BLACK & VEATCH

69/12kV SUBSTATION DESIGN

ISU SENIOR DESIGN GROUP: MAY 15-01

Matthew Backes	**Team Leader**
Faran Malik	**Communications Leader**
Ryan Jerve	**Communications Leader**
Sohail Suryavanshi	**Webmaster**
Kiran Rane	**Key Concept holder**
Bhargav Gouni	**Key Concept holder**

Project Website: http://may1501.ece.iastate.edu/

Project Sponsor and Client: Black and Veatch

Advisor: Dr. Venkataramana Ajjarapu

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1. PROBLEM STATEMENT

Due to an increased energy demand from a new factory, a 69kV/12kV transmission substation will need to be designed by Black & Veatch. Our senior design project team will be responsible for the complete design of the substation which includes physical design, protection and control design, and associated construction deliverables.

2. PROJECT SCOPE

The scope of this project has been predefined by our client, Black & Veatch, in a “Project Description” document. A summary of the different aspects to the scope can be found below. 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.

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 conscious and wary of use of space to avoid using excess space, while at the same time provided room for future expansions if the load requirements ever increased. The elevation cuts will be provided at a later date by the client, Black & Veatch.

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.

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 within and outside of the control house. Within 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.

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 how long to provide power via the battery to the service station based upon traditional service station outages.

2.5. GROUNDING GRID DESIGN

An integral part of substation design is the design and layout of the grounding grid, and the team is expected to complete this. 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 conductors being able to handle rated fault currents.

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.

3. EXCLUDED FROM PROJECT SCOPE

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.

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.

4. PROJECT REQUIREMENTS

The following list of expected deliverables was set forth by Black & Veatch. The first deliverable will be to develop 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.

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).
- 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.

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

5. ASSESSMENT OF PROPOSED SOLUTION

As with any design solution, there will be strengths, weaknesses, and trade-offs. This section will highlight some of the design choices, why they were made, and any implications, good or bad, that the design choices will entail.

5.1. BUS CONFIGURATION

The backbone of a substation is the bus configuration. There are many configurations that can be utilized, each calling for a different situation and budget configuration. Our choice for bus configuration is the sectionalized radial bus. The benefits of this configuration are its flexible operation, it can isolate bus sections for maintenance, and in the event of a breaker failure, we will not lose the entire substation. There are disadvantages compared to other bus configurations. Our configuration requires an additional breaker for sectionalizing, thus a higher cost is associated with this configuration as compared to a simple single bus configuration. The sectionalizing may cause interruption of non-faulted circuits. In consideration of these factors, we decided the sectionalized radial bus would provide us with the best flexibility and resilience for the cost. Main and transfer bus configuration was considered, as well, but the protection and relaying may become too complicated for our design group. Additionally, a bus fault in the main and transfer bus configuration results in a loss of the entire substation.

5.2. CONTROL HOUSE

Another design component of the substation is the control house. The control house aggregates all the switchboard panels, batteries, battery chargers, relay, metering, and control equipment. The layout of the control house was provided by the client. However, future design solutions will include a battery system, which will be chosen in the second semester. We will need to determine the load size of all the auxillary equipment and make sure our battery can provided power to the auxillary equipment for an acceptable amount of time.

5.3. RELAYS

Protection and relaying is paramount in the design of a substation. The client specified which company to use for our relays, but the design team is in charge of choosing a suitable relay. For our transformer protection relay, we chose the SEL-487E. This relay has many functionalities. It will provide us with protection of the transformer, enable Ethernet communication, and current differential protection. The weakness of this choice is that it may have too many functions, and that we are paying a higher cost for unutilized features.

6. VALIDATION & ACCEPTANCE TEST

During the design process, we will be getting our drawings verified by Black & Veatch engineers for accuracy and proper implementation. Designs will be revised if drawings are unable to meet the criteria given by the client and also based on the feedback received from the B&V engineers.

7. CONTENT

7.1. 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:

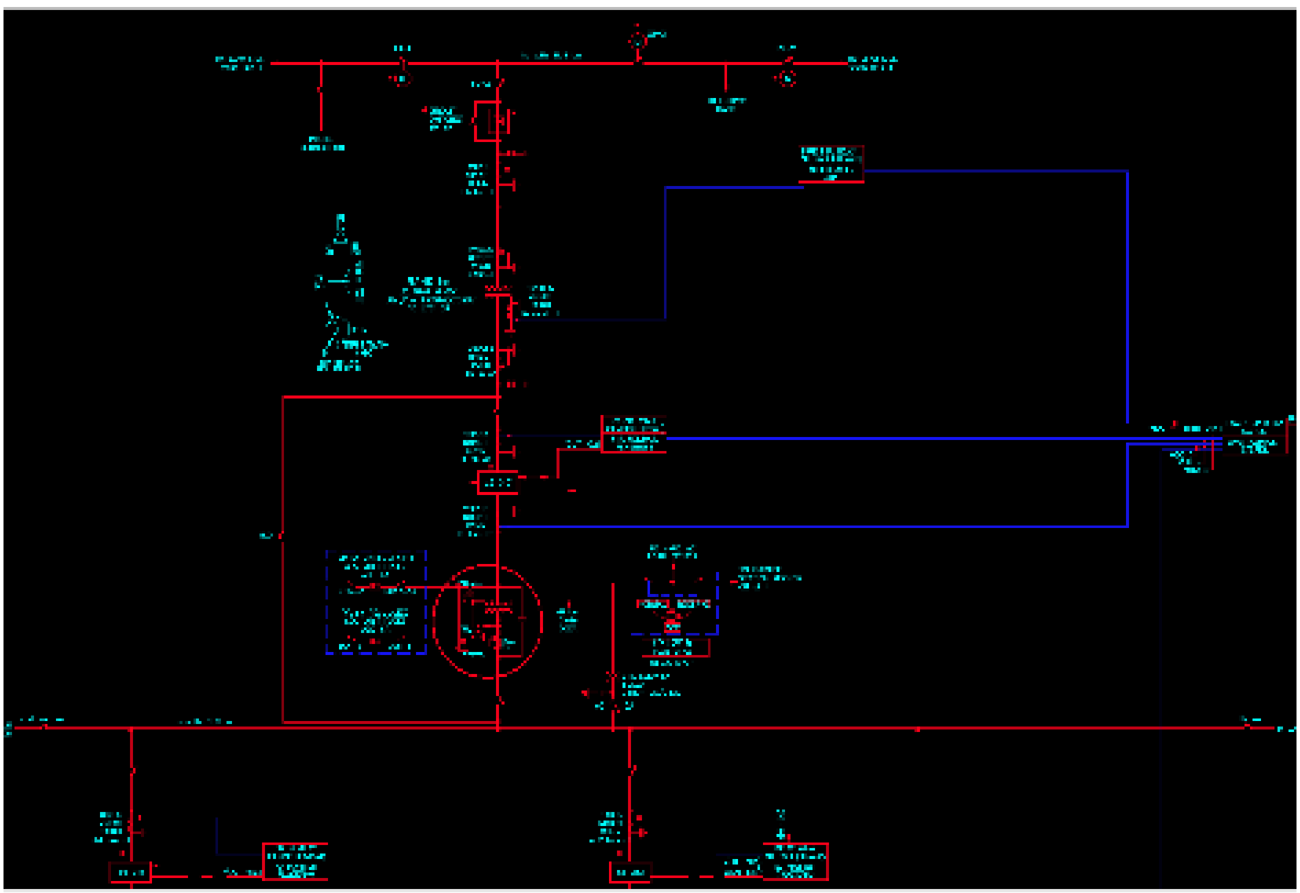

Figure 1: One Line Diagram

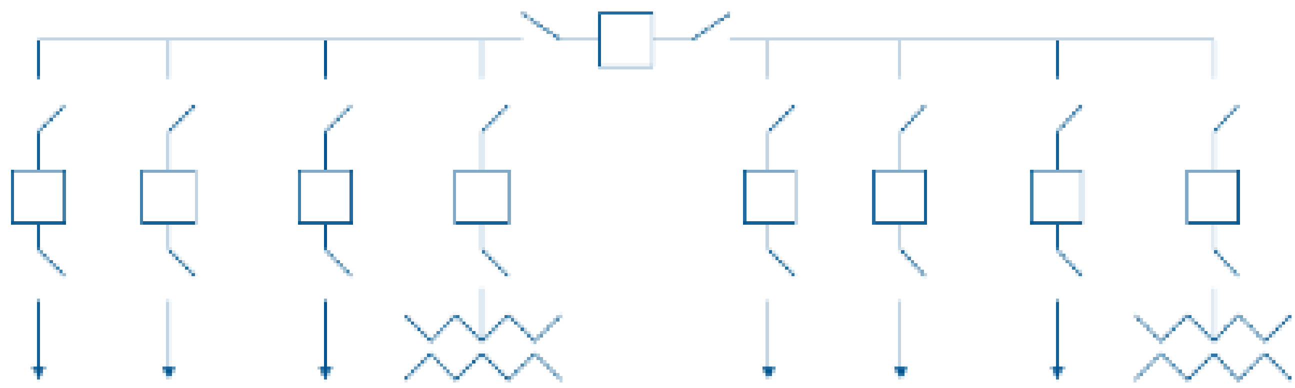

Figure 2: Bus Configuration

7.2. 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

7.3. 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.

7.4. 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.

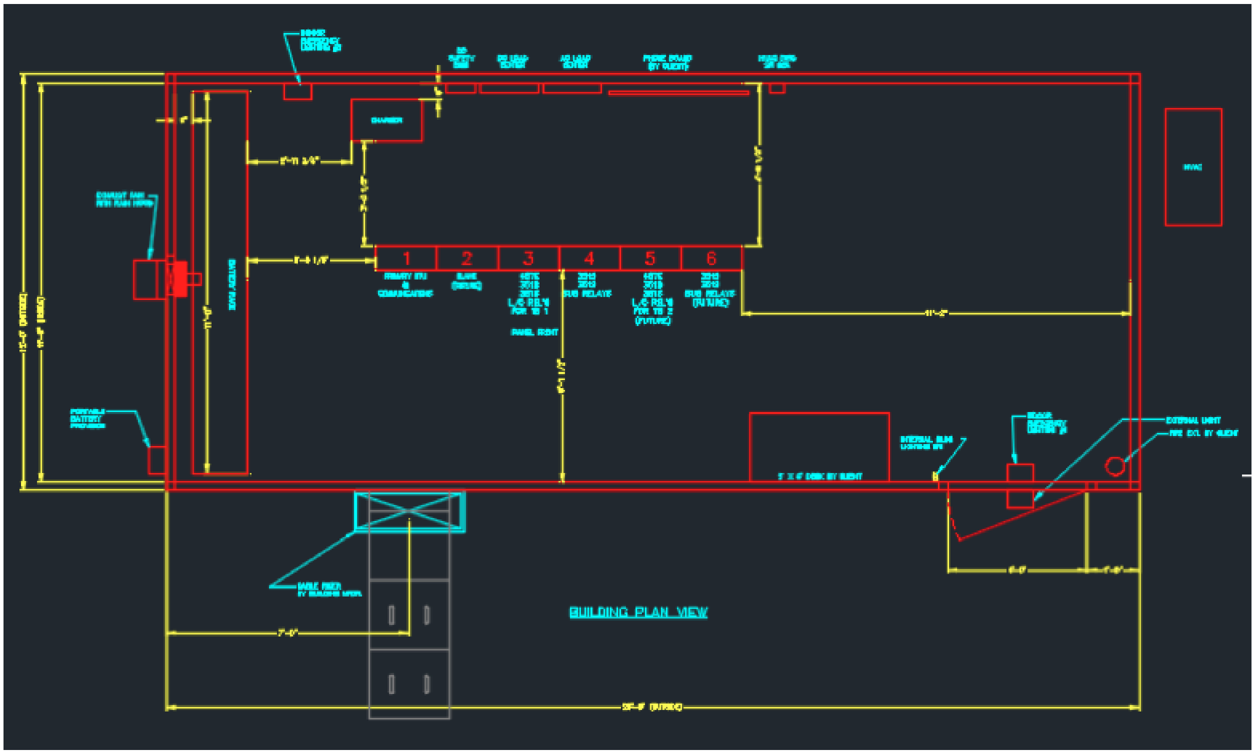

Figure 3: Control House Building Plan View

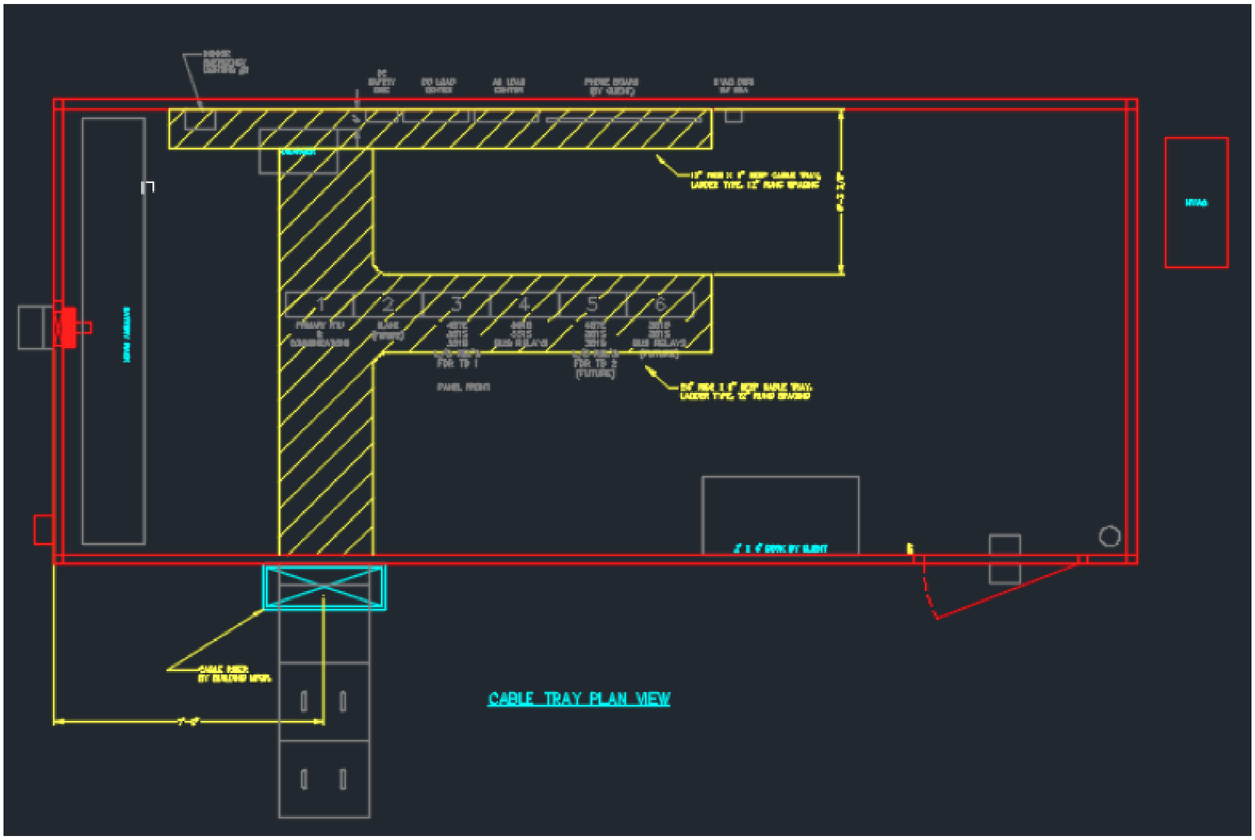

Figure 4: Control House Cable Tray View

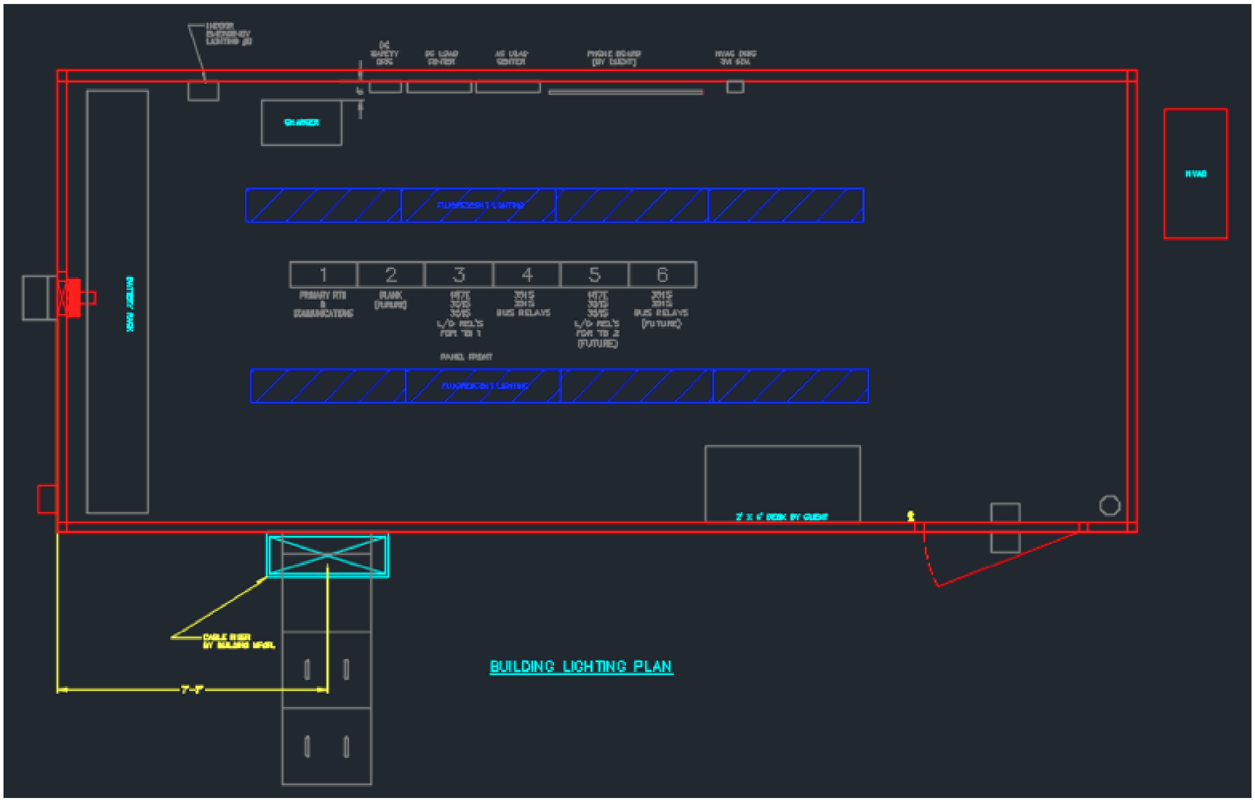

Figure 5: Control House Lighting View

8. DESIGN CONSTRAINTS

8.1. 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.

8.2. 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"

9. TECHNICAL APPROACH

This design project has been broken down into five different phases to better facilitate it. A block diagram below lists the five different phases and its intermediate steps.

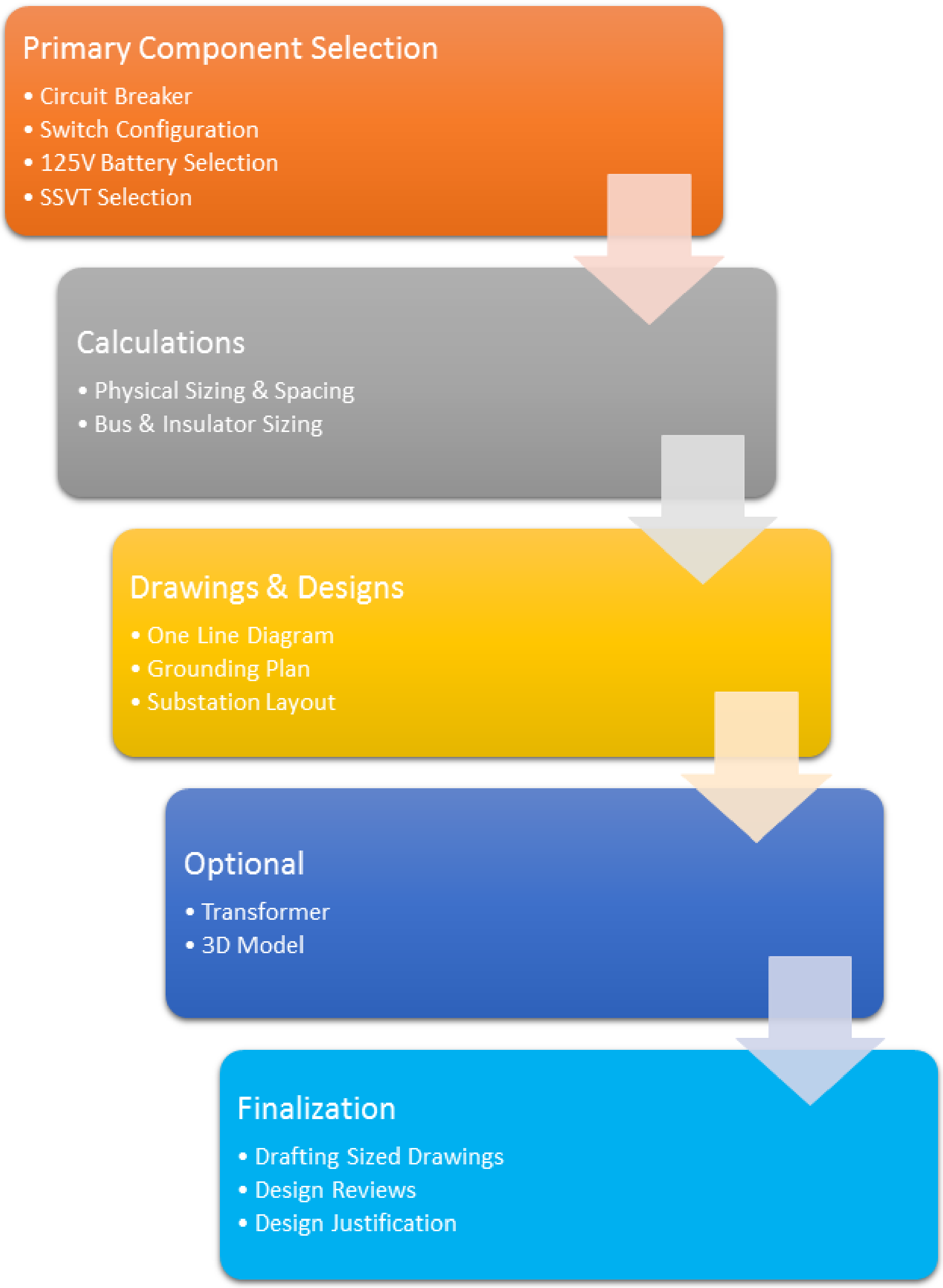

Figure 6: Design Phase Block Diagram

10. PROCESS DETAILS

10.1. SYSTEM INPUT/OUTPUT ANALYSIS

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

10.1.1. 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.

10.1.2. 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.

10.2. HARDWARE/SOFTWARE SPECIFICATIONS

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

10.2.1. 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.

11. TEST PLAN

No formal testing is required for the project since testing is excluded from the project scope for this substation design. 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.

12. REQUIREMENTS

No physical items are expected within the scope of this project. All the requirements are for the proper design of a functional substation.

12.1. RESOURCE REQUIREMENTS

We will need access to the computer-aided design software package AutoCAD to be able to build our one-line and three-line diagrams. We may also need access to a ground fault calculation software. This may turn out to be WinGIS.

13. PROJECT SCHEDULE

September	Learn project scope, develop project plan
October	Develop man-hour budget, modify one-line diagram
November	Design panel layouts, design schematic diagrams
December	Develop design document, station battery design
January	Station service and transformer and power requirements, complete wiring diagrams and cable sizing
February	Design physical layout and grounding
March	Complete bus and insulator sizing design
April	Complete project report, design project poster, IRB presentation practice
May	Presentation

Table 1. Schedule for both semesters.

13.1. GANTT CHART

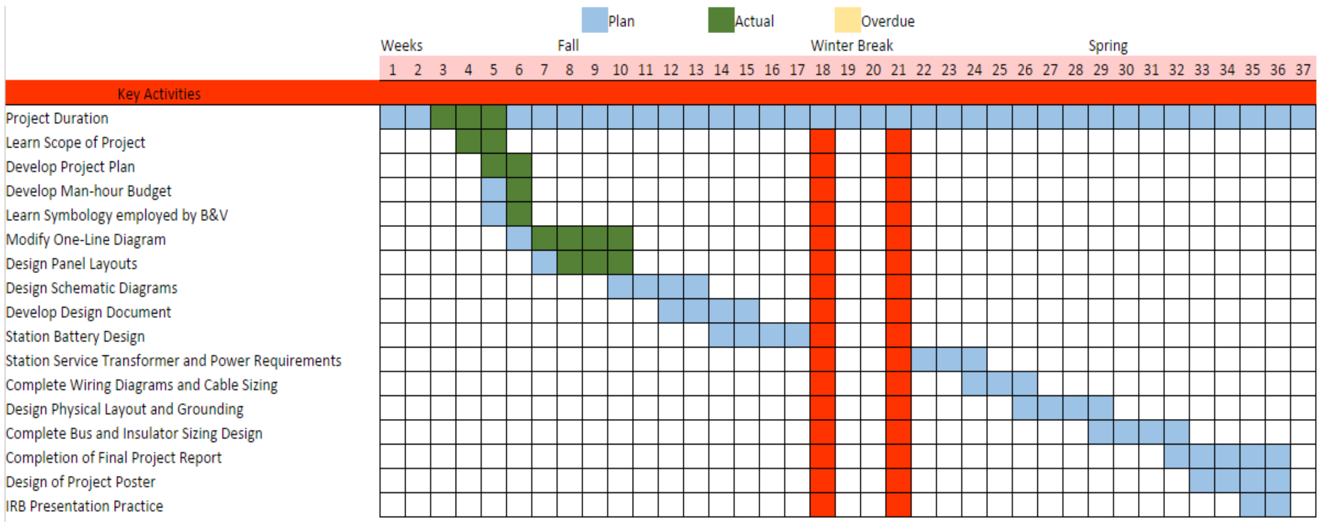

Figure 7. Gantt chart for both semesters.

13.2. 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, Sohail Suryavanshi Bhargav Gouni, Ryan Jerve, Faran Malik	Draft Project Plan Draft Design Document
Layout	Bhargav Gouni, Kiran Rane Faran Malik, Ryan Jerve Matt Backes, Sohail Suryavanshi	One-line Diagram Control House Layout Protective Relay Layout
Protection & Control Design		Relaying and Controls 125V DC Station Battery Design Bus and Insulator Sizing

Table 2. Breakdown of tasks and who completed each one.

14. 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 and control and complying with project deadlines. Proximity of the substations to wetlands to avoid its flooding and its proximity to animals such as rodents can have some adverse effects on the substation functioning. In a similar way, choosing of appropriate protection and control hardware can be a risk as well.

14.1. 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.

15. COST CONSIDERATIONS

Position	**Rate/Hour**	**Hours**	**Costs**
Administrative assistant	$60	11	$660
Project controls/accounting	$79	44	$3,476
CAD Tech I	$62	0	$0
CAD Tech II	$86	0	$0
Engineering tech I	$69	0	$0
Engineering tech II	$75	403	$30,225
Engineering tech III	$82	0	$0
Senior Engineering tech	$118	163	$19,234
Engineer I	$86	0	$0
Engineer II	$100	559	$55,900
Engineer III	$111	30	$3,300
Senior Engineer	$135	0	$0

Project manager	$162	22	$3,564
Expenses		**1232**	**$116,389**
Total Expenses*			9,311
			$123,700
<u>Expected drawings</u>	**<u>Quantity</u>**		
KPD/PNL layouts	7		
Schematics	25		
Wiring diagrams	30		
Total	**62**		

Table 3. Expenses and expected drawings table.
*Expenses were estimated at 8% of marked up salary, billing will actually be pass through

16. MARKET/LITERATURE SURVEY

This project will require a significant amount of market research and literature research. We will need to do some literature research to gain background knowledge on the components of a substation. The team will also need to do some literature research on the various protection schemes for a substation. We will need to delve into current market product datasheets to select components that are necessary and fill our specifications. A significant time requirement will be needed for the market research to make sure we have done a thorough review for the best product available for our specific situation.

17. CONCLUSION

A 69kV/12kV distribution substation is being designed for an industrial load customer. The substation, at a high level, provides the customer with a usable voltage level and sufficient power. System protection is a key element in a substation, and this substation is no different. The protective relays now use Ethernet as a way to communicate with the control house. The bus configuration is of the type sectionalized radial bus. This configuration reduces outages for breaker failure operations. It also enables future expansion of the substation in a convenient and inexpensive way. Many instrumentation devices, enabled by utilizing current and potential transformers, are deployed to enable substation health monitor. All the devices are connected in a central location to enable convenient monitoring. Our transformer and circuit breakers were sized to allow for contingency events and for rated fault currents.

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 components 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 as a team.