



BLACK & VEATCH

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69/12KV SUBSTATION DESIGN

ISU SENIOR DESIGN GROUP: MAY 15-01

Matt Backes	Team Leader
Faran Malik	Communication Leader
Ryan Jerve	Communication Leader
Bhargav Gouni	Key Concept Holder
Kiran Rane	Key Concept Holder
Sohail Suryavanshi	Webmaster

Project Website: <http://ecemay15-01.weebly.com/>

Project Sponsor: Black and Veatch

Advisor: Dr. Venkataramana Ajarappu

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1. PROJECT OVERVIEW

1.1 PROJECT DESCRIPTION:

Electrical substations are an essential part of an electrical generation, transmission and distribution system where voltage is transformed from high to low or in reverse. It links various power system components such as transmission lines, transformers, generators, and loads.

The primary function of a substation includes:

- Transforming voltages to different levels by use of transformers
- Communication with other substations and the regional control center
- Interconnection of various transmission lines across a region
- Monitoring of system health via the control center
- System protection

These functions are vital to the reliability of continued power to the grid and are addressed via comprehensive substation design and maintenance. The focus of this project is to complete the detail physical and protection and control design of a 69kV/12kV distribution substation. The transmission station is a 69kV/12kV, sectionalized radial bus substation with one of the 69kV outgoing lines feeding a distribution substation.

1.2 PROJECT SCOPE

The scope of this project has been predefined by our client, Black & Veatch, in a "Project Description" document. The scope of this project is summarized within this section. Black & Veatch has required a comprehensive design plan that incorporates physical design, protection and control design, and engineering management services. While the technical requirements of this project are highlighted, the ability to provide professional documentation and communication is just as imperative within the scope of this project.

1.2.1 PHYSICAL LAYOUT DESIGN

The team will be responsible for determining the layout of the components that we select to comprise the substation. The substation will be designed to avoid using excess space, while at the same time providing room for future expansions in case of increase in load requirements. The elevation cuts will be provided at a later date by the client, Black & Veatch.

1.2.2 STATION SERVICE TRANSFORMER & POWER SPECIFICATION

The team will be required to calculate and determine the associated specifications of the station service transformer and power. This will be based on the expected load from the industrial

center's load. After selecting the transformer, sizing will be determined for other associated components of the substation.

1.2.3 WIRING DIAGRAMS & CABLE SIZINGS

Proper documentation of the design and wiring diagrams will be provided by the senior design team. Wiring diagrams will be needed for both within the control house and outside. The inside of the control house will focus on panel wiring. Outside the control house, we will need to properly connect all conductors. In addition, based on rated loads, we will need to verify that the conductors are properly sized to handle power and current requirements.

1.2.4 STATION BATTERY & BATTERY CHARGER SPECIFICATION

A battery is needed prior to the development of the control house. The design team is expected to carry out the sizing of the batteries, battery chargers, and panels that will utilize this system. The team will need to consider the length of time to provide power via the battery to the service station based upon traditional service station outages.

1.2.5 GROUNDING GRID DESIGN

An essential part of the substation design is the design and layout of the grounding grid. We do not currently know which grounding software we will utilize. The client will provide us with a suggestion at a later date. The design of the grounding grid will follow all appropriate standards for the conductors' ability to handle rated fault currents.

1.2.6 SUBSTATION PROTECTIVE RELAYING & CONTROL SYSTEM DESIGN

The team will be expected to design a protective relaying scheme for the substation. This will include circuit breakers, circuit switches, and other components. All models will be verified for proper operation via their datasheets.

1.3 EXCLUDED FROM PROJECT SCOPE

1.3.1. SITE SURVEY INFORMATION

The design team will not be expected to evaluate and consider different geographical areas for feasibility of potential siting. The client has agreed to provide the design team with elevation cuts at a later date.

1.3.2. SYSTEM SIMULATION AND TESTING

While all due diligence will be paid to make sure the system is built for safe and reliable operation, no simulations will be ran on the design. No other type of formal testing will be done with the exception of the grounding software to be chosen. Verification of the team's design documents will be done via design review meetings with the client, Black & Veatch. A review with external professionals is also planned.

1.4 DELIVERABLES

The following list of expected deliverables was set forth by Black & Veatch. The first deliverable is the development of an engineering man-hour budget and schedule for this project in order to plan the overall senior design project. Black & Veatch will work with our team to manage the scope of the project to allow completion during the Fall and Spring semesters.

Some examples of these deliverables include, but are not limited to, equipment sizing calculations, substation layout drawings, station power design, protection and control schematics & project schedules.

1.4.1. FIRST SEMESTER (FALL 2014)

- Development of an engineering man-hour budget and schedule for the project with tracking of hours spent on each task (for comparison to actual budgeted engineering man-hours, presented at each design review)
- Design One-line Diagram
- Design Panel Layouts
- Design Schematic Document
- Calculations to determine service transformer and station power requirements
- Selection of equipment size and requirements including circuit breaker, disconnect switches, CCVTs, PTs, station service transformer, etc

1.4.2. SECOND SEMESTER (SPRING 2015)

- Calculations to determine battery and battery charger size
- Calculations to determine cable sizing
- Calculations to determine grounding requirements
- Complete Wiring Diagrams
- Design Physical Layout
- Bus and Insulator Design
- Design Justifications
- Three-line Diagrams

1.4 DESIGN CONSTRAINTS

1.4.1 OPERATING ENVIRONMENT

As this project is about building a hypothetical substation, the environment and weather of the location will serve as constraints for this project. Though these will not directly affect any of our calculations, these constraints need to be taken into account when considering soil type, humidity, temperatures, snow etc. All of these parameters will affect some of our layout design such as foundation planning and grounding.

1.4.2 STANDARDS APPLICABLE

Standards will play a significant role in optimizing the design process and will serve as rigid design constraints. There are several standards set by international authorities that will govern the design of this substation. Below are a few of the primary standards that are appropriate in terms of the early phases of the project's development. As the project progresses, more standards will be explored and documented.

Environmental Standards

RUS Environmental Policies and Procedures, 7 CFR 1794

This Regulation specifies RUS environmental requirements pursuant to the implementation of the National Environmental Policy Act of 1969 and Council on Environmental Quality Regulations. It also references additional authorities, directives, and instructions relevant to protection of the environment.

Public Safety

Substations should be safe for people who may have occasion to be near them. The primary means of ensuring public safety at substations is by erecting a suitable barrier such as a metal fence. Unless local restrictions are more conservative, the fence needs to meet the minimum requirements set by IEEE St. 1119, 'IEEE guide for Fence Safety Clearances.'

Weather

As dependence on the use of electricity grows, it is increasingly important that substations operate more reliably in extremes of weather than in the past. The substation must be impervious to snow damage and consideration needs to be given to snow accumulation and maintenance of clearances. Extreme

temperatures could affect circuit breakers, relay protection, or the bus. Hence the engineer should seek local data on this weather variable.

Foundation Standards

IEEE Std. 691

The objective of this guide is to provide valuable information on design methods for foundation design engineers. The information contained in this guide covers the different kind of foundations for various types of transmission structures; drilled shafts, pile foundations, and anchors; and procedures for conducting load tests.

Power Transformer Standard

Power transformers need special care in their application, specification and procurement because of their great importance and complexity. Hence they need to follow some industry standards and guides of national organizations such as the American National Standards Institute (ANSI), IEEE, etc., and RUS IP 202-1, 'List of Materials Acceptable for use on Systems of RUS Electrification Borrowers.'

Grounding Standards

The most recommended authoritative guide for grounding safety and standard: **IEEE Std. 80, "Guide for Safety in Substation Grounding"**

1.5 RISKS

Designing a substation often involves some risks associated with it. While designing a substation, the designers need to consider various risks such as its location, its weather conditions, protection, control and complying with project deadlines. Proximity of the substations to wetlands is essential in order to avoid flooding and its proximity to animals such as rodents can have some adverse effects on the substation functioning. In a similar way, the selection of appropriate protection and control is critical to avoid risk.

1.5.1 RISKS TO THE PROJECT TIMELINE

It is easy to get distracted and wander off from the project timeline. Best possible practices and measures should be taken to work hand-in-hand with the planned project timeline.

2. SYSTEM LEVEL DESIGN

2.1 SYSTEM LEVEL REQUIREMENTS

2.1.1 FUNCTIONAL REQUIREMENTS

Due to the theoretical nature of this project, no physical items are expected as deliverables. The requirements given are all necessary to the proper design of a functional distribution substation. Therefore, the following requirements are considered to be **functional**:

- Development of an engineering man-hour budget and schedule for the project with tracking of hours spent on each task (for comparison to actual budgeted engineering man-hours, presented at each design review)
- Substation layout of the sectionalized radial transmission substation
- Calculations to determine station power requirements
- Calculations to determine battery and battery charger size
- Calculations to determine cable sizing
- Calculations to determine grounding requirements
- Selection of equipment size and requirements including circuit breaker, disconnect switches, CCVTs, PTs, station service transformer, etc.
- Development of protection and control design documents based upon the protective relay scheme identified by B&V

2.2 SYSTEM DESIGN

2.2.1 CONCEPT BLOCK DIAGRAM

This project has been divided up into five different design phases to organize the design process more effectively and improve the efficiency of our work. The following block diagram outlines the five phases and their intermediate steps.



Figure 1: Block Diagram

3. DESIGN PROCESS AND FUNCTIONAL DECOMPOSITION

3.1 SYSTEM INPUT/OUTPUT ANALYSIS

The substation is a sectionalized radial bus system with one incoming line and three outgoing lines.

3.1.1 SYSTEM INPUTS

The input to the system is a line carrying power delivered from transmission lines coming from a transmission substation. This is labeled "HS Volts line" on the one-line diagram. This line has communications signals which are sent with one phase of the power line and later filtered off the power line using a wave filter.

3.1.2 SYSTEM OUTPUTS

The system has three outgoing lines, labeled "Cir 1", "Cir 2", and "Cir 3." One of these lines is feeding an industrial load. Each relay within the substation can be considered a subsystem with its own outputs.

3.2 HARDWARE/SOFTWARE SPECIFICATIONS

The project is entirely software based and no physical deliverables are required. We will primarily be working with AutoCAD.

3.2.1 SIMULATIONS AND MODELING

The project will be almost entirely modeled in AutoCAD. The one-line diagram, three line-diagram, physical layout, control house arrangement, panel layouts, and AC/DC Auxiliary system schematics will all be developed in AutoCAD. The only deliverable that will not be developed in AutoCAD will be the grounding system. The grounding system will be developed using WinIGS.

Simulations will not be required for our project. Only the software models are included in the deliverables.

3.3 PROCEDURES AND SPECIFICATIONS

3.3.1 TESTING

No formal testing is required for the project since we are only providing software models of the substation. We will verify our designs by consulting with professional engineers at Black and

Veatch. Professor Dr. Ajjarapu will be looking over our designs as well. Black and Veatch conducts internal reviews of its substation design documents within the company, so this process reflects the industry's standards.

3.3.2 IMPLEMENTATION ISSUES

There are many challenges associated with this project. Each of our project group members had little to no substation knowledge before starting this project so we have all needed to learn an immense amount of information about substations before beginning the design process. Finding a good starting point for the design process was difficult because the research process is quite extensive.

4. DESIGN DECISIONS, DISCUSSIONS AND JUSTIFICATIONS

4.1 ONE LINE DIAGRAM

The one line diagram is a simplified graphical representation of three phase power system. Electrical equipment such as circuit breakers, transformers, capacitors, bus bars and conductors are shown by standardized schematic symbols. Elements on the diagram do not represent the physical size or location of the equipment. The one line diagram we came up with is as follows:

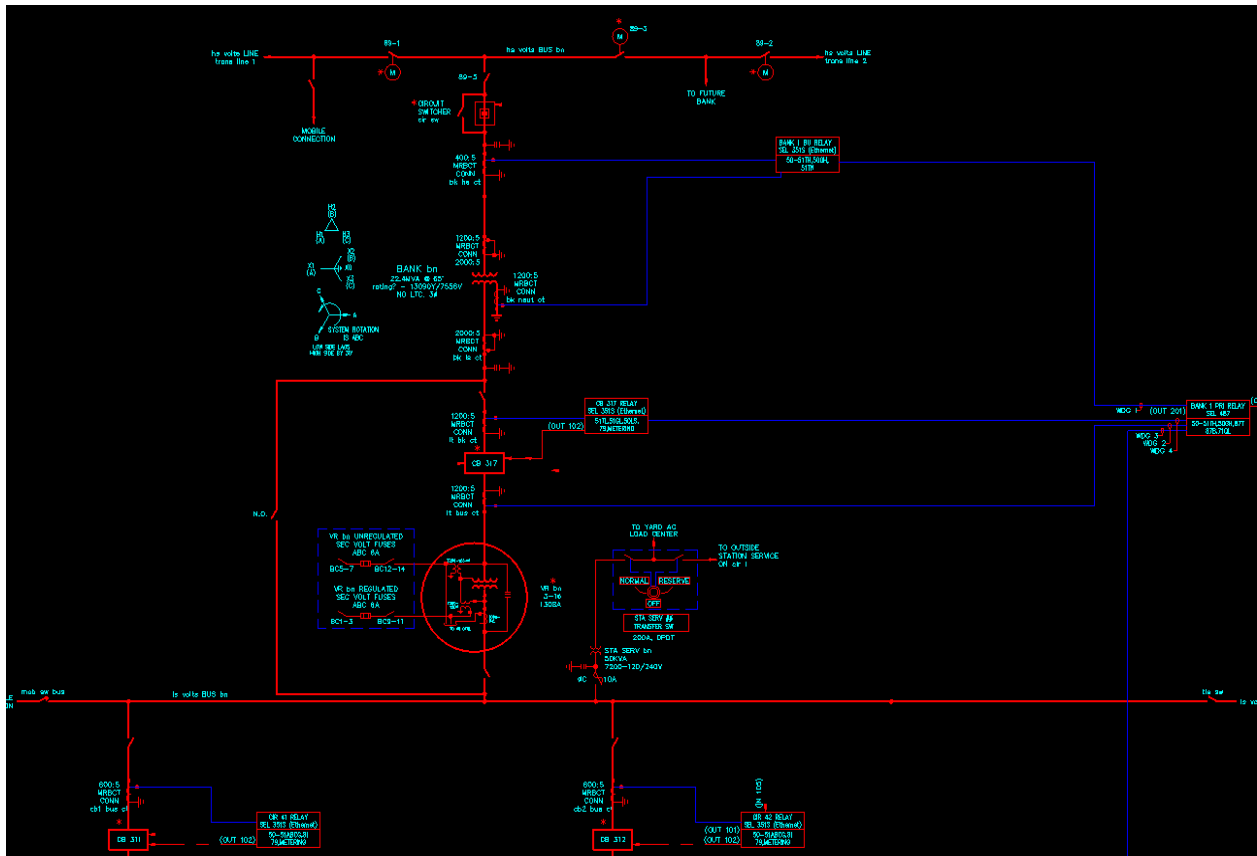


Figure 2: One Line Diagram

4.1.1 FORMATION

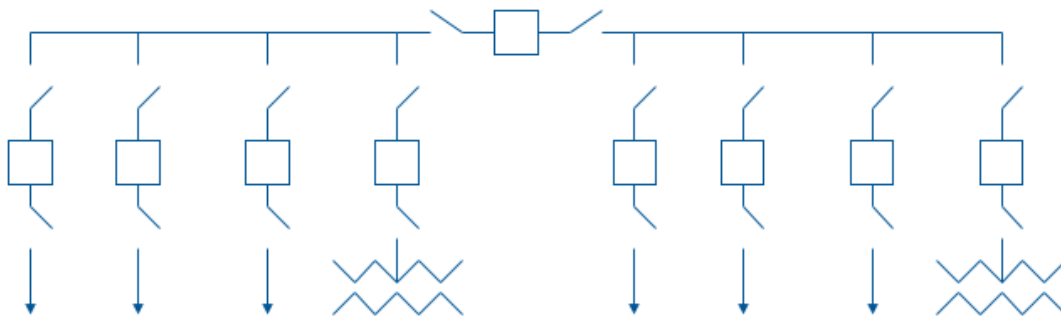


Figure 3: Bus Configuration

In every substation, a circuit breaker formation must be selected for the system. In certain systems, the formations are very complex and redundant to increase the reliability and safety of the substation, whereas in other systems simple formations are used for the sake of cost and lack of necessity for complicated systems. Our substation formation is called a sectionalized radial bus formation. A radial bus formation is one of the simplest formations. It is simplified

and low in cost, but if a circuit breaker fails to trip, the entire substation is lost. To prevent loss of the entire substation, a sectionalizing circuit breaker is added on the bus. If there is a fault on the bus, a sectionalizing circuit breaker will trip and protect the rest of the substation. It is called a sectionalizing bus because they divide the substation up into sections. The following image is a sectionalizing radial bus.

4.2 CONTROL HOUSE LAYOUT

The control house houses the switchboard panels, batteries, battery chargers, relay, metering, and control equipment. It provides year round weather protection and security for the control equipment. It is arranged to resemble actual equipment and the circuit layout. Cables enter the house via windows, sleeves, or cable pits and are handled with cable trenches, false floors, or conduits.

CONTROL PANEL ARRANGEMENT

Black and Veatch sent us a standard panel general arrangement for the control building and the clients control panel arrangement. Changes are to be made to the standard panel general arrangement drawing so that it and control design.

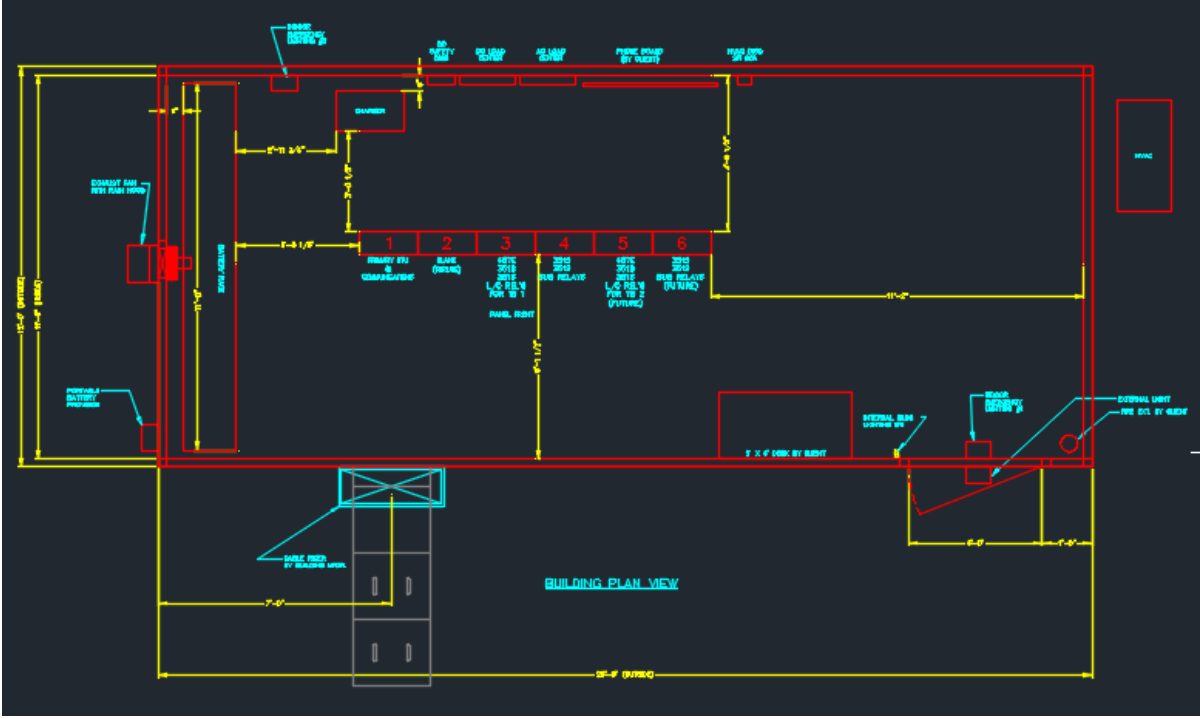


Figure 4: Control House Building Plan View

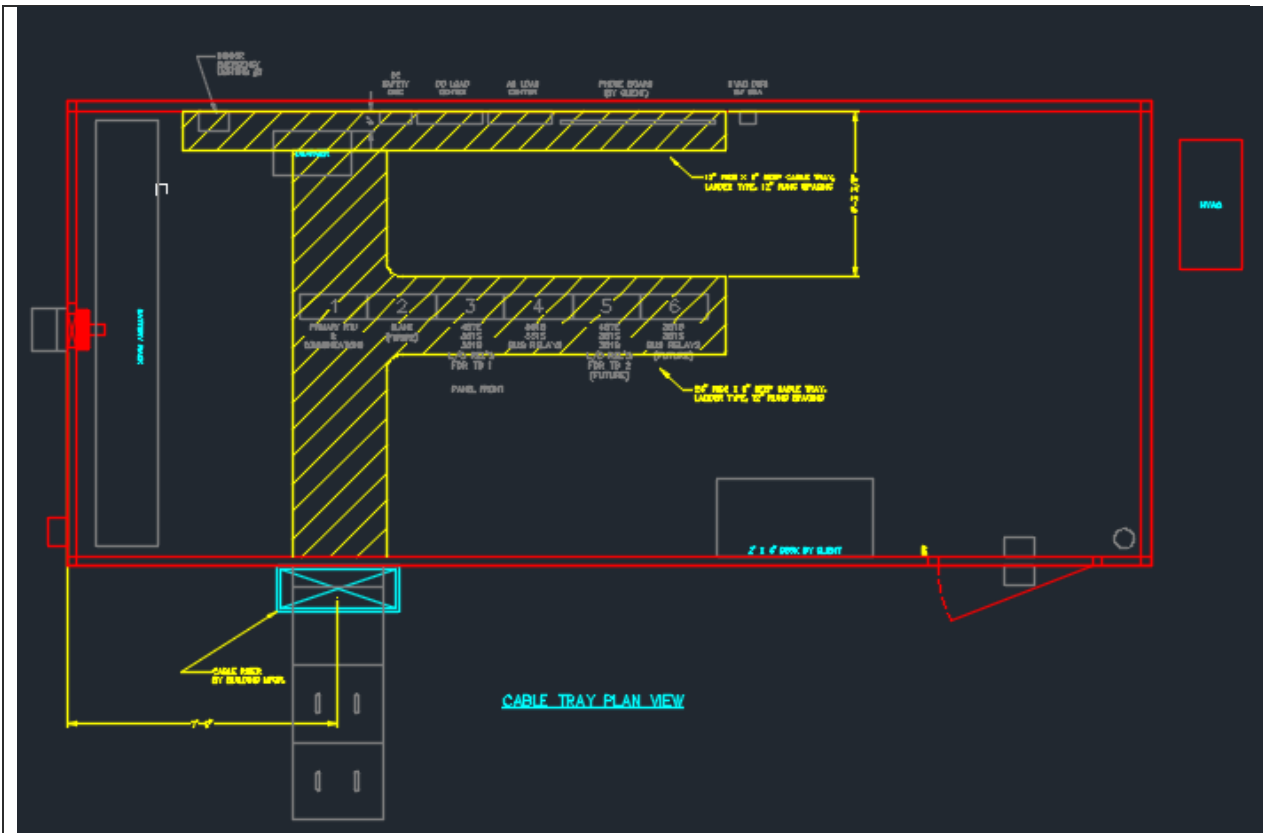


Figure 5: Control House Cable Tray View

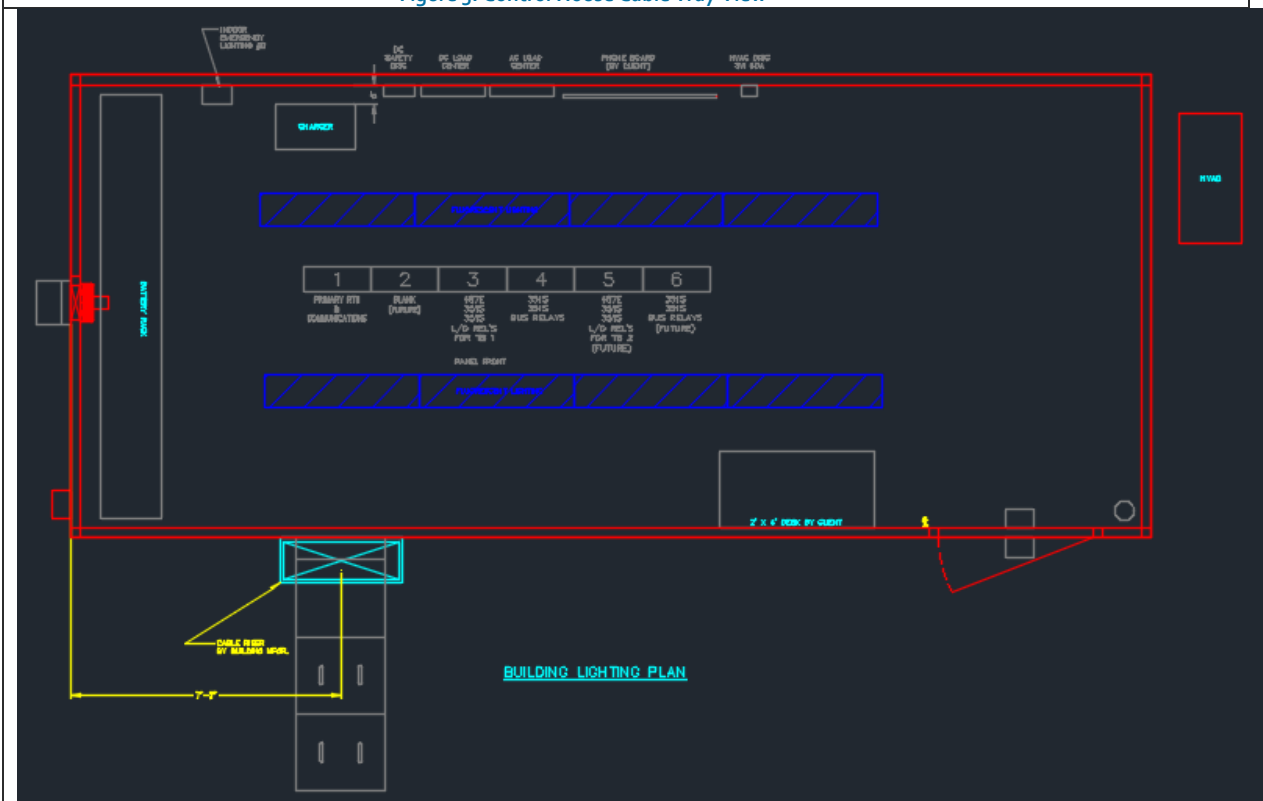
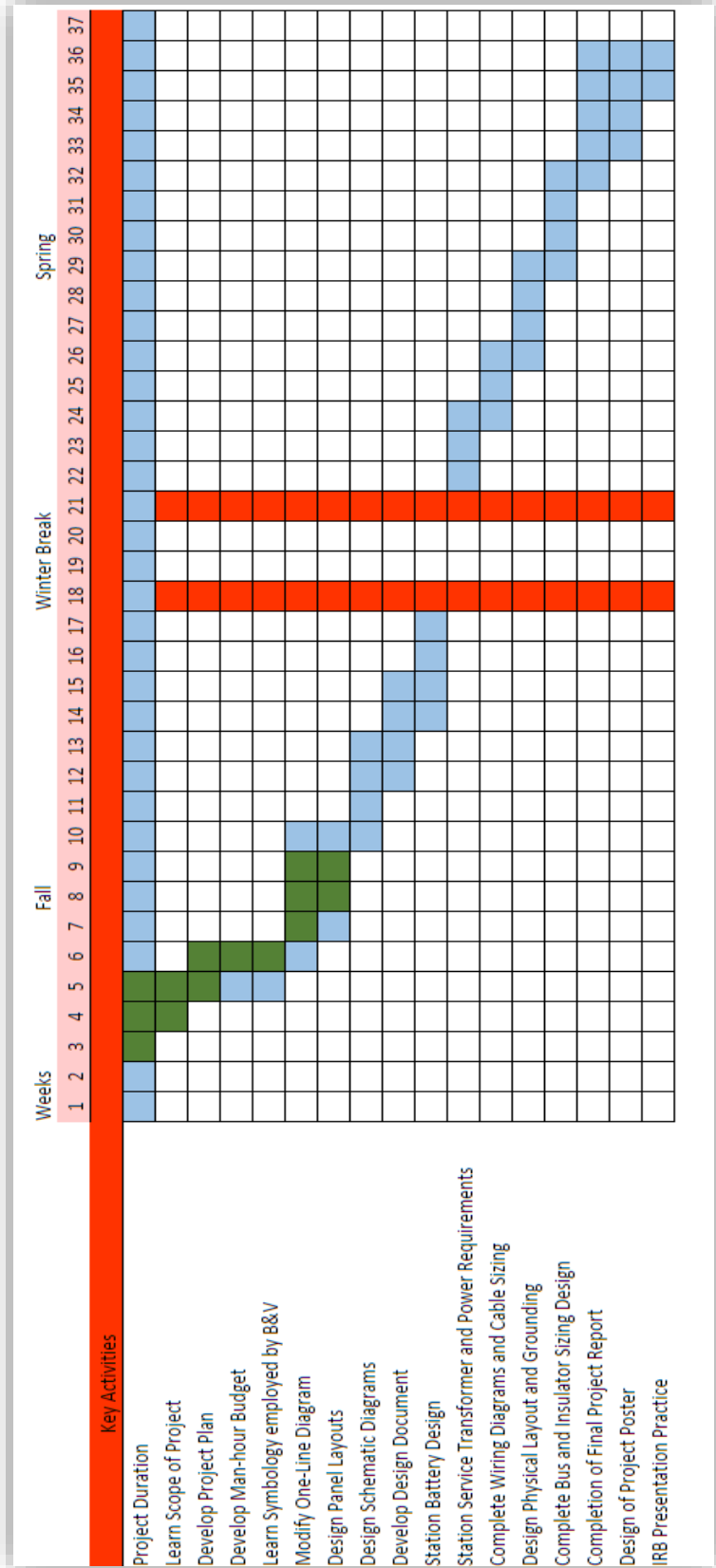


Figure 6: Control House Lighting View

5. WORK PLAN

5.1 SCHEDULING: AUG 26, 2014 – MAY 10, 2015



5.2 WORK BREAKDOWN STRUCTURE

Review Materials	Responsible Party	Details
Understanding Requirements and Specifications	Entire Team	Substation Design manual Scope Document
Project Documents	Matt Backes, Kiran Rane Bhargav Gouni, Ryan Jerve, Faran Malik	Draft Project plan Draft Design Document
Layout	Bhargav Gouni, Kiran Rane Faran Malik, Ryan Jerve	One Line Diagram Control House layout Foundation Plan Grounding layout Raceway
Protection & Control Design		Relaying and Controls 125V DC Station Battery Design Bus and Insulator Sizing

5.3 RESOURCE ALLOCATION

Software	AutoCAD WinIGS
Hardware	ECPRE Lab Resources
Advisor	Dr. Venkataramana Ajarappu
Black & Veatch Contacts	Adam Lieterski Josephine

Name	Personal Role
Matt Backes	Team Leader
Bhargav Gouni	Key Concept Holders
Kiran Rane	Key Concept Holders
Faran Malik	Communication Leaders

Ryan Jerve	Communication Leaders
Sohail Suryavanshi	Webmaster

6. CONCLUSION

This senior design project has helped us learn the physical, protection, and control design of a 69kV/12kV distribution substation along with the different components that are used within a substation. As a team, we developed an engineering man-hour budget, one-line diagram, three-line diagram, panel layout design, schematics, bus and insulator design, and selected equipment sizes for various component along with performing various substation level calculations. This project was very helpful in learning about the various components that are used within a distribution substation. We obtained real world experience by working with an off-campus client virtually along with learning to deal with time constraints and working as a team.