Cyclone Substation Design

DESIGN DOCUMENT

Senior Design Team 04

Client: Burns & McDonnell

Adviser(s): James McCalley

Team Members/Roles:
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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

We 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. We appreciate 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 capacitors 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 taken into account 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:

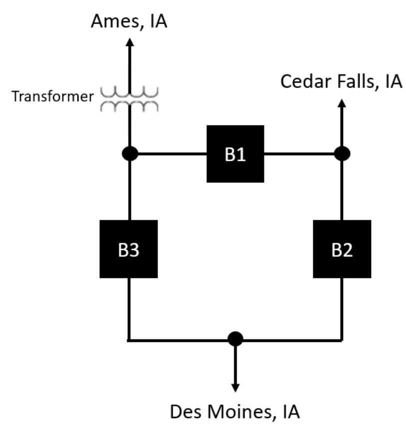

Figure 1 - Ring-Bus Configuration

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:

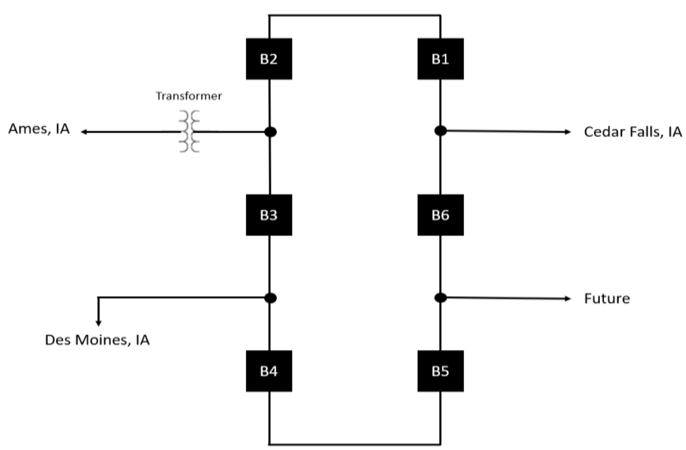

Figure 2 - Six-Position Breaker-and-a-Half Configuration

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, we will decide if we want to reassign teams to get the group exposed to other group members because we 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, we 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 we must be careful of is meeting our 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 we should have little trouble with, thus a supposed probability of this occurring is 0.3. One thing we 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

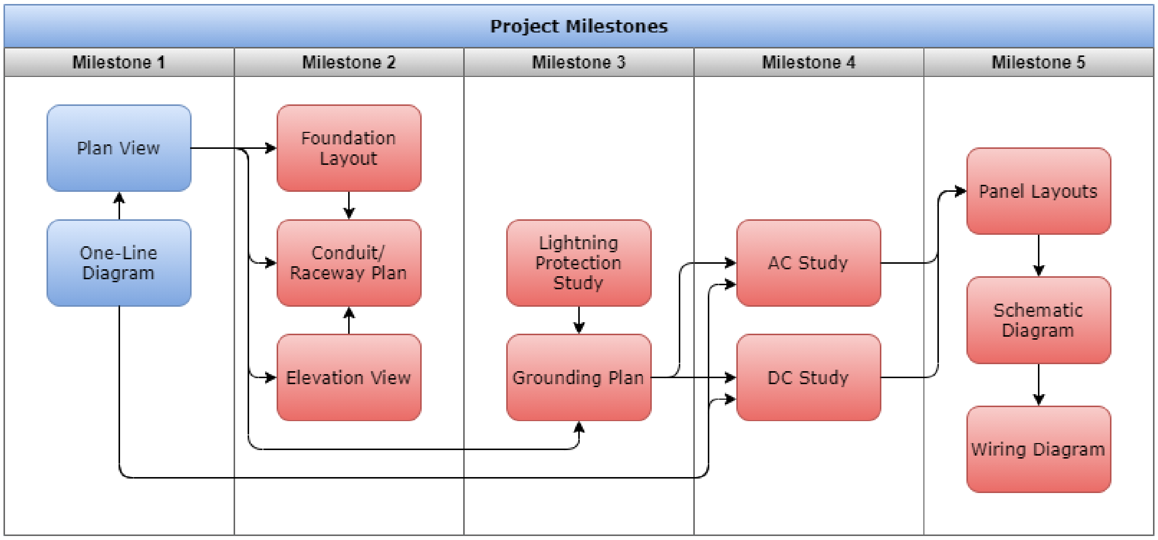

Figure 3 - Project Milestones

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

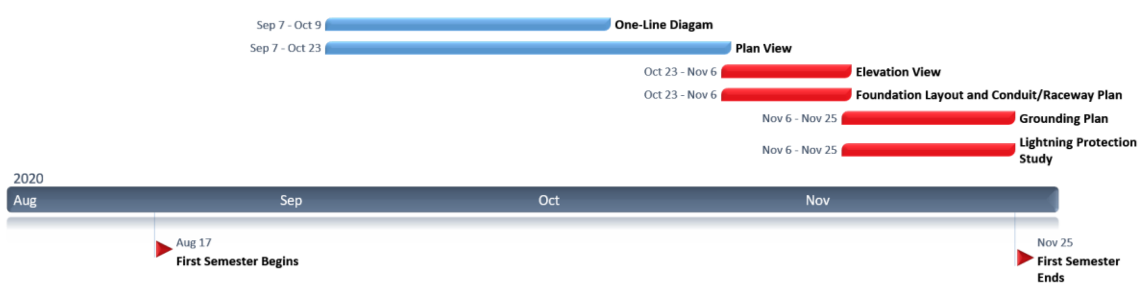

Figure 4 - Semester 1 Gantt Chart

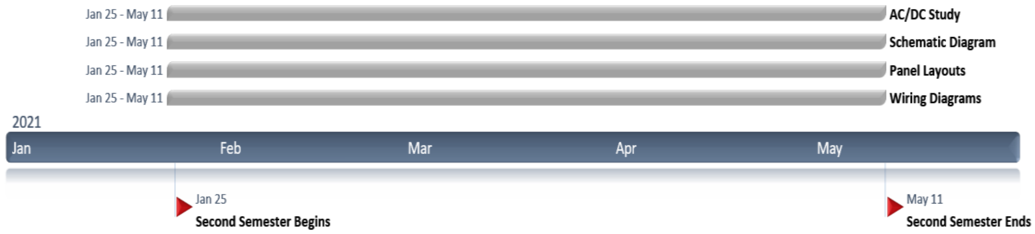

Figure 5 - Semester 2 Gantt Chart (Exact Dates TBD)

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
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

Include relevant background/literature review for the project

– If similar products exist in the market, describe what has already been done

– If you are following previous work, cite that and discuss the **advantages/shortcomings**

– Note that while you are not expected to “compete” with other existing products / research groups, you should be able to differentiate your project from what is available

Detail any similar products or research done on this topic previously. Please cite your sources and include them in your references. All figures must be captioned and referenced in your text.

3.2 Design Thinking

Detail any design thinking driven design “define” aspects that shape your design. Enumerate some of the other design choices that came up in your design thinking “ideate” phase.

3.3 Proposed Design

Include any/all possible methods of approach to solving the problem:

- Discuss what you have done so far – what have you tried/implemented/tested?
- Some discussion of how this design satisfies the **functional and non-functional requirements** of the project.
- If any **standards** are relevant to your project (e.g. IEEE standards, NIST standards) discuss the applicability of those standards here
- This design description should be in **sufficient detail** that another team of engineers can look through it and implement it.

3.4 Technology Considerations

Highlight the strengths, weakness, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

3.5 Design Analysis

– Did your proposed design from 3.3 work? Why or why not?

– What are your observations, thoughts, and ideas to modify or iterate over the design?

3.6 Development Process

Discuss what development process you are following with a rationale for it – Waterfall, TDD, Agile. Note that this is not necessarily only for software projects. Development processes are applicable for all design projects.

3.7 Design Plan

Describe a design plan with respect to use-cases within the context of requirements, modules in your design (dependency/concurrency of modules through a module diagram, interfaces, architectural overview), module constraints tied to requirements.

4 Testing

Testing is an **extremely** important component of most projects, whether it involves a circuit, a process, or software.

1. Define the needed types of tests (unit testing for modules, integrity testing for interfaces, user-study or acceptance testing for functional and non-functional requirements).
2. Define/identify the individual items/units and interfaces to be tested.
3. Define, design, and develop the actual test cases.
4. Determine the anticipated test results for each test case
5. Perform the actual tests.
6. Evaluate the actual test results.
7. Make the necessary changes to the product being tested
8. Perform any necessary retesting
9. Document the entire testing process and its results

Include Functional and Non-Functional Testing, Modeling and Simulations, challenges you have determined.

4.1 Unit Testing

– Discuss any hardware/software units being tested in isolation

4.2 Interface Testing

– Discuss how the composition of two or more units (interfaces) are to be tested. Enumerate all the relevant interfaces in your design.

4.3 Acceptance Testing

How will you demonstrate that the design requirements, both functional and non-functional are being met? How would you involve your client in the acceptance testing?

4.4 Results

– List and explain any and all results obtained so far during the testing phase

- Include failures and successes
- Explain what you learned and how you are planning to change the design iteratively as you progress with your project
- If you are including figures, please include captions and cite it in the text

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

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

6.3 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar data that does not directly pertain to the problem but helps support it, include it here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc,. PCB testing issues etc., Software bugs etc.