138kV / 13.8kV Substation Protection Design Project

Design Document

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1 Introduction

1.1 Acknowledgement

We would like to extend a, “thank you”, to the following resources for their help throughout this project to Adam Literski and Cole Beaulieu the design team of Black & Veatch and also Professor Ajjarapu our academic advisor from Iowa State University.

1.2 Problem and Project Statement

Electrical substations serve as an integral part of the power network, serving as a conduit between the different components of the network transmission, distribution, and generation of power. The primary tasks of substations includes transformation of voltage to different levels via transformers, communication with other substations and the regional control center, connection of various transmission lines across a region, monitoring of system health via the control center and system protection.

These tasks are crucial to continued power grid reliability and are addressed via sound substation design and maintenance. The focus of this senior capstone project is to serve as a contracting team responsible for the design of a new 138kV/13.8kV distribution substation for Black & Veatch to serve the Ames area, specifically, the Jack Trice Stadium area. This new substation is required to be designed and built on the Jack Trice Stadium to allow for the expansion of the local power grid.

This project focuses on upgrading the controls and protection schematics of the substation of Jack Trice Stadium. The one-line diagram that was designed is used as the main guideline of the requirements and standards as it is the highest level drawing in this project. The protection communication will be upgraded to using an ethernet communication method and replacing the existing communication processor with the Orion LX by Novatech as shown in Figure 1. Plus, additional Cisco Router and Cisco Switch are being implemented to provide SCADA and engineering access as these are the standard protocol to ensure that there is communication with the main grid control center. Besides that, these devices will then connect to the SEL relay devices and the transformer annunciator to complete the whole system design.

Figure 1: Orion LX as our communication processor

The scope has been pre-defined and provided by the client, Black & Veatch as the document: "University of Iowa State Senior Design Substation: System Protection Requirements"**[3]**. This project will in turn help us to understand and be familiarized with the industrial practice and standard. Participating in this project will also help us connect the dots on the theories that we learn in class to real life properties. That said, this project is only for educational purposes and everything will be conceptual, as physically building a substation is close to impossible with the resources that we have.

The contents of this document are outlined below. Black & Veatch has requested a comprehensive design plan for a 138kV/13.8kV distribution substation. The design is intended to account not only for the physical design of the substation, but also the protective relaying and communication components. Following are the components that are to be addressed in the substation design.

1.3 Operational Environment

The operational environment will be a non-factor when designing the various documents required to build a 138kV/13.8kV substation. The substation however, will be outdoors, so outside factors will be required. The key protection plan, lighting arresters as well as a control house will be used to ensure the working capability of the substation.

1.4 Intended Users and uses

The intended user of these substation design documents will be Black & Veatch. Black & Veatch will then use these documents to build the substation in order to provide electricity for commercial uses or as a distribution line which, later, could be stepped down for the use of general residence.

1.5 Assumptions and Limitations

Assumptions:

- Must be used within United States or Countries with AC Electrical Frequency of 60Hz as the usage with different frequency could damage the load or electrical components.
- Capacitor bank has to be present to control the reactive power as stated in the NEC standards.
- Protection and relays are compatible with the NEC code **[1]** to protect both the substation and the Transmission Grid.
- A generic location in United States will be used as our control location for simulation purposes.

Limitations:

- The load of the substation must be able to take in 13.8kV as the output would be a stepped down voltage of 13.8kV.
- The tapping of the substation from the transmission lines has to be 138kV at all running times.
- No prototyping will carried out due to the feasibility.
- The end product will only go through simulations for testing purposes.
- The design of the substation is based on the one-line diagram of the substation which includes most specification requirements.

1.6 Expected End Product and Deliverables

Deliverables

1.6.1 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.

1.6.2 Development of panel arrangements (panel layouts), one-line diagrams, three-line diagrams, protection and control AC and DC schematics and wiring diagrams based upon the protective relay scheme identified by B&V and the provided equipment (circuit breaker, disconnect switches, Coupling Capacitor Voltage Transformers (CCVTs), Current Transformers (CTs), station service transformer, etc).

1.6.3 Development of a Materials List for the project which includes equipments needed for the specifications of the Substation as it is tailored made for it.

1.6.4 Weekly teleconference, via Google Hangout, with B&V and weekly progress reports in email format to Black & Veatch.

1.6.5 Project design reviews, to constantly improve the drawings up till the best of quality.

1.6.6 Create various situations in which a fault current will travel through the relays, as well as what disconnecting switches would be tripped in cases where fault current is detected.

1.6.7 Final report and presentation to Black & Veatch. The final report should include a section listing any lessons learned during the design process. This should take place in Spring 2018.

Deliverables Timeline

Task	Deliverable Date
Man-Hour Budget	21-Sep
Key Protection Plan	27-Oct
Final One-Line Diagram	27-Oct
Initial Three-Line Diagram	30-Nov
Protection & Control Schematics	15-Dec
Final Three-Line Diagram	28-Dec
Materials List	15-Feb
Project Design Review	15-Mar
Final Report to Black & Veatch	15-Apr

2 Specifications and Analysis

Functional requirements for this particular project are limited due to the theoretical nature of this project, the requirements given are all necessary to the protection functionality design of our substation.

- Design services
- Layout will allow for future expansion
- Station battery supply for station service outage
- Ethernet communication between substations
- The substation will be designed with Iowa weather in mind
- Ensuring proper electrical contacts throughout the substation

- Provide various calculations at various points in our substation to see if the fault current going through each component won't damage any part of the substation
- Clearance for emergency vehicles
- Clearance for removal of defective parts
- Ground grid capable of handling a fault
- Follow industry and company standards such as the document [1]

Up till now, we have been meeting weekly with Black & Veatch to discuss our findings and our work progress over the week. During the meetings, we reviewed what we've done for validity and consider how best to proceed with the project. Besides the weekly meetings, deliverables that we have achieved so far have been on a man hour budget, Gantt chart the Key Protection Plan (KPP), and the AC protection diagrams. We've been able to split the work among us but usually find ourselves meeting as a group to tackle some of the more difficult parts of the design. The KPP is our first major piece of work as everything we do from now is based on the KPP. We modified an existing KPP template to suit specifics of our substation. We have a number of resources available to do this outside of those weekly meetings talked about earlier. Mainly, we're following the single-line diagram given to us by Black & Veatch for this project and translating it into the KPP which can be found in section 8 references. The AC protection diagrams were then created from the Key Protection Plan. This document shows the three phases and shows the individual disconnecting switches which would be tripped in case of a fault. We also received a document describing the scope of the project which included more specific information on what's needed to go into our substation and what the inputs and outputs to relevant banks should be.

Questions regarding the elements for the KPP can be answered through the scope document, asking Black & Veatch during a weekly meeting, asking Dr. Ajjarapu during one of our weekly meetings with him or through independent research online. If the question is regarding its use in the substation, Black & Veatch is a good source of information. If the question is regarding its general function, information on the element is best found through Dr. Ajjarapu or independent research. We've made a document for each device with an ANSI number **[5]** that includes a picture and description of what the device does.

2.1 Proposed Design

As discussed earlier, our team has a number of items we wish to complete. Some of these will be delivered to our clients at Black & Veatch and some of them will be used solely for our benefit. These deliverables can be found in section 1.6. They include a man hour budget which was compiled with the help of Black & Veatch during an in person

meeting, a key protection plan based on the single-line diagram which we were given along with a document describing the scope of the project, a three-line and wiring diagrams which expand upon the other design documents for our substation and a final presentation of our work which will be given in Kansas City.

The process flow of all the drawings can be depicted in 3.2 mainly by producing a more detail low level drawings every cycle. These drawings will match the specifications, requirements and various standards to ensure the drawings produced are up to the best of quality.

We have worked on several documents for our own reference already and it is likely that more will come up as we proceed with the project. These describe how parts of the substation or how the substation as a whole may work and are not delivered to our client but used by us during the design process.

2.2 Design Analysis

So far we have completed our work on the KPP, AC Schematics, and the panel layouts. We have created a number of documents which we can use to reference how parts of the substation work. Standards and requirements by the client will be used in cooperation with the the previous higher level documents to produce a lower level design with more detail entailed with it. These specifications are entailed for a SEL-487E relay which will act as our primary relay and the multiple SEL-351S relays acting as the back-up and lt relays. We've meet with both our advisor and our client each week consistently and are continuing to bounce ideas off of them to further our progress. Feedback of the documents reviewed from them are positive as the designs that we produced have showed significant progress.

One of the challenges that we foresee is understanding the existing work and documents which we have been given has been the first step into designing. Following that we have been able to make adjustments to the KPP and think about future steps in the process of designing a substation.

We are going above and beyond the specifications given to us by our client by providing a series of power calculations to B&V. We have already calculated many different components of our substation to see what would happen if the rated amount of fault current the device was regulated at could indeed satisfy the needs of our substation. We have already found some inconsistencies in our design and our specifications, which we continue to update providing a more accurate, working substation protection design.

3 Testing and Implementation

No formal testing is required for this project, the team will verify the design documents by conducting numerous design review meetings with experts in the field. Ultimately engineers from Black & Veatch Design Team will be reviewing our work. However, as mentioned in the design analysis section, we will be providing B&V with various power calculations of the fault current traveling through the substation components.

3.1 Hardware and software

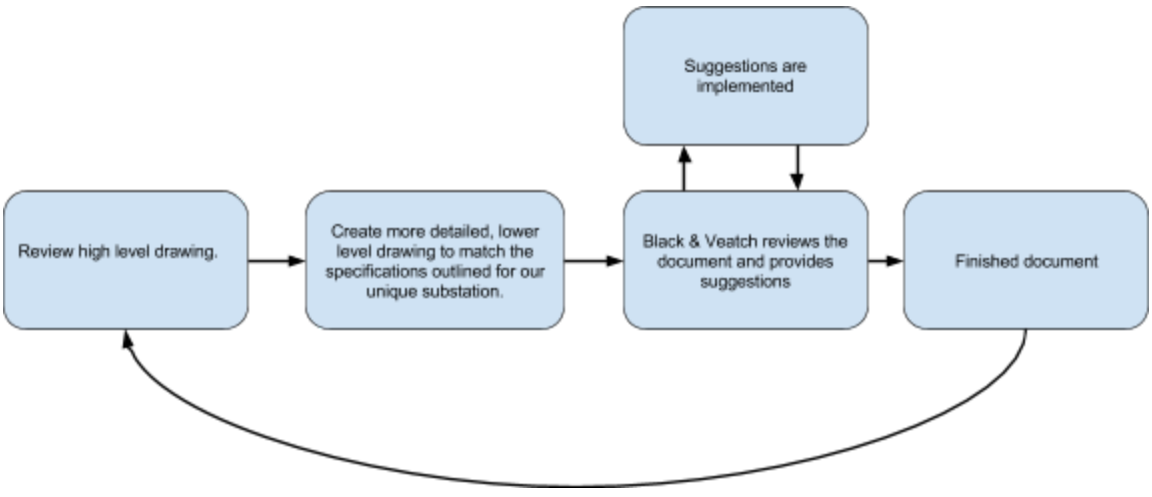
For testing AutoDesk's AutoCAD will be used to view and make changes of the designs as we perform tests. Simulation will also be deployed to test the maximum fault current the substation is able to handle. However, the simulation is still under discussion with the experts.

AutoCAD excels at editing the drawing the files we will be creating. It will allow our team to quickly view and analyze the diagrams and any changes changes in a fast efficient manner.

Interface Specifications

This project focuses on the design of the functional components of a 138 kV substation. We will be concerned with providing power to the control house but the interface of that house, or any other interface, is beyond the scope of this project.

3.2 Process



As shown in the figure above describes the process flow of how each design is produced. So at the very beginning, a completed high-level drawing that summarizes the whole

substation design will be used as a guideline to produce low level and more in depth design. Specification and standards will also help us while creating the new low level document. Then, the design engineers from Black & Veatch will review the document and provide feedback as we correct the design until the design is complete and error proof. Once the new document is completed, the whole cycle will be repeated again and producing a lower level document.

3.3 Functional Testing

We will testing 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 will be designing the electrical contacts within the substation including the SEL-487E relay and the multiple SEL-351S relay as well as designing the wiring diagrams of each relay and circuit breaker. Programing 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.

We have already implemented several changes in our substation that were not entailed in our specifications provided by Black and Veatch. Some of these calculations we have completed are calculating the Max Power at each current transformer, as well as the power needed to operate the control house in case of an outage to ensure all the relays are protected. This method is what we will be using to model and simulate for various fault currents. We have gone beyond the scope of work entailed by our client Black & Veatch, as we felt we did not have an efficient way to test the protection diagrams we've created.

3.4 Non-functional testing

The biggest non-functional component of this project is weekly meetings with Black & Veatch via Google Hangout to provide updates on our progress, with meeting agendas beforehand and meeting minutes after. The other non-technical deliverables include a Gantt chart, man-hour budget, materials list, and final presentation to Black & Veatch.

3.5 Results

From the results that we have gotten up to this point was positive from Black & Veatch Design Team. Although the designs were not fully completed without errors at the first revision, we are generally going into the right direction. If the designs are not matching up or contains issues to be resolved we will then revise it and have Black & Veatch Design Team to review it until it is error free. These designs will then be used on the next design phase. The completed designs can be viewed in the drawing in 4.3Appendices.

4 Closing Material

4.1 Conclusion

In conclusion, this substation design will bring us a lot of industrial experience that will help us as young engineers in our professional career. Project wise, we are responsible for designing a substation and all the protection schemes, controls, wiring the wiring of each electrical contact to understand the specifications of how to design and implement a protection scheme in a substation. The designing process includes us brainstorming and working together in a team to ensure fairness 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, will be used to ensure our design is of the best quality before finalizing it. To ensure the design is accurate, various power calculations to ensure each component of the substation will not be harmed in the case of a fault. At the very end of the project, we will showcase our final substation design to Black & Veatch and demonstrate our skills and knowledge along the way on working on this project.

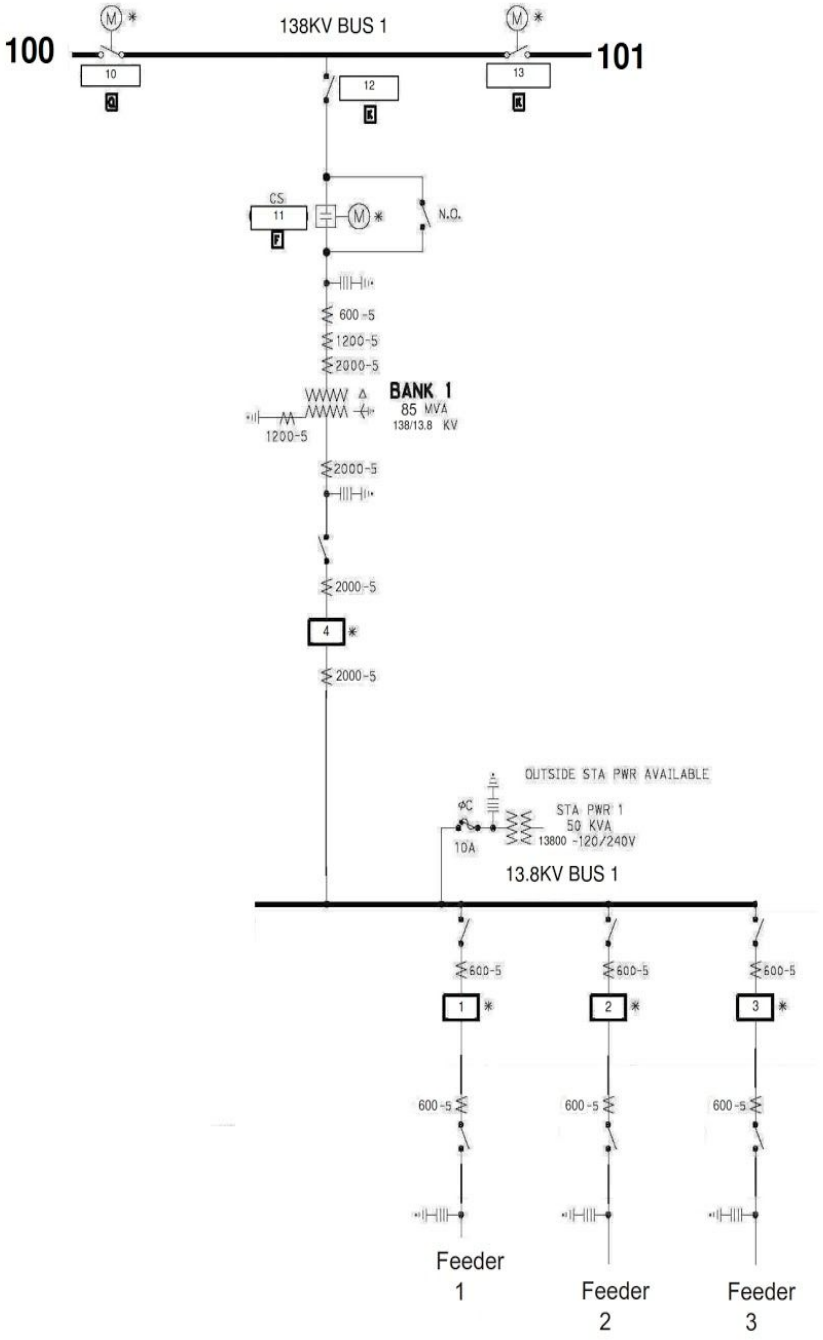
4.2 References

References for this project includes but not limited to:

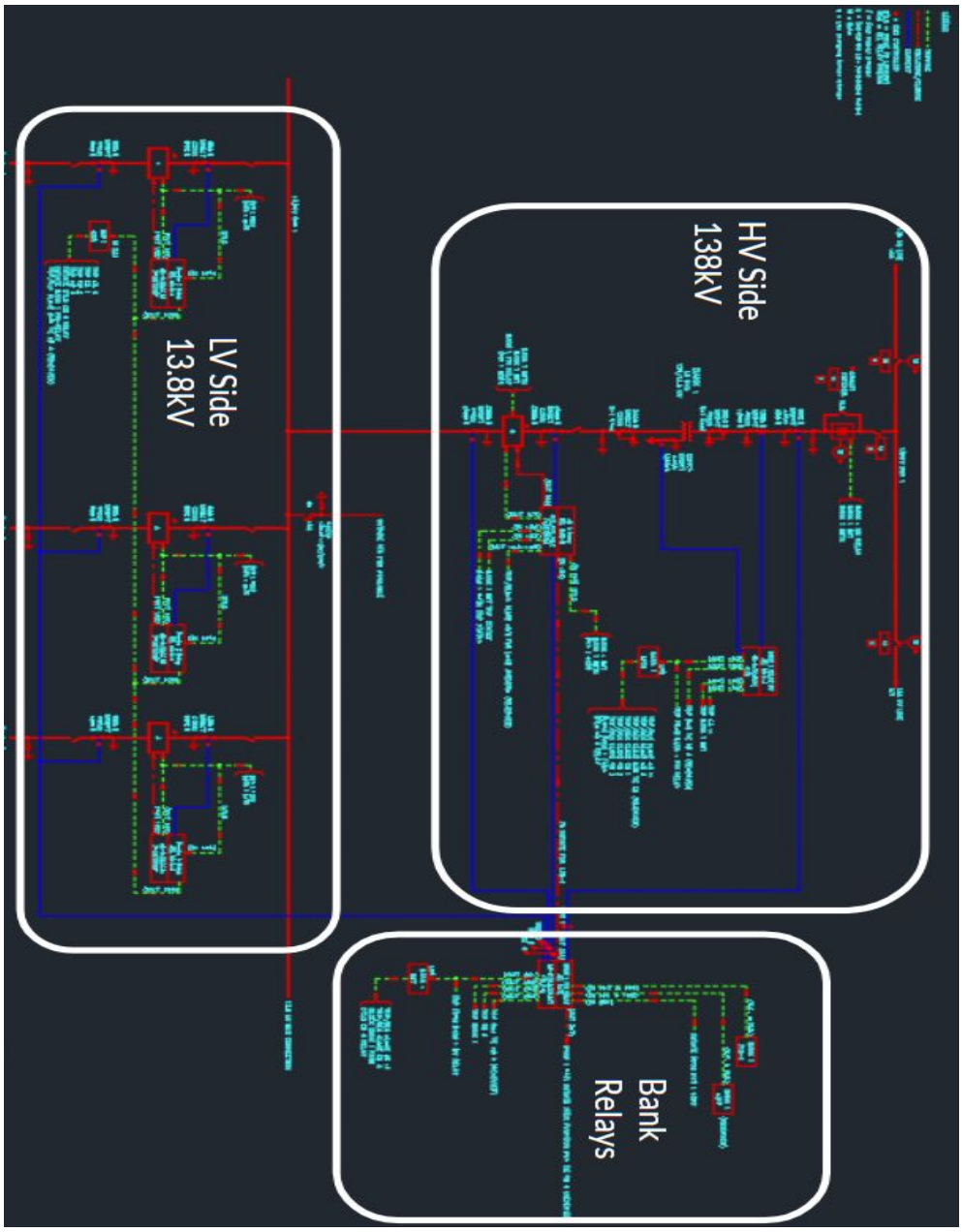
1. Key Protection Plan created by us.
2. One Line Diagram provided by Black & Veatch
3. University of Iowa State Senior Design Substation: System Protection Requirements provided by Black & Veatch
4. HV Substation Design Notes by Professor Ajjarapu
5. ANSI Standard Device Number List
6. 2014 NFPA National Electrical Code
7. IEEE HV Substation Design Presentation Slides

4.3 Appendices

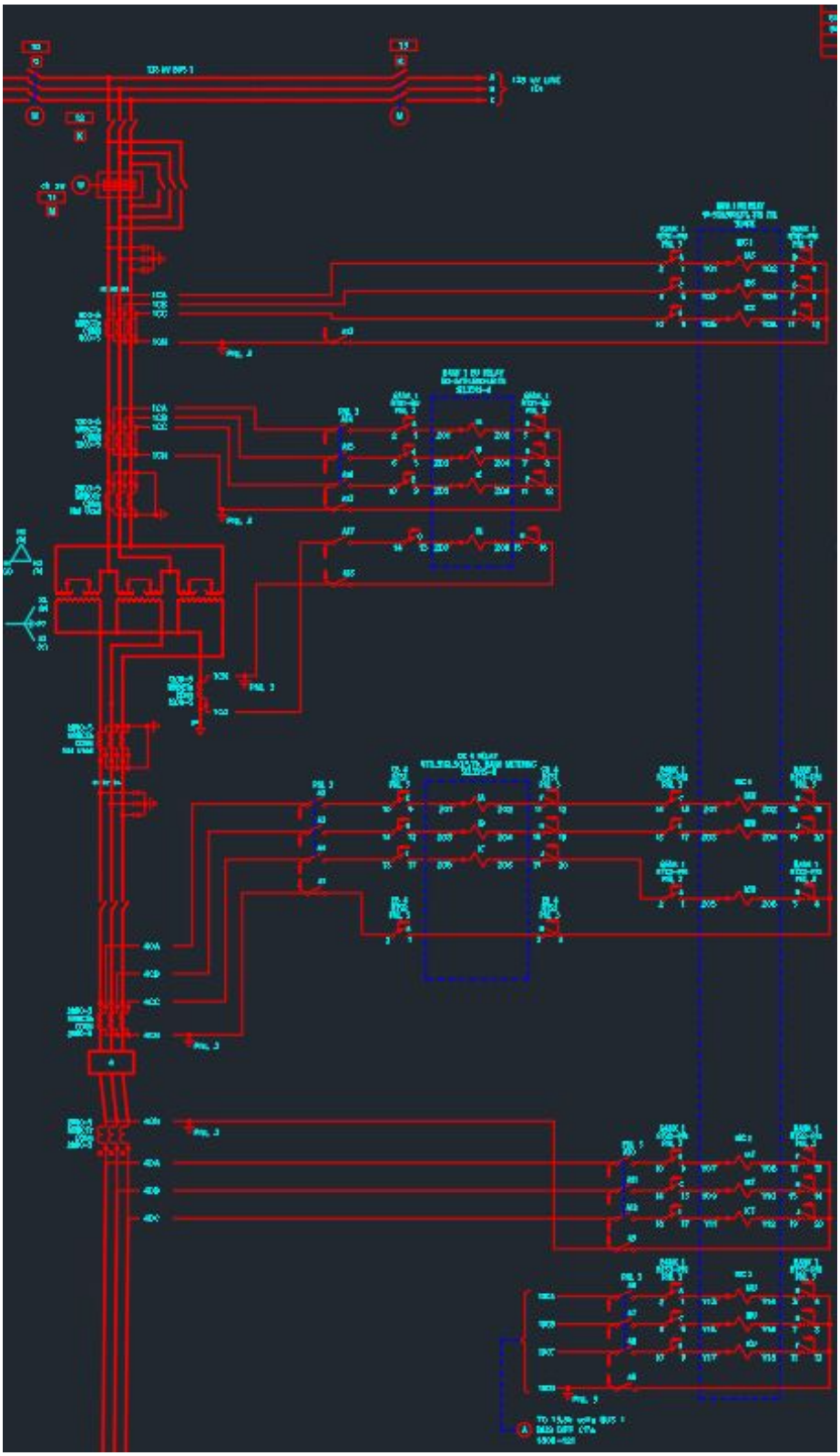
The figures and drawings below include the work that we have done and parts of references used or will be used in the future while designing.



The drawing above is the one line diagram a higher level than the Key Protection Plan drawing below which is also the part of the specifications requested by the client, Black & Veatch.

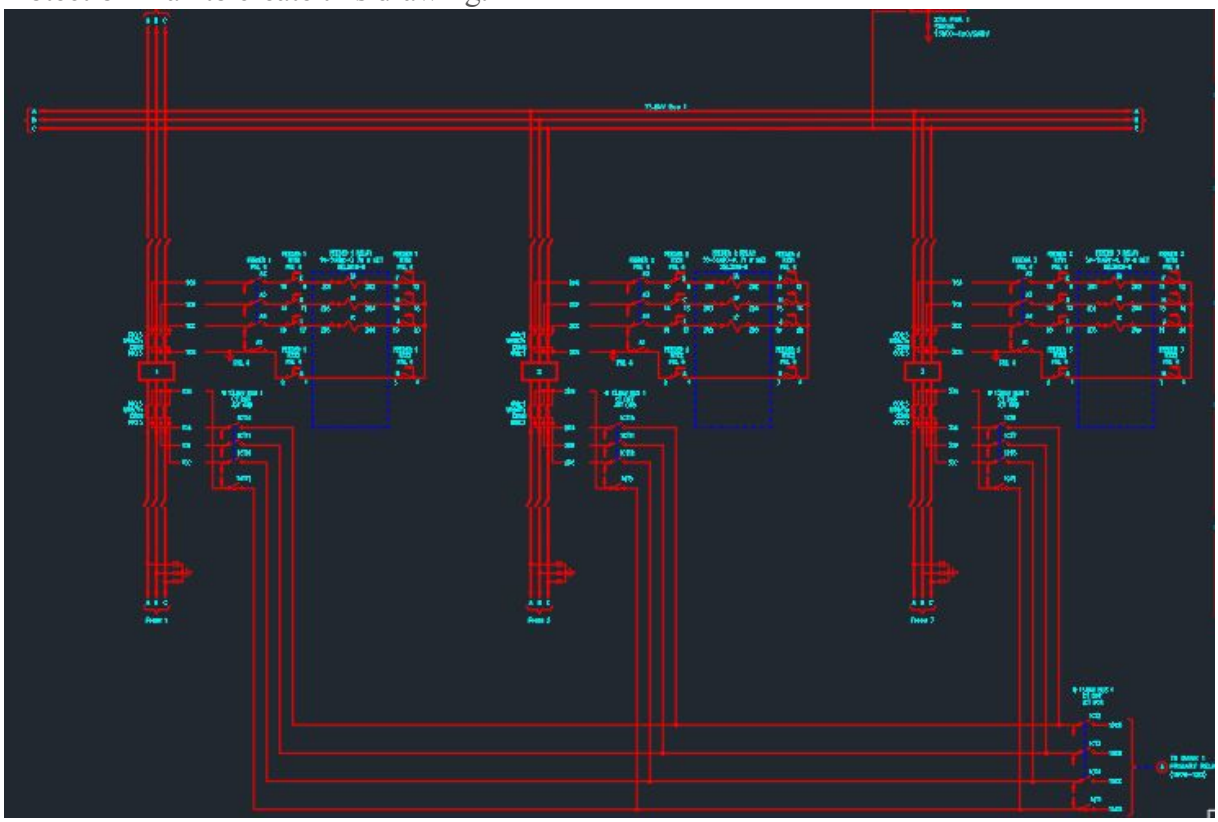


The drawing above shows the Key Protection Plan which is a lower level drawing than the one line diagram as this drawing shows the various components and connections in which this substation will be protected under. We created this document from the one-line diagram.

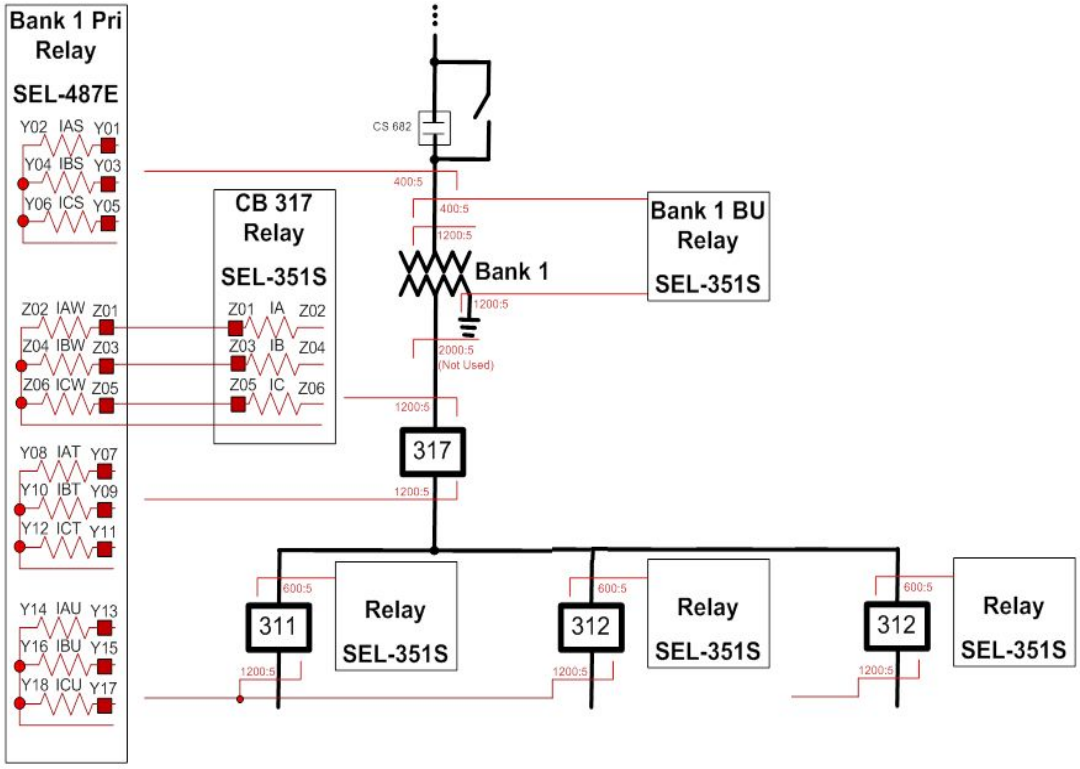


The three line drawing above is the AC Schematic 1 that shows the various switches to be tripped in the case of a fault in the substation. This drawing shows the in depth

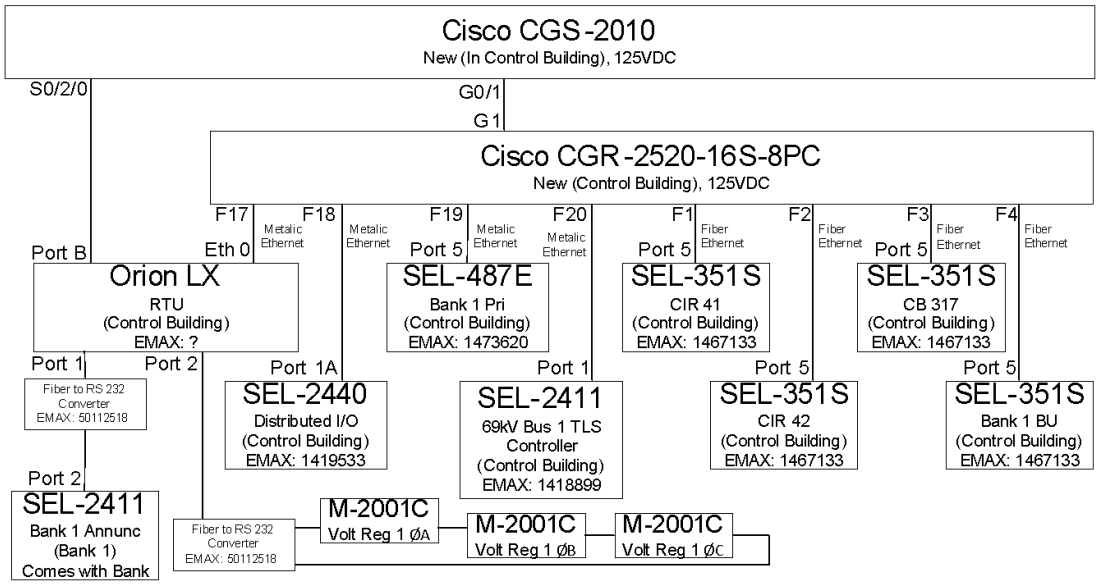
protection schemes used in the high voltage side (138kV). We used the Key Protection Plan to create this drawing.



The three line drawing above is the AC Schematic 2 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.



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



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.