Failure Mode and Effects Analysis of Atwater Kent Sustainable and Modular Display System

A Major Qualifying Project Report

Submitted to the Faculty of the

Worcester Polytechnic Institute

in partial fulfillment of the requirements for the

Degree of Bachelor of Science in Electrical & Computer Engineering

Dec. 13th, 2019

Team Members

Lauren Conroy, *lconroy@wpi.edu*

Advisor
Alexander M. Wyglinski, *alexw@wpi.edu*

Co-Advisor
Shamsnaz V. Bhada., *ssvirani@wpi.edu*

Worcester Polytechnic Institute
Worcester, MA

I. Abstract

The focus of this project was to develop a sustainable and modular display that could be used to display the unique technology and innovation the ECE department has to offer for both current and prospective students. The system is composed of three subsystem that are codependent on each other to function. This paper focuses on the specific failures that this system may encounters the project will continue on for another term. The largest failures are based in the power production of this system since the system is off-gird and the only way it can receive power is through the solar panel. As the project progresses with the remaining members, the team should focus on the reduction of power for the display subsystem as well as the relocation of the panel to an unobstructed area. The off-grid nature of the system denotes a delicate balance between the power production and power draw of the system.

II. Acknowledgements

The following organizations and people have aided in the betterment of this project:

- Guidance from advisors, Professor Wyglinski and Professor Bhada,
- Support from Zach Bergquist, Olivia Hanson, Jonathan Lee, Quincy Rhodes, Brandon Terry, and Tim Vermilyea
- Knowledge and solar panel donation from Justin Woodard of National Grid an alumnus of the WPI ECE Department,
- The donation of a WPT Developmental Kit from Wurth Elektroniks, and
- Technical and tool support from Bill Appleyard in the ECE shop

Thanks to everyone for their time and contributions!

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ECE – Electrical and Computer Engineering

FMEA – Failure Mode and Effect Analysis

kWh – kilowatt hours

RPN – Risk Priority

WPT – Wireless Power Transfer

VI. Executive Summary

Worcester Polytechnic Institute (WPI) is one of the over 20 ABET accredited engineering schools in Massachusetts. As the number of high school applicants reduce in the next few years, WPI has been starting multiple initiatives to engage those prospective students and show what WPI has to offer in the engineering fields. Efforts such as building new building and upgrading new labs have not gone unnoticed.

Our project combines the need for WPI to advertise the Electrical and Computer Engineering (ECE) Department while providing a self-generating energy display system to offset the power generation needed to run the campus. The project is composed of three subsystems that are then broken into the individual components. The three main subsystems focus on the solar aspect of the project, wireless power transfer, and the display. The solar subsystem consists of a solar panel, charge controller, and boost converter to generate and level out the voltage needed to power the system. The wireless power transfer subsystem consists of a transmitter and receiver coil that move the energy wirelessly through a window to avoid damaging the preexisting building. The last subsystem is the display that takes that energy from the receiver and stores it in a battery. The microprocessor and LEDs draw the power from the battery with a charge controller making sure the current is not over draw.

This system, like every system, has the possibility of technical and human error which risks the systems completion and overall function. There are techniques currently in place in industry to methodically analyze the causes of errors and the effects on the system.This paper specifically focuses on Failure Mode and Effects Analysis (FMEA). FMEA is a systematic method to identify, evaluate, prevent control or eliminate the causes and effects of potential risks in a system before a final product is delivered to a final user.

The system's operation and experimentation will be continued on by the remaining members of the team. The results of the testing and usage will be documented by the team in the end of C-term and will be in the overall document.

1 Introduction

Globally, the US is facing an energy crisis where it is consuming more energy than it can produce. In 2018 alone, the US consumed 101.3 quadrillion British thermal units or 29688100741667 kWh (29.68 trillion kWh) of energy. [8][9]. However, the US had only produced 4.18 trillion kWh of energy through various forms of electricity generation. Many of the options for producing power have had a detrimental effect on our environment and result in the production of greenhouse gases. In 2017, it was found that 27.5% of greenhouse gas was produced by electricity production with 62.9% of electricity coming from burning fossil fuels, mostly coal and natural gas [10]. Due to these environmental concerns, many residences and businesses are looking to renewable energy to power their daily operations to reduce the amount of natural gas, petroleum and coal needed.

Locally, WPI has not been exempt from this crisis with statistics showing an increase inpower usage over the past years.Large power drawing installments on campus include the display screen in Foisie Innovation Studio. Recently, the ECE department has been keen on displaying its projects and the offerings of the Electrical and Computer Engineering department (ECE) to the multitude of prospective students and their accompanying families. In doing so, the department still wants to be conscientious of the concerns of energy draw. Any additional grid tied projects only add to this growing concern. Therefore, there is a need for a way to advertise the WPI ECE department while having a self-generating energy display system.

This self-generating energy display system has the ever-present possibility of technical and human error which risks the systems completion and overall function. There are techniques currently in place in industry to methodically analyze the causes of errors and the effects on the system with this paper specifically focusing on Failure Mode and Effects Analysis (FMEA).

FMEA is a systematic method to identify, evaluate, prevent control or eliminate the causes and effects of potential risks in a system before a final product is delivered to a final user [2][4]. These failures are prioritized in accordance with the seriousness of the effects, how often they occur and how evident they are to the user. During the design phase, FMEA is used to prevent failure. Afterwards, it uses to control the system knowing when or if it will fail and where that failure could occur [6]. This paper documents the system's failure modes and effects analysis to identify and evaluate certain subsystems and where, how and why it may fail. It will also discuss how those failures impact the system in terms of cause and effects and prioritizes the failures in terms of most detrimental to least.

The purpose of Chapter 1 is to express the motives to create a system that is reliant on itself for power and describes how it would be used as a recruiting tool to encourage more students to apply and attend WPI. Chapter 2 reiterates and outlines the systems function and flow for the readers who may not have read the initial report that includes this paper as a section. Chapter 3 pin points the failures, the effects they have on the system, and proposes modifications and solutions to the failures. Chapter 4 concludes the results and impacts of the failure modes and effect.

2 Previous Work

This paper is a part of a large paper that will be written by the rest of the MQP group. To get a better understanding of the AK Sustainable and Modular Display System separately from the other paper, this section will provide a brief overview of how the overall system works and the different technologies that are utilized in this project. The paper will not cover the basics of how the individual parts work such a solar panel turns the light it receives into energy. Instead, it will discuss the Failure Mode and Effects Analysis (FMEA).

Within the large project, there are 3 subsystems that are then broken into the individual components. The physical view of the overall system below was created by Tim Vermilyea and updated for this paper to objectively looks at the different subsystems and how they interact.

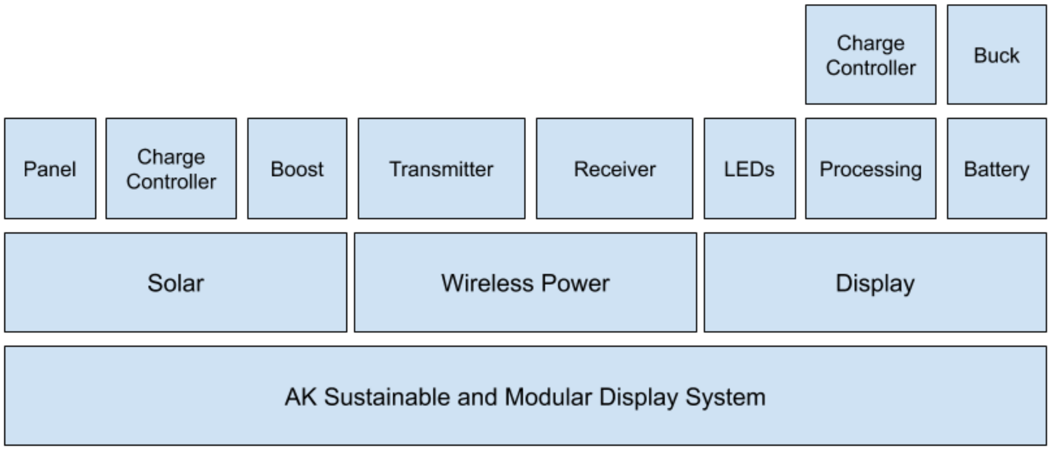

Figure 1: Physical View of System

Figure 1 is a wholistic view of the system and breaks down the system into subsystems and subsubsystems. The main subsystems are solar, wireless power transfer, and display.

For the solar subsystem, the subsystem is using a 305-watt panel that is mounted at a 15-degree angle facing southwest. The panel will not be generating the maximum wattage due to risks and failures that will be discussed late in the paper, but will ultimately be able to power the full systems including all of the smaller components. The panel is directly connected by wires to a charge controller to take in the power generated from the solar panel. The charge controller outputs the same power while optimizing the conversion of the higher DC voltage output from the panels to the lower voltage of the batteries or off-grid system [7]. From the output of the charge controller, the voltage is 12V which differs from the 24V needed for the wireless power transfer receiver. Therefore, a boost converter was implemented to increase the voltage coming from the charge controller.

For the wireless power transfer subsystem, the near field wireless power system transfers the power generated by the solar panel across a 1cm thick window to get the power into Atwater Kent (AK) without long cables or drilling through the preexisting building. The transmitter takes in power from the charge controller and generates a time-varying electromagnetic field that can be received from across a 1 cm distance. The transmitter coil will be located outside the building. The receiver receives the time-varying electromagnetic field and extracts power from it and supplies it to an electrical load which is a battery for this system. The receiver coil and the rest of the system is located in Atwater Kent [7].

For the display panel subsystem, the initial voltage coming from the wireless power receiver ranges from 15V to 20V and the battery is 12V, so a charge controller is used to prevent the over drawing of current from the battery. The sealed lithium-ion battery that located near the displays power connection. The voltage coming from the battery is 12V and the display and processor run off of 5V therefore the voltage need to be regulated down.

The diagram below shows the configuration described above.

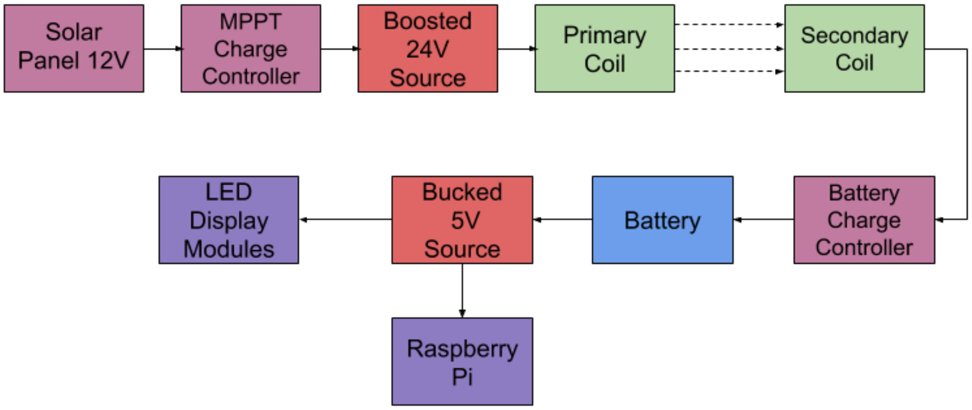

Figure 2: System Block Diagram of the Current System

Figure 2 is a representation of Figure 1 as a system block diagram. It denotes the path that each subsubsystem takes to get to the next. The next chapter uses this figure as a basis for the quantitative analysis of each subsubsystem which is denoted by each module above.

2.1 Quantitative Analysis

This section covers the mathematics of each subsystem so that later in the paper a discussion of different situations can occur. For determining the difference between the power production vs. the power draw, the time tested for the system was 1 hour.

Solar Panel: The panel is rated 305W and the system is being tested for a 1 hour run. The table below initially calculates at standard testing conditions (STC). However, due to the placement of the panel, this number is bound to go down depending on the partial coverage of the system.

Maximum Power Point Tracking (MPPT) Charge Controller: The charge controller is rated for an 8-68V input voltage range and is rated for over 750W/12V. It tracks the maximum power point (MPPT) ensures that the panel is transfer of energy is amplified. The specification sheet denotes that it is 98.6% efficient for DC/DC transfer efficiency.

Wireless Power Transfer: The varying voltage output of the wireless power transfer system has made it difficult to pinpoint the exact power output which consequently split the math down into two sections. For an input voltage is 24V and the output voltage is 15V resulting in a loss of 9V and for an input voltage is 24V and the output voltage is 20V resulting in a loss of only 4V. The WPT system specifications sheet stated that the percent efficiency was at a maximum of 91%. We found that the current from the Tx to the Rx was the same leading us to determine the efficiency of the transfer to be around 83%. This number fell within the specifications sheet and it determined the approximate efficiency of our subsystem in our project's use case.

Charge Controller: Due to the undetermined current draw and pull of the system, a charge controller is necessary to ensure the system does not over draw current damaging the system. This will be built by the remaining team members and tested after B term.

Battery: Every battery has an internal resistance which results in a loss of power due to heat. The battery the system is using is 12V and the charging rate is 164.2W or 218.9W depending on the WPT voltage drop. Ideally, the battery would need 12A to charge the 12V battery but the average battery has around 1 ohm of resistance resulting in the need to have 13V to supply 156W to get 144W [3]. After preforming the calculations, the battery would lose 12W from heat however we used 20W loss for safety reasons making the battery efficiency around 90%.

Processor: The Raspberry Pi Model 4b 2GB requires 5V input and maxes out at around .855A of current meaning it draws around 4.27W of power.

LEDs: The table below, created by Brandon Terry, determined the power draw of the LED panels by calculating the current draw per LED. Then it was multiplied by the 5V constant input voltage. For 2 colour LEDs at 50% power usage, the power draw was 125.65 W.

Table 1: LED Display Current Draw

Two Color @ 100%			
# of LEDs	Current Draw	Total # of LEDs	Total Current (A)
1	0.059	1600	50.453
10	0.343	1600	50.08
20	0.656	Average:	50.267

Table 1 is a breakdown of the current usage in terms of how many LEDs are used in the display. The current usage is not linear so the current was measured at 1, 10, and 20 LEDs and the calculation for 1600 LED was achieved from those numbers. This number was then multiplied by 5V to get the full power draw

Table 2: Current System Calculations

	Wattage (W)	Voltage (V)	Current (A)	Efficiency (%)
PV Panel	305	37	8.25	N/A
MPPT Charge Controller	300.7	12	25.06	98.6
Boost	273.66	24	11.40	91
WPT	171.04	15	11.40	83
	228.05	20	11.40	83
Charge Controller	164.19	12	13.68	96

	218.93	12	18.24	96
Battery	147.77	12	12.64	90
	197.04	12	16.86	90

Table 2 tracks the power, voltage, current and efficiency of each subsubsystem. The % efficiency and voltage dictated the output power is most subsubsystems.

Table 3: Current System Power Production

	Total Power Production (W)	Total Efficiency (%)
15V WPT	147.78	48.45204
20V WPT	197.03	64.60272

Table 3 is the total output power of the system after all the losses as the power goes from subsubsystem to subsubsystem. The 15V and 20V is the range at the output of the wireless power transfer and overall the output can be as low as 48.45% efficiency and as high as 64.6% efficiency.

Table 4: Current System Total Power Draw

Display @ 50% 2 Colours (W)	Raspberry Pi (W)	Display Power Draw Total (W)
125.65	4.2775	129.9275

Table 4 displays the power being draw from the system and then sums it. This number needs to be less than the power produced.

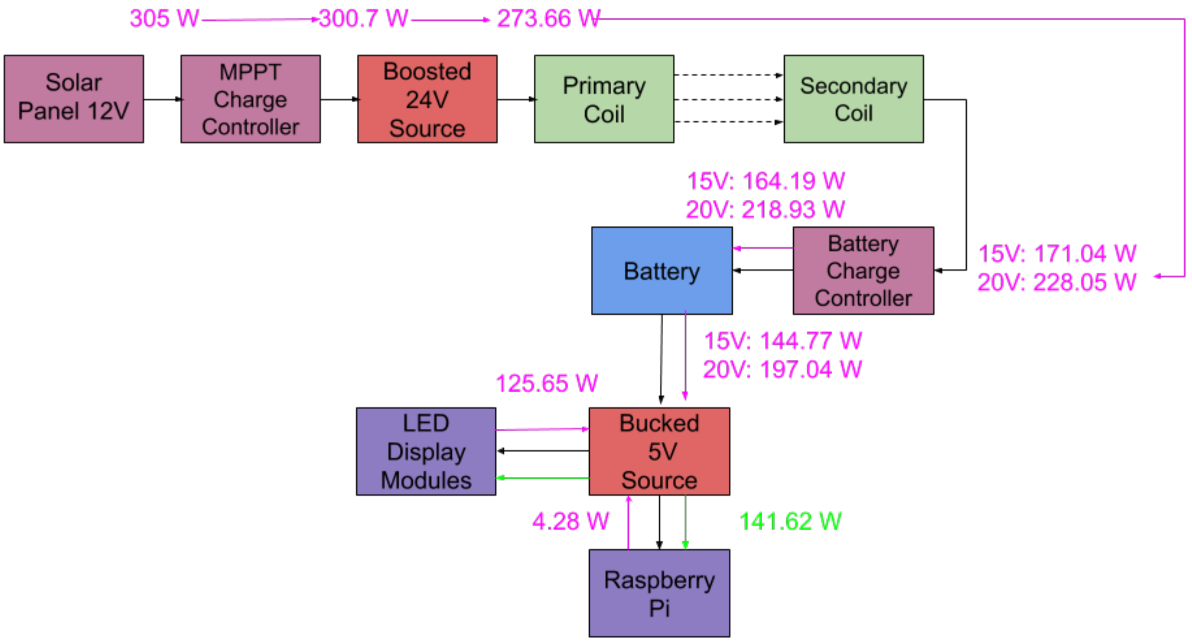

Figure 3: System Block Diagram of the Current System Power Loss

Figure 3 above uses the diagram from Figure 3 and describes the power transfer and loss from subsubsystem to subsubsystem.

In the current calculations, the battery is able to be charged and the power produced in 1 hour is greater than the power used in 1 hour.

Chapter Summary

Overall, this section breaks down the current system into a description of how each subsubsystem/component works individually, a description of how each subsubsystem/component works together, and calculations of the integration of the components in terms of loss per component. This section will serve as a basis for the following section as it will go through the subsubsystems and identity potential faults and failures.

3 Analysis

This paper will be discussing the failure modes and effects analysis of the overall system and the three individual subsystems. This will failure or success of managing these failure modes and the effects will dictate the success or failure of the overall system.

The chart below ranks the failure mode in 3 numerical values. The severity rating is ranges from 1 to 10 with 1 being not a problem at all and 10 being a full system failure. The occurrence rating ranges from 1 to 10 with 1 being that it has only occurred once and 10 being that it is a constant problem. For example, weather related failures such as snow and falling leaves only occur for a certain amount of time per year. The detection rating is the level at which the customer or the general public could see the system not working. The rating ranges from 1 to 4 with 1 being undetectable and 4 being very apparent. For example, if the panel is not working, the entire system is not working. That is very evident to the general public if they had seen the system working previously. The RPN or risk priority number is the product of the severity, occurrence and detection ratings [5]. A failure is usually ranked as critical if the severity of occurrence rating is over 9 or if the detection rating is over 3.

Table 5: FMEA of System

Function/Process	Potential Failure Mode	Potential Effects of Failure	Severity Rating	Occurrence Rating	Detection Rating	Critical Characteristic	RPN (Risk Priority Number)
Power Generation	Tree line blocking sun	Not maximized power output	10	6	3	Y	180
	Snow and leave blockage	Loss of usable cells	8	4	2	N	64
	Failure of MPPT charge controller	Not maximized power output	7	2	1	N	14
	Falling snow from roof	Broken/damaged panel	9	2	3	Y	54

Power Transfer	Inability to modify the program controller	Person will need press a button to turn on transfer	10	2	3	Y	60
	Misalignment of coil	Less voltage output	8	2	1	N	16
Power Usage	LED burnout after certain time	Dimmer LEDs after a short time then rated	3	2	4	Y	24
	Max number of LEDs that can be driven on one data line	Not all of the LEDs will turn on	4	2	4	Y	32

Table 5 is a representation of the FMEA in terms of the issues that arise in each subsystem. It places numbers to represent the severity, occurrence, and detection with the RPN representing the overall risk. For power generation, the RPN was very high due to the importance of power in terms of this system being fully off-grid. Without power, there is a failure of the entire system. For power transfer, the lack of ability to modify the controller results in the need for a person to start the system daily. For power usage, both failures have low occurrence rates like the LED burnout. The LED's are rated for a certain lifespan that could be diminished due to temperature condition of extreme heat. The max numbers of LEDs can be adjusted in the RasPi config files.

Table 6: Subsubsystem Identification and Effects

Limitation	Subsystem	Subsubsystem	Number	Subsystems its effects
Tree line blocking sun	Solar	Panel S1	A1	S2, S3, WPT, Display
Snow and leave blockage	Solar	Panel S1	A2	S2, S3, WPT, Display
Failure of MPPT charge controller	Solar	Charge Controller S2	A3	S2, S3, WPT, Display
Falling snow from roof	Solar	Panel S1	A4	S2, S3, WPT, Display
Inability to modify the program controller	WPT	Transmitter W1	B1	W2, Display
Misalignment of coiled	WPT	Transmitter and Receiver W1 and W2	B2	W2, Display
LED burnout with sunlight/heat	Display	LED's D1	C1	Display

Max number of LEDs that can be driven on one data line	Display	LED’s D1	C2	Display

Table 6 identifies the earlier potential failure modes and displays how it will affect the rest of the system. Its primary purpose is emphasizing the fact that each subsystem is reliant on the previous one.

3.1 Solar Panel Limitations

Tree Line Blocking Sun: Based on the location of the panel, the chance the panel will receive full unobstructed sunlight for 6 or so hours are very unlikely. The typical panel and the panel that was selected is broken up into three sections that are then run in parallel. If the trees surround the building partially block a section of the panel, the power from that section is zero essentially serving as an open circuit to the rest of the panel while reducing the overall power output of the panel. The team has tried to mitigate the issue by moving the panel farther from the sidewalk and closer to the building. Ideally, the panel would be moved to a location with an unobstructed sightline to the sun, but because the panel would be part of the intrigue for prospective students, the panel needs to stay close to the building.

Based on the chart below, which took measurements of a 200W panel at on a sunny and cloudy day in December, and information of the amount of sun hours in Worcester, the tentative solar panel output wattage was able to be predicted.

Table 7: Solar Production in Current Location

	200 W Panel Reading Sunny	200 W Panel Reading Cloudy
8:00	Blocked	Blocked

9:00	Blocked	Blocked
10:00	10W	None
11:00	30W	30W
12:00	60W	40W
13:00	80W	30W
14:00	60W	10W
15:00	20W	None
16:00	10W	None
17:00	Sun Set	Sun Set
Total	270W	110W
Display Power Draw	129.9275	129.9275

Table 7 displays the wattage of the solar panel on a sunny and cloudy day. It shows that on a sunny day it would only be able to power the display for 2.07 hours and .846 hour on a cloudy day. This data shows that this location is not optimal for the panel.

Snow and Leaf Blockage on Top of Panel: After speaking with Justin from National Grid, it was learned that a normal 200 to 300-watt panel is divided into three sections that are subsequently connected in parallel. Depending on the location of the snow or leaves, the panel could lose some or all of its ability to produce power. The diagram below shows the two configurations of obstruction patterns and the table below displays the power output.

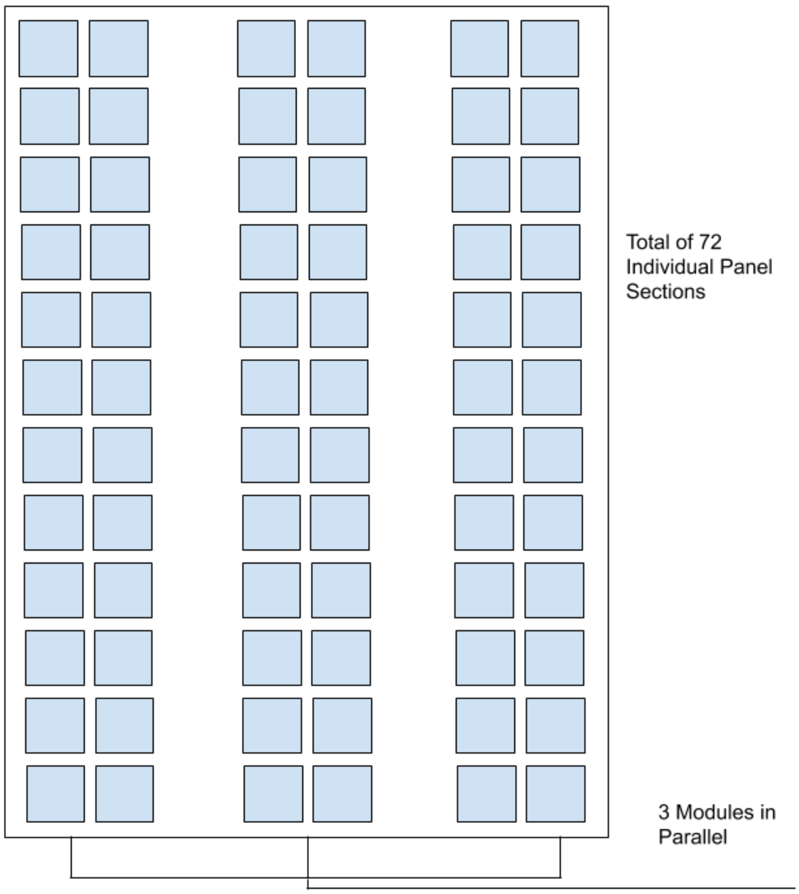

Figure 4: Solar Panel Configuration

Figure 4 shows the configuration of the panel with 3 modules in parallel consisting of 24 individual panel sections per module.

Table 8: Solar Panel Obstruction Data

Obstruction (%)	Power Output at STC (W)
1/3	101.66
2/3	203.33
1/3 in horizontal direction	0W

Table 8 displays the % blockage of sun to the panel. If a leave or piece of large debris falls on the panel block most of the module, it would lose 1/3 of the power if the block ran vertical.

Falling Snow from Top of Building: Based on the location of the panel and observations from the latest snow storm, it has been found that after an initial snow fall and the temperature warms, large piles of snow fall off the from right onto the proposed location of the panel. The weight of the wet snow falling from that specific spot can range from. All panels are rated for certain weather conditions. For example, an Astro Halo 350W ~ 370W Mono PV Panel passes a hail test certifying that it will sustain ice balls of d=45mm and a velocity of 30.7 m/s. For mathematic purposes, say the pile of wet snow is 5 kg, there is not gusts of wind so, and it took approximately 2.5 second for the snow pile to hit the ground. That means the velocity of the snow pile was 9.81m/s^2*2.5 seconds = 29.43m/s. This velocity is extremely close to the rated velocity of the panel [1].

Figure 5: Prospective Snow Damage

Figure 5 above is a picture of the snow that falls in large, heavy wet chunks onto the currently proposed location of the solar panel. This snow puts the panel in position to be damaged.

Failure of MPPT Charge Controller: After researching a bit about MPPT charge controllers, it was discovered that there is no standardization to the testing method the produced power from using MPPT. With the seller's site saying that the DC/DC transfer is up to 98.6%, it leaves the buyer wondering what the is the actual output. If the MPPT aspect of the charge controller doesn't work, the power output can be assumed at a constant voltage and current [3]. For this system it will be for a 12V battery and an 8.25A from the panel so a constant steam of 100W into the battery.

3.2 Wireless Power Transfer Limitations

Inability to modify the program controller:

Currently, the only way to start the WPT is by pressing down on a button to start the transfer. This means that each time the system turns off a person needs to press the button for the WPT to start transmitting the energy to the receiver. Since the WPT is a kit, the only way to change this feature is by reprogramming it. The kit did not come with the programming cable or software to fix this issue.

Misalignment of coiled: When calculating the output of the receiver, the location of the coils dictates the how well the electrical energy is being transferred. In this case, the coils are using resonant inductive coupling which the receiving coil frequency is tuned to resonate at the same frequency as the driving frequency. Therefore, if the coils are misaligned the frequency from coil to coil is slightly altered.

Length of WPT Coil Blocks = 5.3cm

Table 9: Misalignment of Coil Data

Voltage In	Voltage Out	Distance off from Edge
24V	15V	0
24V	12.5	.5cm
24V	8.2V	1cm
24V	5.3V	1.5cm
24V	0	2cm

Table 9 shows the horizontal distance shift in comparison to the voltage output. At perfect alignment, the coil can receive 15V and after a 2cm offset the coil could not receive anything.

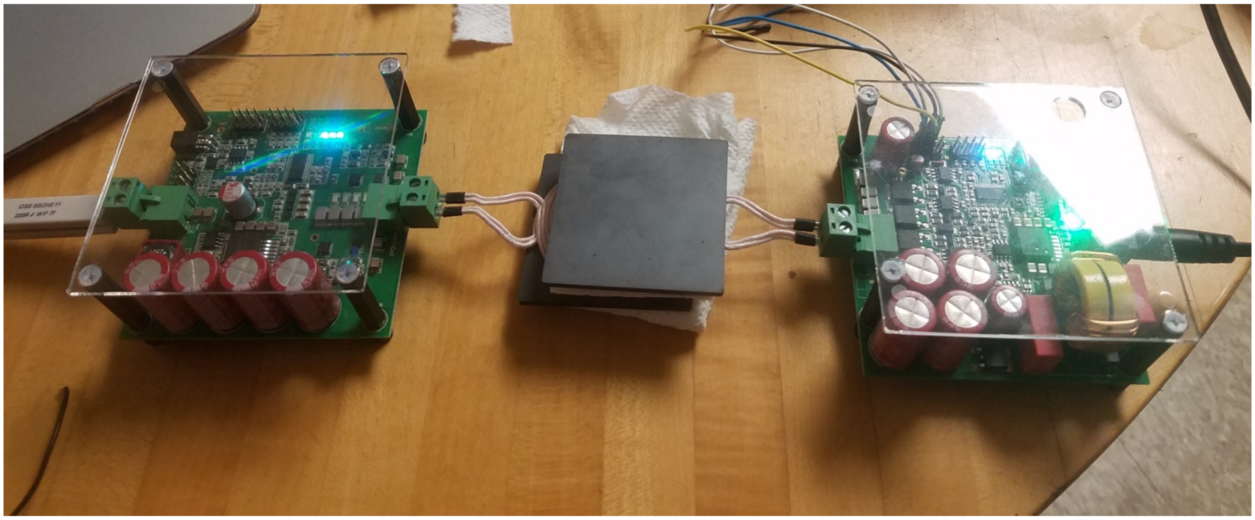

Figure 6: Misaligned Coil

Figure 6 displays the wireless power transfer subsystem an offset of .5cm. The two coils are separated with exactly 10mm of paper towel.

3.3 LED Display Limitations

LED Burnout with Heat: The SK9822 LED's are rated for 5 to 30 degrees Celsius with a 60% relative humidity. The current position of the LEDs is located above a large heater that is meant to provide heat to AK. By being placed there, the heat will slowly degrade the LEDs during cool months causing the life of the LED's to be shorter. The specification sheet has no details about

Max Number of LEDs that can be Driven on One Data Line: After reading the datasheet for the controller, it was found that the default SPI (Serial Peripheral Interface) was set to size 4096. The SK9822 LED's data sheet says that each LED uses 4 bytes. When calculating the total bytes, there are bytes at the beginning and end of frame. The data sheet says that the beginning frame uses 4 bytes and end frame uses 4 bytes, it was found that 1022 is the maximum you can run without losing integrity of the signal. This makes the goal of using 1600 LEDs difficult using the default configurations.

3.4 Analysis of Solar Panel Limitations

Tree Line Blocking Sun: No matter what arrangements and configurations the panel moves to on the ground, the amount of power generated from the original spot chosen is dismal and it is unlikely that the system will run as long as expected. Therefore, the panel needs to more to a location where it will receive the fullest amount of sun as possible. The better location would be the roof of Atwater Kent to the left of the entrance of the building. This way the wires running from the panel will run straight down the outside of the building to the WPT transmitter.

Pro: The panel will receive more sunlight and generate more power throughout all seasons.

Con: The panel will not be viewable by the general public reducing the interestingness factor and lessening the value of the project as an ECE recruiting method.

Recommendation: Move the panel to the top of the roof

Snow and Leaf Blockage on Top of Panel: Snow and leave blockage can only be mitigated so far since our project should need little to no human intervention to continue its use. For snow, there are two options. With the pitch of the panel, there is a chance that when the weather gets warmer the snow will eventually slide off. However, in the dead of winter it could stay very cold for a long duration of time leaving the system without power for an undetermined amount of time. This leads to the second option of having facilities physically remove the snow after the storm has passed.

Leaving snow to melt & Facilities removing snow

Pro: Keeping the system running during any weather restrictions.

Con: Loss off power generation for an undetermined amount of time.

Con: Must work with facilities schedule and they very well may say no.

Recommendation: Kindly ask facilitates to remove the snow. If the system is unable to generate power it is ultimately useless.

For leaves, the hope is that the pitch of the panel will let the leaves slide off when its dry also if the panel is moved from the ground to the roof, there is an absence of trees. Therefore, even if a few leaves somehow fall on the panel, they will eventually get removed by the wind.

Recommendation: Move panel to roof and let the leaves fall off on their own.

Falling Snow from Top of Building: Due to the current placement of the panel, the position leaves it susceptible to being damaged or broken by falling heavy snow. The only way to fully remove the possibility of panel damage by falling items is by moving it to an open area such as an open field or the top of a roof.

Pro: The panel will receive more sunlight and it will be unlikely that large, heavy items will fall on it if the roof do not have trees over it.

Con: The panel will not be viewable by the general public reducing the interestingness factor and lessening the value of the project as an ECE recruiting method.

Recommendation: Move the panel to the top of the roof

Failure of MPPT Charge Controller: Even if the MPPT portion of the charge controller is not functioning fully, the system is still receiving power, it is just not optimized. There is no way of guaranteeing the MPPT portion’s success. The alternative is just using a PWM charge controller that doesn’t adjust the input voltage to collect the maximum power from the panel turning it into a varying voltage supply for the rest of the system.

Pro: A guaranteed power output that won’t fluctuate.

Con: It is not maximized so it could be losing power that could be stored for a later use.

Recommendation: Continue using the MPPT charge controller since it is equipped with the ability to adjust the voltage.

3.5 Analysis of Wireless Power Transfer Limitations

Inability to modify the program controller: One of the team members has a sister software that could potentially program the controller. If this doesn't work, the software and wires to reprogram the transmitter can be bought online. This will cost upwards of $60.00 and will take time to learn the programming language.

Pros: Buying the software guarantees that the transmitter can be used without a person touching the on button.

Cons: It was not calculated in our original budget and our budget already tight.

Recommendation: The probability that using the sister software and blindly programming the transmitter is going to yield in a productive output is very low. The team should spend the time using the software they know that will work.

Misalignment of coils: The alignment of the coils is key to powering the rest of the system. The current attachment design as of writing this paper has not been formulated making it difficult to make recommendations on changes. Therefore, in the improvements to current design section, a discussion of a proposed design will be discussed.

3.6 Analysis of LED Display Limitations

LED Burnout with Heat: The heat from the radiators can be avoided by moving the display to a different location.

Max Number of LEDs that can be Driven on One Data Line: Having all the LEDs working is a key component to showing our message and mission to the current and prospective students of WPI. Therefore, after doing research it was found that a user could change the SPI configuration settings to allow for a high level of bytes. For 1600 LEDs with a 4 byte start and 4 byte end frame, a SPI size of 8192 which is 2^13 would allow for enough buffer room for more LEDs. The maximum SPI size for the RasPi is 2^16 which is 65536. That can be set if more LED's need to be added later on.

Recommendation: Edit the configuration size to fit the number of byte needed.

3.7 Improvements to Current Design

Consolidate Components: While calculating the initial systems overall efficiency it became clear that one portion could be consolidated and the two separate components only added to the power loss. The MPPT charge controller into boost could be consolidated by removing the boost and changing the MPPT charge controller to be 24V taking in the solar power at around 37V and stepping it down to the 24V that would be usable by the wireless power transfer transmitter. The math and diagram below show that removing it increases the efficiency by 5% or 6%.

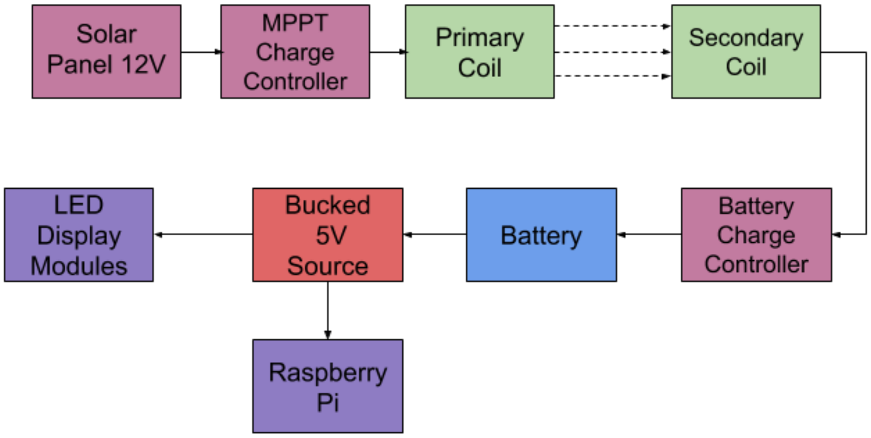

Figure 7: System Block Diagram of the Proposed System

Figure 7 above shows a block diagram level of the overall proposed system change which removes the boost and increases the voltage of the MPPT charge controller. This will increase the efficiency by 5% to 6% from the original system.

Table 10: Current System Calculations

	Wattage (W)	Voltage (V)	Current (A)	Efficiency (%)
PV Panel	305	37	8.25	N/A
MPPT Charge Controller	300.7	24	12.53	98.6
WPT	187.95	15	12.53	83
	250.60	20	12.53	83
Charge Controller	180.43	12	15.03	96
	240.584	12	20.04	96
Battery	162.39	12	12.31	90
	216.52	12	16.42	90

Table 10 tracks the power, voltage, current and % efficiency as the power goes through each subsubsystem. The % efficiency and voltage dictated the output power is most subsubsystems.

Table 11: Current System Power Production

	Total Power Production (W)	Total Efficiency (%)
15V WPT	162.39	53.24
20V WPT	216.52	70.99

Table 11 is the total output power of the system after all the losses as the power goes from subsubsystem to subsubsystem. The 15V and 20V is the range at the output of the wireless power transfer and overall the output can be as low as 53.24% and as high as 70.99%.

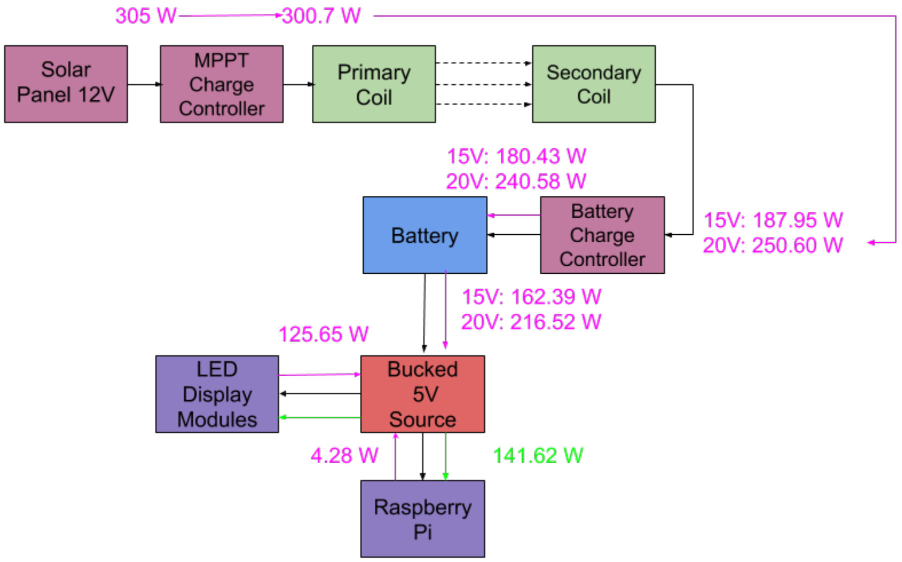

Figure 8: System Block Diagram of the Proposed System Power Loss

The Figure 8 above uses the diagram from Figure 7 and describes the power transfer and loss from subsubsystem to subsubsystem. This diagram is an improvement of the system used in Figure 2 and 3 by removing the boost subsubsystem and reducing the voltage of the panel from 37V to 24 by using a MPPT charge controller subsubsystem rated for 24 volts.

Attachment and Storage of Wireless Power Transfer Coils: The wireless power transfer system has a transmitter that will be located outside on the window and a receiver on the inside. First to attach the WPT Tx and Rx to the window, it would be advantageous to use industrial grade double sided tape on the four corners of the coil blocks being careful to not increase the distance the coil is from touching the window. Similarly, when installing the alignment of the coils must be exact. This can be done by measuring out the exact location of one coil and mimicking the exact dimensions for the other coil. For the controller, the use of industrial double-sided tape would be very useful. To protect the Tx and Tx controller from the outdoor climate, a plexiglass case with a key-locked door and mesh covered ventilation gaps will keep the items dry. It is easy to access the components while keeping them safe.

Chapter Summary

Overall, this section identifies potential failure modes for each subsystem as well as the subsubsystems. Each failure is detailed out with data to back why the subsubsystem could fail with the failure being rated on the overall severity, occurrence and detection in accordance with FMEA. The overall Risk Priority Number denotes the importance of the failure with the higher the number being most important to address. The section then addresses the failures by suggesting options to either mitigate or eliminate the failures.

4 Conclusion and Future Work

After analyzing the current system and making suggestions for the improvement of certain subsystems using FMEA, specifically the solar subsystem, the system will be able to have a self-powered display system used for the purpose of engaging current and prospective students into the Electrical and Computer Engineering Department. Due to the many moving parts of the system, there are quite a few improvements that the team next term should consider. Most importantly, the solar panel's current location needs to change. Its current location will not generate nearly enough power for the panel to run over 2 hours a day due to unchangeable conditions such as the tree line blocking the panel for most of the day. Similarly, falling snow and leaves will block the panels from producing energy and the falling snow can damage the panel. As the team continues, it should look into optimizing the LED display so that even if it receives only 2 hours of power, it will be able to display creative engaging content. This would require careful monitoring and the implementation of sensors to determine when the screen needs to be on.

This project has provided a good background on multiple facets of electrical engineering such as Power Systems Engineering, Microelectronics, RF, and Systems Engineering. The project is set on the path for a wonderful system that embodies all of the team's hard work.

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