Utility Scale Lithium-ion Battery Energy Storage System

DESIGN DOCUMENT

Sddec24-18

Client Burns & McDonnell

Advisor Zhaoyu Wang

Team Members

Oksana Grudanov - Team Leader/ Cable Sizing & Cable Schedule

James Mendenhall - Document Report/ One-line diagram

Sarah Ebert - Organizer & Editor/ One-line diagram

Cole Dustin - Point of Contact/ AutoCAD site layout design

Team Website: https://sddec24-18.sd.ece.iastate.edu/

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

BURNS McDONNELL

Executive Summary

Developed Standards & Practices Used

The engineering standards that apply to this project are:

- NFPA, National Electric Code Article 310 Conductors for General Wiring
- NFPA 855 Standard for the Installation of Stationary Energy Storage Systems
- UL 9540A Test Method
- NFPA, National Electric Code Article 311 Medium Voltage Conductors and Cables
- NFPA, National Electric Code Article 300 General Requirements for Wiring Methods and Material

Summary of Requirements

The requirements for our design include:

- Follow the National Electric Code for all electrical installations
- Deliver 25 MW of power for 4 hours (100 MWh)
- 10% overbuild at BOL (beginning of life) to account for battery capacity loss over time

Applicable Courses from Iowa State University Curriculum

Many Iowa State classes have prepared us to tackle this project. However, a few pertain directly to this project. These include:

- EE 456 Power Systems Analysis I
- EE 457 Power Systems Analysis II
- EE 303 Energy Systems and Power Electronics

New Skills Acquired

New skills acquired during this project that were not included in the Iowa State curriculum include:

- AutoCAD
- Conductor sizing knowledge
- Understanding how to use the NFPA National Electric Code (NEC)

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Definitions and Abbreviations Used

BESS: Battery energy storage system.

BOL: Beginning of life

NEC: National Electric Code

KCMil: Thousand circular

NFPA: National Fire Protection Association

PCS: Power conversion system

CLF: Current limiting fuse

EXF: Explosion fuse

MPT: Main power transformer

ETAP: Electrical Transient Analyzer Program

1. Introduction

1.1. PROBLEM STATEMENT

Our project attempts to solve one of the primary problems associated with transitioning to renewable energies. The generation of power from renewable sources is variable and is not able to match fluctuating demand. In other words, peak windy or sunny hours are not consistent with when consumers use the most energy. The utility-scale battery energy storage systems (BESS) that we are designing address this problem by allowing excess energy to be stored during peak production times and then released during times of high demand.

1.2. PROJECT OVERVIEW

Our project is to design a BESS that will be constructed in the Ames area. It will be located near the Ames substation and support wind and solar energy use. With the implementation of our project, the local utility landscape will be able to rely more on renewable energy and less on fossil fuels.

Utility Scale Lithium-ion Battery Energy Storage Systems take excess energy from renewable energies or conventional power plants to charge up the large lithium-ion batteries. Our client has specified that we will design a 25 MW, 4 hr system.

The system will have a 30-year life cycle and two augmentations throughout its lifetime. It will have a 10% overbuild at BOL. This means that at the beginning of its life it will exceed the power ratings, so it will still meet requirements at the end of its life. We need to account for this because the capacity of lithium-ion batteries naturally decreases throughout their lifetime due to their internal chemistry. We will be designing this system on a 15-acre plot of land in Ames, Iowa. However, this system could be implemented anywhere in the country by changing the rating of the transformer that connects it to the electric grid.

1.3. INTENDED USERS

The intended users of our project are the residents of Ames, Iowa, the construction and maintenance teams, and the local utility's engineers. Each of these three groups will interact with our BESS differently, have a variety of needs, and will benefit from it in different ways.

The people of Ames will interact with our project only by using electricity. This group includes college students, middle-class residents, homeowners, and business owners. They need to be able to work and live undisrupted by power outages. Many are also concerned about the environmental impact and need to have environmentally friendly options available. However, the primary concern of this group with respect to our project is financial, meaning they don't want their utility bills to increase. This group will benefit from this project because it will save them money on their utility bills in the long run. Additionally, those with environmental concerns will benefit from knowing that more electricity comes from renewable sources.

The construction and maintenance teams will interact with our project during the building phase and throughout its lifespan for upkeep. This group includes blue-collar workers and site supervisors. They need to work in a safe environment and complete the project and maintenance in a timely manner. To satisfy these needs, we will provide a detailed and complete site layout diagram. It should include accurate measurements that comply with NEC (National Electric Code) standards. This group will benefit from our project because it will provide them the opportunity to work on a well-organized, safe, and efficient construction project.

The local utility will interact with our project through the distribution substation that we are connecting to, and mainly consists of electrical and civil engineers. This group needs to monitor the loads on each of the substation's feeders and the load from our BESS. Connecting our system may also require additional equipment, such as cables and breakers, to be installed in the substation. This will require a detailed one-line diagram of our site with equipment sizes and ratings. The local utility will benefit from our BESS because they will be able to monitor the power it is generating and drawing easily.

2. Requirements, Constraints, and Standards

2.1. REQUIREMENTS & CONSTRAINTS

Functional Requirements:

- Design a battery energy storage system (BESS) capable of generating 25 MW of power.
- Design the BESS deliver energy for four hours continuously.
- BESS must deliver 100 MWhs of energy.
- The BESS must have a 10% BOL to compensate for battery degradation.

Resource Requirements:

- The site may only use 20 acres of land.
- The land must be flat.
- The location of the site must have ambient temperatures between -30°C ~ +55°C.

Constraints:

- The largest cable size available is aluminum 1000 KCMil.
- The cables must be rated for 40°C.
- The power factor at the inverter must be 0.95.
- The construction layout must have roads with a 25-foot turn radius around the equipment.

2.2. ENGINEERING STANDARDS

NFPA, NEC Article 300 General Requirements for Wiring Methods and Material

This code covers general requirement for wiring methods and materials for wiring installation. This provided guidelines used in creating our cable schedule document.

NFPA 70, NEC Article 310 Conductors for General Wiring

This code provides general requirements for conductors rated up to 2000 volts and their type designations, insulations, markings, mechanical strengths, ampacity ratings, and use. We used this when selecting the cable sizes and types in the low voltage parts of our system.

NFPA, NEC Article 311 Medium Voltage Conductors and Cables

This code covers the use, installation, construction specifications, and ampacities for voltage conductors and cables rated from 2 kV up to 35 kV. We used this standard when selecting cables for the medium voltage parts of our system.

NFPA 855 Standard for the Installation of Stationary Energy Storage Systems

This standard defines the design, construction, installation, commissioning, operation, maintenance, and decommissioning of stationary energy storage systems. This was used in the development of our site layout to ensure that the design met safety requirements.

UL 9540A Test Method

This method is used to determine the fire and explosion protection required for the installation of a BESS. Large batteries carry high risks of thermal runaway leading to dangerous fires and explosions. We used the test method outlined in this code to ensure our design meets fire safety standards.

3. Project Plan

3.1. PROJECT MANAGEMENT/TRACKING PROCEDURE

We have adopted a waterfall management style for our BESS design. A waterfall management style involves detailed upfront planning and sequential phases. This is suitable for our project because there are a lot of regulations and requirements in this industry. We determined the system capacity and site location in our first planning phase. We needed to know this before completing any of the following tasks.

We have been keeping track of our team's projects on Microsoft Teams. This is an easy way for us to share documents with our industry advisors, whom we have been working very closely with. It is also their preferred platform for our weekly video calls.

3.2. TASK DECOMPOSITION

Our project follows very clearly defined sequential steps.

1. Establish the system's capacity and location.
    a. Our clients already knew the capacity they wanted and the general location.
    b. Decide on a specific location near Ames and adjacent to a distribution substation for easy interconnection.
2. Determine specifications for the main equipment.
    a. Examine documentation on various lithium-ion battery containers and power conversion systems (PCS).
    b. Complete calculations to determine how many containers and inverters we will need based on the values in the spec sheets of our chosen equipment.
3. Draw our site layout on AutoCAD.
    a. Download and learn AutoCAD basics since no one on the team had used it prior.
    b. Use the dimensions and quantities of the equipment determined in the last step.
    c. Closely adhere to NEC construction codes.
4. Create a one-line diagram of our system.
    a. Complete relevant calculations to design the auxiliary power system and determine the rating of main power transformer.
    b. Follow industry standards and reference the training materials provided by our industry advisors.
5. Complete string sizing calculations.
    a. Reference completed one-line diagram for voltage levels and currents at different points in the system.
    b. Find appropriate cable sizes.
    c. Review NFPA NEC Code 2020 for various articles and tables.

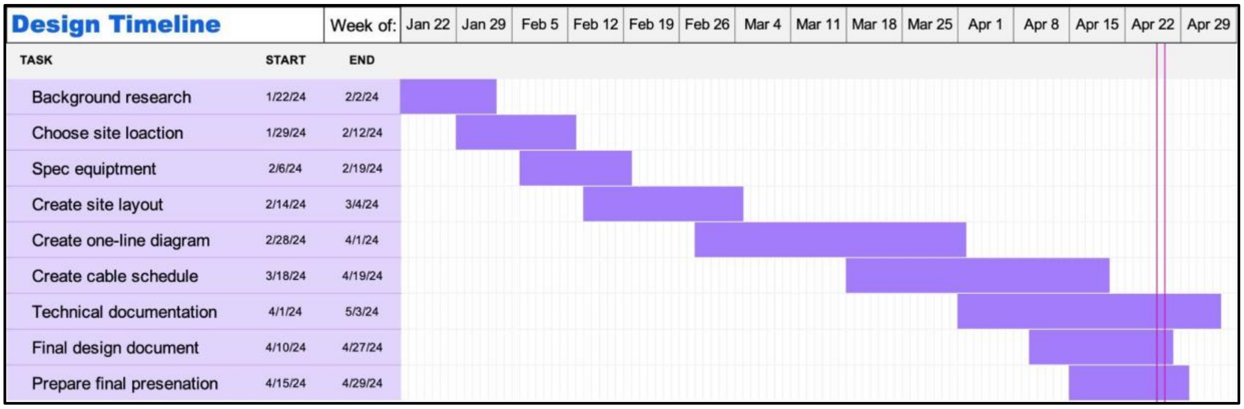
6. Learn how to use the software required to model our system
    a. ETAP (Electrical Transient Analyzer Program) is an industry standard software used to model electrical systems under various conditions. It will allow us to test the reliability and safety of our design without a physical system.
    b. Enter the equipment ratings, line impedances, and load profiles to build our system in ETAP.
7. Complete load flow and short circuit analysis using ETAP.
    a. Conduct load flow analysis to determine the electrical system's steady-state voltage and power flow. This helps ensure that the system operates within acceptable voltage and power limits under normal operating conditions.
    b. Perform short circuit analysis to assess the system's response to fault conditions. This involves calculating fault currents and determining the magnitude and duration of short-circuit events to ensure that protective devices can operate effectively and safely.
8. Compile all our work in one report.
    a. We will add to this as we complete each step.
    b. This completed report should give the reader a full understanding of both how our system works and our team's design process.

3.3. PROJECT PROPOSED MILESTONE, METRICS, AND EVALUATION CRITERIA

The key milestones for our project align closely with the completion of the previously identified tasks. The evaluation criteria for all our steps are approval from our industry partners. They are familiar with the standards and regulations related to our project and, therefore, can easily determine if our project is up to standards. When we finish a task, we present the results to our client in our weekly meeting. They will either approve of our work or give us specific feedback for improvement. We then make changes as directed and present them at the following week's meeting.

3.4. PROJECT TIMELINE

The Gantt chart below is a detailed schedule of our project. It only covers the spring '24 semester tasks. We will determine the timeline of next semester's tasks after discussing them more in-death with our industry partners.



Design Timeline

TASK	START	END
Background research	1/22/24	2/2/24
Choose site loaction	1/29/24	2/12/24
Spec equiptment	2/6/24	2/19/24
Create site layout	2/14/24	3/4/24
Create one-line diagram	2/28/24	4/1/24
Create cable schedule	3/18/24	4/19/24
Technical documentation	4/1/24	5/3/24
Final design document	4/10/24	4/27/24
Prepare final presenation	4/15/24	4/29/24

Figure 1: Gantt Chart

The first two tasks identified correspond step one and two detailed in section 3.2. We spent the most of our first week together familiarizing ourselves with energy storage systems. After meeting with our industry partners and signing an NDA, we were able to start discussing the specifics of the project, including finding a potential site location. This involved reaching out to engineers at the local utility. While we waited for a response from the local utility, we began comparing different manufacturers' battery containers and power conversion systems, as these are the most crucial pieces of equipment in our system. After we decide on a battery container and PCS, we spent about three weeks creating a site layout. We needed the dimensions and installation standards for the equipment to create this.

We determine we needed about four weeks to complete our one-line diagram. This involved initial calculations, a hand drawn rough draft, and a final draft created in AutoCAD. Once we had the rough draft completed, we were able to start on the cable schedule. This also took about 4 weeks. The final three tasks in our timeline involve compiling our work with technical documentation.

3.5. RISKS AND RISK MANAGEMENT/MITIGATION

Task #	Risk	Risk Factor	Mitigation Strategy
1	The local utility company may not cooperate with us fully, making it difficult to find information about interconnecting to the grid and the nearby substation.	0	Connect with the faculty advisor and or client to gain connections to someone who can give us an idea of what we will be working with for the substation voltage.
2	The manufacturers might have incomplete documentation.	0.75	Work with our client to get access to multiple spec sheets.
3	The drawing might not fully meet NEC standards.	0.2	Receive feedback from our client and reference the NEC code.

4	The documentation for our one-line could be incomplete.	0.5	Have our clients review our work at many steps throughout the process.
5	The calculations may be inaccurate because we make incorrect assumptions about our system.	0.7	Discuss standard cables in this type of system with our client.
6	We may have trouble accessing and using the software on campus.	0.3	Work with our client to ensure we can complete the analysis even if we have access problems.
7	The analyses may reveal severe weaknesses in our system.	0.3	Pay close attention to potential problems in our initial design.
8	The report could be disjointed because many people are working on it separately at different times.	0.6	Assign one group member to be the document proofreader. They will make sure the writing flows in all reports before submitting.

3.6. PERSONNEL EFFORT REQUIREMENTS

A detailed estimate has been conducted relating to tasks completed for this project. Below is how much time has been delegated to each of those tasks.

Task #	**Man-Hours Required**	**Explanation**
1	5 hours	**Site Location** The system capacity and site location were discussed during the first two of our weekly client meetings. We also emailed an engineer at the local utility company.
2	20 hours	**Equipment Selection** We spent several meetings discussing this as a group before deciding on our equipment. Individually, two group members spent about 3 hours comparing spec sheets.
3	12 hours	**AutoCAD familiarization** This time involves time familiarizing ourselves with AutoCAD, a tool we have never used before. It also involved reading NEC construction standards and building the layout in AutoCAD.
4	30 hours	**One-line diagram creation** For this task, we completed training from our client on how to draw one-line diagrams and do relevant calculations. We drew several rough drafts and received feedback from our clients in our

		weekly meeting after each iteration. Then, we made a final draft in AutoCAD. Finally, we added notes and a key to the AutoCAD draft and completed technical documentation to justify the values and drawing.
5	20 hours	**Cable Sizing and Cable Schedule** To complete the cable sizing and cable schedule, we will review industry standards. Then we will do calculations based on our one-line to determine the load on each part of the system. After deciding on the cable size for each part of the BESS, we will write a detailed report explaining and justifying our decisions.
6	8 hours	**ETAP Familiarization** Each member of our group will need to be familiar with this software, so we will work with our clients to get adequate training to run the required simulations.
7	30 hours	**ETAP Design** We will need to build our BESS in the software and run the required analyses. Based on those results, we will complete a report highlighting our system's limitations and fault conditions.
8	30 hours	**Final Report** We will work on our final report as we complete each task.

4. Design

4.1. DESIGN CONTEXT

4.1.1. Broader Context

We are designing a battery energy storage system to be implemented in Ames, Iowa. This section discusses the context of implementing a BESS in an any community in America. Our project addresses the increasingly important need to support a transition to renewable energy. However, there are significant public health and safety considerations, environmental considerations, and economic considerations and some cultural and social considerations related to installing this large, expensive system.

Area	**Description**	**Examples**
Public health, safety, and welfare	Our project affects the safety of the construction and maintenance teams that work on it.	There are electrical hazards, chemical hazards, and physical hazards associated with the building and operation of this system.
Global, cultural, and social	Our project's goals reflect the values of the community that it provides energy to.	Many people in the community value having reliable and clean energy sources.
Environmental	Our project has both positive and negative environmental impacts because of the materials used and its impact on the energy grid.	The BESS decreases demand for energy from non-renewable sources. The mining of certain materials used in lithium-ion batteries has negative environmental effects.
Economic	Our project has a high initial cost due to expensive materials.	Consumers of electricity in the community do not want to pay higher utility bills.

4.1.2. Prior Work and Similar Projects

Before beginning the design process, we conducted background research into current technologies, resource constraints, and risks associated with integration into the distribution network. We referenced a paper in the Journal of Energy Storage from 2021, which provided us with an understanding of different battery technologies, various applications, and the main issues these systems have [1]. This was essential for us to understand how our system related to these considerations.

Energy storage systems include utility-scale systems and residential systems. Almost all of them use lithium-ion batteries because they have high energy density. The market for utility-scale battery energy storage systems is currently growing very rapidly. This is due to decreasing costs of lithium-ion batteries and the growth of solar and wind energy generation [1]. Our system, at 25 MW, is on the smaller side of utility scale systems, some of which are as large as 500 MW.

There is demand for our system because there are no battery energy storage systems in Ames, and the city would benefit from its ability to store excess wind energy. The city of Ames uses 36MW of power from a wind farm near Zearing, Iowa [2]. While there are no similar systems in Ames, MidAmerican current operates a small, 1 MW BESS in Knoxville, Iowa [3]. There is another similar 20 MW BESS in norther Illinois operated by Blattner Energy [4]. Our client, Burns and McDonnell, designed several battery energy storage facilities in west Texas, for a total capacity of 60 MW [5].

4.1.3. Technical Complexity

Our design consists of several components and subsystems. The subsystems include the batteries, inverters, cables, auxiliary power system, transformers, and system protection. The design deliverables for our project included a site layout, one-line diagram, and cable schedule. Choosing the equipment for our system required utilizing engineering principles to ensure they functioned optimally together. Making the site layout also utilized engineering principles because of the many safety codes it needed to follow. Creating the one-line diagram and cable schedule utilized significant use of scientific and mathematical principles because they required detailed calculations to obtain accurate sizing, ratings, and power in different parts of the system.

Our problem scope matches current industry standards. The 25 MW size is similar to other systems, such as the Blattner project in Illinois, mentioned in the previous section [4]. All of the operating BESSs discussed are also designed to deliver power for four hours.

4.2. DESIGN EXPLORATION

4.2.1. Design Decisions

One major design decision that we made was the battery manufacturer and model. We chose a battery from BYD that has around 4700 kWh of energy and pairs well with the inverter we had chosen. We found that the 0.25 C-rate (4 hr charge/discharge) version of the battery worked best with the specifications we were given. C-rate is a measure of how fast a battery charges and discharges.

Using the specification sheet of the battery and the inverters, we decided we would need 22 batteries to meet our minimum energy needs. We rounded up to 24 so all inverters would have the same number of batteries, power, and energy output. Having an even number of batteries and inverters makes the design process more straightforward, as instructed by our client.

Another major design decision was the type of transformers we used for the system. There are two ways to cool transformers: liquid-based and air-based. Depending on what type we chose, we would need different fuses to follow safety guidelines. We ended up with a liquid-based transformer for our auxiliary power. While this type is far better at cooling the air-based transformer, it has many safety and environmental concerns. The oil would be detrimental to the environment if it were to leak, so we need to have a trough to catch any leaking oil. We also must be aware of the unlikely situation of the transformer's oil getting too hot and catching fire.

This means we will need two types of fuses to protect the downstream equipment: a current limiting fuse (CLF) and an expulsion fuse (EXF). The names of the fuses describe what they do. A current-limiting fuse will limit the current and open the circuit if the current exceeds the rated levels. The expulsion fuse is high-speed and will almost instantly explode when the requirements, such as lightning strikes, are met to protect from surges.

4.2.2. Ideation

When deciding on the technology we would use, we had to balance several of the pros and cons of the different manufacturers and types of batteries. We used a lotus blossom to figure out what was essential to the project and decided accordingly, a seen in figure 2. The manufacturers that we considered were BYD, Hithium, and LG. To compare these options, we used a spreadsheet to see the relevant specifications side-by-side. Each manufacturer also had several different models that we had to compare. The BYD models consisted of a 0.5 C battery container and a 0.25 C battery container. After considering all the specifications and discussing with our client, we decided on the BYD battery rated at 0.25 C.

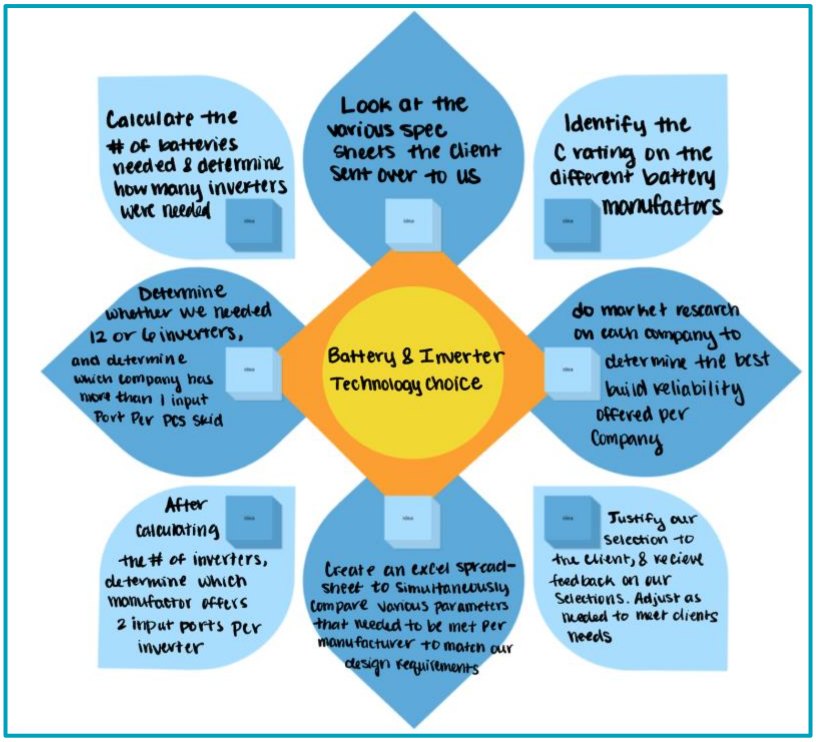


Figure 2: Lotus blossom used to determine the type of battery and inverter.

4.2.3 Decision-Making and Trade-Off

When deciding the type of battery and inverter, we used several methods to narrow the choices. First, several inverters and batteries would not go together because the battery's output voltage was not within the range of the inverters' input voltage. After eliminating many of the possible configurations because they are incompatible, we looked at the number of batteries it would take to reach the 100 MWh threshold. We eliminated several battery types due to needing well over 50 batteries. We decided on the four to six MWh range for the batteries; this led us to the BYD batteries, which all fell within this range. After we found the specific battery we wanted, it was a matter of balancing power and energy for each inverter.

4.3 PROPOSED DESIGN

4.3.1 Overview

Burns and McDonnell asked us to design a 25 MW/100 MWh battery energy storage system that will perform in a moderate climate. It needs to be 10% overbuilt to account for the degradation of the system over its 30-year life. It must also be upgrade-ready to account for the two augmentations it will sustain in its life.

The system will include three subsections: the inverters, the batteries, and the auxiliary power. The main power transformer and the substation are located offsite at a nearby substation. The batteries can convert electrical energy into chemical energy and back to electrical energy when needed. The batteries operate in direct current (DC), but the grid operates in alternating current (AC). This difference in current is why the inverters are necessary. Moving energy from the batteries to the electric grid will change the direct current into alternating current. The last subsection is the auxiliary power, where all the monitoring equipment is located. Auxiliary power also provides power to the cooling systems of the batteries and the inverters.

For power to be at the correct voltage when entering or leaving our BESS, we need a transformer to take the grid voltage (138 kV) and lower it to the voltage we are using (34.5 kV). To accomplish this, we need a main power transformer (MPT) in the interconnecting substation. The high-level block diagram below (figure 3) shows how all of these systems are connected. It also shows how our system interconnects to the distribution grid.

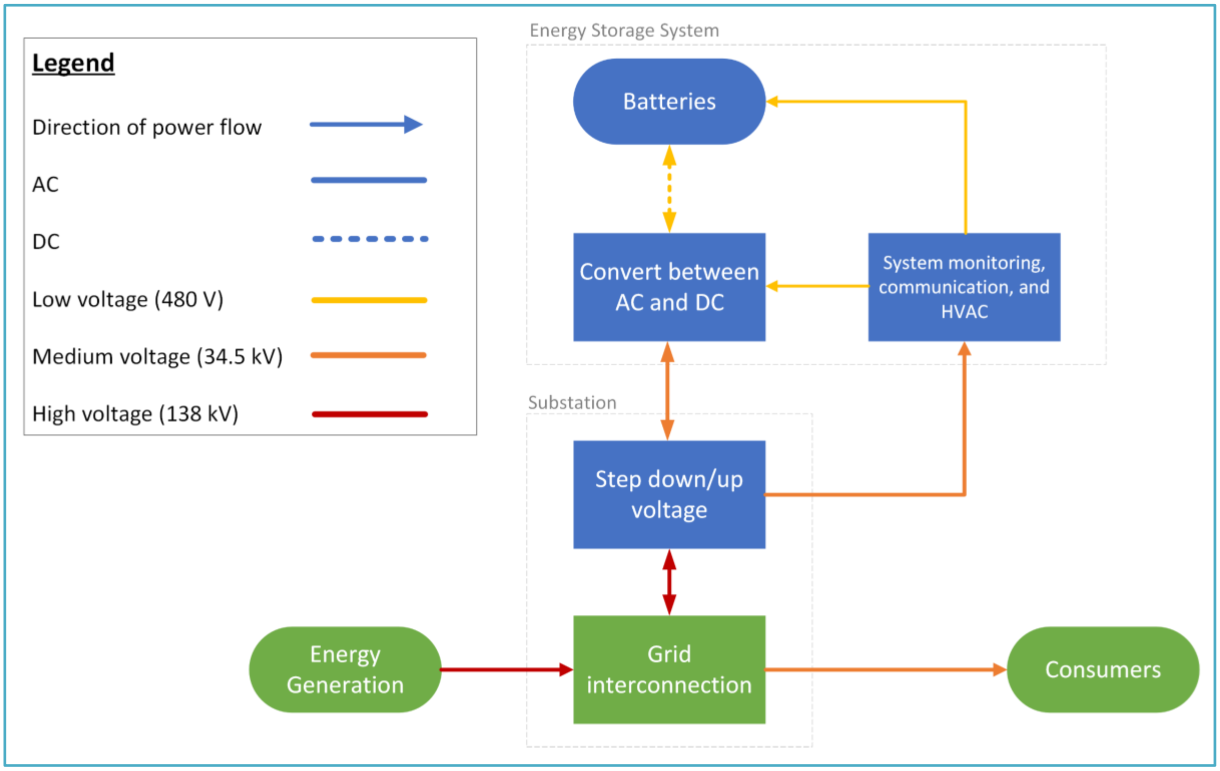


Figure 3: High-level block diagram of the battery storage system

4.3.2 Detailed Design

One of the most essential parts of designing a battery energy storage system is the electrical connections between components. This concept is illustrated with a one-line diagram. The one-line diagram includes every connection, from the substation to the main power transformer, the inverters, the batteries, and the auxiliary power. It also reveals important information, such as the transformers' substation voltage and voltage ratios.

Figure 4 shows the interconnection of the major equipment that will be used to design the BESS. The purpose of this diagram is to depict an overview of where each component will connect and the substation. This image will depict a three-phase cable as one cable for simplicity.

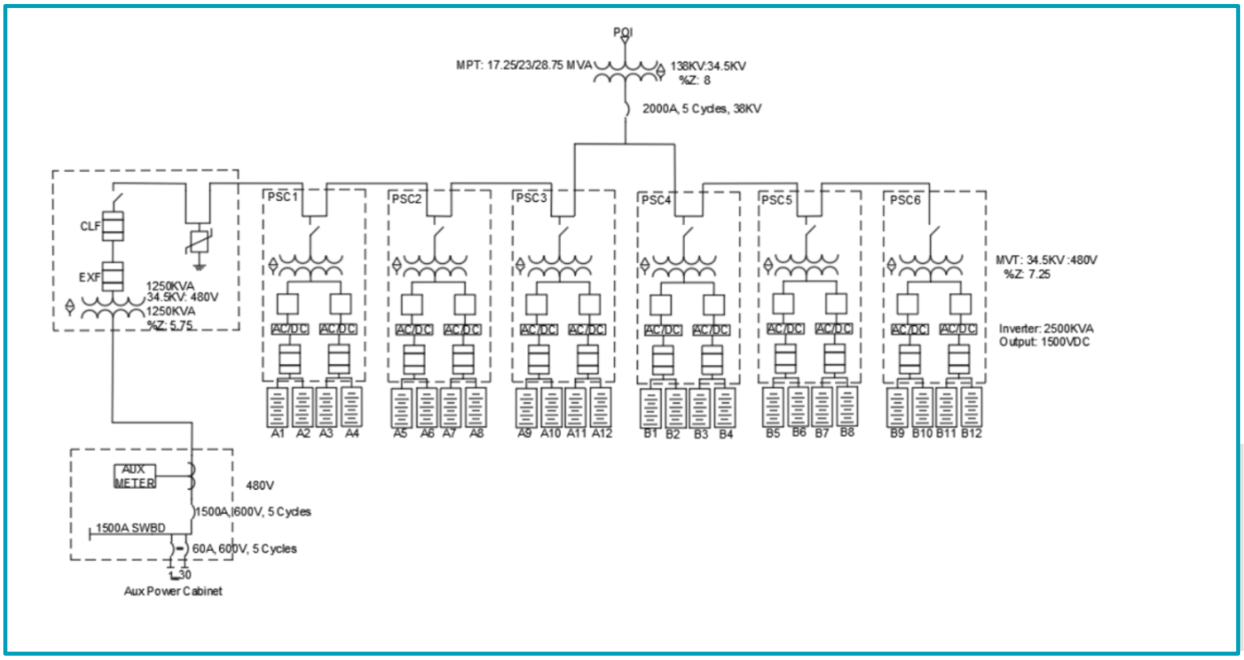


Figure 4: One-line drawing

4.3.3 Functionality

This system is intended to reduce the energy demand from power plants during peak demand. This is achieved by charging the batteries when energy demand is low, which could be during the night or hours before the hottest time of the day in summer. The system will then discharge when demand is highest, such as 2 p.m. in the middle of August when air conditioning systems run as hard as possible.

What this accomplishes is more consistent energy prices throughout the day. When the grid's energy storage is high enough, it can reduce the need for additional power plants whose power only needs a couple of days throughout the year when demand is highest.

4.3.4 Areas of Concern and Development

Since we work very closely with Burns and McDonnell and meet weekly, we do not stray far from the intended design. If the Burns and McDonnell team comes across a problem with our actions, they will explain what we are doing wrong and guide us in the correct direction. We still have ample freedom in how we complete the project. if there are multiple ways of doing something, we have the freedom to choose as adheres to standards.

4.4 TECHNOLOGY CONSIDERATIONS

We are using relatively modern technologies that are rising in popularity, such as large lithium-ion battery containers and DC-to-AC inverters. These two technologies go together very well. They have many advantages and disadvantages compared to not storing energy. One advantage is the need for smaller fossil fuel plants because of their ability to store energy during low demand and discharge the batteries when the demand peaks. Another advantage is smoothing the cost of energy throughout the day. The last significant advantage is allowing renewable energy to become available even when it is dark or there is no wind.

Some disadvantages include having a significant portion of the energy cost devoted to energy storage instead of focusing purely on production. Having an energy storage system raises the cost of energy due to imperfect efficiency and maintenance. Another disadvantage is that lithium-ion batteries degrade in capacity relatively quickly. This makes the project more expensive through overbuilding at BOL and augmentations throughout its life.

4.5 DESIGN ANALYSIS

Since we started working with Burns and McDonnell on the battery energy storage system, we have completed many steps of the process. We have decided on the system's size and location. We found that a BESS of this size would fit well in Ames. We then found a location in south Ames close to a substation with some unoccupied land.

After finding a location, we needed to determine what components we would use. We were given a list of possible batteries and inverters that Burns and McDonnell have used in the past. We found the batteries and inverters that worked well and gave our justifications to the team at Burns and McDonnell, and they agreed with our reasoning. Once we know what components we will use, we need to draw them in AutoCAD. We used a version of AutoCAD that allows us to overlay our site on top of maps to see what this will look like at our location.

The next thing we worked on was the one-line drawing. The one-line helps everyone who looks at the system understand what we're working on. Comparing our progress to an example one-line of a similar system showed us what we were missing and what we could improve upon. One of the last major parts of the design part is the cable schedule. The cable schedule describes the parameters of every cable, including the size, length, how many cables we need, and the maximum temperature of the cable.

Finally, we will test the system we designed under various conditions. We will use a simulation software that will tell us whether we have correctly sized each component of the BESS. It will also help us find ways to increase our system's safety and efficiency and ensure compliance with safety regulations.

5. Testing

Next semester, we will be using ETAP software to test our design. We will be conducting load flow and short circuit analysis. This will help us verify our design decisions such as cable sizing, inverters, and batteries.

5.1. UNIT TESTING

Our client wants our testing to begin starting next semester. We will be using ETAP software to do the testing, which we cannot access yet. We will be running tests on our BESS with ETAP to determine how the system will operate when contingencies are in place such as a fault.

5.2 INTERFACE TESTING

The interface we will be using is ETAP software to complete short circuit analysis to test our design under hypothetical loads. Electrical Transient Analyzer Program (ETAP) is a software engineers use to model and simulate electrical systems.

5.3 INTEGRATION TESTING

The critical integration path would be to prove that our cables, batteries, and inverters do not fail during a 4-hour 25MW discharge load. All of our cables and circuit analysis will be tested during this phase.

5.4 SYSTEM TESTING

All of the system testing will take place using ETAP software which will take place next semester. This feedback will be critical in verifying that we made the correct decisions for cable sizes, inverters, and batteries. This will also ensure that our calculations are correct.

5.5 REGRESSION TESTING

Our system is modular. This will allow us to expand the scope and scale of this project. This would expand the power output capacity for this project.

5.6 ACCEPTANCE TESTING

We will use ETAP software to complete short-circuit testing. However, our client does not want to begin this part of the project until next semester.

5. 7 RESULTS

Our results will be verified during the fall semester when we receive access to the testing software from our client.

6. Implementation

For the implementation of our project our final deliverables are about 30% of the necessary documents to implement our design. Next semester, we intend to test our design with specific software. The software is called ETAP and will be useful for short-circuit and load flow design analysis.

7. Professional Responsibility

7.1. Areas of Responsibility

For our project, we will follow the IEEE code of ethics. The seven professional responsibilities are work competence, financial responsibility, communication honesty, health, safety and well-being, property ownership, sustainability, and social responsibility.

7.2. Project Specific Professional Responsibility Areas

Area of Responsibility	Professional Context	Team Performance
Work Competence	Our team has been working to provide a solution to inconsistencies in renewable energy generation. With this project, we are contributing to making the world a cleaner place while our need for energy grows	High
Financial Responsibility	We have not been considering the financial implications of our design as directed by our industry partners.	Low
Communication and Honesty	Create the best product we can without taking shortcuts. Being open about how the team came to conclusions	High
Health, Safety and Well-being	Follow all safety and fire codes closely. Adhere to our client's specifications.	High
Property Ownership	We signed an NDA before beginning work and are respecting that	High
Sustainability	Our project uses large lithium-ion batteries, which have significant environmental impacts. It also decreases the need for fossil fuels.	Medium
Social Responsibility	It benefits the Ames community by making the energy landscape more sustainable	High

7.3. MOST APPLICABLE PROFESSIONAL RESPONSIBILITY AREA

The most applicable section to our project is sustainability. Improving the sustainability and reliability of the energy grid is the primary reason for building battery energy storage systems. Every aspect of the system has an environmental impact. It is crucial that we keep this in mind in every design decision we make, from the location of our site to the equipment we select.

8. Closing Material

8.1. DISCUSSION

The main results from the project consisted of successfully creating a single line with every little detail listed for easy identification. We implemented a single-line diagram, listing values for the main power transformer, fuses, panels, and the battery and inverters. Another result that has been met is to create a cable schedule listing conductor sizes, cable lengths, how many conductors per phase, the quantities of wires, and raceway lengths. With these two components, we have implemented a design for our BESS and prepared us for the final stages of designing in ETAP and short circuit analysis for next semester.

8.2. CONCLUSION

To implement the design of our BESS, we did research, calculations and learned how to operate a new software for this project. Our goals this semester were to establish the system's capacity and location, determine specifications for the main equipment, draw our site layout on AutoCAD, create a one-line diagram of our system, and complete string sizing calculations. Next semester our goals are to learn how to use the software required to model our system, complete load flows, and short circuit analysis, and finally compile all our work in one report.

The best strategy we found to achieve these goals was to work sequentially and consult our industry advisors frequently. To improve our design in the future, we could do more independent background research.

8.3. REFERENCES

[1] M. A. Hannan et al., "Battery energy-storage system: A review of technologies, optimization objectives, constraints, approaches, and outstanding issues," Journal of Energy Storage, vol. 42, no. 103023, p. 103023, Oct. 2021, doi: https://doi.org/10.1016/j.est.2021.103023.

[2] "Renewable Energy | City of Ames, IA," www.cityofames.org. https://www.cityofames.org/government/departments-divisions-a-h/electric/renewable-energy

[3] "Battery Storage," www.midamericanenergy.com. https://www.midamericanenergy.com/battery-storage (accessed Apr. 28, 2024).

[4] "Northern IL Energy Storage Project," www.blattnerenergy.com. https://www.blattnerenergy.com/projects/northern-il-energy-storage-project#:~:text=The%2020%2Dmegawatt%20battery%20energy (accessed Apr. 27, 2024).

[5] B. & McDonnell, "Case Study | Texas Trio Battery Energy Storage Facilities Address Grid Stability in West Texas Wind Resource Area," info.burnsmcd.com. https://info.burnsmcd.com/case-study/texas-trio-battery-energy-storage-facilities-address-grid-stability-in-west-texas-wind-resource-area (accessed Apr. 27, 2024).

[6] National Fire Protection Association, “Article 310”, National Electric Code, NFPA, 2020, pp. 164. Table 310.16.

[7] National Fire Protection Association, “Article 311”, National Electric Code, NFPA, 2020, pp. 180. Table 311.60(C)(86).

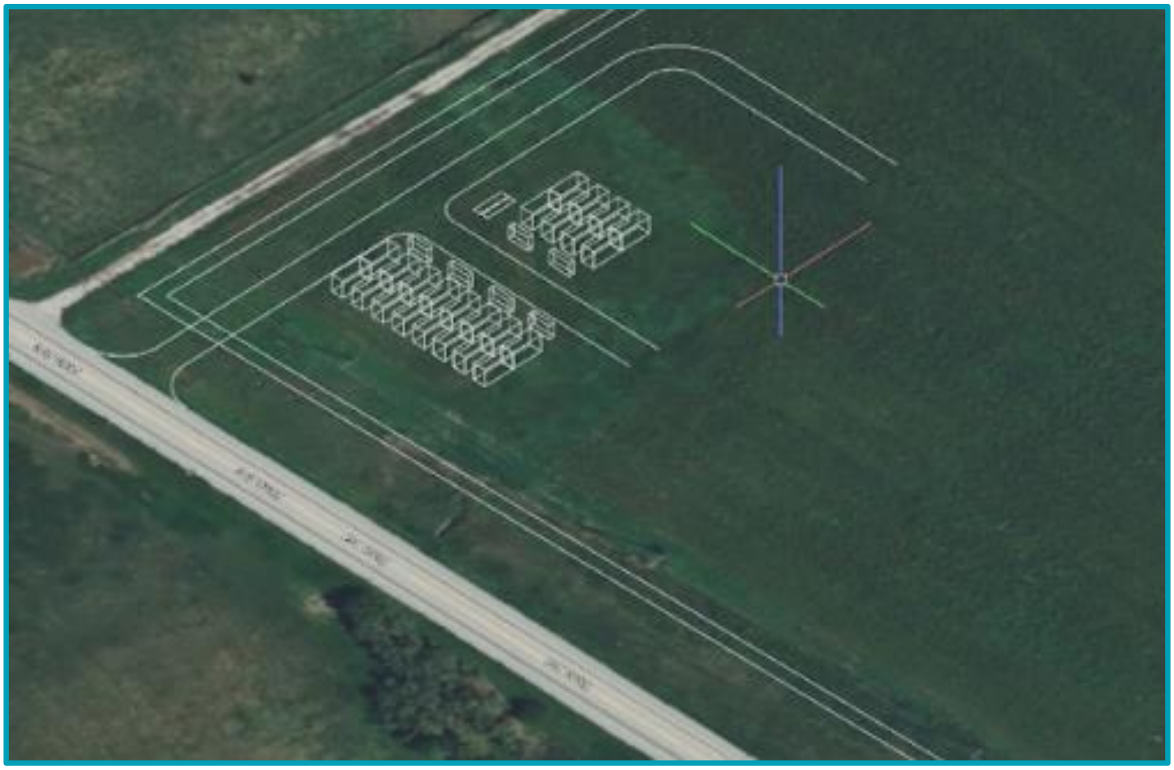
[8] National Fire Protection Association, “Article 310”, National Electric Code, NFPA, 2020, pp. 162. Table 310.15(B)(1).

[9] National Fire Protection Association, “Article 300”, National Electric Code, NFPA, 2020, pp. 146. Table 300.5.

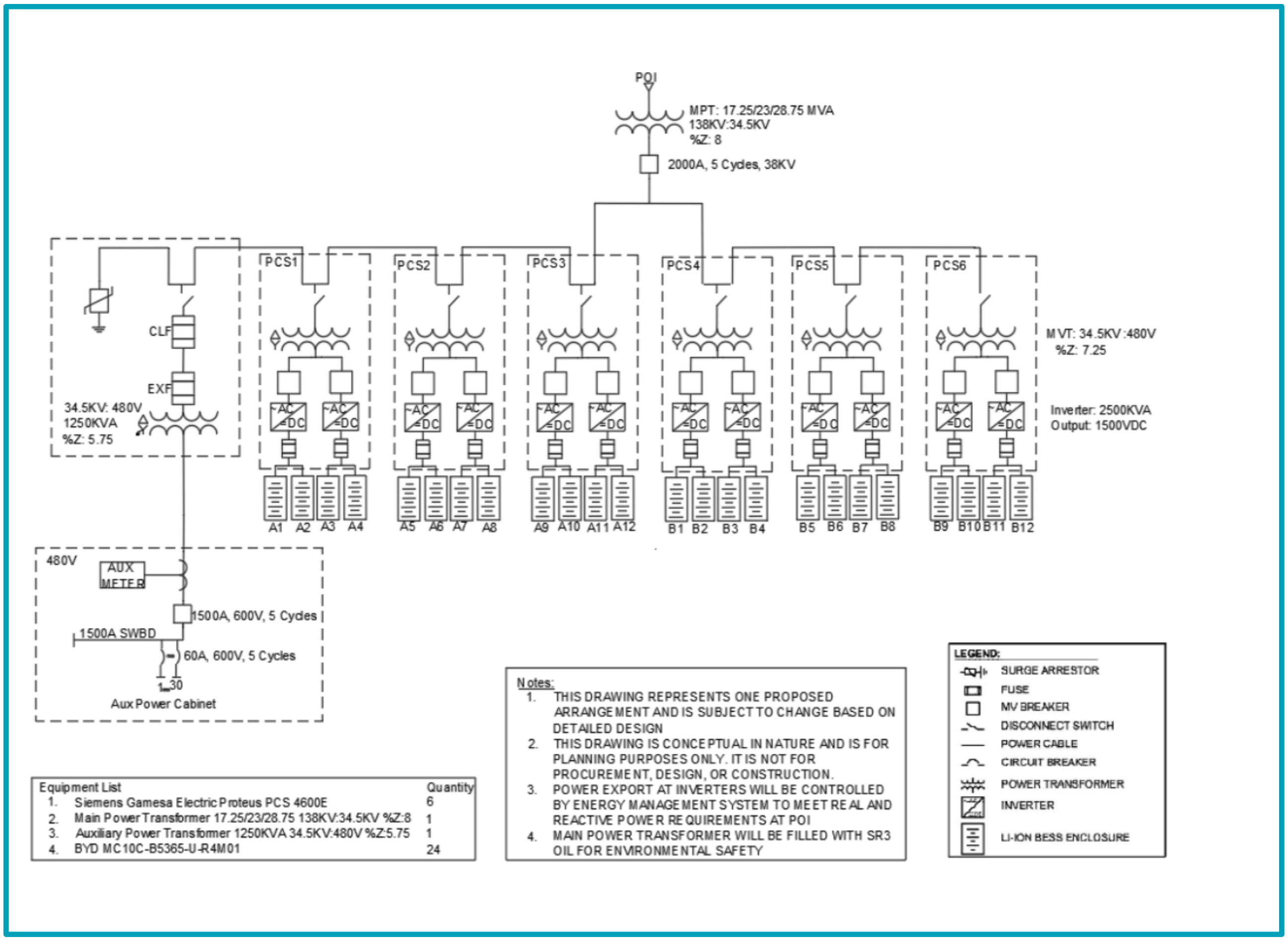
[10] National Fire Protection Association, “Article 300”, National Electric Code, NFPA, 2020, pp. 153. Table 300.50.

8.4. APPENDICES

Site Layout:



One-line diagram:

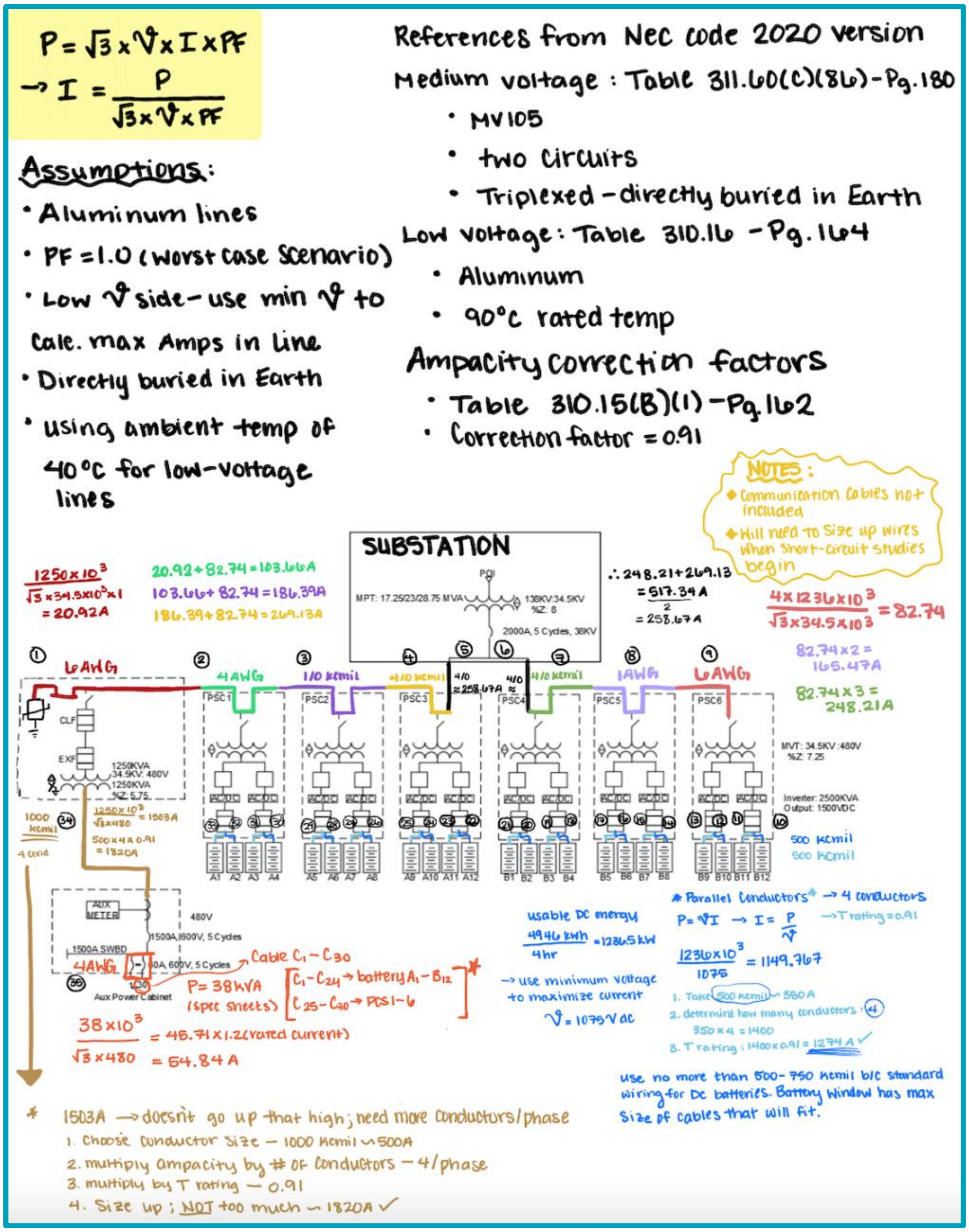


Equipment List	Quantity
1. Siemens Gamesa Electric Proteus PCS 4600E	6
2. Main Power Transformer 17.25/23/28.75 138KV:34.5KV %Z:8	1
3. Auxiliary Power Transformer 1250KVA 34.5KV:480V %Z:5.75	1
4. BYD MC10C-B5365-U-R4M01	24

Notes:

1. THIS DRAWING REPRESENTS ONE PROPOSED ARRANGEMENT AND IS SUBJECT TO CHANGE BASED ON DETAILED DESIGN
2. THIS DRAWING IS CONCEPTUAL IN NATURE AND IS FOR PLANNING PURPOSES ONLY. IT IS NOT FOR PROCUREMENT, DESIGN, OR CONSTRUCTION.
3. POWER EXPORT AT INVERTERS WILL BE CONTROLLED BY ENERGY MANAGEMENT SYSTEM TO MEET REAL AND REACTIVE POWER REQUIREMENTS AT POI
4. MAIN POWER TRANSFORMER WILL BE FILLED WITH SR3 OIL FOR ENVIRONMENTAL SAFETY

Conductor Sizing:



$P = \sqrt{3} \times V \times I \times PF$

$\rightarrow I = \frac{P}{\sqrt{3} \times V \times PF}$

Assumptions:

- Aluminum lines
- PF = 1.0 (worst case scenario)
- Low V side – use min V to calc. max Amps in line
- Directly buried in Earth
- using ambient temp of 40°C for low-voltage lines

References from NEC code 2020 version

Medium voltage: Table 311.60(C)(86) – Pg. 180

- MV105
- two circuits
- Triplexed – directly buried in Earth

Low voltage: Table 310.16 – Pg. 164

- Aluminum
- 90°C rated temp

Ampacity correction factors

- Table 310.15(B)(1) – Pg. 162
- Correction factor = 0.91

NOTES:

◆ Communication cables not included

◆ Will need to size up wires when short-circuit studies begin

$\frac{1250\times10^3}{\sqrt{3}\times34.5\times10^3\times1} = 20.92A$

20.92 + 82.74 = 103.66A

103.66 + 82.74 = 186.39A

186.39 + 82.74 = 269.13A

$\therefore 248.21 + 269.13 = \frac{517.34A}{2} = 258.67A$

$\frac{4\times1236\times10^3}{\sqrt{3}\times34.5\times10^3} = 82.74$

82.74 × 2 = 165.47A

82.74 × 3 = 248.21A

$\frac{1250\times10^3}{\sqrt{3}\times480} = 1503A$

500 × 4 × 0.91 = 1820A

Cable $C_1 - C_{30}$

P = 38kVA (spec sheets)

$\left[\begin{array}{l} C_1 - C_{24} \rightarrow \text{battery } A_1 - B_{12} \\ C_{25} - C_{30} \rightarrow \text{PCS } 1-6 \end{array}\right]$ *

$\frac{38\times10^3}{\sqrt{3}\times480} = 45.71 \times 1.2 \text{(rated current)} = 54.84A$

usable DC energy

$\frac{4946 \text{ kWh}}{4 \text{hr}} = 1236.5 \text{kW}$

→ use minimum voltage to maximize current

V = 1075 Vac

* Parallel Conductors* → 4 conductors

$P = VI \rightarrow I = \frac{P}{V}$ → T rating = 0.91

$\frac{1236\times10^3}{1075} = 1149.767$

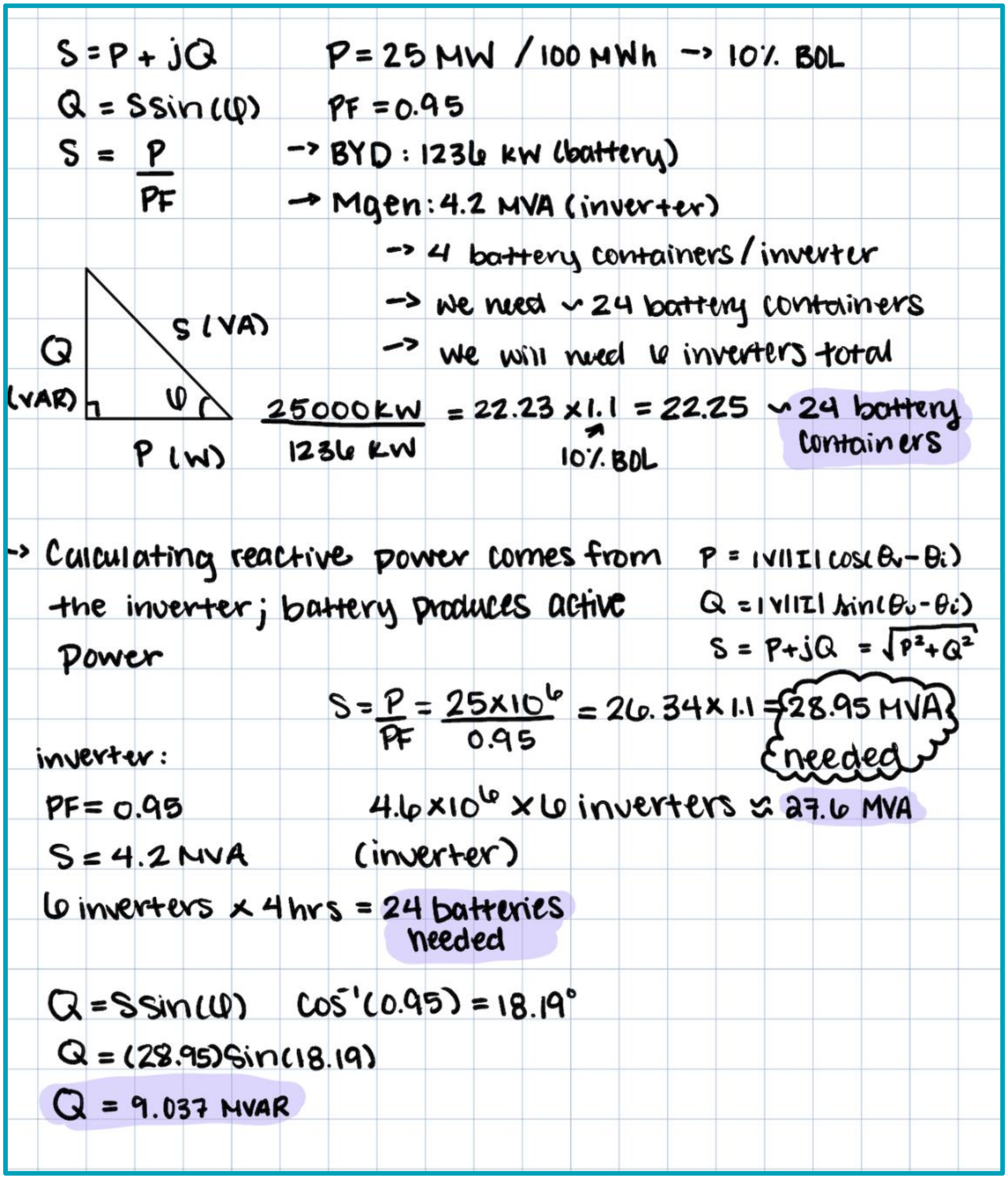
1. Take 500 kcmil ~ 380A
2. determine how many conductors : ④
   350 × 4 = 1400
3. T rating : 1400 × 0.91 = 1274 A ✓

use no more than 500–750 kcmil b/c standard wiring for DC batteries. Battery window has max size of cables that will fit.

* 1503A → doesn't go up that high; need more conductors/phase

1. Choose conductor size – 1000 kcmil ~ 500A
2. multiply ampacity by # of conductors – 4/phase
3. multiply by T rating – 0.91
4. Size up ; NOT too much ~ 1820A ✓

Battery Calculations



$S = P + jQ$ $P = 25$ MW / 100 MWh → 10% BOL

$Q = S\sin(\varphi)$ $PF = 0.95$

$S = \frac{P}{PF}$ → BYD: 1236 kW (battery)

→ Mgen: 4.2 MVA (inverter)

→ 4 battery containers / inverter

→ we need ~24 battery containers

→ we will need 6 inverters total

$\frac{25000\,kW}{1236\,kW} = 22.23 \times \underset{\uparrow \; 10\%\ BOL}{1.1} = 22.25$ ~24 battery containers

→ Calculating reactive power comes from the inverter; battery produces active power

$P = |V||I|\cos(\theta_v - \theta_i)$

$Q = |V||I|\sin(\theta_v - \theta_i)$

$S = P + jQ = \sqrt{P^2 + Q^2}$

$S = \frac{P}{PF} = \frac{25\times10^6}{0.95} = 26.34 \times 1.1 = 28.95$ MVA needed

inverter:

$PF = 0.95$

$S = 4.2$ MVA

$4.6\times10^6 \times 6$ inverters ≈ 27.6 MVA

(inverter)

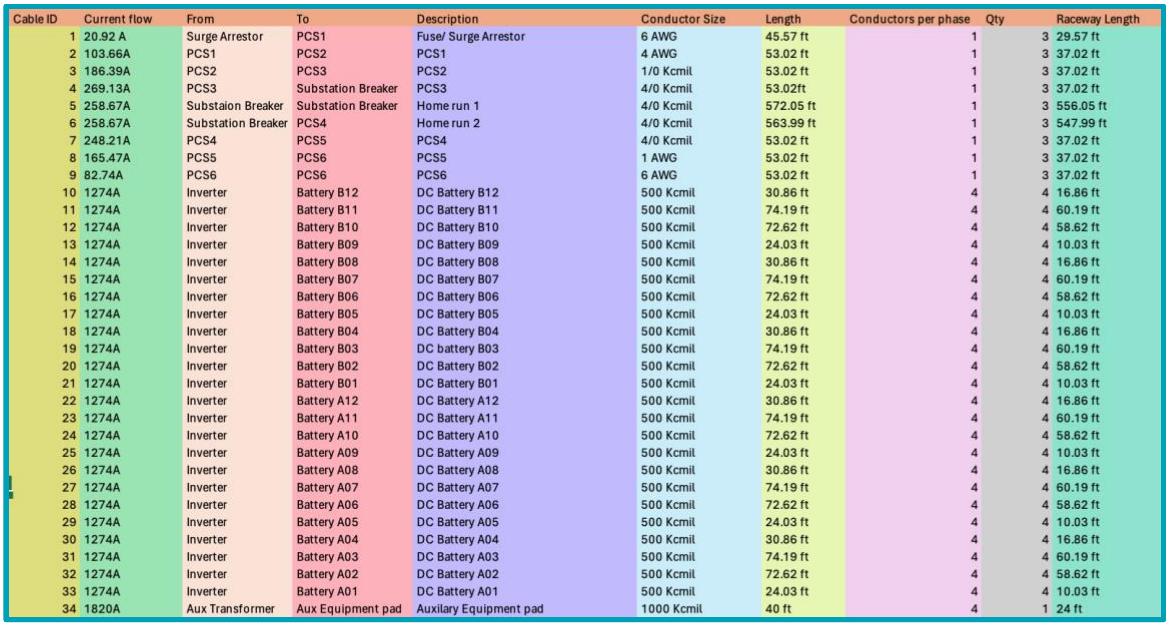
6 inverters × 4 hrs = 24 batteries needed

$Q = S\sin(\varphi)$ $\cos^{-1}(0.95) = 18.19°$

$Q = (28.95)\sin(18.19)$

$Q = 9.037$ MVAR

Cable Schedule



Cable ID	Current flow	From	To	Description	Conductor Size	Length	Conductors per phase	Qty	Raceway Length
1	20.92 A	Surge Arrestor	PCS1	Fuse/ Surge Arrestor	6 AWG	45.57 ft	1	3	29.57 ft
2	103.66A	PCS1	PCS2	PCS1	4 AWG	53.02 ft	1	3	37.02 ft
3	186.39A	PCS2	PCS3	PCS2	1/0 Kcmil	53.02 ft	1	3	37.02 ft
4	269.13A	PCS3	Substation Breaker	PCS3	4/0 Kcmil	53.02ft	1	3	37.02 ft
5	258.67A	Substaion Breaker	Substation Breaker	Home run 1	4/0 Kcmil	572.05 ft	1	3	556.05 ft
6	258.67A	Substation Breaker	PCS4	Home run 2	4/0 Kcmil	563.99 ft	1	3	547.99 ft
7	248.21A	PCS4	PCS5	PCS4	4/0 Kcmil	53.02 ft	1	3	37.02 ft
8	165.47A	PCS5	PCS6	PCS5	1 AWG	53.02 ft	1	3	37.02 ft
9	82.74A	PCS6	PCS6	PCS6	6 AWG	53.02 ft	1	3	37.02 ft
10	1274A	Inverter	Battery B12	DC Battery B12	500 Kcmil	30.86 ft	4	4	16.86 ft
11	1274A	Inverter	Battery B11	DC Battery B11	500 Kcmil	74.19 ft	4	4	60.19 ft
12	1274A	Inverter	Battery B10	DC Battery B10	500 Kcmil	72.62 ft	4	4	58.62 ft
13	1274A	Inverter	Battery B09	DC Battery B09	500 Kcmil	24.03 ft	4	4	10.03 ft
14	1274A	Inverter	Battery B08	DC Battery B08	500 Kcmil	30.86 ft	4	4	16.86 ft
15	1274A	Inverter	Battery B07	DC Battery B07	500 Kcmil	74.19 ft	4	4	60.19 ft
16	1274A	Inverter	Battery B06	DC Battery B06	500 Kcmil	72.62 ft	4	4	58.62 ft
17	1274A	Inverter	Battery B05	DC Battery B05	500 Kcmil	24.03 ft	4	4	10.03 ft
18	1274A	Inverter	Battery B04	DC Battery B04	500 Kcmil	30.86 ft	4	4	16.86 ft
19	1274A	Inverter	Battery B03	DC battery B03	500 Kcmil	74.19 ft	4	4	60.19 ft
20	1274A	Inverter	Battery B02	DC Battery B02	500 Kcmil	72.62 ft	4	4	58.62 ft
21	1274A	Inverter	Battery B01	DC Battery B01	500 Kcmil	24.03 ft	4	4	10.03 ft
22	1274A	Inverter	Battery A12	DC Battery A12	500 Kcmil	30.86 ft	4	4	16.86 ft
23	1274A	Inverter	Battery A11	DC Battery A11	500 Kcmil	74.19 ft	4	4	60.19 ft
24	1274A	Inverter	Battery A10	DC Battery A10	500 Kcmil	72.62 ft	4	4	58.62 ft
25	1274A	Inverter	Battery A09	DC Battery A09	500 Kcmil	24.03 ft	4	4	10.03 ft
26	1274A	Inverter	Battery A08	DC Battery A08	500 Kcmil	30.86 ft	4	4	16.86 ft
27	1274A	Inverter	Battery A07	DC Battery A07	500 Kcmil	74.19 ft	4	4	60.19 ft
28	1274A	Inverter	Battery A06	DC Battery A06	500 Kcmil	72.62 ft	4	4	58.62 ft
29	1274A	Inverter	Battery A05	DC Battery A05	500 Kcmil	24.03 ft	4	4	10.03 ft
30	1274A	Inverter	Battery A04	DC Battery A04	500 Kcmil	30.86 ft	4	4	16.86 ft
31	1274A	Inverter	Battery A03	DC Battery A03	500 Kcmil	74.19 ft	4	4	60.19 ft
32	1274A	Inverter	Battery A02	DC Battery A02	500 Kcmil	72.62 ft	4	4	58.62 ft
33	1274A	Inverter	Battery A01	DC Battery A01	500 Kcmil	24.03 ft	4	4	10.03 ft
34	1820A	Aux Transformer	Aux Equipment pad	Auxilary Equipment pad	1000 Kcmil	40 ft	4	1	24 ft

9. Team

9.1. TEAM MEMBERS

Oksana Grudanov– Team Leader; Sizing conductors and creating a cable schedule

Sarah Ebert– Team Organizer; One-line diagram research

James Mendenhall – Documentation Leader; Technical documentation for the project and the status report updates; responsible for the final draft of one-line created in AutoCAD

Cole Dustin - Point of Contact; Responsible for site layout in AutoCAD

9.2. REQUIRED SKILL SETS FOR YOUR PROJECT

- AutoCAD
- One-line Diagram Analysis
- Cable Sizing
- Communication
- Ability to Implement NEC Code

9.3. SKILL SET COVERED BY THE TEAM

James Mendenhall - AutoCAD, One-line Diagram Analysis, Cable Sizing, Communication

Cole Dustin- AutoCAD, Cable Sizing, Communication, Ability to Implement NEC Code

Sarah Ebert- AutoCAD, One-line Diagram Analysis, Cable Sizing, Communication

Oksana Grudanov- AutoCAD, One-line Diagram Analysis, Cable Sizing, Communication, Ability to Implement NEC Code

9.4. PROJECT MANAGEMENT STYLE ADOPTED BY THE TEAM

Our management style amongst our team was a round-table approach. We took feedback from our client and worked together to create and update our solution.

9.5. INITIAL PROJECT MANAGEMENT ROLES

Weekly Meeting Times: Thursdays at 2:00 pm in SIC

Meeting with faculty and industry point of contact: Mondays at 3:00 pm via Teams

Additional meeting times as necessary: Monday, Tuesday, and Wednesday evenings

Communication: Day-to-day: Text and email

Meeting virtually: Microsoft Teams

Decision-making policy: We will come to a consensus on issues. If we have differing opinions, we will work out a compromise that includes everyone's ideas.

Record keeping: Cole will keep track of what we did in the weekly meetings and record our goals for what to complete before the next meeting in a single Google doc. We will all be able to edit this document and record notes from work we do outside of the weekly meeting. We will reference this document to help keep track of our goals and what each group member is contributing.

9.6 Team Contract

Team Members: Sarah Ebert, James Mendenhall, Cole Dustin, Oksana Grudanov

Team Procedures

Weekly Meeting Times: Thursdays at 2:00 pm in the library

Meeting with faculty and industry point of contact: Mondays at 3:00 pm via Teams

Additional meeting times as necessary: Monday, Tuesday, and Wednesday evenings

Communication: Day-to-day: Text and email

Meeting virtually: Microsoft Teams

Decision-making policy: We will come to a consensus on issues. If we have differing opinions, we will work out a compromise that includes everyone's ideas.

Record keeping: Cole will keep track of what we did in the weekly meetings and record our goals for what to complete before the next meeting in a single Google doc. We will all be able to edit this document and record notes from work we do outside of the weekly meeting. We will reference this document to help keep track of our goals and what each group member is contributing.

Participation Expectations

Attendance: Everyone is expected to attend all weekly meetings and meetings with industry point of contact. Each team member should make it a priority to keep this time available and work on tasks for our project during the meeting (not doing other coursework).

If you are unable to attend a meeting, give a couple of hours' notice to team members (via text).

Deadlines: Our team's schedule will allow some flexibility with the exact date we meet our goals. Communication with the group via text is expected if a team member is unable to meet a deadline on our timeline.

Communication: Before submitting any work, group members should notify the team for approval. Members should keep track of work they do outside of team meetings in the shared team meeting document. This will ensure that everyone is aware of other team members' progress.

Leadership

James: (Document Reporter) Technical Documentation for the project and status report updates

Oksana: (Leader) Keeping the team on track and making sure we stick to a timeline we create

Cole: (Point of Contact/ Communicator) Sending emails, scheduling meetings, Record Keeping

Sarah: (Organizer, editing, and submitting) Organizing documents, editing final drafts, making things look presentable

Strategies for effective teamwork

We will try to work as a team as much as possible and not break the project up into tasks that we complete individually. In meetings, we will make sure that all team members have the opportunity to voice their opinions. In order to recognize the contributions of all team members, we will keep detailed records of our individual and team progress.

Collaboration and Inclusion

James: I will always respond to others in a timely manner and make sure everyone is heard. I will be as flexible as possible with others and their time constraints.

Oksana: I have taken power classes and have an understanding of the basic concepts needed to succeed in this project. I will respond to everyone in a timely manner and make an effort to be inclusive to everyone.

Cole: I have experience working in teams on multiple types of projects in different environments. I like to learn new things, so I am excited to take what I have learned at Iowa State and apply it to this project.

Sarah: I have experience doing research with lithium-ion batteries, so I have a good understanding of their chemistry and operation. I am very detail-oriented and organized.

To support and encourage ideas from all team members, we will make sure every group member has the opportunity to voice their opinions/ideas/concerns by including everyone in every conversation. We will also rotate who is presenting/leading meetings every week.

If collaboration/inclusion issues arise, we will encourage team members to voice their concerns during team meetings.

Goal Setting

Team goals: This semester, we will select appropriate equipment (battery, inverter, cables, etc.), complete a one-line diagram, and do the site layout. Next semester, we will complete load flow/short circuit/arc flash studies and consider construction logistics.

Keeping on task: We will create a detailed timeline with dates and goals (minor tasks and major deadlines) to keep on task. Oksana will hold us accountable for this and update the dates/goals as needed. Cole will be responsible for being the point of contact between the company and setting up meetings.

Assigning individual and teamwork: To decide who will work on different tasks, we will discuss the responsibilities with our point of contact. The work will be divided up based on our roles and availability.

Consequences for not adhering to the contract

We will be lenient for occasional infractions. We understand that this course will not always be the top priority.

For repeated offenses, problems will be discussed as a team. If behavior does not improve in a timely manner, the course instructor will be notified. We will communicate with the entire team before any actions are taken.

****

a) I participated in formulating the standards, roles, and procedures as stated in this contract.

b) I understand that I am obligated to abide by these terms and conditions.

c) I understand that if I do not abide by these terms and conditions, I will suffer the

consequences as stated in this contract.

1) Oksana Grudanov DATE: 16 Apr 2024

2) Sarah Ebert DATE: 16 Apr 2024

3) Cole J Dustin DATE: 16 Apr 2024

4) James Mendenhall DATE: 16 Apr 2024