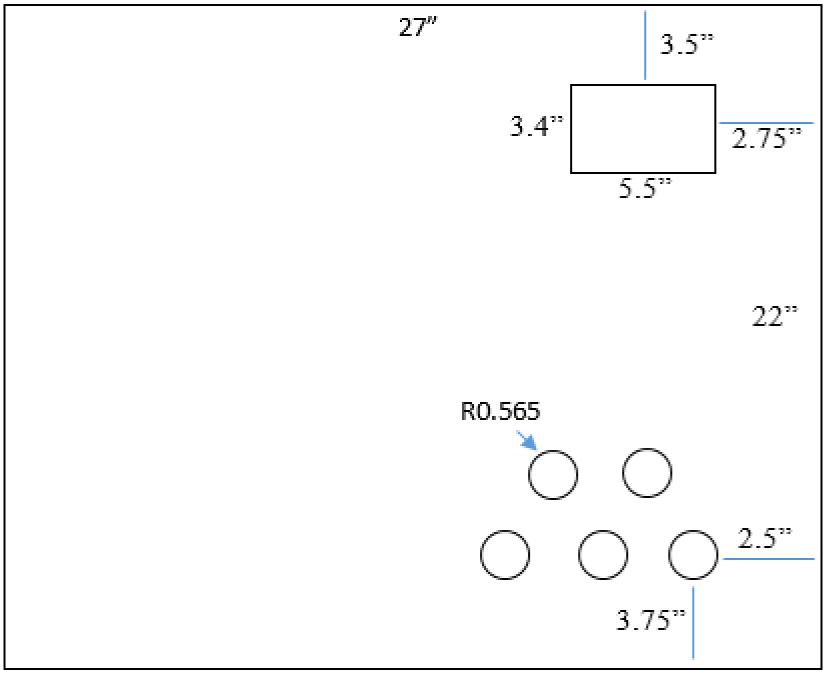

Figure C-1: Faceplate Mechanical Dimensions

Appendix D – Testing: Charging

Table D-1: Charging Tests April 23rd, 2016 in Grand Rapids, MI

Time Log	Panel Voltage (V)	Panel Current (A)	Battery Voltage (V)	Battery Current (A)	Load Voltage (V)	Load Current (A)	SOC (%)	Load	Notes
1334	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Measured PV: Voc = 20.97 Isc = 5.09
1336	13.4	4.8	13.6	4.7	13.8	0	58	Car Adapter (Has blue LED indicating power)	Green PV indicator light ON
1339	13.9	4.6	14	3.4	14	1.3	68	Car Adapter, 2x DC Motors (Rated at 13.7V)	
1340	16.4	2.9	14.4	3	14.5	0	82	Car Adapter	
1419	18.2	1.5						Car Adapter	PV rotated to align long edge tangential to sun, new alignment
1420	18.5	1.5	14.4	1.5	0	0	91	Car Adapter	PV temporarily tilted to face directly at sun for this reading
1437	18.4	1.3	14.5	1.3	0	0	95	Car Adapter	
1440	-								Loads found to be not active. Menu -> Load Set -> Manual -> ON. Enabled loads.
1448	18.3	1.3	14.4	1.3	14.4	0	94	Car Adapter	
1450	16.5	2.7	14.4	1.3	14.5	1.4	96	Car Adapter, 2x DC Motors	
1509	16.5	2.6	14.4	1.3	14.4	1.3	95	"	
1541	16.5	2.6	14.4	1.3	14.4	1.3	99	"	
1554	16.5	2.4	13.8	1	13.9	1.4	100	"	
1602	16.2	2.4	13.8	1	13.8	1.4	100	"	
1605	18.3	1	13.8	1	13.8	0	100	None	"Batt: Float/Normal"
1608	17.2	1.7	13.8	1	13.8	0.7	100	Car Adapter, 1x DC Motor	

Table D-1 (cont.): Charging Tests April 23rd, 2016 in Grand Rapids, MI

Time Log	Panel Voltage (V)	Panel Current (A)	Battery Voltage (V)	Battery Current (A)	Load Voltage (V)	Load Current (A)	SOC (%)	Load	Notes
1622	17.9	1.7	13.8	1	13.8	0.7	100	"	PV temporarily tilted toward sun for this reading
1625	17.1	1.7	13.9	1	13.9	0.7	100	"	Removed loads (Motor getting warm)
1658	18.3	0.8	13.8	0.8	13.8	0	100	None	
1709	18.4	0.9	13.9	0.9	13.9	0	100	"	
1721	15.8	0.8	13.8	0.8	13.8	0	100	"	
1723	13.2	1.1	13.4	-0.3	13.3	1.4	100	Car Adapter, 2x DC Motors	
1731	6.3	0	12.9	-1.3	12.9	1.3	93	"	PV physically fully shaded, Green PV indicator light OFF, Batt icon FULL and static
1743	5.1	0	12.8	-1.4	12.8	1.4	62	"	"PV:Disconnect" noted on CC. PV then physically disconnected (Limited sun available)
1745	0	0	12.8	-1.4	12.8	1.4	61	"	
1805									
1806	0	0	12.7	-1.4	12.7	1.4	59	"	Fuse test successful: Fuse on port #3 blown
1820									
1821	0	0	12.7	-1.4	12.7	1.4	57	"	
1833	0	0	12.7	-1.4	12.7	1.4	56	"	
1908	0	0	12.6	-1.4	12.6	1.4	53	"	
1937	0	0	12.6	-1.4	12.6	1.4	50	"	
1959	0	0	12.5	-1.4	12.5	1.4	48	"	
2059	0	0	12.5	-1.4	12.5	1.4	45	"	
2127	0	0	12.5	-1.4	12.5	1.4	44	"	

Table D-1 (cont.): Charging Tests April 23rd, 2016 in Grand Rapids, MI

Time Log	Panel Voltage (V)	Panel Current (A)	Battery Voltage (V)	Battery Current (A)	Load Voltage (V)	Load Current (A)	SOC (%)	Load	Notes
2156	0	0	12.5	-1.7	12.5	1.7	44	Car Adapter, 2x DC Motors, PC Fan	
2204								None	Loads disconnected

Table D-2: Charging Tests April 24th, 2016 in Grand Rapids, MI

Time Log	Panel Voltage (V)	Panel Current (A)	Battery Voltage (V)	Battery Current (A)	Load Voltage (V)	Load Current (A)	Temp. (°C)	SOC (%)	Load	Notes
1133										
1144										Cloudy day
1145	12.6	2.9	12.7	1	12.7	1.9	21.9	30	Car Adapter, 2x DC Motors, PC Fan	
1148	13.2	2.7	13.5	0.8	13.7	1.9	22	30	"	Battery Charger Connected (In addition to PV)
1150	13.8	2.9	14	2.9	14	0	22.1	34	None	
1152	0	0	13.9	0	13.9	0	22.3	42	-	Disconnected PV Panel
1210	0	0	13.9	0	13.9	0	22.8	100	-	
1212	0	0	13.2	0	-	-	22.9	96	-	Battery Charger Disconnected
1213	0	0	13.9	0			23.2	94	-	Battery Charger Reconnected
1225	0	0	14	0	-	-	-	100	-	Battery Charger Disconnected
1226	0	0	13.2						-	

Table D-2 (cont.): Charging Tests April 24th, 2016 in Grand Rapids, MI

Time Log	Panel Voltage (V)	Panel Current (A)	Battery Voltage (V)	Battery Current (A)	Load Voltage (V)	Load Current (A)	Temp. (°C)	SOC (%)	Load	Notes
1227	13.8	5.8	14	5.8	14	0	24	90	-	PV Connected
1252	13.7	2.9	13.8	2.9	13.8	0	24.6	68	-	
1318	13.6	2.4	13.7	2.4	13.7	0	23.8	64	-	Cloudy outside. Noted "Batt:Boost/ Normal"
1413	13.5	1.3	13.7	1.3	13.7	0	23.1	64	-	Battery Charger Connected
1452	13.3	0.8	13.5	0.8	13.5	0	22.2	53	-	
1505	14.1	0.7	14.3	0.7	14.3	0	22.3	85	-	
1522	13.7	1.3	13.8	1.3	13.8	0	22.7	81	-	
1544	13.6	1.6	13.8	1.6	13.8	0	23.3	65		
1607	17.9	1.6	14.4	1.6	14.4	0	23.6	91	-	
1650	18	1.2	14.4	1.2	14.4	0	23.5	92	-	
1704	15.2	1.1	14.4	1.1	14.4	0	23.8	89	-	Battery Charger Disconnected
1721	16.2	1	14.4	1	14.4	0	23.7	91	-	
1816	13.3	0.5	13.5	0.5	13.5	0	23.2	56	-	
1841	13.3	0.4	13.5	0.4	13.5	0	23.2	54	-	

Appendix E – Testing: Discharging

Table E-1: Discharge Testing, May 6th, 2016

Time log	Voltage (V)	Amperage (A)	SOC (%)	Load=4/3 Ω
1559	12.6	n/a	69	Not connected to CC
1605	12.4	n/a	47	Not connected to CC
1612	12.4	n/a	37	Not connected to CC
1617	12.4	n/a	38	Not connected to CC
1623	12.4	n/a	37	Not connected to CC
1629	12.4	n/a	37	Not connected to CC
1634	12.4	n/a	36	Not connected to CC
1640	12.4	n/a	36	Not connected to CC
1646	12.4	n/a	35	Not connected to CC
1650	12.4	n/a	35	Not connected to CC
1656	12.4	n/a	34	Not connected to CC
1702	12.3	n/a	33	Not connected to CC
1707	12.3	n/a	33	Not connected to CC
1713	12.3	n/a	31	Not connected to CC
1718	12.3	n/a	31	Not connected to CC
1723	12.3	n/a	30	Not connected to CC
1729	12.3	n/a	30	Not connected to CC
1734	12.3	n/a	29	Not connected to CC
1845	12.2	n/a	23	Not connected to CC
1857	12.2	n/a	22	Not connected to CC
1907	12.2	n/a	21	Not connected to CC
1917	12.1	n/a	20	Not connected to CC
1935	12.1	n/a	18	Not connected to CC
1947	12.1	n/a	17	Not connected to CC
1959	12.1	n/a	16	Not connected to CC
2009	12.1	n/a	15	Not connected to CC
2020	12	n/a	14	Not connected to CC
2031	12	n/a	n/a	Not connected to CC
2042	12	n/a	n/a	Not connected to CC
2055	12	n/a	10	Not connected to CC
2108	12	n/a	9	Not connected to CC
2118	11.9	n/a	8	Not connected to CC

Table E-1 (cont.): Discharge Testing, May 6th, 2016

Time log	Voltage (V)	Amperage (A)	SOC (%)	Load=4/3 Ω
2126	11.9	n/a	7	Not connected to CC
2142	11.9	n/a	5	Not connected to CC
2146	11.7	8.4	14	Connected to CC
2200	11.6	8.4	10	Connected to CC
2211	11.6	8.4	n/a	Connected to CC
2222	11.6	8.4	7	Connected to CC
2234	11.6	8.3	n/a	Connected to CC
2244	11.5	8.3	5	Connected to CC
2255	11.5	8.3	3	Connected to CC
2306	11.5	8.3	2	Connected to CC
2316	11.5	8.3	1	Connected to CC
2325	11.4	8.3	n/a	Connected to CC
2335	11.4	8.2	0	Connected to CC
2345	11.4	8.2	n/a	Connected to CC
2355	11.4	8.2	0	Connected to CC
0008	11.3	8.2	0	Connected to CC
0016	11.3	8.2	0	Connected to CC
0024	11.3	8.2	0	Connected to CC
0033	11.3	8.1	0	Connected to CC
0039	11.2	8.1	0	Connected to CC
0047	11.2	8.1	0	Connected to CC
0100	11.2	8.1	0	Connected to CC
0108	11.2	8.1	0	Connected to CC
0116	11.1	8	0	Connected to CC
0124	11.6	0	n/a	Connected to CC