

Substation Design

DESIGN DOCUMENT

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Executive Summary

Development Standards & Practices Used

Software practices used in this project include AutoCAD for circuit design. Engineering Standards which apply include IEEE standard AC Substation Grounding, IEEE standard Lead Acid Battery Sizing, and IEEE standard Lightning Protection.

Summary of Requirements

- three 138kV gas circuit breakers
- one 69/138kV transformer
- two 138kV line positions
- one 69kV line position
- one 69kV gas circuit breaker
- 138kV yard will be energized in a ring bus configuration with plans for future expansion into a six-position breaker-and-a-half configuration

Applicable Courses from Iowa State University Curriculum

EE 201, EE 230, EE 303, EE 456

New Skills/Knowledge acquired that was not taught in courses

AutoCAD Circuit Design, Large Scale Power System Drawings and Design, Professional Documentation

Table of Contents

1 Introduction	4
Acknowledgment	4
Problem and Project Statement	4
Operational Environment	4
Requirements	4
Intended Users and Uses	5
Assumptions and Limitations	5
Expected End Product and Deliverables	5
2. Specifications and Analysis	6
Proposed Design	6
Design Analysis	7
Design Plan	7
3. Statement of Work	7
3.1 Previous Work And Literature	7
3.2 Technology Considerations	8
3.3 Task Decomposition	8
3.4 Possible Risks And Risk Management	8
3.5 Project Proposed Milestones and Evaluation Criteria	9
3.6 Project Tracking Procedures	9
3.7 Expected Results and Validation	9
4. Project Timeline, Estimated Resources, and Challenges	10
4.1 Project Timeline	10
4.2 Feasibility Assessment	10
4.3 Personnel Effort Requirements	11
4.4 Other Resource Requirements	11
4.5 Financial Requirements	11
5. Testing and Implementation	11

Interface Specifications	11
Hardware and software	12
Functional Testing	12
Non-Functional Testing	12
Process	12
Results	13
6. Closing Material	13
6.1 Conclusion	13
6.2 References	14
6.3 Appendices	14

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

1 Introduction

1.1 ACKNOWLEDGMENT

We would like to acknowledge and thank Burns & McDonnell for their assistance in our project, technical advice, and project documentation.

1.2 PROBLEM AND PROJECT STATEMENT

-General problem statement – The city of Ames, Iowa requires a new 69/138 kV substation to be designed, and later constructed by Burns & McDonnell. It will serve as an interconnection for a new renewable wind generation farm being built outside the city. The substation must be economically viable and laid out in a way as to allow for future expansions of equipment and relaying.

-General solution approach – Burns & McDonnell has provided our senior design team with scope documents that comprehensively cover all relaying and equipment specifications. With these specifications, we are required to complete the design phase of this substation. In order to complete the design of the substation, we must design the following: one-line diagram, physical plan of the substation, schematics and wiring diagrams. In conjunction with this, we must complete the following studies: AC/DC study, and Lightning study. Once all of the previous steps have been completed we will have a design package that will be ready to be issued for construction.

1.3 OPERATIONAL ENVIRONMENT

The Cyclone Substation will be an open-air environment located in Ames, Iowa. It will be exposed to all forms of weather such as thunderstorms and temperatures ranging from extreme heat to extreme cold. The perimeter of the substation will be enclosed with a fence but still may be exposed to certain forms of wildlife such as birds, and rodents

1.4 REQUIREMENTS

Functional Requirements - As a Senior Design team, we are required to design the substation to have both primary and backup line protection relaying for the Des Moines, Cedar Falls, and Iowa City line exits. The line exits must be protected using the relays provided to us by Burns & McDonnell. Along with line protection, we must also include transformer protection relaying. Differential relaying will be used to protect both the primary and secondary sides of the 138/69kV transformer. Fiber optic cable will be used to communicate between substations for both primary and secondary relays.

Economic Requirements - No specific budget is given to us; however, we are required to physically plan the substation to allow for future expansion and flexibility as to not take on more of a financial burden in the future.

Environmental Requirements - We must show a perimeter fence in our physical layout so that we can prevent both humans and wildlife from entering the substation and causing damage. Also, we must include fire protection walls on two sides of our transformer to not cause further damage to the environment and substation in the event that the transformer catches on fire.

1.5 INTENDED USERS AND USES

The primary end users of the substation are the citizens of Ames who will rely on the substation to power their homes and workplaces. Other users include nearby utility companies and power plants that will also be dependant on the functionality of the substation as part of the local power grid.

1.6 ASSUMPTIONS AND LIMITATIONS

- Assumptions:

The wind energy farm is rated at 138kV

The ground on which the substation is to be built has already been leveled

The equipment and relaying specifications given to us by Burns & McDonnell are appropriately rated for the substation we are designing

- Limitations:

The design phase of the project must be completed by May 1st.

The substation must service incoming lines of 138kV and exiting lines of 69kV

Battery bank must be rated at 125V DC and in accordance with IEEE 485

Lightning protection must be in accordance with IEEE STD 998-2012

All substation drawings will be done using AutoCAD

1.7 EXPECTED END PRODUCT AND DELIVERABLES

The deliverables for our project are as follows: One line diagram, physical plans, and sections, lightning study, AC/DC Study, Schematics/Wiring diagrams.

One line - Due 10/18/2019

The one-line diagram is the overarching design of the substation. This drawing, as well as all of the others, will be done on AutoCAD. The drawing will include the transformer, all 4 breakers and relaying equipment wired together in a 3 ring bus configuration on the high side and single breaker configuration on the low side. It will also show the future equipment and how it will be connected while signifying that it is not part of our current scope. The one-line diagram will show all the interconnection in the substation yard as well as the incoming and outgoing lines. It will not show the specifics of the wiring i.e port to port contacts, rather it will simply show which devices and equipment are wired together and where the busses will land.

Physical Plan & Sections - Due 11/22/2019

The physical plan will show precisely where all equipment is laid out in the substation yard. It will also show the substation enclosure, road access, rigid bus, structures, and perimeter fence. We will submit an AutoCAD drawing to Burns & McDonnell with all relevant and future equipment with adequate descriptions and applicable standards used. We will also generate three section cuts from the overall plan drawing. Elevation section cut drawings will include general Bill Of Material callouts for major items.

Lightning Study - Due 12/20/2019

As a team, we will evaluate and design lightning protection for complete station protection against direct lightning strikes in accordance with IEEE STD 998-2012 Electro Geometric Model using the empirical curves method. In this report we will submit the following:

- Definitive calculations used in developing the layout of lightning protection.
- Summarize the orientation and protection results for each grouping of shielding electrodes
- Provide a recommended configuration of the shielding electrodes which includes the maximum effective heights of the lightning masts and shield wires.

AC/DC Study - Due 3/13/2020

Similar to the Lightning Study we will be providing calculations and the subsequent consequences of the calculations to our client. The study will be predicated on the AC and DC loads in the substation yard and enclosure and will require a power flow analysis of the substation.

Schematics/Wiring - Due 5/1/2019

We will develop the AC and DC schematics for the 69kV circuit breaker, 138kV circuit breaker, 69kV line relay, and all the transformer protection. Also, we will supply the panel layouts and schematics for the panel vendor's use. The wiring diagrams will show all of the interconnections between the relays and enclosure equipment.

2. Specifications and Analysis

As a group, our various skill levels with substation design has allowed all of us to have different learning experiences as this project progresses. Due to those differences, we used weekly meetings as a group as well as weekly meetings with Burns McDonnell to allow the group to develop questions and new ideas for each meeting.

2.1 PROPOSED DESIGN

Due to the nature of substation design, the majority of the project is a proposed design. Our design criteria, given by Burns McDonnell, is to create a complete substation design drawing set for a 69kv to 138kv station. As of this point in the project, we have submitted a one-line drawing of the substation that is in the process of being reviewed. This one line was composed by using the substation design guide and the scope documents given to us by Burns McDonnell.

The first stage of the submitted design was to create a "ring" bus configuration and after the work has been reviewed we will then develop a "future" section of the design to allow for expansion by using a "breaker and a half" configuration.

Each design we will submit will be in a state of constant revisions, as we get feedback for each design we submit, there can be other related drawings that will need to be modified as well. Burns McDonnell emphasized revision and document management is a key factor in completing the project efficiently and correctly.

2.2 DESIGN ANALYSIS

At this point in the project, we have completed a first revision of the one-line diagram. Our client has met with us every week to answer questions we have about configuration and how we need to tailor our design to match their standard. The first review of our work will be done on October 8th and we will understand revisions that need to be made for the next submission date on October 14th.

Due to the single drawing nature of this stage of the project, it was difficult to work as a team on the design. We met as a group to create the drawing and help explain why the system is configured in the manner it is, but an Auto CAD drawing is a one computer process.

From our understanding, to fix this it would be best to divide the work more evenly. In the next few stages of the project, such as the plan views, we will have multiple drawings. Working on those will require more coordination but we will be able to divide the work more evenly.

2.3 DESIGN PLAN

Prior to our submission, we asked our client to perform a quick review of our work to see if there were any key details to let out of our design. After that meeting as a group, we decided to scrap our original design for a more efficient and more easily configurable design. Our design plan at that point was to follow the examples given to us by the client, but modifying them to fit the scope.

For the plan view drawing set, we again are planning on using the one line as a top-down layout for the substation and basing our plan and equipment views due later in November.

3. Statement of Work

3.1 PREVIOUS WORK AND LITERATURE

The idea of substation design has been common for many years. The idea for this project is that Burns and McDonnell proposed a substation that they needed built, and tasked us to use their current technology in order to complete the design process. In industry, the initial modeling, physical diagram and one line are done with AutoCAD. After using proprietary software and go byes to analyze Grounding Studies, Lightning Studies and AC/DC Studies, they would plan and build the substation with contractors.

For this project, Burns and McDonnell supplied reference materials. These materials included general overviews of substation concepts, examples of various substation design components, and in-depth descriptions of regulations and standards. These materials are the primary reference for this project.

3.2 TECHNOLOGY CONSIDERATIONS

As far as technology for substations, the actual components making up the substation are all highly specified based on IEEE standards, connections available and Burns and McDonnell’s capabilities. For this project, the specific components are specified within the scope documents provided by Burns and McDonnell.

For Modeling, we are using AutoCad. This is a software that some of us are partially familiar with, and what is used in industry. By using this software, we are able to easily send our files to our contacts at Burns and McDonnell and receive examples or edits in return. While we often have minor issues working with this software it is relatively easy to use, we have experience within the group and its use in industry gives us valuable experience and communication ease in terms of file sharing.

3.3 TASK DECOMPOSITION



3.4 POSSIBLE RISKS AND RISK MANAGEMENT

Possible restrictions for this project are mainly related to either inexperience or our dependence on our contacts at Burns and McDonnell. As we are not equipped to perform the extensive studies required for substation design, Burns and McDonnell will provide the data from the studies for us to analyze. As supplying this data is completely dependent on our contacts, and delay in receiving this data will hinder our process.

Though we have some experience from past internships relating to this project, many in the group are new. Due to this, many people are learning and are likely to make mistakes. Though we make an effort to determine any errors, an error due to inexperience could cause setbacks.

3.5 PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

For this project, major milestones would be considered the major deliverables for this project. One major milestone is the completion of the one line, which passes the review of Burns and McDonnell. The one line needs to be redone until it is acceptable before we can continue. Another major milestone is the completion of the physical diagrams, also passing a similar inspection.

For our deliverable of the studies, we will mainly focus on revising our one line and physical drawing. Major milestones for this are submitting the final revisions of these diagrams for each study completed and analyzed. Our diagrams will be evaluated by Burns and McDonnell representatives and will be heavily edited and critiqued.

3.6 PROJECT TRACKING PROCEDURES

For project tracking, a Google Drive folder is shared between the group and Burns and McDonnell. This folder contains all the reference materials, as well as our deliverables, and each revision made to our documents, detailing our process. It also contains any formal report given to Burns and McDonnell. Our internal weekly reports will be included in our team website. This will detail our individual contributions and progress, though the overall progress and major developments will be included in the Google Drive folder.

3.7 EXPECTED RESULTS AND VALIDATION

The desired result is a full set of diagrams detailing the electrical and physical connections, which fulfills all standards, restrictions and regulations. This plan should be “as built”, ready for construction. Our final project will be evaluated by a final presentation to Burns and McDonnell, and the final review. A success in this project is a substation plan that Burns and McDonnell deems fit for construction.

4. Project Timeline, Estimated Resources, and Challenges

4.1 PROJECT TIMELINE

PROGRESS TRACKER/SCHEDULE			
Assignment	Status	Start date	Due on
One Line		9/20/2019	10/18/2019
Physical Plan & Sections		10/21/2019	11/22/2019
Fall Break (Nov. 25-29)			
Lightning Study		12/2/2019	12/20/2019
AC Study		2/13/2020	2/14/2020
DC Study		2/17/2020	3/13/2020
Spring Break (Mar. 16-20)			
Schemes/Wiring		3/23/2020	5/1/2019
Final Exams (May 4-7)			

The timeline of our project is broken up into these discrete components: The one-line diagram; the physical plan and designs of the sections; The three studies necessary, the lightning study, AC and DC study; the schemes and wiring components.

The one-line diagram for our project has already been roughed out. We have completed the first revision and upon client review, we will proceed with the second and potentially final revision.

The physical plan is the next component, there can be no overlap with the one-line diagram as the one line must be referenced to complete the physical plan. The physical plan will be completed before the fall break ending the first portion of our design.

After we return from break we will begin to work on the multiple studies that need to be performed in order to safely and efficiently operate the substation. The studies will be done individually with no planned overlap although it is not critical that they be completed before starting the next. This will allow us extra time should we fall behind schedule. We can finish up one study while beginning another. These studies will span both semesters also giving us a chance to work over the winter break. After spring break next semester we will begin the final wiring diagram of the substation. This must be done last after all the previous designs and studies have been completed and checked off by the client. The final diagram will then be reviewed, edited and reworked until a satisfactory conclusion is met as determined by both the client and our advisor.

4.2 FEASIBILITY ASSESSMENT

The final product of this project will include the design phase services necessary to serve as an interconnection for a new wind generation plant being built in the area. We will provide all specified designs, drawings, and protection services to Burns and McDonnell.

4.3 PERSONNEL EFFORT REQUIREMENTS

The project is estimated at 400 man-hours and should be completed by the end of the spring semester 2020. With approximately 26 weeks, we will need to put in about 16 hours of cumulative work a week. Each phase should take about a month given our deadline, and our work will be allocated appropriately in order to effectively complete our tasks on time.

This will include 2 meetings a week, one which will be spent with just our team aimed to organize plans and peer review individual work and one which will be spent with our advisor and client aimed to finalize and perfect work, in conjunction with planning our next steps as a team to ensure we move forward cohesively and effectively.

Beyond these team meetings, our efforts will be split between individual and group work. All individual work will be peer reviewed by other members of the team to ensure correctness. Each member will spend about 3 hours a week dedicated to a specific portion of the project to be allocated and assigned to them.

4.4 OTHER RESOURCE REQUIREMENTS

Necessary resources for this project include design specification documents as provided by Burns & McDonnell and the necessary software to complete proper drawings; all substation designs will be developed using autoCAD.

4.5 FINANCIAL REQUIREMENTS

There are no significant financial requirements to include with our project.

5. Testing and Implementation

5.1 INTERFACE SPECIFICATIONS

Since we are using AutoCAD as the software for circuit design, in order to conduct testing we have to follow the guidance requirements from Burns & McDonnell. There are two weekly meetings where

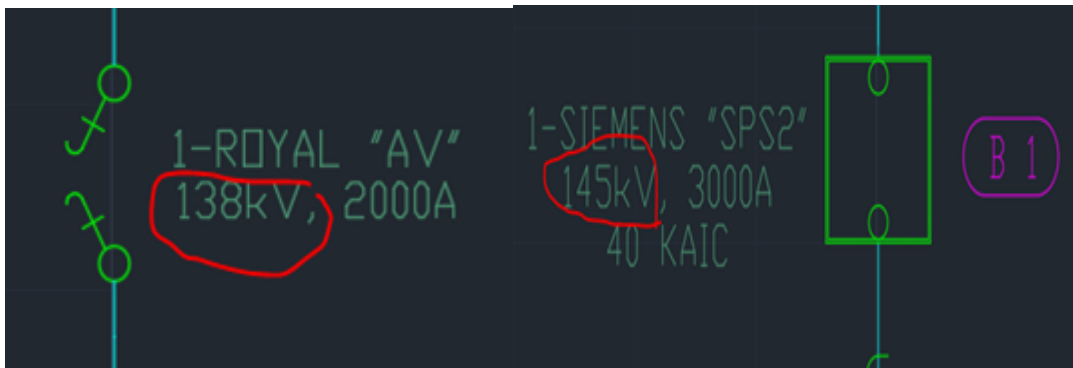
the team conducts a visual test/review of all elements and components. Everyone is aware to record any alternation that is being made into the main one-line diagram drawing. There will be more tests on the ratings, design and software testing as the drawings get completed.

5.2 HARDWARE AND SOFTWARE

Again, all drawings will be done using AutoCAD where a series of visual tests can be done by multiple people to increase the correctness on the project. For example: we can zoom in on each switch to double checked they are properly rated to what they will be used for. It is a priority to label all circuit breakers, switches, lines, correctly.

5.3 FUNCTIONAL TESTING

For example: we can zoom in on each switch to double checked they are properly rated to what they will be used for. It is a priority to label all circuit breakers, switches, lines, correctly. Substations rated 69kV must have switches and breakers rated for the same voltage.



5.4 NON-FUNCTIONAL TESTING

By practicing non-functional testing with the substation, we are expecting to facilitate the equipment to be installed, setup, executed, managed, monitored and developed properly.

5.5 PROCESS

1	Proposed Design	The project is mainly serving as a proposed design. A design drawing has been created and set for a 69kV to 138kV station. Once the proposed design was finished there was multiple visual inspections by all members to ensure the substation meets Burns McDonnell expectations.
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2	Design Analysis	The one-line diagram has been completed. There were weekly meetings with our client and the team to keep everyone updated how the drawing was being done. It was challenging to divide the work evenly, however, everyone had the opportunity to design their drawing using AutoCAD. On the team meetings there were a series of comparisons and discussions of why certain way would be better. There was multiple creative discussions and shared ideas to create the best drawing.
3	design plan	There was multiple creative discussions and shared ideas to create the best drawing. In addition, our client has been great answering questions, mentioning suggestions and asking questions. There are previous projects that have been designed for our client before, making ours more efficient has been the test.

5.6 RESULTS

Today, one-line diagram was reviewed by our mentors from Burns & McDonnell and our senior design team received some very useful feedback. One of the things they pointed out was not all of our ratings were correct for our switches and circuit breakers. In addition, the way it was model on the layout can be made a lot simpler and easier to follow. We learned that all details are important and we have to be more careful circuit design using AutoCAD. They gave us some useful tips connecting lines, components, transformers etc.

The desired outcome is set and includes a process of putting a decision into effect. The implementation of the design plan has started looking good but there is still a lot to be done. There are many challenges and issues that still need to be solved. Not everyone had been exposed to use AutoCAD, design a substation, know what do substations do? what components do they have? what ratings are they? This project will test our knowledge from many EE courses but also force us to learn new skills.

6. Closing Material

6.1 CONCLUSION

To date, we have completed our first drawing of a one-line diagram; this is in accordance with our expected timeline. From here, we intend to work on the physical plan and sections as requested by

Burns & McDonnell. Ultimately, it is our goal to create a new substation design which will be used as an interconnection for a wind generation plant near Ames, IA.

The substation design will include three 138kV gas circuit breakers, one 69/138kV transformer, two 138kV line positions, one 69kV line position, and one 69kV gas circuit breaker. The 138kV yard will be energized in a ring bus configuration with plans for future expansion into a six-position breaker-and-a-half configuration. We will continue to work within our specified timeline in order to ensure efficient, reliable, and consistent work is done within our group. We will also remain consistent in this plan so as to allow Burns & McDonnell sufficient time to evaluate our work and provide feedback; with this plan, by the end of Spring semester 2020, we will have our substation design perfected.

6.2 REFERENCES

Braunstein, A., et al. "External Lightning Protection-Israeli Standard and Code of Practice." 2006 *IEEE 24th Convention of Electrical & Electronics Engineers in Israel*, 2006, doi:10.1109/eeei.2006.321082.

"IEEE Guide for Safety in AC Substation Grounding." *IEEE*, 15 May 2015, doi:10.1109/ieeestd.2015.7109078.

"IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications." *IEEE*, 19 Dec. 1994, doi:10.1109/ieeestd.2011.5751584.

6.3 APPENDICES

There is no additional information to be included at the moment.