Cyclone Substation Design

DESIGN DOCUMENT

Senior Design Team 04

Client: Burns & McDonnell

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Executive Summary

Development Standards & Practices Used

For this project, several IEEE standards were considered as follows:

- Grounding - IEEE Standard 80
- Battery Sizing - IEEE Standards 450,484,485,1187,1188
- Lightning Protection - IEEE Standard 998

The team also implemented formatting standards across all of our produced drawings using industry-standard symbols to represent the equipment in the substation.

Summary of Requirements

The following indicates the requirements for the project as specified by Burns & McDonnell:

- 69 kV line entrance from Cyclone Generation facility in Ames, IA is to be increased in voltage and serve a 138 kV line to Cedar Falls, IA, and a 138 kV line to Des Moines, IA
- The substation is to include the following equipment at a minimum:
  - (1) 69 kV to 138 kV power transformer
  - (1) 69 kV breaker
  - (3) 138 kV breakers in ring-bus configuration
  - (3) sets of capacitors coupled voltage transformers
  - (1) station service transformer
  - (1) motor operated air breaker switch
- Lightning, grounding, and AC/DC studies must be performed
- Plans for future expansion to a six-position breaker-and-a-half configuration must be considered

Applicable Courses from Iowa State University Curriculum

- EE 201 Electrical Circuit(I).
- EE230 Electrical Circuit (II).
- EE 303 Power systems.

New Skills/Knowledge acquired that was not taught in courses

- AutoCAD.
- Drawing calculation.

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

1 Introduction

1.1 Acknowledgment

Tom Kelly and Riley O'Donnell, both substation engineers at Burns & McDonnell, provided technical support for this project. The design team appreciates their time and meticulous answers to our questions during the design process. Their assistance made this project possible.

1.2 Problem and Project Statement

The city of Ames, IA needs a new substation to increase the voltage level coming from a newly installed wind power generation facility. The voltage is to be increased from 69 kV to 138 kV to improve the efficiency of long-distance power delivery. Larger voltages reduce transmission line losses via a decrease in line current. The substation will feed two transmission lines: one going to Cedar Falls, IA, and the other going to Des Moines, IA. The primary objective of this project is to produce a set of computer drawings detailing the construction and electrical connections within the substation to meet the needs of the cities using the station. The cities have worked with Burns & McDonnell to contract the work to engineers.

Burns & McDonnell selected the senior design team at Iowa State to complete the substation design. The engineers have been provided with guidelines on the arrangement of the equipment, specifications of protections/controls equipment, and vendor prints detailing major equipment to be used.

To complete the design of the substation, the design team will work in phases to complete the different components of the design and send them to Burns & McDonnell for review. Upon completion of the review by Burns & McDonnell, the engineers will make changes to the design according to received comments. The specific items to go through this process are outlined in § 1.7 of this document. At the completion of the project, the entire set of drawings will be issued for the construction of the substation.

1.3 Operational Environment

The majority of the substation, excluding the protections/ controls equipment, will not be enclosed by any sort of shelter. Thus, the substation will be susceptible to weather, animals, and unwanted intrusion by people. To keep wildlife and unwanted onlookers out of the substation, a fence will be erected enclosing the entirety of the station. Of utmost concern is the impact that a lightning strike could have on the station. As a result, a study will be conducted to determine the location of lightning masts to protect the station from this hazard.

1.4 Requirements

The substation is to include the following equipment at a minimum:

- 69 kV to 138 kV power transformer with current transformers to provide input currents to instrumentation to monitor the system.
- (1) 69 kV breaker with current transformers to provide input currents to instrumentation to monitor the system.
- (3) 138 kV breakers with current transformers to provide input currents to instrumentation to monitor the system.

- (3) sets of capacitor coupled voltage transformers to provide input voltages to instrumentation to monitor the system.
- (1) station service transformer to provide power to lights and the control building within the substation.
- (1) motor operated air breaker switch to disconnect the substation in the event of maintenance or faults

Redundancy in power systems is essential to ensure continuous supply of electricity to customers. As a result, careful consideration is considered when determining the breaker arrangement such that any breaker may be disconnected from the substation and allow it to continue to operate. In the first phase of construction, the 138kV breakers are to be placed in a ring-bus configuration. The ring-bus configuration can be seen in Figure 1:

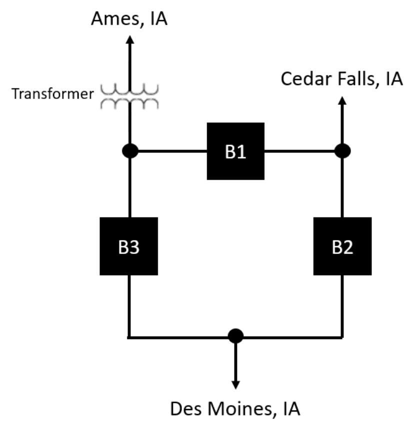


Figure 1 - Ring-Bus Configuration

In the ring-bus configuration, anyone breaker can be disconnected, and the system will still be able to supply the desired voltage level to both outbound lines. The design must also allow for future expansion into a six-position breaker-and-a-half configuration as seen in Figure 2:

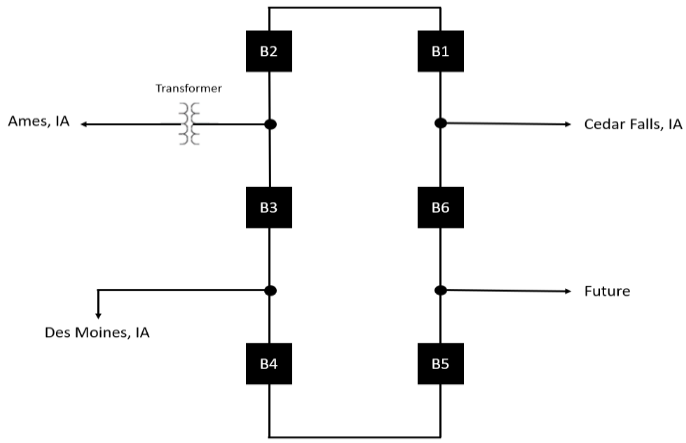


Figure 2 - Six-Position Breaker-and-a-Half Configuration

In the six-position breaker-and-a-half configuration, the convenience of maintenance remains where anyone breaker can be taken out of service without affecting the operation of the substation.

Lightning protection and grounding layout at this site are required and should be planned according to the IEEE standard 998 and 80.

Adequate DC battery supply as well as AC supply at the control house must be determined as per IEEE standards 450, 484, 485, 1187, and 1188.

The last required item of the design is that the protections/ controls equipment is connected as per the ISU Senior Design Protection Requirements_2020-2021 document provided by Burns & McDonnell.

1.5 Intended Users and Uses

The utilities within the three cities will work together to maintain the substation upon construction. Ultimately, the primary users will be the daily consumers of the electricity produced by the wind-generation facility in Ames. The consumers of the electricity will be satisfied if there are no interruptions to their electrical consumption due to the substation's design.

1.6 Assumptions and Limitations

Assumptions

- The transformers and breakers selected by Burns & McDonnell are sufficient for their application.
- The protections/control specifications provided for design use are adequate.
- Future expansion will take place.
- The operating frequency of the power system is 60 Hz.
- The design will be constructed.
- A site can be located to meet the size requirements of the completed design.
- Wiring design will only be completed if time permits.

Limitations

- Breakers must be arranged in a ring-bus configuration with room for future expansion into a six-position breaker-and-a-half arrangement.
- Incoming voltage level is 69 kV.

1.7 Expected End Product and Deliverables

As per the problem statement in § 1.2 of this document the completed design will be an issuance of the following documents for construction. The dates provided herein represent the date the drawings will be sent for review to Burns & McDonnell. Dates have only been determined for work to be completed during the fall semester due to the uncertainty of the spring schedule due to COVID-19 impacts.

- One-Line Diagram (For Review: 10/09/2020)

  The one-line diagram shows the interconnection of the major equipment in the substation as well as the associated protections/controls devices relevant to each piece of equipment. The purpose of this document is to provide an overview of the substation with the abstraction of representing three phases as a single line. This document allows any substation engineer to understand the function of the station and the associated relay at a glance.

- plan-view (For Review: 10/23/2020)

  The plan-view depicts a physical representation of the major equipment inside the substation yard. In addition, the plan-view shows the control building location, fence perimeter, and the associated roadway access to the site. The plan-view is synonymous with the expected satellite view of the substation if it were to be seen via satellite mode in Google Maps.

- Elevation View (For Review: 11/06/2020)

  During the construction of the substation, it is helpful for the field engineers and construction crews to visualize their work. As such, an elevation view is produced, the view depicts section cuts of the plan-view as though a person were standing on the ground looking at the completed structure. The elevation view also calls out a specific bill of material items such that the proper type of bus connectors can be established and used in their appropriate application.

- Foundation Layout (For Review: 11/06/2020)

  After the land has been cleared for the substation to be erected the first task is to pour the appropriate foundations for the various pieces of equipment. The location of these foundations must be clearly specified as to avoid design conflicts. The foundation layout serves to provide this level of clarity by accurately depicting the position and type of foundation to be poured.

- Conduit/ Raceway Plan (For Review: 11/06/2020)

  Connecting the equipment to the control house for monitoring is done through the use of cable trenches and conduits underground. To place these correctly a plan is created showing the proper run of the cable trench and conduits to each piece of equipment.

- Lightning Study (For Review: 11/25/2020)

  As stated in § 1.3 of this report, lightning strikes are of grave concern to the substation designers. Thus, a lightning study is conducted to determine the zones of protection for the station. This study is conducted through the practice of empirical curves in conjunction with the IEEE standard 998. The zones of protection are then indicated on the plan-view created earlier.

- Grounding Plan (For Review: 11/25/2020)

  To protect the equipment, but more importantly people, from the live voltage on the metal casing of the equipment it must all be grounded. Thus, a study will be conducted through the use of the CDEGS (Current Distribution, Electromagnetic interference, Grounding, and Soil structure analysis) software in conjunction with the IEEE standard 80 to study the effective size of the grounding grid required for the station. Once the study has been conducted, a drawing will be created indicating the appropriate grounding for the station.

- AC / DC Study (For Review: TBD)

  Under normal operating conditions, the substation will use AC to provide electricity to relays, lights, equipment heaters, battery chargers, and HVAC systems. The AC study focuses on sizing a breaker cabinet for the station which can handle the load that the substation demands during operation. In the event that the incoming power to the station is lost then batteries are used to provide short-term power to the essential items. The DC study focuses on sizing the battery bank to serve the station long enough to bring it back online. The battery sizing is done through the use of IEEE standards 450, 484, 485, 1187, and 1188.

- Schematic Diagrams (For Review: TBD)

  Drawings are created which are based on the protection specifications which show how the relaying connects to the equipment in the substation. The schematic representation does not show point-to-point wiring, but instead shows the relaying connections in more of a block-diagram manner. Schematics will be created for the transformer, breakers, and line relaying.

- Panel Layouts (For Review: TBD)

  The relaying equipment resides within the control house in housings similar to conventional server racks. The placement of the devices in these racks must be carefully throughout to ensure the easy operation of the equipment by field personnel. Thus, panel layouts are generated which show the physical arrangement of the relays.

- Wiring Diagrams (For Review: TBD)

  To connect the relays to the equipment the schematics are used to generate point-to-point wiring diagrams. These diagrams can be used to have a company wire the relay panels and then allow the field to connect the fully wired panels to the equipment in the substation yard. These diagrams also assist the field personnel in troubleshooting should something go wrong (i.e., a fire in the back of a relaying panel).

2 Project Plan

2.1 Task Decomposition

For specific details on tasks, which are our team's deliverables, see § 1.7. For a rough timeline of when each task is to be completed, see § 2.4.

The first two tasks of the project are the one-line diagram and the plan-view. These drawings are designed by two teams of three simultaneously. The one-line diagram is designing the overall layout of the substation and is due for review two weeks before the plan-view. The plan-view should mimic the one-line layout but depict the physical representation of the major components.

While the plan-view team is completing their design, other team members will work on the elevation view. Once completed with the plan-view, that team will tackle the foundation layout as well as the conduit/raceway plan. Both the elevation view and foundation layout are due two weeks after the plan-view is due. The one-line team will need more time on the elevation view because several section cuts and a bill of materials are required to be completed.

The next steps are the lightning study and grounding plan which are due towards the end of the semester. At this point in the project, the team will decide if they want to reassign teams to get the group exposed to other group members because the team will be working together for a full year. If time permits at the end of the first semester, the team should complete the AC/DC studies.

In the spring semester, the design team will first change the lightning studies and grounding plan based on the feedback provided by Burns and McDonnell and finish up the AC / DC studies to submit for review. The focus of the spring semester is developing schematic and wiring diagrams. These diagrams are required for each major piece of equipment and panel to be installed. Upon completion of the wiring and schematic diagrams the project is ready to be issued for construction.

2.2 Risks And Risk Management/Mitigation

The project is relatively risk-free, as nothing physical will be constructed. Designing and calculating are low risk activities. One aspect that the design team must be careful of is meeting its review deadlines with Burns and McDonnell and making necessary changes to be able to move onto the next task with the correct designs in place. This is something the team should have little trouble with, thus a supposed probability of this occurring is 0.3. One thing the team could do to combat this risk is to task one person to make the changes that Burns & McDonnell comes up with while the rest of the team moves onto the next tasks. All of the deliverables build off the previous one, thus it is important for the proper design to be maintained throughout the entire project. Any changes must be accurately recorded and reflected across the entire design package.

Another possible risk comes from the hand calculations for the lightning protection of the substation. The lightning protection is a critical part of protecting the substation and ensuring continuous power flow. The risk of wrongfully conducting the calculations occurs at a probability of 0.75. A risk mitigation plan for ensuring the calculations are accurate would be to have at least two team members perform the same calculations without influence from one another and confirm the results are identical.

2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

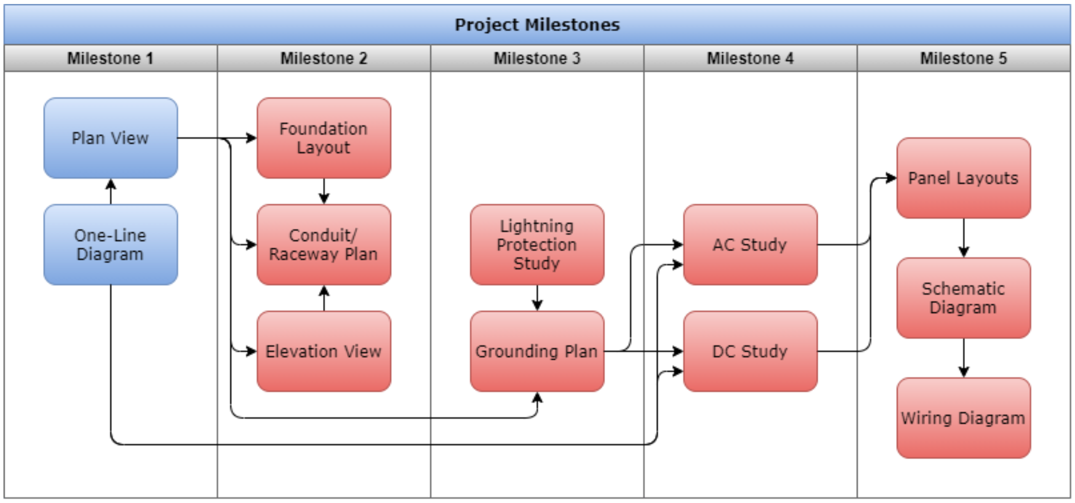


Figure 3 - Project Milestones

Due to the nature of the project the criteria of evaluation shall be determined based on the approval of our client representatives from Burns & McDonnell during weekly meetings

2.4 Project Timeline/Schedule

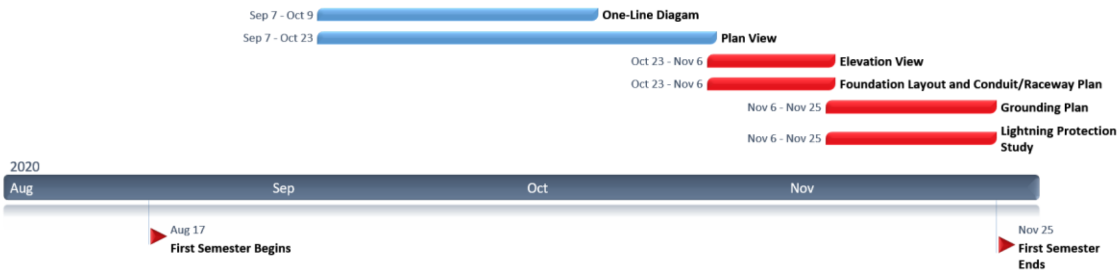


Figure 4 - Semester 1 Gannt Chart

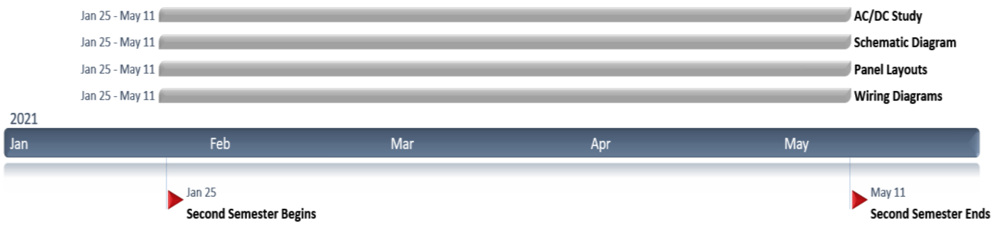


Figure 5 - Semester 2 Gantt Chart (Exact Dates TBD)

2.5 Project Tracking Procedures

To communicate with one another the team members will use Slack. Slack is a convenient way to communicate because specific channels can be created for each part of the project. Communicating in this way allows the team to compartmentalize specific conversations to make communication more streamlined.

To allocate tasks to individuals of the group Trello is being used. Trello allows the group to specify action items to be completed, assign them, and view the progress of each task. Thus, if a task is in the "working" section for a prolonged period of time then the group knows to ask questions to those assigned to that task to see what is holding the task up. Task check-ins are completed during the weekly team meetings.

Google Drive is being used to manage document control. Google Drive offers version control, cloud workspaces, and a direct interface with a computer's file explorer. This tool enables the team to manage many documents all in one place.

2.6 Personnel Effort Requirements

The estimates in Table I are estimates of hours and the number of personnel required to complete each deliverable. The values in this table will likely deviate from the estimation as it is discovered that different parts of the project are more/less complex than anticipated. The two items that will take the longest amount of time are the schematic and wiring diagrams because these diagrams are technical and have a steep learning curve associated with them. At the same time, some drawings are relatively straightforward to create such as the foundation layout. Thus, the total estimated hours for this project are around 510 person-hours not including report creations.

Table 1 - Projected Numbers of Hours for Deliverables

Deliverable	Number of Team Members	Projected Hours
One-Line	3	40
Plan-view	3	40
Elevation View	2	30
Foundation Layout	2	20
Conduit Plan	2	20
Lightning Study	3	40
Grounding Plan	2	40
AC/DC Study	3	40
Schematic Diagram	6	100
Panel Layouts	2	40

Deliverable	Number of Team Members	Projected Hours
Wiring Diagrams	6	100

2.7 Other Resource Requirements

To complete the project the following tools will be used:

- AutoCAD - Student license is free
- CDEGS - Software to be provided by Burns & McDonnell
- Computer access - Each member of the team has their own computer

2.8 Financial Requirements

There are no financial requirements associated with this project.

3 Design

3.1 Previous Work And Literature

Substations are integral in any bulk power distribution system; they are built on either side of transmission lines to reduce power losses from generation to the end user. At the source of generation, a transmission substation is used to increase voltage. At the load end of the transmission line, a distribution substation is employed to reduce the voltage. As of December 31, 2018, there were 9,719 power plants within the United States [1]. It follows that there are tens of thousands of substations within the United States.

Power systems planners, such as local utility companies and independent system operators, determine when a new substation is required. Having substations distributed across the generation and distribution space limits the probability of a large-scale blackout in the event of a catastrophic event such as a lightning strike, storm, or maintenance caused faults. Renewable energy generation is expected to become the largest source of energy by 2045 as can be seen in Figure 6 [2]. Due to the increase in renewable energy generation and other generation resources there will be a need for the construction of more substations.

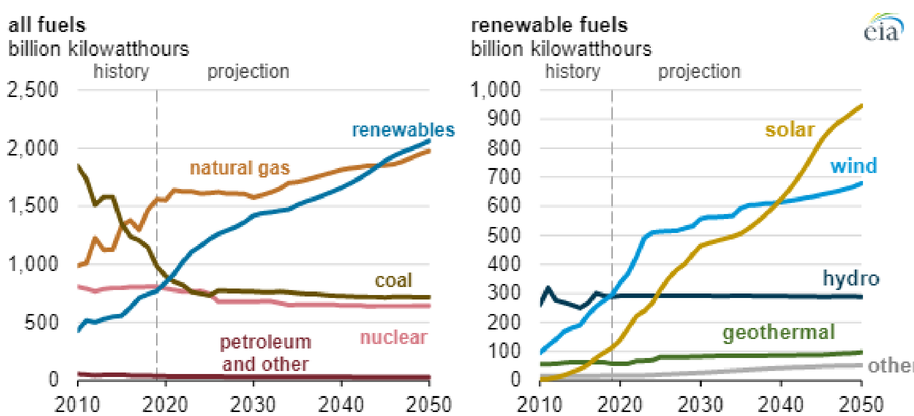


Figure 6 - Projected Energy Growth by 2050

Because substations are integral to efficient power transmission and distribution, they are heavily monitored and protected. The protection of substations is done via protective relaying [3]. The primary goal of protective relaying is to monitor system voltages and currents through the use of voltage and current transformers to detect when values are out of range. Relays use the currents and voltages to trip breakers to protect station equipment which can be costly or difficult to replace due to manufacturing time constraints.

Remote monitoring for a substation is done via a Supervisory Control and Data Acquisition (SCADA) [4] system. Remote monitoring allows system operators to determine what relays have been activated and which breakers are tripped. Monitoring allows for better control and automation of the power system.

Several companies design substations such as Burns & McDonnell, Black & Veatch, Olsson, POWER Engineers, RUE, and many more. However, the work done by these companies is dependent upon client standards. Oftentimes specific client standards enforce uniformity across all stations and are rarely updated and thus do not necessarily involve current industry practices. The work done by the design team aims to incorporate all required IEEE standards as stated in § 1.4 of this report. The uniqueness of the design will result from limited client standards which will allow the team to innovate. Because the design team is working with Burns & McDonnell and not a utility company there exist no strict client standards.

3.2 Design Thinking

During design thinking it is important to have a clearly defined problem statement. The problem statement is typically given by a client through a list of requirements and constraints. But, the problem is better understood upon conversations with the client and understanding the scope of the project.

Problem definition: A new substation needs to be constructed to increase the voltage level coming from the Cyclone Generation facility from 69 kV to 138 kV to reduce transmission losses. Drawings and studies need to be created to aid in the construction of the new substation. The design must incorporate all major equipment and relaying devices as specified in the protections document provided by Burns & McDonnell (see Appendix A). The new substation will benefit the communities around Des Moines and Cedar Falls as the new substation is to have line exits to these two cities. An explanation of the requirements is specified throughout § 1 of this report.

After the problem has been identified, the ideation phase begins. During the ideation phase the team explores different avenues to fulfill the requirements. To date, the team brainstormed about what the physical arrangement of major equipment within the substation will look like. Two possibilities were identified to meet the requirements of the project.

The first design considered allowed for two future line expansions with the following system diagram:

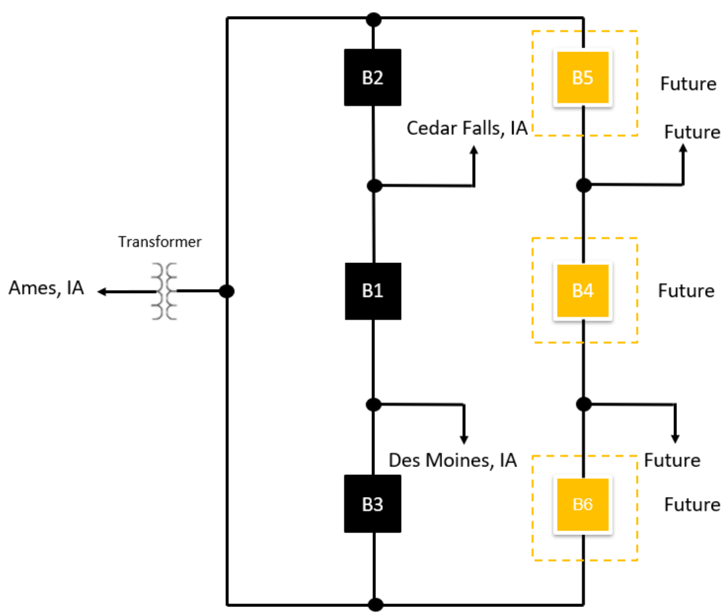


Figure 7 - Considered Design #1

The second design considered allowed for one future line expansion with the following system diagram:

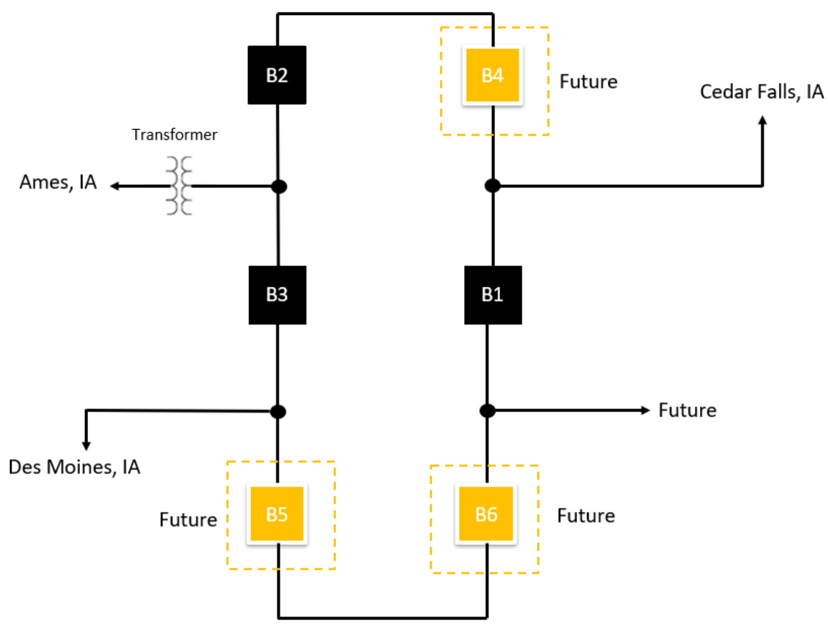


Figure 8 - Design Considered #2

Both designs feature the ability to expand from ring-bus to six-position breaker-and-a-half. The primary difference is the number of future line exits available.

3.3 Proposed Design

Of the two system diagrams proposed in § 3.2 of this report, the design team moved forward with the design which has one possible future line expansion. This design was chosen based on the feedback provided by Burns & McDonnell when the team presented them with the options. The design in Figure 8 fits the design constraints because of its ring-bus configuration. In the event of future construction, the system can be easily modified to become a six-position breaker-and-a-half configuration. The one-line (as seen in appendix B) shows, in more detail, the exact system diagram with all of the other equipment and relaying as specified in § 1.4 and Appendix A of this report.

The proposed design meets the requirements for the project as it fully incorporates all of the major equipment and relaying that the client has specified. The plan-view (as seen in appendix B) has been drafted such that there is ample room for maintenance personnel to drive their bucket and service any part of the facility.

As of now, the team has not incorporated any of the standards into our design as these are more pertinent to specific drawings that will be drafted later in the project. When the grounding study is to be created IEEE standard 80 will be utilized and IEEE standard 998 will help to determine the location of the lightning rods in the station. When the DC study is performed IEEE standards 450, 484, 485, 1187, and 1188 will be enforced. To date, the team has not had to design to any applicable standards other than client specifications of 84-inch phase-to-phase spacing and 50.5-inch phase-to-ground spacing for the conductors. When drafting the plan-view the 84-inch phase-to-phase requirement was enforced.

3.4 Technology Considerations

For this project, the main considerations the team makes are component choices which fulfill requirements set forth by Burns & McDonnell. Some equipment, such as the breakers and transformer are already specified by Burns & McDonnell. The current transformers are directly coupled to the breakers and transformers. Additionally, the specific relays being used are specified by the client in the protection specification (see Appendix A).

The design team has specified the following items: capacitive coupled voltage transformers, bus conductors, wave trap, and a service station voltage transformer.

- Capacitive Coupled Voltage Transformer (CCVT): The voltage transformers reduce the voltages in the substation to a voltage which can be used by the protection relays. The CCVTs are to be rated at 80.5, 500 volts phase-to-neutral. And have secondary voltages of 115/67 volts. The team selected to use Arteche DDB-145 CCVTs as they fit the design requirements. There are several other manufacturers which produce CCVTs, but the documentation for the Arteche model is easily available.
- Bus Conductor: The bus conductor connects the major pieces of equipment in the substation. It is commonplace to use aluminum tubing for bus conductors in a substation. The requirements specify that the bus conductors are rated for 2000 amps of current. The design team selected to use AFL global seamless bus pipe. Specifically, the team opted for the use of 3-inch schedule 80 pipe as it is the lowest diameter which meets design requirements. The other option considered was 4-inch schedule 80. The advantage of the 4-inch pipe is that it would not require as many bus supports as the 3-inch. However, the 4-inch pipe would be more expensive than the 3-inch so it was ultimately decided that the 3-inch would be better.
- Wave Trap: The wave trap decouples communication frequencies from the 60-hertz carrier frequency. The requirements for the project specify that the wave trap is to be tuned to 142.5 kHz and rated for 2000 amp continuous current. The design team opted to use Trench wave traps as they meet the design requirements and documentation is widely available.
- Station Service Voltage Transformer (SSVT): The SSVT transforms voltages from the substation down to typical voltages used in residential buildings (120/240 volts). This voltage is used to supply power to the control building and the substation lights. The voltage is also used in some of the control enclosures for the other equipment in the yard to power heaters. The design team opted to use ABB Kuhlman SSVTs because they are reputable and widely used in industry. There are other SSVTs manufacturers, but the ABB device meets the design requirements for the project.

3.5 Design Analysis

The design proposed in § 3.3 coupled with the selected components in § 3.4 meets all of the requirements set forth by the client. More specifically, the one-line in Appendix B shows how the relaying requirements specified in Appendix A are met. The team continues to evaluate and modify previous documentation, such as the one-line, as the team discovers more details about the project. Once the lightning study is completed more devices will be added to the one-line and plan-view documents. These devices are known as surge arrestors and allow a path for the high-voltage lightning strike to ground and not to the electrical equipment in the station.

The design team is currently awaiting comments on the one-line diagram from Burns & McDonnell to determine what other possible changes will need to be made to the system sketch.

3.6 Development Process

For any project it is important to develop a process which sets the pace for how a design will be created. For this project, the design team opted to use the waterfall model. The waterfall development process is linear and in general is depicted as in Figure 9.

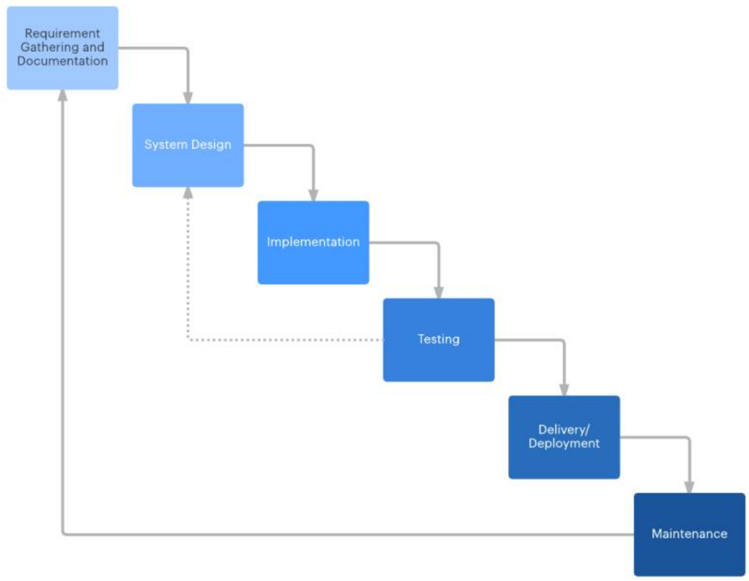


Figure 9 - Waterfall Development Process [5]

It was determined that the waterfall process is best as it enforces that requirements are enforced at the early stages of the design and carried throughout the remainder of the project. Because of all of the interdependence of deliverables this development process also enables the team to work in an efficient and well-defined manner. It is also easy to track progress and plan ahead as the workflow is linear. Furthermore, because the project is well-defined and the requirements are relatively strict, this method works better than the agile development process for this project.

3.7 Design Plan

During the design phase of the project the team reflects back on the use cases and the requirements specified for the project because the substation will need to be maintained. It is important to design the substation such that maintenance can be performed easily. Furthermore, the substation needs to be designed such that minimal service interruptions occur due to the expectations of the customers benefiting from this substation.

Figure 10 is a flowchart showing how the design of the substation is split up. Upon completion of each major drawing/study, the team ensures that the project fulfills the use cases and the requirements of the project. In Figure 10, the peach and green colored blocks represent the different design periods for the deliverables and are also points in which the deliverables are evaluated against the use cases and requirements. As a last step, the entire package will be examined to ensure that the design lives up to the use cases and the client requirements. This being said, the client requirements are viewed as the minimal expectation. The design team's goal is to innovate beyond the requirements ensuring that the client is satisfied, but that new and creative designs are being generated.

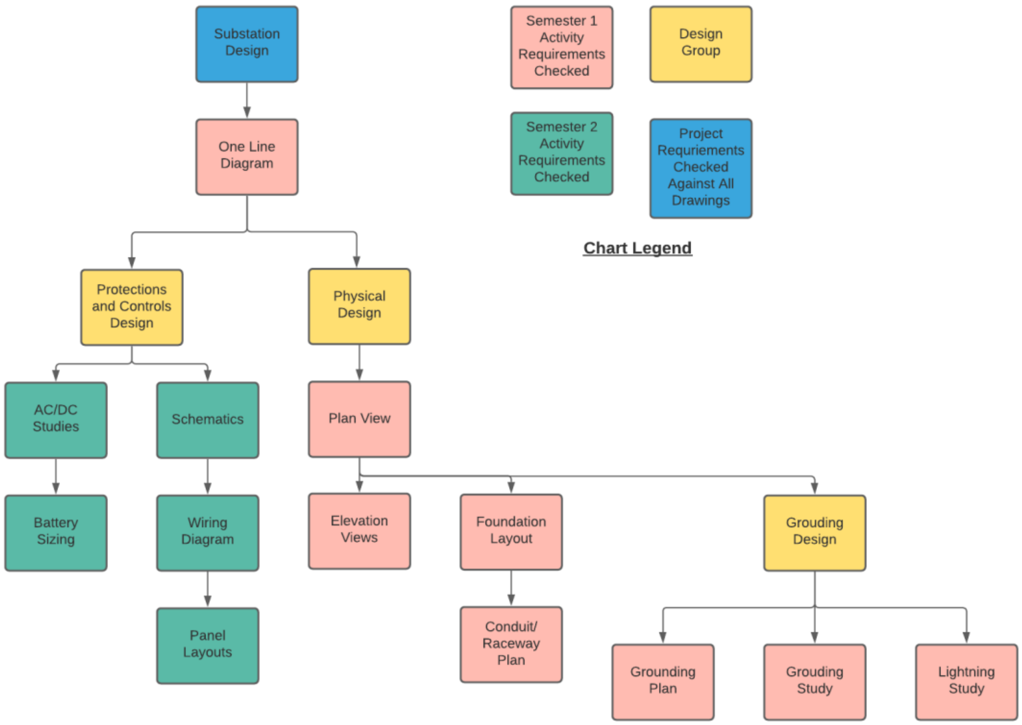


Figure 10 - Modules of Design Showing Interfaces

4 Testing

4.1 Unit Testing

This project does not require the testing of any hardware/software, instead the electrical components are connected to one another via drawings in AutoCAD. The AutoCAD drawings such as the one-line and plan-view connect multiple different electrical elements together. For each drawing being generated, the system sketch is referred to as a way to ensure that the components are connected correctly.

During the QA/QC process each drawing is checked over itself to ensure that the entire drawing is correct. A QA/QC review is done for each document separately from the other documents. The unit testing phase ensures that the drawing is technically correct with respect to the information on that drawing.

4.2 Interface Testing

Each drawing in this process depends on and calls on other drawings. Thus, the interface testing is also checked during the QA/QC process. For example, the one-line diagram acts as a detailed system sketch showing the configuration of the electrical components within the substation. Thus, when the plan-view is analyzed it is checked in isolation first (unit testing as discussed in § 4.1) then it is compared against the one-line to make sure that the two drawings make logical sense and are accurate. Each deliverable goes through interface testing with the deliverables issued before it. See § 1.7 for a list of deliverables in sequential order. § 3.7 also provides a logical flow chart of the deliverables showing their interdependence. As the design progresses, these checks will continue until the entire substation package is checked. When the whole package is complete, it will be confirmed that all drawings make logical connections to others and are technically accurate.

4.3 Acceptance Testing

Due to the nature of this project, the acceptance testing will result in reviewing the produced drawings and comparing them to related standards and specific requirements. The team has a plan in place to review each document individually and compare it to standards. The QA/QC will be done at least once by the creators of the document after it is completed, and then again by the team members who were not working on the related document. Checking for quality assures that the team will be successful in meeting the design requirements. The client, Burns and McDonnell, will then review the deliverable provided by the team to check for accuracy and application of the necessary standards/requirements.

4.4 Results

While checking the documentation through the testing procedures in § 4.1 -4.3, the team has discovered a few errors that were corrected through the testing process. Once errors are identified they are immediately corrected and the entire document is again reviewed to ensure that no more errors were created in updating the drawing.

- One-Line Diagram: Once the one-line diagram was completed, it entered the testing phase. The team found that some of the information given to us by the client was different throughout the protection specification. This caused some confusion as part of the one-line was created using the information in one place and the other was created using information from another place. After discovering this error, the team met with the client and was able to clear up the confusion by determining which information was correct. The client is currently participating in acceptance testing for this drawing.

- Plan-View: The plan-view went through various reviews once it was completed. Unit testing was completed by the plan-view sub-team. In this review, the basic layout was reviewed for errors and it was found that the design did not meet the bus support length requirements on a few bus sections. The team was able to fix this issue by adding four bus supports on the longer bus sections. Interface testing was conducted with the whole design team. In this review, it was found that the team needed to fix the labels on a few pieces of equipment as they were inaccurately labeled compared to the information on the one-line diagram. There have been other small changes corrected throughout the review process such as changing font sizes and capitalization to maintain consistent formatting practices.

5 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3.

6 Closing Material

6.1 Conclusion

Summarize the work you have done so far. Briefly re-iterate your goals. Then, re-iterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

6.2 References

[1] U.S. Energy Information Administration. "How many power plants are there in the United States?" U.S. Energy Information Administration Frequently Asked Questions (FAQs). https://www.eia.gov/tools/faqs/faq.php?id=65&t=3 (accessed Oct. 17, 2020).

[2] U.S. Energy Information Administration. "EIA expects U.S. electricity generation from renewables to soon surpass nuclear and coal." U.S. Energy Information Administration Today in Energy.https://www.eia.gov/todayinenergy/detail.php?id=42655#:~:text=In%20the%20latest%20long%2Dterm,surpass%20natural%20gas%20in%202045 (accessed Oct. 17, 2020).

[3] S. R. Chano et al., "Ancillary Protective and Control Functions Common to Multiple Protective Relays," *2011 64th Annual Conference for Protective Relay Engineers*, College Station, TX, 2011, pp. 396-482, doi: 10.1109/CPRE.2011.6035640.

[4] P. Rajagopal and S. Sayapogu, "Effective utilization of SCADA for substation protection and control applications," *13th International Conference on Development in Power System Protection 2016 (DPSP)*, Edinburgh, 2016, pp. 1-5, doi: 10.1049/cp.2016.0120.

[5] Lucidchart Content Team. "What the Waterfall Project Management Methodology Can (and Can't) Do for You." Complete Guide to Waterfall Project Management Methodology. https://www.lucidchart.com/blog/waterfall-project-management-methodology (accessed Oct. 24, 2020).

6.3 Appendices

Appendix A - Protection specifications as provided by Burns & McDonnell

Appendix B - Drawings created

Appendix A

Protection specifications as provided by Burns & McDonnell

Relay Specification

Project ID:	**Iowa State EE Senior Design Project**
Description:	**Substation Design**
Author:	**Tom Kelly & Riley O'Donnell**
Revision Date:	**7/21/2020**

PROJECT SCOPE

The new Cyclone Substation will be a 138kV three breaker ring bus with a 138/69kV transformer (XFMR1) and a single 69kV line exit with a breaker. The station should be physically designed for the future expansion to a breaker-and-a-half arrangement.

Primary (DCB over Power Line Carrier) line protection for the 138kV Des Moines line exit will use a SEL-321 relay. Backup line protection for both the line exits will use a SEL-311B relay.

Primary and Backup line protection for the 69kV Cedar Falls line exit will be SEL-311L relays. Fiber optic cable will be used for relay communication between substations for both primary and backup relays.

SEL-352 relays shall be used for breaker failure protection on the 138kV ring bus breakers as well as the 69kV exit breaker. Separate primary and backup DC protection paths should be used to for all 138kV breakers and all protection schemes.

MAJOR EQUIPMENT

1. Install three (3) 138 kV circuit breakers (B1, B2 & B3), to be used for the transformer high-side.
   - The standard short circuit rating is sufficient.
   - Four (4) sets of 1200/5 ampere, MR, C800 accuracy class, rf=2.5 CT's per breaker (two (2) CT's per bushing)

2. Install one (1) 69 kV circuit breaker (B4), to be used for the transformer low-side.
   - The standard short circuit rating is sufficient.
   - Four (4) sets of 1200/5 ampere, MR, C800 accuracy class, rf=2.5 CT's per breaker (two (2) CT's per bushing)

3. Install three (3) Coupling Capacitor Voltage Transformers (CCVT's) (one per phase) on all three of the ring bus exits.
   - CCVT's to be rated 80.5,500V phase-to-neutral on the primary.
   - CCVT's to have two (2) secondary windings rated at 115/67V.

4. Station surge arrester specification to be determined by substation engineer.

5. All substation equipment and bus should be rated for at least 2000A. All line conductor and equipment should be rated for at least 750A.

6. Install one (1) station service transformer on the 138 kV bus side of the 138/69kV transformer MOAB to provide AC station service and relaying potentials.
   - 40250 – 120/240V, 100 kVA.

7. New 3-phase 140-72-13.2 Kv, 100/134 MVA OA/FOA power transformer with Z1 = 5.6% on 100 MVA base.
   - Complete with the following CTs.
     a. 2 sets of 138 kV CTs, — 1200:5 A MR, C800 @ 1200:5A
     b. 2 sets of 69 kV CTs — 2000:5 A MR, C800 @ 2000:5A
     c. 1– 13.2 kV CT — 1200:5 A MR, C400 @ 1200:5A
     d. All CTs shall have a thermal factor equal to 2.0

8. Install one (1) 138kV motor operated air break switch (A1).

RELAY SPECIFICATIONS

SCADA (control, indication and metering) will be required for the new equipment. This will include SCADA control (trip and close) of all circuit breakers, breaker status (52a) indication as well as additional SCADA indication and metering as indicated in the following:

138 kV Breaker B1 (Des Moines/Cedar Falls) Breaker Failure-to-Trip Relay

1- Schweitzer SEL-035210325HXX4XX, (BFR/B1) Breaker Failure relay, suitable for use at 125V DC. To be used for 138 kV Breaker B1 failure-to-trip protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 138 kV Bkr B1, Des Moines Line side, top CT (Backup line Relay CT), 1200/5 (240/1)
PT – Wire the potential circuit of the SEL-352 relay to both 138 kV Des Moines line and Cedar Falls line CCVT Y-Windings, 1200/1

Input Contact Assignments:
IN101 – Bkr GCB1 Breaker Failure Initiate
IN102 – Bkr B1 Status – 52/a contact
IN103 – spare
IN104 – spare
IN105 – spare

Output Contact Assignments:
OUT101 – Trip 138kV Bkr B1 86BFT aux relay
OUT102 – Re-trip Bkr B1
OUT103 – Enable Bkr B1 Close (Sync Check)
OUT104 – Init Send TT (Des Moines Line)
OUT105 – Init Send TT (Cedar Falls Line)
OUT106 – spare
OUT107 – spare

Electroswitch series 24 switch to be used as a Failure to Trip cutoff switch (FT/CO). This switch shall be utilized to disable the Failure to Trip relaying for testing and maintenance. Escutcheon to read "ON" and "OFF" with the "ON" position to be in the twelve o'clock position.

Electroswitch series 24 Lock-Out Relay (86BF/B1)
Contacts to be utilized as follows:

- Trip Bkr B2 and Block Close
- Trip Bkr B3 and Block Close
- Block Close Bkr B1
- Send DTT to Des Moines via primary SEL311L
- Send DTT to Des Moines via backup SEL311L
- Stop Carrier on Cedar Falls Line
- SCADA Indication (closed in "OFF" position)

138 kV Breaker B1 (Cedar Falls/Des Moines) Automatic Reclosing Relay

1- Schweitzer SEL-0351A00H23554X, (79/B1) Breaker Auto-reclosing relay, suitable for use at 125V DC. To be used for 138 kV Breaker B1 Automatic Reclosing.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.
3. Install two automatic reclose cut-off switches which shall provide inputs into the SEL-351A, one each for the Des Moines and Cedar Falls exit.

PT – Wire the potential circuit of the SEL-351A relay to both 138 kV Des Moines line and Cedar Falls line CCVT Y-Windings, 1200/1

Output Contact Assignments:

OUT101 – Close Bkr B1 (Automatic reclose)
OUT102 – spare
OUT103 – spare
OUT104 – spare
OUT105 – Relay Alarm
OUT106 – LOP Alarm
OUT107 – spare

Input Contact Assignments:

IN101 – Bkr B1 Status
IN102 – Cedar Falls Auto-Reclose Initiate
IN103 – Des Moines Auto-Reclose Initiate
IN104 – Cedar Falls Auto-Reclose Cut-Off Switch
IN105 – Des Moines Auto-Reclose Cut-Off Switch
IN106 – spare

138 kV Breaker B2 (Cedar Falls/XFMR1) Breaker Failure-to-Trip Relay

1- Schweitzer SEL-035210325HXX4XX, (BFR/B2) Breaker Failure relay, suitable for use at 125V DC. To be used for 138 kV Breaker B2 failure-to-trip protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 138 kV Bkr B2, XFMR1 side, top CT (Backup line Relay CT), 1200/5 (240/1)
PT – Wire the potential circuit of the SEL-352 relay to the 138 kV Cedar Falls line CCVT Y-Winding, 1200/1

Output Contact Assignments:
OUT101 – Trip 138kV Bkr B2 86BFT aux relay
OUT102 – Re-trip Bkr B2
OUT103 – Enable Bkr B2 Close (Sync Check)
OUT104 – Init Send TT (Cedar Falls Line)
OUT105 – spare
OUT106 – spare
OUT107 – spare

Input Contact Assignments:
IN101 – Bkr B2 Breaker Failure Initiate
IN102 – Bkr B2 Status – 52/a contact
IN103 – spare
IN104 – spare
IN105 – spare
IN106 – spare

Electroswitch series 24 switch to be used as a Failure to Trip cutoff switch (FT/CO). This switch shall be utilized to disable the Failure to Trip relaying for testing and maintenance. Escutcheon to read "ON" and "OFF" with the "ON" position to be in the twelve o'clock position.

Electroswitch Series 24 Lock-Out Relay (86BF/B2)
Contacts to be utilized as follows:

- Trip Bkr B1 and Block Close
- Trip Bkr B3 and Block Close
- Trip Bkr B4 and Block Close
- Block Close Bkr B2
- Stop Carrier on Cedar Falls Line
- SCADA Indication (closed in "OFF" position)

138 kV Breaker B3 (XFMR1/Des Moines) Breaker Failure-to-Trip Relay

1- Schweitzer SEL-035210325HXX4XX, (BFR/B3) Breaker Failure relay, suitable for use at 125V DC. To be used for 138 kV Breaker B3 failure-to-trip protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 138 kV Bkr B3, XFMR1 side, top CT (Backup line Relay CT), 1200/5 (240/1)
PT – Wire the potential circuit of the SEL-352 relay to the 138 kV Des Moines line CCVT Y-Winding, 1200/1

Output Contact Assignments:
OUT101 – Trip 138kV Bkr B3 86BFT aux relay
OUT102 – Re-trip Bkr B3
OUT103 – Enable Bkr B3 Close (Sync Check)
OUT104 – Init Send TT (Des Moines Line)
OUT105 – spare
OUT106 – spare
OUT107 – spare

Input Contact Assignments:
IN101 – Bkr B3 Breaker Failure Initiate
IN102 – Bkr B3 Status – 52/a contact
IN103 – spare
IN104 – spare
IN105 – spare
IN106 – spare

Electroswitch series 24 switch to be used as a Failure to Trip cutoff switch (FT/CO). This switch shall be utilized to disable the Failure to Trip relaying for testing and maintenance. Escutcheon to read "ON" and "OFF" with the "ON" position to be in the twelve o'clock position.

Electroswitch Series 24 Lock-Out Relay (86BF/B3)
Contacts to be utilized as follows:

- Trip Bkr B1 and Block Close
- Trip Bkr B2 and Block Close
- Trip Bkr B4 and Block Close
- Block Close Bkr B3
- Send DTT to Des Moines via primary SEL311L
- Send DTT to Des Moines via backup SEL311L
- SCADA Indication (closed in "OFF" position)

Project ID:	**Iowa State EE Senior Design Project**
Description:	**Substation Design**
Author:	**Tom Kelly & Riley O'Donnell**
Revision Date:	**7/21/2020**

138 kV Cedar Falls Line Exit

1- Schweitzer SEL-32111-4256-HNB3X4, (PR/C) phase distance relay and ground directional overcurrent relay with fault locator and fast meter communications. New to be used to provide phase and ground protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 138 kV Bkr B1 Des Moines line-side, bottom CT, 1200/5 (240/1)
CT – 138 kV Bkr B2, XFMR1-side, bottom CT, 1200/5 (240/1)
PT – Wire the potential circuit of the SEL-321 relay to the 138 kV Cedar Falls line CCVT X-Winding, 1200/1

Output Contact Assignments:
OUT1 – Trip 138kV Bkr B1
OUT2 – Trip 138kV Bkr B2
OUT3 – Initiate Breaker Failure on 138kV Bkr B1
OUT4 – Initiate Breaker Failure on 138kV Bkr B2
OUT5 – Initiate Auto-Reclose of Bkr B1 (SEL-351A Relay)
OUT6 – Start Carrier (Cedar Falls Line)
OUT7 – Stop Carrier (Cedar Falls Line)
OUT8 – spare
OUT9 – spare
OUT10 – spare
OUT11 – Loss of Potential Alarm
Alarm – SCADA Relay Failure

Input Contact Assignments:
IN1 – 138 kV Bkr B1 status (52a)
IN2 – 138 kV Bkr B2 status (52a)
IN3 – DCB Carrier Receiver Output in parallel with the Primary DCB Cutoff Switch
IN4 – 138kV Breaker Failure to Trip (Send TT)
IN5 – spare
IN6 – spare
IN7 – spare
IN8 – spare

1- Schweitzer SEL-311B-00H24254XX, (BU/C) phase distance relay and ground directional overcurrent relay. New to be used to provide one set of phase and ground protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 138 kV Bkr B1, Des Moines line-side, top CT, 1200/5 (240/1)
CT – 138 kV Bkr B2, XFMR1-side, top CT, 1200/5 (240/1)
PT – Wire the potential circuit of the SEL-311B relay to the 138 kV Cedar Falls line CCVT Y-Winding, 1200/1

Output Contact Assignments:
OUT101 – Trip 138kV Bkr B1
OUT102 – Trip 138kV Bkr B2
OUT103 – Initiate Breaker Failure on 138kV breaker B1
OUT104 – Initiate Breaker Failure on 138kV breaker B2
OUT105 – spare
OUT106 – spare
OUT107 – Loss of Potential Alarm
Alarm – SCADA Relay Failure

Input Contact Assignments:
IN101 – 138kV Bkr B1 status (52a)
IN102 – 138kV Bkr B2 status (52a)
IN103 – spare
IN104 – spare
IN105 – spare
IN106 – spare

138 kV Des Moines Line Exit

1- Schweitzer SEL-311L1H-3254-XXXX, (PR/R) current differential relay and phase and ground distance relay and ground directional overcurrent relay. New to be used to provide current differential plus phase and ground primary protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.
3. Connect Des Moines fiber optic channel to the fiber port on the back of the relay.
4. Install a Line Differential Cut-Off Switch for primary line relay which shall provide and input into the SEL-311L.

CT – 138 kV Bkr B1, Cedar Falls line-side, bottom CT, 1200/5 (240/1)
CT – 138 kV Bkr B3, XFMR1-side, bottom CT,1200/5 (240/1)
PT – Wire the potential circuit of the SEL-311L relay to the 138 kV Des Moines line CCVT X-Winding, 1200/1

Output Contact Assignments:
OUT101 – Trip 138kV Bkr B1
OUT102 – Trip 138kV Bkr B3
OUT103 – Initiate Breaker Failure on 138kV breaker B1
OUT104 – Initiate Breaker Failure on 138kV breaker B3
OUT105 – spare
OUT106 – spare
OUT107 – spare
Alarm – SCADA Relay Failure
OUT201 – Loss of Potential Alarm
OUT202 – Channel Alarm
OUT203 – spare
OUT204 – spare
OUT205 – spare
OUT206 – spare

Input Contact Assignments:
IN101 – 138kV Bkr B1 status (52a)
IN102 – 138kV Bkr B3 status (52a)
IN103 – 138kV Breaker Failure to Trip Operation (Send TT)
IN104 – spare
IN105 – Line Differential Cut-Off Switch
IN106 – spare
IN201 – spare
IN202 – spare
IN203 – spare
IN204 – spare
IN205 – spare
IN206 – spare
IN207 – spare
IN208 – spare

1- Schweitzer SEL-32111-4256-HNB3X4, (BU/R) phase distance relay and ground directional overcurrent relay with fault locator and fast meter communications. New to be used to provide phase and ground protection.

1. Access to back of Schweitzer relays is required for PC connection.
2. Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 138 kV Bkr B1, Cedar Falls line-side, top CT, 1200/5 (240/1)
CT – 138 kV Bkr B3, XFMR1-side, top CT, 1200/5 (240/1)
PT – Wire the potential circuit of the SEL-311L relay to the 138 kV Des Moines line CCVT Y-Winding, 1200/1

Output Contact Assignments:
OUT1 – Trip 138kV Bkr B1
OUT2 – Trip 138kV Bkr B3
OUT3 – Initiate Breaker Failure on 138kV Bkr B1
OUT4 – Initiate Breaker Failure on 138kV Bkr B3
OUT5 – Initiate Auto-Reclose of Bkr B1 (SEL-351A Relay)
OUT6 – spare
OUT7 – spare
OUT8 – spare
OUT9 – spare
OUT10 – spare
OUT11 – Loss of Potential Alarm
Alarm – SCADA Relay Failure

Input Contact Assignments:
IN1 – 138 kV Bkr B1 status (52a)
IN2 – 138 kV Bkr B3 status (52a)
IN3 – spare
IN4 – spare
IN5 – spare
IN6 – spare
IN7 – spare
IN8 – spare

138/69kV Transformer (XFMR1) Differential Relaying

1- Schweitzer "SEL-0587103X5X1" (87T/TR1) Current Differential relay to be used as primary transformer low impedance differential protection. Appropriate test switches are required to provide connections for relay testing and isolation.

- Access to back of Schweitzer relays is required for PC connection.
- Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – XFMR1 138kV side, top CT, 1200/5 (240/1) [Input to I_W1]
CT – XFMR1 69kV side, top CT, 1200/5 (240/1) [Input to I_W2]

Output Contact Assignments:
OUT1 – Trip 86T/TR1and 86TX/TR1 Lockout Relays
OUT2 – spare
OUT3 – spare
OUT4 – spare

Input Contact Assignments:
IN1 – 69kV Bkr B4 (52a)
IN2 – SEL387 (87OA/TR1), OUT102

Electroswitch "LOR", (86T/TR1) spring operated, Manual reset, multi-stage auxiliary tripping relay. New, to be used with the above SEL-587 relay for XFMR1 differential relaying.

Output Contact Assignments:
1 – Trip 69kV Bkr B4
2 – Transformer differential relay operation alarm.
3 – De-energize XFMR1 fans
4 – SCADA Indication

Electroswitch "LOR", (86TX/TR1) spring operated, Manual reset, multi-stage auxiliary tripping relay. New, to be used with the above SEL-587 relay for XFMR1 differential relaying.

Output Contact Assignments:
1 – Trip 138kV Bkr B2
2 – Trip 138kV Bkr B3
3 – Initiate Breaker Failure on 138kV breaker B2
4 – Initiate Breaker Failure on 138kV breaker B3
5 – SCADA Indication

Note: LOR 86TX/TR1 is reset by an 89b contact from the high side MOAB (A1). This is to allow the 138kV breaker to be closed after the XFMR MOAB is open.

138/69kV Transformer (XFMR1) 138kV Lead Differential Relaying

1- Schweitzer "SEL-0587Z0X325H12XX" high impedance bus differential relay with high energy (2) clamping MOVs. Horizontal rack mount. New, to be used for XFMR1 138kV bus differential protection.

- Access to back of Schweitzer relays is required for PC connection.
- Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – XFMR1 138kV side, bottom CT, 1200/5 (240/1)
CT – 138 kV Bkr B2, line-side, bottom CT, 1200/5 (240/1)
CT – 138 kV Bkr B3, line-side, bottom CT, 1200/5 (240/1)

Output Contact Assignments:
OUT1 – Trip 86TH/TR1 Lockout Relay
OUT2 – SEL387 (87OA/TR1)
OUT3 – spare
OUT4 – spare
Alarm – SCADA Relay Failure

Input Contact Assignments:
IN1 – spare
IN2 – spare

Electroswitch "LOR", (86TH/TR1) spring operated, Manual reset, multi-stage auxiliary tripping relay. New, to be used with the above SEL-587Z relay for XFMR1 138 kV leads/bus auxiliary.

Output Contact Assignments:
1 – Trip 138kV Bkr B2
2 – Trip 138kV Bkr B3
3 –Trip 69kV Bkr B4
4 – Initiate Breaker Failure on 138kV breaker B2
5 – Initiate Breaker Failure on 138kV breaker B3
6 – Initiate Breaker Failure on 138kV breaker B4
7 – Short 138kV relay phase A CT inputs
8 – Short 138kV relay phase B CT inputs
9 – Short 138kV relay phase C CT inputs
10 – SCADA Indication

138/69kV Transformer (XFMR1) Overall Differential Relaying

1- Schweitzer "SEL-038750-4X5HXX4XX" (87OA/TR1) current differential relay. New, to be used for XFMR1 overall differential protection.

- Access to back of Schweitzer relays is required for PC connection.
- Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.

CT – 69kV Bkr B4, line-side, top CT, 1200/5 (240/1) [Input to I_W1]
CT – 138 kV Bkr B2, line-side, top CT, 1200/5 (240/1) [Input to I_W2]
CT – 138 kV Bkr B3, line-side, top CT, 1200/5 (240/1) [Input to I_W3]

Output Contact Assignments:
OUT101 – Trip 86OA/TR1 & 86OAX/TR1 Lockout Relays
OUT102 – SEL587 (87T/TR1), IN2
OUT103 – spare
OUT104 – spare
OUT105 – spare
OUT106 – spare
Alarm – SCADA Relay Failure

Input Contact Assignments:
IN101 – 138kV Bkr B2 (52a)
IN102 – 138kV Bkr B3 (52a)
IN103 – 69kV Bkr B4 (52a)
IN104 – SEL587 (87T/TR1). OUT 2
IN105 – spare
IN106 – spare

Electroswitch "LOR", (86OA/TR1) spring operated, Manual reset, multi-stage auxiliary tripping relay. New, to be used with the above SEL-587 relay for XFMR1 differential relaying.

Output Contact Assignments:
1 – Trip 69kV Bkr B4
2 – Transformer differential relay operation alarm.
3 – SCADA Indication

Electroswitch "LOR", (86OAX/TR1) spring operated, Manual reset, multi-stage auxiliary tripping relay. New, to be used with the above SEL-587 relay for XFMR1 differential relaying.

Output Contact Assignments:
1 – Trip 138kV Bkr B2
2 – Trip 138kV Bkr B3
3 – Initiate Breaker Failure on 138kV breaker B2
4 – Initiate Breaker Failure on 138kV breaker B3
5 – SCADA Indication

Note: LOR 86TX/TR1 is reset by a 89b contact from the high side MOAB (A1). This is to allow the 138kV breaker to be closed after the TR MOAB is open.

138/69kV Transformer (XFMR1) Ground Overcurrent Protection

1- Schweitzer "SEL-055100-3X5X1X," overcurrent relay, with metering, suitable for use at 125V DC. New, to be used for XFMR1 tertiary ground protection. 5A Phase input, 5A neutral.

- Access to back of Schweitzer relays is required for PC connection.
- Appropriate test/disconnect switches are required to provide connections for relay testing and isolation.
- Series the Phase A and IN CT circuits.

CT – XFMR1 tertiary CT, 800/5 (30/1)

Output Contact Assignments:
OUT1 – Trip 94G/TR1 Aux Tripping Relay
OUT2 – spare
OUT3 – spare
OUT4 – spare
Alarm – SCADA Relay Failure

Input Contact Assignments:
IN1 – spare
IN2 – spare

1- ABB "AR" aux tripping relay. New, to be used with the above SEL-551 relay for XFMR1 ground overcurrent.

Output Contact Assignments:
1 – Trip 138kV Bkr B2
2 – Trip 138kV Bkr B3
3 –Trip 69kV Bkr B4
4 – Initiate Breaker Failure on 138kV breaker B2
5 – Initiate Breaker Failure on 138kV breaker B3
6 – Initiate Breaker Failure on 138kV breaker B4
7 – SCADA Indication

138 kV Cedar Falls Line Exit Communications Equipment

1 - RFL 9785 65-156 kHz frequency range 10 watt, 1000 Hz bandwidth, carrier relaying transmitter-receiver assembly complete with keying unit, checkback module, and auxiliary power supply at 125V DC. To be tuned to 142.5 kHz. New, to be used for DCB communications on the Cedar Falls 138kV exit.

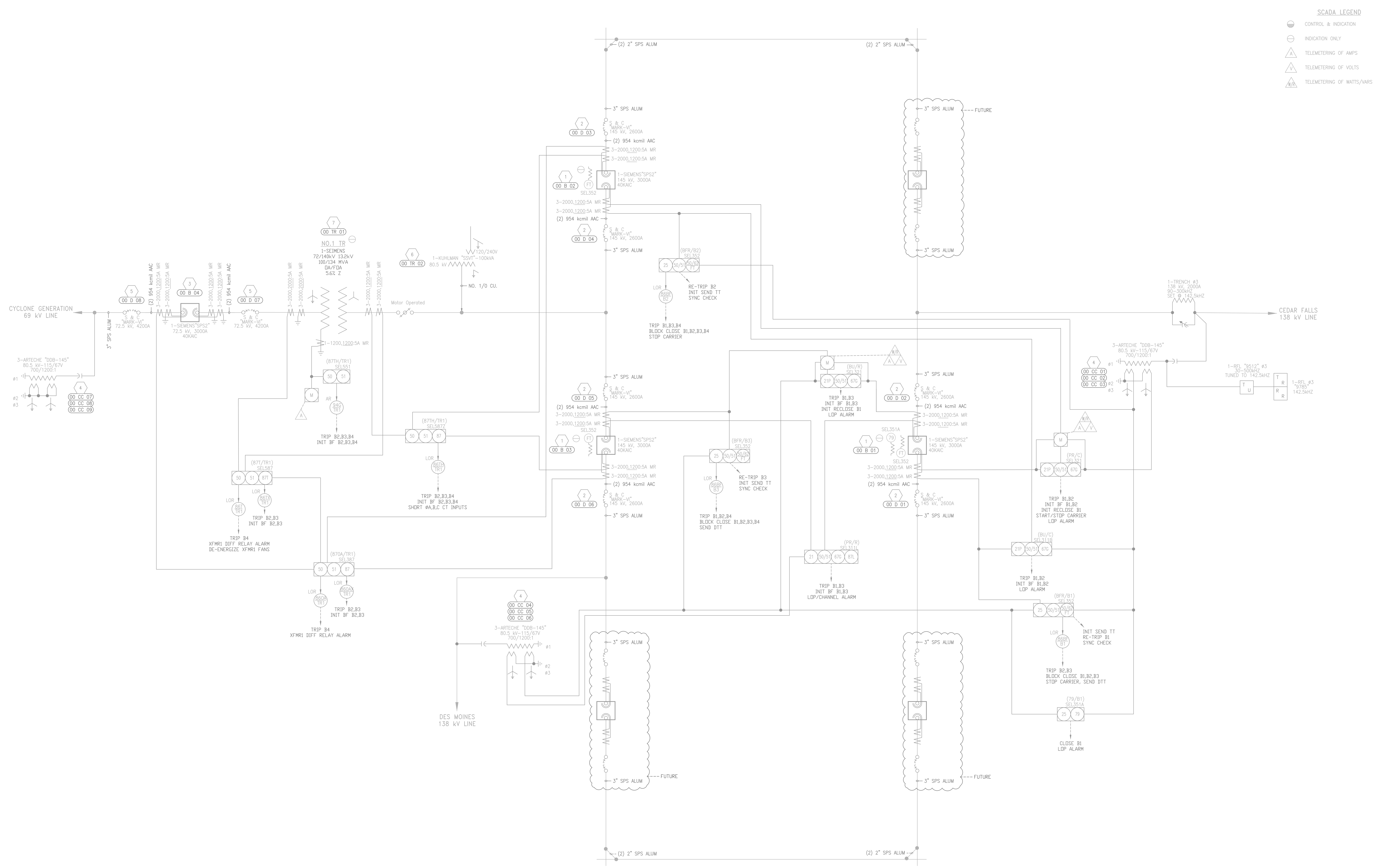
- Monitor the checkback failure alarm by SCADA alarm point.
- Include hardware necessary to capture sequence of events.
- No voice functions necessary.

1 - 138kV Single Frequency Wave Trap for use at 142.5 kHz, minimum 2000A continuous. New, to be used for 138kV Cedar Falls DCB communications on the Cedar Falls circuit exit. Unit shall be coupled to phase 3.

1 - Single Frequency Resonant Line Tuner. New, to be used for 138kV Cedar Falls DCB communication on Cedar Falls circuit exit. Unit shall be tuned to 142.5 kHz and be used with phase 3 wave trap.

Appendix B

Drawings created



FOR REVIEW

NOT FOR CONSTRUCTION

ENG: AA/DS/JM
APP: JDM
DATE: 10/09/20
ISSUE: For Review
DRAWING CREATED BY IOWA STATE SENIOR DESIGN 2020.

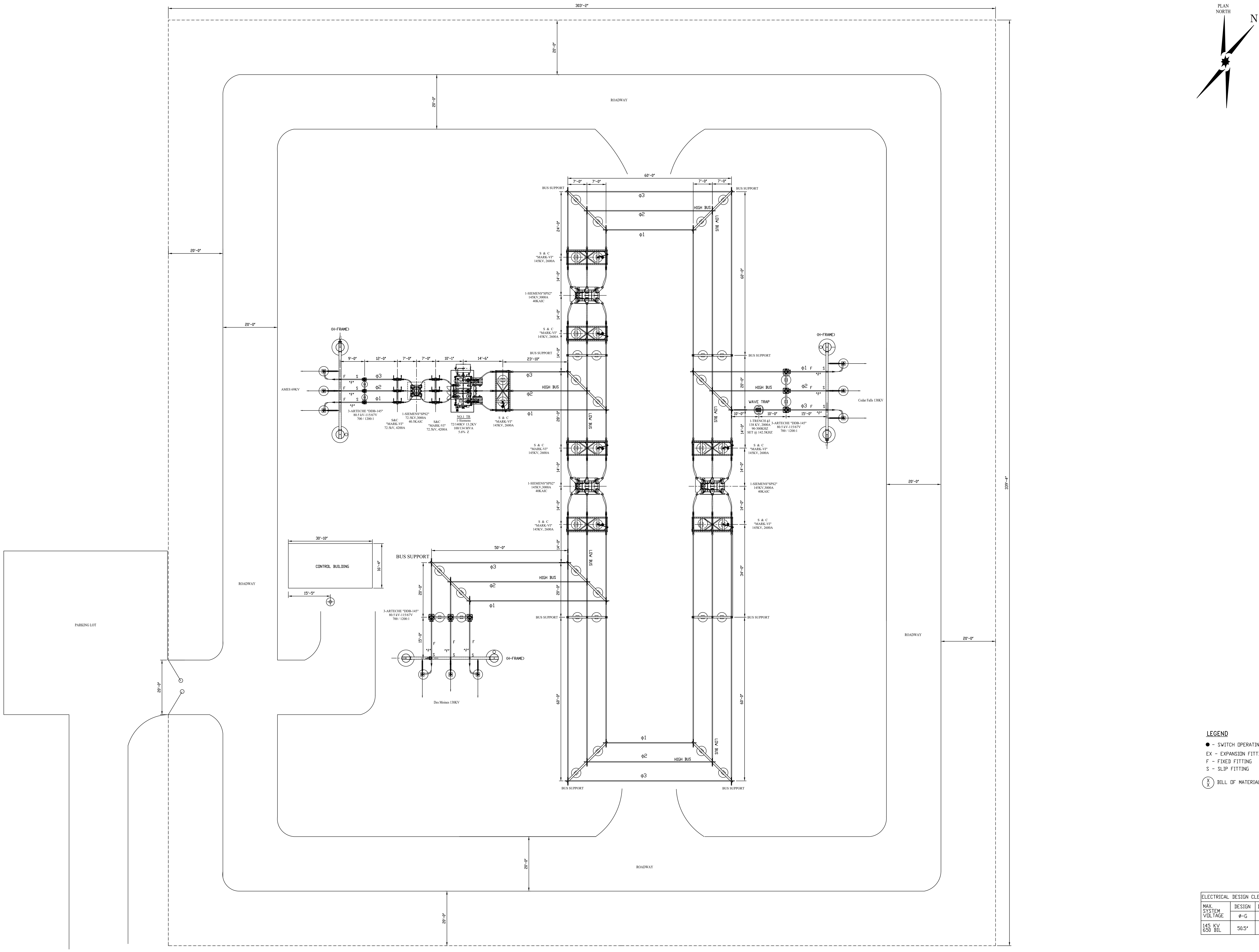
BURNS McDONNELL

CYCLONE

CITY: AMES | STATE: IOWA | ZIP: 50014

ONE-LINE DIAGRAM

ISU-SD-04 | IA-000-02-01 | -



LEGEND

● - SWITCH OPERATING SHAFT LOCATION
EX - EXPANSION FITTING
F - FIXED FITTING
S - SLIP FITTING
(X/X) BILL OF MATERIAL

ELECTRICAL DESIGN CLEARANCES		
MAX. SYSTEM VOLTAGE	DESIGN ϕ-G	DESIGN ϕ-ϕ
145 KV 650 BIL	50.5"	84"

ENG: CC / MH / ZL
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DATE:10/23/20
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PLAN VIEW

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