Ames Substation

Design Document

Team: 02
Client: Burns & McDonnell
Advisor: Hugo Villegas Pico

Team Members:

Derek Elkins	Project Lead
Nathan Tegeler	Research & Simulation Lead
Mackenzie Ray	Recorder & Client Correspondent
Matthew Wells	Report Manager
Patrick Musoy	Research & Simulation Lead

Website: https://sddec24-02.sd.ece.iastate.edu/
Contact: sddec24-02@iastate.edu
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Executive Summary

Our project's purpose is to design an electrical substation that will connect a 69 kV, 2 MW solar farm to the power grid. The substation should be capable of connecting the solar farm with three 138 kV power lines feeding neighboring cities. As climate change affects the environments we live in, we start to run low on non-renewable resources, and the demand for energy increases, we need to strat moving towards alternative energy sources. These alternative resources must be connected to the power grid and a substation helps in that process. Much of the design requirements are determined by IEEE, NEMA, ANSI, and more organizations. There are very strict guidelines for electrical substations and they must be followed to maximize safety and reliability. We were asked to design a general overview, elevation diagram, one-line diagram, and select our relays. The relays are essential for communication between equipment at both our substation and distant substations our lines are connected with. We used AutoCAD and PSCAD to help with our designs and testing. We were able to test three of lines, getting results showing the relays successfully communicating to equipment. When a fault occurred on a line, they were successfully cleared by the protection schemes we selected. In our event analysis report we show calculations verifying accuracy. On the fourth line, we noticed an over tripping issue due to issues with the distance relay settings. More investigation would be needed to figure out where this issue is occuring. In the future, this would be our next step to be taken to ensure the protection schemes on all lines are active, reliable, and successful in clearing faults.

Learning Summary

DEVELOPMENT STANDARDS & PRACTICES USED

Engineering Standards

C37.91-2021 - Guide for Protecting Power Transformers

C37.119-2016 - Guide for Breaker Failure Protection

C37.234-2021 - Guide for Protecting Power System Buses

C37.113-2015 - Guide for Protecting Transmission Lines

C37.32-2002 - Guide for Phase Spacing & Ground Clearances

SUMMARY OF REQUIREMENTS

Spring 2024

- Report for Bus Configuration Selection
- Site Layout/General Overview Drawing
- Pilot Scheme Report
- Report for Relaying and I/O assignments

Fall 2024

- One-line Diagram Showing the Protection System
- Dynamic Simulation using PSCAD
- Event Analysis Report
- Elevation Drawings

APPLICABLE COURSES FROM IOWA STATE UNIVERSITY CURRICULUM

EE 455 - Introduction to Energy Distribution Systems

- This class focuses on the distribution of systems, including calculating loads, modeling transformers, and series components.

EE 456 - Power Analysis I

- This class discusses power transmission lines and transformers as well as machine modeling.

EE 457 - Power Analysis II

- This class focuses on the protection required for power systems alongside studying faults and stability of a power system.

NEW SKILLS/KNOWLEDGE ACQUIRED THAT WAS NOT TAUGHT IN COURSES

Our work on this project over the last semester has allowed us to gain many skills and acquire knowledge that was not taught in our courses.

Skills

- Reading data sheets
- Writing professional reports
- AutoCad

Knowledge

- Bus configurations
- Protection for specific relays
- General layout of substation

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INTRODUCTION

1.1 PROBLEM STATEMENT

Our design project addresses a critical need for sustainable energy integration into the existing power infrastructure near Ames, Iowa, through constructing a 69 kV 2 MW solar farm and the corresponding Ames Substation. The broader context of this initiative is rooted in the global and societal shift towards renewable energy sources to combat climate change, reduce dependency on fossil fuels, and promote energy security. As the electricity demand grows, integrating renewable energy sources like solar power becomes crucial to meet this demand sustainably.

Our primary issue in this context includes the technical and logistical challenges of connecting renewable energy sources to the existing power grid. Integrating a 2 MW solar farm into the grid (*An electrical grid or electricity network is an interconnected network for electricity delivery from producers to consumers*) entails the physical construction of the solar farm and substation and ensuring that the new infrastructure can communicate effectively with existing substations and the broader power system. It includes managing differences in voltage levels, ensuring the reliability and safety of the power supply, and providing protection and fault (*abnormal electrical currents)* management capabilities that comply with industry standards.

The lack of fiber optics on one of the transmission lines makes communication more complicated. That means we need to find other ways to securely and reliably manage the system and handle any faults that occur.
The project also faces the challenge of ensuring that all new and modified power system components—such as transmission lines, transformers, and the substation itself—are designed and built to handle the specific demands of the solar farm's output and the existing grid's requirements.

The issues addressed by integrating a solar farm into the existing power grid are of paramount importance for several key reasons:

- **Sustainability and Environmental Impact:** The global shift towards renewable energy sources is driven by the urgent need to reduce greenhouse gas emissions and combat climate change. Being clean and inexhaustible, solar energy plays a significant role in this transition. By integrating solar power into the grid, this project contributes to a more sustainable energy mix, reducing reliance on fossil fuels and lowering the carbon footprint of electricity generation.
- **Energy Security:** Diversifying the energy portfolio with renewable sources like solar power enhances energy security. It reduces dependency on imported fuels, which can be subject to price volatility and geopolitical tensions. Local, renewable energy sources provide a more stable and secure energy supply.
- **Economic Benefits:** Investing in renewable energy infrastructure can stimulate local economies by creating jobs in constructing and maintaining solar farms and associated infrastructure. Over time, the lower operational costs of renewable energy sources can also lead to more affordable electricity for consumers.

Addressing these issues is crucial for the technical success of the solar farm project and the broader goals of enhancing the sustainability and resilience of the energy supply in the Ames area and beyond. By carefully designing the Ames Substation to accommodate both the solar farm's connection and the existing infrastructure's needs, the project aims to create a model for successful renewable energy integration. It includes selecting appropriate protection and piloting schemes, ensuring redundancy and reliability in relaying systems using the IEEE standards for safety and performance. Ultimately, the project seeks to demonstrate how renewable energy sources can be effectively and reliably integrated into the grid, contributing to a more sustainable and secure energy future.

1.2 INTENDED USERS

The product created through the Ames Substation project, including the integration of the solar farm into the existing power infrastructure, will serve multiple users and stakeholders, each with distinct interests and dependencies on the project's success, such as:

Local utility companies, renewable energy developers, residential and commercial electricity consumers, electrical engineers, and industry professionals (e.g., the technical community, including students and faculty from Iowa State University's Electrical and Computer Engineering Department, who are interested in power system-renewable energy will use the design and implementation process as a learning and development opportunity.)

The substation has multiple users. These include the standard American consumer, and the stakeholders involved in owning, maintaining, and constructing the substation. The average American works online or uses computers to aid them in their work. They regularly use refrigerators and air conditioning to keep themselves and their food cool. They also use lights during the winter to see when it is dark out. They cook food using electric appliances like ovens and microwaves.

The stakeholders involved in owning, maintaining, and constructing the substation are likely very knowledgeable about technical details and work directly with substations regularly. They will have preconceived notions about what the substation should look like but might not be aware of the differences inverter-based resources (IBRs) like solar panels create with substation protection. The average American usually needs reliable electricity so they can work. Most Americans use the internet or a computer to aid them in work. If they don’t have access to electricity, they can’t work, so they cannot pay bills. They also need heating and air conditioning to stay healthy during summer and winter's extreme heat and cold. They require electricity to safely cook food inside their home.

The user is expressing the need to effectively communicate the benefits and importance of a new substation to the general public, particularly to address any skepticism they may have towards public infrastructure projects. Additionally, there's a focus on ensuring that stakeholders are well-informed about the design decisions and that the substation is adequately protected from faults to safeguard the investment in the infrastructure. Overall, the user highlights the importance of clear communication, environmental consideration, and risk mitigation in implementing the substation project.

The average American will benefit from our project for two main reasons. The first is that our project intends to provide grid reliability. This means that all of the transmission lines are properly protected using redundant systems so that if the power goes out due to a fault, such as a tree branch hitting a line or a lightning strike, the power supply is not interrupted for long. The second reason they will benefit from the substation is the added power source from the solar farm will accommodate the increase in demand as Americans continue to electrify their everyday activities like cooking food and commuting. The atypical American will benefit from this project because it might inspire them to implement their own solar panels to power their home. This ties nicely to the problem statement because it shows how the substation has the potential to influence the continuation of the necessary transition to renewable energy for energy sustainability.

The stakeholders for this project will benefit as the design will provide them with a framework for constructing the substation. By adding the extra power source to the grid, the stakeholders will make more money as the solar panels require little input after they are installed. Stakeholders will also be provided with all of the necessary documentation that will be needed should they need to upgrade equipment or complete any other required work on the substation. This project will also prove the resilience and reliability of the substation through simulations of the fault protection schemes.

REQUIREMENT, CONSTRAINTS, AND STANDARDS

2.1 REQUIREMENT & CONSTRAINTS

- **Functional requirements** (specification):
  - All transmission lines must be piloted by at least one of the following methods: A Directional Comparison Blocking (DCB), Directional Comparison Unblocking (DCUB), Permissive Overreaching Transfer Trip (POTT), or Line current differential (87L).
  - All transmission lines must be capable of receiving and transmitting Direct Transfer Trip (DTT).
  - All relaying, except for breaker failure, must have a redundant system.
  - Each transformer and line must have a device capable of interrupting fault current installed to be isolated from the rest of the system.
- **Resource requirements:**
  - Short-circuit study information is critical for designing protective schemes, coordinating protective devices, and ensuring the safety and reliability of the electrical system under fault conditions that include the magnitude of fault current, locations of maximum fault currents, duration of fault, and voltage levels during faults.
  - AutoCAD and PSCAD.
  - Reference relay specifications.
- **Physical requirements:**
  - The Ames Substation must accommodate 138kV transmission lines from the Ankeny Substation, Boone Substation, and Nevada Substation.
  - An auto-transformer of 69/138KV must be installed to interface the solar farm with Ames Substation.
- **Economic/Market requirements** (Constraints):
  - The project must be completed within the allocated budget.
  - The project schedule must be adhered to, prioritizing timely completion.

Meeting deadlines and adhering to project milestones is critical, specifically when considering factors such as divergences of timing in weather conditions or regulation deadlines for renewable energy projects. The budget constraint is also a factor, as the project must be completed within the given financial resources. Other restrictions could include adherence to regulatory requirements and standards, availability of skilled labor or technical equipment, and potential environmental considerations, such as environment protection or land use restrictions.

- Environmental requirement:
  - Electrical clearances must satisfy relevant industry standards for air-insulated substations. Those electrical clearances refer to the minimum distance required between conductive parts and grounded surfaces to prevent electrical breakdown or arcing during fault or under normal operating conditions. It ensures safety and reliability in the context of air-insulation substations (AIS).

2.2 ENGINEERING STANDARDS

- All protection schemes must satisfy IEEE recommendations:
  - C37.91-2021 – Guide for Protecting Power Transformers
  - C37.119-2016 – Guide for Breaker Failure Protection
  - C37.234-2021 – Guide for Protecting Power System Buses
  - C37.113-2015 – Guide for Protecting Transmission Lines
  - C37.32-2002 – Guide for Phase Spacing & Ground Clearances

PROJECT PLAN

3.1 PROJECT MANAGEMENT/TRACKING PROCEDURES

Our project management has specific characteristics of Agile project management principles. There are several reasons why Agile is a suitable approach for our project:

- Frequent adjustment to deliverables and timeline: The methodologies of Agile are designed to accommodate change and repetition throughout the project lifecycle. Since we are still figuring out our final deliverables and frequently adjusting the timeline due to new requirements, Agile's flexibility allows us to continuously adapt to the project needs.
- Inexperience with AutoCad and potential delays: The Agile management style encourages transparency and collaboration among team members. Relating to our

situation, many team members are unfamiliar with AutoCAD and may take longer to complete tasks. Agile allows for open communication and the ability to address challenges effectively as a team. It also encourages learning and improvement through regular feedback and analyzing past experiences, which can help mitigate the impact of inexperience on project progress.

- Interdependent subteams and waiting for research completion: Based on the project management chosen; Agile emphasizes cross-functional teams and close stakeholder collaboration. In a situation where each subteam relies on the other, there may be dependencies on research completion before specific tasks can begin. Agile's repetitive approach encourages continuous communication and coordination between the teams. It helps manage dependencies effectively and ensures the work progresses despite potential delays.

Adopting Agile project management will benefit our project due to its flexibility, which is focused on collaboration and communication, adaptability to change, allowing our team to respond quickly to evolving requirements and deliver value incrementally, and ability to manage dependencies effectively. This was incredibly helpful as our final deliverables were still being decided.

To effectively track the progress of our project throughout the course, we employed a combination of several project management tools and communication platforms, such as:

- Microsoft Teams and Discord are the primary communication platforms for transferring information, allowing us for real-time communication, discussion, and sharing of updates. Microsoft Teams serves us as the primary platform to communicate with our clients and advisors bi-weekly.
- Google Drive is the primary project management tool for sharing and saving project documentation, meeting notes, design files, and other relevant materials such as research, weekly reports, etc. This method allows us to share folders to ensure all team members can access the latest files and resources. Microsoft SharePoint is the project management tool shared between the team and our client. This method allows our client to share files to view and our team to upload deliverables.
- Weekly meetings are held to discuss project progress, address challenges, and align

priorities for upcoming tasks. Those meetings allow team members to provide any updates, seek assistance if needed, and ensure everyone is on the same page regarding project expectations, goals, and objectives.

By applying these tools and practices, the team was able to effectively track progress, facilitate collaboration, and ensure transparency throughout the project. Regular communication, clear task assignments, and well-defined workflows contributed to the successful execution of the project and the achievement of its goals.

3.2 TASK DECOMPOSITION

By organizing the project into sprints and focusing on delivering specific features or functionalities in each sprint, the team effectively manages the project's progress while adapting to changes and feedback. Team task decomposition for this semester is following as:

Table I: Requirement Gathering and Initial Planning

Task No	Task Decomposition
1	Gather requirements for bus configurations, piloting and relaying schemes, I/O assignments, site layout, and elevation plan.
2	Define project scope and constraints.
3	Allocate resources and roles within the team.
4	Choose project management tools and set up communication channels.

Table II: Bus Configurations Design

Task No	Task Decomposition
1	Research different bus configurations based on project requirements and IEEE specifications.
2	Design various selected bus configurations and their layouts.
3	Review and revise bus configurations based on feedback.

Table III: Piloting & Relaying Schemes Design

Task No	Task Decomposition
1	Research different relay/pilot schemes suitable for the project.
2	Design pilot/relay schemes for the selected bus configurations.
3	Review and refine relaying schemes based on project or client preference.

Table IV: Overview and Elevation plans

Task No	Task Decomposition
1	Develop an overview of the entire project, including bus configurations, relaying schemes, and site layout.
2	Design elevation plans for equipment placement and infrastructure.
3	Review and finalize the overview and elevation plans.

Table V: I/O Assignments and Site Layout

Task No	Task Decomposition
1	Determine which I/O assignments are needed for the selected bus configurations and relaying schemes.
2	Design the site layout considering the placement of equipment and infrastructure.
3	Review and adjust site layout and I/O assignments as needed or with client preference.

Table VI: Integration and Testing

Task No	Task Decomposition
1	Conduct testing to verify the functionality and viability of the integrated design.
2	Address any issues or identify any complications during testing.
3	Integrate bus configurations, relaying schemes, I/O assignments, and site layout into design structure.

Table VII: Documentation and Reporting

Task No	Task Decomposition
1	Document all design project processes, including decisions, choices, changes, preferences, and specifications.
2	Generate design reports detailing bus configurations, relay schemes, I/O assignments, site layout, elevation plans, and other required information.
3	Project update and report change.

Table VIII: Finalize and Delivery

Task No	Task Decomposition
1	Finalizing the design documentation and reports.
2	Organizing or managing the design project relevant to the stakeholders or production environment.
3	Provide training or any necessary support for the users.

3.3 PROJECT PROPOSED MILESTONES, METRICS, AND EVALUATION CRITERIA

Table IX: Finalized Design Choices

Timeline	Metrics	Evaluation Criteria
March 26th, 2024	• Completion of bus configurations and relaying schemes. • Accurately and complete design report documents.	• All bus configurations and relaying schemes have been chosen and documented. • Design documents cover all aspects of configurations and schemes.

Table X: I/O Assignments

Timeline	Metrics	Evaluation Criteria
April 23rd, 2024	• Specificity and clarification of I/O assignments for relaying schemes. • Alignment of I/O assignments with project requirements and IEEE specifications.	• Detailed I/O assignments have been outlined for each relaying scheme. • I/O assignments are designed with project requirements and meet IEEE specifications.

Table XI: Site Layout

Timeline	Metrics	Evaluation Criteria
April 23rd, 2024	• Accuracy of site layout design. • Refer to IEEE specifications for site layout dimensions, specifics, and requirements.	• Site layout design is provided with dimensions and specifics required. • I/O assignments are designed with project requirements and meet IEEE specifications.

Table XII: Elevation Plan

Timeline	Metrics	Evaluation Criteria
September 15th, 2024	● Accuracy of specific elevation plans for equipment and line/bus. ● Following IEEE specifications regarding elevation details.	● Elevation plans accurately display the elevations of equipment, lines, and buses. ● Plans attach to IEEE specifications regarding elevation details and configurations.

Table XIII: One-Line Diagram

Timeline	Metrics	Evaluation Criteria
November 20th, 2024	● Implementation of relaying specifications and I/O assignments ● Following IEEE specifications regarding relay equipment	● Clear and concise protection relaying for entire site ● Output functions, current inputs, and voltage inputs for all relays and subsequent equipment coincide with criteria from client

In addition to these milestones, metrics, and evaluation criteria, regular progress reviews and quality checks must be conducted throughout the project to ensure the designs meet the desired standards and requirements. Feedback from clients, advisors, and team members should also be considered to improve the designs as needed iteratively.

3.4 PROJECT TIMELINE/SCHEDULE

Table XIV: Projected Project Timeline

Task	Due Date	Name
Bus Configuration Report	03-26-2024	Kenzie/Derek
Pilot Scheme Report	04-01-2024	Nathan/Matt/Patrick
Relay Selection and I/O Assignments	04-23-2024	Nathan/Matt/Patrick
Site Layout/General Arrangement	04-23-2024	Kenzie/Derek
One-line Diagram	09-10-2024	Kenzie/Derek
Elevation Drawing	09-15-2024	Kenzie/Derek
Lightning Study	11-12-2024	Kenzie/Derek
Dynamic Simulation	10-15-2024	Nathan/Matt/Patrick
Event Analysis Report	11-26-2024	All

3.5 RISKS AND RISK MANAGEMENT/MITIGATION

Table XV: Risks Management

Task	Risk	Probability	Mitigation
File Management	Accidental removal of file.	Low (0.2)	Execute regular file backups or use a control system such as Excel to prevent data loss for file management.
Rating Electrical Components	Selecting components with inappropriate ratings.	Medium (0.4)	Conduct complete research on component specifications and consult with an expert, such as our advisor or client, to ensure the selected components are appropriate to the requirements.
Relay Selection	Choosing the wrong relay can necessitate starting the selection process.	Medium (0.3)	Apply the re-verification or re-checking process to verify relay specification according to the project requirement. Consult with IEEE specification, client, advisor, or any regulation documents.
I/O Labeling	Mislabeling I/O connections can lead to errors or confusion.	High (0.5)	Conduct peer reviews to verify connections between drawings. Apply standard label verification.
Calculations	Making a miscalculation can impact project outcomes.	Medium (0.3)	Double-checking procedures for all calculations. Conduct peer review to validate calculations.

3.6 PERSONNEL EFFORT REQUIREMENTS

Table XVI: Predicted Tasks Requirement

Task	**Estimated Hours**	**Description**
Bus Configuration Report	10	Kenzie/Derek
Pilot Scheme Report	35	Nathan/Matt/Patrick
Relay Selection and I/O Assignments	60	Nathan/Matt/Patrick
Site Layout/General Arrangement	30	Kenzie/Derek
One-line Diagram	40	Kenzie/Derek
Elevation Drawing	30	Kenzie/Derek
Lightning Study	40	Kenzie/Derek
Dynamic Simulation	50	Nathan/Matt/Patrick
Event Analysis Report	50	ALL

Table XVII: Actual Tasks Requirement

Task	Actual Hours
Bus Configuration Report	15
Pilot Scheme Report	60
Relay Selection and I/O Assignments	70
Site Layout/General Arrangement	40
One-line Diagram	45
Elevation Drawing	35
Lightning Study	10
Dynamic Simulation	120
Event Analysis Report	30

Reviewing the estimated time to the actual time we were a bit off on our predictions. The obvious mismatch is the dynamic simulation. We were unaware how indepth and tedious PSCAD would be for our simulations. However, at the beginning of the fall semester we were informed that we would need to be dedicating a lot more time than expected. Most of our estimations for designs were accurate but we did not include the time needed for changes after review.

3.7 OTHER RESOURCE REQUIREMENTS

- Software (AutoCAD and PSCAD)
- Substation design guide: *Design Guide for Rural Substations* National Rural Electric Cooperative Association
- Example substation set: One-line, schematics, wiring diagrams, and site layouts.
- Short circuit study
- Relay specification report

DESIGN

4.1 DESIGN CONTEXT

The Ames substation project provides an excellent opportunity for the community, specifically the City of Ames, to reap the benefits of adding renewable energy to its city. The design for this substation addresses several environmental, public welfare, and economic needs of the city. The substation will connect solar-generated energy to the grid through reliable design solutions and provide reliable electricity to the city through backup power sources from remote communities.

4.1.1 BROADER CONTEXT

The first of the significant considerations listed above addressing environmental sustainability in Ames is a fundamental part of the substation's purpose. Through the connection of a 2MW solar farm, the substation will help mitigate carbon emissions. In addition the reduced use of fossil fuels due to the solar farm will help reduce significant land disturbances from mining processes necessary for extraction.

The second consideration for this design is the impact on public welfare. This substation must meet industry standards to ensure reliability, sometimes at the cost of extra-economic strain. The devices selected for the substation are all expensive, robust equipment. As a requirement the substation shall ensure the solar farm connects to the grid seamlessly without interrupting power. This means selecting the cheapest devices is not always the best option for this project.

The third consideration is the economics of the substation. Though the protection equipment may not be the cheapest upfront, protecting the equipment, in the long run, will save the client money should power be disrupted. The additional reliability the design will provide should negate the extra capital upfront.

4.1.2 PRIOR WORK/SOLUTIONS

Substations are often designed to be expanded by leaving extra space between the equipment and providing space for making extra connections. This is a common practice for building substations as it can improve the life span of the substation by allocating space for future upgrades. The devices should be sized to suit these upgrades as it is not economical to fully replace a substation because the station devices are not rated to handle the additional fault currents generated by the extra connections [1].

Substations are also often used to connect utility-scale solar to the grid, but this project deals with a community-sized solar project. Most utility-scale solar projects are larger than 10MW. The fact that this is a community-scale project means there is the option to simply use a line tip connection to the grid rather than to set up a substation [2]. This solar farm is on the high end for a community-sized solar farm so the cost of connection with just a line tap would likely be higher. Adding the substation will ensure enough capacity for the City's grid and provide more protection for the equipment from faults. Other solar connections can directly tap into the grid, but they are much smaller scale. The scale of this project means high currents, which lead to more significant power losses through transmission lines. By constructing a substation to step up the voltage instead of a simple line tap, the current is reduced as does the power losses. This is because transformers reduce currents proportionally to the voltage step up.

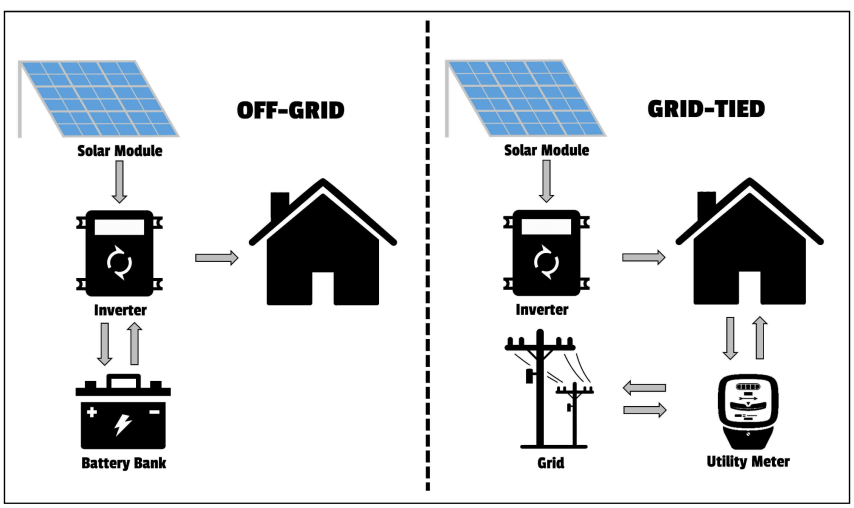


Figure 1: Alternate Grid Connection Types [3]

4.2 DESIGN EXPLORATION

Each deliverable for the substation design requires the following three processes before completion: Initial design decisions, ideation, and decision-making and trade-off. These steps are critical to the accuracy and quality of the final design. Our design decisions provide a groundwork for the final design deliverables. Ideation offers the opportunity to generate ideas for how the deliverables will be completed and how they should look. Lastly, decision-making and trade-offs provide the final deliverable documents.

4.2.1 DESIGN DECISIONS

Ideation in the context of this design project involves generating and exploring various ideas, concepts, and approaches to address the project's requirements and constraints effectively. We explored the ideation process to understand the different design decisions across our project:

- **Piloting Schemes**:
    - *Ideation:* The ideation process for piloting schemes involves brainstorming various communication and protection strategies to ensure reliable operation and fault management within the power grid. It will include considering different communication protocols, such as Directional Comparison Blocking (DCB), Permissive Overreaching Transfer Trip (POTT), or Line current differential (87L), and evaluating their suitability based on factors like system complexity, reliability, and cost-effectiveness.
    - *Design Decision:* After considering various options, the design decision involves selecting a combination of piloting schemes tailored to the project's specific requirements, ensuring strong communication and fault detection capabilities across the transmission lines.
- **Bus Configurations**:
    - *Ideation:* Ideating on bus configurations entails exploring different arrangements for connecting and isolating transmission lines and equipment within the substation. This could involve considering options like ring bus, breaker-and-a-half, or double bus configurations, each offering distinct

advantages regarding reliability, scalability, and maintenance.

  - *Design Decision:* The design decision involves selecting the most suitable bus configuration, such as the ring bus configuration, which offers redundancy and fault tolerance while facilitating efficient power flow management within the substation.

- **Relay and Protection Device Selections**:
  - *Ideation:* Ideating on relay and protection device selections involves researching and evaluating various relay types, current transformers (CTs), voltage transformers (VTs), and breakers to ensure optimal fault detection, isolation, and system protection. It includes considering factors such as sensitivity, speed, coordination, and compatibility with the chosen piloting schemes.
  - *Design Decision:* Based on ideation and analysis, the design decision entails selecting a combination of relays, CTs, VTs, and breakers that meet the project's protection requirements, ensuring reliable operation and adherence to industry standards such as IEEE recommendations.
- **Input and Output Assignments**:
  - *Ideation:* Ideating on input and output assignments involves determining the connections and interactions between protection devices, relays, and other components within the substation. It includes matching signal paths, logic functions, and fault response sequences to ensure proper coordination and functionality.
  - *Design Decision:* The design decision involves finalizing the input and output assignments based on ideation, ensuring clear communication pathways and logical control logic implementation to facilitate fault detection, isolation, and system operation.

By engaging in a systematic ideation process across these design aspects, the project team can explore and evaluate various design options to make informed decisions that align with the project's goals and requirements. This iterative approach fosters creativity, problem-solving, and optimization, ultimately leading to a complete and effective design solution for the Ames Substation project.

4.2.2 IDEATION

The ideation for making each design decision required research and review of IEEE standards to identify if the component would be the best solution for each design part. We had to choose between several relay options for each piloting scheme. One criterion was the relays had to all be from the same company to improve compatibility. The following companies were identified by searching the relay needed for implementing the piloting scheme:

- ABB
- GE
- SEL
- Siemens
- Eaton

4.2.3 DECISION-MAKING AND TRADE-OFF

A decision matrix was created to evaluate the criteria identified to efficiently determine which company to work with. SEL came out as the clear winner.

Table XVIII: Comparison of Companies

	Weight	**ABB**	**GE**	**SEL**	**Siemens**	**Eaton**
Cost	0.2	3	3	2	3	5
Online Reviews	0.4	1	1	5	3	3
Group Members' Past Experience	0.2	2	1	5	1	1
Available Functions	0.2	5	5	5	5	1
Total		2.4	2.2	4.4	3	2.6

The ratings in the decision matrix were developed based on the evaluation criteria identified for selecting the most suitable company to work with. Each criterion was assigned a weight representing its relative importance in decision-making. Here's how the ratings were developed and what distinguishes a 5 rating from a 1 rating:

- **Cost**:
  - Ratings were assigned based on the perceived cost-effectiveness of each company's products or services relative to the project budget. A rating of 5 would indicate the lowest cost, while a rating of 1 would suggest the highest price. Factors influencing the rating could include upfront costs, ongoing maintenance expenses, and overall affordability compared to competitors.
- **Online Reviews**:
  - Ratings were determined by considering the feedback and reviews available for each company's products or services from online sources such as customer reviews, industry publications, and forums. A rating of 5 would signify irresistibly positive reviews, indicating a solid reputation for reliability, performance, and customer satisfaction. Contrarily, a rating of 1 would suggest poor or negative reviews, signaling potential concerns regarding product quality or customer support.
- **Group Members' Past Experience**:
  - Ratings were based on the team members' previous interactions or experiences with the companies, including firsthand knowledge of product performance, customer service, or overall satisfaction. A rating of 5 would indicate extensive positive experiences, suggesting a high level of trust and confidence in the company's capabilities. Conversely, a rating of 1 would suggest minimal or negative experiences, raising doubts about the company's suitability for the project.
- **Available Functions**:
  - Ratings were assigned based on the comprehensive and suitability of each company's offerings to meet the project requirements and provide necessary functionalities. A rating of 5 would imply that the company offers a wide range of functions that align closely with the project's needs, providing great options and

flexibility. A rating of 1 suggests limited or inadequate offerings, potentially requiring additional customization or integration efforts to meet project requirements.

4.3 FINAL DESIGN

4.3.1 OVERVIEW

The substation design includes several drawings showing the necessary equipment and location to build the substation. The substation will take a lower voltage from a solar farm and step it up to a higher voltage that can be used for other transmission lines. The design includes selecting switching schemes that protect the high-value infrastructure, such as transformers (devices that change voltage levels). The design include multiple drawings show casing different parts of the system. We have two different scopes, one focusing on the physical looks and formation of the substation and one foscuing on the controls and communication in the substation. The elevation drawings, site layout, 3-D diagram, and one-line diagram were designed to show how the system is connected both physically and how it communicates.

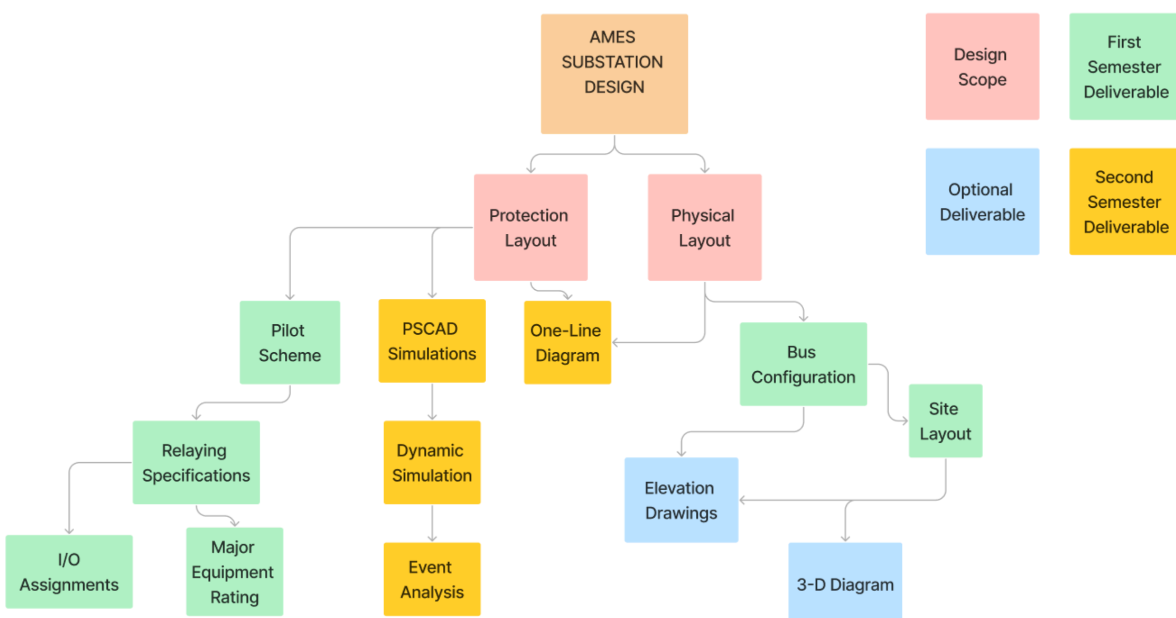


Figure 2 Project Workflow

4.3.2 DETAILED DESIGN AND VISUALS

The first design decision is the selection of the bus configuration. The ring bus configuration will be used for this substation and is one of the most common bus configurations used in substation design.

There are several factors to consider regarding why the ring bus configuration is much better than other bus configurations have to offer:

- **Fault Tolerance**: In a ring bus configuration, if one node or segment of the ring fails, the rest of the network can continue to function without disruption. Data can travel in the opposite direction around the ring to reach its destination, minimizing downtime and increasing network reliability.
- **Efficiency**: Unlike linear buses, where data packets must traverse the entire length of the bus, ring bus configurations offer more direct routes between nodes. This can result in faster data transfer speeds and reduced latency, particularly in networks with many nodes.
- **Scalability**: Ring bus configurations can easily accommodate additional nodes by simply connecting them to the existing ring. This scalability makes it well-suited for expanding networks or accommodating future growth without requiring significant redesign or infrastructure changes.
- **Equal Access**: Each node in a ring bus configuration has equal access to the network and can communicate directly with any other node on the ring. This equitable access ensures that no single node has priority or monopolizes network resources, promoting fairness and balanced network performance.
- **Simple Configuration**: Setting up a ring bus network is relatively straightforward compared to other topologies. Nodes are connected in a closed loop, eliminating the need for complex routing protocols or centralized management systems.

Overall, the fault tolerance, efficiency, scalability, equal access, and simplicity of configuration make the ring bus topology a favorable choice for specific network applications, particularly those requiring high reliability and performance.

They are reasonably simple to implement with a relatively low cost and high level of reliability. A ring bus connects two open ends of two main buses through a breaker. This allows for a separate "section" of the bus for each input. In the event of a fault on one line, the other line would not be affected; therefore, there would not be a complete loss of power, which would put a significant load on the different sources.

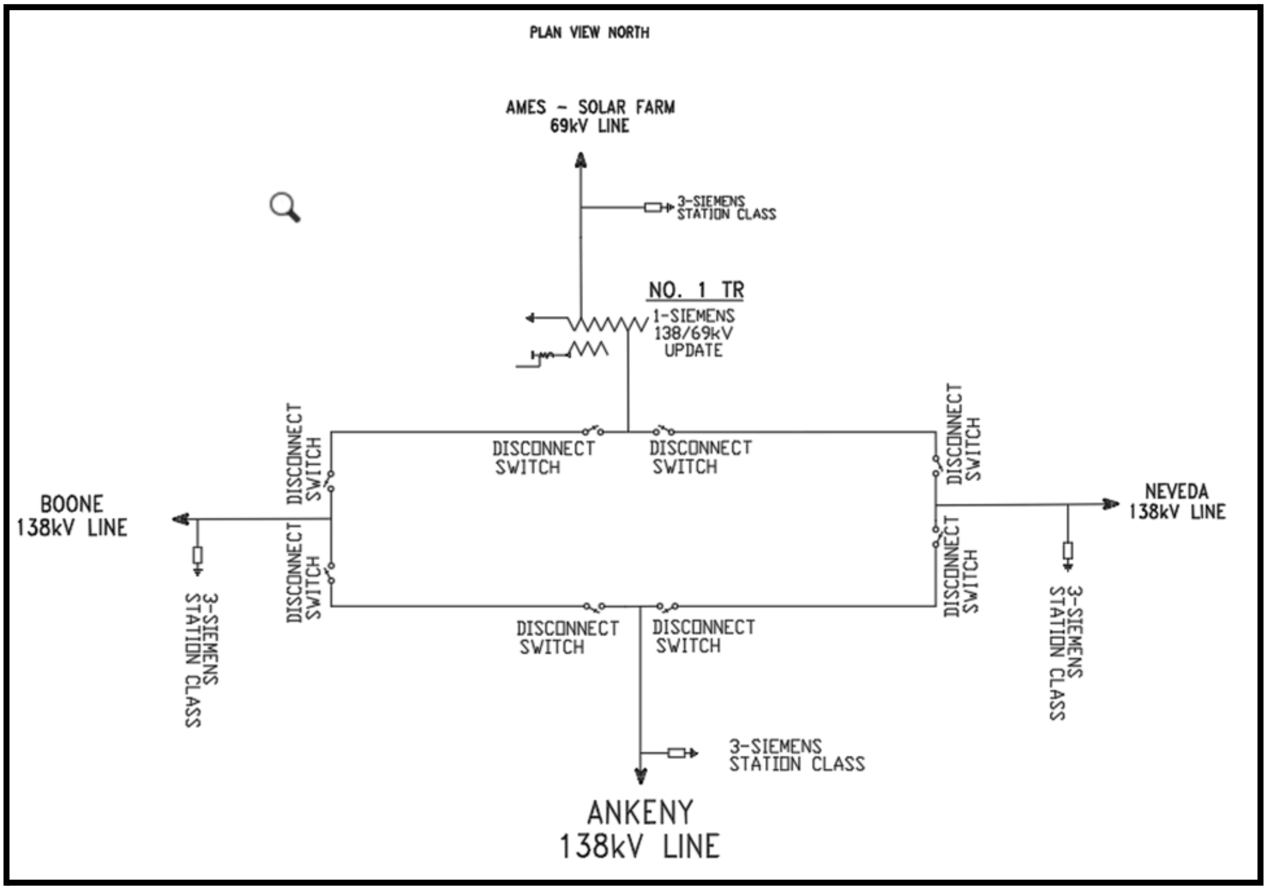


Figure 3: Ring Bus Configuration

The design included the selection of piloting schemes for each transmission line. All four lines must be piloted using DTT piloting, which locks equipment with a direct trip signal during a catastrophic event. Various POTT, DCB, DCUB, and 87L piloting schemes also pilot the lines. For the shorter lines like the Boone and the Ames Solar Farm lines, the current differential protection 87L shall be implemented. Due to the power line carrier, the Ankeny line requires on/off type communication, so we selected DCB and DCUB. The Nevada line is sufficiently long enough to use distance relays so that the POTT will be used in addition to the 87L. All protection schemes require a variety of selected relays to monitor line current and voltage and provide automated control over the substation equipment.

Once we were able to select the bus configuration and the piloting schemes we will use for each line, we were able to complete the designs of the general site layout, the elevation designs, and the one-line diagram. The general overview shows a clear "ring" and includes different equipment that is essential for operation. Equipment includes a 69/138 kV transformer, disconnect switches, circuit breakers, wave traps, CCTVs, and more. This equipment is also shown also in the elevation design but focuses on the spacing and heights of the equipment. The transformers purpose to increase the 69 kV from the solar farm to the 138 kV used in the transmission lines from the Ames substation to surrounding stations. Disconnect switches are manual switches used to separate sections from live lines without turning off an entire station. These are mostly used to separate a section for maintenance purposes and commonly seen on both sides of breakers. Circuit breakers are placed to automatically "open" or break a circuit. These are vital to the systems as they protect the substation during faults. When an abnormal level of current or voltage is read, the circuit breaker opens in milliseconds in order to minimize the damage on equipment and lines. Wave traps are basically band pass filters and are used to block out high frequency communication signals that is unwanted. These are commonly seen on lines with a tap-off or a substation that pulls power from the line.

4.3.3 FUNCTIONALITY

Our substation system does not interact directly with the end users. We make considerations for the technicians, utility companies, and other engineers that will interact with our design. For this reason, we will weigh some design aspects to minimize complexity and confusion. The primary consideration is designing a reliable autonomous system with manual control for maintenance and repair.

4.3.4 AREAS OF CONCERN AND DEVELOPMENT

The current design does a great job of addressing the user's needs. The substation design has protection schemes that vary between primary and secondary systems, ensuring that each line is well protected. The bus configuration selection is simple, as is the substation itself, making protection schemes less complex and providing overall system resilience. The sight layout follows industry standards to reduce losses from linked flux between transmission lines and lower risks from arc flash or line-to-line faults.

One issue was the DC input and output connections. They required us to properly select equipment such as current transformers and capacitive coupling voltage transformers and then route the I/O to properly to provide communication connections needed for monitoring the breakers, line voltages, and currents. To address these concerns, several iterations for the I/O assignments were presented and reviewed by the client to ensure that this deliverable was completed to the level of detail anticipated by the client.

4.4 TECHNOLOGY CONSIDERATIONS

We used various state-of-the-art equipment, including modern solid-state protective relay equipment, autotransformers, current transformers, voltage transformers, and fiber optic communication where possible. The only major issue is the extra cost of the selected relay manufacturer. SEL relays tend to be more expensive than other companies' equipment. The main advantage of choosing this company is that the relays provide an extensive range of options, making the substation more adaptable to future upgrades should more loads or lines be added to the substation in the future. Also, SEL has an excellent reputation in the power industry for creating reliable products and exceptional service.

4.5 DESIGN ANALYSIS

The protection schemes were rigorously tested using the software PSCAD. This software provides detailed information on how the designed substation will handle various fault conditions. This helped provide feedback on changes that needed to be made to the final design. This part of the project was crucial to ensure that the substation is constructed correctly without the need for any expensive updates or improvements after the final construction. Overall confidence in the design comes from strict guidelines listed in the IEEE standard for transmission line protection. Simulations will provide data to support our selections and implementation of these standards.

TESTING

Testing in our design is split into two modules: The review process and simulation testing. The review process starts with depicting our deliverables in terms of the IEEE standards. We implement specific standards that are technically relevant to our design. After making informed decisions about our design, we document them in a report and subject them to peer review. After the cross-examination between group members, we submit the report to our client for their feedback. After a final group review, we complete our deliverable. In the second semester, we utilized PSCAD software to simulate fault response events in our system rigorously. This type of testing is very specific to our project and required substantial time allotted for learning the software.

5.1 UNIT TESTING

Each deliverable undergoes a form of testing, whether it is through the review process or technical simulation. We test for compliance with the standards and meet our client's expectations. We also tested our design for explicit errors using PSCAD. PSCAD provided a good proof of concept which allowed the team to identify issues with chosen relay settings. It provided an opportunity to explore troubleshooting and testing of the circuit designed. Lastly it created a better understanding for the system operation showing what worked and what did not.

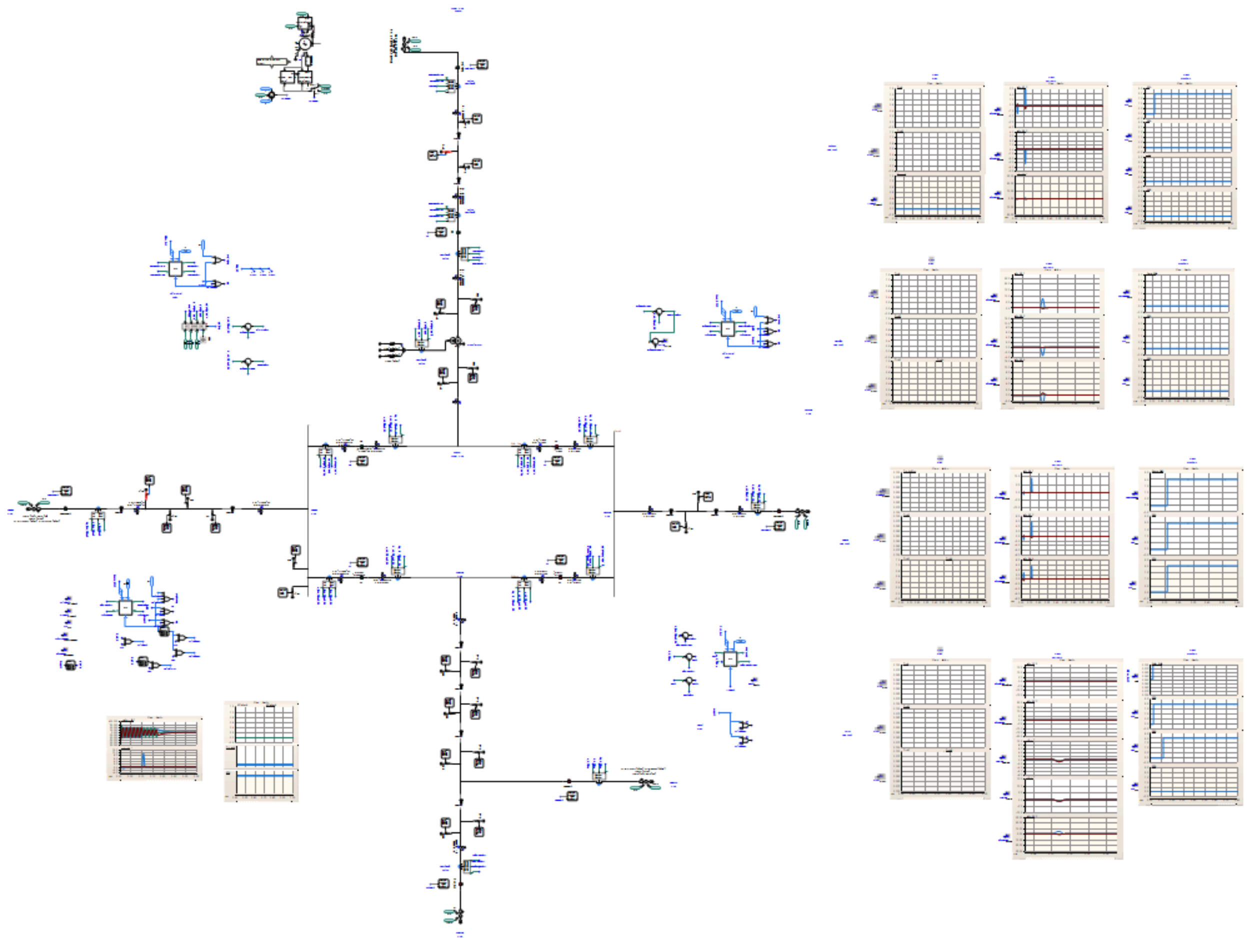


Figure 4: Full one line showing the full PSCAD model

5.2 INTERFACE TESTING

Each electrical component selected in the protection report has been connected and simulated with PSCAD, this provided data necessary for the completion of an event analysis report. The specific components that were tested included the functions selected for each relay and the corresponding piloting schemes. This includes setting up fault scenarios and testing how the relays function. A wide range of faults were set up at different locations on the lines. This resulted in exposing any issues with relay settings, communication, or design.

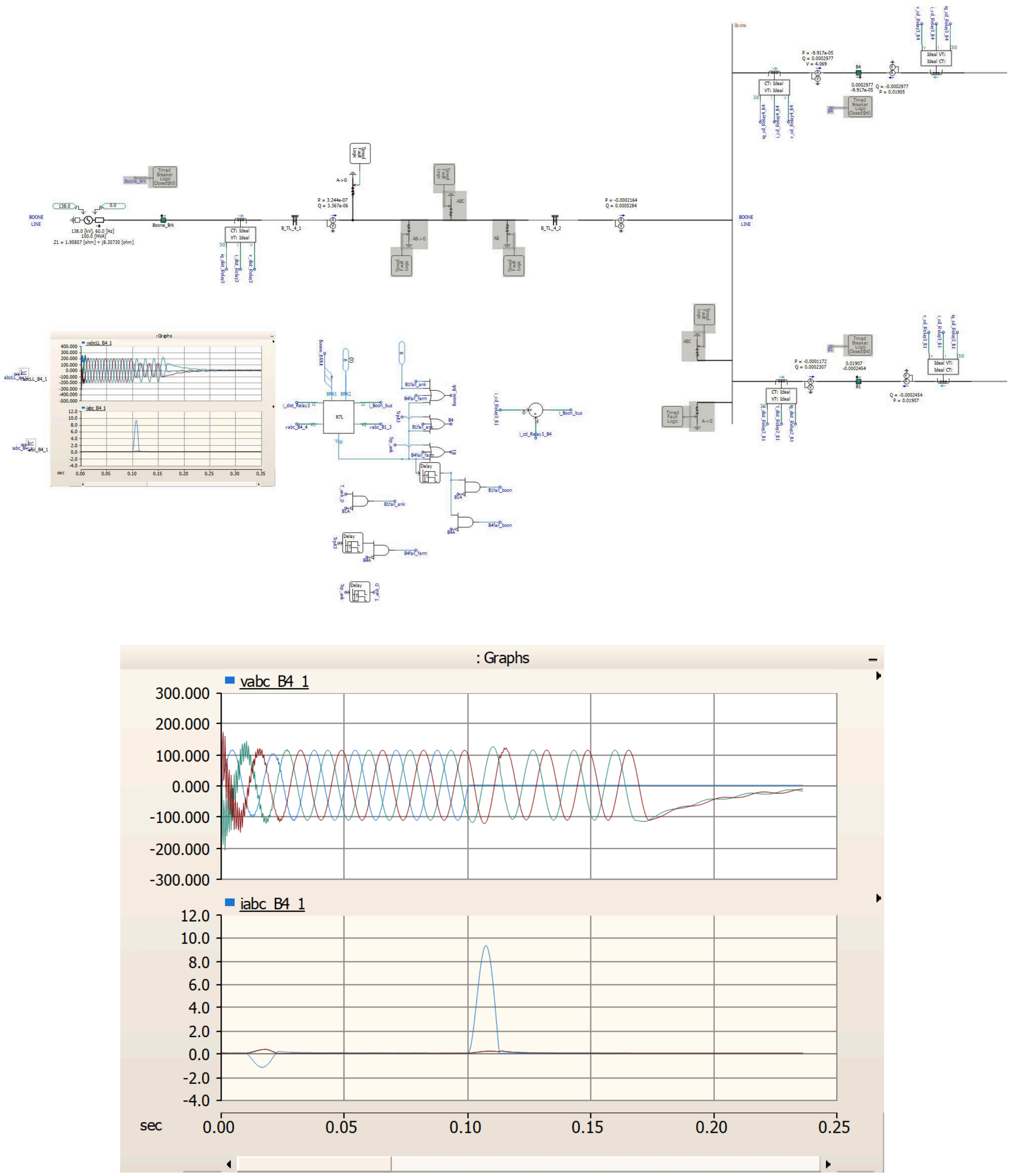


Figure 5: Fault simulation single line to ground fault Boone Line

The breakers turned green and the plot of the current and voltage show that the 87L line current differential scheme functioned correctly isolating the fault in the Boone Line.

5.3 INTEGRATION TESTING

Several layers of the substation design must be integrated throughout the design process. Starting with the pilot scheme report and bus configuration report, we build on those concepts to create a more detailed layout and protection report. We then compile those deliverables into a one-line diagram and a PSCAD simulation. For PSCAD simulations integrating the relays required building out additional logic as the relays provided did not have features built in to allow for coordination of multiple relay and piloting schemes needed to simulate a full substation.

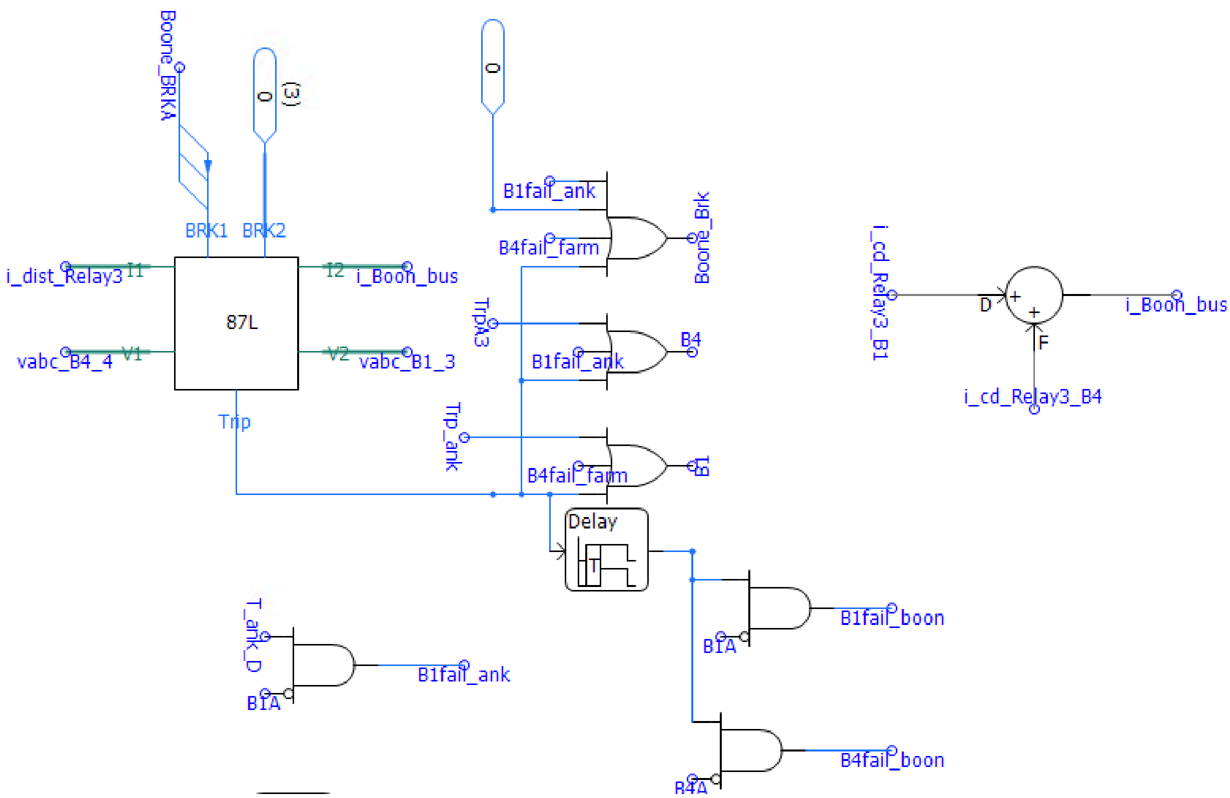


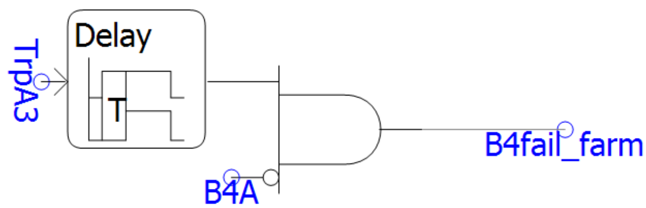
Figure 6: Boone line 87L relay with additional tripping logic for system integration with other line relays

To ensure that all of the breakers could be correctly operated by the relays OR gates were used to allow any one relay needed to trip the breaker to be allowed to by sending a 1 to that gate. The signal then operates the breaker. Additionally coordination between breakers is added to ensure that in the event of a breaker failure the adjacent breakers will trip instead known as direct transfer trip. The breaker failure signal can be sent to the other breaker's OR gates to be included in those breakers trip logic.

Table XIX: Breaker Failure Logic

Breaker Trip Signal Received from Relay	Breaker Position	Breaker Failure Occurred
0	0	0
0	1	0
1	0	1
1	1	0

Signal logic in PSCAD using an and gate with one terminal inverted:



A .025 second delay is added to the trip signal accounting for breaker operation delay.
Signal B4A is the breaker B4 position. TrpA3 is one of the trip signals from a relay that normally trips breaker B4.

Transfer Trips Intended:

- For Fault on Transformer Section
  - Boone_Brk
  - B1
- For Fault on Boone Line
  - B5
  - B3

5.4 SYSTEM TESTING

PSCAD provided simulations for not only connections between the relays, but the entire system as a whole. This included testing how all piloting schemes interacted with each other during different fault conditions. The aim was to see if any logic in the design conflicts with another. If this happens, then over-tripping of breakers may occur.

System Testing with Ankeny Line:

This test successfully exposed design issues. Due to time constraints on the project, a suitable solution to these over tripping issues specifically with the distance relays went unsolved. However the problem was identified by plotting the relay Zone pickups. These Zones act as a way for the relay to determine if the fault has occurred on the transmission line or somewhere else. Several possible solutions that could be tested if there was more time for this project include:

1. Check the current and voltage measurements. One issue that may be causing this error is if the measured values are reported as Volts or Amperes, but are actually in per unit.
2. Try tuning the Zones to prevent over and under tripping through trial and error by plotting the impedance calculated by the relay for each fault then setting the Zones accordingly.
3. For the phase to phase faults more research would be needed to properly calculate these Zones.

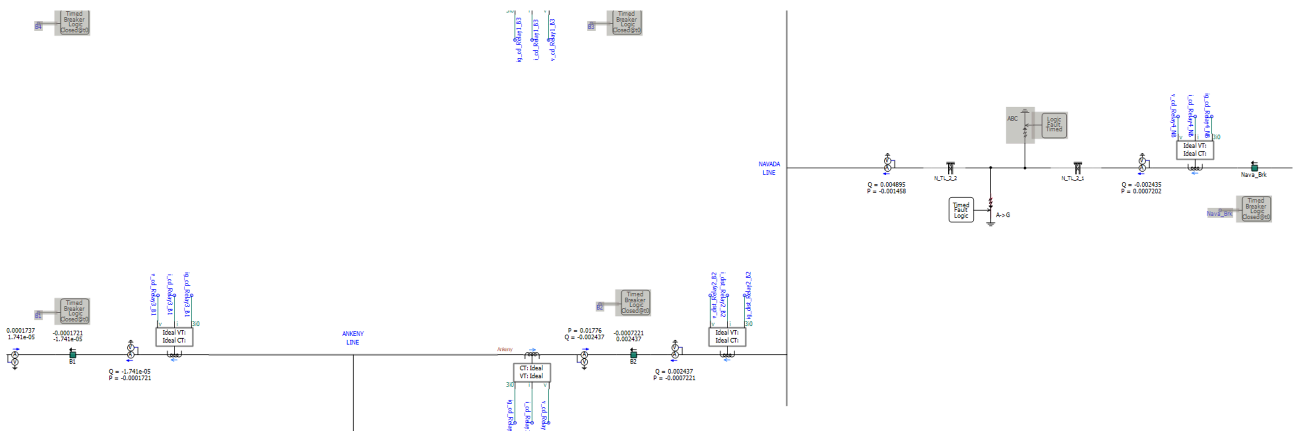


Figure 7: Over tripping of Breaker B1 for fault on Nevada line

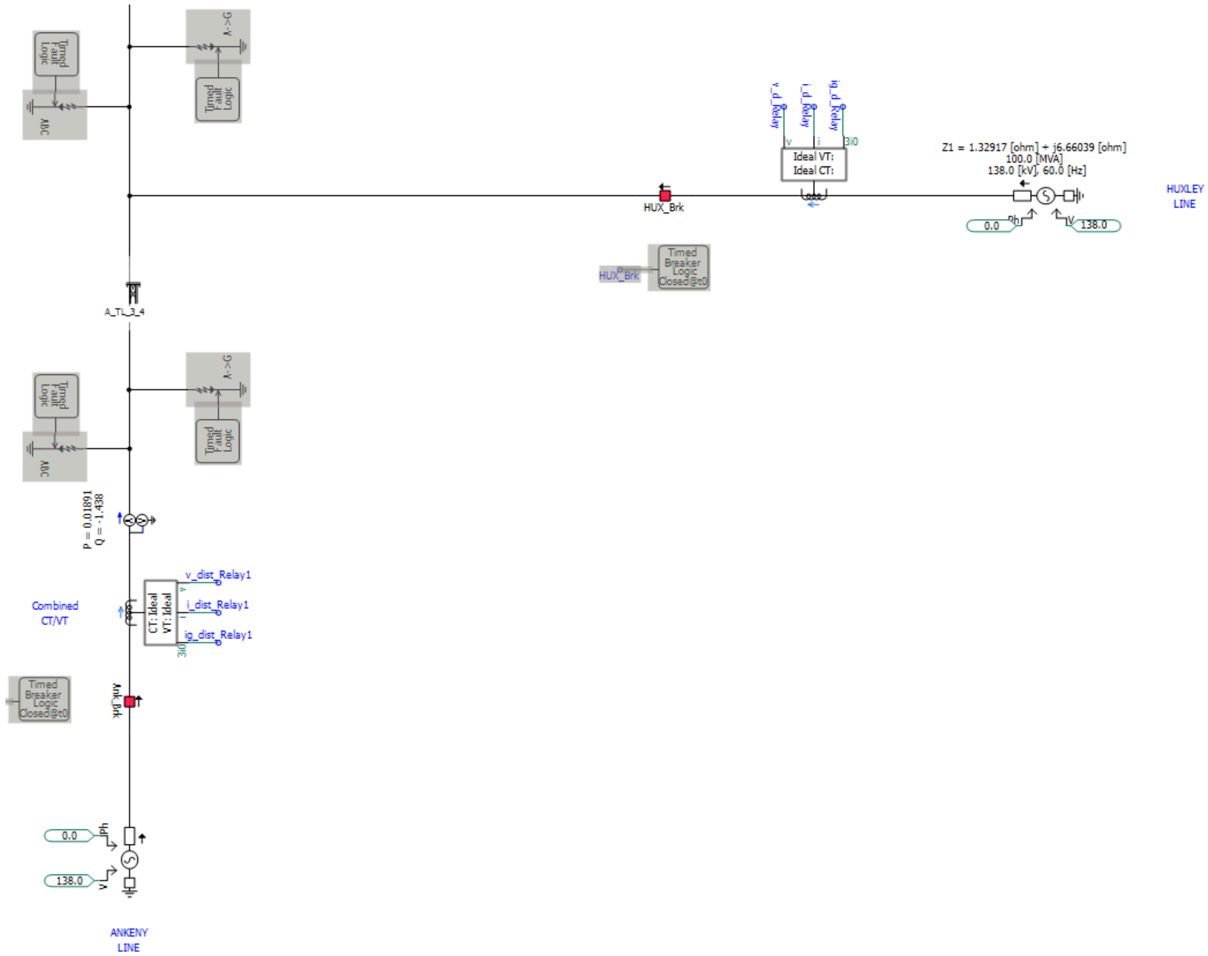


Figure 8: Distance relay for Ankeny end does not over trip for fault indicating an issue with the local distance relays.

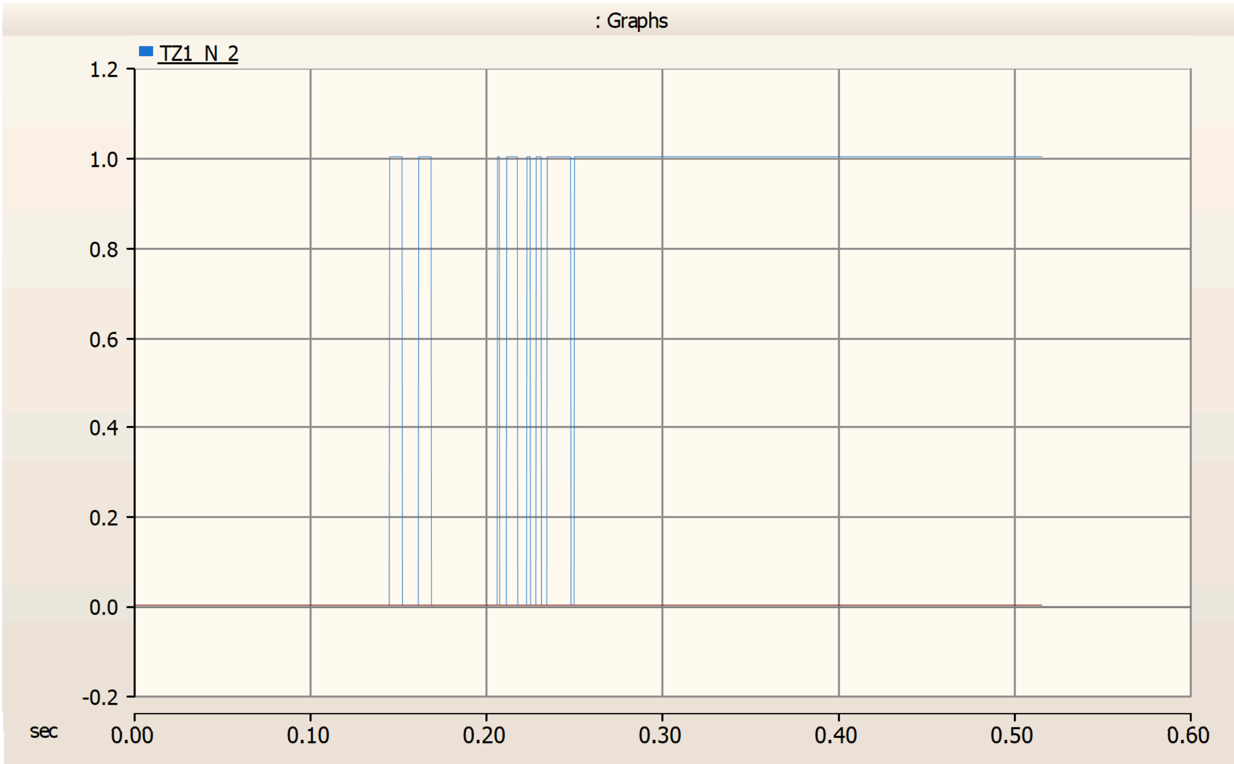


Figure 9: Plot of the distance relay Zone One (1) pickup over tripping for reverse fault outside of its intended zone.

Figures 7-9 show how the distance relays failed to function properly for external faults. Because the Zone One (1) settings are too sensitive they over trip for faults outside of the Ankeny Line. This is a problem because it provides a reliability issue with supplying power from the solar farm to Huxely and Ankeny.

Other System Testing:

Coordination between all of the current differential and the transformer differential schemes were successful. The group only had time to implement the primary protection scheme for each zone in the substation.

5.5 REGRESSION TESTING

Adhering to standards and the feedback of our client and advisor allowed our group to move through the substation design process with agility. Our expectations are clearly defined, allowing us to confidently make informed decisions and progress. Also, the flow of our project is sequential, so each deliverable builds upon the last. Having a thorough review process for each deliverable lets us proceed in our project without having to worry about back-tracking.

5.6 ACCEPTANCE TESTING

As a part of the final deliverables, a fault analysis report was used to communicate the test findings. This document fully described any changes made to the design as well as the effectiveness of the design. Due to challenges with learning about distance relays and PSCAD software we modified the scope of the project attempting to reduce the number of tests done to complete on time. Additionally the realization was made that the distance relays would not fully function as they are intended. This means as the design sits it is capable of protecting the system from all types of faults, but with some mild reliability issues due to the Anknеy Line over tripping.

The other deliverables discussed in the design section, including bus configuration, piloting scheme, protection relaying, and I/O assignments, were submitted multiple times for review. The client has provided detailed comments on these reports and necessary revisions were completed to improve the design documents.

5.7 RESULTS

As discussed in prior sections the faults are all successfully cleared by the protection schemes and the design functions well to protect equipment from damaging fault currents. However extensive testing of the system shows an over tripping issue due to issues with distance relay settings. This caused the Ankeny connection to be disconnected from the bus for all faults that occur in the system. As system reliability is one of the major requirements of this project, if this project was to be implemented in a real substation, further research shall be done to calculate settings that prevent this overtripping from occurring.

IMPLEMENTATION

For this project the design process for the protection system started with selecting piloting schemes for each relay to communicate and provide adequate protection. Then relays that are compatible with each pilot scheme were selected. An inputs and outputs list was created for each relay to provide a detailed description for how each relay will communicate tripping of the breakers and monitor the system. This list was used to develop a one-line diagram showing more detail on how the relays and their respective tripping elements such as distance (21N/21P) or differential elements (87L) interact with each other.

Then the relays were implemented in PSCAD. The final simulation was able to simulate all primary protection schemes for the solar farm, Nevada, and Boone lines. The Ankeny line was most complicated as it used the distance relays which required precise calculations and due to time constraints the group was unable to complete this. The project required group members to learn about not only how distance relays should operate but also how to implement them in PSCAD. Major roadblocks occurred due to poor understanding of PSCAD for example the group was delayed for two weeks because the compiler used was not compatible with the relays. Despite this all faults set up on the system are cleared meaning that at the very least faults will not damage the system, however due to extreme overtripping of the Ankeny line this current system is not reliable enough to be implemented into a real world application.

This project showed the group that the current differential scheme is very simple and much more reliable compared to the distance relays. This means that if it is possible to implement the current differential scheme it should be the first choice for primary protection.

6.1 DESIGN ANALYSIS

The design worked very well for protecting the system, but as discussed there are major system reliability issues for the Ankeny line. Assuming the distance relay settings could have been adjusted to stop over tripping for faults outside of the Zone One (1) it is likely the design would have worked very well. This is because all faults are cleared by the relays. Additionally the system was designed with redundancy including implantation of DTT for breaker failures. One thing that could have been improved on would be to try checking the fault impedances measured by the distance relays during faults at the edges of the protection zone. Then using this value adjust the distance relay to only operate up to this impedance value. This could have been used as a substitute for the method attempted utilizing formulas from the SEL-411L relay manual to calculate the values needed for each zone of protection.

PROFESSIONAL RESPONSIBILITY

7.1 AREAS OF RESPONSIBILITY

Areas of responsibility are aspects that apply to many engineers in their day-to-day tasks. These responsibilities are essential to creating an ethical work environment. Engineers have the knowledge and power to change the world. Ethics paves the path to change the world for better rather than worse. Below we explain what time of responsibilities apply to our project and design.

7.2 PROJECT-SPECIFIC PROFESSIONAL RESPONSIBILITY AREAS

With the design of a substation, we must keep several responsibility areas in mind. These areas include work competence, financial responsibility, communication honesty, health, safety, well-being, and social responsibility. Work competence and communication honesty are critical aspects that every professional must abide by. Work competence is performing work that is of high quality, integrity, timeliness, and professional competence. Communication honesty is reporting our work accurately, clearly, and without deception to the public, employees, and stakeholders. If we want to expand our client base and succeed long term, these principles must be followed when designing our product. We have a huge financial responsibility for creating this substation. We must provide our product and service at a reasonable cost. However, cheap doesn't necessarily mean great. All of the significant equipment in a substation is very expensive. However, most of this equipment is also essential. This means that in the long run, it is better to have a more expensive protection system as it will help minimize the potential costs if a fault were to occur. Finally, the last area is social responsibility. Almost every person in Ames is impacted by power in one way or another. This substation must be beneficial to the community of Ames. Luckily, adding our substation will be helpful as it will provide another energy source to the power grid, increasing its reliability.

7.3 MOST APPLICABLE PROFESSIONAL RESPONSIBILITY AREA

The most applicable professional responsibility area would be work competence. Work competence includes but is not limited to high-quality work, integrity, timeliness, and professionalism. Abiding by this responsibility is essential. The design of a substation can impact many future decisions. In today's society, reliable power is vital to one's academic, professional, or personal life. We are constantly on our appliances, heating or cooling our houses, and needing to see light in dark areas. Without the constant supply of power, our lives would be drastically affected. This means that the quality of our design needs to be at the highest degree. The design of our substation not only needs to be high quality but needs to be completed with integrity and in a timely manner. As our society continues to advance, the load on the power grid is increasing. We want to produce our product fast without sacrificing quality. All of these aspects are important to consider when designing our project.

CONCLUSIONS

8.1 DISCUSSION (SUMMARY OF PROGRESS)

We were able to complete many aspects of our project. The general overview, elevation design, and the one-line diagram have been fully reviewed by our client and cleared. Our designs were able to implement industry standards and replicate the work that a few of us will be proceeding with after graduation. Selecting our piloting schemes and implementing them was challenging. Being able to successfully show they are executing their job was a great relief. We were able to use PSCAD to demonstrate our system clearing faults on three of the four lines. At the beginning of the semester our advisor advised us to focus on one line as one line would be complicated enough. We were able to complete the majority of the tasks our client wanted. At the beginning of the semester, our client was hoping we would be able to complete all lines but understood that this would be challenging.

8.2 CONCLUSION (VALUE PROVIDED)

Our design addresses the users needs quite well. Our goal is to provide sustainable, reliable power to the city of Ames. With the protection schemes being able to clear the faults, it provides the amount of reliability we were hoping for. In a broader scope, there are events that will still cause damage and power outages at substations, but being able to use the protection relays to communicate between equipment and substations will limit the amount of damage.

8.3 NEXT STEPS

mage. If another team were to take over our project. The main problem for them to solve would be to figure out the distance relay settings and fix the over stepping that is occurring. Once this is fixed, the protection scheme for the substation would be completely operational. As there is many aspect in substation design, they would be able to move forward with different designs and studies to further the project. Some of these could be AC/DC studies, a lighting study, bill of materials, conduit plans, and more.

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[4]"IEEE Guide for Protective Relay Applications to Transmission Lines," in IEEE Std C37.113-2015 (Revision of IEEE Std C37.113-1999) , vol., no., pp.1-141, 30 June 2016, doi: 10.1109/IEEESTD.2016.7502047. keywords: {IEEE Standards;Relays;Power transmission lines;AC transmission lines;Mutual coupling;Communication channels;Transmission line protection;distance protection;IEEE C37.113(TM);pilot protection;protective relaying;relay application;relaying;transmission line protection},

APPENDICES

- Bus Configuration Report
- Piloting Scheme Report
- Relay Selection & I/O Report
- General Overview Drawing
- Empathy Map
- Event Analysis Report
- Elevation Drawing
- One-Line Diagram

TEAM

10.1 TEAM MEMBERS

1. Derek Elkins
2. Nathan Tegeler
3. Mackenzie Ray
4. Matthew Wells
5. Patrick Musoy

10.2 REQUIRED SKILL SETS FOR YOUR PROJECT

Much of this project is us researching the different specifications that are required in substation design. With that, there are very little required skill sets for our project. Although there are very few specific requirements, our projects require skill in CAD, PSCAD, and documentation. We will be using CAD and PSCAD for the designs and testing of our substation. Documentation is necessary in explaining why our decisions are the right ones.

10.3 SKILL SETS COVERED BY THE TEAM

For CAD, the skill set will be covered by Derek, Kenzie and Nathan. All three have had past experience with CAD. Derek will be the primary designer in CAD with Kenzie assisting when necessary and Nathan has great experience and is a good resource to reach out to if needed. For PSCAD, this skill set will be covered by Derek, Nathan, and Patrick. They have taken Power Analysis II (EE 457) which required the use of PSCAD in their class. Finally, documentation will be covered by everyone as technical communication is a required course. However, Kenzie and Matthew will be the leaders in documentation.

10.4 PROJECT MANAGEMENT STYLE ADOPTED BY THE TEAM

For this project, we adopted an agile project management style. This project management style focuses on dynamically updating the project plan based on team members and client feedback. We are still unsure of all deliverables we may complete as our client is considering adding more if time allows. Due to this, the agile project management style fits our needs. While following this management style, we have shifted focus from one deliverable to another based on how each was progressing, emphasizing deliverables due during the first semester.

10.5 INITIAL PROJECT MANAGEMENT ROLES

Derek Elkins	Project Lead
Nathan Tegeler	Research & Simulation Lead
Mackenzie Ray	Recorder & Client Correspondent
Matthew Wells	Report Manager
Patrick Musoy	Research & Simulation Lead

10.6 TEAM CONTRACT

10.6.1 TEAM PROCEDURES

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

We will hold weekly meetings on Mondays from 8:30 – 9:30 pm in the TLA in Coover Hall.

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

We will use Discord or Email as our primary form of communication. We will use the "General" section on Discord or Email for essential communication updates. We will make different server names in Discord so communication regarding those specific tasks can occur in those sections. Regarding Scheduling, everyone will be held accountable for remembering scheduled events as we all use different scheduling formats, but Derek will send reminders for meetings with our client. Meetings with our client have been planned via Outlook Calendar.

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

Majority Vote

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

Kenzie will take notes during meetings. We will use a Google Document/Folder to keep the minutes shared/archived.

10.6.2 PARTICIPATION EXPECTATIONS

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

We expected attendance at every team meeting and client meeting. As many people as possible will attend meetings with our advisor, but we understand that some have classes. If you are to be late, send a message in the team Discord. During meetings, everyone can speak their thoughts, no one person should control the meeting's ideas.

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

We are expecting everyone to take responsibility for their roles and tasks. Everyone will update their share of the weekly reports. Everyone must be coming to our team, client, and advisor meetings with their material prepared and updates ready. Each person is responsible for tracking the time spent on tasks (estimation is okay).

10.6.2.3 Expected level of communication with other team members:

Ideally, we expect responses as soon as possible, but we are setting a guideline to respond within a day or two. We are expected to communicate progress in each meeting and challenges we may face.

10.6.2.4 Expected level of commitment to team decisions and tasks:

We expect full commitment to the teams' decisions and tasks. We want each member to commit as much to the project as they would at a full-time job.

10.6.3 LEADERSHIP

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

Derek – Project Lead: Derek will keep track of the project's progress, keep the team on track, and ensure the work's quality is prestige.

Patrick – Research & Simulation Leader- Create research documents based on IEEE standards. Develop simulations in PSCAD.

Nathan – Research & Simulation Leader- Create research documents based on IEEE standards. Develop simulations in PSCAD.

Matthew – Report Manager – Synergize the material from our pilot scheme and IEEE standard research team. Finalize weekly reports.

Mackenzie – Recorder and Client Correspondent – Will keep track of minutes throughout all meetings and will be the main contact between the Client and Advisor.

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

During each meeting, we will check the progress of each deliverable. No one will be working alone on a deliverable, so each person will have at least one other person to lean on for support or guidance. However, everyone is willing to help with a different deliverable if asked. We will communicate with each other if we are struggling with a task. If a deliverable is looking to miss a deadline, that group working on it needs to inform everyone on the team at least 2 weeks before the deadline so we have adequate time to assist.

10.6.3.3 Strategies for recognizing the contributions of all team members:

In our weekly report, we will indicate what each member contributed to and the amount of time for that week. We will create a shared folder to view each other's progress and keep track of an individual's work.

10.6.4 COLLABORATION AND INCLUSION

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

Derek: I have taken Energy Systems and Power Electronics (EE 303), Power System Analysis 1 (EE 456), and I am currently enrolled in Analysis of Energy Systems (EE 351), Introduction to Energy Distribution Systems (EE 455), and Power System Analysis 2 (EE 457). I had an internship with Burns and McDonnell previously, so I have some knowledge regarding substations. I was tasked with completing field lighting designs, wiring diagrams, and voltage drop calculations for multiple substations. I completed and reviewed documents like the Bill of Materials, Issue for Construction, and Issue for Record. I also found power consumptions for equipment and completed AC load calculations. However, I do not know how much will transfer over to this project.

Patrick: I took Energy Systems and Power Electronics (EE 303), Power System Analysis I (EE 456), and I am currently taking Power System Analysis II (EE 457). Those courses familiarized me to understand the fundamentals of power systems, per unit system, load flow analysis, short circuit analysis, introduction to power system protection, transient stability analysis, dynamic system analysis, advanced load flow analysis, and the understanding of the basics of load flow to the advanced dynamics of transient stability and the integration of modern technologies like renewable energy and energy management systems. Through those courses, I became knowledgeable about PSS/E, Matlab for simulation, and PSCAD simulation.

Nathan: Taken Energy systems and power electronics EE 303, Power systems Analysis 1 EE 456, I am taking Power Systems Analysis 2 EE457 and Energy Distribution Systems EE455. These classes will be useful for this project as I learned about 3 phase power flow analysis, PSS/E, MATLAB, and PSCAD. I have interned at the City of Ames power plant. During this job I updated protective relaying drawings in AutoCAD, so I have a general understanding of creating wiring diagrams, schematics, and layouts.

Mackenzie: I took and successfully passed 303. The past two summers, I also had an internships in substation design, although it was focused on protection and controls, it gave me a good understanding of the working parts of a substation. During these internships I also got exposure to AutoCAD and other drafting softwares which will allow me to create the necessary drawings for this project.

Matthew: I took EE 303 Power System Analysis and am currently taking EE 455 Distribution Systems. I'm familiar with the fundamentals of power flow and bus configuration. I also worked in a manufacturing plant where I built and repaired relay systems for automated systems using wiring schematics. I also installed a 3-phase step-up transformer to power large machinery in the plant there.

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

Focus on listening to understand rather than listening to respond. Before moving on during Team Meetings, Derek will ensure everyone is given a chance to speak.

10.6.4.3 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?

If it regards a specific person, talking to them individually before calling them out in the group is the first step. However, at every meeting, we will check in to allow everyone to speak up if they feel they are not doing enough. One can also send a message in Discord. The tracking of time worked per week on our weekly reports will also indicate if someone is working less than the rest of the group.

10.6.5 GOAL-SETTING, PLANNING, AND EXECUTION

10.6.5.1 Team goals for this semester:

- Meet our clients' deliverables.
- Impress the client with our work.
- Finish work in advance if possible
- Learn as much as possible

10.6.5.2 Strategies for planning and assigning individual and teamwork:

When deciding on individual work and teamwork, we will rely primarily on what we want to do. Our client made it clear that he wanted this to be a learning experience and we may add more deliverables on what we personally want to learn. This way, each team member can decide what they want to learn. We will segment the project into individual deliverables and plan according to those.

10.6.5.3 Strategies for keeping on task:

Having time set aside in weekly meetings for task updates will allow the team to understand where we are. It will also indicate if we are not on schedule.

10.6.6 CONSEQUENCES FOR NOT ADHERING TO TEAM CONTRACT

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

Communicate with instructors about the issue. If the issue continues to discredit people from the project and remove them from the team.

10.6.6.2 What will your team do if the infractions continue?

We will talk to both our advisor and 491 professors/TAs'.

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a) I formulated 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) Derek Elkins	DATE 01/29/2024
2) Nathan Tegeler	DATE 01/29/2024
3) Matthew Wells	DATE 01/29/2024
4) Patrick Musoy	DATE 01/29/2024
5) Mackenzie Ray	DATE 01/29/2024