

138kV / 13.8kV Substation Protection and Control Design Project

Final Report



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1 Introduction

1.1 PROJECT STATEMENT

The purpose of this project is to design a the protection systems and layout of a 138kV / 13.8kV greenfield, radial bus distribution substation that safely steps down voltage. A 138kV transmission line is connected to the distribution substation primary bus, where the power goes through a step-down transformer, until reaching three feeders where the power then is distributed to the general population. The protection system for the substation consists of various current transformers connected to relays that are designed to prevent overcurrent, a relay for the voltage transformer with a number of grounding contacts, as well as communication with other substation and regional control center (SCADA). All components involved in the distribution substation will be interconnected and having a protection plan design for each component.

1.2 PURPOSE

The purpose of this project is to create a protection scheme for a 138kV / 13.8kV distribution substation. Our client, Black & Veatch, has provided us with a list of relays they would like to use for the project, and we are tasked with connecting these relays to the substation via current transformers to protect against overcurrent. Throughout this project, we will create a database of drawings detailing the protection system, including the relay connections, control house layout, panel layouts and diagrams, and so forth.

1.3 GOALS

The goals for this senior design project are as follows:

- Design and refine a 138kV / 13.8kV substation one-line and three-line diagram
- Design the substation protection and control schematics
- Plan the layout for the substation control house

2 Deliverables

To meet our goals for this project, we have the following list of deliverables:

- Based on the protective relay scheme identified by Black & Veatch:
 - System one-line diagram
 - System three-line diagram

- Protection and control schematics
- Panel layouts
- Weekly teleconference with Black & Veatch
 - Weekly progress report & meeting minutes
 - Weekly meeting agenda in advance of meeting
- Project Design Review
- Final Presentation to Black & Veatch

3 Design

In designing this substation, we were provided with a preliminary one-line diagram from Black & Veatch and created a more detailed lower level design to suit the design requirements, standards and guidelines such as those mentioned in section 8. We also created a three-line diagram from our final version of the one-line diagram for the system protection and controls. Substation design is more than a simple transformer that steps down high voltages to low voltages; it has to be designed with protective and communication equipment to ensure faults can be cleared safely in order to protect transmission lines and consumers.

3.1 Previous Work/ Literature

Due to the prevalence of distribution substations, there is a lot of information at our disposal. Black & Veatch was our primary source of information, and they provided us with standard drawings, as well as a overview presentation that explained various concepts we can use for the one-line and three-line diagrams. Standard drawings were provided from Black & Veatch and were templates of the key protection diagram, one-line diagram, three-line diagrams, AC-DC protection documents and relay diagrams. A powerpoint on high voltage substations and previous senior design projects were given to us from our faculty advisor, which will also help the design process.

These works from previous groups have a persistent pattern of time-management issues. To overcome this problem, we will be implementing strict deadlines which we will stick to throughout the semester. Besides that, often these equipment could be outdated and it will be our job to update the equipments to use the latest technology for the optimal utilization of the equipment.

One challenge previous senior design teams have had was finishing all of the drawings entailed in the scope of work. In order to prevent this, we will be enforcing strict deadlines for every drawing to ensure all works will be completed. We are also going above and beyond

other projects, for we will be doing various power calculations to ensure the equipment can handle the current at which it is regulated for.

3.2 Proposed Block Diagram System

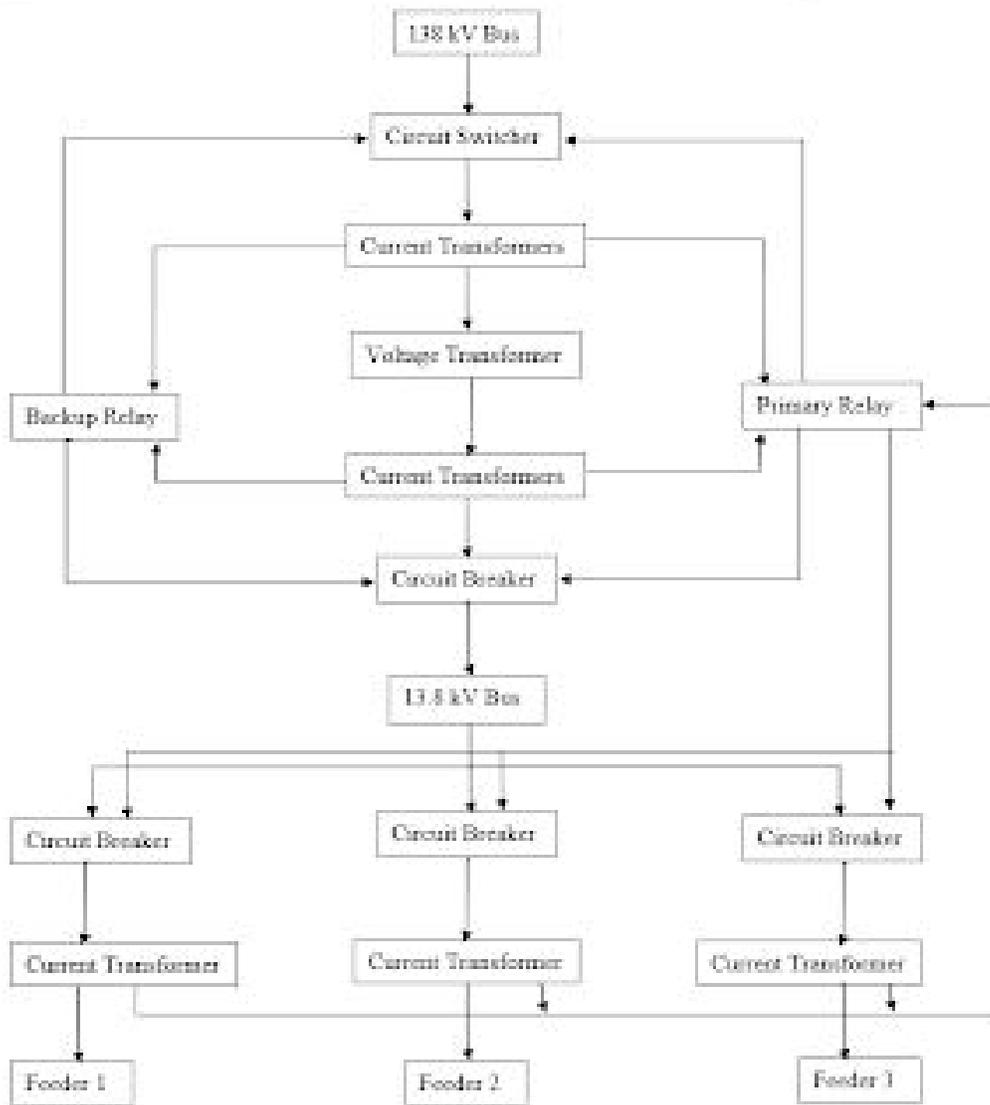


Figure 1. Block diagram of the protection system for the substation.

The substation transforms 138kV to 13.8 kV, and is protected by a SEL-487E transformer relay as well as multiple SEL-351S overcurrent protection relays. The relays are attached to the main line via a number of current transformers. There are circuit breakers designed to trip in case of overcurrent on the main line and each of the feeder lines, as well as a circuit switcher on the main line capable of handling up to 25kA of fault current. The main purpose was to design and understand what type of electrical contacts will be made throughout the various relays and why we are making them.

3.3 Assessment of Proposed Methods

We took an approach to our design project that involved laying out our schedule first with a Gantt chart and man-hour budget, and then creating one-line and three-line diagrams, panel layouts, and control schematics in AutoCAD. Since we worked with Black & Veatch, we are using an approach very similar to their own. However, technical manuals, requirements and standards have to be met. We have finished our Key Protection Diagram, the document in which all other documents will be based off of. In this document, we specify the relays in which fault currents will travel.

Specifically, we designed the electrical contacts within the substation, including the SEL-487E relay and the multiple SEL-351S relays. The design included disconnect switches that we will be designing the wiring diagrams of each relay and circuit breaker, as well as the different disconnecting switches will be switched depending on the type of fault that is detected. For example, if a fault is detected in phase A, but phase B and phase C are working properly, phase A will trip independently from the other phases.

3.4 Validation

Since the scope of this project was to design a greenfield substation, we used our weekly teleconferences with Black & Veatch to validate our design. Black & Veatch has a wealth of experience with distribution substations that we will be using not only for guidance, but also for confirmation that our design project is successful. A deadline for each rough draft of every document was set in order to receive proper feedback and validation in a timely fashion. Calculation of the power used by the AC and DC devices in the control house were used to size the fuses protecting each device. There were also calculations to properly size the transformers and relays.

4 Project Requirements/Specifications

4.1 FUNCTIONAL TESTING

The technical requirements for this project included designing a distribution substation to convert 138kV to 13.8kV using a radial bus system, and the panel layout, protection and control schematics. All of the functional components for this project will be designed in AutoCAD.

Testing included the protection status of the substation by doing several power calculations testing the amount of current going through the SEL-487E and the multiple SEL-351S relays. We designed the electrical contacts within the substation including the SEL-487E relay and the multiple SEL-351S relay. Programming the disconnecting switches will be switched depending on the type of fault that is detected. For example, if a fault is detected in phase A, but phase B and phase C are working properly, phase A will trip independently from the other phases.

4.2 NON-FUNCTIONAL TESTING

The non-functional component of this project was weekly meetings with Black & Veatch via Google Hangouts where we provided updates on our progress through meeting agendas beforehand and meeting minutes after. The other non-technical deliverables include a Gantt chart, and a man-hour budget.

4.3 STANDARDS

The standards for our design project are based on the 2014 NFPA National Electrical Code which played a huge role in governing the design process and served as rigid design constraints. However, it should be noted that this project draw upon guidelines set forth by industry, local, environmental and component-specific standards that can be found in the reference section 8. We used the SEL-487E relay for the primary protection of Bank 1. We will also be using the SEL-351S for the back-up relays, IT relay, as well as the relays which will be used to protect the feeders.

5 Challenges

The main challenge we faced as a group is understanding the project material such as the key protection plan, one line diagram, and the protection schematics. The reason this is such a major challenge is due to the fact that the project is very complicated and bulky because it is a real world design problem. Additionally we had minimal knowledge about the material going into this project. Even if we manage to pull off the project it wouldn't mean anything to us if we don't understand the reasoning behind the decisions made while revising the drawings.

Hence, at times, when we are could not figure out the materials at hand, we consulted multiple experts and resources in the field which included our Senior Design Advisor Professor Ajarapu, Black & Veatch Experts, National Electrical Code and of course, researching through the internet.

Another challenge we faced was designing the lower level documents in the future as the drawings requires more and more detail as we proceed with the project. These documents were based off of the key protection diagram, standard drawings, as well as the project scope document which was provided by Black & Veatch. This process required significant cross referencing of completed documents.

The next challenge we faced was ensuring that the specified amount of fault current will safely pass through the substation and be dispersed in a safe manor without harming the substation equipment. In order to do these calculations, we rated the current transformers 25% greater than listed, as per ANSI standards, to ensure the substation works correctly and safely.

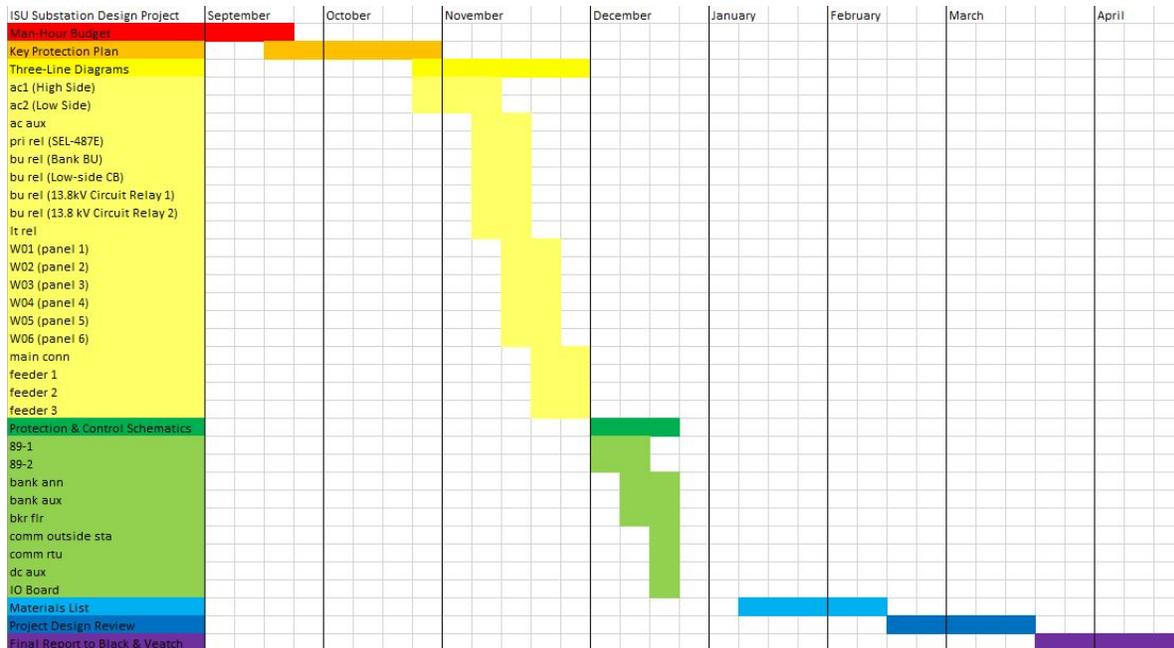
Besides that, another challenge that our group was facing is using AutoCAD to complete our designs. AutoCAD was very new to our team, so we had lots to learn for that portion of our project. Even simple tasks such as creating a PDF proved to be difficult. However, as time went by, we got more and more familiar with the different functionality of AutoCAD.

Cost and materials were not considered, as this project is a conceptual design performed together with our stakeholder, Black & Veatch. There was no cost implication as our main purpose of this project was to understand the basics on substations and the protection scheme as it is not as simple as placing a transformer. Therefore free CAD software available to us through Iowa State to omit the cost portion, and there will be no physical materials involved in the project.

There are no true health risks associated with this project. This is due to the fact that the project was intended for educational purposes only and there wasn't any physical component. However, there were possible risks associated completing this project that existed in the form of bottlenecks. Bottlenecks on this project included AutoCAD and becoming familiar with the industry safety and design standards.

6 Timeline

The initial timeline for our project is outlined in the following Gantt chart:



6.1 FIRST SEMESTER

For the first semester of our senior design project, we are developing a Gantt chart and man-hour budget for the project. We are also finalizing the one-line diagram of the substation, as well as our key protection plan for the substation. Lastly, we will be starting the three-line diagram of the substation and the schematics for protection and control.

6.2 SECOND SEMESTER

During the second semester of our design project finalized all the drawings including the three-line diagrams, DC schematics, and layout diagrams of the substation, as well as the protection and control schematics. We have created a database containing all of the drawings we have completed during our senior design project shown in section 9.1.8. We will be developing a materials list for the project, and send our design to Black & Veatch for review. With feedback from Black & Veatch, we will make any necessary changes to our design and create a presentation for Black & Veatch of our final design.

7 Conclusion

In conclusion, this substation design brought us a lot of industrial experiences that helped us have a taste of the things we do out in the job market. As we learned various methods to solve problems as well as the standards and requirement.

Project wise, we are responsible for designing a substation and all the protection schemes, and controls a whole so that we can truly understand the in depth details of designing a substation. The designing process included us brainstorming and working together as a team to ensure fairness, equal opportunities, and the healthy balance of workload in the team. The design documents, which will be reviewed according to our standard reviewing procedure as mentioned before, was used to ensure our design is of the best quality before the documents were finalized. At the very end of the project, we will showcased our final substation design to Black & Veatch and demonstrated our skills and knowledge along the way on working on this project.

8 References

References for this project includes but not limited to:

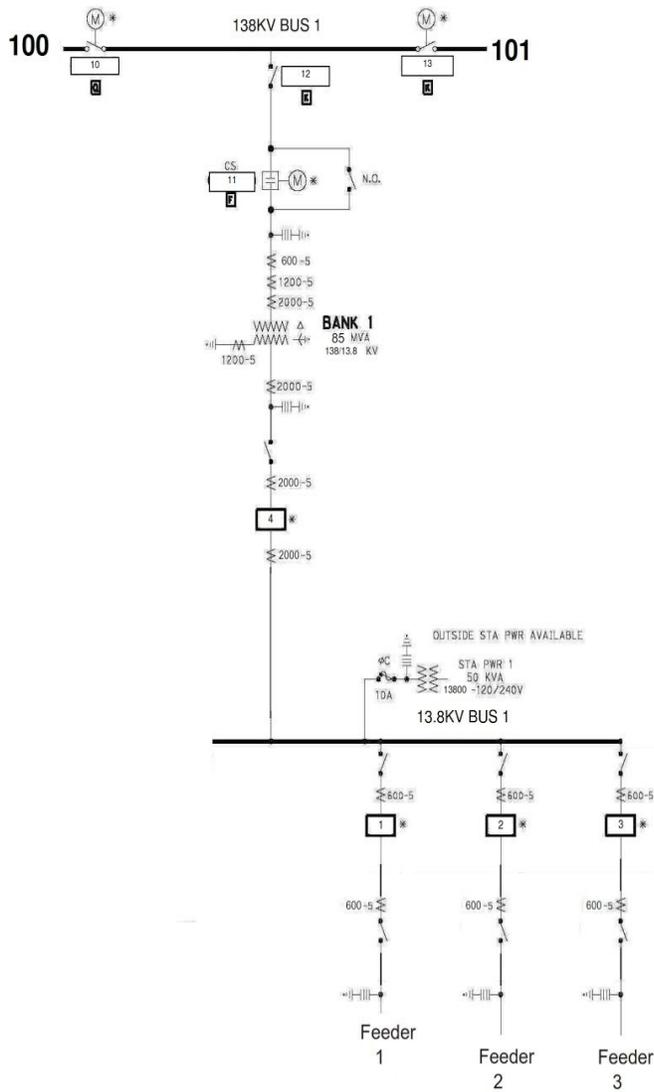
1. University of Iowa State Senior Design Substation: System Protection Requirements provided by Black & Veatch
2. HV Substation Design Notes by Professor Ajjarapu
3. ANSI Standard Device Number List
4. 2014 NFPA National Electrical Code
5. IEEE HV Substation Design Presentation Slides

9 Appendices

9.1 Design Documents

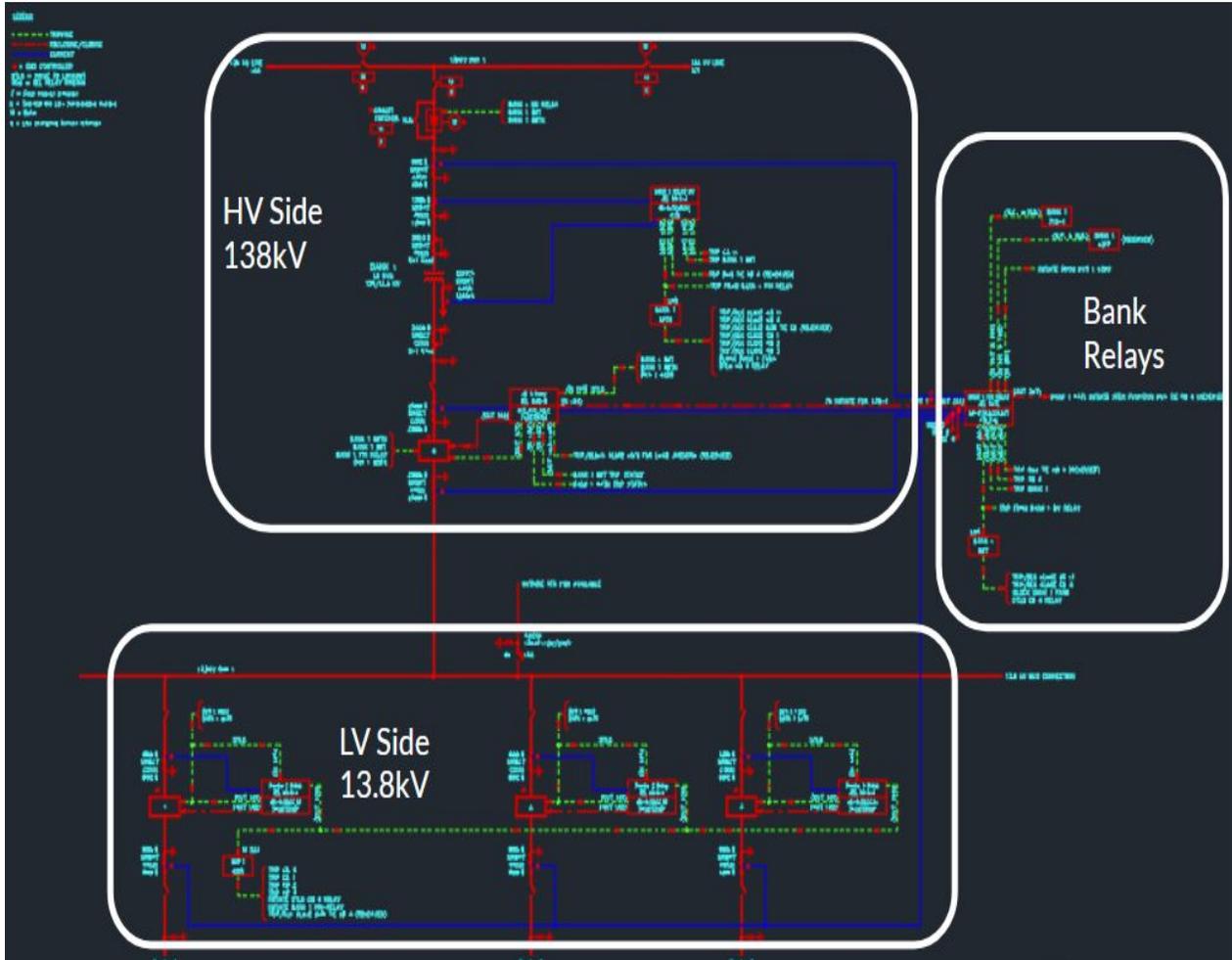
The figures and drawings below include the work that we have done and parts of references that were used.

9.1.1 One Line Diagram



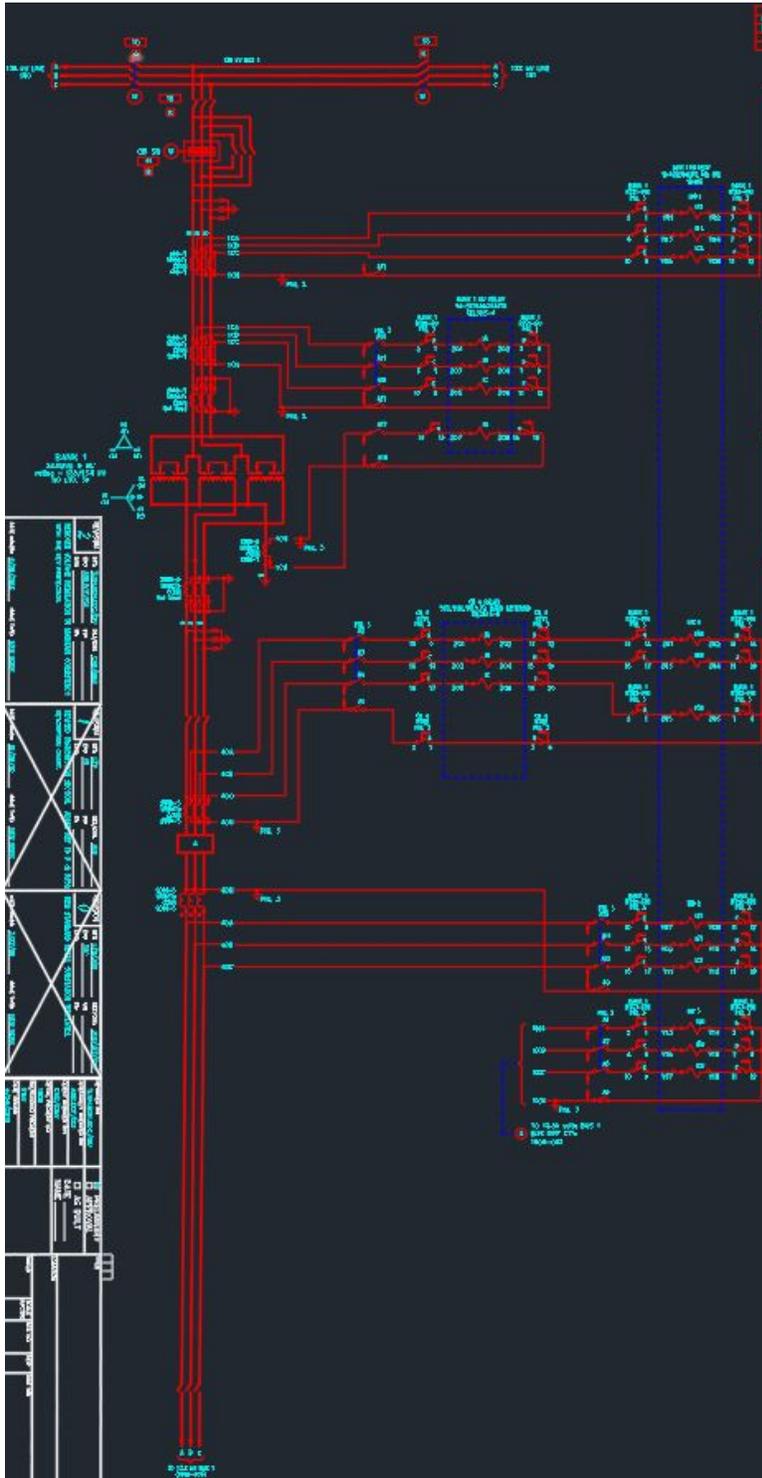
The drawing above is the one line diagram, a higher level than the Key Protection Plan drawing (shown below), which is broad overview of the functional components of the substation.

9.1.2 Key Protection Plan



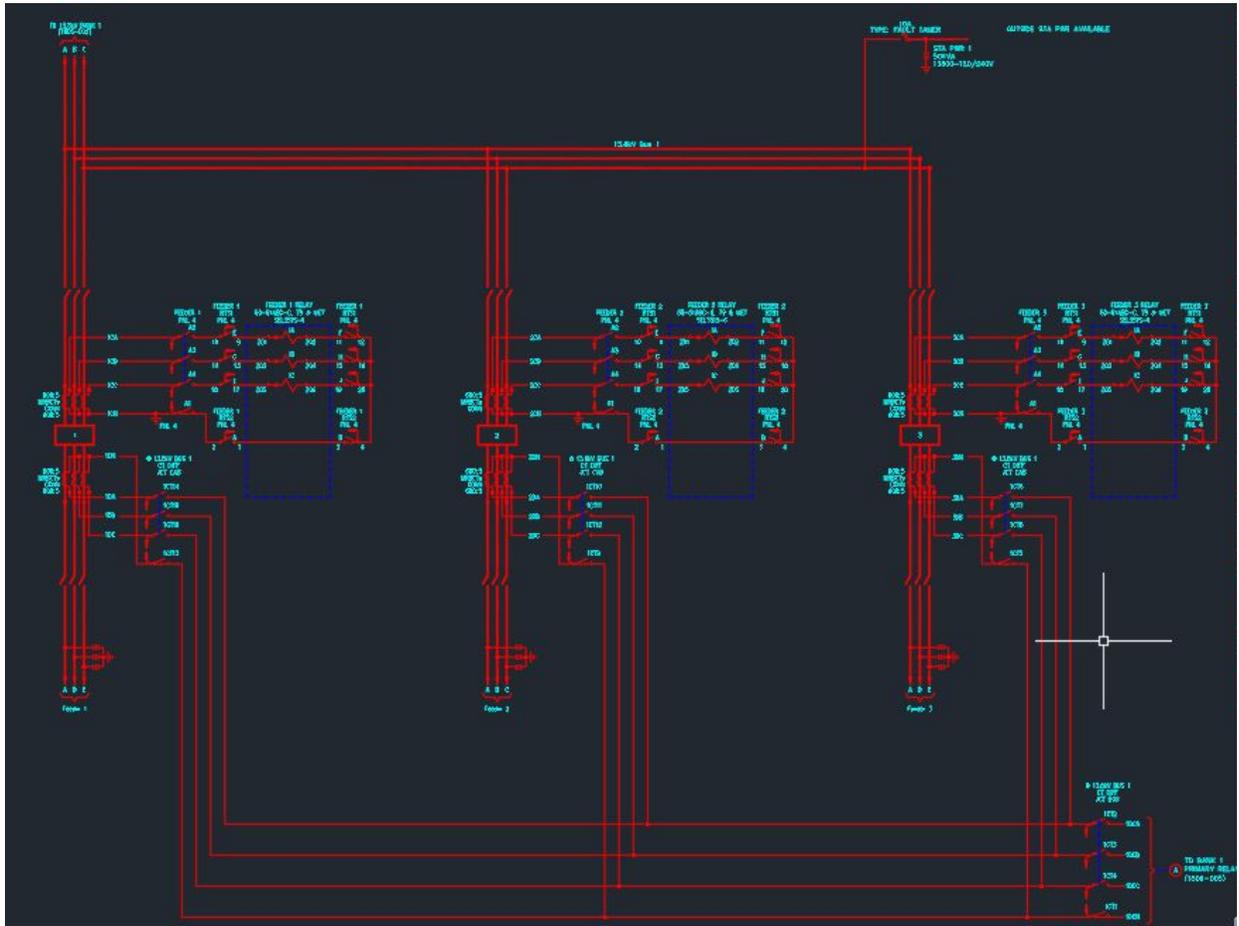
The drawing above shows the Key Protection Plan which is a lower level drawing than the one line diagram as this drawing shows the various components and connections in which this substation will be protected under. We created this document from the one-line diagram.

9.1.3 Three Line High Side



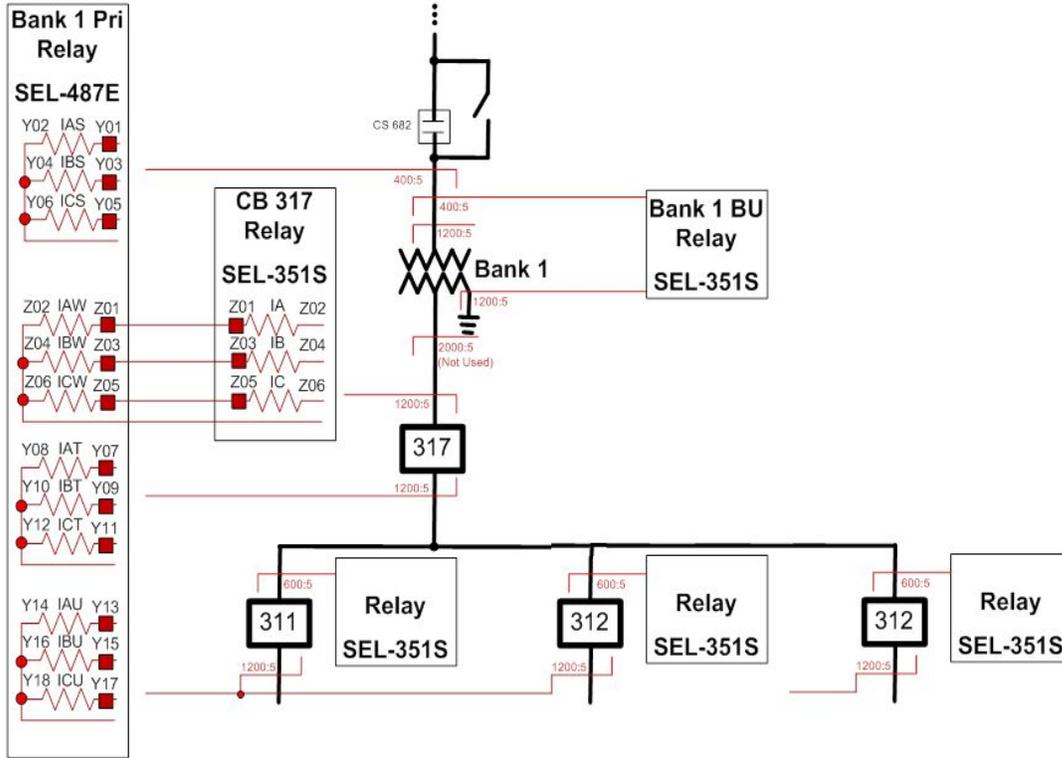
The three line drawing above is the AC Schematic 1 which shows the various switches to be tripped in the case of a fault in the substation. This drawing shows the in depth protection schemes used in the high voltage side (138kV). We used the Key Protection Plan to create this drawing.

9.1.4 Three Line Low Side



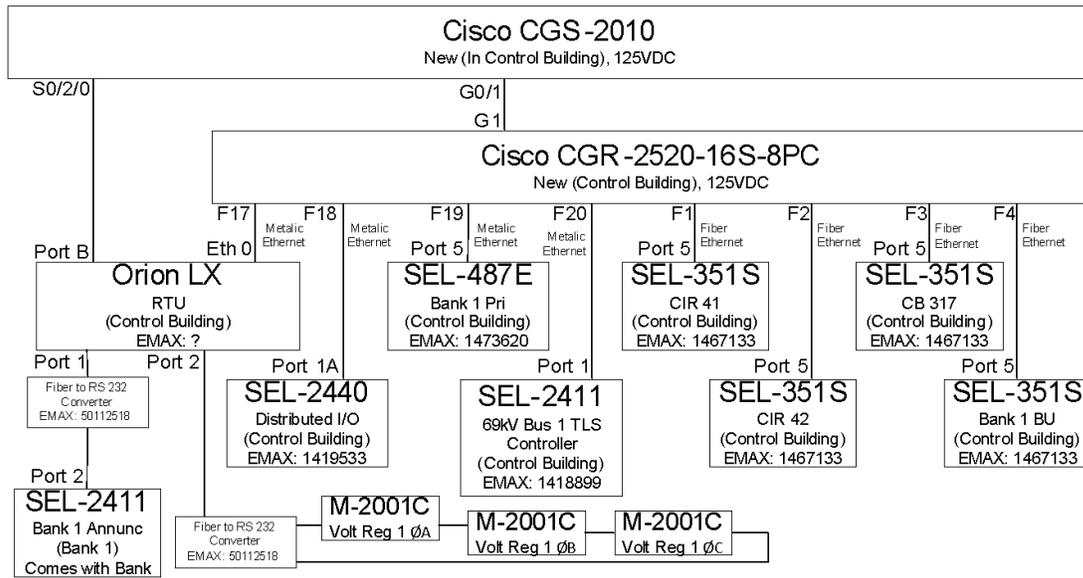
The three line drawing above is the AC Schematic 2 which shows the various switches to be tripped in the case of a fault in the substation. This drawing shows the in depth protection schemes used in the low voltage side (13.8kV). We used the Key Protection Plan to create this drawing as well.

9.1.5 Bank 1 Relay Connections



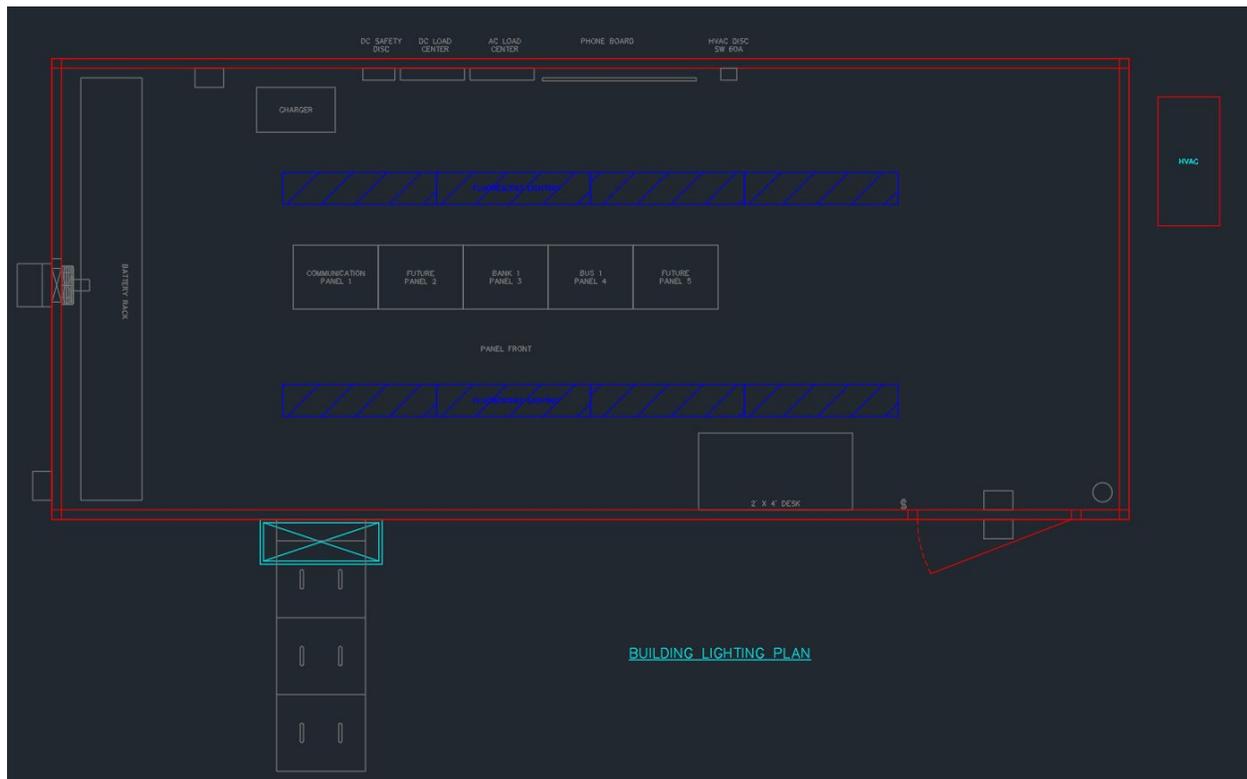
The figure above shows a Primary Protection Circuit Diagram which describes the connection between relays and protective equipment in the substation. This is sourced from the Project Description document provided by Black & Veatch. It is our primary source when designing the protection schematics of this substation. If you would like a copy of this document please let us know.

9.1.6 Communications



The figure above shows the Communication Schematics used in the control building that controls the protective equipment in the substation. This is from the same document mentioned above.

9.1.7 Lighting Layout



The drawing above shows the physical layout out of the substation that we had to plan for external factors such as lightning strike.

9.1.8 Design Documents List

DWG NO	Rev	TITLE v1	TYPE	DATE ISSUED	DESIGNED BY	INTERNAL REVIEWED BY	CLIENT REVIEWED BY	STATUS
		ONE LINE DIAGRAM						
1806-001	2R	KEY PROTECTION PLAN	1 LINE DIAGRAM	1/9/2018	ABB,BDH,GDC/ ISU	ECF,TLWH/ISU	CAB/ B&V	COMPLETE
1806-002	2R	AC 1 138kV	3 LINE DIAGRAM	11/8/2017	BDH,GDC,TLWH/ISU	ABB,ECF/ISU	CAB/ B&V	COMPLETE
1806-003	2R	AC 2 13.8kV	3 LINE DIAGRAM	11/8/2018	BDH,GDC/ ISU	ABB,TLWH/ISU	CAB/ B&V	COMPLETE
1806-004	2R	AC LOAD CENTER	PROTECTION & CONTROL SCHEMATICS	1/9/2018	BDH, TLWH/ ISU	ECF/ ISU	CAB/ B&V	COMPLETE
1806-005	2R	BANK 1 PRIMARY RELAY	PROTECTION & CONTROL SCHEMATICS	1/8/2017	BDH, TL, GDC/ ISU		CAB/ B&V	COMPLETE
1806-006	2R	BACKUP RELAY	PROTECTION & CONTROL SCHEMATICS	1/8/2017	ABB, GDC, TLWH/ ISU		CAB/ B&V	COMPLETE
1806-007	2R	CB 4 RELAY	PROTECTION & CONTROL SCHEMATICS	3/5/2017	ABB, ECF/ ISU	BDH/ ISU	CAB/ B&V	COMPLETE
1806-008	2R	CONTROL HOUSE PANEL LAYOUT	LAYOUT DIAGRAM	11/20/2017	ABB, GDC/ ISU		CAB/ B&V	COMPLETE
1806-009	2R	CONTROL HOUSE CABLE TRAY	LAYOUT DIAGRAM	11/20/2017	ABB, GDC/ ISU		CAB/ B&V	COMPLETE
1806-010	2R	CONTROL HOUSE LIGHTING LAYOUT	LAYOUT DIAGRAM	11/20/2017	ABB, GDC/ ISU		CAB/ B&V	COMPLETE
1806-011	2R	PANEL 1 COMMUNICATION	PANEL ELEVATION	11/3/2017	1806/ ISU		CAB/ B&V	COMPLETE
1806-012	2R	PANEL 3 BANK 1	PANEL ELEVATION	11/20/2017	1806/ ISU		CAB/ B&V	COMPLETE
1806-013	2R	PANEL 4 BUS 1	PANEL ELEVATION	11/3/2017	1806/ ISU		CAB/ B&V	COMPLETE
1806-014	2R	MAIN AC 138kV/13.8kV	3 LINE DIAGRAM				CAB/ B&V	UNEDITED
1806-015	2R	FEEDER 1 RELAY	PROTECTION & CONTROL SCHEMATICS	1/8/2017	ABB/ ISU		CAB/ B&V	COMPLETE
1806-016	2R	FEEDER 2 RELAY	PROTECTION & CONTROL SCHEMATICS	1/8/2017	ABB/ ISU		CAB/ B&V	COMPLETE
1806-017	2R	FEEDER 3 RELAY	PROTECTION & CONTROL SCHEMATICS	1/8/2017	ABB/ ISU		CAB/ B&V	COMPLETE
1806-018	2R	ABS SWITCH 10	PROTECTION & CONTROL SCHEMATICS	2/8/2018	GDC/ISU	BDH,TLWH/ISU	CAB/ B&V	COMPLETE
1806-019	2R	ABS SWITCH 13	PROTECTION & CONTROL SCHEMATICS	2/8/2018	GDC/ISU	BDH,TLWH/ISU	CAB/ B&V	COMPLETE
1806-020	2R	BANK ANNUNCIATOR	PROTECTION & CONTROL SCHEMATICS	3/5/2018	TLWH/ISU	GDC/ISU	CAB/ B&V	COMPLETE
1806-021	2R	BANK 1 AUXILIARIES	PROTECTION & CONTROL SCHEMATICS	2/27/2018	TLWH/ISU	GDC/ISU	CAB/ B&V	COMPLETE
1806-022	2R	BREAKER FAILURE	PROTECTION & CONTROL SCHEMATICS	3/23/2018	GDC,TLWH/ISU	ABB,BDH/ISU	CAB/ B&V	COMPLETE
1806-023	2R	COMM OUTSIDE STA	PROTECTION & CONTROL SCHEMATICS	3/10/18	ABB/ISU	BDH,TLWH/ISU	CAB/ B&V	COMPLETE
1806-024	2R	COMM RTU	PROTECTION & CONTROL SCHEMATICS	3/10/18	ABB/ISU	BDH,TLWH/ISU	CAB/ B&V	COMPLETE
1806-025	2R	DC AUX	PROTECTION & CONTROL SCHEMATICS	1/10/18	BDH/ ISU	EF/ ISU	CAB/ B&V	COMPLETE
1806-026	2R	IO BOARD(SEL-2440)	PROTECTION & CONTROL SCHEMATICS	3/10/18	GDC,TLWH/ISU	BDH,ABB/ISU	CAB/ B&V	COMPLETE
1806-027	2R	SEL-2411 RELAY	PROTECTION & CONTROL SCHEMATICS	3/23/2018	GDC,BDH/ISU	ABB,TLWH/ISU	CAB/ B&V	COMPLETE

The Design Document List above helps us, client and advisor to keep track on our documents to make sure we are have all the drawings covered.