Substation Design

Project plan

Team Number
SDMAY19-17

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List of Definitions

AC: Alternating Current
DC: Direct Current
IEEE: Institute of Electrical and Electronics Engineers
NIA: Networks, Integration, and Automation
P&C: Protection and Controls
RTU: Remote Terminal Unit
SCADA: Supervisory Control and Data Acquisition
EMS: Energy Management System

1 Introductory Material

1.1 Acknowledgement

The Substation Design team would like to thank Grant Herrman, Abeer Hamzah, and Brian Obermeier, employees of Burns & McDonnell, for their willingness to oversee this project and for serving the team as technical advisors. The Substation Design team would also like to Craig Rupp, the faculty advisor for this project, for serving the team as a technical and professional advisor.

1.2 Problem Statement

While electric power transmitted a long distance has a high voltage which reduces power losses as electricity flows from one location to another, it is unsafe to distribute electricity at such a voltage directly to consumers. Similarly, though the production capabilities of electric power generators vary, electric power generators are incapable of generating electric power at voltages necessary to transmit that electric power long distances.

General Purpose
For this reason, substations are necessary throughout power grids. The primary function of a substation is to raise or lower the voltage of the electric power flowing into the substation. The main piece of equipment located at a substation is a power transformer. The transformer is an electromagnetic apparatus capable of raising or lowering an input voltage. The power supply voltage is scaled and then transmitted long distances or distributed to power consumers.

Substations also help to ensure the reliability of the power grid. Two other pieces of equipment located at substations are circuit breakers and disconnect switches. This protective equipment allows utilities to isolate electrical equipment from the rest of the power circuit/power grid in the event of a fault.

General Problem Statement
Burns & McDonnell has tasked the Substation Design team with designing a new, 138/69 kilovolt (kV) substation that will not be built, but that could theoretically “be used as an interconnection for a new wind generation plant near Ames, IA.”

General Solution Approach
The Substation Design team will need to do the following to complete this project:

1. Specifications:

Relay Panels – The Iowa State Senior Design team will create all relay panels including protective relays.

2. Substation Layout:

The Iowa State Senior Design team will submit a substation layout—including substation equipment, the control building, rigid bus, structures, and perimeter fence—based on the most economical option, which allows for future expansion with maximum flexibility.

3. Bus and Insulator Sizing Design

The Iowa State Senior Design team will perform calculations using predicted fault levels and weather criteria to establish the mechanical forces resulting at each of the substation buses.

4. Ground grid

The Iowa State Senior Design team will utilize software provided by Burns & McDonnell to design and analyze the grounding system. The grounding design will be consistent with IEEE 80 techniques, using a combination of ground mat and rods for arriving at acceptable step and touch potential limits and resistance to remote earth.

5. Raceway

The Iowa State Senior Design team will design a conduit plan using a combination of surface trenches, subsurface conduits, and equipment riser conduits.

6. Control Building

The Iowa State Senior Design team will prepare control building equipment layout drawings for the substation. The control building will be sized to accommodate the 125V DC battery and charger, AC & DC panels, SCADA RTU and all protective relay panels required for the initial installation.

7. 125V DC Station Battery Design

The Iowa State Senior Design team will develop a battery design for the substation using IEEE 485 techniques. Loads will be sized, including future loads, for the sizing of batteries, chargers, and panels used in the 125V DC system. The time period for a station service outage will be considered when arriving at the required battery size.

The Iowa State Senior Design team will submit a report which:

i. Clearly summarizes the design requirements
ii. Defines the calculations used
iii. Summarizes the results and recommended battery design

8. Relaying and Controls

The Iowa State Senior Design team will generate a one-line diagram, one 69kV circuit breaker schematic, one 138kV circuit breaker schematic, one-line relay schematic, and the transformer schematics.

9. Lightning Protection

The Iowa State Senior Design team will evaluate and design lightning protection for complete station protection against direct lightning strikes in accordance with IEEE STD 998-2012 Electro Geometric Model (EGM) using the empirical curves method.

The Iowa State Senior Design team will submit a report which:

i. Defines the calculations used in developing the layout of the lightning protection
ii. Clearly summarizes the orientation and protection results for each grouping(s) of shielding electrodes
iii. Summarizes the failure rate of the substation
iv. Provides a recommended configuration of the shielding electrodes which includes the maximum effective heights of the lightning masts and shield wires.

10. Communications

The Iowa State Senior Design team will do the following:

i. Create a communications block diagram and design the substation communications network using a combination of serial and ethernet network equipment.
ii. Design microwave radio system for communications transport. This will include frequency selection, tower sizing and placement.
iii. Provide equipment quotes and engineering cost estimate.
iv. Generate a SCADA points list from a provided template.
v. Configure the RTU and protective relays, as specified by the points list and comm block diagram, to provide SCADA information to a remote master station.
vi. Program a local Human-Machine Interface (HMI) in the RTU to show an animated one line with real-time values and an alarm annunciator.
vii. Program a remote Energy Management System (EMS) master using Kepware on Windows.

1.3 Operating Environment

When engineers are designing a new substation that will be built, they must design it so that, once built, it will remain functional when exposed to regional extreme temperatures and regional extreme weather. Though the substation designed by the Substation Design team will not be built, Burns & McDonnell still expects the Substation Design team to design a substation that would remain functional if exposed to regional extreme temperatures and regional extreme weather.

1.4 Intended Users and Intended Uses

If the substation designed by the Substation Design team were to be built, the intended use of the substation would be to raise the voltage of the electric power generated by wind turbines so that that electric power could be injected into the power grid and distributed to electricity consumers.

The intended user of the substation would be whichever utility owned it, as that utility would use the substation to distribute more electric power to its customers. Electricity consumers would benefit from the operation of the substation, though they would not technically be using it.

1.5 Assumptions and Limitations

Assumptions:

- A new substation in or near Ames, IA is needed
- A 138/69 kV power transformer should be located at the new substation
- The new substation should have a ring bus configuration

Limitations:

- The new substation would be built in or near Ames, IA
- The new substation must be designed such that it complies with relevant client and industry standards
- The only major pieces of equipment to be located at the new substation are three 138 kV circuit breakers, one 138/69 kV transformer, and one 69 kV circuit breaker
- The new substation should have a ring bus configuration

1.6 Expected End Product and Other Deliverables

The majority of the deliverables for this project will be in the form of documents and drawings given as a final package to the client. Along with the documents and drawings, our team will also be providing studies that are the basis for our design package decisions. In addition, our team will be providing a 3D model of the completed substation, with the major equipment being displayed in an easy to view manner.
The first deliverable to the client is the grounding and lightning studies. This deliverable shall be turned over to the client by November 2nd, 2018. The grounding study utilizes software provided

by the client to assist in the design and analysis of the grounding grid. The grounding design will be reliant on this study and with this study, we will be able to appropriately design a ground grid that is consistent with IEEE 80 standards and ensures the step and step potential limits and resistance to remote earth are all within acceptable parameters. The lightning study is an important piece for designing a substation's lightning protection in accordance with IEEE Standard 998-2012. The lightning study will define our calculations used in developing the layout of the lightning protection, clearly summarize the orientation and protection results for each grouping of shielding electrodes, summarize the failure rate of the substation, and provide a recommended configuration of the shielding electrodes which includes the maximum effective heights of the lightning masts and shield wires.

Our second deliverable to the client is the physical design of the substation, which shall be turned over by November 30th, 2018. The physical design of the substation will include drawings which show the layout of the whole substation. The physical design will be shown on a plan view drawing which will include the locations of the following: the substation equipment, control building, rigid bus, structures, and the perimeter fence. This deliverable will also include section cuts from the overall plan view, which will show the elevation view of the substation and also include the Bill of Material call-outs for major equipment shown in the drawing. This deliverable will be designed based on the most economical option, which allows for future expansion and with the client preferences in mind. The grounding and lightning studies will also be taken into account and the physical design will be shaped by their specifications.

Our third deliverable is the AC/DC studies, which shall be turned over to the client by March 1st, 2019. The AC/DC will specify the size of battery size that will be needed to power the station during a station service outage. The study will take into account all of the equipment on the site and will need to follow the standards laid out in IEEE 485. Our study report will need to include a summary of the design requirements, definitions of the calculations used, and a summary of the results and our recommendation for the battery design.

Our fourth and final deliverable is the Controls and the Networks, Integration, and Automation (NIA) design package, which shall be turned over to the client on April 12th, 2019. These packages will include the final design of the substation's controls and communications equipment. The controls package will include several drawings which represent the complete controls for the substation. These drawings will include a one-line diagram, a 69kV circuit breaker schematic, a 138kV circuit breaker schematic, a line relay schematic, and the transformer schematics. Along with these drawings, the package will include the relay panel layouts for an outside panel vendor to manufacture. The NIA design package will include a layout for the communications system used at the substation. The package will include: a communications block diagram and the design of the substation communications equipment using combinations of serial and Ethernet network equipment, the design of the transport via fiber to a neighboring substation, quotes for the equipment, an engineering cost estimate, and a simulation of the network topology using CISCO Packet Tracer.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

The objective of our project is to provide our client with design phase services for the new Cyclone Substation. When completed, the Cyclone Substation will serve as a means of interconnection between a new wind generation plant being constructed outside of Ames, IA and the pre-existing transmission system. In order to meet our objectives, our team aims to design a substation that meets the requirements as specified in the Scope of Services provided by our client, Burns & McDonnell (BMcD).

2.2 Functional Requirements

Included below is a list of the functional requirements specified in the Scope of Services provided by BMcD.

Functional Requirement 1 - Specifications

The Cyclone Substation will be prepared with BMcD standard specifications for substation structural steel, electrical equipment and materials. All required drawings will be generated and provided by the design team.

Functional Requirement 2 - Site Design

Level ground is assumed during the layout design of the substation. BMcD has provided designs for the desired site layout by including roadway access to the site, road details and fencing details.

Functional Requirement 3 - Substation Layout

The Cyclone Substation will be designed with consideration to the most economical option that provides flexibility towards future expansions. In addition to two (2) or three (3) elevation section cut drawings, all substation equipment, control building, rigid bus, structures, and perimeter fence will be generated and indicated on the plan drawings provided by the design team.

Functional Requirement 4 - Bus and Insulator Sizing Design

The design team will perform calculations using predicted fault levels provided by BMcD and weather criteria to establish the mechanical forces resulting at each of the substation buses.

Functional Requirement 5 - Ground grid

Through hand calculations and the use of software provided by BMcD, the design team will design the grounding system. The grounding design will be consistent with IEEE 80 techniques, using a combination of ground mat and rods for arriving at acceptable step and touch potential limits and resistance to remote earth. Grounding conductors will be sized based on the calculated fault current value and relay clearing times.

Functional Requirement 6 - Raceway

The design team will design a conduit plan using a combination of surface trenches, subsurface conduits, and equipment riser conduits.

Functional Requirement 7 - Control Building

The Cyclone Substation will include a control building that accommodates the 125V DC battery and charger, AC & DC panels, SCADA RTU and all protective relay panels required for the initial installation. The design team will prepare equipment layout drawings for the substation.

Functional Requirement 8 - 125V DC Station Battery Design

Using IEEE 485 techniques, the design team will develop a battery design for the Cyclone Substation. Along with considerations of periodic station service outages, loads will be sized, including future loads, for the sizing of batteries, chargers, and panels used in the 125V DC system. The design team will develop and submit a report summarizing design requirements, calculations performed, and results and recommendations for the battery design.

Functional Requirement 9 - Relaying and Controls

The design team will generate a one-line diagram, one 69kV circuit breaker schematic, one 138kV circuit breaker schematic, one line relay schematic, and the transformer schematics. Relay panel wiring diagrams will be generated by an outside panel vendor as part of the relay package.

Functional Requirement 10 - Lightning Protection

The Design Team will evaluate and design lightning protection for complete station protection against direct lightning strikes in accordance with IEEE STD 998-2012 Electro Geometric Model (EGM) using the empirical curves method. The design team will develop and submit a report that summarizes calculations used, the orientation and protection results for each grouping(s) of shielding electrodes, the failure rate of the substation, and a recommended configuration of the shielding electrodes which includes the maximum effective heights of the lightning masts and shield wires.

Functional Requirement 11 - Communications

The Cyclone Substation will be completed with a communications system that provides methods of voice and data transmission among the various system parts in order to maintain satisfactory operation and control. Communication systems are used in protective relaying schemes to initiate tripping control schemes of power circuit breakers; in supervisory control systems to operate remote equipment, for transmission of data indicating equipment status and system conditions, and for voice communications for system operation and maintenance.

2.3 Constraints Considerations

2.3.1 Constraints

This project is constrained by the fact that the Cyclone Substation is not going to be physically constructed. The objective of this project is to provide engineering design services.

2.3.2 Standards

The Cyclone Substation will be designed in accordance to the BMcD and IEEE standards relevant to the functional requirements previously specified.

When performing studies and design of the Cyclone Substation grounding system, the IEEE 80 Guide for Safety in AC Substation Grounding will be referenced. BMcD has directed us to run several simulations of the grounding grid in order to identify the most efficient and optimized layout.

When performing calculations and designing the 125V DC station battery, the IEEE 485 Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications guide will be referenced.

When performing studies and design of the Lightning Protection System for the Cyclone Substation, the IEEE 998 Guide for Direct Lightning Stroke Shielding of Substations will be referenced. Specifically, we will be heavily referencing the formulas and procedures regarding the “Empirical Curves” approach discussed in this guide. BMcD as directed us to perform the lightning study using the empirical curves approach, both my hand and with software.

Throughout this project, the design team will advocate all aspects of the IEEE Code of Ethics as well as all standards set by our client, BMcD. More specifically, our team will be submitting our reports to BMcD, where they will review and critique our work. Many of the topics within this substation design are new to several team members; therefore, we will be assisting one another in learning the technical aspects as well as overall professional development. If our team raises the question of business and/or engineering ethics at any point during the development of the Cyclone Substation, BMcD will be contacted.

2.4 Previous Work And Literature

2.4.1 Existing tools

Burns and McDonnell has supplied us with several templates, example and to-modify substation drawings, a detailed Scope of Services, and a start-to-finish Substation Design Guide. Several aspects of the Cyclone Substation design require the use of IEEE Standard Reference Guides. The “Design Guide for Rural Substations” that BMcD has supplied to us will prove the most useful when designing the Cyclone Substation. This guide provides an in-depth treatment in every aspect of designing a substation. The pros of having a well defined procedure guide is that it will aid us significantly in familiarizing ourselves with the different aspects of substation design. The design guide will aid us in formulating better, more specific questions that our team can ask BMcD during our bi-weekly conference call meetings. All of this should prove to aid us in efficiently completing tasks and meeting set deadlines.

Due to the fact that BMcD has supplied our team with significant literature regarding substation design, it is evident that BMcD has developed set standards for completing projects similar to the new Cyclone Substation. The design team will adhere to these standards set by the client.

2.4.2 Relevant Literature

“The 21st century substation design: Vision of the Future” includes discussion on Green Field Substation design. Because today’s power systems are becoming more and more delocalized, Green Field substations consider system operation and expansions, the economics of the power market, and profit optimization. The Cyclone Substation is considered a Green Field substation. When designing the substation, economics and future expansion into the “Smart Grid” are being considered. While BMcD has provided us with a concrete plan towards designing the Cyclone Substation and power economics are outside of the scope of this project, understanding where the power market is trending will aid us in understanding the big picture of this project.

“Transient Performance of Substation Grounding Systems Subjected to Lightning and Similar Surge Currents” includes in-depth discussion on performance issues regarding surge protection in relation to lightning strikes and the design of an optimized grounding system. As this is the first task to be completed in our design, this article provides us with good background into aspects that must be considered. Grounding systems are designed to protect equipment from inducing too high of an electromagnetic field produced from a lightning current. Before performing simulations of our optimized grounding grid, team members were advised to read and gain background knowledge regarding how grounding systems function, why they are necessary, and what can go wrong.

2.5 Proposed Design

The design of this substation will be done in accordance with IEEE standards and standards set by the client. The solution is simple in theory, to design a substation which will serve as an interconnection for a new wind generation plant being built nearby. However, to design this substation, data will need to be collected and analyzed. This data will be collected in the form of the lightning study and the grounding study. These studies will affect the layout of the substation yard and will need to be analyzed to provide the most economical and efficient layout for the physical layout of the substation. To complete these studies, we will need to gather information collected by our client and determine the appropriate spacing for the grounding grid, lightning masts, shield wire, and the physical equipment in the yard, all by using the proper equations and methods outlined in the IEEE standards that have been given to us. To design the substation layout we will also use the following schematic as an example to help us. This example will help us to decide where to place the major equipment and how to best optimize the substation yard space.

Figure 1: Example Substation Layout

The substation will also need to be designed with the considerations of the client, physical obstructions, and many other factors. So, in theory, the layout of the yard may be best optimized when it's in one configuration, the client has other standards that they adhere to, or there is physically something there that cannot be moved that we would have to adjust for. The studies are a great design start, but we also need to take into account many other factors. The physical design will be completed and all the equipment in the yard will have a defined location and once that is done, we will need to design how to actually connect all of the equipment. This step is known as Protection and Controls (P&C) design, and during this phase, we will also design the communications system. The following example diagram will help us to design our protection and controls. This diagram has all of the major equipment on it and how all of the equipment is connected together via relays and terminal blocks.

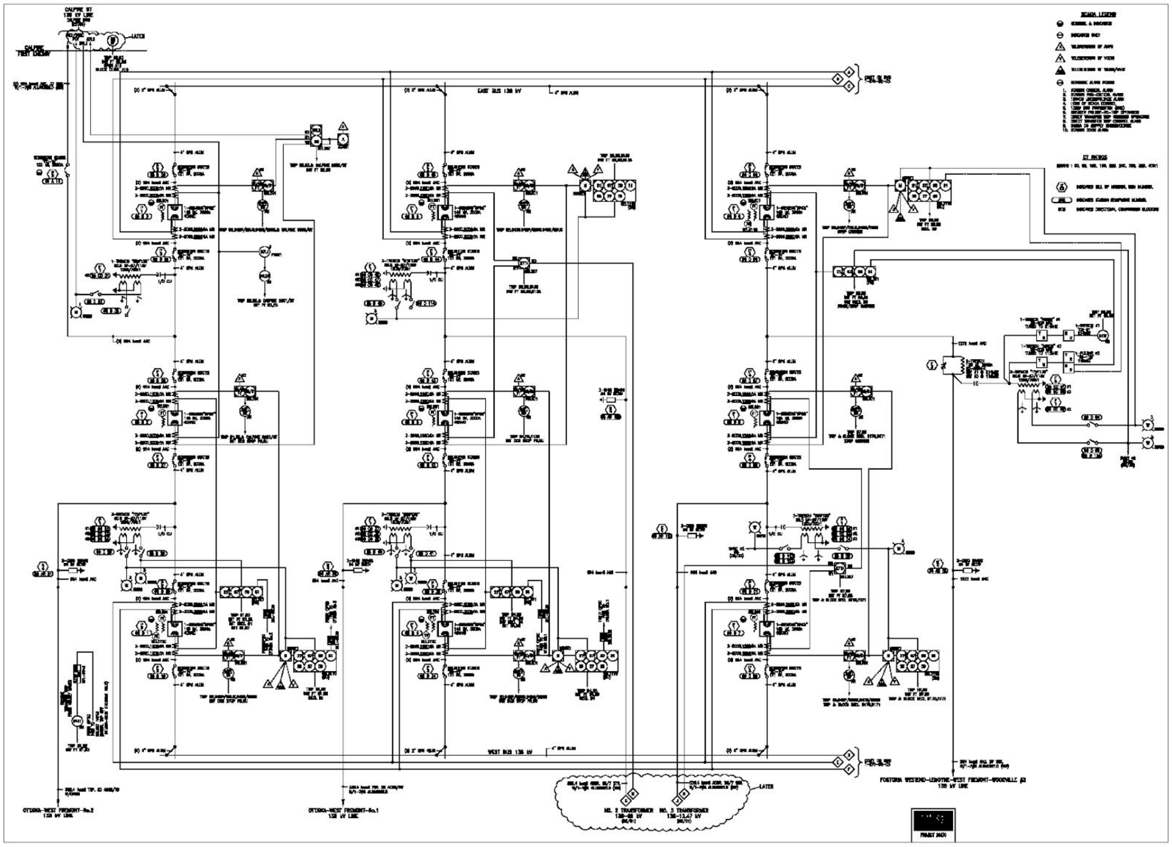

Figure 2: Example Protection and Controls One-Line

During the P&C design, our group will consider the protection schemes that are provided by the client and adhere to them and also to the IEEE standards. Within the substation, there will be Schweitzer relays that will need to be wired correctly to ensure that the substation properly detects faults and communicates that with the system. These relays are the primary part of the protection schematics and will be connected to a major piece of equipment, i.e. a breaker, or a transformer, and it will also be connected to a central data aggregator. This data aggregator will then be connected to an RTU, which is where the communications design comes into play.

The communications system will need to be able to connect via fiber to surrounding substations and remotely to the service center where all the data about the grid is moderated by qualified persons at all hours of the day. The communications system will consist of the RTU, router, fiber distribution panel and many other pieces of equipment that ensure a safe and reliable mode of transportation for the data. The design for this system will be done in accordance with Burns and McDonnell standards, and the design will be closely overseen by project engineers from the client. There are very specific port assignments and connections for these devices that will need to be adhered to, to ensure that the devices can be properly connected and will communicated with one another. All of the P&C and communications systems will have drawings created for the connections and the devices that are being installed that will need to be reviewed and approved by the client.

There are very few design alternatives foreseeable in the progression of this project as the project is being constructed in accordance to client and IEEE standards. The main design alternative that we foresee is changing of the of the layout of the substation yard due to unforeseen factors. In the real world, there would be many design alternatives that would have to be considered during the construction phase. During the construction phase, equipment is known to not work exactly as designed and will need to have changes applied. For example, say a lead on a relay is burnt, then we would have to issue an engineered change and reissue the affected drawing with an updated design. Since we are not going through a construction phase, these problems will not affect our project, but will need to be kept in mind for when we design substations in the future.

Some pros for our proposed design is that it follows all of the IEEE standards and therefore will be designed safely and all to code. The design will also be done with close communication to the client and therefore all of the design aspects will be done to client specifications and will work properly to how the client wants it. The substation will be laid out so that it is most economically viable for the client. The runs of cable will be designed so that they will connect to the control building so that the least amount of cable will be used. Another pro is that there is plenty of room in the substation yard for future expansions and to upgrade the substation to a breaker and a half formation.

Some tradeoffs for our proposed design is that the layout of the substation is very flexible. There is really no set standard for the design and the design will be able to function with many different layouts. The layout will mostly be determined by client's standards and their preferences. The client will determine if they like the location of all of the major equipment in the yard. The communications systems and protections and controls have a very set standard for where to plug in the devices and how to connect all of the equipment together, but the location of the equipment is not set. As long as all of the equipment is with the control building, the project will function properly and pass all of the checks given by our client.

There is a flow chart included in section 2.8 that describes the flow of the project from start to finish.

2.6 Technology Considerations

Multiple studies are performed throughout the process of designing a substation. These studies can be done by hand-written calculation, or with the use of computer programs. Our client has assigned three studies to be performed for this project: a grounding study, a lightning study, and a DC/AC sizing study. The lightning study and DC/AC sizing study will be done by hand-written calculation, while the grounding study will be done using a computer program called CDEGS. The lightning study will be done by hand-written calculation and checked using a Microsoft Excel program made and given to us by Burns and McDonnell.

2.7 Safety Considerations

The main concern for safety throughout our project is the safety of those working in or near the vicinity of the substation we are designing. A substation design works around numerous standards, set by a committee, IEEE. These standards are in place to ensure the quality, safety, and ethical background of all things that fall under the direction of IEEE.

Two deliverables in our project scope are specifically designed to ensure the safety of any person working or near the substation site in normal conditions, as well as when a fault may occur, such as in a an obstruction in the path of current flow or a lightning storm. A ground study is performed to ensure that if a fault occurs, the ground grid design can withstand the worst fault current inside the substation and dissipate the possible electric shock into the earth below the site. We will perform a grounding study on our initial ground grid design, taking into account various characteristics of our site, substation layout, and data given by the client, and modify our design until a safe touch and step potential voltage is achieved.

A lightning study is performed to ensure that a person in the substation during a lightning storm is protected, as well as the necessary equipment inside the substation such as circuit breakers and transformers. The lightning study will be done after our initial substation layout is designed. Research is done to find the values necessary to perform the calculations and our design is tested against this criteria. The results of the lightning study will help us indicate where lightning masts and shield wires need to be placed throughout the substation to ensure a zone of protection from a lightning strike.

2.8 Task Approach

Our client provided us a schedule laying out the order of deliverables. The visual below shows a block diagram of how we will approach the project.

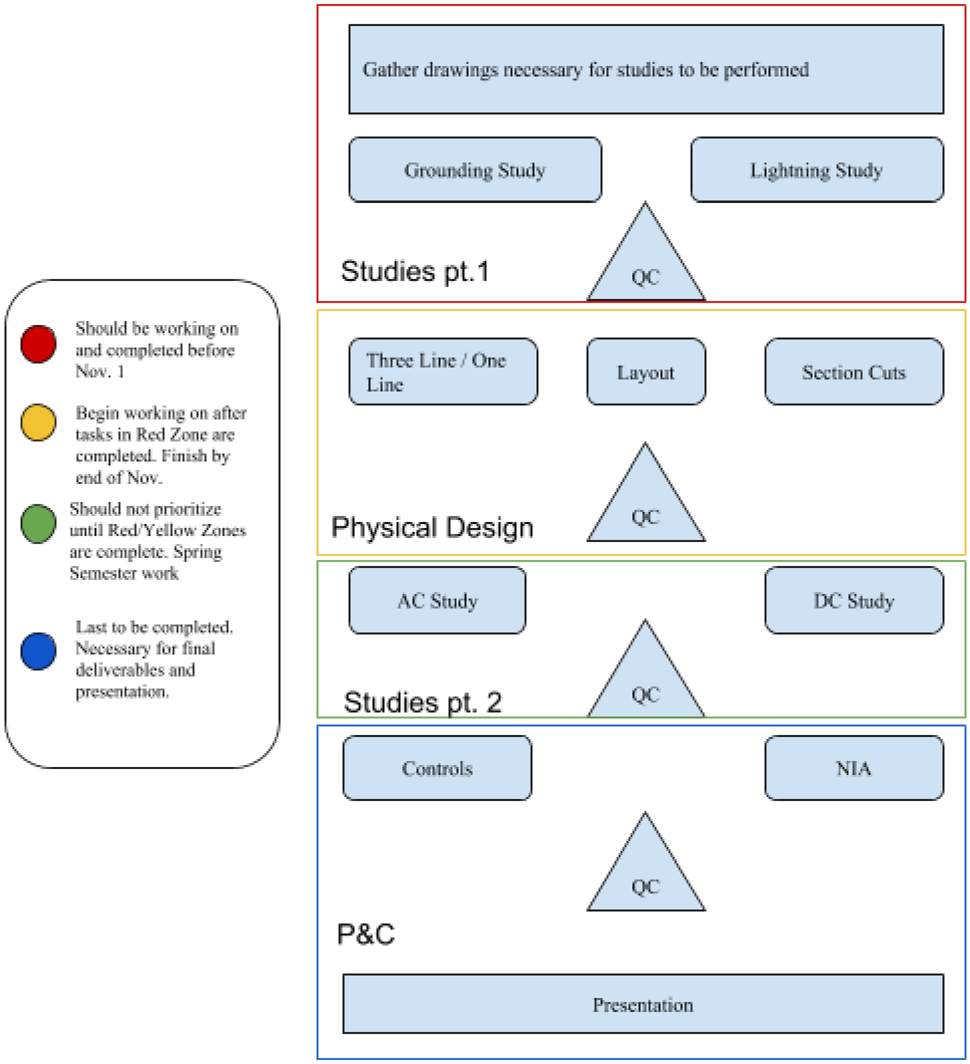

Figure 3: Project Approach

2.9 Possible Risks And Risk Management

Our client has provided us with the process to be followed while going through this project. They also provided instruction for multiple tasks in the project such as studies, drawing examples, and information on the design process. Because we do not have a budget, there is no material requirements, and we have detailed instruction guides to reference throughout the time of this project, there are no foreseen risks.

2.10 Project Proposed Milestones and Evaluation Criteria

The following milestones are proposed as checkpoints for this project:
-Substation Layout Drawing
-Three Line / One Line Drawing
-Studies completion

-Physical Package
-Protection & Control Package

After discussion with our clients, are work will be double checked by the Burns and McDonnell advisors for accuracy. Each deliverable will be checked by the members of the teams before passing them off to the Burns and McDonnell advisors.

2.11 Project Tracking Procedures

Our team will use a task tracker created an EXCEL to keep track of the progress of tasks throughout the project. This tracker includes a task description, due dates, responsible engineers, and a percentage of completion.

2.12 Expected Results and Validation

The desired outcome of our project is a functionable substation with correct safety standards and usability. Our design will incorporate all the characteristics of existing 138/69 kV substations, but will include the possibility of adding future equipment and components if more transmission lines should be interconnected. Our design uses the most cost effective set up, as well as uses the amount of space in our site responsibly. The current substation layout provides the ability to expand to a *breaker and a half* scheme in the future by adding three more breakers into the site. The ability to expand on the current design saves time and money for future additions, as it is ready to be expanded and a new substation will not need to be built. The client, Burns and McDonnell, will confirm our solutions before we submit our deliverables as a package, as well as peer evaluation and feedback from other outside sources such as advisors or other professional contacts who specialize in substation design.

Components of the design can be validated through a number of tests. Starting from the bottom, the ground grid design is tested with an iterative processes using data from field tests, transmission line capacities, and levels of acceptance provided by the client. We will input our ground grid design into a software that runs numerous calculations. These calculations will provide an output stating if our grid design passes or fails in regards to safety standards set by the client and IEEE.

Lightning protection is another main component of the design process that will be tested. The lightning protection design includes the process of deciding where lightning masts are necessary throughout the site to ensure all the equipment is in a safe zone in case of lightning strike in the site. The calculations were done by hand and integrated into the substation plan design. This design will be input into a Microsoft Excel program created by Burns and McDonnell to test the hand written calculation based design.

2.13 Test Plan

To test the ground grid design, we will being using software called CDEGS. CDEGS allows the user to run simulations of various ground grid designs. It allows the user to optimize the design by changing conductor sizing and grid spacing using soil resistivity measurements similar to the job site. An iterative process is used to ensure that the ground design meets industry safety standards.

To test the lightning protection design, we will use a Microsoft Excel program created by Burns and McDonnell. The calculations for the lightning protection will all be completed by hand and tested with this software to ensure all equipment is protected from lightning. This program tests the design based off the empirical curve analysis, the method that we will use to design the lightning protection.

Burns and McDonnell has instructed us to test our design using a Q review process similar to what Burns and McDonnell does before submitting to their clients. This Q review process involves two different steps, a Q3 and a Q4. The first step in the Q process involves validating one's own work once fully completed. The second step of the Q process involves a peer cross-checking the completed work. The final step in this process will be sending the completed package to the client, Burns and McDonnell, to receive final feedback. This process will continue to repeat until the client approves the design.

3 Project Timeline, Estimated Resources, and Challenges

The biggest challenge we will encounter in this project is that is will not be physically built. We will have to rely on past projects, design guides, IEEE standards, and client specifications. There are no physical tests that can be run to ensure our design is safe; however, we will utilize various software to simulate the substation protection performance.

3.1 Project Timeline

The client has opted to break down this project into four major deliverables: Grounding and lightning studies, physical design, AC/DC Studies, and Controls & NIA. Within these phases, there are many subphases that are broken down in section 3.3 Personnel Effort Requirements. The dates for these deliverables are broken down in the two figures below by semester. Semester 1 will incorporate these phases: project introduction and research, grounding and lightning studies, and physical design. It is important to do the grounding and lightning studies before the physical design to ensure that the soil is safe and that enough lightning masts are incorporated into the physical design to ensure safety. Semester two will incorporate the phases AC/DC Studies and Controls & NIA.

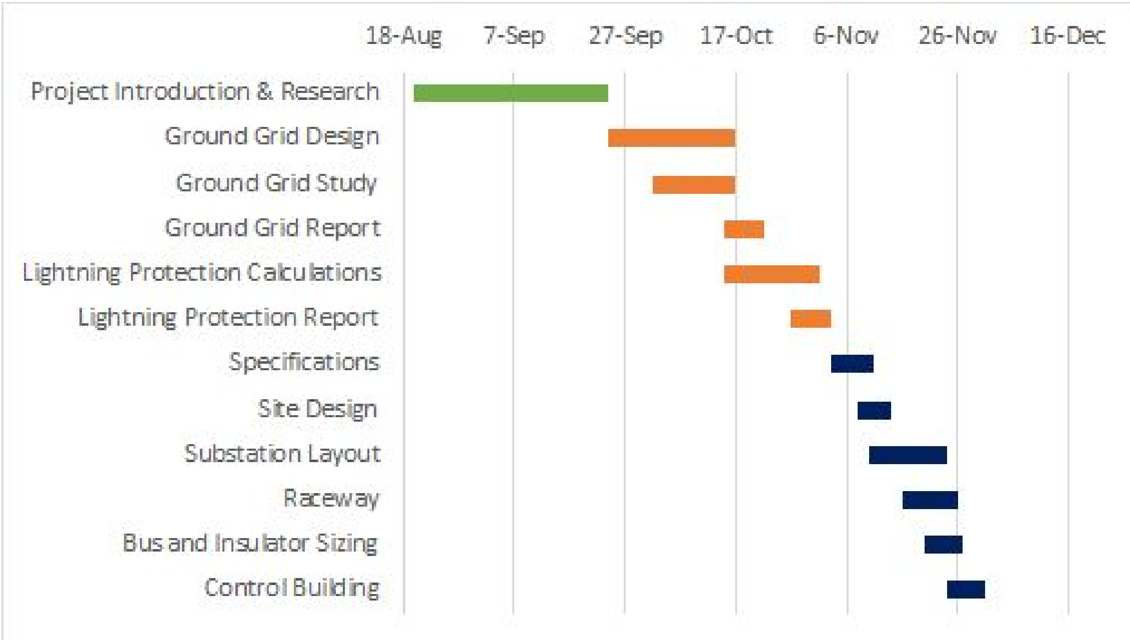

Figure 4: Semester 1 Gantt Chart

<u>Description of Figure 4: Semester 1 Gantt Chart</u>

This semester will begin with an introduction to our project and extensive amounts of research for the design of the substation. During this phase, we will meet with the client, understand the scope of work, and create a relationship with our academic advisor. With each member of the group having various backgrounds on substation design, the introduction and research phase will ensure that we are all on the same page with similar knowledge. This phase begins on the first day of school, August 20 and goes to September 23. This phase is shown in the red color. After the introduction phase, we will enter the grounding and lightning studies phase. This phase begins on September 24 and the final deliverables of this phase is due to the client on November 2. This phase is broken down and shown in the orange color. This phase deadline is crucial because we cannot begin the physical design until the grounding and lightning studies are complete. The physical design phase begins November 3 and the final deliverables of this phase is November 30. This phase is broken down into many subphases and is shown in the dark blue color.

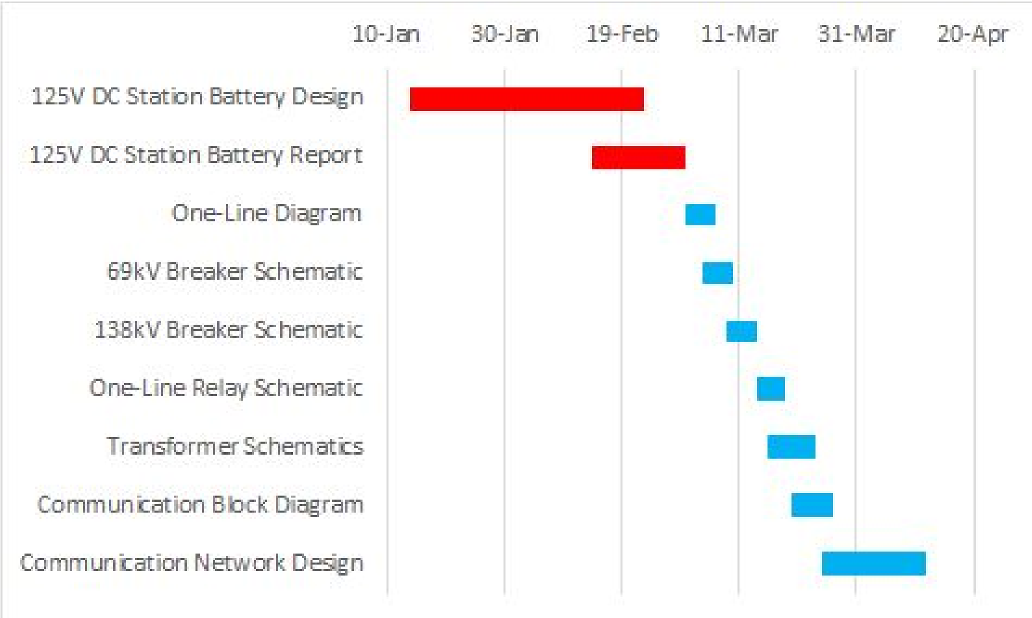

Figure 5: Semester 2 Gantt Chart

Description of Figure 5: Semester 2 Gantt Chart
During the second semester, we will pick up on the design phase right away. These two phases will be broken down almost evenly throughout the semester. We will begin with the AC/DC Studies on January 14. This phase has a little bit of time worked into it to get back into school and to get a feel for the second senior design class. The final deliverables for this phase are due March 1. After completion of the AC/DC Studies, we will begin the Controls & NIA phase. This phase will begin March 2 and the final deliverables will be due on April 12. This semester has more leeway with finals not being until May 6 to complete any deliverables that we may have been behind on and to put the finishing touches on the substation design. This also gives us time to complete any deliverables we may have for the senior design class and ensure we have time to prepare our presentation.

3.2 Feasibility Assessment

This project design will involve following IEEE Standards, looking at previous drawings, and using supplementary materials such as the design guide for rural substations that were all given to us by the client. This project may prove to be difficult because it is such a large-scale problem. The design guide that was given to us by the client is over 700 pages long and therefore may be difficult to search through when various problems arise. There is also a huge learning curve for this project. Some members in our group are familiar with substation design, whereas others are not at all familiar or very vaguely familiar. This will mean that we will have to take more time to ensure that we are all on the same page and that we are completing the tasks accurately and efficiently.

Another challenge that we will face will be learning the new software involved in running our studies. We will do many calculations by hand, but will check these calculations using the software. An issue that we may run into is if our studies will not pass or how to optimize our design to ensure that we are saving the client time and money.

3.3 Personnel Effort Requirements

Table 1- Table 4 below show a list of all the major tasks that need to be done to complete the project. The tables below are split up by the major deadlines the client has given us: Grounding and Lightning Studies, Physical Design, AC/DC Studies, and Controls & NIA. This project is projected to take 400 man-hours. These hours do not consider the introductory research phase nor the meetings with the clients and our academic advisor.

Grounding and Lightning Studies		
Task	**Description**	**Estimated Time (hours)**
Ground Grid	Design and analyze grounding system consistent with IEEE 80 using CDEGS software.	20
Lightning Protection	Evaluate and design lightning protection for substation in accordance with IEEE STD 998-2012 using the empirical curves method.	30

Table 1: Tasks for Grounding and Lightning Studies Phase

Physical Design		
Task	**Description**	**Estimated Time (hours)**
Specifications	Create specifications using BMcD standard specifications for substation structural steel, electrical equipment, and materials.	20
Site Design	Design roadway access to substation, road details, and fencing details.	10
Substation Layout	Layout the substation with the economics and future expansion in consideration.	70
Raceway	Design conduit plan for substation equipment requiring power or control connection.	30
Bus and Insulator Sizing Design	Complete calculations for bus and insulator sizes using predicted fault levels.	15
Control Building	Design the layout of the control building for the substation. This control building will be sized to fit the battery system, AC & DC panels, SCADA RTU and all protective relay panels.	15

Table 2: Tasks for Physical Design Phase

AC/DC Studies		
Task	**Description**	**Estimated Time (hours)**
125V DC Station Battery Design	Design a battery system using techniques from IEEE 485. This battery system will be designed with future loads in mind.	20

Table 3: Tasks for AC/DC Studies Phase

Controls & NIA		
Task	**Description**	**Estimated Time (hours)**
Relaying and Controls	Generate a one-line diagram, one 69kV circuit breaker schematic, one 138kV circuit breaker schematic, one line relay schematic, and the transformer schematics.	75
Communications	Create communications block diagram and design the communication network using both serial and ethernet network equipment.	95

Table 4: Tasks for Controls & NIA Phase

3.4 Other Resource Requirements

As a final physical deliverable for the project, we will be printing the substation layout in 3-dimensions. This will be done using the Burns & McDonnell 3D printer offered at their headquarters in Kansas City, Missouri. Burns & McDonnell will supply 3D printing filament needed to create the 3D substation layout.

3.5 Financial Requirements

For the project, we have few financial resources required. We will be using the software AutoCAD and CDEGS. AutoCAD has a version available to students for free that should prove to be adequate for our work, so there will be no cost to our client unless the client's specifications change. The software CDEGS will be given to us to use by the client. A license for CDEGS costs roughly $14,000 and will be shared with other senior design groups across the country with the same client, Burns & McDonnell. We will also have the expense of 3D printing our substation design. We will utilize the 3D printer owned by our client, Burns & McDonnell. A 3D printer will usually cost about $1,000, but this cost will not come out of our client's pocket because it is already owned. The material for the 3D printer will cost money out of pocket. The 3D printing filament will cost about $19.19 and will be our only cost expense for our client.

4 Closure Materials

4.1 Conclusion

For our senior design project, we have chosen the design of an electrical power substation. An engineering contracting firm, Burns & McDonnell, has hired our team to develop a 138/69 kV substation. When completed, our substation will serve as a means of interconnection between a new wind generation plant being constructed outside of Ames, IA and the pre-existing transmission system. This substation will raise or lower the voltage of the electric power flowing into the substation. This will maintain the integrity of the electrical grid by being able to transmit massive amounts of energy long distances while minimizing power loss within the system.

The approach to this project will follow the scope of services provided to us by Burns & McDonnell. There are 11 key components of design that we will be breaking up into four components. They are as follows:

PROJECT TASK	**DUE DATE**
GROUND & LIGHTNING STUDIES	11/02/18
PHYSICAL DESIGN	11/30/18
AC/DC STUDIES	3/01/18
CONTROLS & NIA	4/12/18

We will be following these hard deadlines during the completion of our project. Each project task listed above has an array of individual components highlighted in our project scope.

Once we have completed the design of our substation, we will be able to perform functionality tests to prove that our substation will meet all of the required specifications for a power plant. We will be displaying a 3-D model of our substation along with our designed engineering drawings.

4.2 References

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4.3 Appendices

Figures

Figure 1: Example Substation Layout

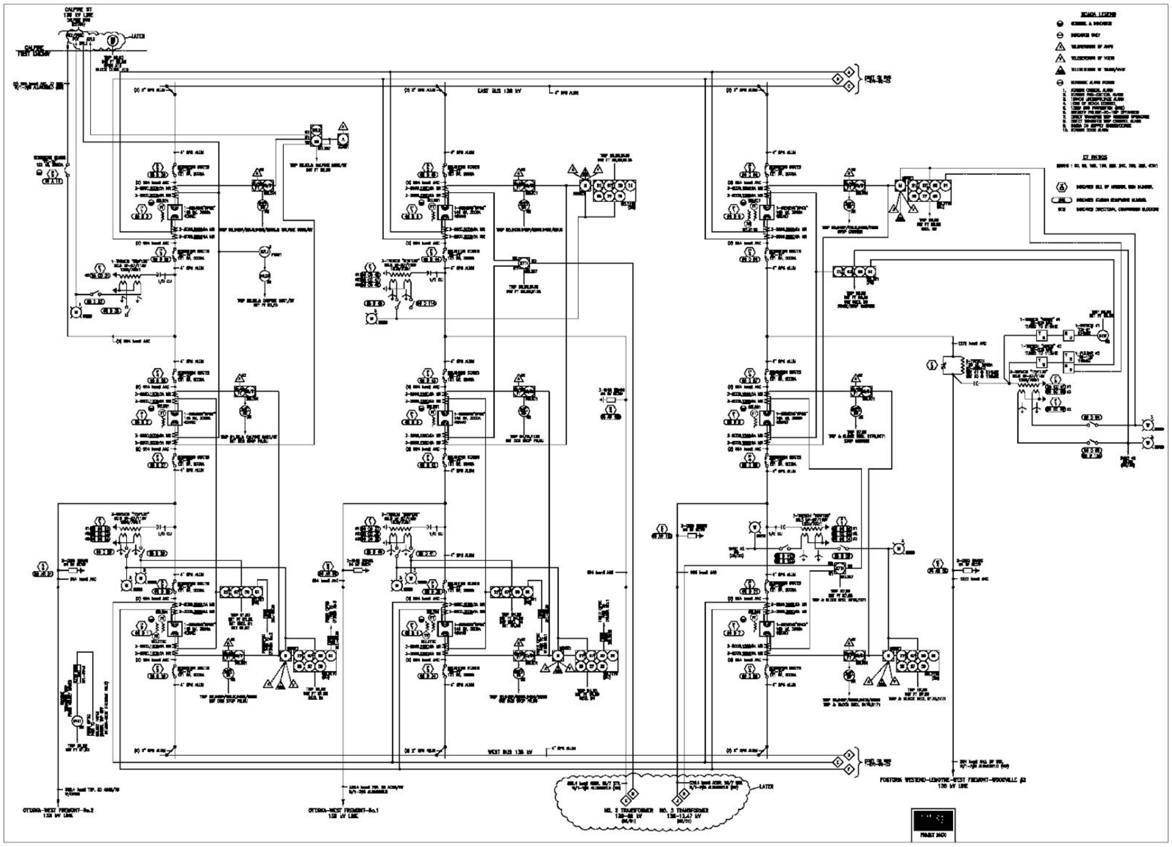

Figure 2: Example Protection and Controls One-Line

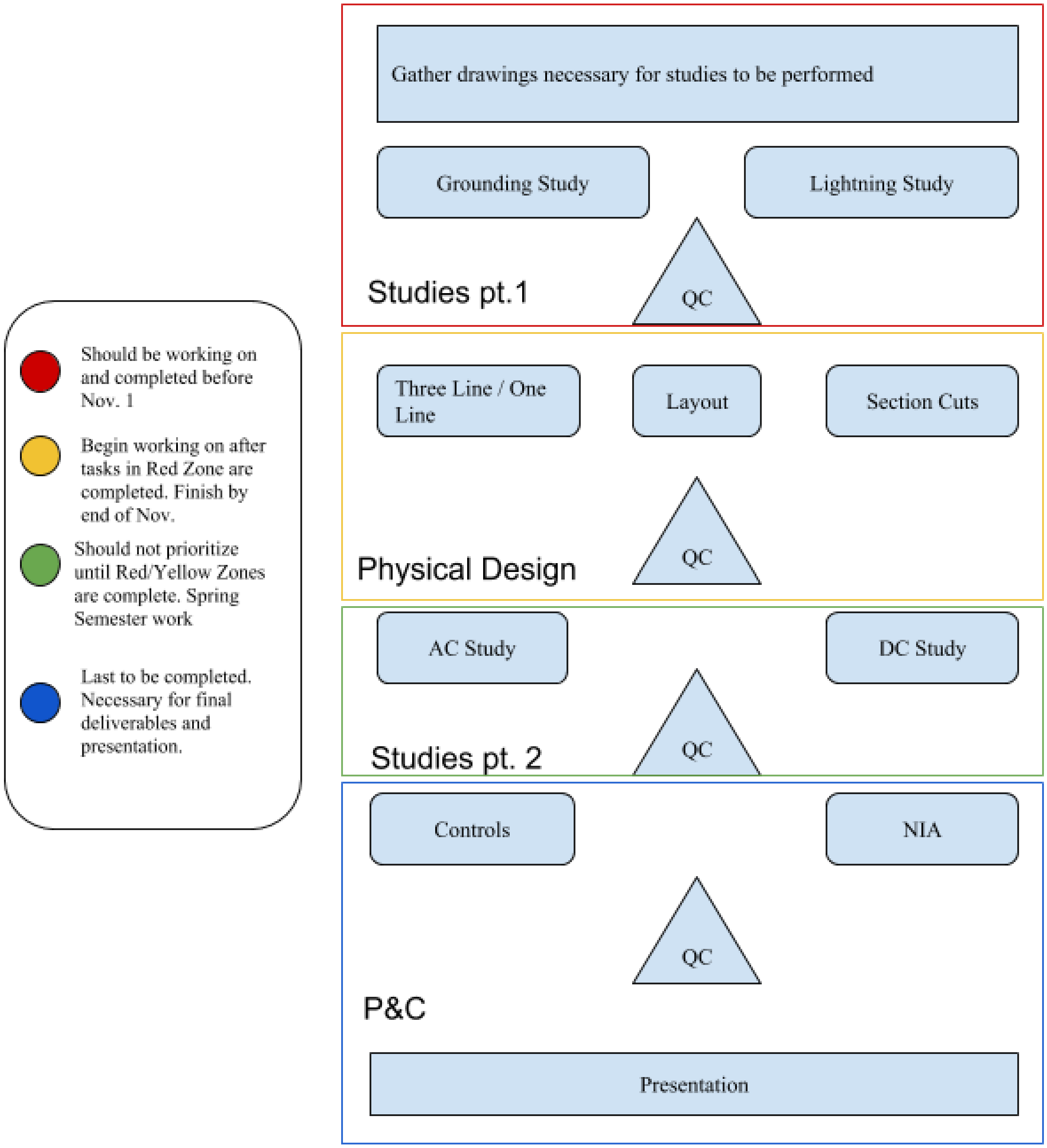

Figure 3: Project Approach

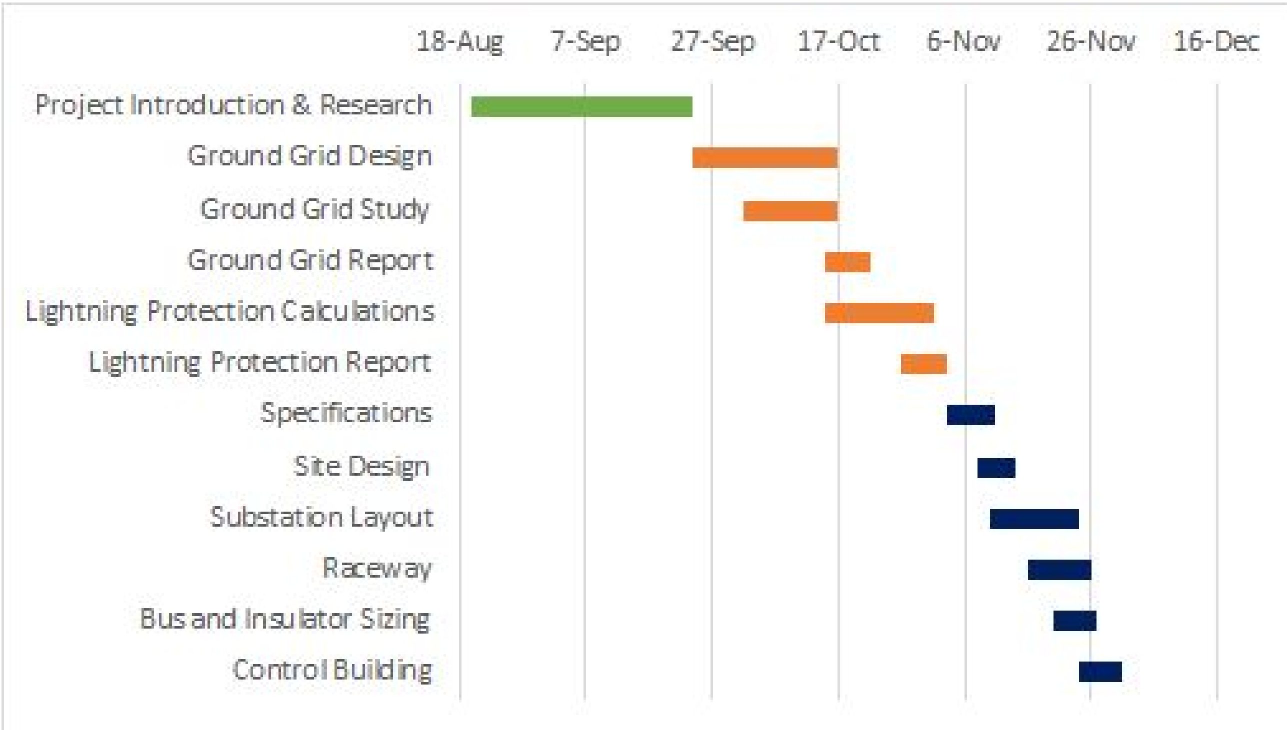

Figure 4: Semester 1 Gantt Chart

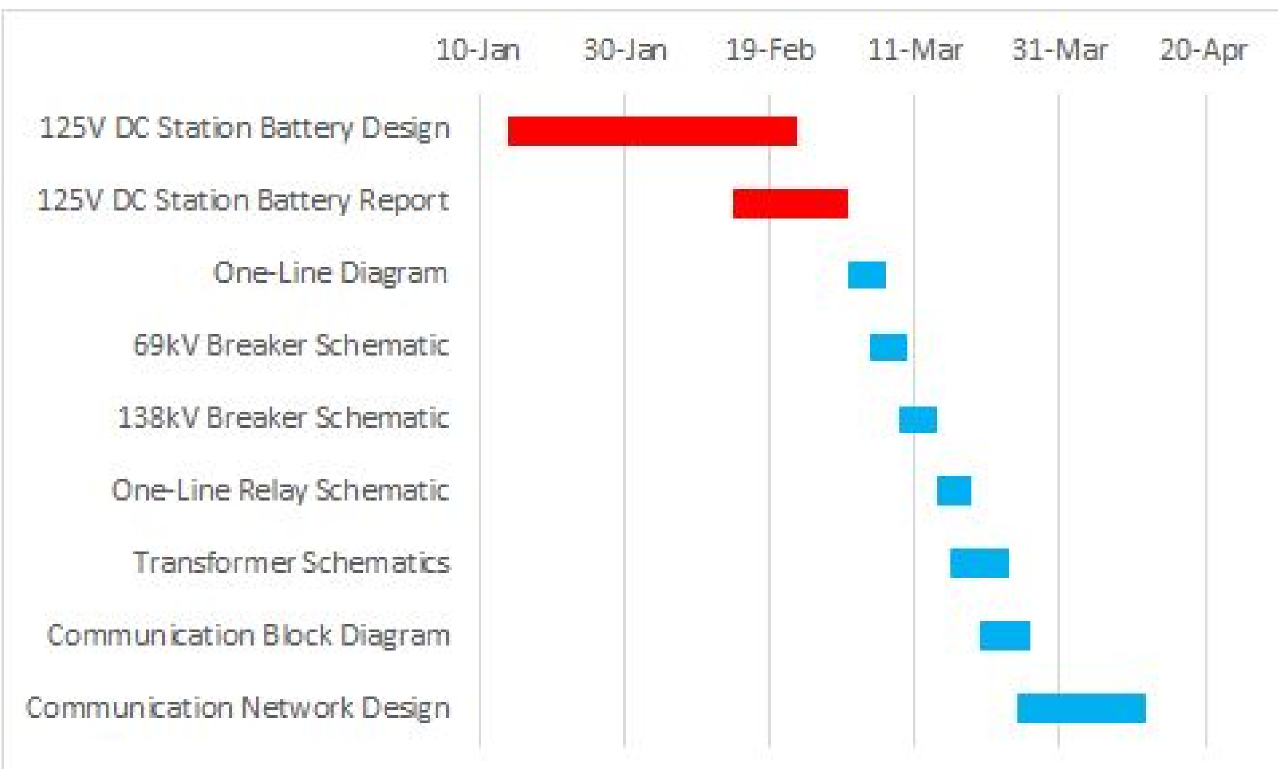

Figure 5: Semester 2 Gantt Chart

Tables

Grounding and Lightning Studies		
Task	**Description**	**Estimated Time (hours)**
Ground Grid	Design and analyze grounding system consistent with IEEE 80 using CDEGS software.	20
Lightning Protection	Evaluate and design lightning protection for substation in accordance with IEEE STD 998-2012 using the empirical curves method.	30

Table 1: Tasks for Grounding and Lightning Studies Phase

Physical Design		
Task	**Description**	**Estimated Time (hours)**
Specifications	Create specifications using BMcD standard specifications for substation structural steel, electrical equipment, and materials.	20
Site Design	Design roadway access to substation, road details, and fencing details.	10
Substation Layout	Layout the substation with the economics and future expansion in consideration.	70
Raceway	Design conduit plan for substation equipment requiring power or control connection.	30
Bus and Insulator Sizing Design	Complete calculations for bus and insulator sizes using predicted fault levels.	15
Control Building	Design the layout of the control building for the substation. This control building will be sized to fit the battery system, AC & DC panels, SCADA RTU and all protective relay panels.	15

Table 2: Tasks for Physical Design Phase

AC/DC Studies		
Task	**Description**	**Estimated Time (hours)**
125V DC Station Battery Design	Design a battery system using techniques from IEEE 485. This battery system will be designed with future loads in mind.	20

Table 3: Tasks for AC/DC Studies Phase

Controls & NIA		
Task	**Description**	**Estimated Time (hours)**
Relaying and Controls	Generate a one-line diagram, one 69kV circuit breaker schematic, one 138kV circuit breaker schematic, one line relay schematic, and the transformer schematics.	75
Communications	Create communications block diagram and design the communication network using both serial and ethernet network equipment.	95

Table 4: Tasks for Controls & NIA Phase