# Ames Microgrid Evaluation & Substation Consulting

## Design Document


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# Executive Summary

The Iowa State University University campus microgrid faces critical challenges that need to be addressed like aging infrastructure, limited capacity, and vulnerability to outages. An overloaded-related fire at the power plant in August 2023 underscored the immediate need for upgrading the system to meet growing energy demands, enhance resilience, and integrate renewable energy. Our project addresses these issues by designing a modernized microgrid and a supporting substation capable of providing reliable, efficient, and sustainable energy to the campus.

The main design requirements are the improvement of system reliability, adherence to the IEEE standards, the use of renewable energy sources, and cost-effectiveness. Safety and sustainability are the most important in our approach, hence the inclusion of solar panels, wind turbines, and battery strigae systems. These solutions balance the environmental benefits of renewable energy with the stability offered by traditional power sources.

The substation design introduces a 69/13.2kV transformer, battery storage for load balancing, and fault protection enhancements to ensure grid reliability. On the distribution side, we've built a detailed load profile of the campus, which is being used to model power flow and develop contingency plans for outages. Tools like OpenDSS and AutoCAD have been instrumental in creating these designs.

So far, we've made significant progress. The substation team has drafted initial diagrams, selected battery technologies, and begun planning renewable energy integration. The distribution team has completed the load profile and is actively modeling the microgrid to identify areas for improvement, such as adding reclosers and capacitor banks for better fault protection. Regular feedback from advisors and industry experts has validated our work and ensured alignment with project goals.

As far as next steps, we will further develop the substation and distribution designs, perform detailed fault analysis, and finalize battery and renewable energy integration. These steps will move us closer to creating a resilient and sustainable microgrid that meets Iowa State University's energy needs.

# Learning Summary

## Development Standards & Practices Used

- IEEE 998-1996 (IEEE Guide for Direct Lightning Stroke Shielding of Substations)

- IEEE 1100-2005 (IEEE Recommended Practice for Powering and Grounding Electronic Equipment)
- IEEE 2030.9-2019 (IEEE Recommended Practice for the Planning and Design of the Microgrid)
- IEEE P2030.12 (IEEE Draft Guide for the Design of Microgrid Protection Systems)

## Summary of Requirements

Fall of 2024:

- Distribution:
    - Load profile development of the ISU campus
    - Distribution network design in OpenDSS distribution software
    - Per-hour data analysis of ISU load profile
- Substation:
    - ACADE justification
    - Substation design
    - One-Line and Three-Line diagrams

Spring of 2025:

- Distribution:
    - Finalization of model development in OpenDSS
    - Contingency and jumpering plans
    - Protection coordination study
- Substation:
    - PSCAD model development and analysis
    - Bill of Materials for upgrades

## Applicable Courses from Iowa State University Curriculum

- EE 3030: Energy Systems and Power Electronics
- EE 4550: Introduction to Energy Distribution Systems
- EE 4560: Power System Analysis I
- EE 4570: Power System Analysis II

## New Skills/Knowledge acquired that was not taught in courses

- OpenDSS
- One-Line Design and Drawing
- Relaying Diagram Creation
- Energy Map Analysis

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# 1. Introduction

## 1.1. Problem Statement

The Iowa State University campus requires a modernized microgrid to meet growing energy demands, enhance resilience, and support sustainability goals. Currently, the Iowa State Microgrid has functional limitations and needs future planning upgrades to ensure long-term energy reliability. These upgrades include connecting the entire campus to the microgrid, planning for future load growth, adding protection coordination to prevent large-scale outages, and replacing outdated, non-functional equipment. Incorporating renewable energy sources such as solar panels and small-scale wind turbines is also crucial, though the landlocked nature of the campus poses challenges for grid integration. Our project involves designing and modeling an upgraded electric distribution microgrid for Iowa State's campus, along with developing a plan for a substation that will effectively manage the new microgrid.

The problem we're addressing stems from the clear need for upgrades, highlighted by the August 2023 overload in power demand that resulted in a fire at the campus power plant. This incident led to power outages, canceled classes, and disruptions in dormitory power supply, underscoring the urgency for a more resilient grid. As new buildings and increasing technology demands continue to drive power usage upward, future planning for load growth is essential. Factors such as electric vehicle charging stations, air conditioning in every dorm, and expanding classroom technologies will contribute to rising power demands. Our project will not only project future load growth to ensure continued power supply but also focus on improving protection coordination by introducing devices like reclosers, which will prevent large-scale faults and mitigate the risk of similar incidents occurring again.

## 1.2. Intended Users

The microgrid and substation design and upgrade plans have three primary users: Iowa State Utilities, Landowners in the area, and Power Consumers on campus.

### 1.2.1. Iowa State Utilities

Iowa State Utilities could be considered the primary user of our product. This group includes all the employees working in the utilities and facilities department at Iowa State University, focusing on those who deal with power generation and power distribution for the campus. All workers who deal with the power distribution and generation facilities on the university microgrid will be considered the users of our design.

The primary need for the campus utility group will be the ability to understand and interpret our designs and upgrade plans. The models, data, and cost estimates that we present to the utility department need to be able to be interpreted by different people and departments within ISU Utilities. As part of our deliverables we will be providing a list of potential reliability upgrades, possible locations and designs to install renewable energy, and a list of other upgrades we plan to make to plan for future load growth within the campus microgrid.

One of the largest parts of our deliverables is to provide approximate cost estimates to ISU utilities for all of our proposed designs and ideas. These estimates, as well as our designs, will help our primary user, ISU Utilities and the university as a whole determine if these upgrades to the system are projects they would like to go through with. The University will have to value our proposals as part of the process to determine the value they will receive from our proposed upgrades to the university microgrid and the ISU substation.

### 1.2.2. Local Landowners

Local Landowners are the people who own land around Ames. Specifically people who own empty lots that may be bought for energy production.

The local landowners need their land to be used in a way that benefits them. There needs to be a balance between the benefits of us using the land and the negative impacts. Wind turbines, for example, may create too much noise if the land is near populated areas. The landowners will not allow us to use their land if our project does not benefit them.

Our project will benefit local landowners as it may become a source of income for them. We may have to rent the land or outright buy it. This would provide income for the landowner. The landowner may also benefit from the moral satisfaction of renewable energy being used on their land.

### 1.2.3. On-Campus Power Consumers

The On-Campus Power Consumer user is a more broad group than the other more specifically defined users. This group includes Iowa State University students, staff, faculty members, and other groups that may not be on campus with as high of a frequency like visiting prospective students, companies giving presentations or participating in club-sponsored activities, and academic conferences that are held on campus.

The main need for the power consumer user will be the need for consistent access to power. That is because their uses for power will include heating and cooling, lighting, and the ability to charge and use technology. These functional needs are currently met, but there have been incidents in the past due to external factors (like weather or power plant fires) where these services have not been readily available. In those cases, the users lose access to electricity and are unable to have their needs met in buildings on the microgrid.

This user group, unlike the other two, is not concerned with the design specifications of the proposed design like the cost value of upgrades or more effective grounding studies. They will, however, derive value from a more consistent source of power. Less power outages and shorter periods when power is lost or shut off for maintenance will mean more productive time available to the consumer on campus, which will lead to higher satisfaction levels. The more environmentally conscious consumers will also benefit from proposed sources of renewable energy, since these sources would reduce the carbon footprint of the Iowa State microgrid and align with their values of protecting the environment.

# 2. Requirements, Constraints, and Standards

## 2.1. Requirements and Constraints

### 2.1.1. Functional Requirements

Accurate Modeling: The models we create are preliminary. They only have to be 100% accurate in the fundamental aspects of our design.

Standards Compliance: All of our designs must comply with industry standards.

Safety Prioritization: Safety cannot be compromised for any reason.

### 2.1.2. Functional Requirements

Cost Effectiveness: The design should maximize our main objectives while using the least amount of resources as possible.

### 2.1.3. Functional Requirements

Land Availability: There is a limited amount of land available. Designs which require land, need to fit on the available land.

Equipment Spacing: Electrical equipment needs to be spaced in accordance to the IEEE and NEC standards.

### 2.1.4. Functional Requirements

Renewable Focus: We have an ethical responsibility to make sure our design doesn't needlessly harm the environment.

## 2.2. Engineering Standards

Engineering standards are the framework for a developed society. Standards are the building blocks for project and product development; they ensure we can build functional systems and designs that can be repeated and have safety in mind.

All in all, engineering standards make engineering easier. Since standards are thoroughly tested and reviewed, they are a repeatable process that engineers use in their everyday lives to speed up the process and make sure they have the information to back up their choices. By having connected standards across different engineering fields and industries, we can ensure that the work remains connected. Standards ensure that devices can work together, that different parts of the country remain connected through communication and power, and there is consistency across the board.

### 2.2.1. Substation Standard 1: IEEE 998-1996 (IEEE Guide for Direct Lightning Stroke Shielding of Substations)

The IEEE 998 standard focuses on methods for protecting substations from direct lightning strikes. It provides guidance on three approaches: the classical empirical method, the electro geometric model, and briefly discusses active lightning terminals. The goal is to minimize the risk of lightning damage to equipment and buswork within substations.

This standard is highly relevant to our project because lightning protection is essential to prevent damage to critical infrastructure. Given the nature of the project, implementing robust lightning mitigation strategies aligns with reliability goals.

To incorporate this standard, we could implement the electrogeometric model for calculating protective zones around key equipment. Additionally, reviewing the classical empirical method to ensure that the buswork and equipment are shielded is important. We also may also explore adding active lightning terminals where necessary, especially in vulnerable areas.

### 2.2.2. Substation Standard 2: IEEE 1100-2005 (IEEE Recommended Practice for Powering and Grounding Electronic Equipment)

This standard provides best practices for powering and grounding electronic equipment in commercial and industrial settings. It aims to resolve conflicting design philosophies and enhance equipment performance, while maintaining safety. It covers power disturbances, quality, protection, grounding systems, noise control, and includes case studies to support the recommendations.

This standard is relevant to our substation design, as proper grounding and power quality are essential for ensuring reliability, performance, and safety in electrical systems. Addressing power disturbances and using diagnostic tools to measure and resolve grounding issues aligns with my project goals.

To align with this standard, we would ensure our design includes robust grounding systems and noise control strategies. Additionally, we would integrate diagnostic and measurement tools to monitor power quality and disturbances, implementing power protection equipment where needed. This will help improve overall performance and reduce the risk of grounding-related issues.

### 2.2.3. Distribution Standard 1: IEEE 2030.9-2019 (IEEE Recommended Practice for the Planning and Design of the Microgrid)

This standard provides a base level understanding of the different considerations that need to be kept in mind when designing a microgrid. For the pre-planning phase, the standard provides advice for load sizing, future growth estimation, and basic system configuration. The standard then goes on to give metrics for the inclusion of renewable energy resources, safety concerns, and grounding considerations. Finally, the standard contains metrics for evaluation like expected power losses and life cycle cost estimations. The standard also cites other referenced IEEE standards that would also be relevant to microgrid design.

IEEE 2030.9-2019 has relevance to our project because the distribution part of our project is focused on the modeling of the Iowa State University Microgrid. Even though we aren't designing a microgrid from scratch like the primary intent of the development of this standard, the use of the different considerations can help us make intentional assumptions about how the system is set up. One of the challenging aspects of the distribution modeling is the fact that all power lines are underground to help with aesthetic and reliability purposes, and so having standards that can give us some clarity will be helpful in further providing bounds for the model.

In order to meet this standard, our documentation that outlines what is known about the Iowa State Microgrid will be adapted to include information provided in the standard. The main focus on obtaining information for the model falls on professionals in industry that have either worked on the system themselves or currently are involved in the maintenance of the system. When these sources are uncertain about different specifications, however, the standards will be assumed to have been met by the design engineers who created the microgrid.

### 2.2.4. Distribution Standard 2: IEEE P2030.12 (IEEE Draft Guide for the Design of Microgrid Protection Systems)

This standard provides the breakdown of the requirements for the control and protection systems of the design of microgrids. Microgrids can require many different assets depending on the different operation modes that the grid is currently in. The protection devices needed for a grid-connected system or an island mode will look very different. This standard covers the different design aspects and how to make the selection of devices on the different modes of operation. Finally, this standard makes sure that the microgrid is protected and dependable with all of its equipment.

This standard has many applications and relevance to our project. This standard covers the design of the control and protection system design of a microgrid. With the Iowa State microgrid able to be connected to the grid and islanded, it's important that we understand the different design standards. This standard will help us break down the different protection coordination we need for the upgrades we want to make to the microgrid.

At this point, there are no modifications that we need to make to the design to incorporate this standard. Currently, we are building our load profile data to be able to then model the Iowa State microgrid. This standard will be more relevant to our project next semester when we are working on making upgrades and resigning the system. What we can do to make sure this standard is included is to read and understand this standard now so we can apply it later.

### 2.2.5. Other Applicable Standards

Other standards that may be applicable, but were not explained in depth are:

- IEEE 1409-2012 (IEEE Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV Through 38 kV)

- IEEE 1854-2019 (IEEE Trial-Use Guide for Smart Distribution Applications)

- IEEE 399-1997 (IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis

- IEEE 493-2007 (IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems)

- IEEE 1899 - 2017 (IEEE Guide for Establishing Basic Requirements for High-Voltage Direct-Current Transmission Protection and Control Equipment)

These additional standards deal with further specifications of microgrid design, and also specifications for high voltage protection and grounding equipment.

# 3. Project Plan

## 3.1. Project Management/Tracking Procedures

For our project, we're adopting a hybrid project management style, combining both waterfall and agile methodologies. Initially, we are using a waterfall approach for the project's early phases, defining scope, establishing detailed requirements, and creating foundational one-line diagrams and system specifications. This structured approach ensures alignment with client expectations from the outset, which is critical given our focus on developing a resilient energy solution through battery integration, load-shedding protocols, and microgrid enhancements.

As we progress, we'll shift to agile principles in the implementation and refinement stages, allowing us to introduce flexibility in response to client feedback and adapt our design as new technical challenges arise, especially around battery system modeling and load prioritization. This hybrid approach, blending waterfall's organization with agile's adaptability, is ideal for managing the evolving needs of our project as we explore the most effective battery-based resilience strategies to maintain essential services during outages.

The project's outcome will be a conceptual design package, a comprehensive documentation set outlining the proposed battery storage, microgrid, and substation integration. This package will include one-line diagrams, battery sizing and specifications, load-shedding protocols, and other technical documentation necessary for guiding future detailed engineering work. Although not intended for immediate physical implementation, this conceptual package provides a strong foundation for subsequent development stages, focusing on the new battery and load-management components.

To effectively track progress and milestones over both semesters, we'll utilize several tools:

- Snapchat: For day-to-day communication, quick updates, and troubleshooting. Snapchat enables fast, informal exchanges, helping the team stay connected outside of formal meetings.

- Project Website: A required class project website will serve as a centralized platform for sharing updates and documentation on our conceptual design package. It will make our work accessible to the client, promoting transparency and collaboration as we refine our battery and microgrid designs.

- Shared Google Drive Folder: This will contain all assignments, reports, and relevant documents for class, ensuring team members have access to the latest materials, which is crucial for efficient collaboration on complex design tasks.

- Discord: Discord will help organize our discussions into channels, segmenting conversations by topic (such as battery modeling, client communications, or load prioritization). Its real-time messaging, voice, and video call features will facilitate quick check-ins, brainstorming, and troubleshooting as we develop the new battery-focused design.

- Microsoft Teams: Used for weekly team and advisor meetings. Teams integrate with Outlook, helping us coordinate schedules, set reminders for key milestones, and maintain regular communication with our advisor.

## 3.2. Task Decomposition

Due to our project having two distinct teams, we have created separate task decompositions for each area of the project. Each team has created a decomposed list of tasks, as well as an approximate timeline for each task and a set of goals that is aimed to be achieved upon completion of the task.

### 3.2.1. Substation Team Tasks

The Transmission Team is updating its project scope to focus on incorporating battery storage solutions and reducing emphasis on the Ames substation upgrades. Sean recently met with our client to discuss this shift in priorities, aligning the project more closely with resilience and load management objectives rather than traditional substation enhancements. We have a client meeting scheduled for November 1st to further discuss these updates and gather feedback on the proposed battery system integration. Below are the previously established team tasks created prior to this significant scope change, which will now require adjustments to reflect our new direction.

**Week 1-2:**

- Task: Introduction to the project, understand initial scope, and gather key requirements

- Goal: Define project goals, identify the needs of the users (ISU Utilities, campus landowners, power consumers)

**Week 2-3:**

- Task: Complete scope definition

- Goal: Submit finalized project scope to the client

**Week 4-6:**

- Task: Begin researching and selecting software/tools for modeling (PSCAD, AutoCAD)

- Goal: Understand software capabilities for the transmission side, prepare software for use, develop initial ideas for one-line diagram and substation concepts.

**Week 5-10:**

- Task: Finalize substation design updates, complete any necessary adjustments to the one-line diagram
- Goal: Iterate through the design process for the one-line and three-line diagram with feedback, produce a final design for review by the client

**Week 7:**

- Task: Integrate additional renewable energy sources into the one-line diagram, such as wind/solar farms
- Goal: Create a preliminary design for the renewable integration

**Week 8-9:**

- Task: Begin initial fault current and grounding studies
- Goal: Conduct preliminary analysis for safety and compliance

**Week 10-11:**

- Task: Develop a mock budget/Bill of Materials (BOM) for substation upgrades
- Goal: Estimate the cost of materials for the project

**Week 12:**

- Task: Prepare for final presentation and submit all project deliverables
- Goal: Ensure all designs, models, and documentation are ready for submission

### 3.2.2. Distribution Team Tasks

**Week 1-3:**

- Task: Define project scope
- Goal: Determine what are reasonable deliverables and what we are looking to accomplish.

**Week 3-5:**

- Task: Research software and tools to use for the project
- Goal: Work with advisors to determine what modeling tool we will use to model the campus microgrid and begin collecting load data to use in our distribution model

**Week 5-7:**

- Task: Request Load Data and Develop Campus Load Profile
- Goal: Obtain all data necessary to create a load profile for all campus buildings connected to the microgrid.

**Week 7-10:**

- Task: Develop model of Campus
- Goal: Learn how to use OpenDSS, and then transfer the data from Objective 3 to create a model of the Iowa State microgrid with the required loads and other system information.

**Week 10-12:**

- Task: Start working on area planning objectives (contingency and jumpering plans)
- Goals: Begin creating deliverables for the microgrid based on the load profile and IEEE standards

## 3.3. Project Proposed Milestones, Metrics, and Evaluation Criteria

### 3.3.1. Substation Team Tasks

**Week 1-3:** We will have a written out scope and key requirements approved by our client and faculty advisor. We will measure the progress of this task by getting the approval.

**Week 4-6:** We will have decided on what software will use to build the model. We will measure this goal by getting our software approved by our client and advisor.

**Week 5-10:** We will create a one-line and three-line diagram with feedback to produce a final design. We will measure this goal by getting our software approved by our client and advisor.

**Week 7:** We will create a design for renewable integration. We will measure this goal by getting our software approved by our client and advisor.

**Week 8-9:** We will conduct preliminary analysis for safety and compliance. We will measure this goal by getting our software approved by our client and advisor.

**Week 10-11:** We will estimate the cost of materials for the project. We will measure this goal by getting our software approved by our client and advisor.

**Week 12:** We will ensure everything is ready to submit. We will measure this goal by getting our software approved by our client and advisor.

### 3.3.2. Distribution Team Tasks

**Week 1-3:** We will have a written out scope and key requirements approved by our client and faculty advisor. We will measure the progress of this task by getting the approval.

**Week 3-5:** We will have decided on what software will use to build the model. We will measure this goal by getting our software approved by our client and advisor.

**Week 5-7:** We will create a load profile data spreadsheet including all buildings on campus. We will measure this goal by getting our software approved by our client.

**Week 7-10:** We will build a model of the campus and its power structure. We will measure this goal by getting our software approved by our client and advisor.

**Week 10-12:** We will determine our schedule of area planning objectives for the spring semester. We will measure this goal by getting our software approved by our client.

## 3.4. Project Timeline / Schedule

Based on the task decompositions outlined in section 3.2, Gantt charts have been designed showing the proposed timeline of completing these tasks. Since we are primarily using a waterfall approach for project scheduling, these deadlines should be fairly rigid in nature and used to keep the project on track. Below are the Gantt charts for the first semester deliverables:

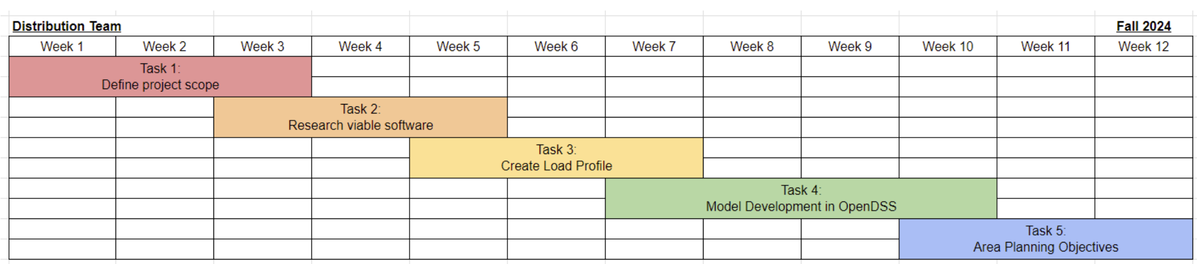


*Figure 1: Distribution Team Gantt Chart*

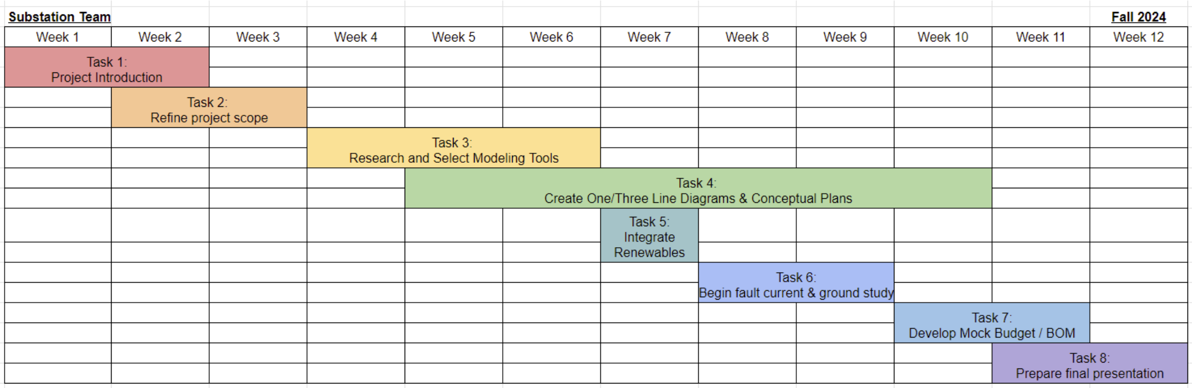


*Figure 2: Substation Team Gantt Chart*

At the end of each period, each tasks' goals are expected to be completed and any deliverables will be sent to the client in order to progress through the design. The completion of these tasks will help set the project up for success for the action phase of the project.

## 3.5. Risks and Risk Management / Mitigation

**Software/Tool Limitations:**

- Risk: The programs (e.g., OpenDSS, AutoCAD) may not fully meet the needs for accurate transmission modeling or may be difficult to integrate with renewable energy sources. As there are better programs that could offer better transmission modeling but they are not free.

- Mitigation: As we research and consult with experts on which program we should use before final software selection. Backup tools (e.g., PSCAD for simulations) should be identified early in case the chosen software fails to perform as expected.

**Battery Integration Complexity:**

- Risk: Difficulty in integrating the battery storage system with the transmission network, especially in terms of load management and ensuring compliance with safety standards.

- Mitigation: Collaborate with the Distribution Team to align load-shedding strategies. Schedule regular consultations with experts in battery storage systems and power resilience. Conduct smaller, iterative tests of battery performance in the model to catch integration issues early, adjusting load-shedding protocols accordingly.

## 3.6. Personnel Effort Requirements

*Table 1: Task Breakdown and Time Allocation*

| Task | Hours |
|---|---|
| Research Software:<br>Find the best modeling software for our purposes. Also find software for substation studies. | 6 |
| Data Collection of Current Microgrid:<br>Coordinate meetings with utilities contacts. Email University contacts to learn all of the relevant characteristics of the microgrid. | 30 |
| Develop Model of Microgrid:<br>Use the characteristics of the current microgrid to develop a model of the grid and the substation. This includes a one-line, three-line, and 3D model. | 100 |
| Area Planning:<br>Create detailed contingency and jumpering plans for the microgrid. | 60 |
| Substation Studies:<br>Perform studies on the new substation to determine fault current, grounding, and other important metrics which impact efficiency and safety. | 60 |
| Battery Research:<br>Research how to best implement batteries into our design. Come up with some potential configurations. | 30 |
| Bill of Materials:<br>Create a list of all equipment and material. Use this and projected labor hours to come up with a reasonable cost estimate for completing the project. | 50 |

## 3.7. Other Resource Requirements

In addition to financial support, our project will require several essential resources to complete our work effectively, especially given the Transmission Team's new focus on integrating battery storage rather than substation upgrades. These resources include:

1. Software Tools:
    a. AutoCAD: Essential for creating detailed one-line diagrams and schematics of the microgrid and battery storage system, allowing precision in design and visualization of electrical component layouts.
    b. OpenDSS: This distribution system simulator will be used to model and analyze the performance of the proposed microgrid and battery system, enabling evaluation of system interactions under varying load conditions and operational scenarios.
2. Hardware:

   a. Computers: Reliable computing resources are required to run design software, perform simulations, and analyze data effectively.

3. Technical Documentation:

   a. Standards and Specifications: Access to industry standards, codes, and best practices documentation will be crucial to ensure our designs adhere to safety and operational guidelines, including resources from IEEE (Institute of Electrical and Electronics Engineers) and IEC (International Electrotechnical Commission)

4. Consultation with Experts:

   a. Advisor and Industry Contacts: Engaging with our faculty advisor and industry experts will provide key insights and guidance. These consultations will be invaluable in refining our battery system integration approach, maintaining industry standards, and addressing technical challenges.

5. Team Collaboration Tools:

   a. Project Management Software: Tools such as Snapchat, Google Drive, Discord, Microsoft Teams, and our Project Website will be vital for effective collaboration, ensuring coordination, communication, and progress tracking across the team.

6. Time Commitment:

   a. Each team member's time and consistent dedication to the project will be critical. Coordinating schedules for meetings, design sessions, and collaborative efforts will be essential to ensure all members can contribute effectively.

By securing these resources, we will strengthen our capacity to produce a comprehensive conceptual design package that aligns with the project's updated scope and objectives.

# 4. Design

## 4.1. Design Context

### 4.1.1. Broader Context

Our project will affect the entire Iowa State University campus. The added reliability provided by the substation additions and the contingency planning will mitigate the effects of power outages. A power outage, whether it is caused due to an issue at the ISU power plant or a city wide outage, can cause lots of damage. Most of the damage caused by a power outage is the losses in research progress. There are many systems that rely on a constant source of power to continue university research. Another side effect of losing power is most classes have to be canceled and professors and university administrators have to work at home. This has a less tangible impact than the research costs, but disruptions like that are annoying for everyone involved on campus.

| Area | Description | Examples |
| --- | --- | --- |

| | | |
|---|---|---|
| Public health, safety, and welfare | The substation will be located on campus and contains extremely dangerous equipment. This equipment can injure people servicing the equipment and the general public. | The substation will contain high voltage equipment. The design must contain adequate safety measures to ensure the safety of maintenance workers. This will also be located on campus so there is likely to be an increase in foot traffic near the substation. It is important to make sure the general public cannot access the substation and possibly injure themselves. |
| Global, cultural, and social | Our project will affect college students and professors. They generally value sustainable energy and reliable energy. The design we are making will provide both of these to both groups. | The wind farm to the north east of Ames will provide clean energy to supplement the energy created on campus. The batteries will be able to store this clean energy and increase the reliability of our campus power system. |
| Environmental | Our project will connect energy systems which can release a lot of carbon into the atmosphere. This carbon will exacerbate global warming and harm our environment. It is important to reduce the total carbon produced by our solution. | Our project will connect the wind turbines north east of Ames with the ISU power grid. The substation will be able to store this renewable energy for later use. |
| Economic | Power equipment is very expensive. The cost of the substation will increase the energy rate that is charged to ISU. Ultimately this will be paid for by government grants and the students. Reducing the cost of this project is a top priority. | This project would cost millions of dollars. Compared to other substation projects, it would be inexpensive. The costs saved from the increased reliability could possibly offset the costs of constructing the substation. |

### 4.1.2. Prior Work/Solutions

**Background and Literature Review**
Microgrids are localized energy systems that combine renewable and non-renewable energy sources to meet specific energy needs. Universities like UC San Diego, MIT, Illinois Institute of Technology (IIT), Princeton, and Santa Clara University have implemented microgrids, each with unique features and shortcomings.

1. **UC San Diego Microgrid**: UCSD uses a combination of gas turbines, steam turbines, and solar cells to supply 85% of its campus's electricity and nearly all heating and cooling. However, it relies heavily on gas-based systems, contributing to carbon emissions
2. **MIT Microgrid**: MIT is transitioning from gas turbines to cleaner energy sources. Although these upgrades lower emissions and enhance future scalability, they face

challenges like high costs, land requirements for renewable systems, and ongoing reliability issues due to aging infrastructure

3. **IIT Microgrid**: IIT emphasizes energy independence, incorporating rooftop solar, battery storage, and smart switches for reliability. However, its reliance on developing technologies like battery storage and risks from environmental factors, such as proximity to Lake Michigan, pose challenges
4. **Princeton Microgrid**: Princeton integrates gas turbines, solar fields, and underground power distribution, enabling resilience during emergencies (e.g., Hurricane Sandy). Still, solar fields require significant land and depreciate quickly
5. **Santa Clara University Microgrid**: SCU employs smart grid technologies that optimize energy savings and sustainability. Despite its high upfront costs and phased development requirements, SCU's microgrid demonstrates potential energy cost reductions of up to 20% while supporting 50% less energy consumption

**Analysis and Opportunity Gaps**

Our project can address gaps in existing microgrid designs by focusing on the following:

- **Mixed Energy Sources**: Combine solar and battery storage with existing fossil fuel systems to balance costs and reliability while reducing carbon emissions.
- **Space Efficiency**: Utilize compact renewable systems and optimize existing infrastructure to overcome land constraints.
- **Resilience and Scalability**: Design a system that maintains operations during outages and adapts to future energy demands.

**Proposed Solution**

Our microgrid will integrate solar panels, battery storage, and a small-scale natural gas generator for peak demand periods. This hybrid approach balances reliability and environmental sustainability while minimizing costs and space requirements. The microgrid will also include advanced energy management software for real-time monitoring and optimization.

**Pros and Cons**

The UC San Diego microgrid provides substantial benefits, such as supplying 85% of the campus's electricity and nearly all its heating and cooling needs through a combination of gas turbines, a steam turbine, and a solar installation. However, it is very costly and still relies heavily on gas-based energy, contributing to carbon emissions. MIT's microgrid is undergoing upgrades, including replacing its gas turbine with cleaner energy sources, offering a path toward reduced carbon emissions and future scalability. Nevertheless, these efforts involve high costs, land usage concerns for renewable energy, and current issues with reliability and resiliency, as power outages are frequent. The Illinois Institute of Technology's microgrid boasts self-sufficiency, enhanced reliability through smart switches, and the integration of solar and wind energy, but challenges include space constraints, developing energy storage technology, and vulnerability to flooding due to proximity to Lake Michigan. Princeton's microgrid includes a solar field and thermal energy storage, enabling resilience during events like hurricanes and participation in the energy market, but it faces difficulties in upgrading solar technology and securing adequate land for expansion. Finally, Santa Clara University's smart microgrid combines renewable energy sources with advanced data utilization to maximize energy savings and ensure operational continuity during outages. However, its implementation is expensive, requires phased development, and some components occupy space that could be used for other purposes. Each system offers valuable insights into clean energy integration, resilience, and efficiency, but also highlights the need to balance cost, reliability, and sustainability.

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### 4.1.3. Technical Complexity

Our senior design project, *Ames Microgrid Evaluation & Substation Consulting*, is a technically complex endeavor that spans both distribution and substation systems. It integrates multiple subsystems, each requiring distinct scientific, mathematical, and engineering principles to address challenging requirements that align with or exceed current industry standards.

**Distribution Component**

The distribution system focuses on optimizing energy delivery across campus, including these critical elements:

1. Feeder Load Balancing
    - Analyzing current and future load distributions across feeders to reduce losses and improve efficiency.
    - Applying power flow equations and optimization algorithms to balance loads dynamically.
2. Renewable Energy Integration
    - Evaluating the feasibility of rooftop solar panels and wind turbines on campus buildings.
    - Using solar irradiance modeling, wind energy analysis, and battery storage calculations to determine viability.
3. Microgrid Control
    - Designing a control strategy for energy generation and distribution in a mixed-source microgrid.
    - Employing control systems theory and energy management system principles to maintain stability under varying conditions.
4. Reliability and Resiliency
    - Enhancing the system to ensure continued operation during outages or extreme weather events.
    - Utilizing fault-tree analysis and redundancy planning to meet or exceed reliability metrics.

**Substation Component**

The substation component of our senior design project involves the design of a theoretical new 69/13.2kV substation, named the Cyclone Substation. This project spans two semesters and incorporates both the physical layout and protection and controls design of the substation, guided by Burns & McDonnell engineers Jenalee Dickson and Emily Straub, who serve as advisors and client representatives.

1. Substation Configuration
    a. Design includes a 69/13.2kV transformer, one 69kV gas circuit breaker, one 69kV line position, two 13.2kV line positions, and two 13.2kV vacuum circuit breakers.
    b. The substation will interconnect with a new Battery Storage System near the Iowa State campus, integrating renewable energy sources for enhanced grid reliability and sustainability.
2. Physical Design
    a. Using Bluebeam and AutoCAD, the team will create detailed substation layout drawings.
    b. Example drawings and standard component templates provided by Burns & McDonnell will ensure design accuracy and adherence to industry standards.
3. Protection and Controls
    a. The team will develop a protection and controls scheme, including relay settings and coordination to safeguard the substation's critical assets.
    b. This work incorporates overcurrent protection principles, short-circuit calculations, and fault analysis to ensure system safety and reliability.
4. Battery Storage System Integration
    a. While the battery's detailed design is outside the scope, the substation team will determine its electrical characteristics in collaboration with the Distribution Planning Team.
    b. This integration involves coordination of electrical parameters to optimize energy storage utilization and system performance.

**Technical Complexity**

1. Multiple Subsystems:
    a. The physical design, protection, and integration of renewable energy require distinct engineering principles, including power systems analysis, electromagnetic theory, and energy storage modeling.
    b. Both the substation and distribution components involve unique engineering challenges, such as transformer sizing, feeder balancing, and renewable energy integration.
2. Challenging Requirements:
    a. The substation must meet industry standards for reliability and incorporate cutting-edge solutions, such as interconnection with a modern Battery Storage System.
    b. The microgrid must meet industry standards for reliability and efficiency while incorporating renewable sources and maintaining affordability.
3. Design Tools and Standards:
    a. Utilizing professional-grade tools like AutoCAD and Bluebeam ensures the design aligns with real-world engineering practices.
4. Advisor Collaboration:

   a. Regular consultations with Burns & McDonnell engineers bridge the gap between academic and industry expertise, ensuring a professional-quality design.
5. Advanced Principles:
   a. The project applies diverse engineering principles, including electromagnetic theory, optimization, energy storage modeling, control systems, and sustainability analysis.
6. Real-World Impact:
   a. The solutions proposed are intended to improve energy reliability and sustainability for the campus, reflecting trends in industry innovation.

## 4.2. Design Exploration

### 4.2.1. Design Decisions

#### 4.2.1.1. Transmission Team

One of the key design decisions is selecting the right battery storage system, such as lithium-ion or flow batteries. This choice is essential because the battery will help manage energy from renewable sources like wind and solar, ensuring the substation can operate efficiently. The right battery will improve performance, cost, and lifespan, while the wrong choice could lead to inefficiency or higher costs. Another critical decision is determining the appropriate transformer size for the 69kV–13.2kV system. The transformer plays a key role in adjusting the voltage between the transmission and distribution systems, and selecting the right size is crucial for stable operations. A transformer that's too small may not handle the power load, while one that's too large could increase costs unnecessarily.

Finally, choosing the right modeling and simulation software is vital for designing and testing the substation, especially for integrating battery storage and renewable energy sources. Tools like PSCAD and AutoCAD will help simulate how the substation interacts with the grid, storage, and renewable energy, allowing the team to identify and fix issues early in the design process. These decisions directly impact the project's cost, performance, and safety, ensuring the substation meets energy needs and is built effectively.

#### 4.2.1.2. Distribution Team

The first choice made was how to develop the campus load profile. Coming into the project, the team was unsure how much power the campus consumed, as this was not information typically shared in class or publicly. In order to figure this out, the client suggested a manual walk around the campus to gauge each building based on size and devices present to estimate the power consumption (in kilowatts). However, we were able to discover a public website that helped show the 12 month power consumption from all buildings on the microgrid, which then helped us define the profile.

Based on the load data available, another subsequent choice that was made was what information would be approximated, and what other data we would attempt to collect from the contacts we had found at the ISU utility from either web searches or our advisor. Information like the voltage rating of the distribution system and the power factor at which buildings on campus were being operated at are crucial to the design of the model and any subsequent improvements. As a team, we decided that we would attempt to obtain as much information as possible from our contacts and ask as many questions necessary, and wherever they declined to share this information or were unable to give us a direct answer we would work with the client to fill in these gaps based on industry standards or recommended operation levels.

The final design choice that was important for the project was the selection of a distribution modeling software. Different softwares will all have the same capabilities in terms of voltage drop calculations, but they will also provide different areas of ease for things like geographic modeling and equipment specifications. This decision will have instant impacts on the different aspects of the microgrid we can look at past the modeling phase.

### 4.2.2. Ideation

#### 4.2.2.1. Transmission Team

For selecting the appropriate battery storage system, we will be using brainstorming to explore various options based on factors like cost, efficiency, lifespan, and scalability. We are currently considering five potential options: lithium-ion batteries, known for their high energy density and efficiency; flow batteries, which offer longer energy storage durations and better scalability; lead-acid batteries, which are cost-effective but have a shorter lifespan and lower energy density; sodium-ion batteries, an emerging technology with similar efficiency to lithium-ion but using more abundant materials; and nickel-cobalt-manganese (NCM) batteries, which offer higher performance but are more expensive. After evaluating the pros and cons of each option, we will be able to choose the best fit for the greenfield substation project, balancing performance and cost while supporting the integration of renewable energy sources and battery storage.

#### 4.2.2.2. Distribution Team

For the selection of a modeling software, our team came up with 5 common industry standard softwares that could all be used for distribution network modeling. The 5 softwares we settled on are: CYME, ETAP, OpenDSS, PSS/E, and SKM. These are softwares that we had heard about from the client (CYME and ETAP), software used by our advisor for his research (OpenDSS), and other industry softwares that have been mentioned in class or briefly other places (PSS/E and SKM). With each of these, there are tradeoffs that come in the forms of familiarity of team members, advisor and the client, as economical considerations such as cost on our budget. There were also considerations on how easy the modeling software is to use, and if it can use a geographic information system (GIS) to help make the layout more accurate.

### 4.2.3. Decision Making & Trade-Offs

#### 4.2.3.1. Transmission Team

For the substation design, we focused on choosing a battery type that would balance cost, efficiency, and long-term reliability, considering the unique needs of the project. The most commonly used batteries in substations are vented/flooded lead acid, sealed maintenance-free lead acid (VRLA), nickel-cadmium (Ni-Cd), and lithium-ion. We used a weighted decision matrix to assess each option against the factors most important to the project: cost, energy efficiency, lifespan, maintenance needs, and environmental impact. We also considered the specific substation design, which involves integrating battery storage with a renewable energy solution and ensuring that the system can operate efficiently over the long term.

*Table 3: Battery Material Decision Matrix*

| Option | Cost (Weight: 30%) | Energy Efficiency (Weight: 30%) | Lifespan (Weight: 20%) | Maintenance (Weight: 10%) | Environmental Impact Weight: 10%) | Total Score |
|---|---|---|---|---|---|---|
| Vented/Flooded Lead Acid | 4 | 2 | 5 | 3 | 3 | 3.7 |
| Sealed Maintenance-Free (VRLA) | 5 | 3 | 4 | 4 | 3 | 4.3 |
| Nickel-Cadmium (Ni-Cd) | 3 | 4 | 5 | 3 | 4 | 4.0 |
| Lithium-Ion | 2 | 5 | 4 | 4 | 5 | 4.0 |

Based on the matrix, sealed maintenance-free lead acid (VRLA) batteries scored the highest with a total of 4.3. These batteries offer a good balance of cost-effectiveness, compact size, and lower maintenance needs compared to other lead-acid types, making them ideal for the space-constrained environment of the substation. Nickel-cadmium (Ni-Cd) batteries scored similarly with a total of 4.0, excelling in lifespan and performance in extreme temperatures, but they were more expensive. Lithium-ion batteries, despite their high energy efficiency and environmental benefits, scored lower due to their high initial cost and safety concerns, making them less ideal for this particular substation project. Vented lead acid batteries, while durable and long-lasting, require more maintenance and are less efficient, making them a less favorable option for this design. Therefore, we chose VRLA batteries due to their lower maintenance needs, suitability for constrained space, and a reasonable balance of cost and performance for the substation's requirements.

#### 4.2.3.2. Distribution Team

For the distribution design, the most important consideration was with what platform was being used to build a model. The three options below were the main options that had been both used by our advisor and client, and also industry standard sites for distribution planning. Software like PSS/E could also have been used, but instead our team chose to focus on packages that had primary use for distribution systems rather than those that just happened to also provide that service. The weighted matrix helped balance the pros and cons of each system, considering both availability and the difficulty of use for a rather short-term project as opposed to use for research or client work where time wasn't as limited as a resource.

*Table 4: Distribution Software Decision Matrix*

| Option | Cost (40%) | Previous Knowledge (30%) | Ease of Use (20%) | GIS (10%) | Total Score |
|---|---|---|---|---|---|
| CYME | 2 | 5 | 4 | 5 | 3.6 |
| ETAP | 3 | 4 | 3 | 0 | 3.0 |
| OpenDSS | 5 | 3 | 3 | 4 | 3.9 |
| PSS/E | 4 | 1 | 3 | 3 | 3.0 |
| SKM | 1 | 1 | 4 | 0 | 1.5 |

Based on the results of the matrix, OpenDSS will be the software used for the design. It scored similar on average with CYME (the software our client prefers), but the main constraint that contributed to this choice ended up being cost limitations and the lack of funding available to cover the $2500 license ended up being a binding constraint.

## 4.3 Proposed Design

### 4.3.1 Overview

#### 4.3.1.1 Transmission Team

Our substation design integrates both renewable energy sources and traditional power sources to ensure a reliable and sustainable electricity supply. The key components of the system include:

1. Transformer: This steps down high-voltage electricity from the grid (69kV) to a lower voltage (13.2kV) for safe use in homes and businesses.

2. Battery Storage System: The battery stores excess energy generated from renewable sources (solar and wind) when supply exceeds demand. This stored energy can then be used later when the renewable sources aren't producing enough power (such as during cloudy days or at night).

3. Renewable Energy Sources (Wind/Solar): The renewable energy systems, such as wind and solar farms, feed electricity into the substation when available. They help reduce reliance on fossil fuels, lowering the environmental impact of the electrical grid.

4. Power Plant/Grid: When renewable sources are not generating enough power (for example, when the wind isn't blowing or it's nighttime for solar), the substation can rely on electricity from the power plant to meet the demand. The grid serves as the backup to ensure continuous and stable electricity supply.

5. Distribution Feeders: These are the power lines that carry electricity from the substation to homes and businesses. They ensure that the electrical system is capable of delivering power from all sources efficiently and safely.

In this design, the battery system works in conjunction with both renewable energy sources and the traditional grid, ensuring that the community always has a reliable source of power, regardless of fluctuations in renewable energy generation. The system supports sustainability and resilience by integrating different energy sources to create a more stable and environmentally friendly power grid.

Basic Block Diagram:

> Power Plant/Grid/Renewable Energy (Solar/Wind) → Transformer → Battery Storage→ Distribution Feeders → Consumers

#### 4.3.1.2 Distribution Team

The main distribution model will approximate the current campus distribution layout, providing an opportunity to improve on the previous solution and increase reliability. The proposed plan will have the following key components:

1. **ISU Campus Data Load profile:** The load profile of the campus will be formed based on a mesh of requested data and a publicly available website that provides the energy consumption on campus. This website shows data in a 12-month range, and will be converted into an average daily power consumption. Using other information such as peak usage times and power factor, a four season model and daily load shapes will be developed.

2. **Modeled ISU Microgrid Power Supply:** This step of the process will take the load profile developed previously and place the loads into OpenDSS, a distribution modeling software. This model will break the campus into multiple circuits and provide guidance for the impedance in the lines and how power flow may be affected.

3. **Contingency and Jumpering Plans:** These plans will serve as n-1 and n-1-1 plans, which are plans to use when power is lost on accident or intentionally. The n-1 plan looks at moving a single circuit's load to another circuit, and the n-1-1 plan will look at the shutdown of an entire transformer, which will house 2-3 circuits.

4. **Potential Equipment Upgrades:** We are looking at adding reclosers or trip savers for the potential equipment upgrades. These will help stop the fault current from reaching the substation or power plant. We will also be looking at adding in capacitor banks to help with reactive power in the circuit to help with the distribution of real power.

### 4.3.2 Detailed Design and Visuals

#### 4.3.2.1 Transmission Team

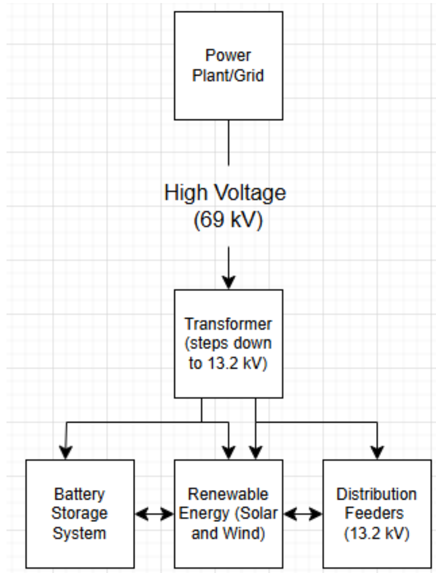



*Figure 3: Simple Block Diagram of Substation Components and Subsystems*

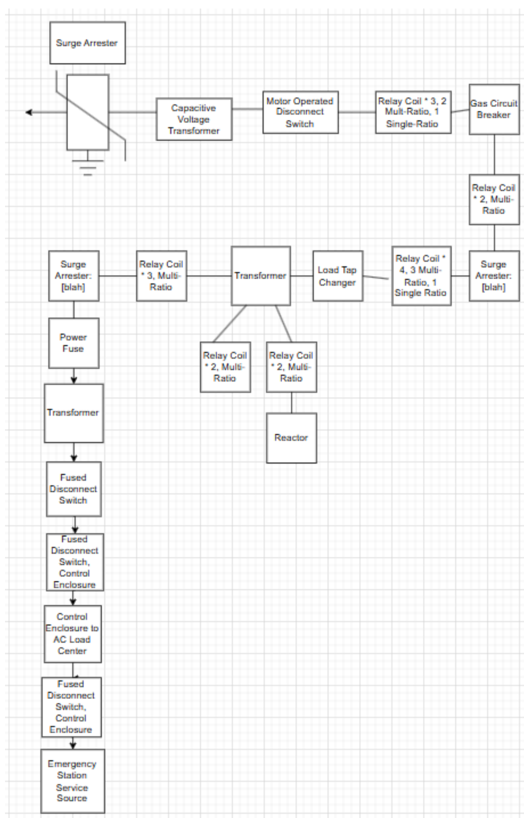



Figure 4: Simple Block Diagram Subset of Substation Components

The proposed substation design integrates renewable energy sources, battery storage, and traditional grid power to ensure reliable, sustainable electricity distribution. Key components include a transformer to step down the voltage from 69kV to 13.2kV, renewable energy sources (solar and wind) to provide clean power, and a battery storage system to store excess energy for later use. The battery system helps balance the intermittency of renewables by storing energy during periods of high generation and discharging when demand exceeds supply. The power grid interface ensures continuous power when renewable generation and battery storage are insufficient.

These systems work together to provide stable and efficient energy to the local distribution feeders. The renewable energy sources feed electricity into the substation through inverters, while the battery storage charges and discharges based on demand. The power plant/grid interface ensures reliability by supplying power when necessary. This design provides a flexible, scalable solution for power distribution, combining energy efficiency, sustainability, and grid resilience to meet modern energy demands.

#### 4.3.2.2 Distribution Team

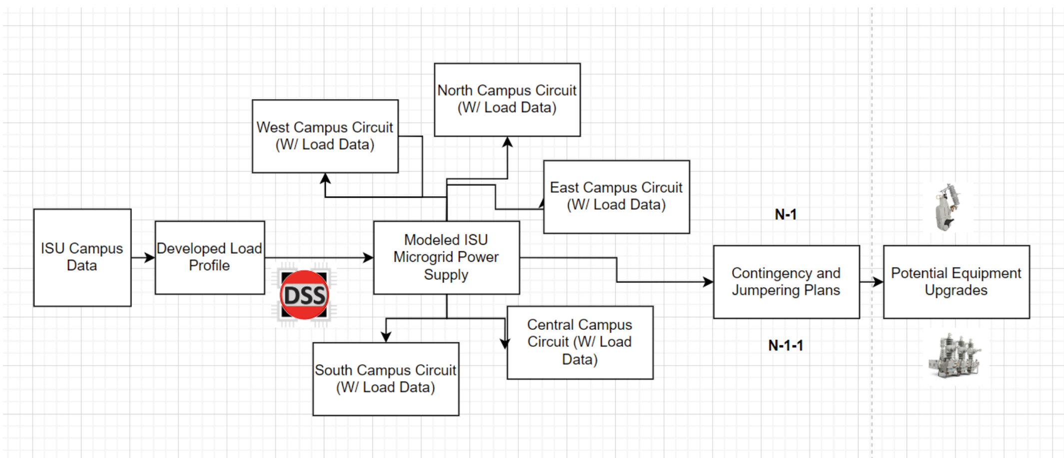



*Figure 5: Simple Block Diagram of the Distribution Components*

The proposed distribution system design implements the real-world campus load data to create a model of the day-to-day power used by the buildings at Iowa State University. From this detailed data, a model will be created to show these loads in relation to the power supply and each other. This model will show the different sectors of campus, and from there will allow for the contingency and jumpering plans to be created.

After the plans showing the movement of the load for loss of power are created, further equipment upgrades can be justified using the model. Devices like reclosers or trip savers can be added, helping stop fault current in the system. We can also advocate for or argue against the additions of solar and battery storage on campus based on the load demand and current power being supplied.

### 4.3.3 Functionality

#### 4.3.3.1 Transmission Team

In its real-world context, the substation design is intended to operate autonomously while being monitored and controlled by system operators. The primary user would be a utility operator or a technician, who oversees the performance of the substation, ensuring its safe operation and efficiency.

When the system is running, renewable energy sources like solar panels and wind turbines generate power, which is fed into the substation. The user can monitor the energy production and demand through a control system interface. If renewable generation exceeds demand, excess energy is stored in the battery storage system. If demand increases beyond renewable production, the battery discharges to meet the demand, while the grid connection provides additional power as necessary to ensure stability.

The user may also intervene in cases where maintenance is required, or if there is a need to adjust parameters for optimal operation (e.g., when a new battery set is added). In case of an issue, such as battery discharge failure or a fault in the renewable generation, the control system would automatically alert the user and possibly redirect power flow from the grid. The system is designed to balance reliability and sustainability, automatically adjusting the generation mix while providing flexibility for manual adjustments.

#### 4.3.3.2 Distribution Team

In a real-world context, the OpenDSS model we are creating from scratch will be used as the base for performing analysis on the Iowa State campus microgrid. The OpenDSS model is an overview of the whole system and will allow us to see power flow throughout the campus distribution system. A utility operator would use the program to analyze how the campus distribution system operates and how the proposed changes affect the grid.

In proposing jumpering plans or installing renewable generation facilities, th eOpenDSS model allows users to analyze how each upgrade affects the system. Using OpenDSS to model new solar facilities or a battery storage dice expelling power back to the grid can help users understand the power flow throughout the campus and determine whether the upgrade will assist in reducing the amount of power needed. The user will use the open DSS model to determine whether different circuits can handle the extra load from the proposed jumpering plans.

Users can also use the OpenDSS model to plan for future growth and increases in load at specific locations. We can use the model to see areas for current system upgrades such as increasing conductor size and installing larger kVA transformers. It will also allow users to visualize the protective scheme of the distribution system.

### 4.3.4 Areas of Concern and Development

#### 4.3.4.1 Transmission Team

The current design is well-positioned to meet the core requirements of the substation project, particularly in terms of integrating renewable energy sources, battery storage, and the existing distribution network. The system is designed to manage energy flow efficiently, store excess renewable energy, and provide reliable power to the grid during periods of high demand. The substation's modular and scalable nature ensures that it can adapt to various user needs, including the integration of additional renewable sources or battery storage as required by the utility.

However, there are a few concerns that need to be addressed to ensure the design fully meets user and client expectations. One primary concern is ensuring that the battery storage system has enough capacity to handle fluctuations in renewable energy production and grid demand. Another concern is the integration of renewable energy sources like wind and solar with the existing infrastructure while maintaining grid stability. Additionally, understanding the exact requirements and constraints of the client's distribution network and making sure the system complies with industry standards for safety and reliability are crucial.

To address these concerns, immediate steps include conducting detailed simulations of energy flow to test the system's response under various load conditions, which our Distribution Team is doing. We also plan to refine the battery sizing calculations and optimize renewable generation integration for peak efficiency. We will engage with clients and TAs to ensure that we are meeting all safety and operational standards, and we plan to have regular check-ins with our advisors to validate our approach. Some key questions for the client would be: What are the specific performance and reliability expectations for the substation? Are there any constraints or preferences related to battery storage size or renewable generation integration? What are the long-term plans for expanding the grid or integrating additional renewable energy sources?

#### 4.3.4.2 Distribution Team

The current design currency meets the needs of the recruitment and users. The majority of the distribution circuit is fed through an underground circuit. This provides fewer faults on the circuit due to tree branches or animals on the power lines.

Where the system is currently lacking in future load growth. As seen in the 2023 power plant fire, the grid is susceptible to overloading. As the university continues to grow in student population and Iowa State continues to grow, this begs the question of if the grid is capable of handling these changes.

Based on our current design, the main concern is making sure that we are working with accurate and up-to-date data. While Iowa State Utilities provides a website with live tracking of the energy usage on campus, it is difficult to access historical data. Additionally, with the distribution circuits being underground circuits, it is difficult to know how the university has the power lines laid out. This makes it to where we are walking campus to make our best judgments on how we believe the circuit planning was completed.

To address these concerns, we have been asking as many questions to Iowa State Utilities and others who have studied the microgrid. We want to ensure that we build an accurate model to study, and the best way we have found to do this is to learn from others. We have also been working very closely with our clients. At every major checkpoint, we are setting up meetings with Adam to have him review our work. This way, we can ensure that we are collecting useful data and making progressive steps.

## 4.4 Technology Considerations

The design incorporates key technologies, including battery storage systems, renewable energy integration (wind and solar), and a distribution management system. For energy storage, we are considering sealed maintenance-free lead-acid batteries due to their compact size and low maintenance, making them suitable for space-constrained substation environments. However, they have a shorter lifespan and lower efficiency in high temperatures compared to alternatives like lithium-ion batteries. To mitigate this, we could integrate temperature controls or explore Nickel-Cadmium (Ni-Cd) batteries, which perform better in extreme conditions but come at a higher cost. For renewable energy, the design integrates wind and solar power, utilizing inverters and energy management systems to convert and distribute energy. While renewable energy is clean and sustainable, its intermittency is a challenge. Increasing battery storage capacity or employing predictive modeling to better manage energy flow could help ensure a reliable energy supply.

The distribution management system ensures efficient energy distribution from renewable sources and stored energy to meet grid demand. The main trade-off here is between cost and system complexity—an automated control system would provide real-time adjustments but at a higher cost, while a semi-automated system would be more affordable but require more human oversight. The key challenges in this design are balancing system costs with performance and addressing renewable energy variability. Alternative approaches, like demand-side management or smart grid technologies, could improve grid stability and enhance the overall system's efficiency. Ultimately, the chosen technologies meet the project's sustainability goals, but further exploration and optimization will help address trade-offs and ensure long-term success.

## 4.5 Design Analysis

### 4.5.1 Transmission Team

So far, we have made progress in the early stages of implementing the updated scope of the project. We've conducted research into potential locations for the new substation, focusing on the old coal lot near Fredrickson Court and Haber Round. This location has been selected due to its proximity to the existing distribution infrastructure and its suitability for accommodating the substation's footprint. Additionally, we have identified the type of battery storage we intend to use, specifically sealed maintenance-free lead-acid batteries, which offer a good balance between reliability, cost, and maintenance requirements for this application. We've also started selecting the software tools necessary for the design and simulation of the substation, evaluating options like PSCAD and AutoCAD for their ability to handle the integration of renewable energy sources and battery storage.

At this point, the proposed design is still in the conceptual phase, so we have not yet implemented or tested the full system. We have encountered challenges with finalizing some technical aspects, particularly in creating the one-line diagram for the substation with battery integration. While the initial research and selection of components have gone according to plan, the main issues lie in the design phase. Our next steps will focus on refining the one-line diagram to properly incorporate the battery storage system and renewable energy sources, ensuring the system's functionality and integration. We also plan to continue refining the location selection and start gathering more detailed data for the substation's power and environmental requirements.

#### 4.5.2 Distribution Team

So far, most of the work of the distribution team has been determining and updating the scope of our project and determining the available resources. The first steps include researching and deciding which distribution system modeling software to use and obtaining the university's load data. In our research to figure out the best software to use for modeling, we ended up choosing to use OpenDSS. In the end, it was the one we could most afford since it was free, and it also helped that one of our faculty advisors used the program to perform research in his field. Our next steps will be to continue refining and obtaining load information.

At this point in time, our design is still mostly conceptual. While we have created the OpenDSS model, building a fully functioning distribution mode will take time and more information. We have encountered some challenges, mostly involving the resources available to us. We depend on the information that campus utilities can provide us; sometimes, it can take up to a week or two before they can get back to us with the information we need. We are still refining the information regarding the load and location of facilities. Once we have those resources we can begin to build our base model of the campus distribution grid that we can use to propose our upgrades.

# 5. Testing

#### 5.1.1. Unit Testing

In our senior design project, unit testing is focused on the functionality of various systems within both the substation and distribution designs. Specifically, we are testing the relay protection schemes, communication protocols, and control systems in each component of the substation and distribution network.

**How?**

- **Substation Systems:**
    - **Relay Protection Logic:** We test the protection schemes for components like the transformer, circuit breakers, and disconnects. Fault simulations, such as short circuits or overload conditions, are used to verify that the relays trigger correctly and isolate faults as intended.
    - **Control Systems:** We test the communication between relays, SCADA systems, and protection devices to ensure real-time data transfer and accurate remote control functionalities.
- **Distribution Systems:**

- **Distribution Protection:** We test the protection schemes in the distribution lines, such as overcurrent protection and coordination between breakers at various voltage levels (69kV to 13.2kV). Simulations are run to check for proper coordination and fault isolation.
- **Communication between Substations and Distribution:** We also test the data flow and response times between the substation and the distribution network, ensuring that voltage, current, and fault information is transmitted accurately.

**Tools:**

- **Simulation Software:** Tools like **ETAP** or **SKM PowerTools** are used to simulate both fault conditions in the substation and load flow in the distribution network. These tools help us verify protection logic and ensure the correct operation of the electrical systems in both subsystems.
- **AutoCAD/Bluebeam:** While primarily used for creating detailed drawings, these tools also help organize and visualize test setups, especially for the physical layout and communication systems between substation and distribution equipment.
- **Relay Test Equipment:** For physical testing of relays in both substation and distribution components, tools like **Omicron** or **Megger** are used to simulate fault conditions and validate the relay responses.
- **Microcontroller Test Setup:** For embedded systems in control and protection units, we use **Oscilloscopes** and **Multimeters** to verify the signals sent between components and ensure the systems are functioning as expected.

By conducting these unit tests, we ensure that both the substation and distribution components work together effectively, meeting all required safety, control, and communication standards.

### 5.2. Interface Testing

In our senior design project, interface testing plays a crucial role in ensuring that all components in both the substation and distribution systems communicate effectively and function as expected. We are testing the interfaces between various systems, including substation control systems (such as SCADA), protection relays, transformers, circuit breakers, and communication protocols. Specifically, we are verifying the communication flow between the SCADA system and the substation components, ensuring that commands can be sent (e.g., trip signals to circuit breakers) and that status updates (e.g., fault conditions, operational states) are received. Additionally, we test the interaction between protection relays and remote control systems, as well as the coordination between the substation and distribution network to ensure proper data exchange for power flow, fault detection, and load balancing.

We conduct tests by simulating fault conditions such as short circuits or overloads and observing how the components interact through their communication interfaces. Real-time data flow and command-response cycles are also verified, ensuring that commands from the control systems are correctly executed by field equipment like relays and breakers. To test coordination, we simulate faults in different parts of the distribution network to ensure that protection schemes correctly isolate faults without impacting the rest of the system.

## 5.3. Integration Testing

In our senior design project, integration testing plays an important role in ensuring that components we chose to implement in the substation and distribution systems can interact with one another. Especially in SCADA controlled units, it is important to test that the different components of the substation or distribution systems can properly interact with each other and that communication flow between devices is solid.

Similar to interface testing, we conduct our test by verifying the interactions between components when we stimulate fault conditions. We must verify that when command by an external unit, the desired response is produced by the component (Relay, Circuit Breaker, Switch), proving that the unit is fully integrand with the command module software.

## 5.4. System Testing

System testing tests our project's overall functionality and whether it meets the requirements specified earlier in this document. System Testing will include confirming that all components (Substation Diagram, OpenDSS Model) of our designs are functional and iperationable. This includes all the unit testing to ensure that every proposed device is functional, all integration tests to confirm that each proposed component can work in conjunction with each other and be controlled remotely.

Ultimately, our system test should show that our OpenDSS model can accurately represent a stable distribution system. This means that our model should show how faults can be isolated and cleared efficiently, and that there is sufficient resilience to the distribution system. Symimerly, Our substation diagrams should show an accurate model of a the campus substation and provide a framework for storge and relay options.

## 5.5. Regression Testing

Regression testing is more specific to the OpenDSS model in the grand scheme. The Distribution teams process of regression testing involves ensuring that whenever we add something new to the OpenDSS model, it will not crash the design and destroy the progress we've made on the model. Likewise, part of regression testing is ensuring that components that we chose such as breakers, reclosers, and switches, can function as we want them too and are compatible with the substation and distribution systems,

## 5.6. Acceptance Testing

Acceptance is one of the final steps in the conclusion of this project. Acceptance testing will include reconfirming all unit, integration, interface, system, and regression tests to produce a complete product. We must confirm all our requirements, ensuring our designs incorporate safety and compliance with engineering standards. Likewise, we need to also complete our requirements that both our distribution and substation system models are functional and can accomplish the goal of allowing us to propose upgrades to the current system Our client will be a large part of the acceptance testing as they will also help make sure we comply will all regulations and requirements

### 5.7. Results

Due to the nature of our projects, our designs cannot be fully tested until we have completed the construction of our models and have chosen the different components we plan to integrate into the distribution and substation systems.

# 6. Implementation

### 6.1. Substation Team

Our senior design project has advanced through several key stages, with notable progress in both design and implementation activities. Following client feedback from Burns & McDonnell advisors, the project has moved into Revision 1 for critical documents, and initial steps have been taken for further detailed design elements.

**One-Line Diagram and Relay Functional**

The one-line diagram and relay functional design have undergone initial development and review. Revision 1 marks the first formal version of these documents, incorporating feedback received from our advisors. The diagrams now reflect the updated design parameters, addressing connectivity between major components such as the 69kV breaker, transformer, and 13.2kV line positions. These updates ensure compliance with the substation's operational requirements and enhance clarity for downstream designs.

**General Arrangement (GA) Drawings**

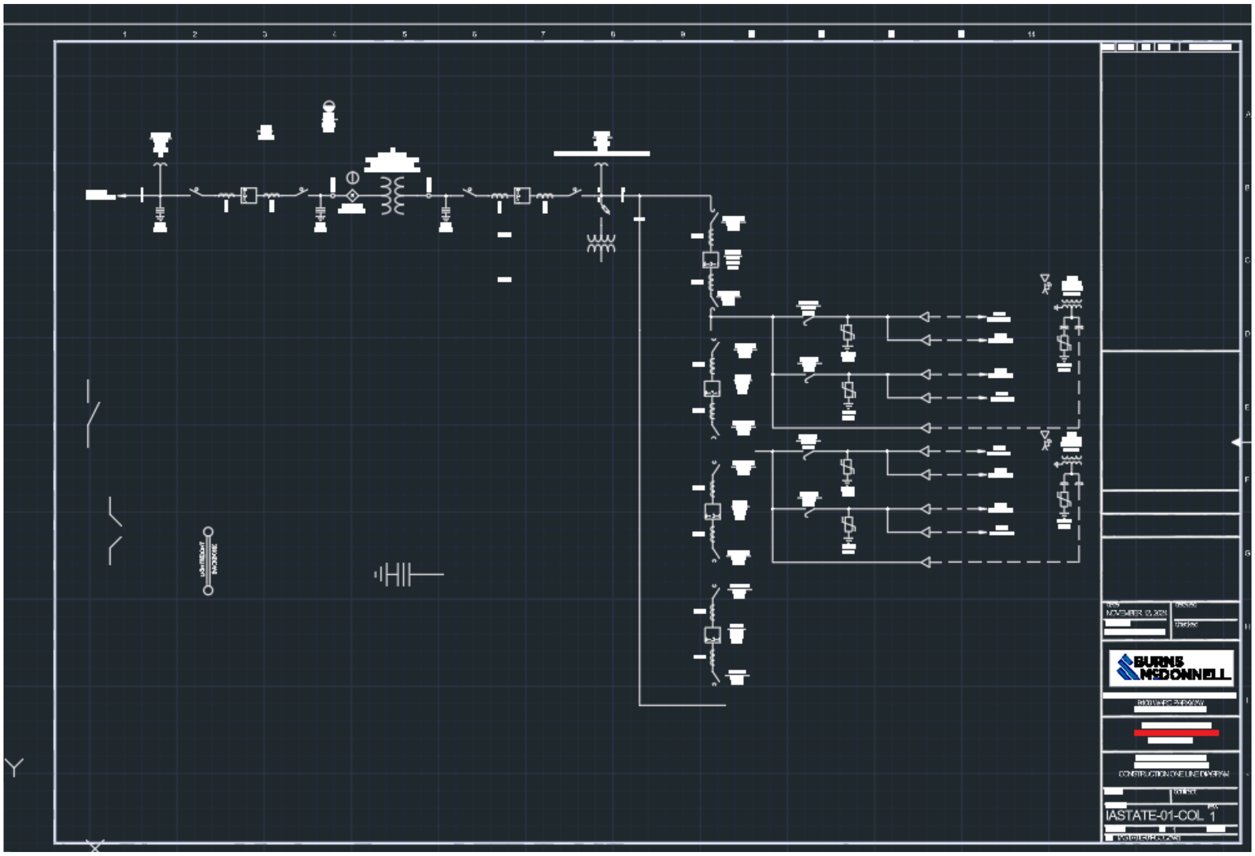
We have begun work on the General Arrangement (GA) drawings, focusing on the physical layout of the Cyclone Substation. These drawings detail the placement of substation components, including breakers, transformers, and support structures, aligning with industry standards and safety considerations. This effort lays the groundwork for integrating the battery storage system and ensures a cohesive design approach.

**Bill of Materials (BOM)**

The initial development of the Bill of Materials (BOM) has commenced. This document itemizes the necessary components, including quantities and specifications, for constructing the substation. The BOM serves as a critical resource for both planning and budgeting, providing a clear overview of material requirements.

**Images**

While formal diagrams and layout drawings are still being finalized, the following provides a conceptual representation of the substation components and design progression:




These preliminary implementations illustrate the iterative nature of our design process. Each stage incorporates feedback to refine the technical and practical aspects of the substation, ensuring a robust and reliable final design.

## 6.2. Distribution Team

Our senior design project has been about research and development this semester. Throughout the semester we have had several key check-in points with our client to ensure we were moving forward with the correct and accurate data. All of us step up to be able to move on to our next large step which is model building and designing.

**Iowa State 2023 Power Data Collection**

In order to be able to simulate and build an accurate model of the Iowa State micro grid, accurate data. Both of the links to the daily and hourly have been provided to show where the data of the model will be pulling from. From this data the peak summer and winter loads can be found. The spring and fall shoulder days can also be located.

2023 Daily Load Data:https://www.fpm.iastate.edu/utilities/energy_dashboard/daily_btu.asp

2023 Hourly Load Data: https://www.fpm.iastate.edu/utilities/energy_dashboard/hourly_btu.asp

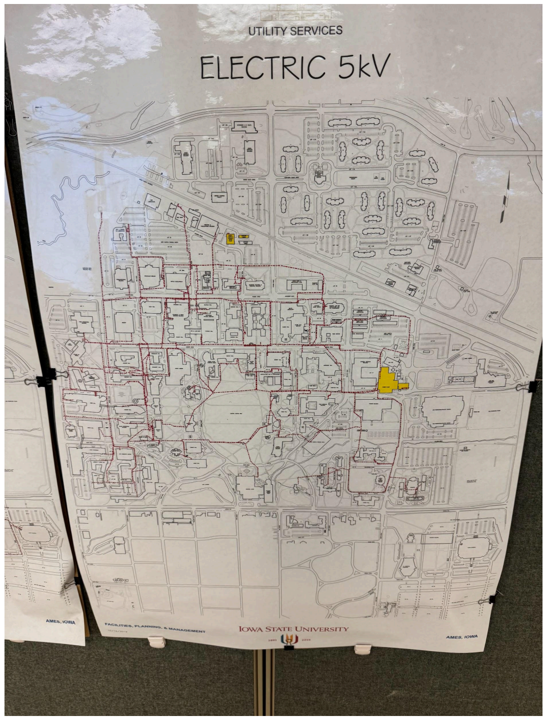
**Iowa State 2023 Power per Building**

From the Iowa State Utilities website information is provided about the total yearly load that is used per each building on campus. With the information from the 2023 daily loads, the daily power usage from each building could be calculated. This information is needed in BTU, kWh, and kVA.

| Building | Load (BTU/sq ft) | Area (sq ft) | Total Yearly Load (BTU) | Total Yearly Load (kWh) | Total Daily Load(kWh) | Total Daily Load(kW) | Avg Daily Load (kVA) | Worst Case Load (kVA) |
|---|---|---|---|---|---|---|---|---|
| Advanced Machinery Systems lab | | | 1.43E+08 | 4.19E+04 | 1.15E+02 | 4.78E+00 | 5.03E+00 | 5.31E+00 |
| Agronomy Hall | | 262568 | 2.51E+10 | 7.35E+06 | 2.01E+04 | 8.39E+02 | 8.83E+02 | 9.33E+02 |
| Armory | | 89,770 | 0 | 0 | 0 | 0 | 0 | 0 |
| Atanasoff Hall | | 39,451 | 3.20E+09 | 9.37E+05 | 2.57E+03 | 1.07E+02 | 1.13E+02 | 1.19E+02 |
| Barton Residence Hall (79,026) | | | 1.70E+09 | 4.98E+05 | 1.36E+03 | 5.68E+01 | 5.98E+01 | 6.32E+01 |
| Beardshear Hall | | 104,292 | 1.10E+09 | 3.22E+05 | 8.83E+02 | 3.68E+01 | 3.87E+01 | 4.09E+01 |
| Bessey Hall | | 232125 | 9.00E+09 | 2.64E+06 | 7.22E+03 | 3.01E+02 | 3.17E+02 | 3.34E+02 |
| Beyer Hall | | 135537 | 2.40E+09 | 7.03E+05 | 1.93E+03 | 8.02E+01 | 8.45E+01 | 8.92E+01 |
| Biorenewable Research Lab | | 72971 | 2.82E+10 | 8.26E+06 | 2.26E+04 | 9.43E+02 | 9.93E+02 | 1.05E+03 |
| Birch Residence Hall (77,386) | | | 2.90E+09 | 8.49E+05 | 2.33E+03 | 9.70E+01 | 1.02E+02 | 1.08E+02 |
| Black Engineering Building | | 117,933 | 6.50E+09 | 1.90E+06 | 5.22E+03 | 2.17E+02 | 2.29E+02 | 2.41E+02 |
| Carver Hall | | 133,454 | 3.70E+09 | 1.08E+06 | 2.97E+03 | 1.24E+02 | 1.30E+02 | 1.37E+02 |
| Catt Hall | | 29745 | 1.50E+09 | 4.39E+05 | 1.20E+03 | 5.02E+01 | 5.28E+01 | 5.57E+01 |
| College of Design | | 163,028 | 9.70E+09 | 2.84E+06 | 7.78E+03 | 3.24E+02 | 3.41E+02 | 3.60E+02 |
| Communications Building | | 59,713 | 4.40E+09 | 1.29E+06 | 3.53E+03 | 1.47E+02 | 1.55E+02 | 1.63E+02 |
| Coover Hall | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Curtiss Hall | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Durham Center | | 108,328 | 1.15E+10 | 3.37E+06 | 9.23E+03 | 3.85E+02 | 4.05E+02 | 4.27E+02 |
| East Hall | | | 259108134 | 75895.76274 | 207.9335966 | 8.663899856 | 9.119894586 | 9.626555396 |
| East Parking Deck | | | 2.20E+09 | 6.44E+05 | 1.77E+03 | 7.36E+01 | 7.74E+01 | 8.17E+01 |
| Eaton Residence Hall | | 86,380 | 9.80E+09 | 2.87E+06 | 7.86E+03 | 3.28E+02 | 3.45E+02 | 3.64E+02 |
| Enrollment Services Center | | | 4.59E+08 | 1.34E+05 | 3.68E+02 | 1.53E+01 | 1.62E+01 | 1.71E+01 |
| Farm House | | | 16525746 | 4840.581722 | 13.26186773 | 0.5525778222 | 0.5816608655 | 0.613975358 |
| Food Sciences Building | | | 9.30E+09 | 2.72E+06 | 7.46E+03 | 3.11E+02 | 3.27E+02 | 3.46E+02 |
| Forker | | 144,049 | 9.80E+09 | 2870533 | 7864.474244 | 327.6864268 | 344.9330809 | 364.0960298 |
| Freeman Residence Hall (80,864) | | | 2.20E+09 | 6.44E+05 | 1.77E+03 | 7.36E+01 | 7.74E+01 | 8.17E+01 |
| Friley Residence Hall | | 363,963 | 1.95E+10 | 5.71E+06 | 1.56E+04 | 6.52E+02 | 6.86E+02 | 7.24E+02 |
| Gerdin Business Building | | | 4.60E+09 | 1.35E+06 | 3.69E+03 | 1.54E+02 | 1.62E+02 | 1.71E+02 |
| Gilman Hall | | 259,262 | 3.43E+10 | 1.00E+07 | 2.75E+04 | 1.15E+03 | 1.21E+03 | 1.27E+03 |
| Hach Hall | | 136,289 | 3.04E+10 | 8.90E+06 | 2.44E+04 | 1.02E+03 | 1.07E+03 | 1.13E+03 |
| Hamilton Hall | | | 764,235,547 | 223853.4115 | 613.2970179 | 25.55404241 | 26.89899201 | 28.39338046 |
| Heady Hall | | | 4.70E+09 | 1.38E+06 | 3.77E+03 | 1.57E+02 | 1.65E+02 | 1.75E+02 |
| Helser Residence Hall | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Hixson-Lied | | 40,528 | 1.00E+09 | 2.93E+05 | 8.02E+02 | 3.34E+01 | 3.52E+01 | 3.72E+01 |
| Hoover Hall | | 81,817 | 3.40E+09 | 9.96E+05 | 2.73E+03 | 1.14E+02 | 1.20E+02 | 1.26E+02 |
| Horticulture Hall & Greenhouse | | | 8.40E+09 | 2.46E+06 | 6.74E+03 | 2.81E+02 | 2.96E+02 | 3.12E+02 |
| Howe Hall | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Human Nutritional Sciences Building | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Jischke Honors Building | | | 297564000 | 87159.9297 | 238.7943279 | 9.949763665 | 10.47343544 | 11.05529296 |
| Knoll | | | 291606720 | 85414.97364 | 234.0136264 | 9.750567767 | 10.26375554 | 10.83396419 |
| Lab of Mechanics | | 16,336 | 3.20E+08 | 9.37E+04 | 2.57E+02 | 1.07E+01 | 1.13E+01 | 1.19E+01 |
| Landscape Architecture | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Larch Residence Hall | | 102,082 | 4.30E+09 | 1.26E+06 | 3.45E+03 | 1.44E+02 | 1.51E+02 | 1.60E+02 |
| LeBaron Hall | | 61,519 | 3.80E+09 | 1.11E+06 | 3.05E+03 | 1.27E+02 | 1.34E+02 | 1.41E+02 |
| Lied Recreation Center | | 236,193 | 9.80E+09 | 2.87E+06 | 7.86E+03 | 3.28E+02 | 3.45E+02 | 3.64E+02 |
| Linden Residence Hall (72,608) | | 99,137 | 5.90E+09 | 1.73E+06 | 4.73E+03 | 1.97E+02 | 2.08E+02 | 2.19E+02 |
| Lyon Residence Hall (78,818) | | | 1.90E+09 | 5.57E+05 | 1.52E+03 | 6.35E+01 | 6.69E+01 | 7.06E+01 |
| Mackay Hall | | 86,648 | 4.60E+09 | 1.35E+06 | 3.69E+03 | 1.54E+02 | 1.62E+02 | 1.71E+02 |
| Maple Residnece Hall | | 101,229 | 1.08E+10 | 3.16E+06 | 8.67E+03 | 3.61E+02 | 3.80E+02 | 4.01E+02 |
| Marston Hall | | | 1.30E+09 | 3.81E+05 | 1.04E+03 | 4.35E+01 | 4.58E+01 | 4.83E+01 |
| Martin Residence Hall | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Memorial Union | | 316713 | 1.70E+10 | 9.10E+09 | 2.49E+07 | 1.04E+06 | 1.09E+06 | 1.15E+06 |
| MLW Common Space | | 61,815 | 1.36E+10 | 3.73E+07 | 1.02E+05 | 4.25E+03 | 4.48E+03 | 4.73E+03 |
| Molecular Biology Hall | | 206,086 | 2.47E+10 | 7.23E+06 | 1.98E+04 | 8.26E+02 | 8.69E+02 | 9.18E+02 |
| Morrill Hall | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Oak-Elm Residence Hall | | 132,483 | 1.26E+10 | | 0 | 0 | 0 | 0 |
| Palmer Building | | | 6.25E+08 | 1.83E+05 | 5.02E+02 | 2.09E+01 | 2.20E+01 | 2.32E+01 |
| Parks Library | | 325,488 | 2.20E+09 | 6.44E+05 | 1.77E+03 | 7.36E+01 | 7.74E+01 | 8.17E+01 |
| Pearson Hall | | 79,848 | 1.90E+09 | 5.57E+05 | 1.52E+03 | 6.35E+01 | 6.69E+01 | 7.06E+01 |
| Roberts Residence Hall (79,414) | | | 2.90E+09 | 8.49E+05 | 2.33E+03 | 9.70E+01 | 1.02E+02 | 1.08E+02 |
| Ross Hall | | | 3.00E+09 | 8.79E+05 | 2.41E+03 | 1.00E+02 | 1.06E+02 | 1.11E+02 |
| Roy J. Carver Co Lab | | 53,192 | 1.05E+10 | | | 0 | 0 | 0 |
| Simon Estes Music Hall | | 62,005 | 2.50E+09 | 7.32E+05 | 2.01E+03 | 8.36E+01 | 8.80E+01 | 9.29E+01 |
| Sloss House | | | 37297264 | 10924.79906 | 29.93095634 | 1.247123181 | 1.312761243 | 1.385692423 |
| Snedecor Hall | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Spedding Hall | | 107,630 | 8.40E+09 | 2.46E+06 | 6.74E+03 | 2.81E+02 | 2.96E+02 | 3.12E+02 |
| State Gym | | 169,509 | 4.70E+09 | 1.38E+06 | 3.77E+03 | 1.57E+02 | 1.65E+02 | 1.75E+02 |
| Student Innovation Center | | 146,323 | 5.70E+07 | 1.67E+04 | 4.57E+01 | 1.91E+00 | 2.01E+00 | 2.12E+00 |
| Student Services | | 34,377 | 4.59E+08 | 1.34E+05 | 3.68E+02 | 1.53E+01 | 1.62E+01 | 1.71E+01 |
| Sukup Hall | | | 2.82E+10 | 8.26E+06 | 2.26E+04 | 9.43E+02 | 9.93E+02 | 1.05E+03 |
| Sweeney Hall | | 91,683 | 9.10E+09 | 2.67E+06 | 7.30E+03 | 3.04E+02 | 3.20E+02 | 3.38E+02 |
| The Hub | | 5,968 | 8.84E+08 | 2.59E+05 | 7.09E+02 | 2.96E+01 | 3.11E+01 | 3.28E+01 |
| Thielen Student Health Center | | 33,555 | 1.70E+09 | 4.98E+05 | 1.36E+03 | 5.68E+01 | 5.98E+01 | 6.32E+01 |
| Town Engineering Building | | | 0 | 0 | 0 | 0 | 0 | 0 |
| Troxel Hall | | | 1.68E+08 | 4.92E+04 | 1.35E+02 | 5.62E+00 | 5.91E+00 | 6.24E+00 |
| Union Drive Community Center | | 58,900 | 1.07E+10 | 3.13E+06 | 8.59E+03 | 3.58E+02 | 3.77E+02 | 3.98E+02 |
| Welch Residence Hall (80,484) | | | 3.97E+08 | 1.16E+05 | 3.19E+02 | 1.33E+01 | 1.40E+01 | 1.47E+01 |
| Willow Residence Hall | | 102,077 | 6.40E+09 | 1.87E+06 | 5.14E+03 | 2.14E+02 | 2.25E+02 | 2.38E+02 |
| Totals: | | | 4.58E+11 | 9.26E+09 | 2.54E+07 | 1.06E+06 | | |
| | | Corresponding Angle | | | | | | |
| **Average Power Factor Per Building:** | 0.95 | 18.195 | | | | | | |
| **Lowest PF Value:** | 0.9 | 25.842 | | | | | | |
| **Highest PF Value** | 0.97 | 14.070 | | | | | | |

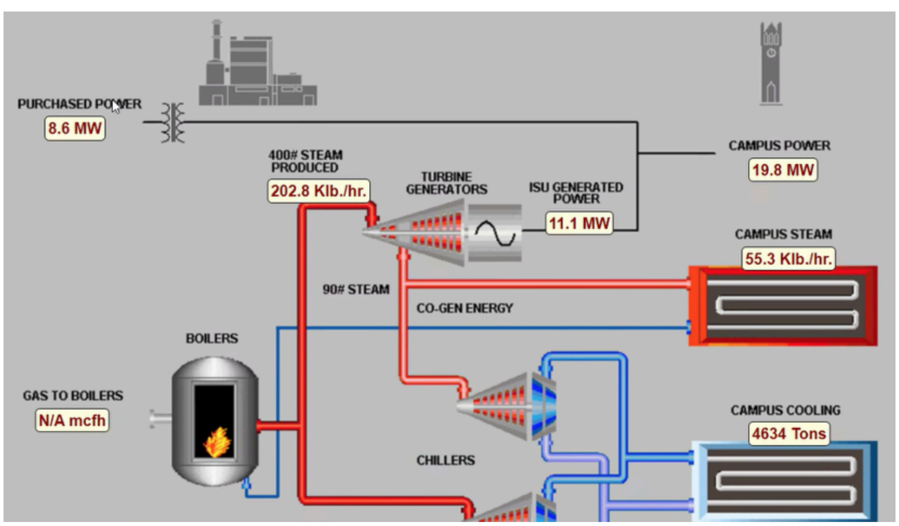
## Model Mapping

In order to determine the mapping needed to model the microgrid, information was gathered through a tour of the power plant on campus. Through the power plant tour the maps of the power grid were shown as well as the different breakers for each circuit.




## OpenDSS Model Research

Having no background knowledge in OpenDSS all members of the team needed to learn how to use the program. Research and test models were build in order to learn how to use OpenDSS.



# 7. Professional Responsibility

## 7.1. Areas of Responsibility

*Table 5: IEEE Ethics Code Areas of Responsibility*

| **Area of Responsibility** | **Definition** | **Relevant IEEE Ethical Code** | **Interaction with the Proposed Design** |
|---|---|---|---|
| Work Competence | Solution contains quality from an engineering professional mindset | 6. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations. | Project is being completed with assistance from a client in industry, as well as guidance from a faculty advisor who is researching distribution systems and microgrids. |
| Financial Responsibility | Solution accounts for the cost aspect of the proposed product | 5. To be honest and realistic in stating claims or estimates based on available data | A budget and bill of materials is being created for the proposed upgrades, as well as financial considerations for software used to model the distribution network. |
| Communication Honesty | Solution is accurately and fairly represented | 5. To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors... and to credit properly the contributions of others. | Discussions are held regularly with the client on progress, as well as a structured feedback process for work products at regular checkpoints. |
| Health, Safety, and Well-being | Solution puts safety first and avoids adverse risk | 1. To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices. | Any proposed upgrades are made only if they are safe and will improve the quality of the experience for the customers. |
| Property Ownership | Solution has respect for | 1. To protect the privacy of others, and to | Sources are cited for any quotes, and formatting for professional |

| | | | |
|---|---|---|---|
| | others' intellectual and physical property | disclose promptly factors that might endanger the public or the environment. | documents is used in the structure recommended by the clients and not shared outside of the context of the class. |
| Sustainability | Solution accounts for environmental consequences | 1. To disclose promptly factors that might endanger the public or the environment. | Renewable resources are attempted to be integrated into the substation upgrade designs |
| Social Responsibility | Solution benefits the consumers and accounts for their well-being | 2. To improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems. | The main goal of the project is to increase power reliability to the consumers by proposing upgrades on both the substation and distribution facets. |

One area of responsibility that is key to the project that the design is performing well in is social responsibility. The distribution model is being produced with the goal of increasing the reliability to the customers that use the Iowa State microgrid. Added layers of protection coordination, as well as recommended substation updates and grounding studies will ensure that the power provided is the most consistent and reliable it can be while respecting the economic tradeoffs. The ethical responsibility for the consumer is upheld by ensuring that the end user is kept in mind when creating plans and discussing options with the client.

On the other hand, an area that the project could improve in is sustainability. Socially, there is a move towards use of "green" energy sources including renewable resources like wind and solar. While these are better for the environment than current solutions with natural gas, they are also more expensive and therefore less appealing to implement for companies trying to find economic solutions. Our design currently has space to further update current energy production which includes very little production from renewable sources. We are working on incorporating more of these resources, however there are logistical issues with these resources like real estate for a solar farm, lower efficiency and reliability and lower levels of operating time that can hinder the feasibility.

## 7.2. Project Specific Professional Responsibility Areas

| | Beneficence | Nonmaleficence | Respect for Autonomy | Justice |
|---|---|---|---|---|
| **Public health, safety, and welfare** | Design helps provide reliable power to customers. | Design will help improve unsafe practices | Allow users to have a reliable access to power | Promotes access to consistent power |
| **Global, cultural, and social** | The upgrades will help meet the needs of the users of the Iowa State Grid | Design will help improve unsafe practices | Affects no cultural practices | Will help provide equal distribution of power |
| **Environmental** | The upgrades will help meet the needs of the users of the Iowa State Grid | Work to add renewable energy sources | Provide a design that increases renewable energy without affect reliability | Would not disturb the environment |
| **Economic** | The design would help increase income, but would require up front cost | Would not disrupt the economy | Increase renewable energy while not affecting the cost | Would not financially harm any party |

*Figure 6: Professional Responsibility Project Breakdown*

One broader context-principle pair that is important to the project is the respect for autonomy and public health, safety, and welfare. One primary goal of the proposed design is to help further ensure reliable and consistent access to power for the users, and so by nature a perfect solution means that the power source is minimally interrupted and allows for customers to operate without worrying if they will or won't have power. A pair that is slightly lacking for the design is the economic beneficence aspect. The proposed design will have a cost to upgrade a system that is already functioning, which in the long term will save the campus money but will have all associated short-term costs as a large expense. This is a tradeoff of having a more secure system, and so it will be a goal to minimize the expense while still upgrading the system.

## 7.3. Most Applicable Professional Responsibility Area

From a professional responsibility perspective, three virtues that are important to our team are commitment to quality, safety, and teamwork. The team's commitment to quality stems from pride in our education and standards at Iowa State, and we have made sure to be thoughtful and thorough when making design decisions and considering any alternative options. The virtue of safety stems from personal experience, but also Burns & McDonnell company culture. One of their more recent initiatives has been the goal to "Live Safer", helping ensure that on any project they are involved in safety is at the forefront of any conversations and processes. Our team has incorporated this into our design by making sure that any updates will be safe and positively impact the previous system. Finally, the virtue of teamwork is key in any group setting. We have established two separate teams to help streamline the process and keep the different aspects of the project at higher levels, and so it is critical that our team values collaboration and feedback. Working with other students, a client and a faculty member has led to high emphasis on being a team player and helping each other.

On an individual level, each member has different personal virtues that they value based on their experiences. Here is a breakdown of the perspective each member has on the project, and what virtues they have practiced and intend to practice with the goal of bettering the project.

Sean: One virtue that I have demonstrated is communication. It is important to me because effective communication is needed to effectively utilize all of your team members' skills. It is also important to make sure everyone knows what you are doing to ensure that there is no overlap in responsibilities which can waste people's time. One virtue that I need to work on is time management. I often give myself too little time to get things done to a satisfactory level of quality. This leads to stalling of other portions of our project which rely on previous portions. I plan to improve this by having more time set aside for project work and setting up times where our group can meet to work on the project.

Bethany: One virtue that is important to me is commitment. Working on a large scale project like this with the university and a client team, there is a high level of commitment that is needed to make sure this project gets done. It's making the time to attend class, all of our team meetings, and to take the time to put into this project. I have shown this virtue by continuing to show up to our meetings, and putting in the effort needed to complete the project. One virtue that I need to start working on is detailed thinking. This is critical to our project as it's made up of so many small details that will come together in the end. I will demonstrate this in the future by taking the time to stop and check in on the small details to ensure our team's success.

Thomas: One virtue that is important to me that I've demonstrated so far is perseverance. Attempting to learn a whole new software package in OpenDSS with limited distribution modeling experience was a process that took more time than expected, and I feel like I demonstrated an ability to stick to the task and research all possible options to come to the best solution. A virtue that I'd like to practice further is a commitment to quality, which will come in the implementation phase of the project in the form of attention to detail and an in-depth self evaluation of any work before I ask for feedback from the client.

Nathan: One virtue I feel that is important to me and that I have demonstrated so far is adaptability. Adaptability has always been an important virtue with my work because I believe it demonstrates a willingness to change and do what is necessary to complete the work. On this project I have had to be adaptable by working on this project while also still working part time, meaning I have not always been able to make every meeting as scheduled. This required me to be extra vigilant and make sure I kept up with all work. One virtue that I feel I need to have a greater focus on is organization and communication. Being better organized and having more constant communication with the distribution team will lead to better results as we continue our project. Part of my goals to accomplish this is to have a set time period each week where I check in with my team and check in on project work.

Mina: One virtue I have demonstrated in this senior design project and which I feel is the most important to me is learning. I have worked on numerous projects while taking electrical engineering classes and during my internships but working on a substation and being on the transmission team is a new experience to me. It's a unique experience in which I wanted to learn the most out of. I feel during this semester I have learned a lot so far and learned a lot of new skills and knowledge that I can use in my upcoming engineering journey. One virtue that is important to me that I have not fully demonstrated yet is effective communication. So far my communication has been asking questions as this is new to me which is a good thing but I want to effectively communicate and bring in new ideas that can help the team.

MacKenzie: One virtue I have demonstrated in my senior design work so far is **diligence**. This is important to me because it reflects my commitment to producing high-quality work and ensuring the success of my team. I have shown diligence by attending all meetings, taking detailed minutes, actively contributing to discussions, and ensuring that tasks such as refining the project scope and drafting initial designs are completed thoroughly and on time. However, one virtue I value but have not yet fully demonstrated is **patience**. While I strive for efficiency, I sometimes feel eager to move forward quickly, which can overlook the need for allowing others time to process and contribute their ideas. Patience is important because it fosters better collaboration and ensures all voices are heard, leading to more comprehensive solutions. To demonstrate this, I plan to actively listen more during team discussions, allowing for pauses and ensuring everyone has the opportunity to share their insights.

# 8. Closing Material

## 8.1. Conclusion

So far, our team has made significant progress on both the distribution and substation aspects of our senior design project. For the substation design, we've completed initial drafts of the one-line and relay functional diagrams, which are now in Revision 1 after receiving client feedback. We've also started working on the General Arrangement (GA) and Bill of Materials (BOM), ensuring the designs meet the specifications for a 69/13.2kV substation that will interconnect with a new Battery Storage System. For the distribution side, we've been focused on coordinating with the planning team and refining the integration of battery storage into the distribution network. Our goal is to deliver a fully designed and integrated substation and distribution system, with all components properly coordinated for optimal performance.

The best plan of action to achieve our goals is to continue refining the designs based on client feedback, ensuring all aspects of the substation, protection, controls, and distribution systems are well-integrated. This includes finalizing the GA, BOM, and protection schemes, and conducting thorough testing of interface communications. A constraint we've encountered is the need for constant coordination and information exchange with the client and advisors, which can sometimes slow progress, especially when awaiting clarification on battery storage characteristics and their impact on the design. In future design iterations, we could enhance the process by establishing more frequent touchpoints with the client for quicker feedback and clearer information flow. Additionally, allocating more time to interface testing early in the process could help identify potential issues sooner.

## 8.2. References

[1] IEEE - IEEE Code of Ethics, https://www.ieee.org/about/corporate/governance/p7-8.html (accessed Dec. 4, 2024).

[2]"IEEE SA - IEEE recommended practice for powering and grounding electronic equipment," IEEE Standards Association, https://standards.ieee.org/ieee/1100/3055/ (accessed Nov. 21, 2024).

[3] "IEEE SA - IEEE Guide for Direct Lightning Stroke Shielding of substations," IEEE Standards Association, https://standards.ieee.org/ieee/998/1376/ (accessed Nov. 21, 2024).

[4] "IEEE SA - IEEE Draft Guide for the design of Microgrid Protection Systems," IEEE Standards Association, https://standards.ieee.org/ieee/2030.12/7398/ (accessed Nov. 21, 2024).

[5] "IEEE SA - IEEE Recommended Practice for the planning and design of the Microgrid," IEEE Standards Association, https://standards.ieee.org/ieee/2030.9/6079/ (accessed Nov. 21, 2024).

[6] Real-time utility consumption, https://www.fpm.iastate.edu/utilities/plantdata/default.asp (accessed Nov. 21, 2024).

## 8.3. Appendices

**Appendix: User Needs and Requirements**

User Personas

Persona 1: Iowa State UtilitiesNeeds Statement: Iowa State Utilities needs to create reliable and resilient power infrastructure because they provide power to all campus buildings.

Persona 2: Landowners around the ISU CampusNeeds Statement: Landowners around Iowa State's Campus need to ensure their land is used in beneficial ways for them and the environment and to ensure that they benefit from the reliability of the upgraded system.

Persona 3: ISU Power Consumers/CustomersNeeds Statement: The ISU power customers/customers need consistent access to power because power brings access to heating, cooling, lights, and the ability to use technology.

List of Requirements

Functional Requirements:

- Capability to provide power to the entire campus.
- Usable model using distribution software of the distribution network based on 2023 data.
- Upgrade and design the microgrid and substation for scalability, handling future demand/growth.

Resource Requirements:

- Good faith estimate in a bill of materials within the budget.
- Balance performance improvements with budget (cost-effective upgrades), ensuring long-term operational efficiency.

Environmental Requirements:

- Implementation of renewable energy/resources to supply power generation.

Aesthetic/Functional Requirements:

- Continue the usage of underground wiring on campus to provide a clean-looking campus and to help stop external faults.

Safety & Compliance Requirements:

- Meet safety standards of the substation through fault current analysis and grounding studies.

Engineering Standards Applicable

**Distribution Side:**

- IEEE SA - IEEE 2030.9-2019: IEEE Recommended Practice for the Planning and Design of the Microgrid.
- IEEE SA - IEEE P2030.12: IEEE Draft Guide for the Design of Microgrid Protection Systems.
- IEEE SA - IEEE 1409-2012: IEEE Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV Through 38 kV.
- IEEE SA - IEEE 1854-2019: IEEE Trial-Use Guide for Smart Distribution Applications.

**Transmission Side:**

- IEEE 998-1996: IEEE Guide for Direct Lightning Stroke Shielding for Substations
- IEEE 1100-2005: IEEE Recommended Practice for Powering and Grounding Electronic Equipment.
- IEEE 399-1997: IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (Brown Book).
- IEEE 493-2007: IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems. This presents the fundamentals of reliability analysis applied to the planning and design of industrial and commercial electric power distribution systems.

IEEE 1899-2017: IEEE Guide for Establishing Basic Requirements for High-Voltage Direct-Current Transmission Protection and Control Equipment.

# 9. Team

## 9.1. Team Members

Sean Carver- Substation Team; Emphasis on Substation General Arrangement and Substation One-Line Diagram documentation.

Bethany Danley- Distribution Team; Emphasis on load profile building and modeling.

Thomas Edwards- Distribution Team; Emphasis on OpenDSS model research and load profile data representation.

Nathan Kallal- Distribution Team; Emphasis in load profile construction and data modeling

Mina Khalil- Substation Team; Emphasis on bill of material and reachering material requirements.

MacKenzie Woods- Substation Team; Emphasis on AutoCADE with respect to the one-line and relay functional and technical documentation.

## 9.2. Required Skill Sets for Your Project

- OpenDSS
- AutoCAD
- Load Profile Analysis Skills
- Material Evaluation
- Communication
- Excel Formatting and Data Analysis

## 9.3. Skill Set Covered by the Team

Sean Carver- My skills have been developed from my internship experience at Burns & McDonnell as a part of the substation business line. During my time there, I developed one-line diagrams, general arrangements, and lightning studies for many substations with varying degrees of depth of detail.

Bethany Danley- My skill set has come from my industry experience working at 1898 and Co. a part of Burns and McDonnell. I have experience analyzing load profile data, contingency planning studies, model building, and area planning skills.

Thomas Edwards- Intern experience in the distribution consulting industry provided experience analyzing load profiles and using distribution modeling software to represent circuits and kVA.

Nathan Kallal- My skills come from my experience working as a distribution engineering intern for two different companies, Ameren Illinois and Midamerican Energy Company. I have experience with design and construction project for distribution systems, as well as experience with load forecast and data models regarding electric distribution circuits

Mina Khalil- My skill set comes from having three summer internships. They were all in three different companies which has made me adaptable in new work environments and working with different people. Two of the internships were in consulting design where I used a lot of Revit and bluebeam to design electrical systems in buildings. The other one was a construction internship in a datacenter project where I got exposed to huge electrical work and equipment.

MacKenzie Woods- My skill set includes a strong foundation in AutoCADE and similar drafting tools, which I use to create detailed engineering designs. I've gained substantial knowledge of substations through my coursework, internship, and my senior design project, where I work on physical layouts, protection and control schemes, and equipment specifications. I also have experience with microcontrollers and embedded systems, which has broadened my technical capabilities. In addition, I've developed project management skills, particularly through leading team discussions and defining project scope. My technical communication skills are also strong, as I'm able to draft clear meeting minutes, explain project details effectively, and engage with advisors and clients in a professional manner.

## 9.4. Project Management Style Adopted by the Team

Our team has adopted a hybrid project management style, merging both waterfall and agile aspects to create a joint approach. The waterfall approach will be primarily used in the early phases of the project. This will be useful for the tasks of defining the scope, establishing detailed requirements, and settling on desired system specifications. The waterfall methodology will guarantee cohesion between student goals and client expectations, helping the project be set up for success. After the project is sufficiently defined, the management will shift to an agile structure to provide for more flexibility and opportunities for direct feedback from the client. The more technical side of the project will create unforeseen technical challenges, and so this format will lend itself better to maintaining forward progress in spite of these challenges.

## 9.5. Initial Project Management Roles

Sean Carver- Substation Team

Bethany Danley- Distribution Team

Thomas Edwards- Distribution Team

Nathan Kallal- Distribution Team

Mina Khalil- Substation Team

MacKenzie Woods- Substation Team

## 9.6. Team Contract

**Team Name:** sdmay25-02: Ames Microgrid Evaluation & Substation Consulting

**Team Members:**

1) Sean Carver
2) Bethany Danley
3) Thomas Edwards
4) Nathan Kallal
5) Mina Khalil
6) MacKenzie Woods

**Team Procedures:**

**Day, time, and location (face-to-face or virtual) for regular team meetings:**

Preliminary plan: Friday at 2 pm (in TLA or virtually) for the whole student team to meet

Every other week: Meetings set up with client contacts (virtually) to talk about progress and keep them in the loop. This meeting with our client is going to be biweekly on Wednesdays at 1:30 pm

To be determined: Level of contact with the faculty sponsor.

**Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):**

The students have a Snapchat group chat to communicate about meetings, updates, and informal communication. For things that need to be documented (like contact with the sponsor or client), email will be the primary method of contact. The biweekly face-to-face meetings will also be used to coordinate future meetings.

**Decision-making policy (e.g., consensus, majority vote):**

For any decisions that may be controversial, the subgroup that has the most to do with the issue will be tasked with deciding. Ideally, more research on the topic or clarification from a sponsor or client will resolve the issue, but if not the relevant subgroup can voice opinions and use a simple majority on how to best proceed. Other group members can help analyze the issue as well.

**Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):**

Meeting minutes will be kept in the shared drive folder. MacKenzie has volunteered to keep minutes for the group meetings, and for subgroup meetings updates will be shared weekly.

**Participation Expectations**

**Expected individual attendance, punctuality, and participation at all team meetings:**

Team members are expected to attend all meetings and be on time. However, stuff happens and so the main requirement is just communication if something happens and a member is running late or unable to make it to a meeting.

**Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:**

A general goal is to have assignments done well before the deadline so that all team members can properly contribute and quality-check the work before submitting. For major assignments, this may mean being due multiple days in advance. For smaller, more routine assignments (like the weekly check-ins), this may just be a simple 24 hours before. Soft deadlines may be set for different checkpoints in the project, and these will be more flexible but still attempted to be met.

**Expected level of communication with other team members:**

The main level of communication is expected to be within each subgroup. Updates on how the project is progressing will be given at our group meetings.

**Expected level of commitment to team decisions and tasks:**

The expected level is to complete a given task. If help is needed, then communication is expected ASAP.

## Leadership

**Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):**

For the project, we are splitting into two teams based on the design category. On the Distribution team, Bethany, Nathan, and Thomas will focus most of their time, and on the Substation team, MacKenzie, Mina, and Sean will be focused.

**Strategies for supporting and guiding the work of all team members:**

Our strategies for supporting and guiding the work of our team members include allocating specific tasks to our subgroups and dividing the remaining work evenly among members to allow for collaboration and meaningful contributions from all the members.

**Strategies for recognizing the contributions of all team members:**

For recognizing the contributions of team members, you will get a sticker and a high five. Team contributions will be tracked in the weekly status reports.

## Collaboration and Inclusion

**Describe the skills, expertise, and unique perspectives each team member brings to the team.**

Sean - Experience with physical design of substations as well as some experience with performing lightning studies.

Mina - I have completed three electrical engineering internships with Weitz, IMEG Corp., and Modus Eng. Over these three internship, I have gained a lot of different skills and programs including Revit (Designing electrical systems including laying out lighting and power equipment, panel board schedules, and one-line diagrams), AutoCad, Bluebeam, PTW (Building one line for Arc Flash calculations), AGI32 (lighting calculations), AmpCalc (Duck back heat calculations) and Excel.

Thomas - Experience on the generation design side for a summer at Burns and McDonnell, and also a summer working on distribution consulting with 1898 and Co. (a part of Burns and McDonnell). He has gained valuable experience looking at different load profiles and developing a model based on assumption in different modeling softwares like CYME.

Bethany - I have completed two internships with 1898 and Co. a part of Burns and McDonnell. During this time, I learned about this distribution system and how it functioned, as well as how to use CYME. During her internships, I learned how to complete contingency studies and build distribution models. I also have experience in communication and leadership, as I am the current president of my technical sorority.

MacKenzie - MacKenzie completed an internship with Burns & McDonnell in their Transmission and Distribution Global Practice, specializing in the substation department. Throughout the summer, she gained hands-on experience with key industry tools, including AutoCAD, where she developed one-line and three-line diagrams, and Inventor, which she used to design substation layouts for major equipment. She contributed to creating facility rating reports, quality checks, and Bill of Materials using Bluebeam, as well as verifying line diagrams and wiring schematics through point-to-point checks. In addition, as president of the Wind Energy Student Organization at Iowa State University, MacKenzie has developed a strong background in renewable energy, particularly in wind turbines.

Nathan - Nathan has completed a co-op and an internship with two different electrical utilities at Ameren Illinois and MidAmerican Energy Company. In both internships, Nathan worked with constructing, planning, and maintaining the electric distribution system. Nathan has gained a deep understanding of how the electric grid operates and has experience modeling distribution systems and understanding the process of distribution automation and the benefits of smart grid devices. Through both of his internships and his experiences at Iowa State, Nathan has developed a great sense of professionalism, and understands what it takes to make a team successful.

**Strategies for encouraging and supporting contributions and ideas from all team members:**

Ideas will be met with respect from each team member. Constructive criticism will be offered, but with a project of this scale all ideas are respected and possible as the scope is quite large.

**Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)**

For any conflicts, resolve it with the team and be respectful. If needed, involve other group members in a calm setting.

**Goal-Setting, Planning, and Execution**

**Team goals for this semester:**

- Complete the distribution model of the Ames Microgrid
- Become familiar with the various software used for each deliverable
- Everyone completes their fair share of the work
- Have fun
- Learn new things
- Set a timeline for work to be completed in the spring semester

**Strategies for planning and assigning individual and teamwork:**

The subgroups will be used as a main way to break up the large workload. From there, each group can divide up work and assign different aspects of the project to each member. Weekly large group meetings will be used to make sure that the work is being completed on pace, and that both sides are somewhat consistent in workload between groups.

**Strategies for keeping on task:**

In order to keep on task, weekly goals should be set in our weekly updates. These should be revisited at the next meeting to judge progress, and adjusted as needed to keep progress going.

**Consequences for Not Adhering to Team Contract**

**How will you handle infractions of any of the obligations of this team contract?**

Any infractions will be discussed with the team member who breaks the contract. If needed we will discuss this infraction with the 4910 instructors.

**What will your team do if the infractions continue?**

We will try to solve it internally as a team and if things escalate we can reach out to the project engineer or the faculty member for guidance to resolve the issue.

***************************************************************************

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

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

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

consequences as stated in this contract.

| | |
|---|---|
| 1) Mina Khalil | DATE 9/6/2024 |
| 2) Bethany Danley | DATE 9/6/2024 |
| 3) Thomas Edwards | DATE 9/6/2024 |
| 4) Sean Carver | DATE 9/6/2024 |
| 5) Nathan Kallal | DATE 9/6/2024 |
| 6) MacKenzie Woods | DATE 9/6/2024 |