Final Report

ECEN 4024 — FAA Power Tower

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1 Introduction

1.1 Project Objective

The FAA utilizes Relocatable Power Towers that operate independent of the power grids. The issue with the current system is the management system on these towers is proprietary so when the system fails, the FAA must pay the vendor to repair it. The goal of this project is to reduce costs by designing a replacement Relocatable Tower for the FAA using non-proprietary commercial off the shelf products including generators, chargers, inverters, and 48V bank of batteries. Our team will provide a more sustainable and efficient replacement power tower that will have the capability to provide up to 3000W continuously and be quickly installed. Using parts of the system that the FAA has in their current power tower, our team has looked into replacing the inverter, solar charge controllers, solar PDP's, automatic generator start, battery bank, and battery monitoring system.

1.2 Strategies

During the MMAC site visit with the FAA representatives, we discussed the different types of power systems that the FAA enjoys working with. The FAA showed us their ideal tower (See Tower 1 in Section 3.1) which consisted of products from Schneider Electric. This was the starting point for our research that was conducted. Our research of Schneider Electric and mobile power systems, led us to discover four different design plans. The four plans were whether the system was open-looped or closed-looped and whether the solar would remain the same or be expanded. With the research conducted, we presented these four different power tower designs, based on the open or closed loop system or whether to go with the solar expansion, to the FAA.

1.3 Team

1.3.1 Advisors

The advisor for the FAA Power Tower capstone project is Dr. Hamidreza Nazaripouya.

1.4 Team Structure

All team members are electrical engineering students. Most team members were involved in most aspects of the project. Some roles for the project were led by each team member as specified below.

1.4.1 John Doudican - Team Lead

John Doudican took the lead on the detailed design, communication with the FAA representatives, power and communication connection diagrams, initial parts list, part research, hazard analysis, risk management, market report for each component of the four systems, four final parts lists, smaller model wiring, and promotional video voice over. John also took on the role of leading meetings with Dr. Pouya and the FAA.

1.4.2 Jaymy Foister - Point of Contact

Jaymy Foister took the lead on the project objective, inspecting present systems, Schneider contact, NREL solar research, initial parts list, detailed budget summary, testing and experimentation plans, system recommendations, representations and results of the smaller model, future project plans, gantt chart, references, additional notes, report formatting, and the promotional video edits. Jaymy also took on the role of setting up meetings with Dr. Pouya and the FAA.

1.4.3 Othman Ahmad

Othman Ahmad took the lead on the constraints, codes and standards, and ethics.

1.5 Constraints and Considerations

1.5.1 Budget

The FAA did not give a specific budget for this project. The team members were told to design a system with a total price included and the FAA representatives would present the costs to someone to approve the purchase order.

1.5.2 Components

The current FAA tower, which was assigned to be fixed by the team, was equipped with two generators and four solar panels. However, the rest of the components picked for the purchase orders were a part of the design plan from the team's research. An initial parts list can be found in Section 4.4 and a final parts list can be found in Section 8.3.

1.5.3 Contractual Constraints

When it comes to designing the system, there are frequently the size constraints, which must be considered. One constraint is the system size of 6ft x 4ft x 5ft. However, it is significant to consider regulations connected to the consumer products, such as the relocatable power systems. These systems are typically regulated by the Commission under the Consumer Product Safety Act. Authority. Another critical consideration is the Clean Air Act (CAA). This is the U.S' main federal air quality law, intended to control and reduce air pollution nationwide. It is important to avoid back feeding electricity to residents, as it is prohibited. The 2005 Energy Policy Act emphasizes sustainable design to reduce the negative environmental impact. In 2015, the International Fire Code (IFC) mandated that mobile power systems obtain a permit and be installed according to the International Building Code. Also, it is important to note that the 2010 ADA Standards sets the minimum requirements for scoping and technical aspects of new designs.

1.5.4 Health and Safety

When conducting our site visit and building the smaller model, it is important to follow the safety measures to protect us and those around us. We made sure not to touch any live wires and made sure those wires were not exposed to anyone else as well. We were also cautious when double checking any wiring before powering a system on and when climbing on the trailer of the 80 foot power tower at the MMAC site. The team was very cautious to avoid harming ourselves or others while following all FCC guidelines to ensure safety.

2 Ethics

2.1 Engineering Code Standards

Engineers should always act honestly, responsibly, ethically, and legally in order to uphold the dignity, goodwill, and practicality of the profession. To assist guide engineers in their work, the National Society of Professional Engineers (NSPE) has formed the code of ethics outlining the standards and principles engineers need to follow while working. The code of ethics represents the engineering professionals from various disciplines. The first principle of NSPE code of ethics is to hold paramount the health, safety, and welfare of the public. This implies that the engineers should prioritize the well-being of the people over any concerns. They should only perform services in areas of their competence, making sure that their work is safe and accurate. Additionally, engineers are expected to issue public statements only in an objective and truthful manner, acting for each employer or client as faithful agents or trustees. This means that they must maintain confidentiality and avoid conflicts of interest. Finally, engineers should engage in professional development programs and uphold and enhance their professional abilities and knowledge. This ensures that they stay up-to-date with the latest technologies and techniques and can continue to provide high-quality services to their clients and the public.

2.1.1 Code of Ethics for IEEE

The IEEE, is association for professionals, represents electrical, electronics, and computer engineers. Accordingly, the IEEE has produced a code of ethics describing the guidelines and expectations that engineers should adhere to while practicing. Engineering professionals have a responsibility to work towards promoting equality, respect, and dignity for every person. This means that engineers must work to ensure that their work is inclusive and respectful towards people of all backgrounds and identities. It's important that engineers remain trustworthy, unbiased, and loyal to the public, companies, and customers at all times. It is crucial that engineers work to create an inclusive and diverse work environment that promotes equity and respects the dignity of all people. Engineers must avoid engaging in any behavior that may cause harm to people, their property, their reputation, or their employment through deceptive or malicious means. It's important for engineers to take accountability for their actions and work to uphold their ethical and professional standards. In addition, engineers must not discriminate against any individual or group based on race, ethnicity, gender, sexual orientation, age, religion, or country.

Engineering Standards	NSPE Code
Can Bus Protocol	ISO 11898
Ethernet Protocol	IEEE 802.3
Current Carrying Cable Sizing	NEC 310.15
Solar Sizing	IEEE 1562
MPPT Disconnect	UL 1699B
MPPT	IEC 62891
Battery	IEEE 1888
AC Breaker	IEEE C37
DC Breaker	IEC 60898
PDB	NEC 376.65
Inverter	IEEE 1547
Generator	ISO 8528
Smart Grid	IEC 61850
Battery Monitor	IEEE 1491
Automatic Generator	94-1991- IEEE

ISO 11898-2: specifies high-speed physical media connection of a controller area network, the serial communication protocol which supports the distributed actual-time control and multiplexing for application within the road vehicles. CAN BUS protocol is the code designed to permit a microcontroller and other gadgets to communicate with one another without any core host computer. The feature which establishes the CAN protocol unique amongst other communication code is a broadcast kind of bus. It is applied in numerous applications together with automation of building and factory, aerospace and aircraft as well in trucks, cars and buses. CAN bus is commonly applied as part of the distributed system of control, linking the vital systems which might be spread all over the facility. Generally the Human Machine Interface permits an operator to interact with this system.

IEEE 802.3 is the Ethernet standard and it describes the media and physical access control of the data connection layer for the wired Ethernet networks. The utmost popular and ancient LAN technology is the Ethernet Protocol, it is very frequently applied in the LAN environments where it is applied in almost all the networks like homes, offices, public places, companies, and learning institutions. Ethernet protocol has gained great popularity due to its maximum rates over lengthier distances applying the optical media. It uses a protocol described as Collision Detection or Carrier Sense Multiple Access. CD/CSMA is the contention protocol type which defines how to react when the collision is detected, or when various devices try to transmit the packages concurrently.

NEC 310.15 provides factors of adjustment when installing greater than three conductors for current-carrying. The neutral conductor which carries only an unbalanced current from conductors of similar circuit should not need to be counted when employing the provisions of NEC 310.15. Current Carrying Cable Sizing; Proper cable sizing is most significant for the consistency, reliability, and safety of a system. An oversized cable is a waste of funds and under-size could cause fire or short circuit. Also, engineers need to consider the type of cable type that is the single-core or multi-core, whatever is appropriate for the application. Selection of the cable size is grounded on three core factors: voltage regulation, the current carrying capacity and the short circuit rating. The maximum voltage amount that would a cable would transfer is reliant on the cable thickness, insulating cable medium and the types and size of the conductor.

Solar Sizing - IEEE 1562 is the sole industry standard for the sizing of the array of photovoltaic and batteries in the system where a solar array is the sole source of charging. This commended practice offers the procedure to size the stand-alone system of photovoltaic. Rendering to common or standard practice, sizing of the solar charge controller involves taking the PV short circuit current, and then multiplying by 1.3. Solar Inverter converts output of the DC from Solar Panels to the Ac power which is usable. Hence sizing a Solar Inverter is significant as the conversion occurs properly. That inverter is rated in the Watts. The solar inverter watt rating needs to be similar or greater than the systems of Solar PV watt rating. In such a case the appliances such as motors, the size of Inverter needs to be the minimum 3 times these appliances capacity. This is to manage the surge current throughout starting those appliances.

UL 1699B, was issued to integrate novel construction requirements to the Part 1: These requirements cover DC photovoltaic arc-fault circuit devices of protection projected for application in the solar PV systems of electrical. MPPT Disconnect: The MPPT disconnect separates the electric grid and solar inverter, permitting the alternate current power to be securely shut off if essential. An MPPT charge controller guarantees that loads get the maximum current to be applied by speedily charging a battery. The maximum point of power would be comprehended as the perfect voltage which the maximum amount of power is delivered to loads, with the losses at minimum. Also, this is commonly denoted as the peak voltage power. The solar panels with the built-in MPPT got the fixed 12V or 5V output and work just satisfactory without a battery.

MPPT: The MPPT or the maximum power point tracker is the converter of electronic DC to DC which optimizes a match amid PV panels, and the utility grid or battery bank. In order to incessantly gather maximum power from a PV array, they have to function at its MPPT notwithstanding of an inhomogeneous alteration in the environmental conditions. The two utmost common PV algorithms applications as they are simple to implement are Observe and Perturb Incremental Conductance. The MPPT controller would raise the voltage in phases to maintain it merely ahead of the voltage of the battery. Averagely, the

MPPT charge controllers provide a 30 percent performance boost, that is like having the free solar panel which is not really present.

IEEE 18880, application of the IEEE standard is completely voluntaryA battery is the device which stores the chemical energy and transforms it to electrical energy. Chemical reactions in the battery encompass the electrons flow from one material that is the electrode to another, via the external circuit. The electrons flow offers the electric current which could be applied to do the work. Batteries generate the DC current or electricity. This implies the flow of electrons in simply one direction to the positive form the negative. An oscilloscope will demonstrate in the DC as some flat line in the positive area. IEEE 18880, application of the IEEE standard is completely voluntary

IEEEC37, the standard for the low-voltage AC circuit power breakers rated greater than 1000 V are provided. The purpose of these standards is to institute basic needs for the ac high-voltage power circuit breaker schemes control so that the manufacturers and users can impact the engineering and manufacturing economies by decreasing the multiplicity of distinctive control schemes which are specified in the standards absence. This standard applies for the power-operated mechanism types and for both dc and ac control power. Only basic elements of control of a circuit breaker, as well as reclosing where needed, are included in the specific standard. The standard does exclude the circuits or devices for the special interlocking, protective relaying, among others, as these are reliant upon the precise application of the specific circuit breaker.

IEC 60898 are the requirements for the automatic reclosing devices for the circuit breakers for the household and other applications. The DC circuit breaker is applied to protect the electrical devices which function with the direct current and contains extra arc-extinguishing measures. The standards It offers the additional needs for two-and single-pole circuit-breakers that, additionally to the characteristics, which are suitable for operation with the direct current, and have DC voltage ratings not surpassing the 220 V for the single-pole and another 440 V for the two-pole circuit-breakers, a current not exceeding the rate of 125 A and the DC rated short-circuit capacity not surpassing the 10,000 A.

IEEE 1547 is the standard of the Institute of Electronics and Electrical Engineers which is supposed to offer the set of requirements and criteria for the interconnection of the distributed resources of the generation into a power grid. The standard for the Interconnecting the distributed resources with the electric power systems. IEEE 1547 has assisted engineers to modernize the electric power infrastructure systems by offering the foundation for integrating the clean technologies which employ renewable energy as well as other distributed generation and electric storage technologies. Power and electrical engineers and other interested experts looking into the future are dignified to integrate 1547 into their acquaintance base to assist transform the nation's aging.

PDB Panels are applied for the fault protection, electric Power Distribution, and monitoring of diverse electrical systems. NEC 376.65 is a series of standards designed for project management, particularly the civil engineering project from beginning to completion, with the purpose of preventing expensive disputes. In a PDB, the identifiers are applied at all structural hierarchy levels in the entry. Engineers are required to remember the intended function of the design when developing the structure.

The ISO 8528 is the standard which defines numerous classifications for rating, application, and performance of alternate current generating sets containing the engines that are reciprocating the internal combustion. The classifications put forth in ISO 8528 are inclined to assist align the generator set producer and client by offering the customers a common ground on which to liken a set of generator ratings from diverse manufacturers. It is significant to note that the set of generator manufacturers might establish ratings of products that go higher and beyond the prescribed standard requirements. ISO 8528-1 protocol defines the power standby as the maximum available power from a generator set to boost the variable electric profile load, which is determined by the aggregate yearly runtime that does not surpass the operation of 200 hours. Additionally, the normal load factor over the 24 hour time frame shall not surpass 70% of the ESP unless or else approved by the set of generator manufacturers.

IEC 61850 is the global standard defining the protocols of communication for the intelligent electronic devices at the substations of electricity generation. It is the part of the global electrotechnical Commission's Technical Committee reference of the electric power systems and smart grid architecture. The main target of the IEC 61850 standard is: to enhance the automation of the substation of electricity**.** Avoiding the proprietary protocols and being capable to integrate the equipment of diverse manufacturers. This idea is called interoperability. Applying the technologies which could reduce the cost in engineering time and wiring. Seeking for the improvements in the maintenance and commissioning tasks for the smart grid.

IEEE 1491 is the standard for selection and use of the battery monitoring equipment in the stationary applications-which involves the measurement and monitoring of the battery parameters. Operational parameters which might be observed by the equipment monitoring the battery applied in the stationary applications and the value relative value to observations. Even though the commercially available lists of the systems are not given, a means for establishing specifications for the desired parameters to be monitored is provided. The critical backup power settings have formed the need for dependable monitoring of the batteries that are stationary to determine the present health state of the systems. Additionally, other parts affecting the battery monitoring, including communication interface, intermittent charging, the operating and security environments, are also guided by these standards.

94-1991 - IEEE is the standard for the recommended Definitions of specific terms for the automatic generation Control on the systems of electric powers. The inconsistency of the terms and demands for standardization from the operating establishment of the interconnected systems of power resulted in the primary development of the definitions. The standards illustrate the continuing requirement to standardize popularly applied terminology unique to the automatic generator control. Additionally, term definitions are anticipated principally as the references, not as the tutorial substitutes for training in the field of control. The definitions offer the simplified, unambiguous implications for engineers having the basic comprehension of the AGC technology.

2.2 Social Context

The use of solar PV systems and the accompanying inverters could assist to increase access to the electricity energy and promote sustainability, particularly in areas which are remote. Nevertheless, as with technology, there would be concerns around accessibility, cost and safety. It is important for us to consider the possible drawbacks and benefits of inverters for the Relocatable Power Towers when evaluating their application.

2.3 Professional Responsibility

Inverters applied in the solar energy systems, would have the installation guidelines and safety regulations which must be adhered to ensure appropriate functioning and minimize the accidents risks or equipment damage. Therefore, it is important when installing and using the inverters for the Relocatable Power Towers we follow guidelines set forth by regulatory bodies and manufacturers to ensure the efficient and safe operation of the tower.

2.4 Environmental Ethics

It is significant to consider the environmental influence of the inverter technologies, during production and after they are no longer needed. Inverters contain a variety of metals and electronic and metal components which could be harmful to the environment if not appropriately disposed of. Additionally, the inverters production needs significant resources and energy that can contribute to degradation of the environment. As such, it is significant for us to consider the environmental impact of the system’s inverters and take steps to decrease the carbon footprint. This may include properly disposing of our damaged or old inverters, and repurposing or recycling materials whenever possible. By practicing best environmental ethics, we could help to minimize the adverse impact that inverter technologies have on the planet.

2.5 Global Ethics

One main ethical consideration for the inverter technologies is adherence to the international regulations and standards for performance and safety. Such standards assist ensure that the inverters are reliable and safe, and meet efficiency and quality standards for reducing impact on the environment. Another global ethical consideration for the solar inverters is their impact on the communities and environment. Our project team plans to have the inverters designed and manufactured with consideration of sustainability, including the eco-friendly processes and materials used, and the commitment to reducing pollution and waste. Our inverters for the Relocatable Power Towers are installed and operated with sensitivity to local community and environment, minimizing any possible negative impacts on biodiversity, ecosystems, and the local cultures.

2.6 Consumer Ethics

There are concerns around the disposal of inverters and other components in the Relocatable Power Towers at the life cycle end. It is significant for us to dispose of such components sensibly, like through returning them or recycling programs to the producer for proper disposal

2.7 Misuse

Regarding solar energy’s inverters, they can be misused if not used or installed properly. Improper use or installation of the inverters could result to electrical hazards, such as electric fires and shocks. Furthermore, if the inverters are not well-maintained, they could fail to convert correctly DC to AC power correctly, resulting in inefficiencies and possible damage to the electrical devices. It is significant for use to employ the qualified experts for installation of the inverters in the Relocatable Power Towers and repeatedly maintain the systems to prevent such types of misuse.

3 Inspecting Present Systems

3.1 FAA Current Systems

During the MMAC FAA site visit, the team inspected two power towers. The first tower, as displayed in Figure 3.1a, was an example power system that the FAA preferred to work with. This tower operated around the Schneider xw5548 Inverter, which was connected to a monitoring system. With the Connect Box monitoring system, the FAA could access load and grid power graphs over a 24-hour period. The tower had four sets of four panels, each rated at 24 volts. The battery bank consisted of eight 24-volt batteries that supplied 3.8 kW of power. The battery monitor system was supplied with the xw5584 inverter. Additionally, the system contained a 240-volt generator for when the system went off-grid, and solar power was low.

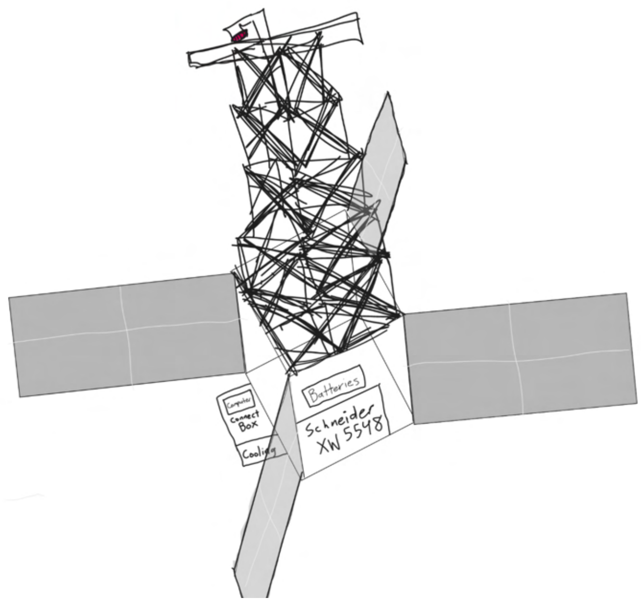

Figure 3.1a: Schneider XW5548 Based FAA Tower 1

The second tower displayed in Figure 3.1b is the mobile power tower that this team is working to redesign. The first issue the team noticed with the design is that if the FAA wanted to use their solar panels, they would have to connect the panels directly to the battery bank. The battery bank consisted of eight 24-volt batteries, with two sets of series connected in parallel. One issue with the battery bank was that if there was an issue with one of the batteries, the FAA would have to carefully disconnect that battery, which required going over all the other batteries in the steel box. The last major issue that the FAA had with this power tower was that the only system interaction they had with the system was through a row of LED lights to show that the system was operating properly. The representatives from the FAA informed our team that we had creative freedom to redesign the second tower, and they encouraged us to apply the insights gained from inspecting the first tower.

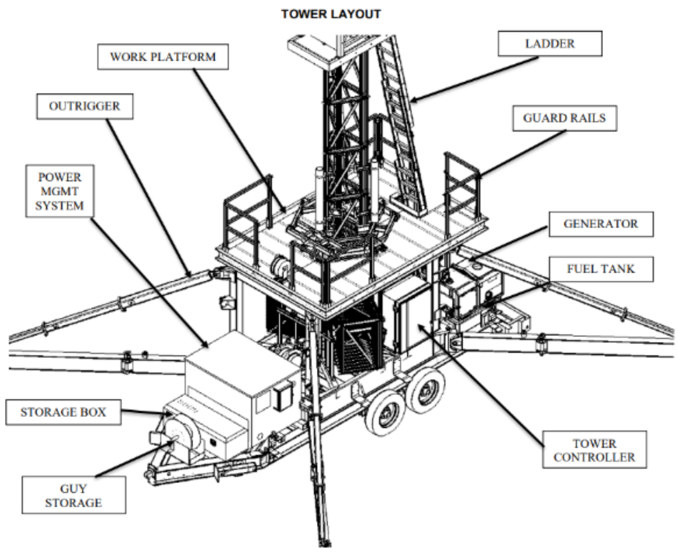

Figure 3.1b: PTX-100-80 Tower Solutions

3.2 Dr. Pouya's Lab

At Dr. Pouya's Lab, the team viewed the Solis RHI-HV Series Hybrid Inverter as shown in Figure 3.2a. During the visit, the team was given a visual of the DC inputs and AC outputs for an inverter. Based on the Solis Hybrid Inverter, we created a set of questions for the MMAC site visit which included information about the FAA needs. These questions covered the voltage level and number of rows/columns of the solar panels. We also wanted to ask about the battery bank and how much voltage and power the batteries are in the current system. There was also the question of what type of auto-transfer was used and the communication protocol used. Dr. Pouya also covered some of the NSPE code of ethics.

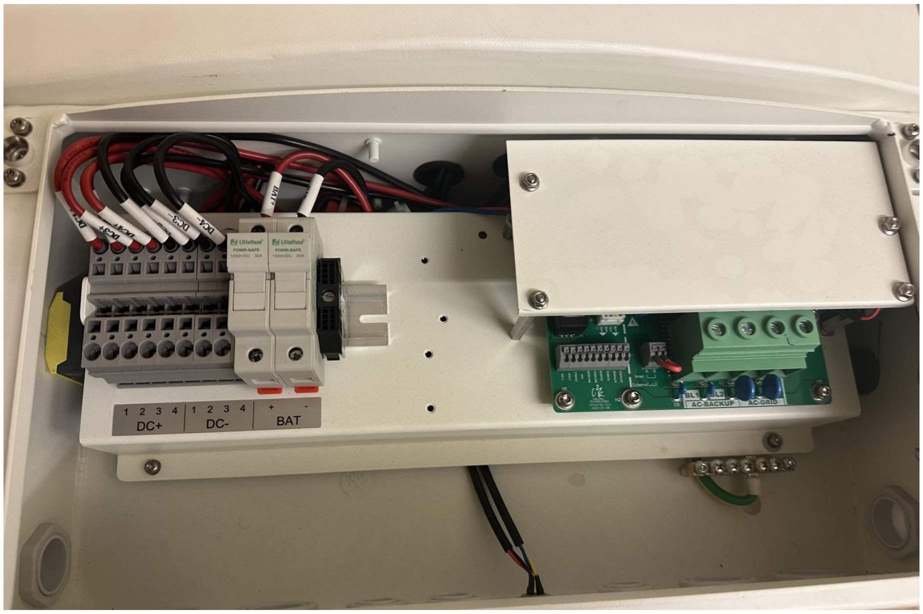

Figure 3.2a: Solis RHI-HV Series Hybrid Inverter

4 Design Details

Design of the system started from picking out an inverter to replace their current inverter. The inverter the FAA showed us on our site visit was the XW 5580. This inverter has been previously discontinued, which led us to finding the XW Pro 6848. This inverter suited our needs: 48V input for the battery bank, solar compatibility, grid forming, and can operate with generators. The generators chosen were the Kubota GL7000 LOWBOY II, due to their ability to operate at 240V and that they are the same units currently used in their system. To properly allow the generators to function, we chose the Conext Automatic Generator Start. This AGS communicates with the generators through the inverter. We will need to obtain two due to the generator redundancy in their system. The two AGSs will communicate with one another via the communication protocol within Schneider's system. The distribution panel we chose was the XW Mini PDP. We chose this one due to the ease of integration with the inverter, as well as the breakers that come with it. The PDP comes with the three 60A AC breakers: one for grid input, one for generator input, and one for load output; and also comes with a 250A main DC breaker for the battery and MPPT. We will also be purchasing an extra 100A breaker for the connection directly with the MPPT within the system between it and the DC bus. The controller we went with is the InsightHome. It is a controller that serves as a hub for the communication between the devices. It communicates via the Xanbus with the MPPT, Battery, Inverter, and the two AGSs. The user can utilize the InsightHome with an application available to download on the google play store or the App Store. The battery we chose was the Discover 42-48-3000. This battery is rated for 48V, 3kWh, and two will be utilized in parallel with one another to properly simulate and integrate with their system. They utilize the Xanbus to communicate with the InsightHome. A battery monitoring system will be utilized if an open-loop battery is chosen. This will communicate via the Xanbus to properly monitor the state of the batteries.

4.1 Power Diagram

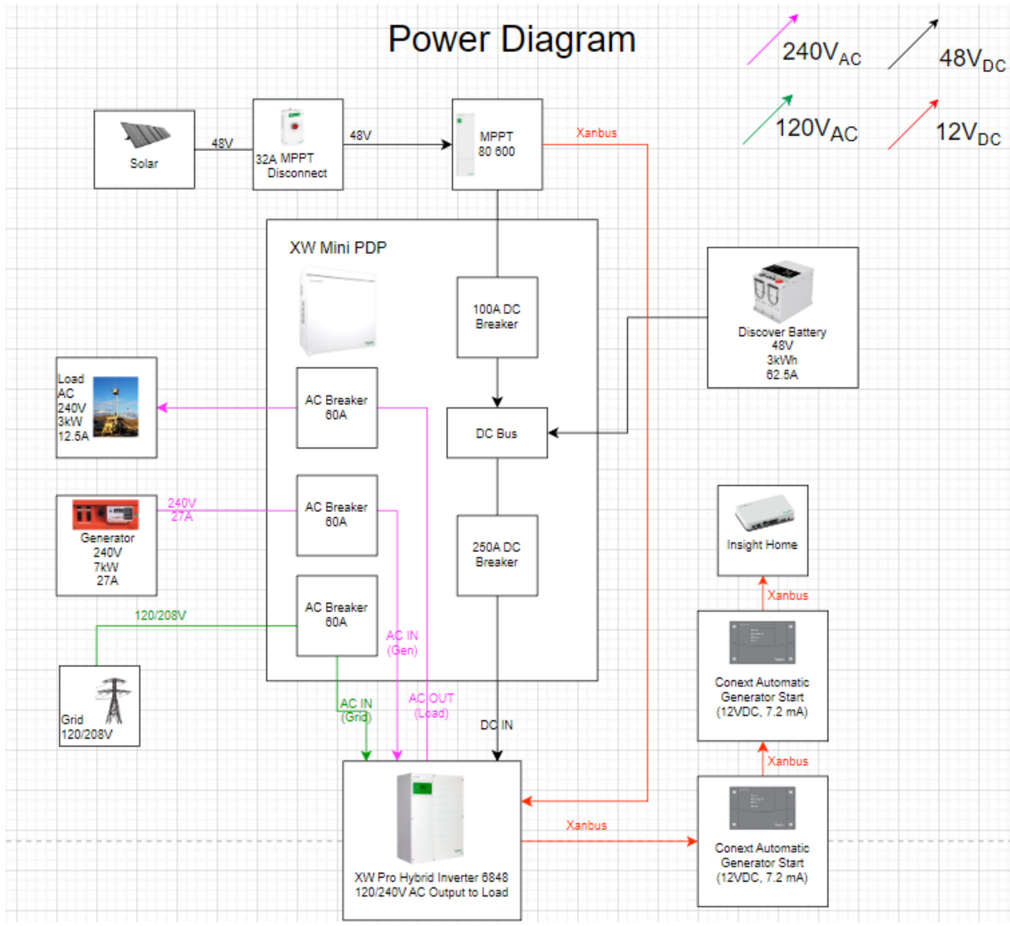

Figure 4.1a: Power Diagram for the system with No Solar Upgrade

Figure 4.1a shows the power diagram for our system without the solar upgrade. The solar voltage supplies 96 volts through the 60A DC breaker to the MPPT 60 150. The MPPT then connects through an 80A DC breaker to the DC Bus. The battery connects to the DC bus with 48 volts. They both then connect through the 250A DC Breaker to the Inverter. The Generator generates 7kW each and can operate on 240V. It connects through the Mini PDP and through one of the 60A breakers then to the inverter. The grid connection runs on 120V through one of the other 60A breakers to the inverter. The Xanbus communication powers the two AGSs at 12 volts and terminates in the InsightHome. The load runs on 240V and is single phase.

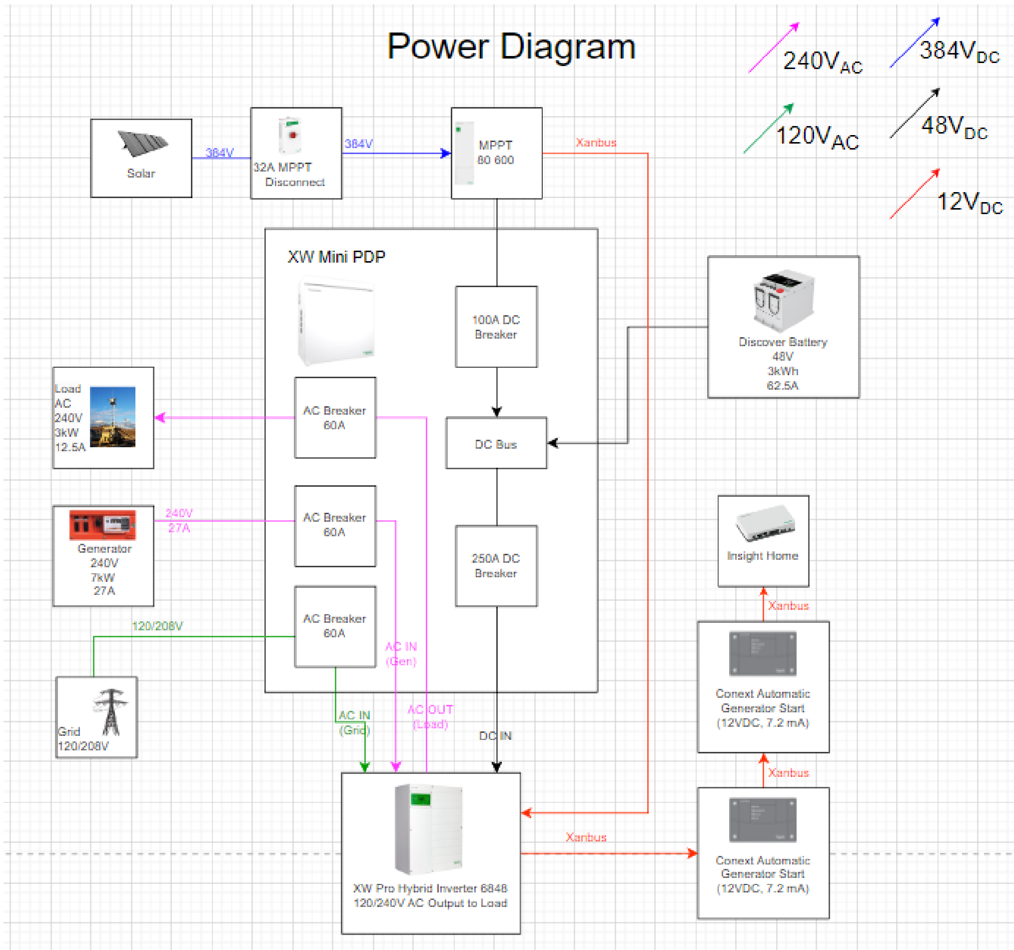

Figure 4.1b: Power Diagram for the system with Solar Upgrade

Figure 4.1b shows the power diagram for our system with the solar upgrade. The differences with the solar upgrade include starts with solar voltage supplies 384 volts through the MPPT Disconnect to the MPPT 80 600. The MPPT then connects through a 100A DC breaker to the DC Bus. There also needs to be only one battery, rather than two, due to the lower power demand of the system.

4.2 Communication Diagrams

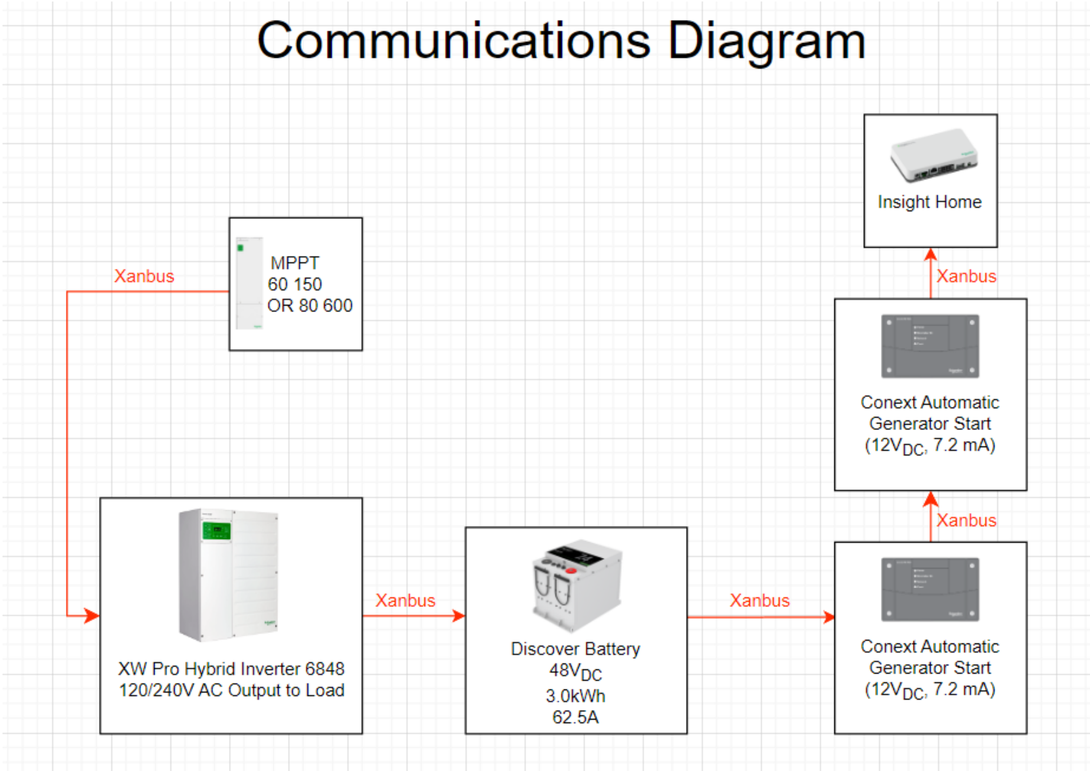

Figure 4.2a: Communications Diagram for the system with a closed-loop battery

As shown in Figure 4.2a, the communication within a closed-loop battery system is all conducted with the Xanbus protocol. The Xanbus protocol is a communication system that is daisy-chained together in series with one another. Each item communicates on the Xanbus protocol in the system. Each piece of information that is transmitted travels along the Xanbus cable and is terminated with a terminator in the last piece of equipment in the network.

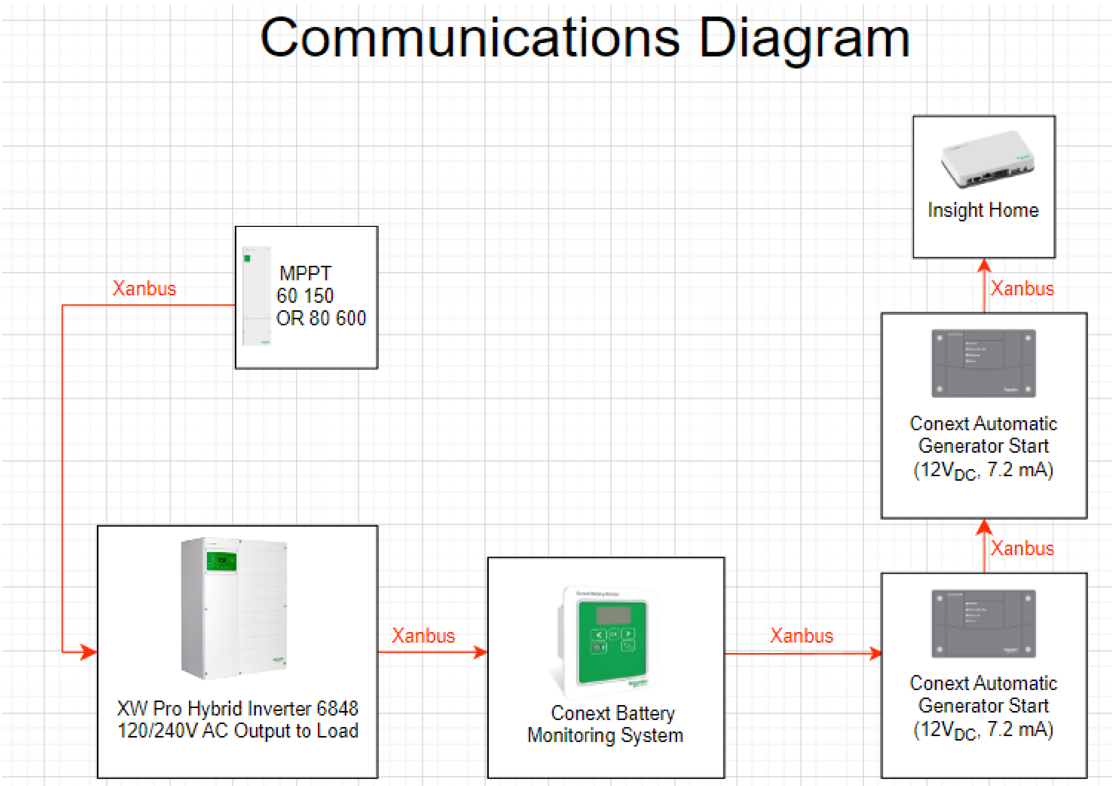

Figure 4.2b: Communications Diagram for the system with an open-loop battery

Figure 4.2b shows the communications diagram for the system with an open-loop battery, as opposed to a closed-loop battery. Comparing this to the closed-loop battery, each piece of equipment utilizes the Xanbus, but has the Battery Monitor in it instead. The open-loop battery has its own Battery Management System, so interfacing it with the InsightHome is not possible. The Battery Monitor is then required to properly detect the necessary information for the state of the batteries.

4.3 NREL Solar Research

NREL solar research consisted of finding the solar levels every day of the year for the MMAC address and calculating what battery level is needed based on these solar numbers. We used the PV Watt calculator on the National Renewable Energy Laboratory (NREL) website to compare solar power for four different DC system sizes. These sizes were 3.5 kW, 3.8 kW, 4.8 kW, and 6 kW. After communicating with the FAA, their current system uses 3.8 kW so this solar research was a way to verify that they had the best kW level for the system we are fixing. When looking into this research, it is important to keep in mind that the MMAC system has a maximum 3 kW nominal maximum load that the towers can handle. Out of the maximum 3 kW load level, the FAA uses on average 2 kW for this system.

The first set of data includes the solar levels at the MMAC site when the DC system size is set to 3.5 kW. Figure 4.3a shows the average hourly solar levels for this system throughout the year based on previous multiple years. Figures 4.3a-h show the hourly solar levels and kWh needed for the load levels based on solar levels.

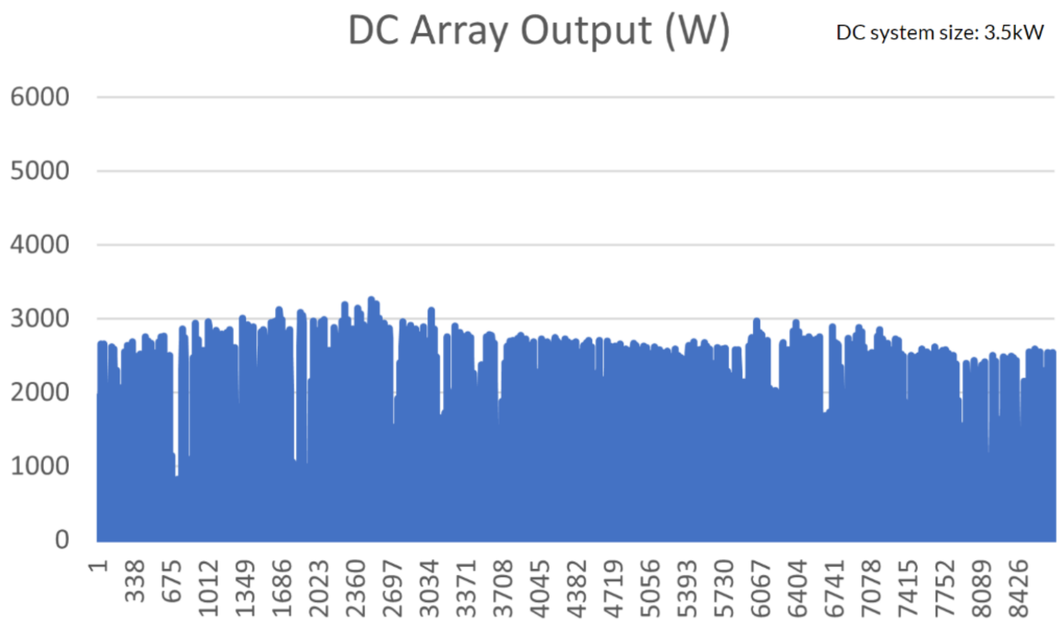

Figure 4.3a: Hourly Solar Levels for 3.5kW DC System

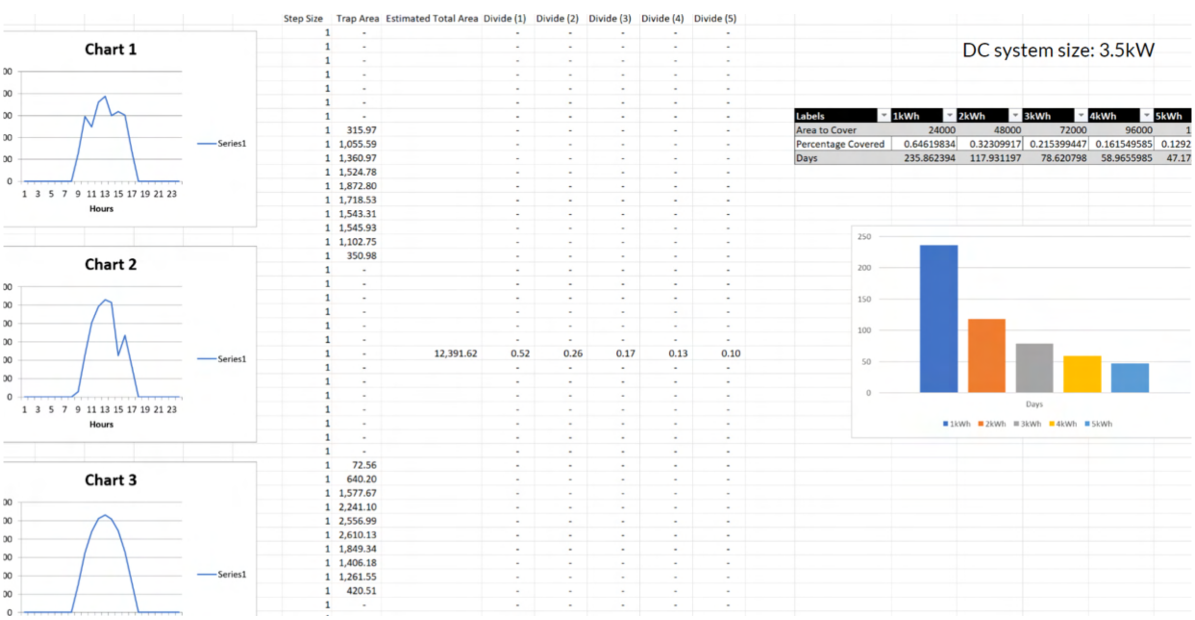

Figure 4.3b: kWh needed for the load of a 3.5kW DC System based on Solar Levels

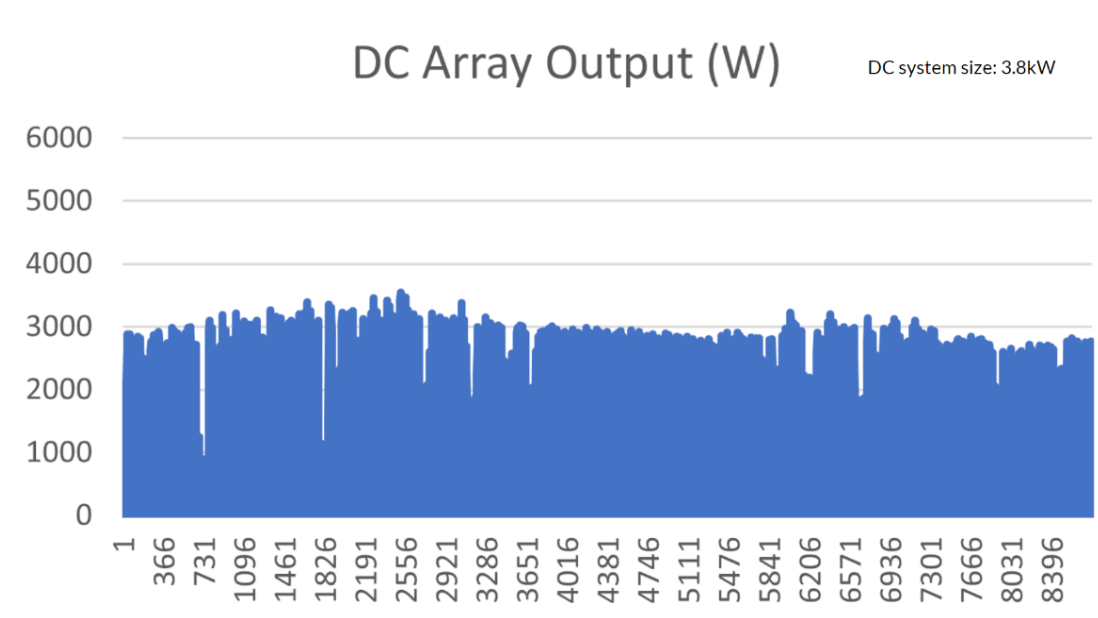

Figure 4.3c: Hourly Solar Levels for 3.8kW DC System

Labels	1kWh	2kWh	3kWh	4kWh	5kWh
Area to Cover	24000	48000	72000	96000	120000
Percentage Covered	0.701587	0.350793	0.233862	0.175397	0.140317
Days	256.0792	128.0396	85.35972	64.01979	51.21583

DC system size: 3.8kW

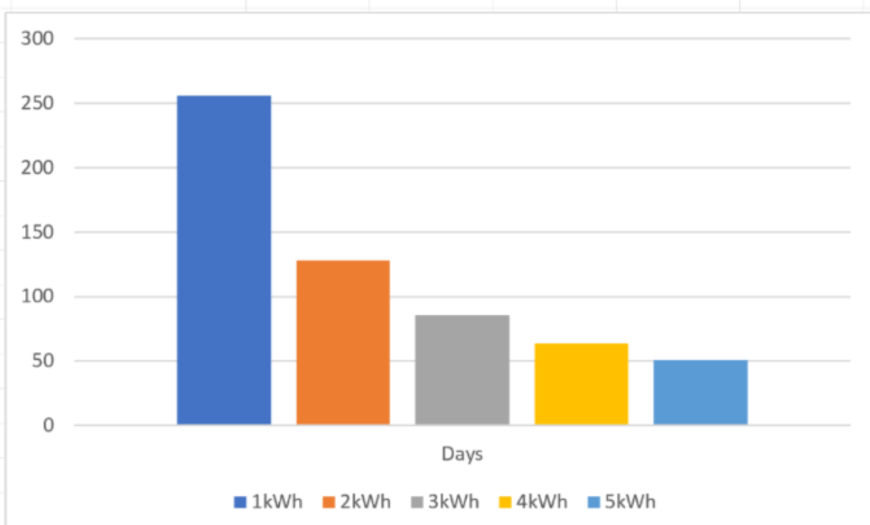

Figure 4.3d: kWh needed for the load of a 3.8kW DC System based on Solar Levels

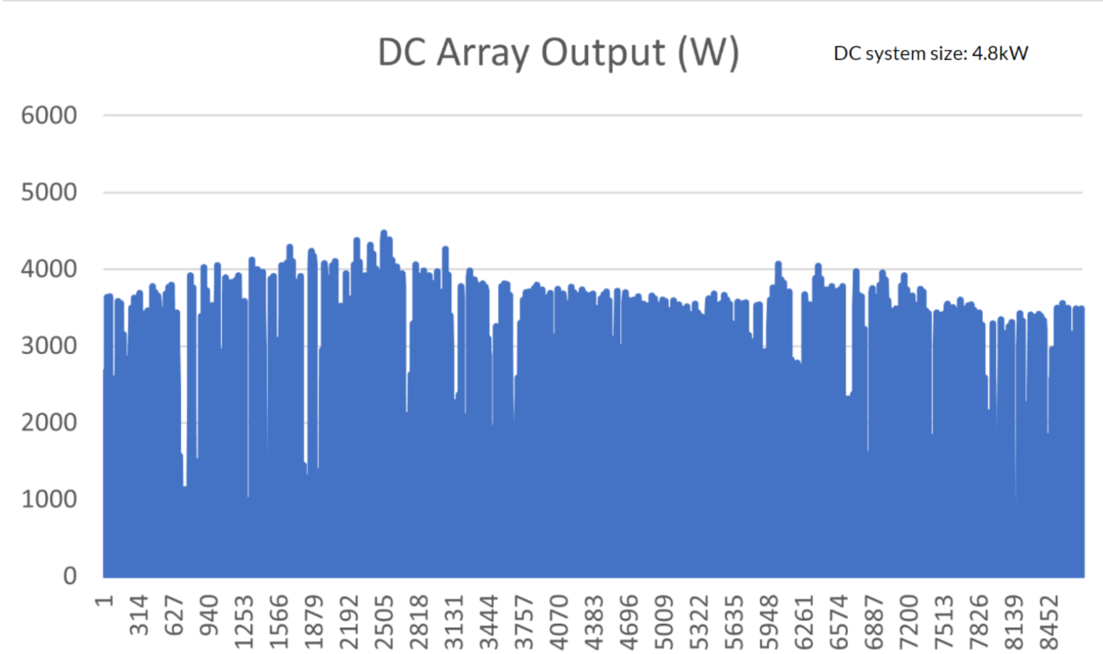

Figure 4.3e: Hourly Solar Levels for 4.8kW DC System

Labels	1kWh	2kWh	3kWh	4kWh	5kWh
Area to Cover	24000	48000	72000	96000	120000
Percentage Covered	0.886215	0.443107	0.295405	0.221554	0.177243
Days	323.4684	161.7342	107.8228	80.86711	64.69369

DC system size: 4.8kW

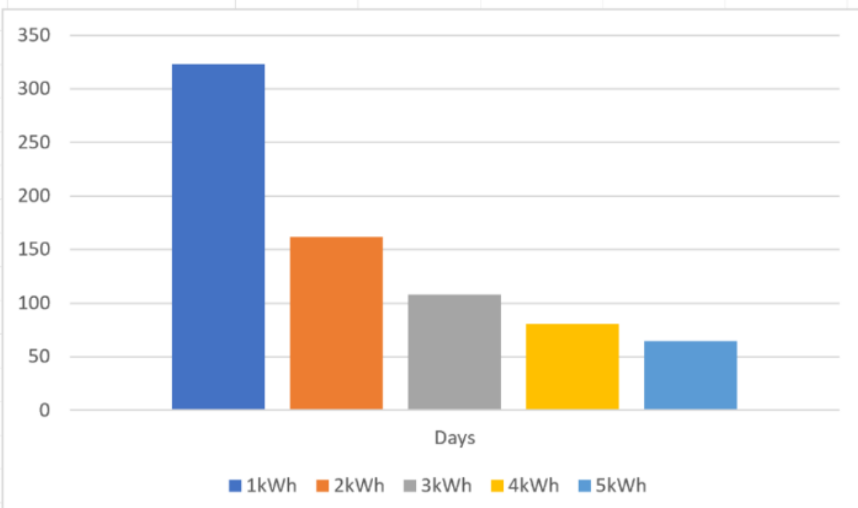

Figure 4.3f: kWh needed for the load of a 4.8kW DC System based on Solar Levels

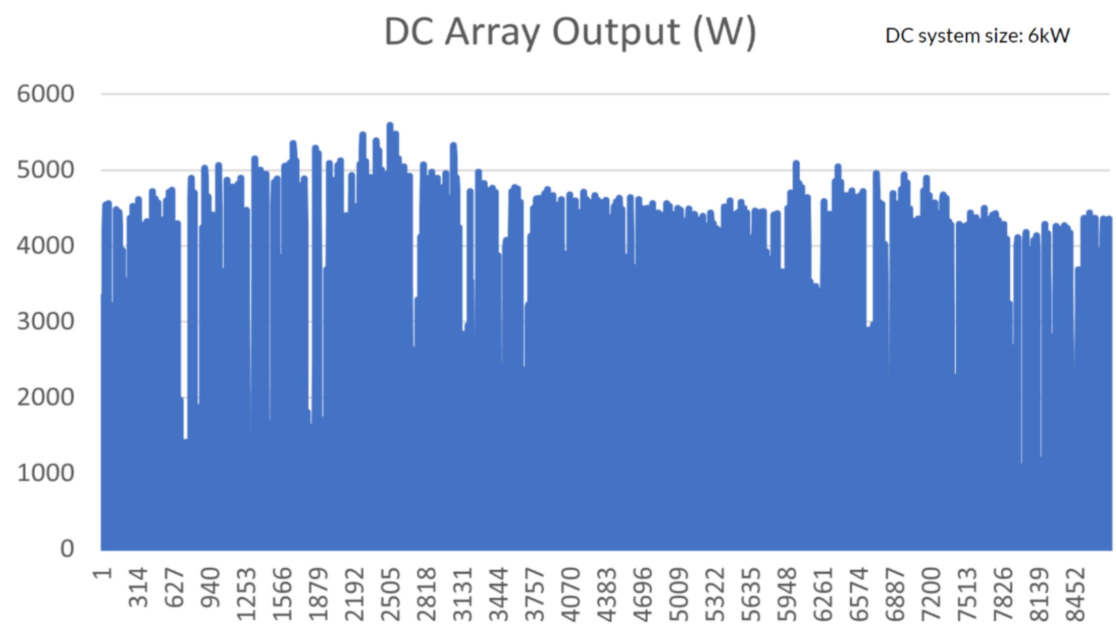

Figure 4.3g: Hourly Solar Levels for 6kW DC System

DC system size: 6kW

Labels	1kWh	2kWh	3kWh	4kWh	5kWh
Area to Cover	24000	48000	72000	96000	120000
Percentage Covered	1.107472	0.553736	0.369157	0.276868	0.221494
Days	404.2272	202.1136	134.7424	101.0568	80.84544

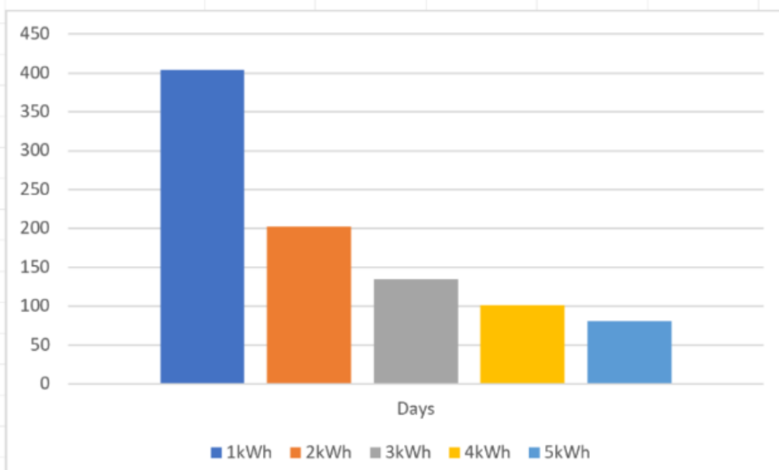

Figure 4.3h: kWh needed for the load of a 6kW DC System based on Solar Levels

The next set of graphs display a further analysis from the data provided above. Figure 4.3i shows the number of hours the solar levels are able to provide positive wattage at each DC system size. This graph simplifies and sums up what is shown in the solar figures above. Figure 4.3j shows the number of hours the solar is charging and discharging throughout the year for each DC system size. These graphs are important when determining the ideal kW level for the system's battery bank. With the FAA's current 3.8kWh system, the solar is able to function with the amount of solar present; however, the design team recommends the FAA expands their solar to 6kWh in order to store energy for the system to use when the solar is low. Figure 4.3k shows the number of days for different levels of net energy in kWh for the amount of solar. These graphs are important when determining the ideal kWh level for the system's battery size.

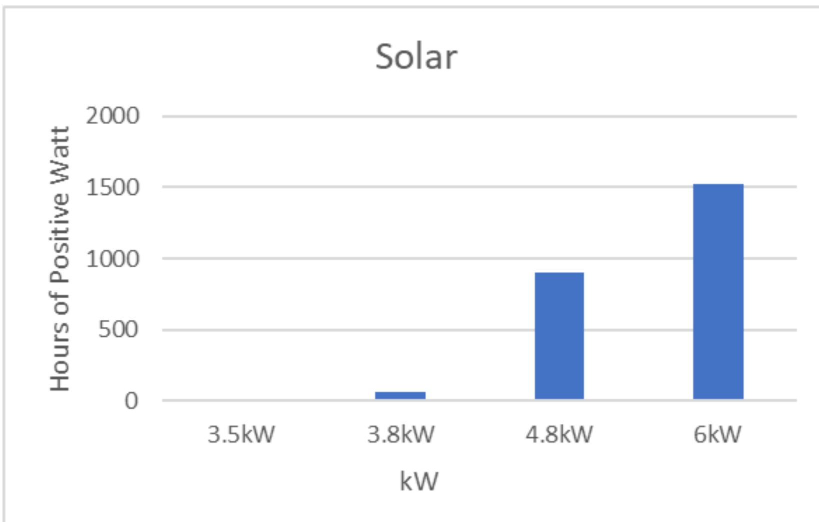

Figure 4.3i: Number of Hours the Solar is able to provide Positive Watts

Figure 4.3j: Number of Hours the Solar is Charging and Discharging

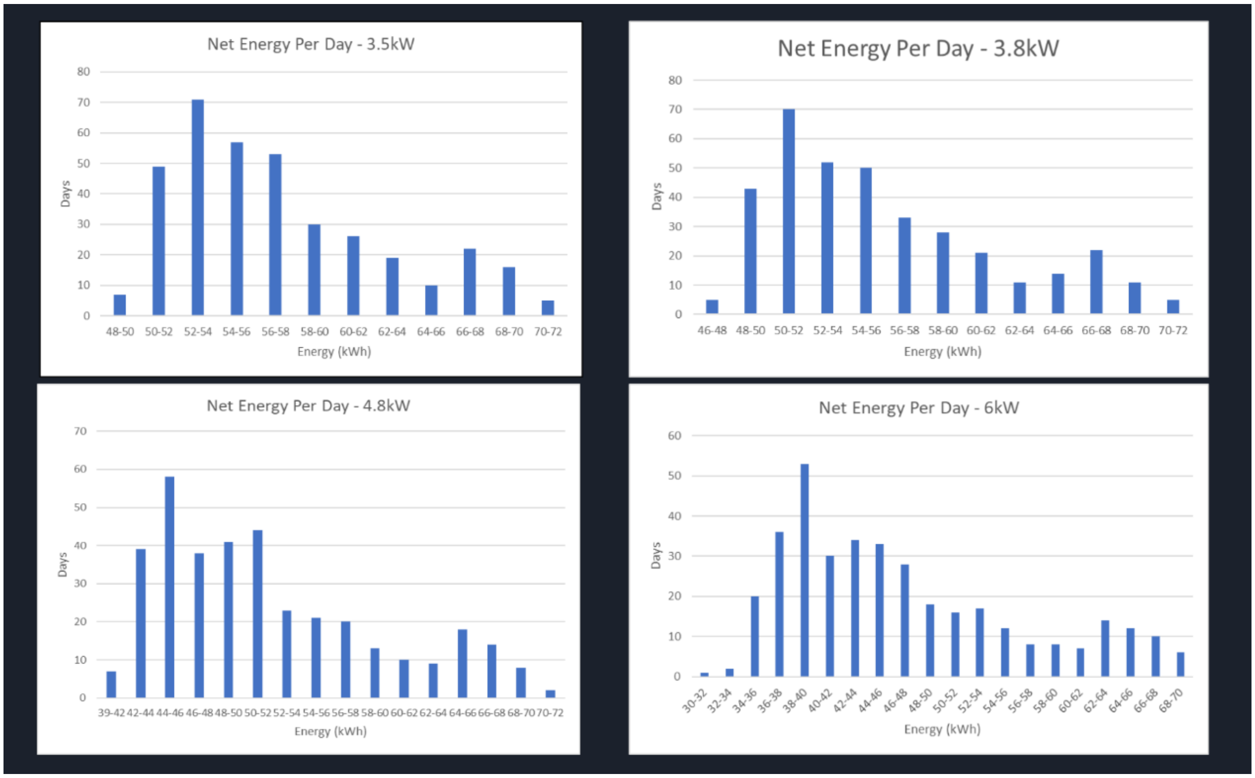

Figure 4.3k: Number of Days the Solar is at different levels of Net Energy in kWh

4.4 Initial Parts List

Part Number	Description	Quantity Used
XW-Pro 6848	Inverter.	1
MPPT 80 600 (865-1032)	Solar Maximum Power Point Tracker	1
MPPT Disconnect	Disconnect for Solar, helps with arc fault detection.	1
XW Mini PDP	Serves as a power distribution panel for inverters. Comes with 3 AC Breakers and 1 DC Breaker.	1
Conext Automatic Generator Start	Automatically Starts the Generators when necessary.	2
Discover Batteries	48V, 3kWh, 62.5A batteries	2

(42-48-3000)	serving as the primary power source when off-grid. BMS Utilizes Xanbus.	
Insight Home	Serves as the controller for the system.	1
865-DCBRK-100	100 Amp Breaker for the MPPT.	1
Kubota GL7000 LOWBOY II	Generators for the System. Runs when solar and batteries can’t supply the system.	2

5 Market Report

The FAA has requested we provide a market report on the other parts we considered.

5.1 Inverters

We considered two different inverters before picking the XW Pro 6848. The other inverter we considered was the inverter the FAA first demonstrated on the site visit. This inverter seemed to fit all of our needs but was a grid follower, rather than grid-forming. This means it would need to draw its power from the grid, rather than operating on its own grid. Due to our system's requirement for mobility, we needed to select a grid-forming inverter. The XW Pro follows these guidelines and will serve as the inverter for our system. This one will cost from $3,000-$5,000.

5.2 Solar Charge Controllers

Two solar charge controllers were considered when selecting the proper MPPT for the system. The MPPTs serve to deliver the maximum available current to charge the batteries and regulate the voltage in the system. The MPPT we chose was the MPPT 80 600. This unit is rated for up to 600V and communicates in the system via the Xanbus. We chose this one due to the ability to integrate with the inverter, and with the maximum output power being 4.8kW and the maximum charge current of 80A . A similar MPPT we considered was the MPPT 100 600. This one essentially serves the same purpose as the MPPT 80 600, but has a higher rating when it comes to the maximum power output of 6kW, and the maximum output charge current being 100A. We chose the MPPT 80 600 over the MPPT 100 600 due to the 80 being more suited to systems with one inverter, and the higher ratings for our system not being necessary. We are also purchasing the MPPT disconnect to properly protect the MPPT and the connection to the solar. The MPPT 80 600 will cost $1321.66, and the disconnect will cost $847.62.

5.3 Power Distribution Panel

Two power distribution panels were considered when selecting the proper part for the system. The one we chose was the XW Mini PDP. This one was chosen due to the system we are designing involving only one inverter. The Mini PDP is more suited for single-inverter systems, rather than other PDP's from Schneider that are better suited for multiple-inverter systems. The Mini PDP comes with three 60 A AC breakers: one for the grid input, one for generator input, and one for the load output. The PDP also comes with a 250A main DC breaker for the battery connection. We also are purchasing a 100A DC breaker to add onto the PDP to add protection for the MPPT. The MPPT connects to the DC bus that also connects to the battery through this breaker to properly protect it. The other PDP considered was the XW PDP. Ordering this with the breakers has all the same breakers as the Mini PDP, but the panel has a larger form factor and is better suited for a multiple-inverter system. The Mini PDI will cost $770.96 and the 125A breaker will cost around $60.

5.4 Automatic Generator Start

The automatic generator start we will utilize with the inverter to properly integrate generators into the system. The AGS will automatically start and stop the generator when it is necessary in the changing of the power demands. For our applications, we will need two of the AGSs due to the redundancy of generators in the current system. The two AGSs will communicate in the Xanbus network to properly utilize the generators. The two combined will cost $449.98.

5.5 Batteries

5.5.1 Closed-Loop Batteries Considered

The first closed-loop battery considered was the Helios from Discover Battery. This battery met the required voltage ratings, but only had a 1.5kWh capacity, which is not enough storage for our applications. The second closed-loop battery considered was the 42-48-6650 from Discover. This also meets the required voltage ratings, but a capacity of 7kWh is too high for our applications. The third one considered was the 42-48-3000 from Discover. This battery meets the voltage requirements of 48V, and a capacity of 3kWh is suitable for our applications. This battery costs about $2,650 and two will need to be purchased. This is the battery-of-choice for the closed-loop battery system.

5.5.2 Open-Loop Batteries Considered

The first open-loop battery considered was the eFlex5.4. This battery met our required voltage ratings, but the capacity of 5.4 kWh is more than is necessary for our application. The second open-loop battery considered was the Phi 3.8. The SimpliPhi batteries work well in Schneider systems, but they are open loop, so the Battery Management is internal, not allowing the InsightHome to precisely monitor the State of Charge of the batteries with the Conext Battery Monitor. This battery is the battery-of-choice in the selection of an open-loop battery due to the 3.8kWh capacity. This battery costs $2,495 and two will need to be purchased.

5.6 Insight

The controller within the system will be the InsightHome. This is a controller that is the start of the Xanbus network and can be accessed with an application downloaded from the Google Play store, or the App Store. The InsightHome was chosen due to the number of devices utilizing the Xanbus communication of 6 or less. If there were more devices utilizing the Xanbus network, the InsightFacility would be necessary to use. The InsightHome will cost $444.18.

5.7 Generator

The generator selected was the Kubota GL7000 LOWBOY II. This generator is the same generator in the FAA's current system. Their system has two generators in it, so ordering two would be necessary to properly simulate it.

6 Detailed Budget Summary

PURCHASE ORDER (Open Loop Simpliphi)

Oklahoma State University
Stillwater, OK

Date: 3/7/23

ITEM #	DESCRIPTION	QTY	UNIT PRICE	TOTAL
865-6848-21	Schneider Electric XW Pro 6848	1	$3,000-$5,000	$3,000-$5,000
865-1032	MPPT 80 600	1	$1,340.00	$1,340.00
865-1036	MPPT Disconnect RS	1	$847.62	$847.62
865-1013-01	XW Mini PDP	1	$770.96	$770.96
865-1060-01	Conext AGS	2	$224.99	$449.98
865-1080-01	Conext Battery Monitoring	1	$534.71	$534.71
865-0330	Insight Home	1	$444.18	$444.18
865-DCBRK-100	100A DC Breaker	1	$60.00	$60.00
N/A	Phi 3.8 (SimpliPhi Power)	2	$2,495.00	$4,990.00
GL7000	Kubota GL7000 LOWBOY II	2	$3,386.50	$6,773.00
			SUBTOTAL	**$18520.45 - $20620.45**

Figure 6a: Purchase Order for the Open Loop System

PURCHASE ORDER (Closed Loop Discover)

Oklahoma State University
Stillwater, OK

Date: 3/7/23

ITEM #	DESCRIPTION	QTY	UNIT PRICE	TOTAL
865-6848-21	Schneider Electric XW Pro 6848	1	$3,000-$5,000	$3,000-$5,000
865-1032	MPPT 80 600	1	$1,340.00	$1,340.00
865-1036	MPPT Disconnect RS	1	$847.62	$847.62
865-1013-01	XW Mini PDP	1	$770.96	$770.96
865-1060-01	Conext AGS	2	$224.99	$449.98
865-0330	Insight Home	1	$444.18	$444.18
865-DCBRK-100	100A DC Breaker	1	$60.00	$60.00
44-48-3000	AES LiFePO4 Solar Stationary Battery	2	$2,650.00	$5,300.00
GL7000	Kubota GL7000 LOWBOY II	2	$3,386.50	$6,773.00
			SUBTOTAL	**$19635.74 - $21735.74**

Figure 6b: Purchase Order for the Closed Loop System

7 Testing and Experimentation Plan

7.1 Individual Part Testing Plan

7.1.1 XW Pro 6848 Inverter

The steps to perform an inverting test for the XW Pro 6848 Inverter were provided by Schneider Electric. First, we will turn on the DC breaker switch to provide a DC source to the inverter/charger. Second, we will set the inverter/charger to “Operating” if “STB " is shown on the information display panel. Then, we will enable “invert” on the system panel. Next, we will confirm the “Inverting” LED on the information display panel is ON. Then, we will check that the output voltage regulation is 110VAC~ 125VAC for the 120VAC line, and 221VAC~260VAC for the 240VAC line. Lastly, we will disable the inverter and remove the load.

7.1.2 Battery Bank

The steps to test the system’s battery bank is similar to testing any battery bank. First, we will use a multimeter to check the voltage of the battery bank. The voltage should be around 51.2V when fully charged. Second, we will use a battery monitor or management system to check the state of charge (SoC) of the battery bank. The SoC should be around 100% when fully charged. Third, we will use a battery analyzer to measure the internal resistance of the battery bank. The internal resistance should be relatively low, indicating that the battery is in good condition. Lastly, we will connect a load to the battery bank and monitor the voltage and current while the load is connected. The voltage should remain stable, and the current should be consistent with the specifications of the battery bank.

7.1.3 Generator

To properly test a generator, there are several steps to complete. First, check the oil and fuel levels to ensure that the generator has enough oil and fuel to operate effectively. Once you've confirmed the oil and fuel levels are sufficient, turn on the generator and let it warm up for a few minutes to prepare it for testing. Using a multimeter, measure the voltage output of the generator, making sure that the voltage falls within the range specified in the generator's manual. To test under load, connect a load to the generator, such as a power tool or appliance, and measure the voltage output again. The voltage should remain stable, and the frequency should be consistent with the specifications in the generator's manual. Check the circuit breakers on the generator to ensure that they are functioning correctly and not tripping. Finally, listen for any unusual sounds or vibrations that could indicate a problem with the generator's engine or other components. By following these steps, you can ensure that your generator is ready for use in a proper and safe manner.

7.2 Overall System Testing Plan

To properly test a mobile power system, there are several important steps to follow. First, conduct a thorough visual inspection of the system and its components to ensure that all connections are secure, wiring is properly sized and protected, and components are in good condition. Next, test the system's electrical output using a multimeter or other electrical testing equipment to ensure that it is producing the correct voltage and amperage. Then, perform a load test on the system by gradually increasing the load to ensure it can handle the intended load. Additionally, check the system's charging and discharging capability, such as its charge and discharge rate, and verify that it can handle the intended cycles. Once all these checks are completed, it is important to test the system in real-world conditions, using intended loads and usage scenarios. By following these steps, you can ensure that the mobile power system is reliable, safe, and capable of meeting your needs.

For all these tests, it is important to have a safety plan in place in case of an emergency, such as fire or electrical malfunctions. Have a fire extinguisher, switch off mechanism and an emergency plan in case of any hazards.

8 Improvements

8.1 System Recommendations

After our system and solar research, we were able to highly suggest the FAA consider the closed-loop system with the solar expansion. When presenting the design choices during the CDR, the FAA agreed with our team on the preference to go with the closed-loop system to maintain better control of the measuring elements and fewer unknown maintenance issues. The NREL solar research shows that the FAA is able to update the mobile power tower without expanding the solar; however, we recommend expanding solar so more energy is created and stored in the Discover batteries for the system to use during lower solar level days. With the FAA's current 3.8kWh system, the solar is able to function with the amount of solar present; however, the design team recommends the FAA expands their solar to 6kWh to store more energy. This can be seen in Figures 4.3j and 4.3k. When expanding solar, the FAA has a couple options. They are able to add 16 more panels of the same solar rating to double their solar size. Another option would be if they replace the 16 solar panels they have now with a higher rating, which would also double their solar usage. These are some of the options that the next design team can research and discuss with the FAA if and when they are ready to purchase the solar upgrade. Compared to the current FAA power tower design, these choices are more cost efficient and able to produce more energy storage out of the four mobile power systems we designed.

8.2 Final Parts Lists

Solar Expansion, Closed-Loop Battery		
Part Number	**Description**	**Quantity Used**
XW Pro 6848	Inverter	1
MPPT 80 600 (865-1032)	Solar Maximum Power Point Tracker	1
MPPT Disconnect	Disconnect for Solar, helps with arc fault detection.	1
XW Mini PDP	Serves as a power distribution panel for inverters. Comes with 3 AC Breakers and 1 DC Breaker.	1
Conext Automatic Generator	Automatically Starts the	2

Start	Generators when necessary.	
Discover Batteries (42-48-3000)	48V, 3kWh, 62.5A batteries serving as the primary power source when off-grid. BMS Utilizes Xanbus.	2
Insight Home	Serves as the controller for the system.	1
865-DCBRK-100	100 Amp Breaker for the MPPT.	1
Kubota GL7000 LOWBOY II	Generators for the System. Runs when solar and batteries can't supply the system.	2
New Solar Panels	Higher-Power Solar Panels allowing support for the system for longer with solar power.	16 or 4 sets of 4 panels

Solar Expansion, Open-Loop Battery		
Part Number	**Description**	**Quantity Used**
XW Pro 6848	Inverter	1
MPPT 80 600 (865-1032)	Solar Maximum Power Point Tracker	1
MPPT Disconnect	Disconnect for Solar, helps with arc fault detection.	1
XW Mini PDP	Serves as a power distribution panel for inverters. Comes with 3 AC Breakers and 1 DC Breaker.	1
Conext Automatic Generator	Automatically Starts the	2

Start	Generators when necessary.	
SimpliPhi Phi 3.8 Batteries	48V, 3.8kWh batteries serving as the primary power source when off-grid. Internal BMS.	2
Insight Home	Serves as the controller for the system.	1
865-DCBRK-100	100 Amp Breaker for the MPPT.	1
Kubota GL7000 LOWBOY II	Generators for the System. Runs when solar and batteries can't supply the system.	2
New Solar Panels	Higher-Power Solar Panels allowing support for the system for longer with solar power.	16 or 4 sets of 4 panels

No Solar Expansion, Closed-Loop Battery		
Part Number	**Description**	**Quantity Used**
XW Pro 6848	Inverter	1
MPPT 60 150	Solar Maximum Power Point Tracker	1
XW Mini PDP	Serves as a power distribution panel for inverters. Comes with 3 AC Breakers and 1 DC Breaker.	1
Conext Automatic Generator Start	Automatically Starts the Generators when necessary.	2
Discover Battery	48V, 3kWh, 62.5A batteries	1

(42-48-3000)	serving as the primary power source when off-grid. BMS Utilizes Xanbus.	
Insight Home	Serves as the controller for the system.	1
865-DCBRK-80	80 Amp Breaker for the MPPT.	1
865-DCBRK-60	60 Amp Breaker for the Solar Connection to the MPPT.	1
Kubota GL7000 LOWBOY II	Generators for the System. Runs when solar and batteries can't supply the system.	2

No Solar Expansion, Open-Loop Battery		
Part Number	**Description**	**Quantity Used**
XW-Pro 6848	Inverter	1
MPPT 60 150	Solar Maximum Power Point Tracker	1
XW Mini PDP	Serves as a power distribution panel for inverters. Comes with 3 AC Breakers and 1 DC Breaker.	1
Conext Automatic Generator Start	Automatically Starts the Generators when necessary.	2
SimpliPhi Phi 3.8 Battery	48V, 3.8kWh battery serving as the primary power source when off-grid. Internal BMS.	2
Insight Home	Serves as the controller for the system.	1

865-DCBRK-80	80 Amp Breaker for the MPPT.	1
865-DCBRK-60	60 Amp Breaker for the Solar Connection to the MPPT.	1
Kubota GL7000 LOWBOY II	Generators for the System. Runs when solar and batteries can’t supply the system.	2

9 Testing Smaller Model

In order to have a physical system to display in Expo, Dr. Hamidreza Nazaripouya allowed the power tower team members to wire some of the parts in his lab. These parts represented aspects of the system that the team members designed on a smaller scale.

9.1 Wiring

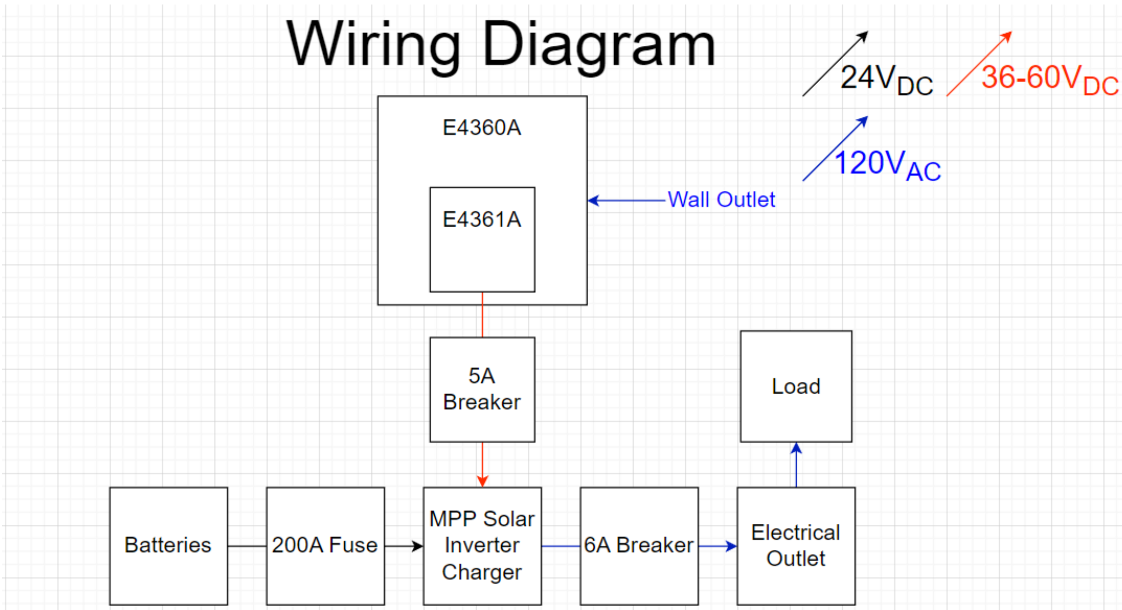

Figure 9.1a: Wiring Diagram for Smaller Model

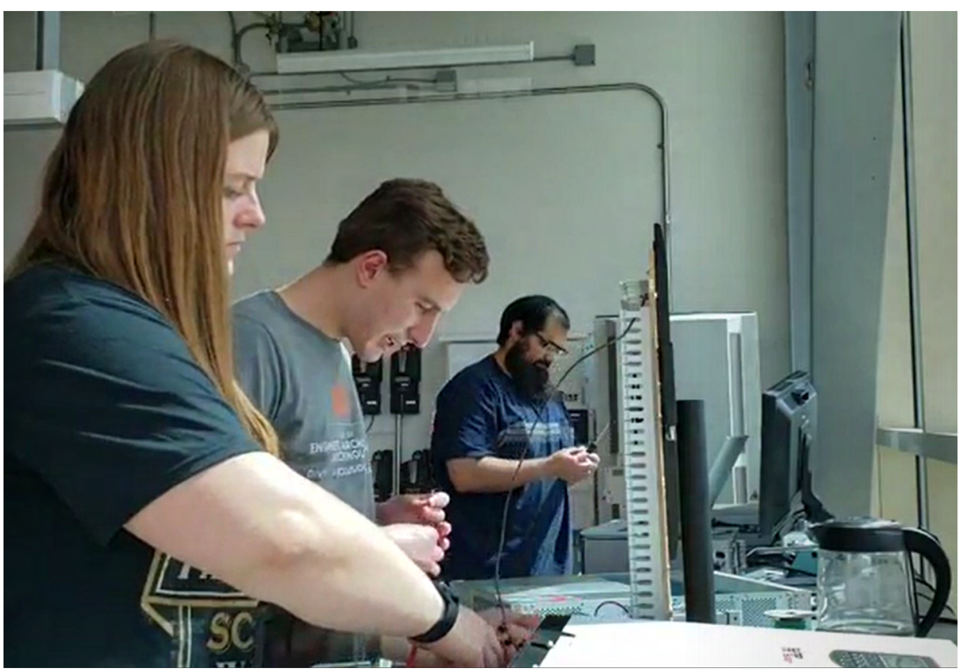

Figure 9.1b: Power Tower Team Wiring Smaller Model

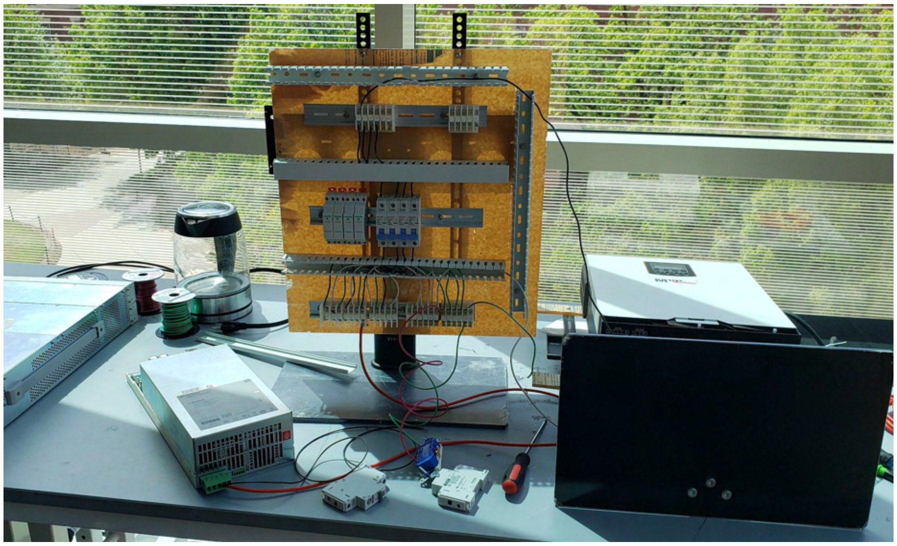

Figure 9.1c: Smaller Model Being Wired

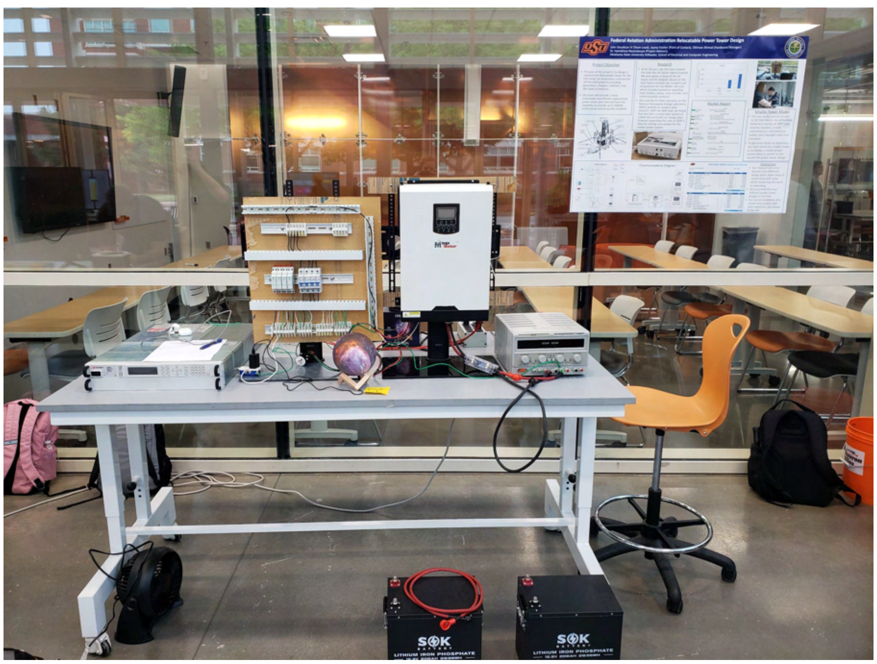

Figure 9.1d: Completed Smaller Model at Expo

9.2 Representations

In the smaller model, we have a MPP Solar inverter to represent the XW Pro 6848 inverter in our system. There are two SOK batteries to represent the Discover batteries in the design plan. However, during Expo these batteries were not charged and a DC Power Supply took the place of the SOK batteries. A simple power distribution board represents the XW Mini PDP. The E4360 Series Modular Solar Array Simulator represents the solar panels in our system design plan. The load in the smaller model for Expo was a sphere night light as shown in Figure 9.1d. This load represents the radio tower in the FAA system.

9.3 Results

The model works when the DC power supply is supplying 17 volts minimum and 30 volts maximum. The MPP Solar inverter recognizes the DC power supply and solar simulator as shown in Figure 9.3a. With the DC power supply, we are able to connect any load that is under 500 W such as a phone charger, nightlight, dehumidifier, small fan, small coffee maker, small blender. The load in the smaller model for Expo was a sphere night light as shown in Figure 9.1d.

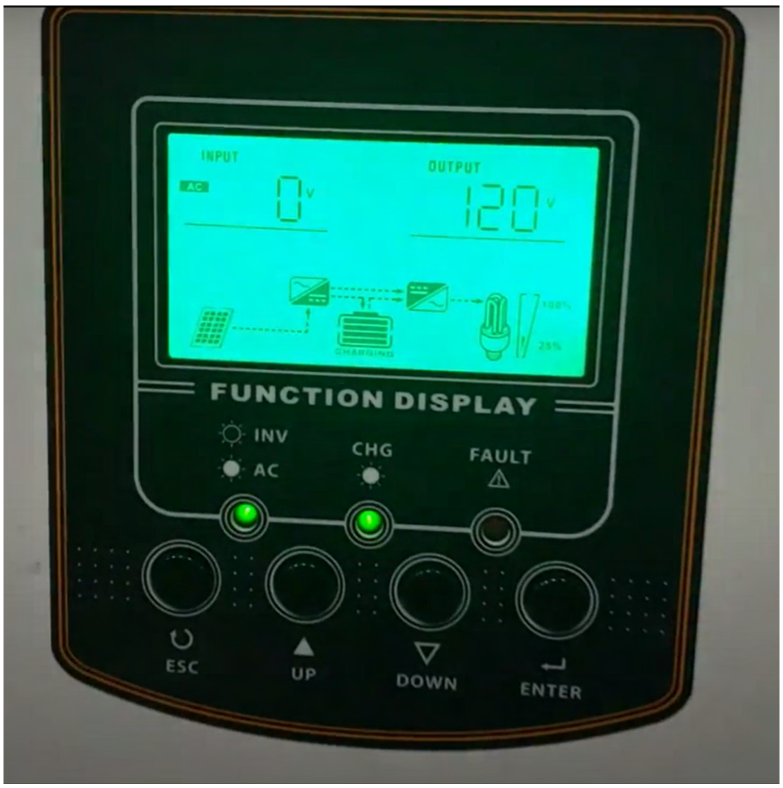

Figure 9.3a: Function Display panel of the MPP Solar Inverter

10 Future Projects

10.1 Departmental Perspective

For future projects, the first steps to take will include individually testing each part as they come in. However, the team members need Dr. Pouya's approval prior to powering any of the units on. The individual testing plans can be found in Section 7 as well as in each of the installation manuals provided in Section 15.2. After performing unit testing, wiring the system together will take place based on the power diagram chosen by the FAA given in Section 4.1. After Dr. Pouya inspects the complete wiring of the entire system and gives his approval, overall system tests will immediately follow. Schneider provides multiple wiring diagrams to follow and provides the necessary coding for the inverter. There are also several videos online regarding the wiring for multiple parts within this system design. While running these tests, weekly meetings with the FAA must take place to give updates about the project and conduct a discussion regarding expanding the solar power. When expanding solar, the FAA has a couple options. They are able to add 16 more panels of the same solar rating to double their solar size. Another option would be if they replace the 16 solar panels that they have now with a higher rating, which would also double their solar usage. The last and final step for the continuation of this project would be for the team members to retrofit the new parts onto the trailer that the FAA has at the MMAC site. After speaking with Brian Fuller at the Expo, he spoke of the possibility of getting one of the power tower trailers delivered to campus for the next group to have better access when retrofitting the parts. However, this was not an official statement and the team members need to confirm with the FAA representatives before they assume that this will happen during the project duration.

10.2 Improvements and Interdisciplinary Perspective

If the FAA would be interested in improving their system even more, computer engineering students can focus solely on coding the inverter to the exact specifications of the FAA's desires of the power system. At this time, for future projects, there should be no aspects of interdisciplinary perspective. However, if the FAA were to expand their budget and choose to upgrade the physical aspects of their system, one possibility for interdisciplinary collaboration would be mechanical engineering students designing new casing for the parts to fit on the trailer in order to protect the power system design from some of the outside elements. This casing would have to be durable and light-weight to fit in the dimensions of the trailer while also not weighing the trailer down enough for the system to still be mobile. The FAA would also need to have easy access to these parts in case of any maintenance needs.

11 Gantt Chart

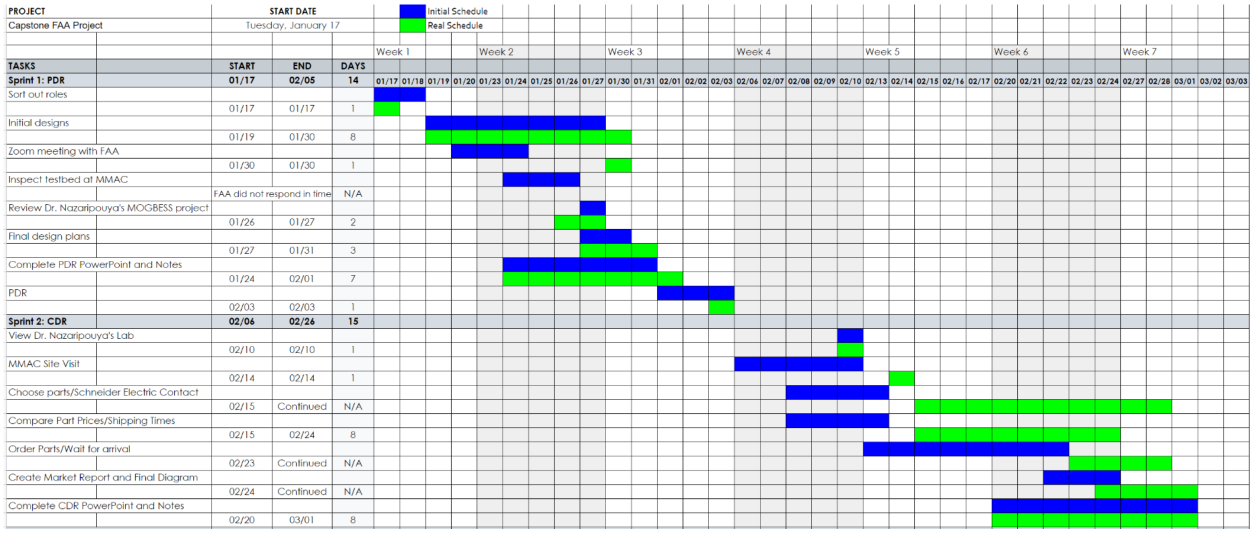

Figure 11a: Sprint 1 and 2 Initial Schedule (Blue) vs. Real Schedule (Green)

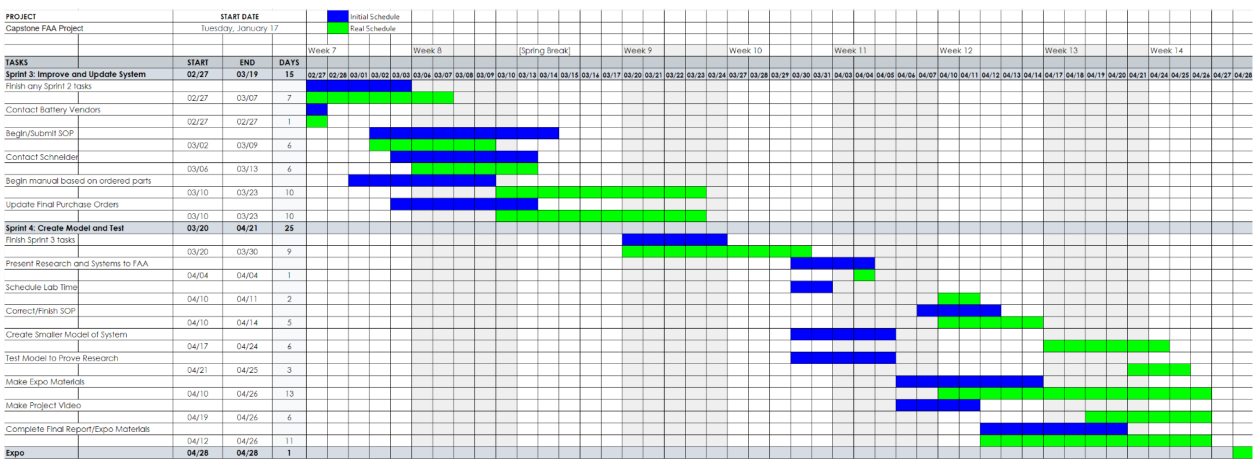

Figure 11b: Sprint 3 and 4 Initial Schedule (Blue) vs. Real Schedule (Green)

12 Risk Management

Risks that are encountered in this system first stem from the ongoing supply chain limitations. Placing an order for parts in a system can lead to an extended shipping time due to the challenges that have faced shipping items to consumers. Another risk that faces the project is the implementation of the system. Implementing the system will take time after receiving the parts. Schneider provides wiring diagrams for the system that will greatly benefit the implementation timeline. Another option is ordering a pre-wired system, but wiring it ourselves will greatly enhance our understanding of all the interconnections present. Another risk that faces the project is the funding. The FAA has not provided a budget to the team, which can lead to a proposal being denied. In the event of denial for the proposed project, our team will still provide a detailed report and market research report on a replacement system.

13 Hazard Analysis

Hazards concerning this system can lead to fatalities and injuries. The load is running at 3 kilowatts and the voltage supplying it is 240 volts, so the current it draws is 12.5 amps. This is fatal because as little as 50 milliamps is enough to permanently injure someone and cause death. Over time, components can degrade and lose functionality, leading to shorts in the system. These shorts created can lead to ground faults. Ground faults are ground connections made that are unplanned in the existing implementation. The faults can lead to destruction of the components, and can also be caused by a person inserting themself in the circuit while it is energized. To avoid inserting oneself in the circuit, the system should be de-energized first. In systems like these that are 120 volts and above, Arc Faults and Arc Flash can occur. These are caused in the event of a short circuit where a component is not rated to handle a certain amount of current, which leads to the excess amount of it arcing out of the part potentially onto a person. To avoid this, again, de-energize the system when working on it, and wear PPE based on the cal/cm^2.

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15 Additional Notes

15.1 Overall Setbacks

Our team encountered several setbacks throughout the semester. First, due to scheduling conflicts, the MMAC site visit had to be pushed back a week from our original plan. This caused us to have less time to complete certain tasks. Additionally, we experienced trouble reaching Schneider Electric, as we received no response from the company for four days. We were finally able to call after trying different numbers, as the customer service number had recently changed. This delay impacted our project timeline and created added stress for the team. Lastly, we faced difficulties sticking to our scheduled plan for ordering parts. While we have the four purchase orders created, the delays in communication and scheduling made it challenging to complete this task in a timely manner. Despite these setbacks, our team worked hard to adapt to changing circumstances and overcome the obstacles we faced to get back on track with our Capstone project. Despite all these setbacks, our team was able to present four well-designed power tower systems to the FAA based on the needs they provided in the first half of the semester.

15.2 All Materials

All materials needed for any additional capstone design teams in the future can be found in Dr. Hamidreza Nazaripouya or Professor Lannan's email sent by these team members (Sent Date: 05/04/2023 Title: "FAA Power Tower Capstone Future Project Information"). The email contains all the datasheets and manuals used by this group for some of the parts, the FAA information about the tower to be worked on, the final design review materials, the solar research information (including the Excel sheet with all solar level graphs for the MMAC), and both purchases orders containing the purchase links.