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, Schedule, and Thermal Analysis

James Mendenhall - Document Report; One-line diagram; Cable Sizing and Analysis

Sarah Ebert - Organizer & Editor; One-line diagram; Arc Flash and Short Circuit Analysis

Cole Dustin - Point of Contact; AutoCAD site layout; ETAP Model and Study Lead

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

Executive Summary

Renewable energy, such as wind and solar, is a rapidly growing sector in the energy market. However, wind and solar energy generation fluctuate with weather. With increasing demand for sustainable energy, added battery capacity is necessary to optimize these renewable energy resources to provide clean power when wind and solar energy are insufficient and to store energy when wind and solar energy generation exceed demand.

Our product enables the use of clean energy in Ames and sheds load during peak energy demand. This product is designed to provide 25 MW of power for 4 hours to ensure energy efficiency and reliability to compensate for uncertainty in renewable energy. For this project, our client, Burn & McDonnell, asked us to provide approximately 30% of the necessary deliverables to complete this project. This includes, but is not limited to, site layout, required materials, one-line diagrams, cable schedule, short-circuit analysis, arc-flash analysis, and cable thermal analysis. This project is strictly hypothetical as the cost of fully implementing of this design would exceed USD 100 million.

For our site layout, we selected a flat 15-acre plot of land that has a point for on-site grid interconnectivity as well as highway access for expedited construction. We modeled our site layout and our one-line diagrams using AutoCAD. The one-line diagrams provide a high-level summary of the components, including the transformers, inverters, batteries, and auxiliary power and their connections, as well as an abridged bill of materials. After the transformers, batteries, and inverters were selected, cables were sized using the NFPA 70 NEC 2020 to tie together components of the BESS.

Electrical Transient and Analysis Program (ETAP) software was used to complete our system studies, including short-circuit, arc-flash, and cable thermal analyses. For cable thermal analysis, our cables were modeled and tested under loads to ensure their integrity would hold during worst-case loading conditions. After some revision our cable schedule was updated, which provides sizes and lengths for each cable. Next, we modeled our short-circuit analysis to confirm whether our protective devices, including fuses and relays, had the correct parameters and settings. Finally, our system underwent arc-flash analysis to provide arc-flash incident energy levels, distances, and boundaries to provide safety information for our client.

Overall, our design met the expectations of our client, even though there are some weaknesses in our system. Designing and building a battery energy storage system is a huge endeavor, and our project only encompasses the initial design and testing aspects. Much more work remains before this system can be constructed, but our team has provided detailed documentation of our work for future engineers to reference.

Learning Summary

DEVELOPMENT 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
- U/G Thermal Neher McGrath calculation module ETAP
- ANSI/IEEE C37 & UL489
- IEEE 1584-2018

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
- Pass case studies for short-circuit, arc flash power flow, and cable thermal

APPLICABLE COURSES FROM IOWA STATE UNIVERSITY CURRICULUM

- EE 456 Power Systems Analysis I
    - In-depth understanding of three-phase systems
    - Load flow analysis
- EE 457 Power Systems Analysis II
    - Fault studies
- EE 303 Energy Systems and Power Electronics
    - Basic understanding of three-phase systems

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)
- Practical understanding of utility standards and practices

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Definitions and Abbreviations Used

BESS: Battery Energy Storage System.

BOL: Beginning of Life

C-Rate: Measure of how quickly a battery is charged relative to its total capacity

NEC: National Electric Code

NFPA: National Fire Protection Agency

IEEE: Institute of Electrical and Electronics Engineers

ANSI: American National Standard Institute

POI: Point of Interconnection

PPE: Personal Protective Equipment

IEEE: Institute of Electrical and Electronics Engineers

KCMil: Thousand Circular

FCT: Fuse Clearing Time

NFPA: National Fire Protection Association

PCS: Power Conversion System

CLF: Current Limiting Fuse

EXF: Expulsion Fuse

MPT: Main Power Transformer

ETAP: Electrical Transient Analyzer Program

TCC: Time Current Curve

1. Introduction

1.1. PROBLEM STATEMENT

Our project attempts to solve one of the primary problems associated with transitioning to renewable energy. The power generation from renewable sources is variable and cannot match fluctuating demand. In other words, peak windy or sunny hours are inconsistent with when consumers use the most energy. The utility-scale battery energy storage system (BESS) we are designing addresses this problem by storing excess energy in batteries during peak production times and then released during periods of high demand.

1.2. PROJECT OVERVIEW

Our project is to create a design for a BESS that could be constructed in the Ames area. This hypothetical project will be located near the Ames substation and support wind and solar energy use and increase grid reliability. 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 the large lithium-ion batteries during periods of low demand. The batteries are discharged when demand increases, or generation decreases. Our client has specified that we will design a system that can provide 25 MW of power for 4 hours at a time (100 MWh).

The system will have a 30-year life cycle and two augmentations throughout its lifetime. It will also need a 10% overbuild at the beginning of life (BOL). This means that at the beginning of its life, it will exceed the power ratings so that it can still meet the 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 primary users of our system include the construction and maintenance teams and the local utility engineers. The secondary users are the residents of Ames, Iowa. 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 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 with 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 to 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 design because they will be able to monitor the power our system is generating and drawing easily, while helping provide green energy to the residents of Ames.

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.

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.
- Delivers energy for four hours continuously (100 MWh).
- 10% overbuild at BOL to compensate for battery degradation.
- Meets electric and safety standards.

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 requirements 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.

U/G Thermal Neher McGrath

This is the specific calculation method used by the cable thermal analysis module in ETAP used to calculate the underground cable temperatures and cable ampacity ratings.

IEEE 1584-2018

This standard was used for the arc flash tests on the low-voltage side of our system.

ETAP AC Arc Fault – High Voltage

This standard is built into the ETAP library and was used for the arc flash tests on the medium voltage side of our system.

ANSI/IEEE-C37 & UL 489

This standard is used for both low and medium-voltage short circuit analysis.

3. Project Plan

3.1. PROJECT MANAGEMENT/TRACKING PROCEDURE

We 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 the main power transformer.
    b. Follow industry standards and reference the training materials provided by our industry advisors.
5. Complete cable sizing calculations.
    a. Reference the equipment datasheets for equipment-rated voltage or power specifications.
    b. Reference completed one-line diagram for voltage levels and currents at different points in the system.
    c. Review NFPA NEC Code 2020 for various articles and tables.

    d. Determine the cable sizes based on calculations and NEC articles 310 and 311 for medium and low voltage lines.

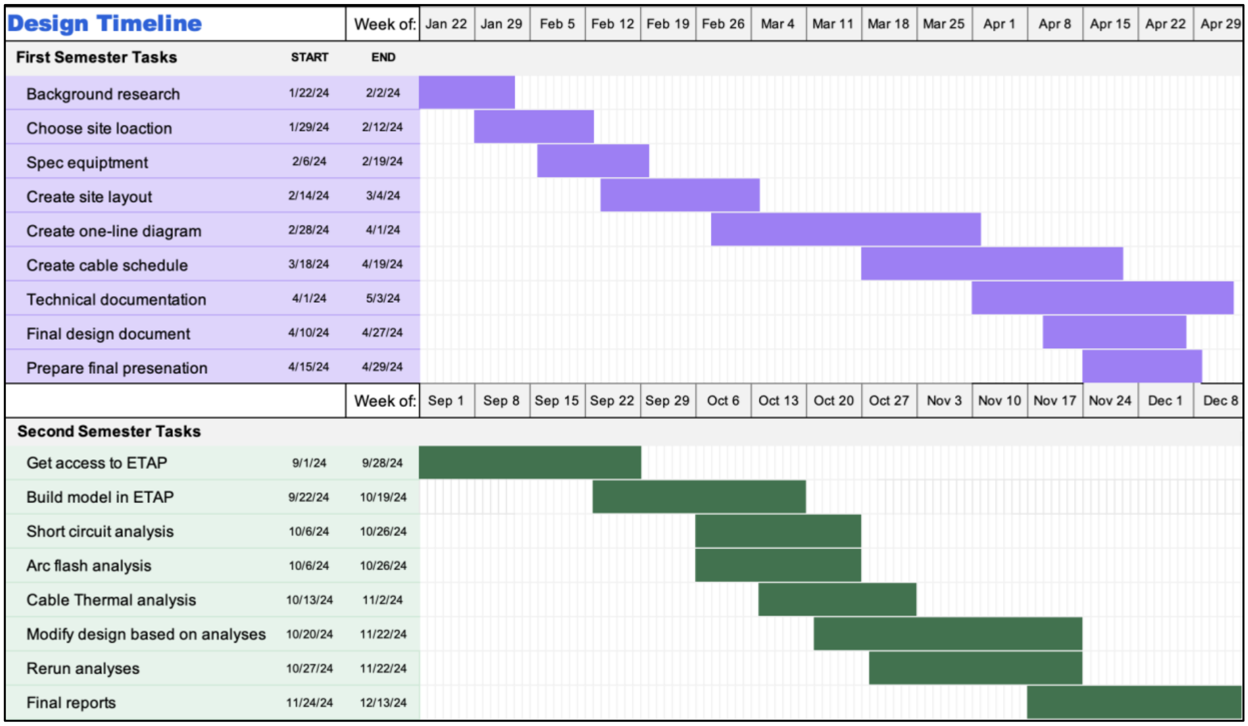
6. Learn how to use the software required to model our system
    a. ETAP (Electrical Transient Analyzer Program) is an industry-standard software used to model electrical systems under various conditions. It will allow us to test the reliability and safety of our design without a physical system.
    b. Enter the equipment ratings, line impedances, and load profiles to build our system in ETAP.
7. Complete short circuit, arc flash, and cable thermal analysis using ETAP.
    a. Arc flash – This test will show the amount of incident energy that will jump from a conductor to a ground point. Our tests make sure that all levels of the one-line diagram are safe for personnel and indicate what protective equipment they need. Arc flash can be mitigated with fuses and breakers that are properly coordinated and sized.
    b. Short Circuit – A short circuit happens when two electrical components at different voltages have direct contact. This can be between two phases from the same line or line to ground. It will cause a tremendous current spike that can damage equipment if not properly handled. Short circuit can be mitigated with fuses and breakers that are properly coordinated and sized.
    c. Cable Thermal – This test shows how hot the cables will become under full loads considering soil temperature and ambient heating from nearby cables. Cables have a temperature rating that, if overheated, will lead to decreased life or even failure.
    d. Coordination – This test will show if the protective equipment trips in the proper order to ensure that expensive equipment will not be damaged. We analyzed time-current curves, which shows the amount of time and current that will cause the protective equipment to trip, melt, or explode.
    e. Cable thermal analysis calculates the cable temperature and ampacity rating after the cables have been loaded long enough to reach steady state. ETAP uses the U/G Thermal Neher-McGrath calculation method. This specific method uses user-defined values such as a load factor as opposed to other methods that assume a unity load factor (LF=1)
8. Compile all our work into one report.
    a. 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 their 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 covers the main tasks for the first and second semesters of senior design and the time that our team worked on them.



First Semester Tasks	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

Second Semester Tasks		
Get access to ETAP	9/1/24	9/28/24
Build model in ETAP	9/22/24	10/19/24
Short circuit analysis	10/6/24	10/26/24
Arc flash analysis	10/6/24	10/26/24
Cable Thermal analysis	10/13/24	11/2/24
Modify design based on analyses	10/20/24	11/22/24
Rerun analyses	10/27/24	11/22/24
Final reports	11/24/24	12/13/24

Figure 1: Gantt Chart

The first two tasks identified correspond to steps one and two detailed in section 3.2. We spent most of our first week familiarizing ourselves with energy storage systems. After meeting with our industry partners and signing an NDA, we started 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 our system's most crucial pieces of equipment. After we decided 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 determined 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 four weeks. The last few tasks we completed in the first semester involved compiling our work with technical documentation.

The work we completed in the second semester of senior design consisted of analyzing our design from the first semester using ETAP software. After building our design in the software, we completed short circuit, arc flash, and cable thermal studies. Then, if the results of the studies revealed flaws in our design, we corrected our design and reran the studies. Lastly, we worked on the technical documentation and presentation.

3.5. RISKS AND RISK MANAGEMENT/MITIGATION

Table 1: Risk and 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.

Table 2: Time Worked

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 three 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	30 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	120 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	50 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 that could be implemented in Ames, Iowa. This section discusses the context of implementing BESS in 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, environmental, economic, and some cultural and social considerations related to installing this large, expensive system.

Table 3: Broader Context

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 and reasonable cost per KWh. The market for utility-scale battery energy storage systems is currently growing 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 36 MW of power from a wind farm near Zearing, Iowa [2]. While there are no similar systems in Ames, MidAmerican currently operates a small, 1 MW BESS in Knoxville, Iowa [3]. There is another similar 20 MW BESS in northern Illinois operated by Blattner Energy [4]. Our client, Burns and McDonnell, designed several battery energy storage facilities in West Texas and California for a total capacity of 60 MW [5].

4.1.3. Technical Complexity

Our design consists of several components and subsystems. The subsystems include batteries, inverters, cables, auxiliary power system, transformers, and system protection. The design deliverables for our project included a site layout, one-line diagram, cable schedule, and system testing. 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 required significant use of scientific and mathematical principles. We performed 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]. The operating BESS systems 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 chose. We found that the 0.25 C-rate (4-hour 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. Transformer cooling system are either liquid-based or 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 both a current limiting fuse (CLF) and an expulsion fuse (EXF) to protect the downstream equipment. 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 determining the technologies we would use, we had to balance several of the factors from the different manufacturers and types of batteries. We used a lotus blossom to figure out what was essential to the project and decided accordingly. 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.

4.2.3 Decision-Making and Trade-Off

We used several methods to narrow the choices when deciding the type of battery and inverter,. 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 the incompatible combinations, we looked at the number of batteries it would take to reach the 100 MWh threshold. Some models had lower capacities, which would require over 50 containers to meet power requirements. We decided on a range of 4 to 6 MWh. This led us to the BYD battery models, which all fell within this range. After we found the specific container model we wanted, it was a matter of balancing power and energy for each inverter.

4.3 FINAL 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. For our project, we first selected the major equipment models. Then, based on the equipment spec sheets we created a one-line diagram, site layout, and cable schedule for our BESS.

The system will be composed of three subsystems: the power conversion system, the batteries, and the auxiliary power system. 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), and the power conversion system changes this to a 60 Hz alternating current (AC) to match grid operation. 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. The high-level block diagram below (figure 2) shows how all these systems are connected. It also shows how our system interconnects to the distribution grid.

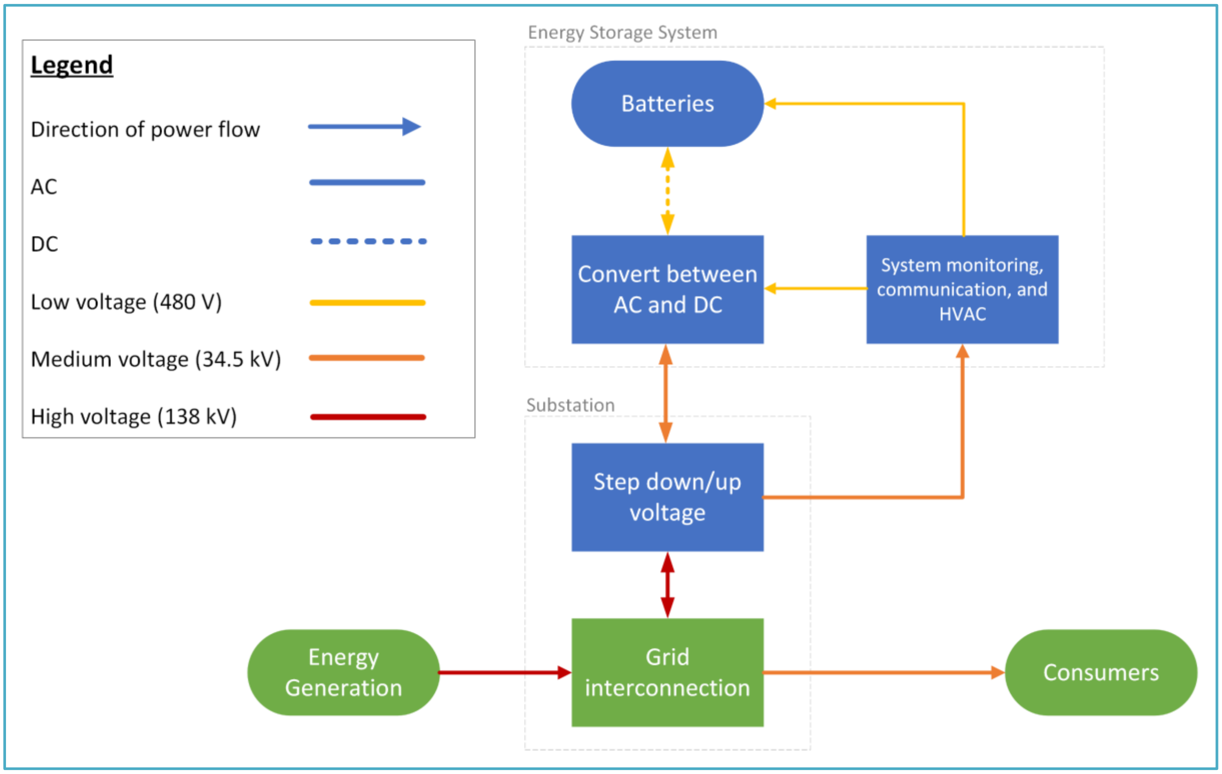


Figure 2: High-level block diagram of the battery storage system

4.3.2 Detailed Design

Equipment Selection Process

We chose to use BYD MC Cube battery containers (figure 3) in our BESS. These power rating of these batteries meant we needed 24 containers to meet the total power. This was ideal because it provided adequate system reliability while having a small enough footprint. In the case where one battery fails, the loss of power is less than 5%. They also had ideal ambient operating temperature range and can operate with many different models of inverters.

Capacity: 5365 kWh
Nominal Power: 1236 kW
Output Voltage: 1081.6 to 1497.6 V
Operational Ambient Temperature Range: −30° C to +55° C

Figure 3: BYD MC Cube Battery Container

Our BESS will use the Gamesa Electric Proteus PCS (figure 4) to convert to DC output power from the batteries to AC power. This power conversion system will perform optimally with the BYD battery model that we selected. The DC voltage range of these inverters fits the output voltage range of the battery containers. Additionally, the power rating allowed us to connect four battery containers to each inverter, so we need 6 PCS skids.

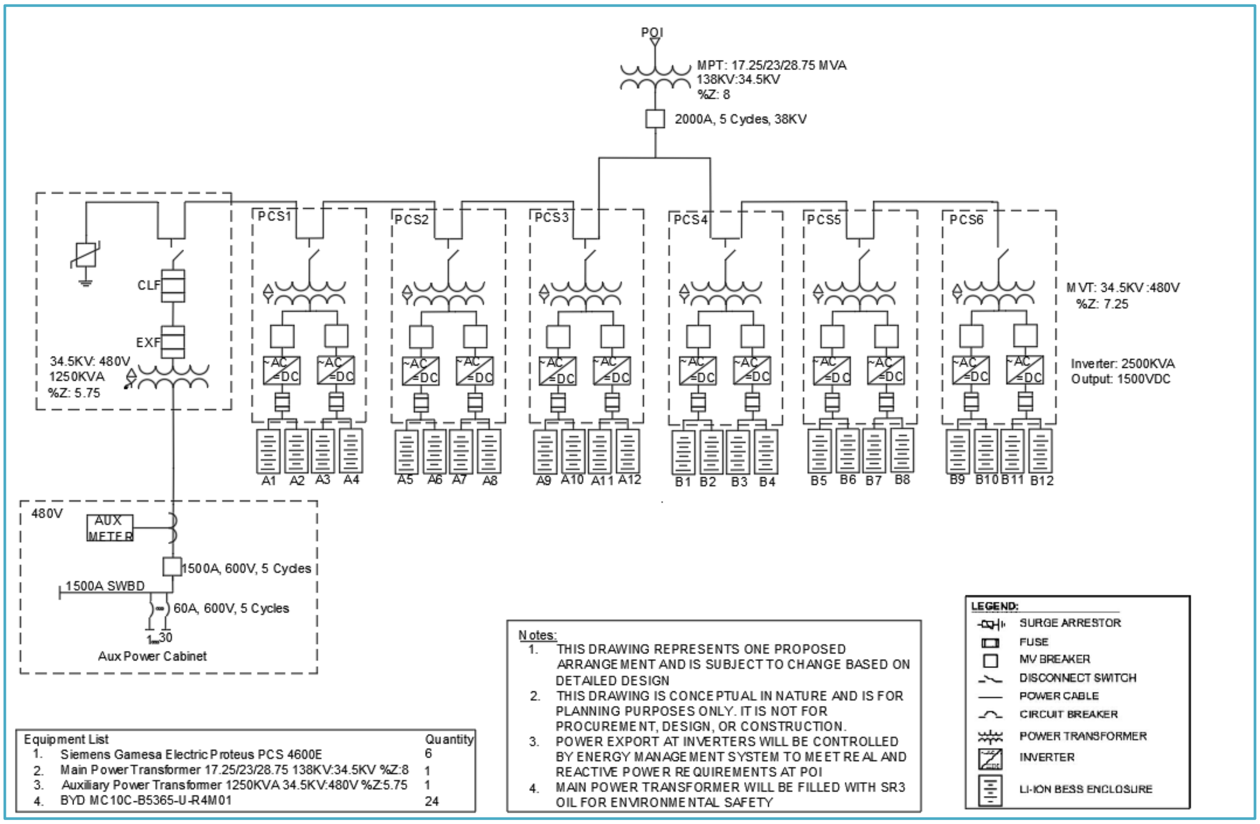
Output Power: 4607 kW
DC Voltage: 1075 to 1500 V
Operational Ambient Temperature Rating: −20° C to +60° C

Figure 4: Gamesa Electric Proteus PCS

One Line Diagram

To show the important electrical connections between the equipment in our BESS, we created a one-line diagram (figure 5). A one-line diagram (or single-line diagram) is a simplified representation of a three-phase power system, showing a single line for each phase, and standard symbols for different equipment. It does not show the physical layout of the system, instead showing the flow of power through the system from the top of the page to the bottom. It also shows important information, such as the transformers' substation voltage and voltage ratios. This allows us to communicate our design to other engineers easily.

Our one-line diagram shows the point of interconnection (POI) to the power grid at the top and a main power transformer (MPT), which are located in the existing adjacent substation. From this, two homeruns, or cables, connect the substation to the energy storage system. One of the homeruns connects three of the inverters in series, and the second homerun connects the other three inverters and the auxiliary power system in series. Each inverter converts AC power to DC power, and vice versa, for four battery containers. The auxiliary (aux) power system consists of a step-down transformer, a switch board, and the auxiliary power cabinet.



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

Figure 5: One-line Diagram

Main Power Transformer Sizing

The bidirectional MPT steps voltage down from the high voltage at the POI, which is assumed to be 138 kV, to 34.5 kV. It will also step up the voltage when the batteries are discharging. We sized it based off the nameplate rating of the site, which is 25 MW. Using factor of 0.69 to determine the minimum operation limit, 0.92 for the nominal rating, and 1.15 for the peak operation limit, the transformer can be sized to perform optimally in many different conditions. These factors are an industry standard for the design of a BESS.

Minimum operation limit: $0.69 \bullet 25 = 17.25\ [\text{MVA}]$

Nominal rating: $0.92 \bullet 25 = 23\ [\text{MVA}]$

Peak operation limit: $1.15 \bullet 25 = 28.75\ [\text{MVA}]$

MPT Rating: 17.25/23/28.75 MVA

The feeder breaker connected to the MPT protects the downstream equipment from overcurrent. Medium voltage circuit breakers are typically either 1200 A or 2000 A. A 1200 A breaker 4 would be sufficient considering the current in this part of the system, but to allows for future expansion, a 2000 A breaker was used in our one-line.

Auxiliary Power System Sizing

The auxiliary (AUX) power system powers the HVAC equipment, communication devices, and fire detection equipment among others in the battery containers and PCS skids. The equipment involved in this system operates on 480 V, so a transformer is needed to step down the string voltage of 34.5 kV. In this BESS, only one auxiliary transformer and cabinet are necessary.

The BYD battery model specifies that the auxiliary power system usage is 38 kVA at its peak. The total auxiliary power consumption is found with the following equation considering that there are 24 battery containers. The PCS doesn't need power from the aux system. Its aux system is powered parasitically, so it is accounted for in the AC power total value of 4950 kVA in the Gamesa PCS spec sheet. The auxiliary transformer is rated based on the power consumption value with a 25% overbuild. In the one-line, the transformer rating is 1250 kVA, which is the calculated rating rounded up to the nearest standard size.

Aux power consumption: $38[\text{kVA}] \bullet 24 = 912\ [\text{kVA}]$

Transformer rating: $912[\text{kVA}] \bullet 1.25 = 1140\ [\text{kVA}]$

To protect the aux transformer and downstream equipment, the system uses a surge arrestor, current limiting fuse (CLF), and an expulsion fuse (EXF). The surge arrester protects against overloading by limiting voltage through discharging surge current. The CLF and EXF work together to protect the transformer because the CLF can interrupt very large shorts while the EXF is fast-acting.

The aux power cabinet contains a switchboard to control the flow of electricity in the BESS and protect form overloading and shorts. It consists of a circuit breaker and switches and is sized based on the total current in this part of the system. Considering the aux power consumption and voltage level, the current is given below. A 25% overbuild is also necessary here, and so the final switch board rating is given as 1500 A in the one-line. This is again due to rounding up to the nearest standard manufactured size.

$$\textbf{Auxiliary current: } \frac{912[\text{kVA}]}{\sqrt{3}\bullet 480[\text{V}]} = 1100\ [\text{A}]$$

$$\textbf{Current with overbuild: } 1100[\text{A}] \bullet 1.25 = 1380[\text{A}]$$

The final part of the aux power system that we sized are the feeder breakers, which protect from overloading on the cables running to each battery container and PCS's auxiliary power input. There are 30 of these breakers because is one for each of the six PCSs and 24 batteries. The current rating is found from the equipment's rated aux power usage with a 25% overbuild. These feeders are not shown on the diagram. Instead, they are numbered 1 to 30 with a note on the bottom.

$$\textbf{Switchboard feeder breaker rating: } \frac{38[kVA]}{\sqrt{3}\bullet 480[V]} \bullet 1.25 = 46[A] \bullet 1.25 = 58[A] \approx 60[A]$$

Medium Voltage Cable Design

In our system, the nominal voltage level on the homeruns, which run from the substation to the energy storage system, are 34.5 kV. There are two homeruns which will daisy chain the PCS skids and aux power system. Using two homeruns limits the current, and daisy chaining avoids connecting too many pieces of equipment to one bus, which both increase the system's resiliency.

The maximum loading on one string is determined by dividing the power rating of a 1000 KCMIL cable by the power of one PCS skid. The AC power of the Gamesa Proteus PCS used is 4950 kVA. Considering that the auxiliary equipment needs to be attached at the end of one of the strings, its power consumption of 1.25 MVA needs to be factored in as well.

$$\textbf{Maximum number of PCS skids per string: } \frac{30\ [\text{MVA}]}{4.95\ [\text{MVA}]} = 6.1 \approx 6$$

$$\textbf{Number of PCS skids on string with aux equipment: } \frac{30[\text{MVA}]-1.25[\text{MVA}]}{4.95[\text{MVA}]} = 5.8 \approx 5$$

Our calculations show fewer than 6 PCS skids should be on one string. Because the BESS uses six PCS skids and one aux power system, three PCS skids will be daisy-chained on one string, and the aux power and the remaining three skids will be daisy-chained on the other. This will provide balance to our system and limit the power on any one part.

Power Conversion System and Battery Containers Sizing

As seen on the one-line, the power conversion is a simplified version of the schematic depicted in the Siemens Gamesa Proteus spec sheet. They contain a bidirectional transformer, which steps the voltage down from 34.5 kV to 480 V. There are two DC outputs, which allow for easier connection of more battery containers. Because of this, there are two parallel motorized AC circuit breakers, bidirectional inverters, and DC fuses. The bidirectional inverter is rated at 2500 kVA and has a DC input voltage of 1500 V.

The BYD battery containers in this system have an output DC voltage range of 1081-1498 V and a maximum discharge power of 1275 kW. Because each DC input of the PCS skid has a maximum current of 2227 A and the maximum voltage level is 1500 V, two batteries can be attached to each input. This results in four battery containers on each PCS skid.

$$\textbf{Maximum power per DC input: } 2227[\mathrm{A}] \bullet 1500[\mathrm{VDC}] = 3{,}340[\mathrm{kW}]$$

$$\textbf{Number of battery containers per DC input: } \frac{3340[\mathrm{kW}]}{1275[\mathrm{kW}]} = 2.6 \approx 2$$

Site Layout

Our BESS site is on a 10-acre plot on Ames on State Ave south of Mortenson Rd. The Ames location is ideal because of its proximity to a substation, the availability of land, and its location right off a wide paved road allows it to accommodate the large trucks needed to get equipment to the site. The AutoCAD drawing of our site below (figure 5) shows the 24 battery containers, six PCS skids, the underground cables, and the on-site roads.

We followed many industry standards to set the location of our equipment. We determined from the battery specification sheet that they must be placed 0.5 feet apart on the short side and 6.5 feet apart on the broad side. These distancing specifications have several purposes. It will allow the service doors to swing freely, provide proper cable space, and follow safety standards. We have chosen to keep the inverters 10 feet apart from the batteries. The equipment pad on the SE corner will house the switchboard, aux power cabinet, and auxiliary power transformer. The roads on the site are 20 ft wide, with the turns having an inner radius of 25 ft and an outer radius of 40ft. Cable location is critical for heat dissipation and construction; because of this, we need to know where the cables will be far before construction starts.

Figure 6: Site Layout AutoCAD Drawing

Cable Schedule

The cable schedule is a document used in the design process that outlines essential characteristics of the conductors used. Many documents were referenced from the NEC 2020 version to determine how the conductors would be sized for the design of the BESS. Articles 300, 310, and 311 were primarily used to determine the sizes and used to determine the insulation, ambient temperature, and cable rating temperatures. Assumptions were made in the design process, which helped decide and calculate this schedule.

Additionally, the process for determining the lengths will be detailed in this report. When we finally ran our cable system during testing, the cables were sized up accordingly based on minimum cable sizes allowed with the library selection in ETAP, as well as to ensure the max ampacity is not exceeded. These tests determined the conductor sizes previously calculated would not be able to withstand the load current without violating cable temperature limits as set by U/G Thermal Neher McGrath.

The assumptions we made to create the cable schedule are listed in detail below:

1. **Aluminum lines will be utilized for all wires, medium and low voltage.**
   Aluminum lines are much cheaper than copper lines, which was why this material was selected.
2. **Power Factor of 1.0**
   Assuming a power factor of 1.0 will ensure the calculations will be sized based on the "worst case" scenario.
3. **Cables will be directly buried in Earth.**
   Upon researching the NEC 2020 version, the most suitable table to reference would be directly buried in Earth [Table 311.60(C)(86)], although conduit was the original ask. The client approved the change, so long as it will be honored throughout the rest of the design process.
4. **Ambient temperature of 40 °C**
   When deciding on the ambient temperature, two options were presented: 40 °C or 30 °C. None had any advantage over the other, and so the assumption was made to be 40 °C. One thing is to be noted: with the use of this ambient temperature, the NEC article 310 needed to be referenced. Table 310.15(B)(1) was referenced to size the conductors by the appropriate correction factor.
5. **Use of minimum voltages in the DC batteries**
   The use of minimum voltage requirement listed in the datasheets of the BYD battery was utilized in the calculation process to ensure the calculations of the maximum current flow through a conductor. This ensures that the size of the conductor will be rated for the maximum current in the case of low-voltage operations.
6. **Changes may be necessary to conductor sizes once short-circuit analysis is run**
   In the case of a short-circuit fault, a spike in current could become present, making the amperage running through the line higher than what it is rated for. In this case, there is a risk of

overheating, so resizing the conductors may become necessary to ensure the reliability of the system.

7. **No communication or grounding cables will be accounted for currently**
   There will not be any sizes calculated for the communication cables to the batteries or inverters, and there will be no grounding cables. There is not enough time to determine these sizes, as it will need to reference different articles in the NEC and new types of conductors.
8. **Medium voltage cables will be of MV105**
   The medium voltage cables used between the inverters, fuses, and aux power will be of MV105. This means medium voltage (MV) and 105°C for the temperature rating.
9. **There will be two circuits of triplexed cables for the medium voltage lines**
   This is because we had two home runs. Because of that, we will have two circuits, and they will be triplexed. Triplexed cables are commonly used in overhead systems and consist of three cables twisted together. As our system for the medium voltage will be three-phase, we will have one conductor per phase.
10. **The low voltage cables will be rated for 90 °C**
    This assumption was made primarily because Iowa's weather fluctuates between hot and cold, so rating the cables at the highest temperature allowed per the NEC 2020 version table 310.16 was at 90 °C. The ambient temperature correction factor was based on this rated temperature.
11. **The low-voltage cables will be parallel conductors**
    Parallel conductors are cables that run parallel with one another, dividing up the current among them. The number of parallel conductors will be determined by the calculation process and approved by Burns & McDonnell.
12. **Cables will be sized up 3x over the recommended ampacity rating due to violations of cable thermal limits**
    When calculating the ampacity needed to select conductor sizes, the cables will be sized up three times over the recommended selection due to the cable thermal analysis indicating the cables were in violation of cable thermal limits, which is the maximum temperature a cable can withstand before overheating or degrading.
13. **The auxiliary equipment cables will be the only lines that are copper**
    When testing our cable system, we were unable to successfully pass the cable thermal analysis temperature rules using the aluminum lines as there was way too much current running through these conductors, and so we needed to change this to copper and split the conductors into two raceways to meet those requirements.

Once the cable assumptions were noted, we were able to begin the calculations for it. We used a three-phase power equation to calculate the ampacity running through the medium voltage lines, and a power equation for the DC battery cables.

$$\textbf{Medium Voltage Ampacity Equation: } \frac{\frac{Power\ Rating\ (VA)}{Voltage\ (V)}}{\sqrt{3}}$$

$$\textbf{DC Battery Ampacity Equation: } \frac{Power\ (W)}{Voltage\ (V)}$$

To calculate the ampacities, we first started off by calculating the medium voltage cables. Using our understanding of power flow, we needed to calculate from the outer PCS skids towards the home run cables that connect to the substation POI (Point of interconnection). Using the medium voltage equation detailed above, we used equipment specification datasheets to determine the power input, and voltage input for one PCS skid, and then using KCL, we continued to add the current from the outer PCS towards the home run. From the specification sheets, we found that each inverter has a power of 4.067 MVA, and the secondary voltage from the POI we used was 34.5 MV. When calculating the ampacities and size, we split it into two sections, right and left side, or home run cable 1 side, and home run cable 2 side. Beginning on the right side on the home run cable 2 we used this approach to calculate the ampacities:

$$I_{PCS6} = \frac{\frac{4.067 \cdot 10^6}{34.5 \cdot 10^3}}{\sqrt{3}} = \mathbf{77.097A}$$

Using the NEC article 311, the cable size that originally was selected was 6 AWG, however, we needed to size it up due to the failed cable thermal test and minimum cable size requirements from ETAP, we went with a cable size of 1/0. Next, since we used KCL to understand that the current continues to increase moving towards the home run cables, the next cable will have double the ampacity as the first cable as this cable will support two PCS skids.

$$I_{PCS5} = 2 \cdot I_{PCS6} = 2 \cdot 77.097 = \mathbf{154.194\ A}$$

As discussed above we needed to size up these cables as well. The first cable was sized up three times over the minimum size listed in the NEC, so the same process was used for this cable. Initially, we determined a cable size of 1 AWG would be needed, but after sizing it up, we determined it would be 2/0.

The next cable will be the home run cable 2, which will support three PCS skids. To calculate the ampacity for the home run cable, the same logic from above was used to determine the size

$$I_{HomeRun2} = 3 \cdot 77.097 = \mathbf{231.291\ A}$$

Initially this cable was intended to be 4/0, however, we sized it up to 350 KCMIL. After the right side of the home run cables, we moved on to the left side. One the left side, we also needed to calculate the ampacity running from the surge arrester cable. To do this, we used the same equation discussed above, however with new values determined from the specs sheets we chose for this specific equipment. The power input for this was 1250 kVA, and the voltage remained the same as above, 34.5 kV.

$$I_{Surge} = \frac{\frac{1250 \cdot 10^3}{34.5 \cdot 10^3}}{\sqrt{3}} = \mathbf{20.918\ A}$$

We determined a conductor size of 6 AWG for this cable initially, however, we sized it up to 1/0 to follow the same process as before. We continued to follow the same process, adding current on to the total until we reached the home run.

$$I_{PCS1} = 20.918 + \frac{4.067 \cdot 10^6}{\frac{34.5 \cdot 10^3}{\sqrt{3}}} = 98.016\text{A}$$

Initially, this cable was 4 AWG, however, we sized it up to 1/0.

$$I_{PCS2} = 20.918 + (2 \cdot 77.097) = \mathbf{175.112A}$$

Initially, this cable was sized to 1/0, but we sized it up to 3/0.

$$I_{Homerun1} = 20.918 + (3 \cdot 77.097) = \mathbf{252.209A}$$

Much like the other home run cable, this was initially 4/0 but sized up to 350 KMCIL following the same tread discussed above.

Next, we calculated low voltage cables: the auxiliary equipment and switchboard cables. To start, the auxiliary equipment pad cables had a large amount of current running through them, so we needed to create parallel conductors for this. In order to limit the large flow of current, we needed to add more conductors per each phase. We also had a maximum cable size of 1000 KMCIL we could not exceed, and this is also the reason we needed to add more conductors per phase.

Since we decided on 40 degrees Celsius for our ambient temperature of the cables, we needed to use NEC article 310.15 correction factor to calculate the ampacity correctly. The auxiliary transformer we used has a secondary voltage of 480, and the power rating for this XFMR is 1250 kVA. Using these values, we calculated the ampacity to be:

$$I_{Equip} = \frac{1250 * 10^3}{\frac{480}{\sqrt{3}}} = \mathbf{1503\ A}$$

1503 A is much too high of a current to run through a cable that is at or less than 1000 kmcil, so we need to break it down to parallel conductors which are two conductors with cables running in parallel to one another in order to lower the current so that we can use the maximum allowed cable size. Additionally, we selected an ambient temperature of 40 degrees Celsius and so we needed to use the correction factor as NEC 310.16 is rated for only 30 degrees Celsius ambient temperature. The reason behind the ambient temperature selection can be found above in the assumptions section of this cable schedule section.

In order to do parallel conductors, we need to follow these steps:

- Chose a conductor size to use: We decided to select 1000 KCMil as that is the largest allowed cable size we could use according to our clients' constraints. They suggested this as it is an industry standard to follow this constraint. 1000 KCMil is rated for current at 500 A

- Take the rated current for that line and multiply it by the number of conductors we would need. We decided on using 4 conductors per phase as by trial and error, we determined this gave us the best results.
- Use the NEC article 310.15 to find the correction factor. We found ours to be 0.91
- Multiply the rated current, number of conductors, and the correction factor together to find the rated current. Sizing up is important. When we did these calculations we got 500 * 4 * 0.91 = 1820A. 1820 A is much higher that 1503 A, so that shows us that the cable size and number of conductors would work well for us, and we would not exceed the temperature limitations.

We did however determine we needed to make a lot of change to this cable due to how hot the cable would get during a fault. We decided we needed to create parallel raceways and divide the current and conductors into different raceways, as well as change the material to copper. This allowed for us to stay below the 90 degrees Celsius rating limit we had with these cables.

Next, we calculated the auxiliary switchboard cables. To do this, we needed to get the power rating from the datasheets and determined that it would be 38 kVA and since this is on the secondary side of the auxiliary transformer, we will continue to use a voltage of 480 V. These cables will connect to each of the DC batteries for protection, and so all 24 cables will be calculated the same way and have the same sized cables.

$$I_{AUXSWBRD} = \frac{38*10^3}{\frac{480}{\sqrt{3}}} = \mathbf{45.707 * 1.25\ (Rated\ Current) = 57.134\ A}$$

We need to multiply this current by 125%. The reason we need to do this is because of the protection system off this cable. Most continuous circuit breakers are not rated for 100% load, and to protect the conductors from overheating during a fault, we need to apply the 125% rule so that the conductor can cool down. We decided to also size up these cables from 4 AWG up to 1/0 to allow for more protection in case of a fault.

Once we got the medium and low three phase cables calculated, we needed to calculate the DC battery cables. These calculations were a bit easier as we needed to only use ohms law. We also needed to do parallel conductors for these cables. We found calculated the power for these batteries by taking the kilowatt hour rating found in the spec sheets and dividing it by the 4 hours we need these batteries to charge/discharge.

$$P = \frac{4946\ kWhr}{4\ Hrs} = \mathbf{1236.5\ kW}$$

Next, we found the voltage in the spec sheets as well. We needed to use the minimum voltage rating for these batteries to maximize the current. This value was 1075 V.

$$I = \frac{P}{V} = \frac{1236.5*10^3}{1075} = \mathbf{1149.767\ A}$$

Much like the auxiliary cables, this current is much too high compared to the rated cable sizes in the NEC, and so we need to add more conductors per phase to limit the ampacity in a cable. Furthermore, according to the battery specification sheets, the maximum allowable conductor size will be 500-750 KCMil as standard wiring for DC batteries need to be at that size or smaller or the cables will not fit through the battery window. Following the same process, we chose a cable size of 500 KCMil, which is rated for 350 A, decided on 4 conductors per phase, and used the same correction factor of 0.91 to determine the ampacity and ensure it will work with the current we calculated. This was sufficent as it came to 1274 A, which is higher than the 1149 we calculated so these cables will work. We did not do any testing on these cables because our clients advised us to focus on the more critical AC conductors.

4.3.3 Functionality

Our 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, typically late at night. The system will then discharge when demand is highest. This typically happens in the late afternoon because household energy use peaks when people return home from work. Using stored energy results in more consistent energy prices throughout the day and better utilization of renewable energy sources. When the grid's energy storage is high enough, it can also reduce the need for higher capacity power plants if that capacity is only needed for a few days of the year.

4.3.4 Areas of Challenge

Since we work very closely with our clients at 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 the direction if it adheres to standards.

4.4 TECHNOLOGY CONSIDERATIONS

We are using relatively modern technologies, including the 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. Some benefits are the need for smaller fossil fuel plants and smoothing the cost of energy throughout the day. Another significant advantage is allowing renewable energy to be available even when it is dark or there is no wind.

Some disadvantages are that a significant portion of the energy cost will be 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 battery capacity degrades relatively quickly. This makes the project more expensive through overbuilding at BOL and augmentations throughout its life.

5. Testing

During the design process of a BESS, electrical studies are typically performed after all components and wires are selected and sized. The software we used to perform the electrical studies on our BESS design was the Electrical Transient and Analysis Program (ETAP). This software is commonly used by power system engineers to model different parts of the electric grid. Our clients decided this would be the ideal program because they are familiar with it and were able to help us learn how to use it and debug problems in our system.

Our studies examined how our system performs in the worst-case scenario. This consideration justifies our equipment selections and confirms that our equipment's safety ratings are adequately measured to keep technicians and equipment safe. Consulting regularly with our clients was crucial because they are experienced in the design of battery energy storage systems and were able to help us interpret results. We performed short circuit, arc flash, and cable thermal studies, which are described in the following sections.

Our testing involved the following steps were to verify our design choices.

1. Test equipment under worst-case scenario conditions.
2. Analyze whether design choices are sufficient using results from ETAP.
3. If equipment selections do not meet requirements, revisit design choices, specifications, capacities, and protection equipment selection.
4. Ensure arc-flash boundaries are sufficient for technicians to service equipment.
5. Finalize testing parameters and results.

5.1. SHORT-CIRCUIT ANALYSIS

We used short circuit analysis to examine how our system behaves during a fault, including line-to-line, line-to-ground, and three-phase faults. This determines the fault current levels throughout the system, which are used to determine proper protective equipment. The fuses and breakers must be sized to handle the maximum fault current to prevent damage to equipment. Based on the results from this analysis, we can ensure that system components, including our fuses, breakers, cables, and equipment, can withstand and isolate faults.

Methodology

In our short circuit analysis, we focused on 3 phase faults. We faulted the medium voltage buses (34.5 kV), and the low voltage buses (480 V and 760V) separately at a 0.95 and a 1.05 power factor. To perform a short circuit analysis, we sized the transformers, cables, inverters, and batteries based on the work we did last semester. Setting up the short circuit study in ETAP involved configuring the settings for the test four cases. To do this we needed to open edit study case details and update the faulted buses, standards used, and pre-fault voltage.

We concluded whether our system passes the short circuit test cases by comparing the fault currents at each bus to a maximum value. Based on industry standards, the maximum allowable short circuit current is 25 kA for medium voltage buses and 65 kA for low voltage buses. We also found the maximum allowable short circuit currents for each of our medium voltage cables, including both home runs and the cables connecting the PCS skids. The equation for insulated aluminum conductors rated for 105° C continuous operation is given as follows:

$$\left(\frac{\mathrm{I}}{\mathrm{A}}\right)^2 \mathrm{t} = 0.0125 \log\left(\frac{\mathrm{T}_2+228}{\mathrm{T}_1+228}\right)$$

Where:

I = short circuit current (amperes)

A = conductor area (circular mils)

t = time of short circuit (seconds) - 0.25 seconds

T_1 = maximum operating temperature - 105° C

T_2 = maximum short circuit temperature - 250° C

This equation can be used to find the minimum conductor for a given short circuit current or the maximum short circuit current a given conductor can withstand. We also used this equation to verify our cable sizing after completing the short circuit studies.

Results

The results from the short circuit studies indicate that our system is properly protected in the event of a fault. Table 4 includes the three phase, line-to-ground, and line-to-line fault currents and the short circuit withstand ratings for each category of bus in our system. Table 5 shows the worst-case cable fault current withstand ratings for the medium voltage side of our system. The short circuit current values for buses in our system are below the industry standard withstand ratings, as seen in table 4 below. They were also below the calculated cable fault current ratings, as seen in table 5.

Table 4: Worst Case Short Circuit Current Value for AC Terminals

Equipment (1.05 PF)	3-Phase (kA)	L-G (kA)	L-L-G (kA)	SC Withstand Ratings (kA)
Home Run Bus (34.5 kV)	5.744	5.897	5.061	25
PCS Skid High Side Terminals (34.5 kV)	5.682	5.797	4.986	25
PCS Skid Low Side Terminals (760 V)	47.071	49.715	41.256	65
Aux Power System High Side Terminal (34.5 kV)	5.662	5.784	4.979	25
Aux Power System Low Side Terminal (480 V)	28.604	28.995	24.772	65

Table 5: Short Circuit Withstand of Aluminum Conductors

Worst case MV Cable ID	Conductor Size	Clearing Time (cycles)	Calculated Cable Fault Current Rating (kA)	System 3P Fault (kA)
Homerun (Cable ID:4)	350 KCMil	15	31.01	5.74
PCS 1-2 (Cable ID: 2)	1/0 AWG	15	9.39	5.67

5.2. EQUIPMENT COORDINATION ANALYSIS

The protective devices in our system must be coordinated to operate effectively. Coordination means the protective device closest to the fault operates first, leaving upstream devices unaffected. This prevents unnecessary disconnection of the entire system and minimizes downtime. It may also reduce arc flash incident energy because the faults can be cleared faster. Time current curves (TCC) are used to visualize the coordination of a system graphically by representing the relationship between the operating time of a protective device and the magnitude of current passing through it. By analyzing the positions of the curves relative to one another, we can ensure that the downstream devices operate faster than the upstream devices.

Methodology

To evaluate the coordination of our equipment using the TCC graphs, we compared the positions of the curves for the protective devices relative to the damage curves for equipment they protect. The graphs axes are on a logarithmic scale and are read from bottom to top and left to right. The curves of the protective devices should be to the left of and below the curves of the equipment they protect to ensure they are activated before the equipment is damaged by the fault. Initially, our TCC graphs revealed

Results

Initially, our TCC graphs revealed several weaknesses in our system. We resized our fuses and breakers accordingly and were able to improve our system's coordination. However, there are still some contingencies that our system is not prepared for, but further analysis was out of the scope of our project.

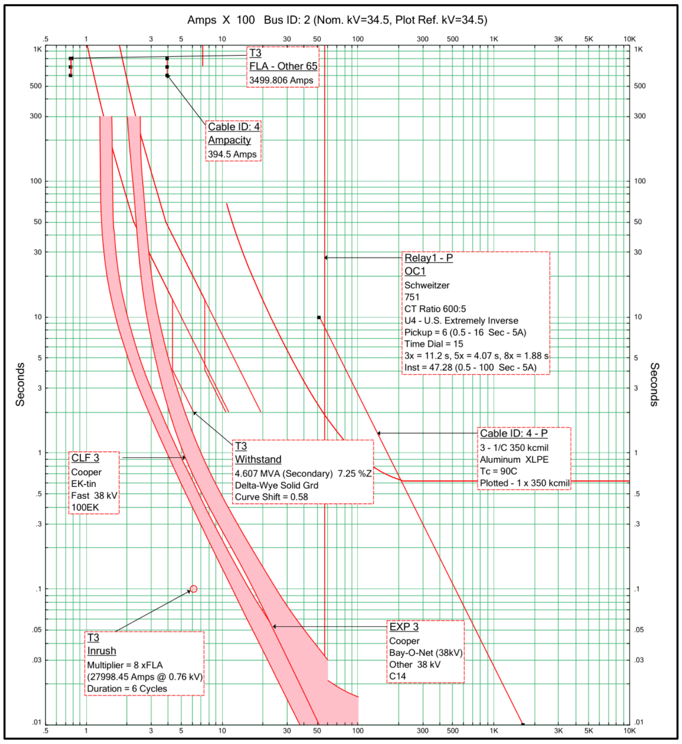


Figure 7: TCC Graph for MPT to PCS

5.3. ARC-FLASH ANALYSIS

An arc flash is a rapid release of energy due to an electrical fault, causing a high-temperature explosion that can severely damage equipment and pose serious safety risks to personnel. Compared with the short circuit study, arc flash analysis is focused on protecting personnel near the equipment rather than the equipment itself. It determines the arc flash boundary; the minimum safe distance personnel should maintain to avoid injury from an arc flash event. It also provides guidance on appropriate PPE for personnel working within the arc flash boundary. For a utility-scale BESS, this typically involves protective clothing, gloves, face shields, and other safety gear.

Methodology

To run the arc flash study, we used the fault current values from short circuit analysis as inputs. It is also essential to have adequately sized fuses. The current limiting fuses are particularly important here because of their ability to rapidly interrupt fault currents and minimize incident energy levels. To set up arc fault study in ETAP, we needed to set up two high voltage cases, a 95% and 105% load, and two low voltage cases, a 95% and 105% load. These use different standards, so they are evaluated differently in the ETAP software. When setting up the cases we had to set the correct buses, arc flash method, standards, FCT (fuse clearing time), and pre-fault voltage. It outputs the incident energy, measured in calories per square centimeter (cal/cm^2), and the arc flash boundary distance, the area within which PPE is required.

We ran a 3-phase fault at because this typically produces the highest fault current. Additionally, running analyses at two different power factors makes our testing more robust. The highest current, at the higher power factor, does not necessarily result in the highest incident energy. This is because incident energy also increases with the duration of the fault and is a product of I^2t, which, depending on the settings and coordination of the fuses and breakers, may be faster at a higher current. With these four tests, we can ensure that we are analyzing the worst-case arc flash scenario.

Results

Table 6 and 7 show the duration of the arc faults, the incident energy, and the recommended working distance for the worst case of each bus voltage in our system. The results from the arc flash studies reveal very high incident energies, greater than 40 cal/cm^2, in some parts of our system.

Table 6: Worst Case 3-Phase AC Arc Flash Results at 1.05 PF

Arc Flash Fault Locations (1.05 PF)	Voltage	Bus $\mathrm{I_a}$ (kA)	Duration (cycles)	Working Distance (in)	Incident Energy $(\mathrm{cal/cm^2})$
MV Buses 1.05 PF	34.5 kV	5.738 kA	120	15	220.6
LV Buses 1.05 PF	760 V	47.071	120*	18	38
LV Buses 1.05 PF	480 V	26.945	1.8	18	1.3

Table 7: Worst Case 3-Phase AC Arc Flash Results at 0.95 PF

Arc Flash Fault Locations (0.95 PF)	Voltage	Bus $\mathrm{I_a}$ (kA)	Duration (cycles)	Working Distance (in)	Incident Energy $(\mathrm{cal/cm^2})$
MV Buses 0.95 PF	34.5 kV	5.16	120*	15	197.5
LV Buses 0.95 PF	760 V	38.2	120*	18	42.8
LV Buses 0.95 PF	480 V	22.8	1.8	18	13.5

*Arc flash durations over the human reaction time of 2 seconds (120 cycles) are not considered from IEEE 1584

5.4. CABLE THERMAL ANALYSIS

Cable thermal analysis is a module in ETAP which uses a U/G Thermal Neher-McGrath calculation method to determine the cable temperature and ampacity ratings. It employs a thermal circuit model to represent heat flow situations. For this module, it is assumed that the cables have been carrying a load long enough that the heat flow has reached its steady state.

Methodology

To run a cable thermal analysis in ETAP, we need to know cable sizes, lengths, insulation type, minimum coverage for cables buried in a conduit, and we need to know the type of soil and temperature it will be buried in. Once this information is gain from the one-line, cable schedule and some assumptions given from our clients, we can create a study case for each cable we are testing, a raceway, and a conduit. Once we have these, we can add the cables into the conduit and test the cables using the Neher-McGrath calculation method in ETAP. We tested each cable/cable ground in a different study case and raceway as cable bundles in adjacent raceways can experience mutual heating from each other.

After initial testing, we needed to size up the cable sizes as the ETAP library we used did not support cables less than 1/0, and our cables during the short circuit and arc flash analyses did not pass. We needed to recalculate the ampacities and size of the cables three times over the recommended ones. Additionally, the auxiliary equipment pad cable had such a high ampacity that we needed to create two raceways and split the conductors and ampacity. We also changed the insulation type to RHW2 and used copper lines for these conductors instead of the aluminum lines we used for the rest of the system. After these changes, we met the temperature requirements to pass the thermal analysis. Full results are attached in appendices.

Results

Table 8: Cable Thermal Study Cases

Cable	Size (kc mil)	Ampacity (A)	Insulation	Length (ft)	Conductors/Phase	Min. Coverage (in)
PCS1-2	1/0	98.016	XLPE	53.02	1	36
PCS2-3	3/0	175.112	XLPE	53.02	1	36
PCS4-5	2/0	154.194	XLPE	53.02	1	36
PCS5-6	1/0	77.097	XLPE	53.02	1	36
Home Run	350	483.500 (total)	XLPE	572.05	1	36
Aux Pad	1000	1820	RHW2	40	4	38
Aux SWBRD	1/0	57.134	XLPE	15	1	30

5.5. DISCUSSION OF RESULTS

The tests we performed on our system allowed us to simulate worst-case real-world scenarios to ensure the safety and reliability of our project. The results of our tests indicate that our system meets the standards expected, considering the scope of our project.

The short circuit tests show that the fault currents are well below the short circuit withstand ratings and the cable fault current ratings of the conductors. However, the arc flash tests show several parts of our system have a very high incident energy, well above 40 cal/cm^2. The parts of our system with an incident energy greater than 40 cal/cm^2 need to be completely deenergized before performing maintenance on them, according to IEEE 1584. This is not ideal for the reliability of our BESS. The results from the TCC graphs show poor coordination of the protective devices. Due to time constraints, we did not go beyond a surface level analysis of the TCC curves. A more in-depth analysis of the protective device ratings would improve device coordination and decrease incident energies. While our arc flash and TCC graph study results are not ideal, our client was satisfied with the state of our design.

The cable thermal analysis tested our system's ability to handle steady-state thermal conditions without degrading cables or the cables' insulation. We used the Neher-McGrath calculation in ETAP to determine heat flow and the presence of mutual heating. This testing revealed many problems with our system and required increasing cables sizes and changing the materials for subsequent iterations. Implementing the modifications decreased the cable temperatures well below the standard maximum rating.

Overall, while our system is clearly not construction-ready, these tests verify our design decisions and provide recommendations for future work.

6. Implementation

Our project was hypothetical, so the implementation of our system was limited to testing the design by modeling it in ETAP. The scope of our project involved a 30% design of a BESS, which included the initial design steps and testing, but no physical implementation. We were able to meet the client's requirements, which are similar to what an engineer in industry would complete. In our first semester we determined the site layout, equipment selection, one-line diagram, and cable schedule. In our second semester we completed arc-flash, short-circuit, and cable thermal studies. We wrote detailed technical documents for each of these steps, which could be referenced by other engineers to do further work on the BESS.

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

Table 9: Area of Responsibilities

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. Conclusion

8.1. SUMMARY OF PROGRESS

The project team has designed a 25 MW/100 MWh lithium-ion battery energy storage system (BESS) for Ames, Iowa, aimed at enhancing renewable energy reliability and grid stability. Key deliverables include a detailed site layout, one-line diagrams, a cable schedule, and system analyses for short-circuit, arc-flash, and cable thermal analysis. The team utilized tools like AutoCAD and ETAP while adhering to NFPA 70 NEC standards. Significant achievements include selecting optimal equipment (batteries, inverters, transformers, fuses and breakers) and successfully integrating client feedback through iterative design reviews. Testing simulations highlighted the system's safety and efficiency, though arc-flash safety requirements require further refinement.

8.2. VALUE PROVIDED

The design addresses renewable energy variability by providing a reliable storage solution that enhances grid stability and reduces reliance on fossil fuels, aligning with community environmental values and lowering long-term energy costs. Detailed deliverables, including one-line diagrams, site layouts, and cable schedules, adhere to NEC and NFPA standards, ensuring safety and ease of implementation. While improvements to arc-flash protection are needed, the design offers a scalable framework for future energy projects, effectively supporting renewable energy integration and sustainable energy use.

8.3. NEXT STEPS

Arc flash protection is not currently passing for all equipment, but addressing protection and coordination issues is beyond the scope of this project. A recommendation for future work would be to further analyze the time-current curves for the fuses and breakers. Additional future work could include performing a load flow analysis, developing a grounding scheme for the system, and conducting DC arc flash and short-circuit analyses.

9. 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.

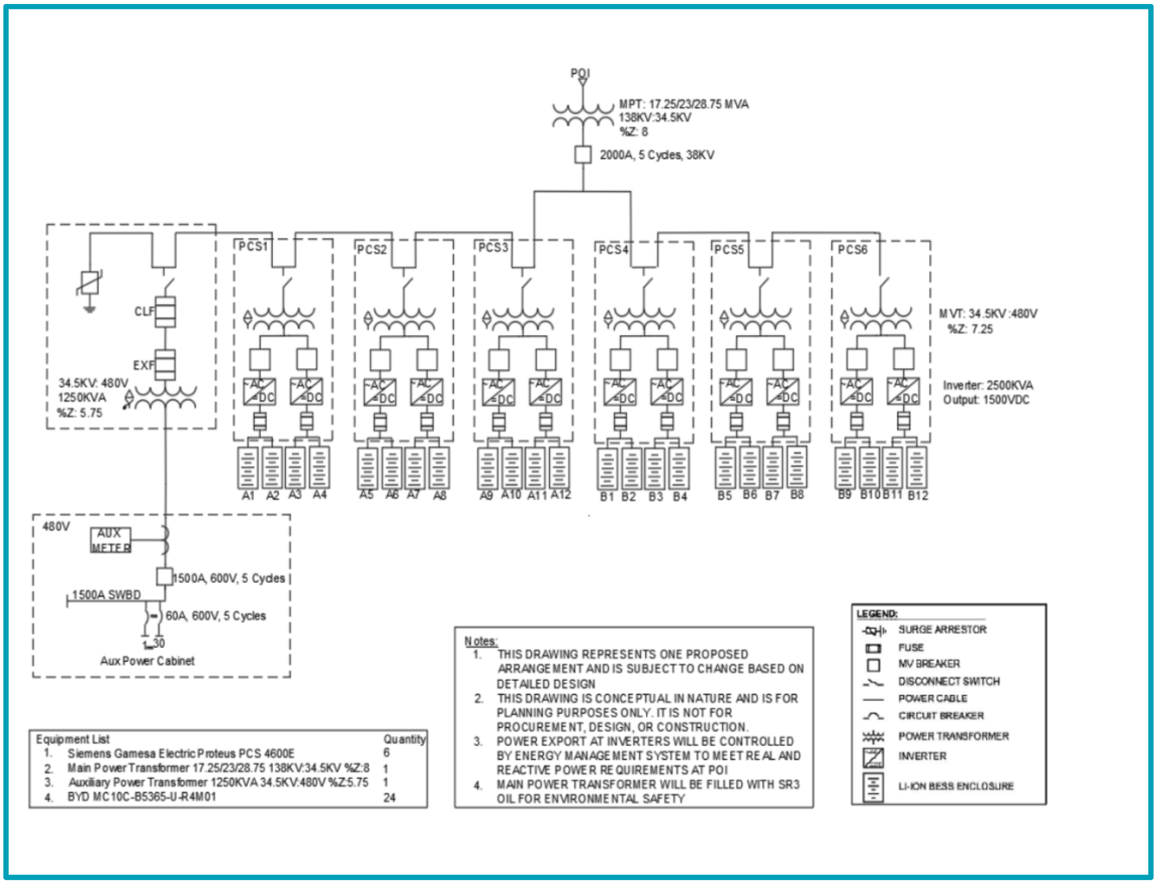
[10] National Fire Protection Association, "Article 300", National Electric Code, NFPA, 2020, pp. 153. Table 300.50.

10. Appendices

APPENDIX 1: IMPORTANT VISUALS

Site Layout:

One-line diagram:



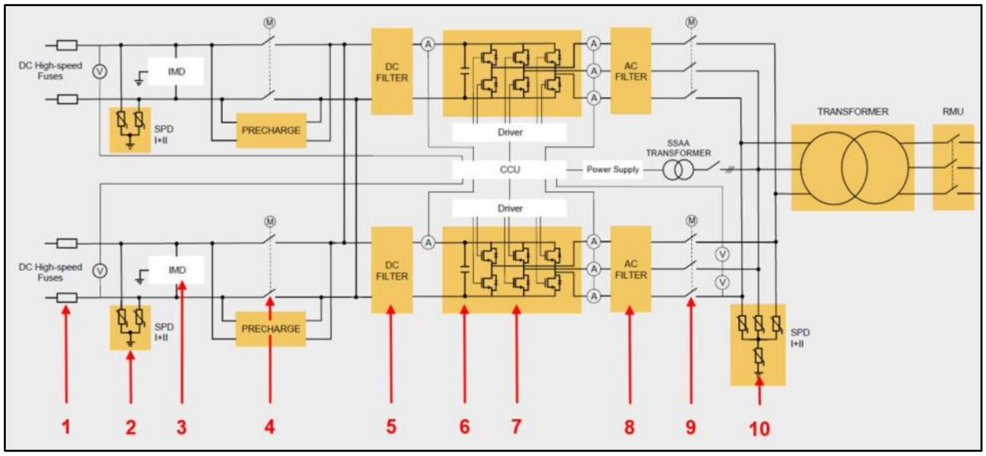
Equipment List	Quantity
1. Siemens Gamesa Electric Proteus PCS 4600E	6
2. Main Power Transformer 17.25/23/28.75 138KV:34.5KV %Z:8	1
3. Auxiliary Power Transformer 1250KVA 34.5KV:480V %Z:5.75	1
4. BYD MC10C-B5365-U-R4M01	24

Notes:

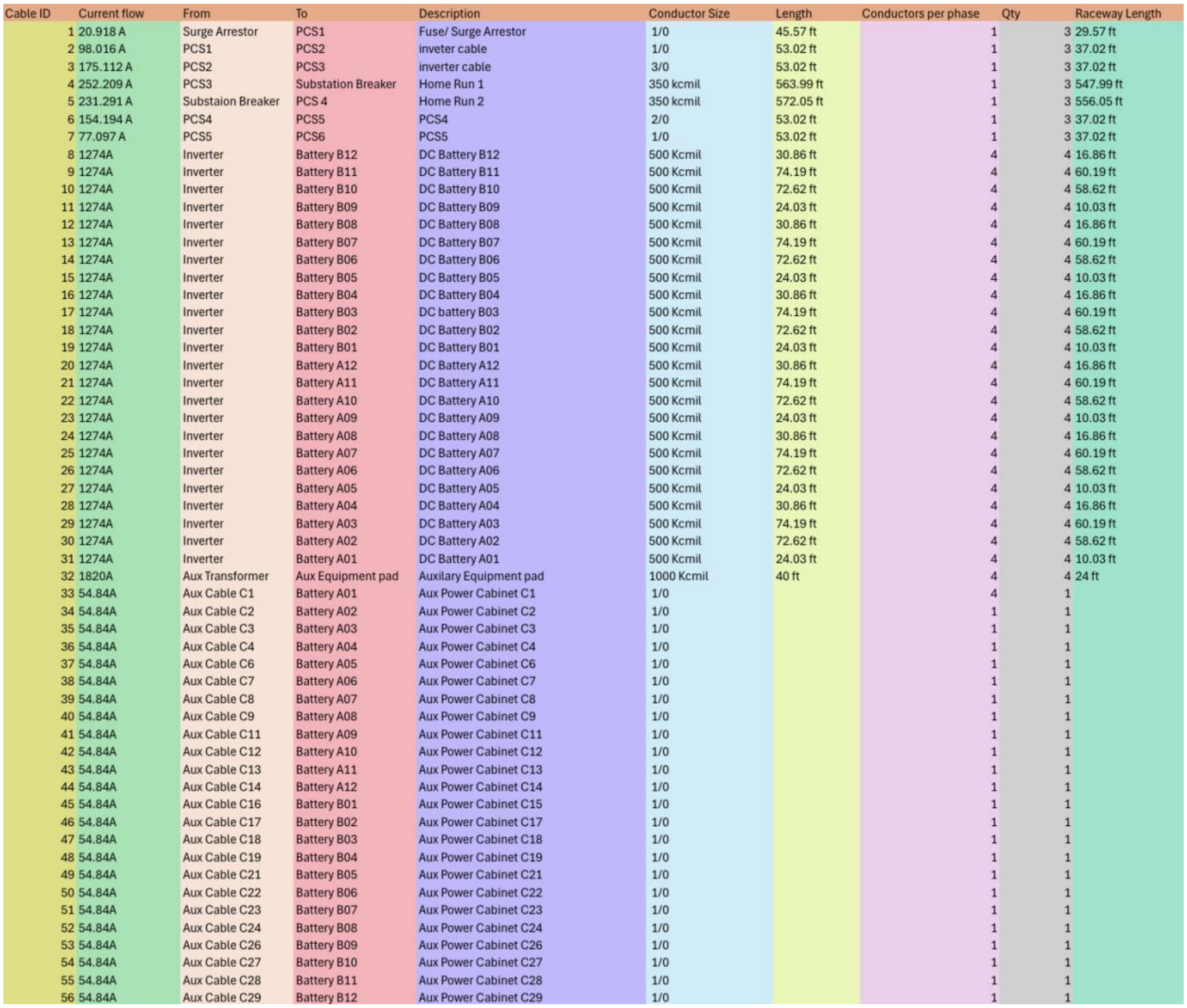
1. THIS DRAWING REPRESENTS ONE PROPOSED ARRANGEMENT AND IS SUBJECT TO CHANGE BASED ON DETAILED DESIGN
2. THIS DRAWING IS CONCEPTUAL IN NATURE AND IS FOR PLANNING PURPOSES ONLY. IT IS NOT FOR PROCUREMENT, DESIGN, OR CONSTRUCTION.
3. POWER EXPORT AT INVERTERS WILL BE CONTROLLED BY ENERGY MANAGEMENT SYSTEM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

LEGEND:

Siemens Gamesa PCS Configuration:

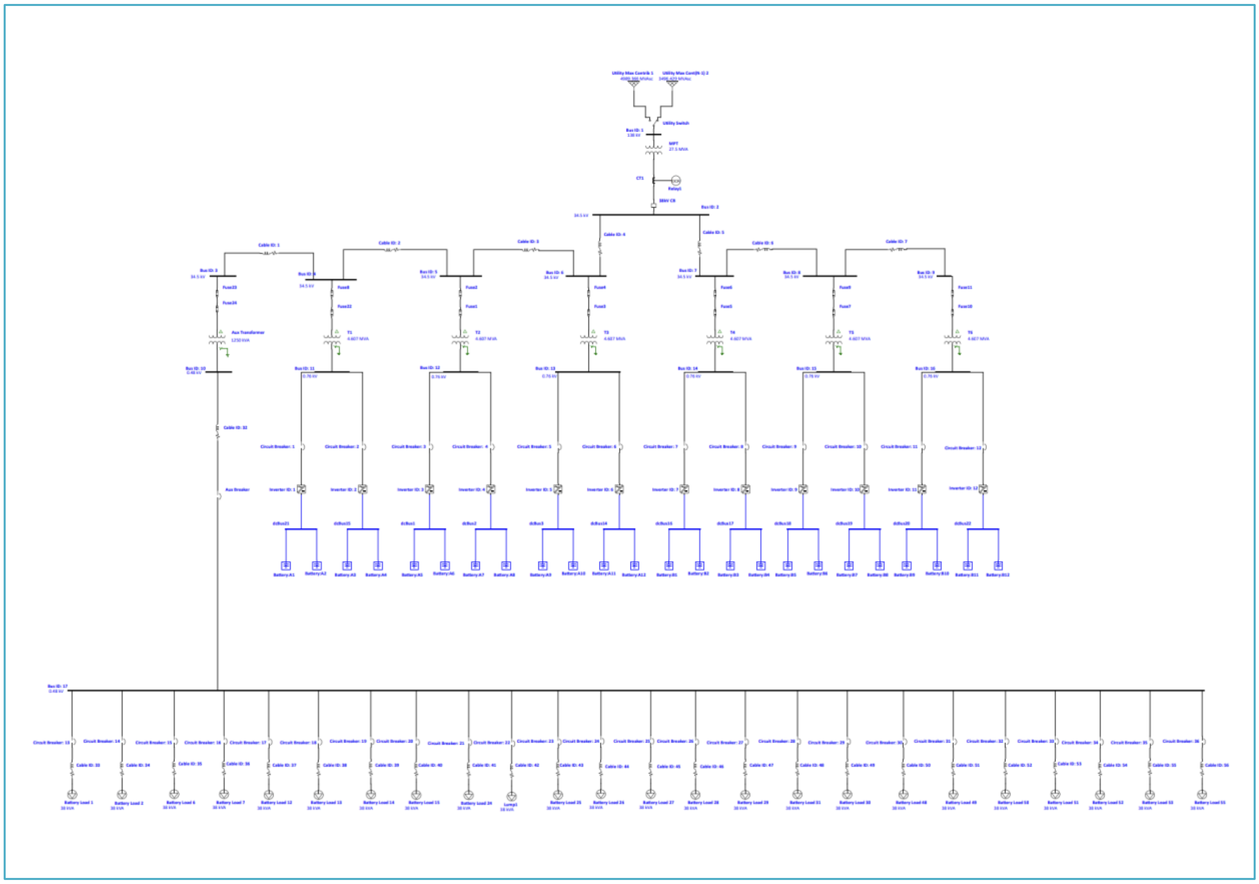


Cable Schedule



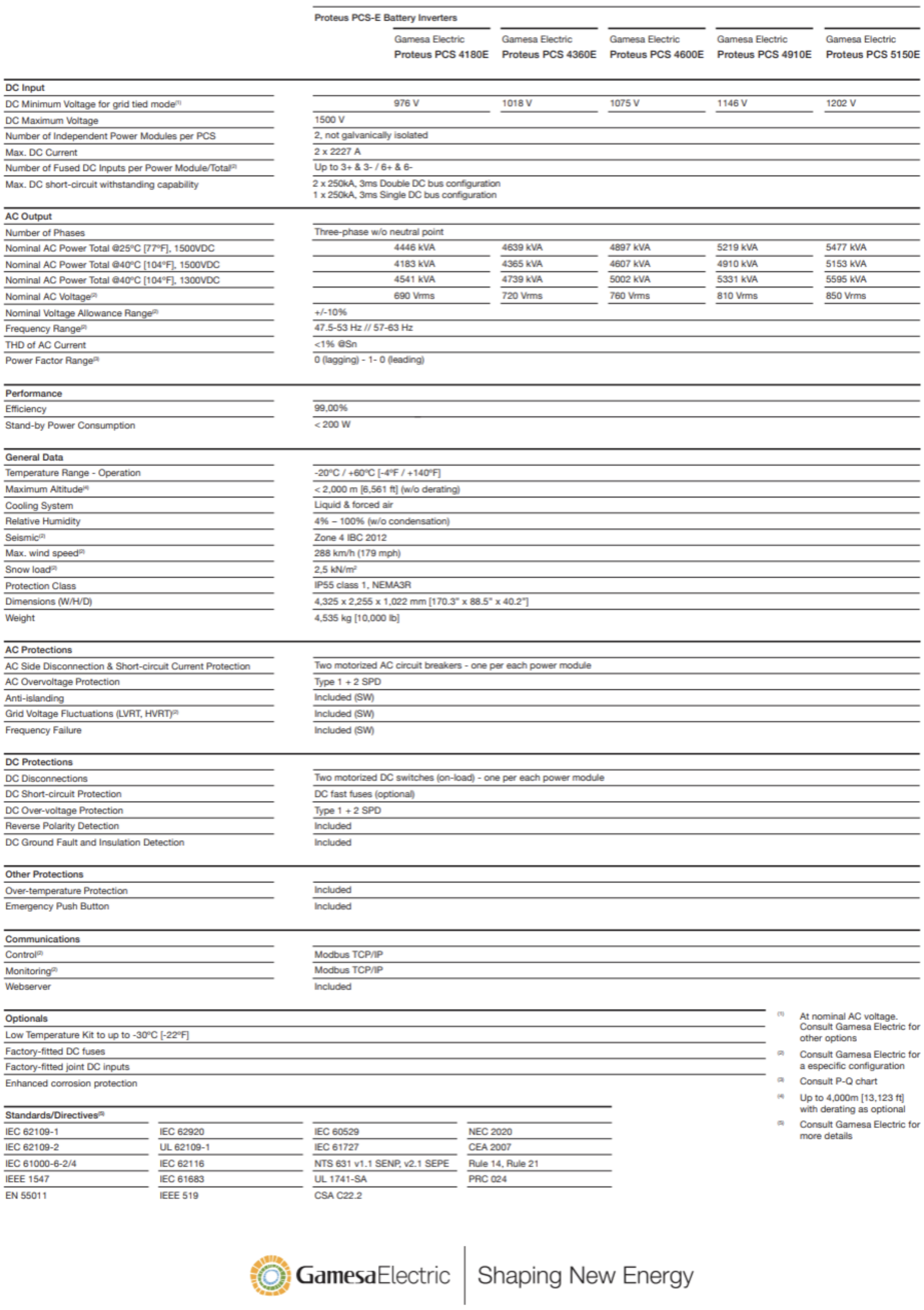
Cable ID	Current flow	From	To	Description	Conductor Size	Length	Conductors per phase	Qty	Raceway Length
1	20.918 A	Surge Arrestor	PCS1	Fuse/ Surge Arrestor	1/0	45.57 ft	1	3	29.57 ft
2	98.016 A	PCS1	PCS2	inveter cable	1/0	53.02 ft	1	3	37.02 ft
3	175.112 A	PCS2	PCS3	inverter cable	3/0	53.02 ft	1	3	37.02 ft
4	252.209 A	PCS3	Substation Breaker	Home Run 1	350 kcmil	563.99 ft	1	3	547.99 ft
5	231.291 A	Substaion Breaker	PCS 4	Home Run 2	350 kcmil	572.05 ft	1	3	556.05 ft
6	154.194 A	PCS4	PCS5	PCS4	2/0	53.02 ft	1	3	37.02 ft
7	77.097 A	PCS5	PCS6	PCS5	1/0	53.02 ft	1	3	37.02 ft
8	1274A	Inverter	Battery B12	DC Battery B12	500 Kcmil	30.86 ft	4	4	16.86 ft
9	1274A	Inverter	Battery B11	DC Battery B11	500 Kcmil	74.19 ft	4	4	60.19 ft
10	1274A	Inverter	Battery B10	DC Battery B10	500 Kcmil	72.62 ft	4	4	58.62 ft
11	1274A	Inverter	Battery B09	DC Battery B09	500 Kcmil	24.03 ft	4	4	10.03 ft
12	1274A	Inverter	Battery B08	DC Battery B08	500 Kcmil	30.86 ft	4	4	16.86 ft
13	1274A	Inverter	Battery B07	DC Battery B07	500 Kcmil	74.19 ft	4	4	60.19 ft
14	1274A	Inverter	Battery B06	DC Battery B06	500 Kcmil	72.62 ft	4	4	58.62 ft
15	1274A	Inverter	Battery B05	DC Battery B05	500 Kcmil	24.03 ft	4	4	10.03 ft
16	1274A	Inverter	Battery B04	DC Battery B04	500 Kcmil	30.86 ft	4	4	16.86 ft
17	1274A	Inverter	Battery B03	DC battery B03	500 Kcmil	74.19 ft	4	4	60.19 ft
18	1274A	Inverter	Battery B02	DC Battery B02	500 Kcmil	72.62 ft	4	4	58.62 ft
19	1274A	Inverter	Battery B01	DC Battery B01	500 Kcmil	24.03 ft	4	4	10.03 ft
20	1274A	Inverter	Battery A12	DC Battery A12	500 Kcmil	30.86 ft	4	4	16.86 ft
21	1274A	Inverter	Battery A11	DC Battery A11	500 Kcmil	74.19 ft	4	4	60.19 ft
22	1274A	Inverter	Battery A10	DC Battery A10	500 Kcmil	72.62 ft	4	4	58.62 ft
23	1274A	Inverter	Battery A09	DC Battery A09	500 Kcmil	24.03 ft	4	4	10.03 ft
24	1274A	Inverter	Battery A08	DC Battery A08	500 Kcmil	30.86 ft	4	4	16.86 ft
25	1274A	Inverter	Battery A07	DC Battery A07	500 Kcmil	74.19 ft	4	4	60.19 ft
26	1274A	Inverter	Battery A06	DC Battery A06	500 Kcmil	72.62 ft	4	4	58.62 ft
27	1274A	Inverter	Battery A05	DC Battery A05	500 Kcmil	24.03 ft	4	4	10.03 ft
28	1274A	Inverter	Battery A04	DC Battery A04	500 Kcmil	30.86 ft	4	4	16.86 ft
29	1274A	Inverter	Battery A03	DC Battery A03	500 Kcmil	74.19 ft	4	4	60.19 ft
30	1274A	Inverter	Battery A02	DC Battery A02	500 Kcmil	72.62 ft	4	4	58.62 ft
31	1274A	Inverter	Battery A01	DC Battery A01	500 Kcmil	24.03 ft	4	4	10.03 ft
32	1820A	Aux Transformer	Aux Equipment pad	Auxilary Equipment pad	1000 Kcmil	40 ft	4	4	24 ft
33	54.84A	Aux Cable C1	Battery A01	Aux Power Cabinet C1	1/0		4	1	
34	54.84A	Aux Cable C2	Battery A02	Aux Power Cabinet C2	1/0		1	1	
35	54.84A	Aux Cable C3	Battery A03	Aux Power Cabinet C3	1/0		1	1	
36	54.84A	Aux Cable C4	Battery A04	Aux Power Cabinet C4	1/0		1	1	
37	54.84A	Aux Cable C6	Battery A05	Aux Power Cabinet C6	1/0		1	1	
38	54.84A	Aux Cable C7	Battery A06	Aux Power Cabinet C7	1/0		1	1	
39	54.84A	Aux Cable C8	Battery A07	Aux Power Cabinet C8	1/0		1	1	
40	54.84A	Aux Cable C9	Battery A08	Aux Power Cabinet C9	1/0		1	1	
41	54.84A	Aux Cable C11	Battery A09	Aux Power Cabinet C11	1/0		1	1	
42	54.84A	Aux Cable C12	Battery A10	Aux Power Cabinet C12	1/0		1	1	
43	54.84A	Aux Cable C13	Battery A11	Aux Power Cabinet C13	1/0		1	1	
44	54.84A	Aux Cable C14	Battery A12	Aux Power Cabinet C14	1/0		1	1	
45	54.84A	Aux Cable C16	Battery B01	Aux Power Cabinet C15	1/0		1	1	
46	54.84A	Aux Cable C17	Battery B02	Aux Power Cabinet C17	1/0		1	1	
47	54.84A	Aux Cable C18	Battery B03	Aux Power Cabinet C18	1/0		1	1	
48	54.84A	Aux Cable C19	Battery B04	Aux Power Cabinet C19	1/0		1	1	
49	54.84A	Aux Cable C21	Battery B05	Aux Power Cabinet C21	1/0		1	1	
50	54.84A	Aux Cable C22	Battery B06	Aux Power Cabinet C22	1/0		1	1	
51	54.84A	Aux Cable C23	Battery B07	Aux Power Cabinet C23	1/0		1	1	
52	54.84A	Aux Cable C24	Battery B08	Aux Power Cabinet C24	1/0		1	1	
53	54.84A	Aux Cable C26	Battery B09	Aux Power Cabinet C26	1/0		1	1	
54	54.84A	Aux Cable C27	Battery B10	Aux Power Cabinet C27	1/0		1	1	
55	54.84A	Aux Cable C28	Battery B11	Aux Power Cabinet C28	1/0		1	1	
56	54.84A	Aux Cable C29	Battery B12	Aux Power Cabinet C29	1/0		1	1	

ETAP Model


Utility Max Contrib 1
Utility Max Cont(N-1) 2
Utility Switch
Bus ID: 1
138 kV
MPT
27.5 MVA
CT1
Relay1
Bus ID: 2
34.5 kV
Cable ID: 1
Cable ID: 2
Cable ID: 3
Cable ID: 4
Cable ID: 5
Bus ID: 3
Bus ID: 4
Bus ID: 5
Bus ID: 6
Bus ID: 7
Fuse23
Fuse24
Fuse8
Fuse22
Fuse2
Fuse1
Fuse4
Fuse3
Fuse6
Fuse5
Aux Transformer
1250 kVA
T1
T2
T3
T4
4.607 MVA
Bus ID: 10
0.48 kV
Bus ID: 11
Bus ID: 12
Bus ID: 13
Bus ID: 14
0.76 kV
Cable ID: 32
Circuit Breaker: 1
Circuit Breaker: 2
Circuit Breaker: 3
Circuit Breaker: 4
Circuit Breaker: 5
Circuit Breaker: 6
Aux Breaker

APPENDIX 2: EQUIPMENT DATA SHEETS

Siemens Gamesa PCS



Proteus PCS-E Battery Inverters

	Gamesa Electric **Proteus PCS 4180E**	Gamesa Electric **Proteus PCS 4360E**	Gamesa Electric **Proteus PCS 4600E**	Gamesa Electric **Proteus PCS 4910E**	Gamesa Electric **Proteus PCS 5150E**
DC Input					
DC Minimum Voltage for grid tied mode[1]	976 V	1018 V	1075 V	1146 V	1202 V
DC Maximum Voltage	1500 V				
Number of Independent Power Modules per PCS	2, not galvanically isolated				
Max. DC Current	2 x 2227 A				
Number of Fused DC Inputs per Power Module/Total[2]	Up to 3+ & 3- / 6+ & 6-				
Max. DC short-circuit withstanding capability	2 x 250kA, 3ms Double DC bus configuration 1 x 250kA, 3ms Single DC bus configuration				
AC Output					
Number of Phases	Three-phase w/o neutral point				
Nominal AC Power Total @25°C [77°F], 1500VDC	4446 kVA	4639 kVA	4897 kVA	5219 kVA	5477 kVA
Nominal AC Power Total @40°C [104°F], 1500VDC	4183 kVA	4365 kVA	4607 kVA	4910 kVA	5153 kVA
Nominal AC Power Total @40°C [104°F], 1300VDC	4541 kVA	4739 kVA	5002 kVA	5331 kVA	5595 kVA
Nominal AC Voltage[2]	690 Vrms	720 Vrms	760 Vrms	810 Vrms	850 Vrms
Nominal Voltage Allowance Range[2]	+/-10%				
Frequency Range[2]	47.5-53 Hz // 57-63 Hz				
THD of AC Current	<1% @Sn				
Power Factor Range[3]	0 (lagging) - 1- 0 (leading)				
Performance					
Efficiency	99,00%				
Stand-by Power Consumption	< 200 W				
General Data					
Temperature Range - Operation	-20°C / +60°C [-4°F / +140°F]				
Maximum Altitude[4]	< 2,000 m [6,561 ft] (w/o derating)				
Cooling System	Liquid & forced air				
Relative Humidity	4% – 100% (w/o condensation)				
Seismic[2]	Zone 4 IBC 2012				
Max. wind speed[2]	288 km/h (179 mph)				
Snow load[2]	2,5 kN/m²				
Protection Class	IP55 class 1, NEMA3R				
Dimensions (W/H/D)	4,325 x 2,255 x 1,022 mm [170.3" x 88.5" x 40.2"]				
Weight	4,535 kg [10,000 lb]				
AC Protections					
AC Side Disconnection & Short-circuit Current Protection	Two motorized AC circuit breakers - one per each power module				
AC Overvoltage Protection	Type 1 + 2 SPD				
Anti-islanding	Included (SW)				
Grid Voltage Fluctuations (LVRT, HVRT)[2]	Included (SW)				
Frequency Failure	Included (SW)				
DC Protections					
DC Disconnections	Two motorized DC switches (on-load) - one per each power module				
DC Short-circuit Protection	DC fast fuses (optional)				
DC Over-voltage Protection	Type 1 + 2 SPD				
Reverse Polarity Detection	Included				
DC Ground Fault and Insulation Detection	Included				
Other Protections					
Over-temperature Protection	Included				
Emergency Push Button	Included				
Communications					
Control[2]	Modbus TCP/IP				
Monitoring[2]	Modbus TCP/IP				
Webserver	Included				

Optionals

- Low Temperature Kit to up to -30°C [-22°F]
- Factory-fitted DC fuses
- Factory-fitted joint DC inputs
- Enhanced corrosion protection

Standards/Directives[5]			
IEC 62109-1	IEC 62920	IEC 60529	NEC 2020
IEC 62109-2	UL 62109-1	IEC 61727	CEA 2007
IEC 61000-6-2/4	IEC 62116	NTS 631 v1.1 SENP, v2.1 SEPE	Rule 14, Rule 21
IEEE 1547	IEC 61683	UL 1741-SA	PRC 024
EN 55011	IEEE 519	CSA C22.2	

[1] At nominal AC voltage. Consult Gamesa Electric for other options

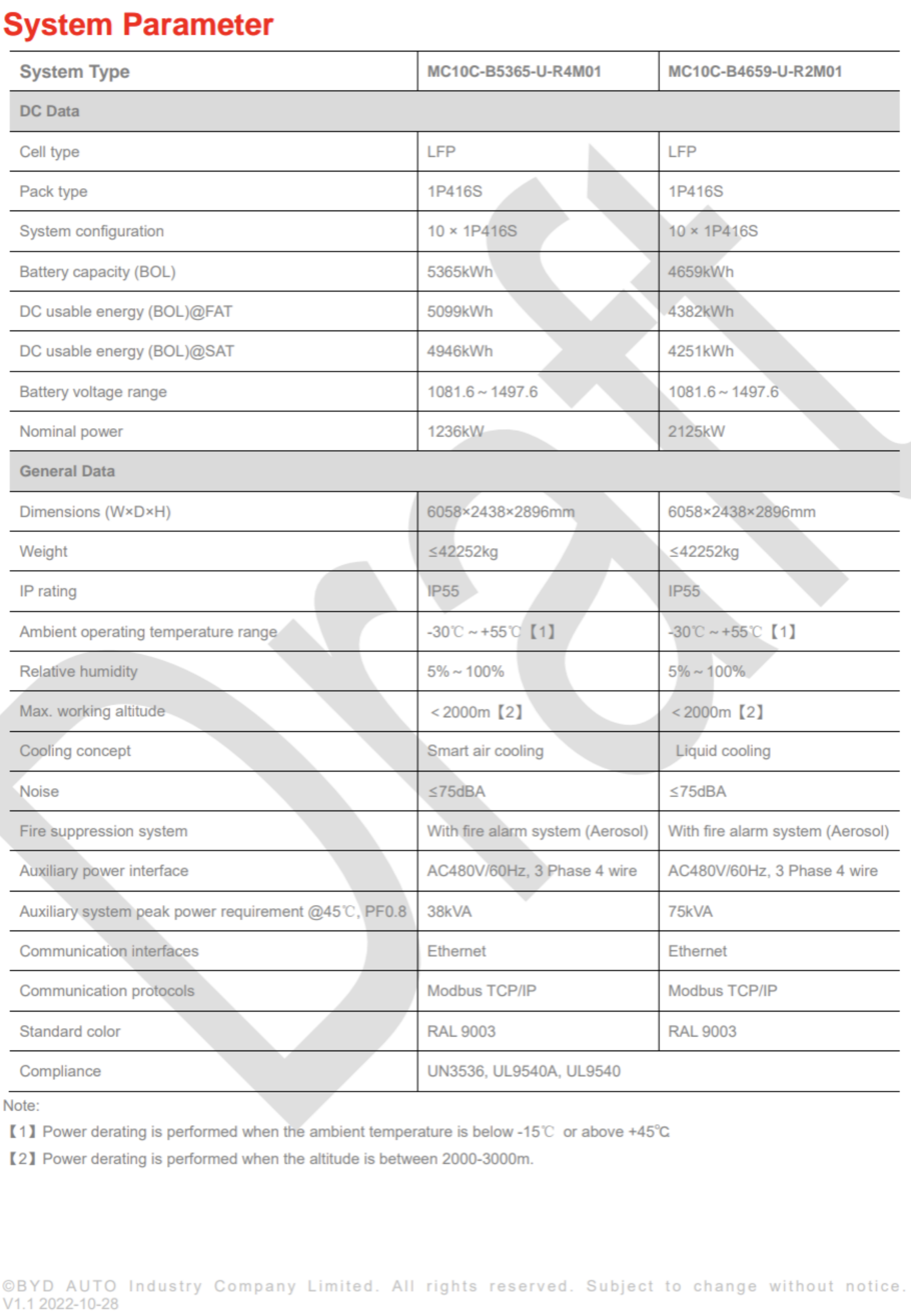
[2] Consult Gamesa Electric for a especific configuration

[3] Consult P-Q chart

[4] Up to 4,000m [13,123 ft] with derating as optional

[5] Consult Gamesa Electric for more details

GamesaElectric | Shaping New Energy



System Parameter

System Type	MC10C-B5365-U-R4M01	MC10C-B4659-U-R2M01
DC Data		
Cell type	LFP	LFP
Pack type	1P416S	1P416S
System configuration	10 × 1P416S	10 × 1P416S
Battery capacity (BOL)	5365kWh	4659kWh
DC usable energy (BOL)@FAT	5099kWh	4382kWh
DC usable energy (BOL)@SAT	4946kWh	4251kWh
Battery voltage range	1081.6 ~ 1497.6	1081.6 ~ 1497.6
Nominal power	1236kW	2125kW
General Data		
Dimensions (W×D×H)	6058×2438×2896mm	6058×2438×2896mm
Weight	≤42252kg	≤42252kg
IP rating	IP55	IP55
Ambient operating temperature range	-30℃ ~ +55℃【1】	-30℃ ~ +55℃【1】
Relative humidity	5% ~ 100%	5% ~ 100%
Max. working altitude	＜2000m【2】	＜2000m【2】
Cooling concept	Smart air cooling	Liquid cooling
Noise	≤75dBA	≤75dBA
Fire suppression system	With fire alarm system (Aerosol)	With fire alarm system (Aerosol)
Auxiliary power interface	AC480V/60Hz, 3 Phase 4 wire	AC480V/60Hz, 3 Phase 4 wire
Auxiliary system peak power requirement @45℃, PF0.8	38kVA	75kVA
Communication interfaces	Ethernet	Ethernet
Communication protocols	Modbus TCP/IP	Modbus TCP/IP
Standard color	RAL 9003	RAL 9003
Compliance	UN3536, UL9540A, UL9540	

Note:

【1】Power derating is performed when the ambient temperature is below -15℃ or above +45℃.

【2】Power derating is performed when the altitude is between 2000-3000m.

V1.1 2022-10-28

Appendix 3: Short Circuit Analysis Results

Low voltage (480-760 V) 95% power factor case

Project:		**ETAP** 24.0.0E	Page:	1
Location:			Date:	11-20-2024
Contract:			SN:	IASTATEPL
Engineer:		Study Case: Low V 95	Revision:	Base
Filename:	AMES_BESS		Config.:	Normal

Short-Circuit Summary Report

1/2 Cycle - 3-Phase, LG, LL, & LLG Fault Currents

Prefault Voltage = 95 % of the Bus Nominal Voltage

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus ID: 10	0.480	3.751	-25.897	26.168	3.737	-25.929	26.197	-22.179	-3.231	22.413	20.308	16.360	26.077
Bus ID: 11	0.760	3.242	-43.032	43.154	3.467	-45.887	46.018	-38.169	-2.787	38.271	-40.224	22.410	46.045
Bus ID: 12	0.760	3.220	-43.046	43.166	3.451	-45.868	45.998	-38.092	-2.767	38.192	-40.231	22.432	46.062
Bus ID: 13	0.760	3.207	-43.057	43.176	3.441	-45.847	45.976	-38.123	-2.756	38.223	-40.238	22.446	46.075
Bus ID: 14	0.760	3.208	-43.055	43.174	3.440	-45.820	45.949	-38.142	-2.758	38.242	-40.237	22.445	46.073
Bus ID: 15	0.760	3.224	-43.043	43.164	3.452	-45.788	45.918	-38.153	-2.772	38.254	-40.230	22.428	46.059
Bus ID: 16	0.760	3.246	-43.029	43.152	3.468	-45.749	45.880	-38.167	-2.791	38.269	-40.222	22.406	46.042
Bus ID: 17	0.480	3.723	-24.431	24.713	3.299	-23.202	23.435	-20.868	-3.202	21.112	19.394	14.385	24.147
Bus1	0.480	9.100	-13.929	16.638	4.730	-11.024	11.996	-12.063	-7.880	14.409	10.655	12.290	16.266
Bus3	0.480	9.025	-11.412	14.549	4.199	-8.979	9.912	-9.883	-7.816	12.600	8.721	11.310	14.282
Bus15	0.480	8.910	-10.641	13.879	4.012	-8.389	9.299	-9.216	-7.716	12.019	8.129	10.955	13.642
Bus16	0.480	9.122	-12.774	15.696	4.502	-10.060	11.021	-11.062	-7.900	13.594	9.768	11.872	15.373
Bus21	0.480	8.912	-10.656	13.892	4.016	-8.400	9.311	-9.228	-7.718	12.030	8.141	10.962	13.654
Bus22	0.480	8.490	-8.927	12.319	3.562	-7.119	7.961	-7.731	-7.353	10.669	6.811	10.054	12.144
Bus23	0.480	8.312	-8.395	11.814	3.412	-6.734	7.549	-7.271	-7.198	10.231	6.402	9.740	11.656
Bus24	0.480	8.748	-9.863	13.183	3.814	-7.807	8.688	-8.542	-7.576	11.417	7.531	10.566	12.975
Bus33	0.480	8.315	-8.406	11.824	3.415	-6.742	7.557	-7.279	-7.201	10.240	6.410	9.746	11.665
Bus34	0.480	7.636	-6.822	10.239	2.939	-5.606	6.329	-5.908	-6.613	8.867	5.192	8.694	10.127
Bus35	0.480	8.105	-7.855	11.287	3.255	-6.345	7.131	-6.802	-7.019	9.775	5.986	9.401	11.145
Bus36	0.480	8.179	-8.040	11.469	3.309	-6.478	7.275	-6.963	-7.083	9.933	6.129	9.519	11.322
Bus37	0.480	7.709	-6.969	10.392	2.985	-5.711	6.444	-6.035	-6.676	9.000	5.305	8.800	10.275
Bus38	0.480	7.620	-6.790	10.206	2.928	-5.583	6.305	-5.880	-6.599	8.839	5.167	8.671	10.094
Bus39	0.480	7.504	-6.568	9.973	2.858	-5.424	6.131	-5.688	-6.499	8.636	4.997	8.508	9.867
Bus40	0.480	8.117	-7.884	11.316	3.263	-6.366	7.154	-6.828	-7.030	9.800	6.009	9.420	11.173
Bus54	0.480	7.819	-7.198	10.627	3.056	-5.875	6.622	-6.233	-6.771	9.203	5.481	8.961	10.505
Bus61	0.480	7.060	-5.792	9.132	2.602	-4.869	5.520	-5.016	-6.115	7.909	4.401	7.902	9.045
Bus63	0.480	6.978	-5.661	8.986	2.557	-4.774	5.416	-4.902	-6.043	7.782	4.300	7.794	8.901
Bus64	0.480	7.444	-6.456	9.854	2.822	-5.344	6.044	-5.591	-6.447	8.534	4.911	8.424	9.751
Bus65	0.480	6.879	-5.506	8.811	2.504	-4.662	5.292	-4.768	-5.957	7.630	4.181	7.663	8.729
Bus66	0.480	6.476	-4.920	8.133	2.297	-4.237	4.819	-4.260	-5.608	7.043	3.731	7.148	8.063
Bus67	0.480	6.403	-4.820	8.015	2.261	-4.164	4.738	-4.175	-5.545	6.941	3.655	7.057	7.947

Low voltage (480-760 V) 105% power factor case

ETAP
24.0.0E

Project:		Page:	1
Location:		Date:	11-20-2024
Contract:		SN:	IASTATEPL
Engineer:		Revision:	Base
Filename:	AMES_BESS	Config.:	Normal

Study Case: Low V 105

Short-Circuit Summary Report

1/2 Cycle - 3-Phase, LG, LL, & LLG Fault Currents

Prefault Voltage = 105 % of the Bus Nominal Voltage

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus ID: 10	0.480	4.124	-28.306	28.604	4.130	-28.659	28.955	-24.513	-3.571	24.772	22.445	18.082	28.822
Bus ID: 11	0.760	3.578	-46.910	47.047	3.827	-49.550	49.698	-41.120	-3.078	41.236	-43.495	24.145	49.747
Bus ID: 12	0.760	3.554	-46.925	47.060	3.809	-49.561	49.707	-41.133	-3.057	41.247	-43.503	24.169	49.766
Bus ID: 13	0.760	3.539	-46.938	47.071	3.798	-49.570	49.715	-41.144	-3.045	41.256	-43.510	24.185	49.780
Bus ID: 14	0.760	3.540	-46.936	47.069	3.799	-49.568	49.714	-41.142	-3.046	41.255	-43.509	24.183	49.778
Bus ID: 15	0.760	3.558	-46.922	47.057	3.813	-49.559	49.705	-41.131	-3.061	41.244	-43.501	24.164	49.762
Bus ID: 16	0.760	3.582	-46.908	47.044	3.830	-49.548	49.696	-41.118	-3.082	41.233	-43.493	24.141	49.744
Bus ID: 17	0.480	4.087	-26.633	26.945	3.646	-25.644	25.902	-23.065	-3.539	23.335	21.436	15.900	26.689
Bus1	0.480	10.057	-15.395	18.389	5.228	-12.185	13.259	-13.333	-8.710	15.926	11.776	13.584	17.978
Bus3	0.480	9.975	-12.613	16.081	4.641	-9.924	10.955	-10.923	-8.639	13.926	9.639	12.500	15.785
Bus15	0.480	9.848	-11.761	15.340	4.435	-9.272	10.278	-10.186	-8.528	13.284	8.985	12.108	15.078
Bus16	0.480	10.082	-14.118	17.349	4.975	-11.118	12.181	-12.227	-8.732	15.024	10.796	13.121	16.992
Bus21	0.480	9.850	-11.777	15.354	4.439	-9.285	10.291	-10.200	-8.531	13.297	8.998	12.116	15.091
Bus22	0.480	9.384	-9.866	13.616	3.937	-7.869	8.798	-8.544	-8.127	11.792	7.528	11.112	13.422
Bus23	0.480	9.187	-9.279	13.057	3.771	-7.443	8.344	-8.036	-7.956	11.308	7.076	10.765	12.882
Bus24	0.480	9.669	-10.901	14.571	4.216	-8.628	9.603	-9.441	-8.373	12.619	8.324	11.678	14.341
Bus33	0.480	9.191	-9.290	13.068	3.775	-7.451	8.353	-8.046	-7.959	11.317	7.085	10.772	12.893
Bus34	0.480	8.440	-7.540	11.317	3.248	-6.196	6.996	-6.530	-7.309	9.801	5.738	9.610	11.193
Bus35	0.480	8.958	-8.681	12.475	3.597	-7.013	7.882	-7.518	-7.758	10.803	6.616	10.390	12.318
Bus36	0.480	9.040	-8.887	12.676	3.658	-7.160	8.041	-7.696	-7.829	10.978	6.774	10.522	12.514
Bus37	0.480	8.520	-7.702	11.486	3.299	-6.312	7.122	-6.670	-7.379	9.947	5.863	9.726	11.357
Bus38	0.480	8.422	-7.504	11.280	3.237	-6.171	6.968	-6.499	-7.293	9.769	5.711	9.584	11.157
Bus39	0.480	8.294	-7.259	11.022	3.158	-5.995	6.776	-6.287	-7.183	9.546	5.523	9.403	10.905
Bus40	0.480	8.972	-8.714	12.507	3.607	-7.037	7.907	-7.547	-7.770	10.831	6.642	10.412	12.350
Bus54	0.480	8.642	-7.955	11.746	3.378	-6.493	7.319	-6.890	-7.484	10.172	6.058	9.904	11.610
Bus61	0.480	7.804	-6.402	10.094	2.876	-5.381	6.101	-5.544	-6.758	8.741	4.864	8.734	9.997
Bus63	0.480	7.713	-6.257	9.932	2.826	-5.277	5.986	-5.419	-6.680	8.601	4.753	8.614	9.838
Bus64	0.480	8.228	-7.135	10.891	3.119	-5.907	6.680	-6.179	-7.126	9.432	5.428	9.310	10.777
Bus65	0.480	7.603	-6.085	9.738	2.767	-5.153	5.849	-5.270	-6.584	8.433	4.621	8.470	9.648
Bus66	0.480	7.158	-5.437	8.989	2.538	-4.683	5.327	-4.709	-6.199	7.784	4.124	7.900	8.912
Bus67	0.480	7.077	-5.328	8.859	2.499	-4.603	5.237	-4.614	-6.129	7.672	4.040	7.799	8.784

Medium voltage (34.5 kV) 95% power factor case

ETAP
24.0.0E

Project:
Location:
Contract:
Engineer:
Filename: AMES_BESS

Study Case: Med V 95

Page: 1
Date: 11-20-2024
SN: IASTATEPL
Revision: Base
Config.: Normal

Short-Circuit Summary Report

1/2 Cycle - 3-Phase, LG, LL, & LLG Fault Currents

Prefault Voltage = 95 % of the Bus Nominal Voltage

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus ID: 1	138.000	1.972	-13.824	13.964	1.653	-11.767	11.882	-11.990	-1.707	12.111	11.295	6.850	13.210
Bus ID: 2	34.500	0.259	-5.212	5.219	0.249	-5.396	5.402	-4.631	-0.220	4.636	4.561	3.084	5.506
Bus ID: 3	34.500	0.351	-5.132	5.144	0.397	-5.284	5.299	-4.551	-0.297	4.561	-4.818	2.513	5.434
Bus ID: 4	34.500	0.338	-5.139	5.150	0.379	-5.297	5.311	-4.558	-0.286	4.567	-4.813	2.532	5.438
Bus ID: 5	34.500	0.322	-5.146	5.156	0.357	-5.313	5.325	-4.566	-0.274	4.575	-4.807	2.554	5.443
Bus ID: 6	34.500	0.313	-5.153	5.162	0.342	-5.324	5.335	-4.573	-0.266	4.581	-4.803	2.569	5.446
Bus ID: 7	34.500	0.314	-5.152	5.161	0.343	-5.322	5.333	-4.572	-0.266	4.580	-4.802	2.567	5.445
Bus ID: 8	34.500	0.325	-5.145	5.155	0.361	-5.309	5.322	-4.565	-0.276	4.573	-4.808	2.549	5.442
Bus ID: 9	34.500	0.341	-5.137	5.149	0.382	-5.294	5.308	-4.557	-0.289	4.566	-4.814	2.528	5.437
Bus7	138.000	1.972	-13.824	13.964	1.653	-11.767	11.882	-11.990	-1.707	12.111	11.295	6.850	13.210
Bus8	138.000	2.469	-19.676	19.830	2.588	-20.622	20.784	-17.040	-2.138	17.174	-18.399	8.694	20.350

All fault currents are symmetrical (1/2 Cycle network) values in rms kA.
* LLG fault current is the larger of the two faulted line currents.

Medium Voltage (34.5 kV) 105% power factor case

ETAP
24.0.0E

Project:
Location:
Contract:
Engineer:
Filename: AMES_BESS

Study Case: Med V 105

Page: 1
Date: 11-20-2024
SN: IASTATEPL
Revision: Base
Config.: Normal

Short-Circuit Summary Report

1/2 Cycle - 3-Phase, LG, LL, & LLG Fault Currents

Prefault Voltage = 105 % of the Bus Nominal Voltage

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus ID: 1	138.000	2.180	-15.273	15.427	1.828	-12.991	13.119	-13.237	-1.887	13.371	12.470	7.565	14.585
Bus ID: 2	34.500	0.287	-5.737	5.744	0.276	-5.890	5.897	-5.055	-0.245	5.061	5.002	3.387	6.041
Bus ID: 3	34.500	0.388	-5.649	5.662	0.440	-5.768	5.784	-4.968	-0.330	4.979	-5.289	2.752	5.962
Bus ID: 4	34.500	0.373	-5.656	5.668	0.419	-5.782	5.797	-4.975	-0.318	4.986	-5.283	2.773	5.967
Bus ID: 5	34.500	0.356	-5.664	5.675	0.395	-5.799	5.812	-4.984	-0.304	4.993	-5.276	2.798	5.972
Bus ID: 6	34.500	0.346	-5.671	5.682	0.378	-5.811	5.823	-4.992	-0.295	5.000	-5.271	2.814	5.975
Bus ID: 7	34.500	0.347	-5.670	5.681	0.380	-5.809	5.822	-4.990	-0.296	4.999	-5.271	2.812	5.975
Bus ID: 8	34.500	0.360	-5.662	5.674	0.399	-5.795	5.809	-4.983	-0.307	4.992	-5.277	2.793	5.970
Bus ID: 9	34.500	0.376	-5.654	5.667	0.423	-5.779	5.794	-4.974	-0.321	4.984	-5.284	2.768	5.965
Bus7	138.000	2.180	-15.273	15.427	1.828	-12.991	13.119	-13.237	-1.887	13.371	12.470	7.565	14.585
Bus8	138.000	2.729	-21.747	21.918	2.860	-22.793	22.972	-18.834	-2.363	18.981	-20.336	9.609	22.492

All fault currents are symmetrical (1/2 Cycle network) values in rms kA.
* LLG fault current is the larger of the two faulted line currents.

APPENDIX 4: ARC FLASH ANALYSIS RESULTS

Low voltage 95% power factor

Project:		**ETAP**		Page:	1
Location:		24.0.0E		Date:	12-05-2024
Contract:				SN:	IASTATEPL
Engineer:		Study Case:	LV ArcF 95	Revision:	Base
Filename:	AMES_BESS~~			Config.:	Normal

Bus Arc Flash Hazard Analysis Summary

Faulted Bus				Fault Current			Trip Device							
				Bolted Fault (kA)										
ID	Nom. kV	Equipment Type	Gap (mm)	Bus	PD	PD Arc Fault (kA)	Source Trip Device ID	Trip (cycle)	Open (cycle)	FCT (cycle)	Arc Flash Boundary (ft)	Incident Energy (cal/cm²)	Working Distance (in)	Energy Level
Bus ID: 10	0.480	Other	13	22.835	0.305	0.214	Aux EXP	25.83	0.00	25.83	6.8	13.5	18	Level D
Bus ID: 11	0.760	Other	13	38.186						120.00	14.1	42.8	18	Level F
Bus ID: 12	0.760	Other	13	38.195						120.00	14.1	42.8	18	Level F
Bus ID: 13	0.760	Other	13	38.203						120.00	14.1	42.8	18	Level F
Bus ID: 14	0.760	Other	13	38.202						120.00	14.1	42.8	18	Level F
Bus ID: 15	0.760	Other	13	38.193						120.00	14.1	42.8	18	Level F
Bus ID: 16	0.760	Other	13	38.184						120.00	14.1	42.8	18	Level F
Bus ID: 17	0.480	Other	13	22.078	21.149	17.038	Aux Breaker	1.80	0.00	1.80	1.4	1.0	18	Level A
Bus1	0.480	Other	13	15.473	14.802	12.083	Aux Breaker	1.80	0.00	1.80	1.1	0.7	18	Level A
Bus3	0.480	Other	13	13.685	13.087	10.675	Aux Breaker	1.80	0.00	1.80	1.0	0.6	18	Level A
Bus15	0.480	Other	13	13.101	12.527	10.212	Aux Breaker	1.80	0.00	1.80	1.0	0.6	18	Level A
Bus16	0.480	Other	13	14.673	14.034	11.455	Aux Breaker	1.80	0.00	1.80	1.0	0.7	18	Level A
Bus21	0.480	Other	13	13.112	12.538	10.221	Aux Breaker	1.80	0.00	1.80	1.0	0.6	18	Level A
Bus22	0.480	Other	13	11.724	11.208	9.112	Aux Breaker	1.80	0.00	1.80	0.9	0.5	18	Level A
Bus23	0.480	Other	13	11.273	10.775	8.749	Aux Breaker	1.80	0.00	1.80	0.9	0.5	18	Level A
Bus24	0.480	Other	13	12.490	11.942	9.725	Aux Breaker	1.80	0.00	1.80	0.9	0.6	18	Level A
Bus33	0.480	Other	13	11.281	10.783	8.756	Aux Breaker	1.80	0.00	1.80	0.9	0.5	18	Level A
Bus34	0.480	Other	13	9.847	9.409	7.602	Aux Breaker	1.80	0.00	1.80	0.8	0.4	18	Level A
Bus35	0.480	Other	13	10.798	10.321	8.368	Aux Breaker	1.80	0.00	1.80	0.8	0.5	18	Level A
Bus36	0.480	Other	13	10.963	10.478	8.501	Aux Breaker	1.80	0.00	1.80	0.9	0.5	18	Level A
Bus37	0.480	Other	13	9.987	9.543	7.715	Aux Breaker	1.80	0.00	1.80	0.8	0.4	18	Level A
Bus38	0.480	Other	13	9.817	9.380	7.578	Aux Breaker	1.80	0.00	1.80	0.8	0.4	18	Level A
Bus39	0.480	Other	13	9.603	9.175	7.406	Aux Breaker	1.80	0.00	1.80	0.8	0.4	18	Level A
Bus40	0.480	Other	13	10.825	10.346	8.390	Aux Breaker	1.80	0.00	1.80	0.9	0.5	18	Level A
Bus54	0.480	Other	13	10.201	9.748	7.887	Aux Breaker	1.80	0.00	1.80	0.8	0.5	18	Level A
Bus61	0.480	Other	13	8.830	8.434	6.782	Aux Breaker	1.80	0.00	1.80	0.7	0.4	18	Level A
Bus63	0.480	Other	13	8.694	8.304	6.673	Aux Breaker	1.80	0.00	1.80	0.7	0.4	18	Level A
Bus64	0.480	Other	13	9.495	9.071	7.318	Aux Breaker	1.80	0.00	1.80	0.8	0.4	18	Level A
Bus65	0.480	Other	13	8.532	8.148	6.542	Aux Breaker	1.80	0.00	1.80	0.7	0.4	18	Level A
Bus66	0.480	Other	13	7.900	7.543	6.033	Aux Breaker	1.80	0.00	1.80	0.7	0.3	18	Level A
Bus67	0.480	Other	13	7.789	7.437	5.944	Aux Breaker	1.80	0.00	1.80	0.7	0.3	18	Level A
Bus69	0.480	Other	13	8.436	8.057	6.465	Aux Breaker	1.80	0.00	1.80	0.7	0.4	18	Level A

Low voltage 105% power factor

Project:		**ETAP**	Page:	1
Location:		24.0.0E	Date:	11-20-2024
Contract:			SN:	IASTATEPL
Engineer:		Study Case: LV ArcF 105	Revision:	Base
Filename:	AMES_BESS		Config.:	Normal

Bus Incident Energy Summary

Bus			Total Fault Current (kA)		Arc-Flash Analysis Results			
ID	Nom. kV	Type	Bolted	Arcing	FCT (cycles)	Incident E (cal/cm^2)	AFB (ft)	Energy Level
Bus ID: 10	0.480	Other	28.604	23.159	1.699	1.296	1.57	Level A
Bus ID: 11	0.760	Other	47.047	32.937	120.000	38.020	13.09	Level E
Bus ID: 12	0.760	Other	47.060	32.944	120.000	38.013	13.09	Level E
Bus ID: 13	0.760	Other	47.071	32.950	120.000	38.008	13.09	Level E
Bus ID: 14	0.760	Other	47.069	32.949	120.000	38.009	13.09	Level E
Bus ID: 15	0.760	Other	47.057	32.943	120.000	38.015	13.09	Level E
Bus ID: 16	0.760	Other	47.044	32.936	120.000	38.021	13.09	Level E
Bus ID: 17	0.480	Other	26.945	21.999	1.783	1.286	1.57	Level A
Bus1	0.480	Other	18.389	15.446	1.800	0.886	1.24	Level A
Bus3	0.480	Other	16.081	13.540	1.800	0.769	1.13	Level A
Bus15	0.480	Other	15.340	12.919	1.800	0.731	1.10	Level A
Bus16	0.480	Other	17.349	14.593	1.800	0.833	1.19	Level A
Bus21	0.480	Other	15.354	12.931	1.800	0.732	1.10	Level A
Bus22	0.480	Other	13.616	11.459	1.800	0.643	1.01	Level A
Bus23	0.480	Other	13.057	10.983	1.800	0.615	0.99	Level A
Bus24	0.480	Other	14.571	12.271	1.800	0.692	1.06	Level A
Bus33	0.480	Other	13.068	10.992	1.800	0.615	0.99	Level A
Bus34	0.480	Other	11.317	9.488	1.800	0.526	0.89	Level A
Bus35	0.480	Other	12.475	10.484	1.800	0.585	0.96	Level A
Bus36	0.480	Other	12.676	10.657	1.800	0.595	0.97	Level A
Bus37	0.480	Other	11.486	9.634	1.800	0.534	0.90	Level A
Bus38	0.480	Other	11.280	9.457	1.800	0.524	0.89	Level A
Bus39	0.480	Other	11.022	9.234	1.800	0.511	0.88	Level A
Bus40	0.480	Other	12.507	10.512	1.800	0.586	0.96	Level A
Bus54	0.480	Other	11.746	9.858	1.800	0.548	0.92	Level A
Bus61	0.480	Other	10.094	8.433	1.800	0.464	0.83	Level A
Bus63	0.480	Other	9.932	8.292	1.800	0.455	0.82	Level A
Bus64	0.480	Other	10.891	9.121	1.800	0.504	0.87	Level A
Bus65	0.480	Other	9.738	8.125	1.800	0.446	0.81	Level A
Bus66	0.480	Other	8.989	7.477	1.800	0.408	0.76	Level A
Bus67	0.480	Other	8.859	7.364	1.800	0.401	0.76	Level A
Bus69	0.480	Other	9.624	8.027	1.800	0.440	0.80	Level A

Medium Voltage 95% power factor

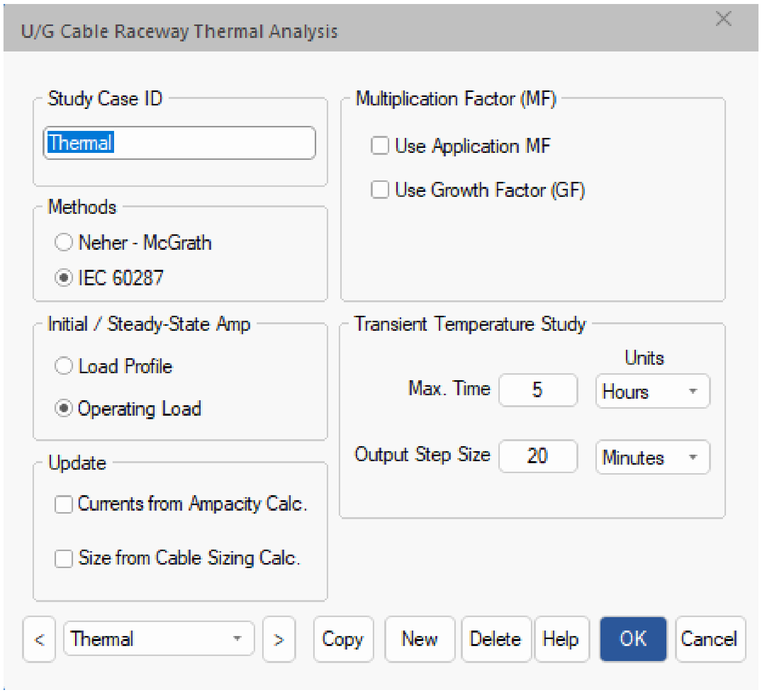
ID	kV	Location	Working Distance LL (in)	Total Energy (cal/cm²)	AFB (ft-in)	Energy Levels	Final FCT (sec)	FaultType	Total Ia" (kA)	Total Ibf" (kA)
Bus ID: 1	138	Bus Arc Fault	37.4	70.95	28'2"	Level F	2	3-Phase	13.956	13.965
Bus ID: 2	34.5	Bus Arc Fault	15	199.84	22'6"	> Level G	2	3-Phase	5.218	5.222
Bus ID: 3	34.5	Bus Arc Fault	15	196.78	22'4"	> Level G	2	3-Phase	5.141	5.148
Bus ID: 4	34.5	Bus Arc Fault	15	197.02	22'4"	> Level G	2	3-Phase	5.147	5.153
Bus ID: 5	34.5	Bus Arc Fault	15	197.29	22'5"	> Level G	2	3-Phase	5.154	5.16
Bus ID: 6	34.5	Bus Arc Fault	15	197.55	22'5"	> Level G	2	3-Phase	5.16	5.166
Bus ID: 7	34.5	Bus Arc Fault	15	197.45	22'5"	> Level G	2	3-Phase	5.158	5.165
Bus ID: 8	34.5	Bus Arc Fault	15	197.19	22'4"	> Level G	2	3-Phase	5.151	5.158
Bus ID: 9	34.5	Bus Arc Fault	15	196.93	22'4"	> Level G	2	3-Phase	5.144	5.152
Bus7	138	Bus Arc Fault	37.4	70.95	28'2"	Level F	2	3-Phase	13.956	13.965
Bus8	138	Bus Arc Fault	37.4	103.97	34'7"	Level G	2	3-Phase	19.816	19.83

Medium voltage 105% power factor

ID	kV	Working Distance LL (in)	Total Energy (cal/cm²)	AFB (ft-in)	Energy Levels	Final FCT (sec)	FaultType	Total Ia" (kA)	Total Ibf" (kA)	Output Rpt.	Configuration
Bus ID: 1	138	37.4	79.01	29'10"	Level F	2	3-Phase	15.416	15.427	MV ArcF 105	Normal
Bus ID: 2	34.5	15	220.6	23'9"	> Level G	2	3-Phase	5.738	5.744	MV ArcF 105	Normal
Bus ID: 3	34.5	15	217.31	23'7"	> Level G	2	3-Phase	5.656	5.662	MV ArcF 105	Normal
Bus ID: 4	34.5	15	217.49	23'7"	> Level G	2	3-Phase	5.661	5.668	MV ArcF 105	Normal
Bus ID: 5	34.5	15	217.84	23'7"	> Level G	2	3-Phase	5.669	5.675	MV ArcF 105	Normal
Bus ID: 6	34.5	15	218.11	23'7"	> Level G	2	3-Phase	5.676	5.682	MV ArcF 105	Normal
Bus ID: 7	34.5	15	218.02	23'7"	> Level G	2	3-Phase	5.674	5.681	MV ArcF 105	Normal
Bus ID: 8	34.5	15	217.74	23'7"	> Level G	2	3-Phase	5.667	5.674	MV ArcF 105	Normal
Bus ID: 9	34.5	15	217.46	23'7"	> Level G	2	3-Phase	5.66	5.667	MV ArcF 105	Normal
Bus7	138	37.4	79.01	29'10"	Level F	2	3-Phase	15.416	15.427	MV ArcF 105	Normal
Bus8	138	37.4	116.2	36'9"	Level G	2	3-Phase	21.903	21.918	MV ArcF 105	Normal

APPENDIX 5: CABLE THERMAL ANALYSIS RESULTS

Cable thermal study ETAP setting screenshot



U/G Cable Raceway Thermal Analysis

Study Case ID: Thermal

Methods
○ Neher - McGrath
● IEC 60287

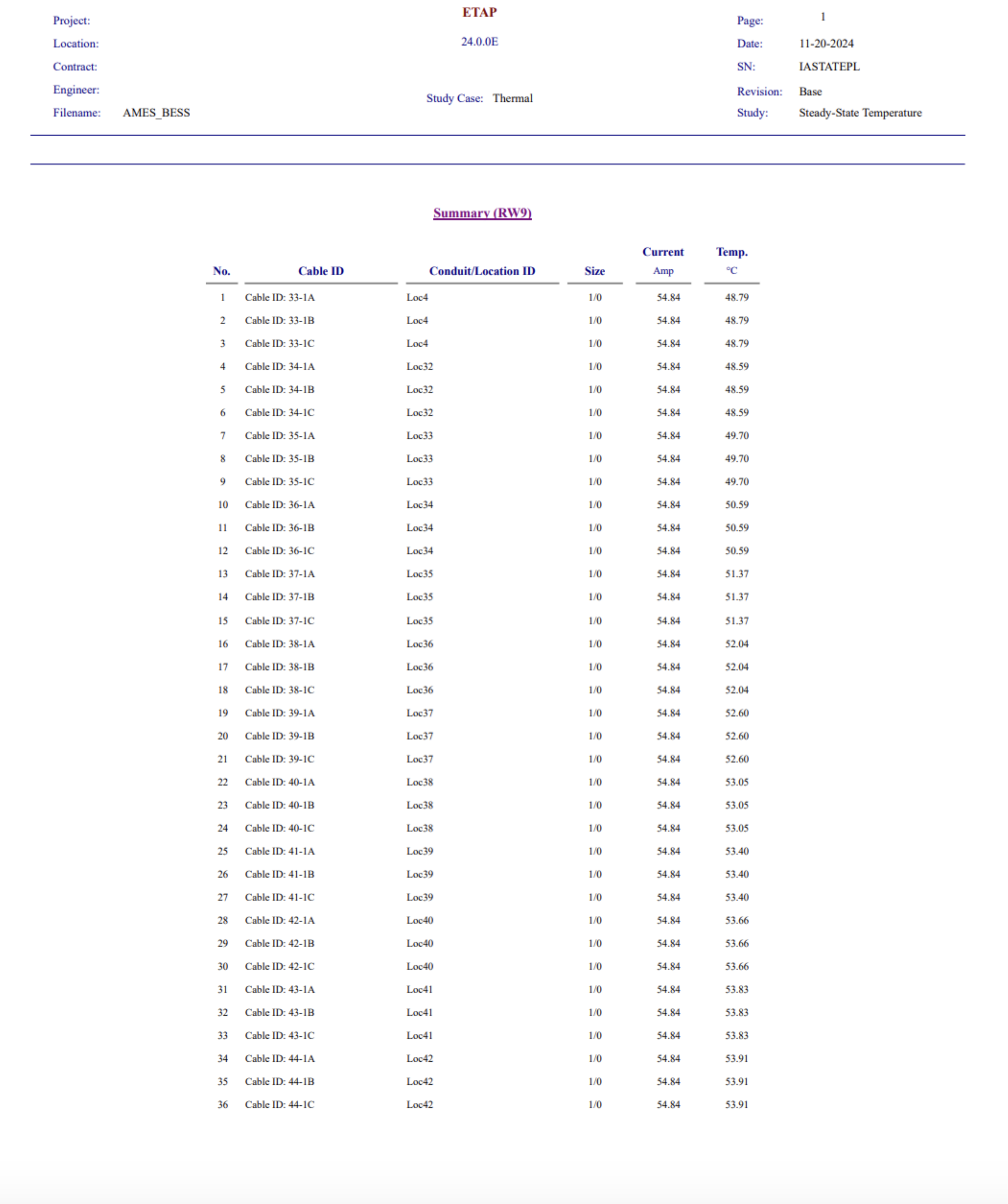
Initial / Steady-State Amp
○ Load Profile
● Operating Load

Update
☐ Currents from Ampacity Calc.
☐ Size from Cable Sizing Calc.

Multiplication Factor (MF)
☐ Use Application MF
☐ Use Growth Factor (GF)

Transient Temperature Study
Max. Time: 5 Hours
Output Step Size: 20 Minutes

Auxiliary Cable Thermal Results



Project:	**ETAP**	Page: 1
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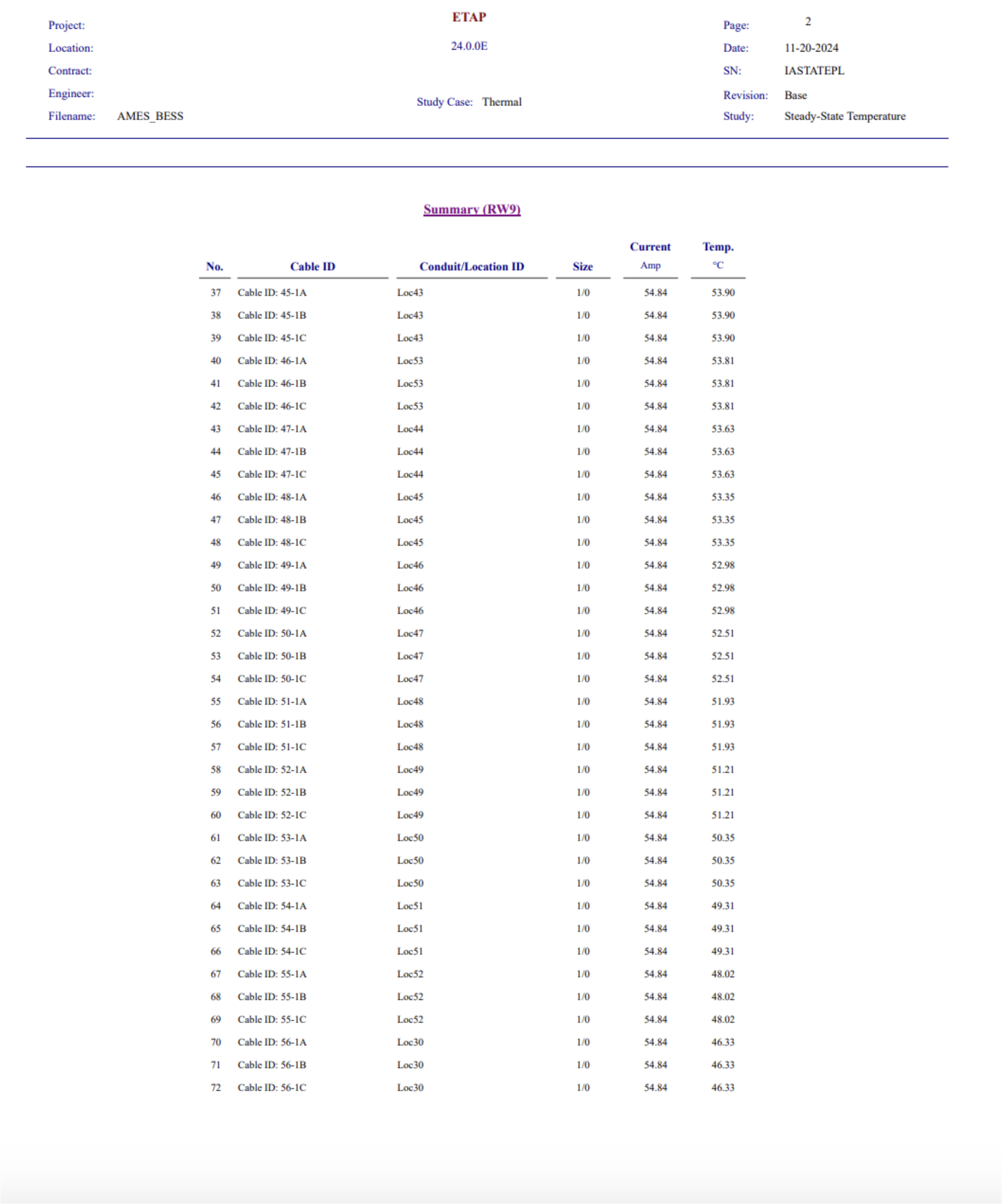
Contract:		SN: IASTATEPL
Engineer:	Study Case: Thermal	Revision: Base
Filename: AMES_BESS		Study: Steady-State Temperature

Summary (RW9)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 33-1A	Loc4	1/0	54.84	48.79
2	Cable ID: 33-1B	Loc4	1/0	54.84	48.79
3	Cable ID: 33-1C	Loc4	1/0	54.84	48.79
4	Cable ID: 34-1A	Loc32	1/0	54.84	48.59
5	Cable ID: 34-1B	Loc32	1/0	54.84	48.59
6	Cable ID: 34-1C	Loc32	1/0	54.84	48.59
7	Cable ID: 35-1A	Loc33	1/0	54.84	49.70
8	Cable ID: 35-1B	Loc33	1/0	54.84	49.70
9	Cable ID: 35-1C	Loc33	1/0	54.84	49.70
10	Cable ID: 36-1A	Loc34	1/0	54.84	50.59
11	Cable ID: 36-1B	Loc34	1/0	54.84	50.59
12	Cable ID: 36-1C	Loc34	1/0	54.84	50.59
13	Cable ID: 37-1A	Loc35	1/0	54.84	51.37
14	Cable ID: 37-1B	Loc35	1/0	54.84	51.37
15	Cable ID: 37-1C	Loc35	1/0	54.84	51.37
16	Cable ID: 38-1A	Loc36	1/0	54.84	52.04
17	Cable ID: 38-1B	Loc36	1/0	54.84	52.04
18	Cable ID: 38-1C	Loc36	1/0	54.84	52.04
19	Cable ID: 39-1A	Loc37	1/0	54.84	52.60
20	Cable ID: 39-1B	Loc37	1/0	54.84	52.60
21	Cable ID: 39-1C	Loc37	1/0	54.84	52.60
22	Cable ID: 40-1A	Loc38	1/0	54.84	53.05
23	Cable ID: 40-1B	Loc38	1/0	54.84	53.05
24	Cable ID: 40-1C	Loc38	1/0	54.84	53.05
25	Cable ID: 41-1A	Loc39	1/0	54.84	53.40
26	Cable ID: 41-1B	Loc39	1/0	54.84	53.40
27	Cable ID: 41-1C	Loc39	1/0	54.84	53.40
28	Cable ID: 42-1A	Loc40	1/0	54.84	53.66
29	Cable ID: 42-1B	Loc40	1/0	54.84	53.66
30	Cable ID: 42-1C	Loc40	1/0	54.84	53.66
31	Cable ID: 43-1A	Loc41	1/0	54.84	53.83
32	Cable ID: 43-1B	Loc41	1/0	54.84	53.83
33	Cable ID: 43-1C	Loc41	1/0	54.84	53.83
34	Cable ID: 44-1A	Loc42	1/0	54.84	53.91
35	Cable ID: 44-1B	Loc42	1/0	54.84	53.91
36	Cable ID: 44-1C	Loc42	1/0	54.84	53.91



Project:
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Summary (RW9)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
37	Cable ID: 45-1A	Loc43	1/0	54.84	53.90
38	Cable ID: 45-1B	Loc43	1/0	54.84	53.90
39	Cable ID: 45-1C	Loc43	1/0	54.84	53.90
40	Cable ID: 46-1A	Loc53	1/0	54.84	53.81
41	Cable ID: 46-1B	Loc53	1/0	54.84	53.81
42	Cable ID: 46-1C	Loc53	1/0	54.84	53.81
43	Cable ID: 47-1A	Loc44	1/0	54.84	53.63
44	Cable ID: 47-1B	Loc44	1/0	54.84	53.63
45	Cable ID: 47-1C	Loc44	1/0	54.84	53.63
46	Cable ID: 48-1A	Loc45	1/0	54.84	53.35
47	Cable ID: 48-1B	Loc45	1/0	54.84	53.35
48	Cable ID: 48-1C	Loc45	1/0	54.84	53.35
49	Cable ID: 49-1A	Loc46	1/0	54.84	52.98
50	Cable ID: 49-1B	Loc46	1/0	54.84	52.98
51	Cable ID: 49-1C	Loc46	1/0	54.84	52.98
52	Cable ID: 50-1A	Loc47	1/0	54.84	52.51
53	Cable ID: 50-1B	Loc47	1/0	54.84	52.51
54	Cable ID: 50-1C	Loc47	1/0	54.84	52.51
55	Cable ID: 51-1A	Loc48	1/0	54.84	51.93
56	Cable ID: 51-1B	Loc48	1/0	54.84	51.93
57	Cable ID: 51-1C	Loc48	1/0	54.84	51.93
58	Cable ID: 52-1A	Loc49	1/0	54.84	51.21
59	Cable ID: 52-1B	Loc49	1/0	54.84	51.21
60	Cable ID: 52-1C	Loc49	1/0	54.84	51.21
61	Cable ID: 53-1A	Loc50	1/0	54.84	50.35
62	Cable ID: 53-1B	Loc50	1/0	54.84	50.35
63	Cable ID: 53-1C	Loc50	1/0	54.84	50.35
64	Cable ID: 54-1A	Loc51	1/0	54.84	49.31
65	Cable ID: 54-1B	Loc51	1/0	54.84	49.31
66	Cable ID: 54-1C	Loc51	1/0	54.84	49.31
67	Cable ID: 55-1A	Loc52	1/0	54.84	48.02
68	Cable ID: 55-1B	Loc52	1/0	54.84	48.02
69	Cable ID: 55-1C	Loc52	1/0	54.84	48.02
70	Cable ID: 56-1A	Loc30	1/0	54.84	46.33
71	Cable ID: 56-1B	Loc30	1/0	54.84	46.33
72	Cable ID: 56-1C	Loc30	1/0	54.84	46.33

Auxiliary Pad Cable Thermal Results

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Filename: AMES_BESS

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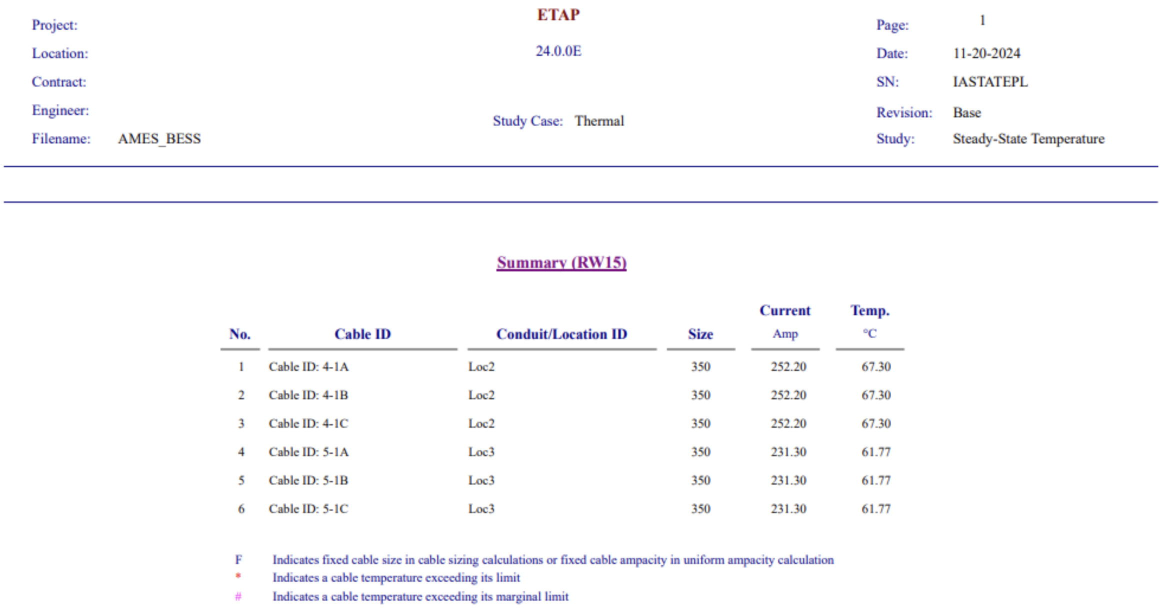
Study: Steady-State Temperature

Summary (RW1)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 32-1C	Loc1	1000	455.00	82.78
2	Cable ID: 32-1B	Loc1	1000	455.00	82.78
3	Cable ID: 32-1A	Loc1	1000	455.00	82.78
4	Cable ID: 32-2C	Loc1	1000	455.00	82.78
5	Cable ID: 32-2B	Loc1	1000	455.00	82.78
6	Cable ID: 32-2A	Loc1	1000	455.00	82.78
7	Cable ID: 32-3C	Loc5	1000	455.00	82.78
8	Cable ID: 32-3B	Loc5	1000	455.00	82.78
9	Cable ID: 32-3A	Loc5	1000	455.00	82.78
10	Cable ID: 32-4C	Loc5	1000	455.00	82.78
11	Cable ID: 32-4B	Loc5	1000	455.00	82.78
12	Cable ID: 32-4A	Loc5	1000	455.00	82.78

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
\# Indicates a cable temperature exceeding its marginal limit

Home Run Cable Thermal Results



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Location:
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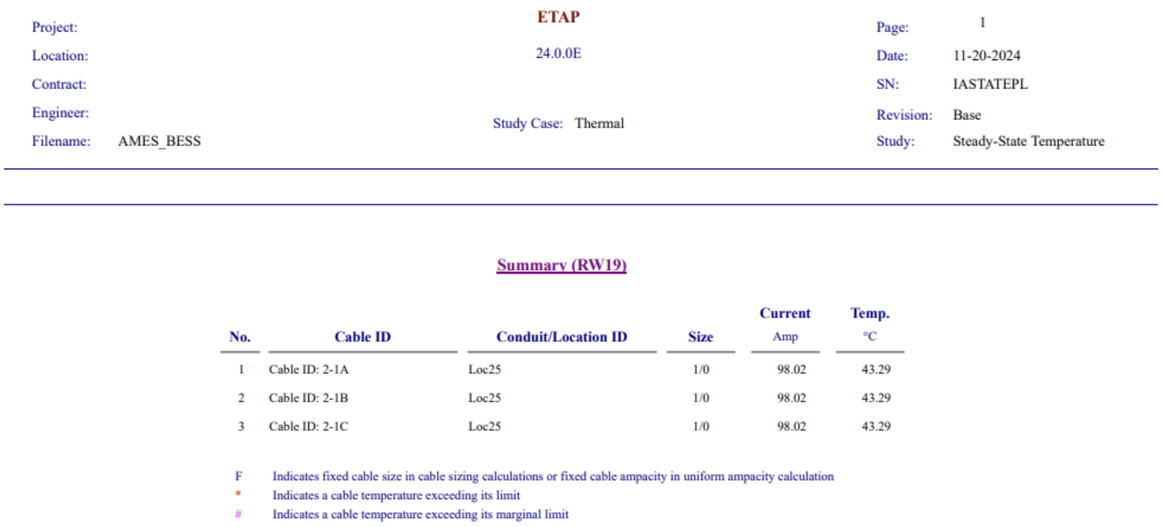
Summary (RW15)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 4-1A	Loc2	350	252.20	67.30
2	Cable ID: 4-1B	Loc2	350	252.20	67.30
3	Cable ID: 4-1C	Loc2	350	252.20	67.30
4	Cable ID: 5-1A	Loc3	350	231.30	61.77
5	Cable ID: 5-1B	Loc3	350	231.30	61.77
6	Cable ID: 5-1C	Loc3	350	231.30	61.77

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
\# Indicates a cable temperature exceeding its marginal limit

PCS 1 – 2 Cable Thermal Results



ETAP
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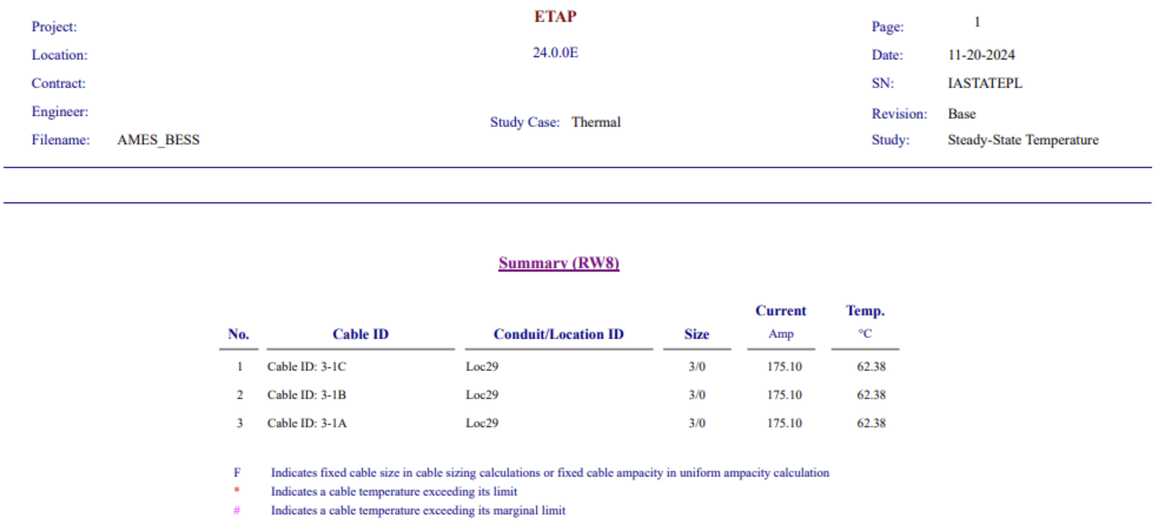
Summary (RW19)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 2-1A	Loc25	1/0	98.02	43.29
2	Cable ID: 2-1B	Loc25	1/0	98.02	43.29
3	Cable ID: 2-1C	Loc25	1/0	98.02	43.29

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
\# Indicates a cable temperature exceeding its marginal limit

PCS 2 – 3 Cable Thermal Results



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Study Case: Thermal

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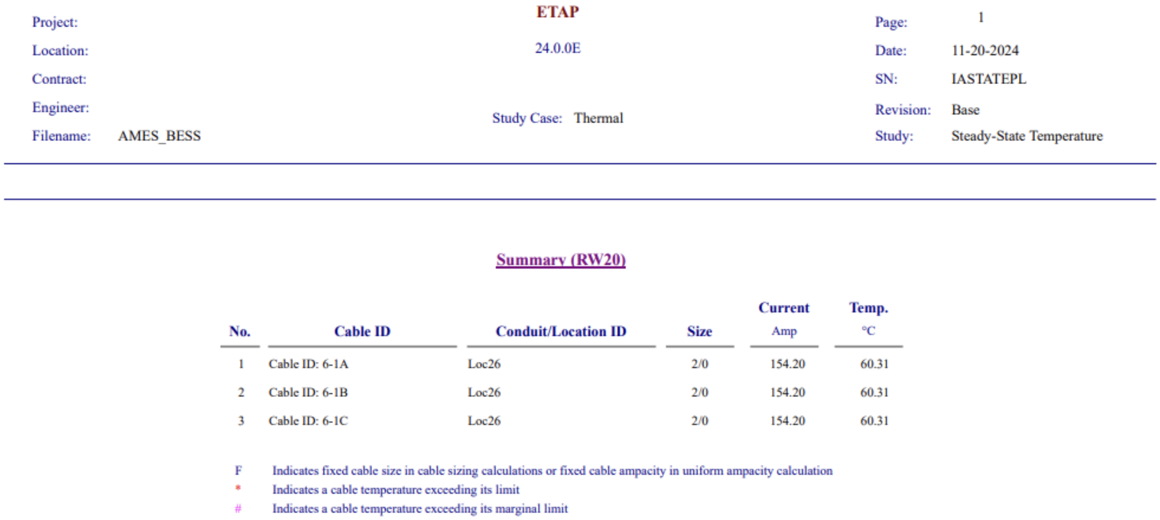
Revision: Base
Study: Steady-State Temperature

Summary (RW8)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 3-1C	Loc29	3/0	175.10	62.38
2	Cable ID: 3-1B	Loc29	3/0	175.10	62.38
3	Cable ID: 3-1A	Loc29	3/0	175.10	62.38

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
\# Indicates a cable temperature exceeding its marginal limit

PCS 4 – 5 Cable Thermal Results



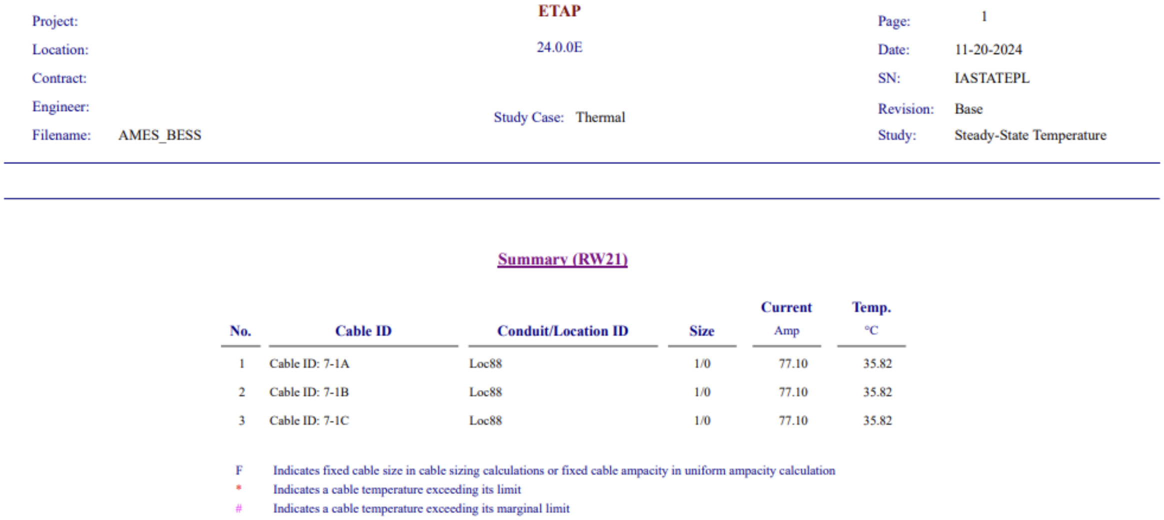
Project:	**ETAP**	Page: 1
Location:	24.0.0E	Date: 11-20-2024
Contract:		SN: IASTATEPL
Engineer:	Study Case: Thermal	Revision: Base
Filename: AMES_BESS		Study: Steady-State Temperature

Summary (RW20)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 6-1A	Loc26	2/0	154.20	60.31
2	Cable ID: 6-1B	Loc26	2/0	154.20	60.31
3	Cable ID: 6-1C	Loc26	2/0	154.20	60.31

F	Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
*	Indicates a cable temperature exceeding its limit
#	Indicates a cable temperature exceeding its marginal limit

PCS 5 – 6 Cable Thermal Results



Project:	**ETAP**	Page: 1
Location:	24.0.0E	Date: 11-20-2024
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Engineer:	Study Case: Thermal	Revision: Base
Filename: AMES_BESS		Study: Steady-State Temperature

Summary (RW21)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 7-1A	Loc88	1/0	77.10	35.82
2	Cable ID: 7-1B	Loc88	1/0	77.10	35.82
3	Cable ID: 7-1C	Loc88	1/0	77.10	35.82

F	Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
*	Indicates a cable temperature exceeding its limit
#	Indicates a cable temperature exceeding its marginal limit

APPENDIX 6: TEAM

Team Members

Oksana Grudanov– Team Leader; Calculated number of battery and inverters needed by determining the reactive power necessary, sized conductors and created cable schedule, Cable thermal analysis Lead

Sarah Ebert– Team Organizer; One-line diagram lead, including research and calculations for equipment sizing; ETAP system development; Short circuit and arc flash study lead in ETAP, including research and evaluation of short circuit and arc flash study

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, ETAP system development, Cable thermal analysis lead

Cole Dustin – Client Point of Contact; Responsible for site layout in AutoCAD; ETAP model lead, including building the model and managing the software

Required Skill Sets for Your Project

- AutoCAD
- One-line Diagram Analysis
- Cable Sizing
- Communication
- Ability to Implement NEC and IEEE Code
- Understanding of Electrical Power systems
- ETAP software

Skill Set Covered by the Team

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

Cole Dustin- AutoCAD, Cable Sizing, Communication, Ability to Implement NEC Code, ETAP Software, Short circuit and arc flash analysis

Sarah Ebert- AutoCAD, One-line Diagram Analysis, Cable Sizing, Communication, ETAP Software, Short circuit and arc flash analysis

Oksana Grudanov- AutoCAD, One-line Diagram Analysis, Ampacity calculations, Communication, Ability to Implement NEC Code, Equipment calculations, Cable Thermal Analysis in ETAP

Project Management Style Adopted by the Team

The management style our team used was a round-table approach. We took feedback from our client and worked together to create and update our solution. Team members would specialize in subsets of the project to save time.

Individual 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.

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.

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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 into tasks we complete individually. In meetings, we will make sure that all team members have the opportunity to voice their opinions. 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 have worked on short circuit and load flow analysis in power classes as well as my internship at a utility company. 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.

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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 adhere to 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