IOWA STATE 115KV SUBSTATION

DEC13_03 Design Document

Jane Peters

Jared Jasper

Matt Murphy

Muzi Li

Riley Groves

Project Sponsor: Burns and McDonnell

Project Adviser: Venkataramana Ajjarapu

Project Website: http://seniord.ece.iastate.edu/dec1303/index.html

Table of Contents

Table of Figures

1 Project Overview

1.1 Project Description

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 include:

- 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
- 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 115-kV distribution substation for Burns and McDonnell Engineering to serve the Ames area, specifically, the Iowa State University Campus. This new substation is required to be designed and built on the Iowa State University Campus to allow for the expansion of the local power grid to include a new wind farm located in the surrounding Ames region.

1.2 Project Scope

The scope has been pre-defined and provided by the client, Burns and McDonnell engineering in a "Scope of Services" document [4]. The contents of this document are outlined below.

Burns and McDonnell Engineering has requested a comprehensive design plan for a new 115kV 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 [3]. Following are the components that are to be addressed in the substation design.

NOTE: This project is purely for academic and learning purposes. The scenarios described and addresses may be fictitious and have been defined by Burns and McDonnell for the purpose of this project.

1.2.1 Included Within Scope

Substation Specification Materials Package

Burns and McDonnell is expecting an inclusive set of specifications and drawings, following Burns and McDonnell, IEEE and acknowledged industry standards. These documents are intended to be used to solicit bids from pre-qualified substation packagers. The specifications included in this package should address such areas as the substation structural steel as well as all electrical equipment and materials required for the project.

Site Design

Burns and McDonnell will provide a location for the new substation site. The team will be responsible for determining the layout of the new site. Considerations shall include details such as site access, construction access, and fencing details. The design will be completed utilizing AutoCAD.

Substation Foundation Design

Burns and McDonnell is expecting a full foundation layout and design. As no member of the team has an civil engineering or construction engineering experience, Burns and McDonnell has agreed to cover a majority of this responsibility. The expectation from the Iowa State University design team will be to provide the location of the required foundation for each component of the substation. In addition to the location, the team will be required to supply the weight that the foundation will be expected to support.

Physical Substation Campus Layout

In addition to the site design, the team will be responsible for determining the layout of the components that comprise the substation. The substation layout is expected to be conservative space-wise to allow for future expansion of the site to allow for additional load requirements. The substation layout will be primarily presented via a one-line diagram, which will illustrate the location of substation components as well as their connections. In addition to an aerial view, the team is expected to provide several cross sectional views with elevation indicators.

Bus and Insulator Design

The senior design team will be responsible for defining the bus and insulator design for the substation. The design will be based upon calculations including weather conditions and expected fault levels. The weather conditions to be used in the consideration of the design will be average weather conditions experienced in Iowa. The fault levels to be used in these calculations will be provided by Burns and McDonnell.

Ground Grid Design

A key expectation for this project is the design and layout of the grounding grid for the substation. The design is to be completed utilizing the WinIGS grounding software. The design of the grounding grid will be based upon standards set defined by IEEE 80 techniques. This also includes sizing the grounding conductors to handle the expected fault current.

Control Station Service Voltage Transformer

The service transformer for the control station will need to be selected by the design group. The transformer will be selected based upon the requirements of the equipment powered by the station service transformer. After selecting the transformer, sizing will be determined for the distribution panel and the incoming conductors. A factor to be considered when selecting the transformer will be needs of not only the current equipment, but also future equipment required to accommodate future loads.

Substation Raceway Design

The senior design team is expected to develop a conduit plan, including a raceway sized to accommodate each specific component of the substation. These raceways will be implemented utilizing a combination of techniques including surface trenches, underground conduits and equipment riser conduits.

Substation Control Building Design

The team will be required to develop sizing requirements for the control house, which will be used by an external construction company to build the structure. The control house will be required to house protective relay panels, the 125V battery and charger, the AC and DC panels and the Scada RTU.

125V DC Station Battery Design

Prior to the development of the control house, the team is expected to select an appropriate

125V battery. The sizing of the batteries, battery chargers and panels utilized by the 125V system will be calculated based upon the expected load on the system. Burns and McDonnell has requested that the team take into account the time period for a service station outing when determining the battery size.

Substation Relay Design and Control System

The team is expected to generate one-line diagrams as well as mechanical drawings for the 115kV circuit breakers required. The model number for the relays to be used will be provided by Burns and McDonnell.

1.2.2 Excluded From Scope

System Simulation and Testing

The team is not expected to run simulations on the design nor do any formal testing. Verification of the design will be completed via review from external experts and design review meetings with the sponsor, Burns and McDonnell. Though a system- wide simulation will not be run, the team will be using the grounding software, WinIGS to simulate various grounding scenarios.

Substation Transformer

At this point in time, the team is not expected to incorporate a substation transformer into the substation design. This may change at a later date, however.

Substation Panel Diagrams – REMOVED FROM SCOPE 10/2013

The senior design ream will be required to create a panel layout and schematic diagram to be furnished to a panel vendor. The vendor will use these materials to generate a wiring diagram. The team will also be responsible for generating wiring diagrams for the yard equipment. **THIS WAS REMOVED FROM THE SCOPE BY BURNS AND MCDONNELL.

2 Project Requirements and Design Constraints

2.1 System 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 substation. Therefore, all requirements are considered to be **functional**.

- Design services
- Layout will allow for future expansion
- 125 Volt Station Battery supply for station service outage
- Fiber-Optics communication between substations
- The substation be designed with Iowa weather in mind
- Safety
- Clearance for emergency vehicles
- Clearance for removal of defective parts
- Ground grid capable of handling a fault
- Follow industry and company standards as listed in section 4.3 of this document

2.1.2 Design Constraints

2.1.2.1 Operating Environment

As this hypothetical substation is intended to be built on the Iowa State University campus, the Iowa environment will be a constraint for this project. Specifically, this will not directly affect any calculations; it will merely be a factor to take into account when considering soil type and humidity. Both of these parameters will affect design steps such as foundation planning and grounding.

2.1.2.2 Applicable Standards

Standards will play a huge role in governing the design process and will serve as rigid design constraints. There are several standards that govern the design of a substation. Below, several of the primary standards that need to be considered are discussed. As the project progresses, more standards will be explored and documented. The standards described thus far are those that have been pertinent to the early phases of development of the project.

Environmental Standards

RUS Environmental Policies and Procedures, 7 CFR 1794

This Regulation specifies RUS environmental requirements legalized to the implementation of the National Environmental Policy Act of 1969. It also references additional authorities, directives, and instructions relevant to protection of the environment. As a general rule, stations 115 kV and below require a Borrower's Environmental Report (BER)

Grounding Standards

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

Foundation Standards

IEEE Std. 691

The objective of this guide is to provide a single source available information on design methods for foundation design engineers. The information contained in this guide covers the modes of foundation loads for various types of transmission structures; the scope of subsurface investigations; alternate methods for designing spread foundations, drilled shafts, pile foundations, and anchors; and procedures for conducting load tests.

Relay Device Numbers

IEEE/ANSI Device Numbers and Functions for Switchgear Apparatus

ANSI C37.2-1970

The following Standard Device Function Numbers are reprinted from IEEE Std. 37.2-1996, "IEEE Standard Electrical Power System Device Numbers and Contact Designations," Copyright © 1997 by the Institute of Electrical and Electronics Engineers, Inc. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner. Information is reprinted with the permission of the IEEE.

Public Safety Standards

Fence: To ensure public safety at substations is by building a suitable barrier such as a metal fence. The fence needs to meet the minimum requirements specified in the NESC and IEEE standard.

Basic Requirements for Transformer Standards

ANSI/IEEE Standards C57

These standards will cover the primary conditions of PTs and CTs (Potential Transformers and Current Transformers)

2.2 Project Deliverables

Following is the list of expected deliverables as set forth by Burns and McDonnell.

- Relaying and controls
- One-line diagram
- Circuit breaker selection and schematic drawings
- Site layout drawing
- Foundation plan drawing
- Grounding plan drawing
- Substation layout (top-down view) drawing
- Substation Elevation section cut drawing
- Conduit plan drawing
- Control building equipment sizing

- Substation battery selection
- SSVT (Station Service Voltage Transformer) selection
- Bus and insulator sizing calculations and material selection
- Design justifications

3 Design Process and Functional Decomposition

3.1 System Input/Output Analysis

This system is designed to be a three-section ring bus system with three external lines, one generation line (labeled: ISU Generation on one-line diagram) and two exit lines (labeled: Coover Line and Campanile Line on one-line diagram).

3.1.1 System Inputs

There are several inputs through the system:

- The **input** to the system as a whole can be represented by the ISU Generation Line. This line carries the power generated at the wind farm into the substation.
- Each delivery line has two-way data communication that is sent and received along one phase of the power line. Upon entering the substation, these communications signals are filtered off the power line via a wave filter.
- Each relay within the substation system can be considered a subsystem with its own inputs.

3.1.2 System Outputs

- The **outputs** from the system as a whole can be represented by the distribution lines, the Coover Line and Campanile Line.
- Each relay within the substation system can be considered a subsystem with its own outputs.

3.2 Hierarchy of Component Dependency

The various design drawings and diagrams follow the following hierarchy of dependencies shown below. Many of the components are logically influenced by each other, with all parts of the design originating from the one-line diagram. Descriptions of each component can be found in the "Project Scope" section of this document.

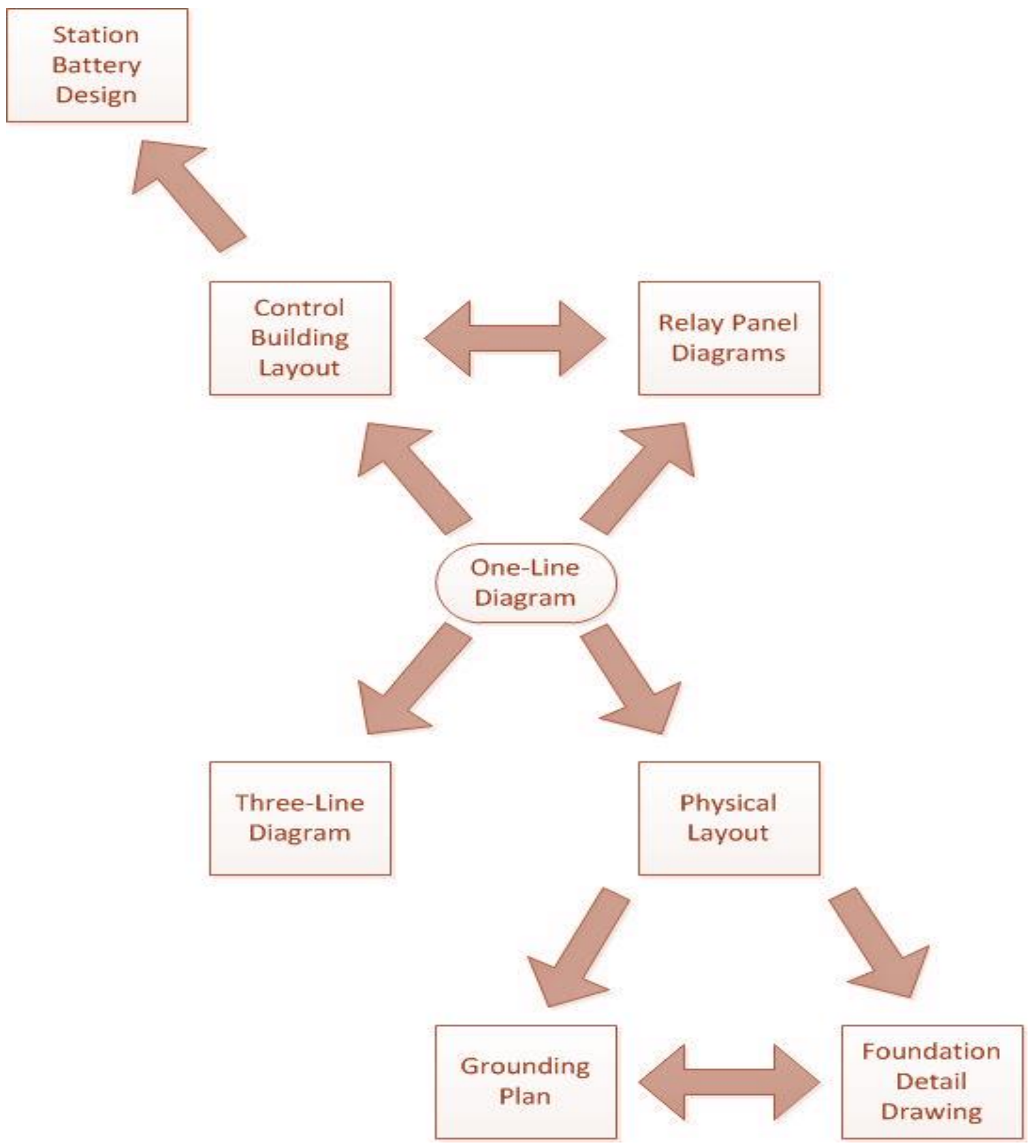

Figure 1: Component Dependency Relationships

3.3 Phase Breakdown

Based on the hierarchy of dependencies, the project has been broken into the following design component phases:

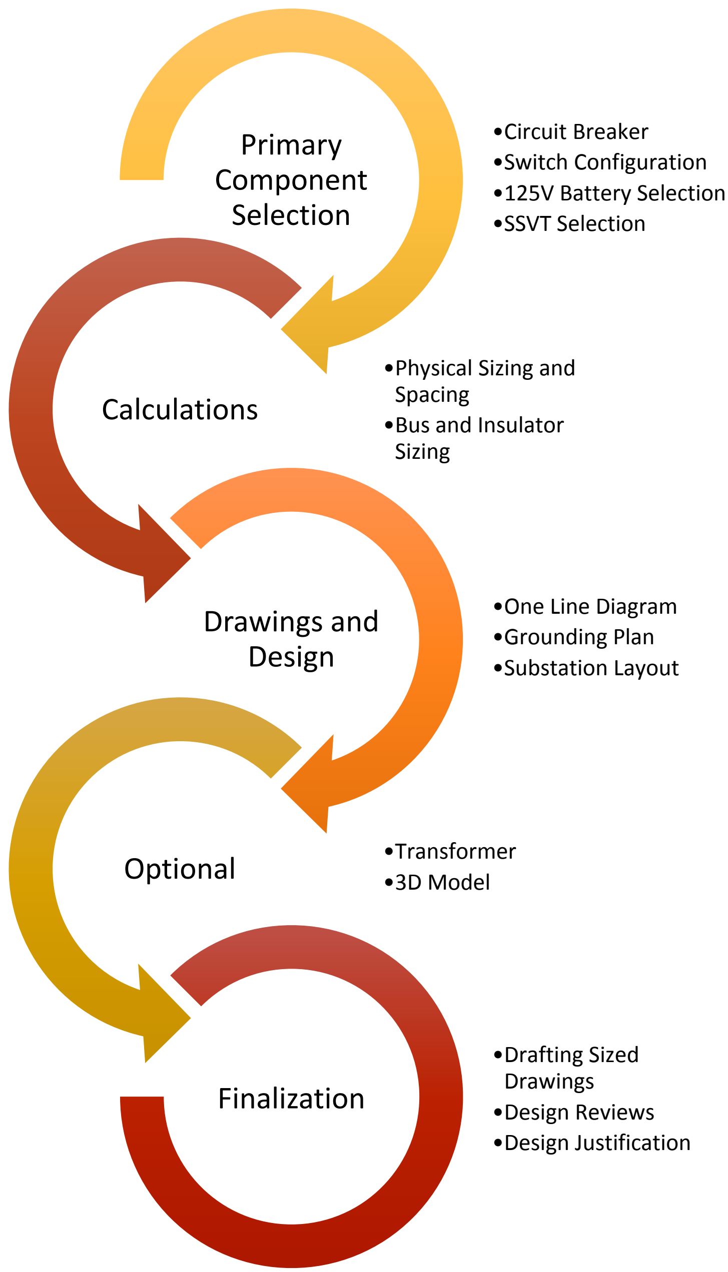

Figure 2: Design Phase Breakdown

4 Design Decisions Discussion and Justification

4.1 One Line Diagram

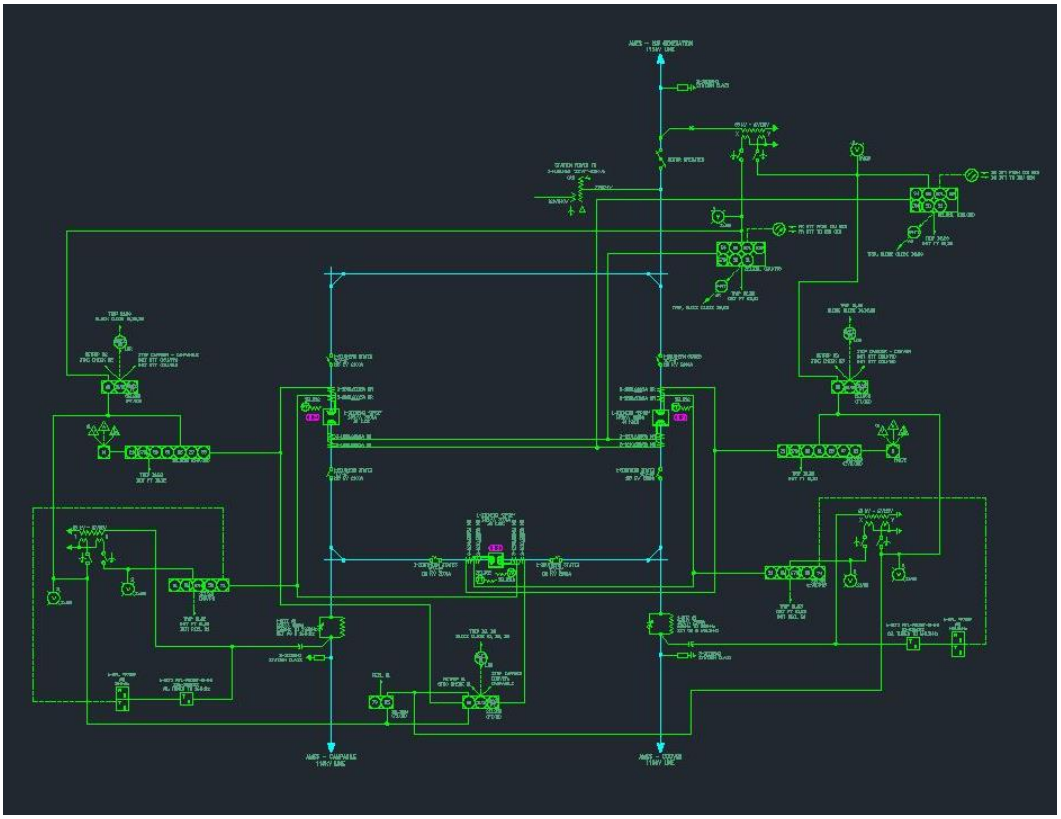

Figure 3: One-Line Schematic

The one-line diagram provides a graphical representation of power flow within the system. This is shown through the connections between the various elements within the substation. To simplify the system, the three phases of the power system are shown as a single line on the one-line diagram.

4.1.1 Formation

Before beginning any of the design drawings, a circuit breaker formation had to be selected for the substation. In each formation option, the quantity and positioning of the circuit breakers is varied to optimize different priorities. For instance, certain formations involve a high level of complexity and redundancy for increased reliability in the event of a fault, while other formations are highly simplified for affordability.

For this project, a ring bus formation, comprised of three circuit breakers was selected. This formation can be easily modified to accommodate future load growth and a substation expansion to include additional circuit breakers. Additionally, this formation is ideal for maintenance. The formation allow for any single breaker to be taken out of service for maintenance without interfering with the functionality of the other two breakers. This results in less downtime for the substation and therefore less revenue lost. The ring bus formation is illustrated below. The three circuit breakers in this substation are illustrated in the diagram below. The right hand image shows the traditional ring bus schematic. On the left is the ring bus formation highlighted on the one-line diagram.

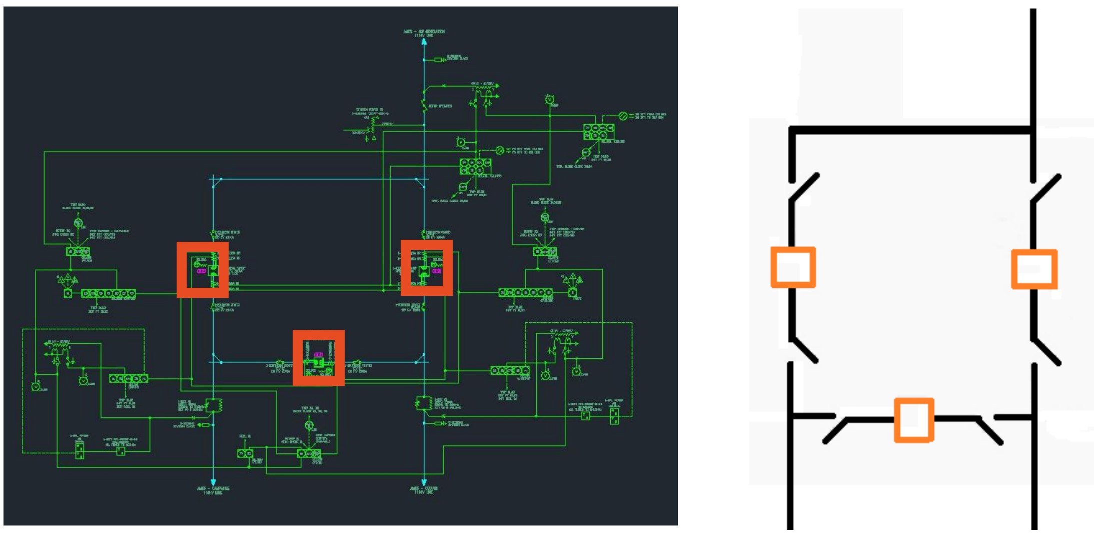

Figure 4: Ring Bus Illustration

4.1.2 Component Selection

4.1.2.1 Circuit Breaker

This substation design calls for the use of three circuit breakers. The main function of these components is to electrically isolate different sections of the substation. This is important for performing maintenance or repair on the system in the event of electrical fault or equipment malfunction. In selecting circuit breaker there are several parameters to consider.

4.1.2.2 Circuit Breaker Selection

Parameters

Figure 5: Siemen's SPS2 Dead Tank SF6 Circuit Breaker

Rating

In selecting a circuit breaker, it is important to consider not only the current rating requirements, but also future requirements. While the current voltage requirement is only 115kV, the breaker should be selected to accommodate a greater future voltage. As this substation will be servicing the Iowa State Campus, a future expansion could include an upgrade to 145kV as this is what the campus is currently run on. Therefore, it is important to select a breaker that can support both 115kV and 145kV.

Casing

There are two types of circuit breaker casings to consider: live tank circuit breakers and dead tank circuit breakers. The difference between the casings is the manner in which they are energized. A dead tank circuit breaker is grounded, while a live-tank circuit breaker is charged to the line voltage. While the live-tank option is cheaper, the dead tank option offers additional flexibility in terms of construction or repair. Since the dead tank casing is tied to ground, additional equipment can be safely mounted to it.

Materials

The third parameter which must be considered when selecting a circuit breaker is the insulating material used within the circuit breaker. Common insulating materials include air, oil and sulfur hexafluoride. Each option comes with a balance of pros and cons.

Selection

After weighing the options, ultimately, the **Siemen's SPS2 Dead Tank Circuit Breaker** (pictured above) was chosen. The SPS2 has a supported voltage range of 15kV to 245kV, which covers both the current requirement of 115kV as well as the future possible requirement of 145kV. The dead tank circuit breaker was selected based on the fact that it was safer for any personnel as it is tied to ground. For insulation, the sulfur hexafluoride, SF6, was chosen as it is environmentally friendlier and is easier to maintain.

4.1.2.2.1 Internal Schematics

After the successful selection of a suitable breaker, the team was next tasked with developing the internal schematics for the breaker. These are important drawings as they illustrate the internal circuitry associated with closing and trip functionality. The image below shows the complete internal schematic associated with the Siemen's SPS2 Dead Tank SF6 Circuit Breaker.

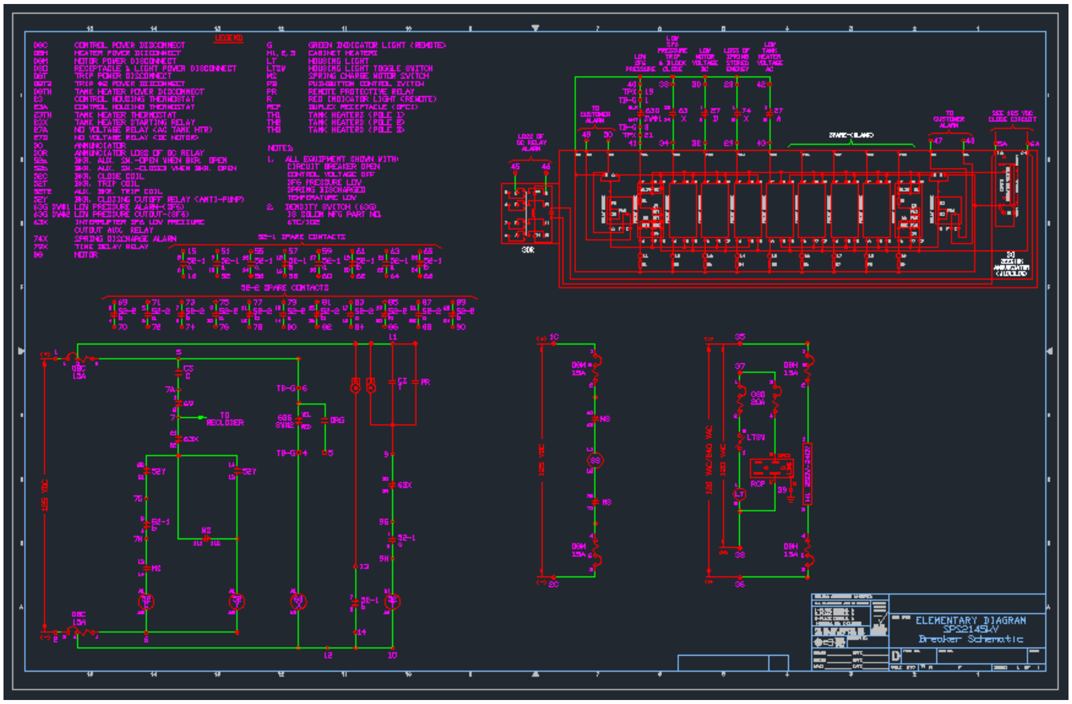

Figure 6: Internal Breaker Schematics

4.1.3 Iteration Description

To date, the team has completed several iterations of the design-review-revise process on the one-line diagram. The final design review was completed on April 19, 2013. The details of each iteration are detailed below.

INITIAL ITERATION – 3/8/2013

This first design review served as a check point for both Burns and McDonnell and the Iowa State senior design team. Prior to this design review, the Iowa State team had received no formal design direction and the first design attempt was based solely on background research and referencing previous substation drawings provided by Burns and McDonnell. The team had successfully positioned the three main breakers as well as the CTs attached to each breaker. The focus of this initial design review was to discuss the functionality of the main substation components with a heavy focus on the relays being used.

SECOND ITERATION –3/15/2013

Following the feedback received at the first design review, the team focused on the two line-exits, the Coover Line exit and the Campanile Line exit. The team re-positioned the PT's and the CCVT's based on feedback from Burns and McDonnell and positioned the primary and secondary relays for the Coover Line and Campanile Line exits. Upon meeting with Burns and

McDonnell, the team received positive feedback on the relay positioning but was given a relay function reference guide, detailing all of the possible functions of each relay, including the function codes. This guide has been appended to the end of this report. The team was advised to research the contents of the document and to update the defined relay functioning to reflect the proper codes.

THIRD ITERATION – 3/29/2013

Based on the function codes listed in the relay reference guide, the team updated the relays to reflect the appropriate function codes and completed the rest of the relay wiring on the line-side exits. This included wiring the primary and secondary relays, the appropriate PT's and CCVT's, failure to trip relays and the necessary meters. The main feedback from the third design review meeting with Burns and McDonnell centered on drafting standards and ensuring that the wiring of the relays reflected Burns and McDonnell convention. Also, the functionality and proper wiring of the CT's and PT's were clarified: the CT's were intended to be connected in series and the PT's were intended to be connected in parallel.

FOURTH ITERATION – 4/5/2013

Following the completion of the wiring on the line-exits, the team focused on the generation line on the one-line diagram. The wiring from the generation line is very different from the wiring on the line exits as different components are required. For example, a wave trap is utilized on the line-exits, but is not present on the generation line side.

FINAL ITERATION – 4/19/2013

The final design review for the one-line diagram was held on April 19, 2013 with Burns and McDonnell. This final review was intended to be the most critical, with the design team at Burns and McDonnell calling out every change they wished to be made.

The result of this iterated design process is a complete and accurate version of the one-line diagram that will be used as a reference for the remaining project designs.

4.2 Physical Campus Layout

4.2.1 Spacing Requirements

Spacing requirements are utilized in the substation for several reasons to make sure each component has the proper footprint area, for proper operating area, and the spacing for Phase-to-Phase so that flashovers (if they should occur) happen at the Phase-to-Ground rather than the Phase-to-Phase. The proper footprint area consist of taking into account the actual size of the component, this is so that the foundation is large enough to encompass the sure size of the component but to support the weight of the component as well. Much of the footprint design was to realize the size of each component by looking up the data sheet for the selected component and taking into account the dimensions provided. The proper operating area is mostly considered in the substation for the switches and what switch is being utilized in the substation.

There are three specific types of switches and are categorized by the way the switch operates, or opens. They are vertical break, side or horizontal, and horn gap switches. Each switch consist of a Centerline –to-Centerline spacing given by Cooperative Research Network (CRN) in the standards book *Design Guide for Rural Substations* in Table 4.8 on page 72. The Vertical Break

Disconnect Switch was used because the Vertical Switch has the smallest footprint. The Phase-to-Phase spacing is dependent on the overall power (kW) the substation is designed to support. As the power is increased the distance between Phase-to-Phase increases as well, the spacing requirements for ranges of kilowatts is provided by Cooperative Research Network (CRN) in the standards book *Design Guide for Rural Substations.* Table 4.7 on page 71 shows for a 115 kV – 121 kV substation the Centerline-to-Centerline spacing should have a clearance of 2.13 meters (84 inches) or 7 feet. By using these standards flashovers are taken into account and will not happen Phase-To-Phase.

4.2.2 Component Orientation/Placement

Component orientation or placement is just as important as anything else when completing the physical layout of the substation. Just as the design compensated to ease the cost of construction the decision to orient the components in a certain fashion could not only add cost in materials but also maintenance cost in the years to come. The substation components were placed so that the maintenance crew can easily monitor each component from the control house. As the vertical switch was used for small footprint it was also selected because of the ease to monitor if a switch has in fact been disconnected do to fault or to ensure that section has no power flowing through it so maintenance can be performed. The breakers in the substation have an orientation due to the control box located on the breaker itself. This was taken into account due to the amount of time it would take for the technician to inspect each breaker and the safety of the technician for the amount of power lines one would have to walk under. The breakers have been oriented to face to the center of the ring bus configuration to allow shorter distances to walk to each breaker from another and to allow the technician to only have one overhead power line to cross under while performing maintenance on the substation.

4.3 Grounding Grid Design

4.3.1 Functional and Safety Requirements

The grounding system serves to meet the following objectives.

1. Ensure a degree of human safety that a person working or walking in the vicinity of facilities is not exposed to the danger of critical electrical shock.
2. Provide a means to carry and dissipate electrical currents into the earth under normal and fault conditions without exceeding any operation and equipment limits or adversely affecting continuity of service.
3. Provide grounding for the surges occurring from the switching of substation equipment.
4. Provide low resistance for the protective relays to see and clear ground fault, which provides protective equipment performance, particularly at minimum fault.

4.3.2 Calculations

The requirements of the equipment protection and system functionality objectives are easily fulfilled by designing a basic grounding system consisting of a square grid of horizontal bare conductors just below the ground, with vertical ground rods connected to the grid. All equipment and structures are electrically connected to the grid, to establish ground and to carry current safely into the earth.

Designing for human safety requires addressing the interactions between the two grounding systems:

1. The intentional ground, consisting of grounding systems buried at some depth below the earth's surface (this is the grounding system we are designing to be physically installed in the substation).
2. Accidental ground, temporarily established by a person exposed to a potential gradient in the vicinity of a grounded facility.

To minimize the possibility of the interaction between the two grounding systems resulting in an electrocution, first the limit of permissible body current must be considered. The two cases used to evaluate human safety are step and touch voltages. **Step voltage** is defined as the difference in surface potential experienced by a person bridging a distance of 1 meter with the feet without contacting any other grounded object. **Touch voltage** is defined as the potential difference between the ground potential rise and the surface potential at the point where a person is standing while at the same time having hands in contact with a grounded structure. The following figures of common step and touch voltage scenarios illustrate basic circuit analysis utilized.

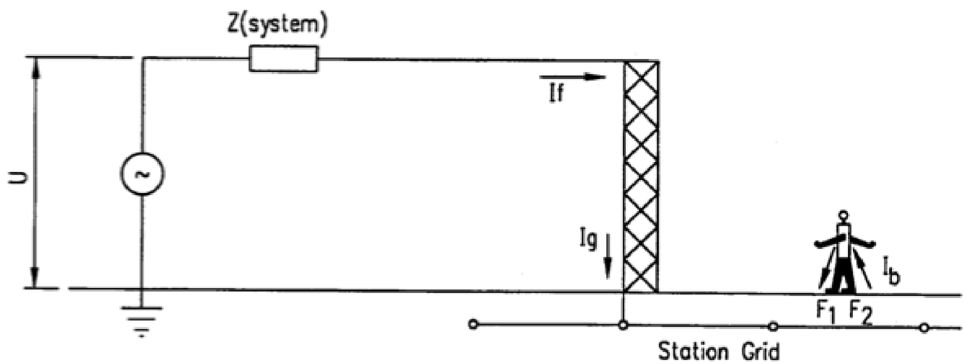

Figure 7: Exposure to Step Voltage. IEEE Std. 80-2000.

To determine the maximum permissible step voltage:

$$E_{step} = (R_B + 2R_f)I_b$$

Where:

E_{step} = Step voltage (volts)

R_B = Resistance of the human body (W), estimated to 1000 W

R_f = Ground resistance of one foot (W):

$$R_f = C_s 3 r_s$$

C_s = Surface layer derating factor

$r_s =$ Resistivity of the protective surface layer used at the substation (W -m)

$I_B =$ Magnitude of the current through the body (A) able to be withstood by 99.5% of all persons

$$I_B = \frac{k}{\sqrt{t_s}} = \frac{0.116}{\sqrt{0.25}} = 0.232$$ A

$k =$ Constant related to electric shock energy, for a 50kg human, k = 0.116

$t_s =$ Duration of the current exposure (seconds), $t_s =$ 0.25

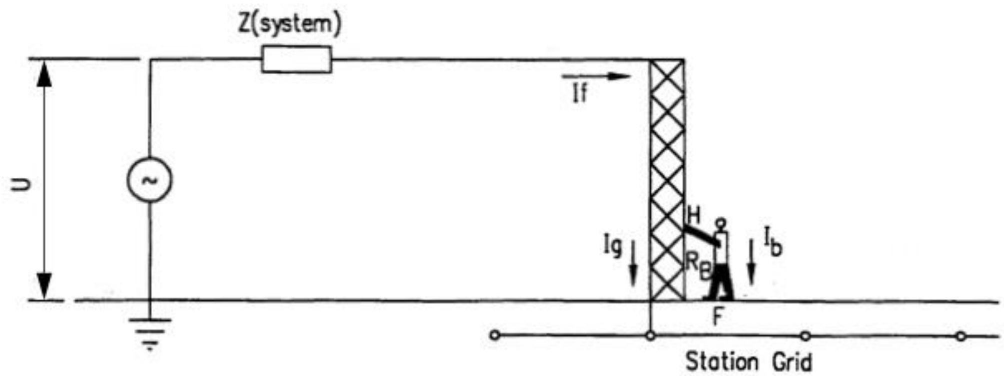

Figure 8: Exposure to Touch Voltage. IEEE Std. 80-2000

To determine the maximum permissible touch voltage:

$$E_{touch} = (R_B + \frac{R_f}{2})I_b$$

Where:

$E_{touch} =$ Touch voltage (volts)

$R_B =$ Resistance of the human body (W), estimated to 1000 W

$R_f =$ Ground resistance of one foot (W):

$R_f = C_s 3 r_s$

$C_s =$ Surface layer derating factor

$\rho_s =$ Resistivity of the protective surface layer used at the substation (W -m)

$I_B =$ Magnitude of the current through the body (A) able to be withstood by 99.5% of all persons

$$I_B = \frac{k}{\sqrt{t_s}} = \frac{0.116}{\sqrt{0.25}} = 0.232$$ A

$k =$ Constant related to electric shock energy, for a 50kg human, k = 0.116

$t_s =$ Duration of the current exposure (seconds), $t_s =$ 0.25

4.3.3 Testing

The team modeled the grounding system using WinIGS software by creating the grounding system and specifying the proper materials. This also included the physical characteristics of the substation: fence layout, soil resistivity modeling, and the layer of crushed rock covering the surface of the substation. The desired tolerable step and touch voltages were entered using IEEE Std. 80-2000. This model was then used to simulate fault conditions using the maximum single phase fault current and ensure that the maximum step and touch voltages occurring were within the calculated maximum permissible step and touch voltages.

4.4 Bus and Insulator Sizing

Bus and Insulator sizing is commonly based on operating ratings. Conductor material can be a significant cost, so monitoring the cost/benefit ratio merits consideration. The team investigated shielding materials and sized the conductors to ensure we would be within specified operating ratings without unnecessarily inflating our budget.

4.5 125V Battery Selection

The 125V DC battery design is a critical system in the case of power outage to serve as the backup power supply or an auxiliary dc power system for the 115kV substation. In the case of a system failure the fault detection would be inoperable and would cause extreme damage to the substation. Remote switching, fault detectors, breakers, switches, etc., would be unable to perform their tasks and expose the substation to even more damage. It is very important to have a backup supply that can withstand the load of the major components needed to operate and maintain a safe reliable substation.

4.5.1 Sizing Calculations

It's typical to begin looking at the standards that are already in place to size battery capacities for a given load profile. IEEE-1106 and IEEE-1115 are used for select battery types. In this project, the team focused on the Nickel-Cadmium (N-C) battery type. While most industries today have software programs that can automatically calculate the load and the size the battery cells needed to serve a substation, basic calculations for the ISU substation battery design will be examined. For the sizing design, the power outage calculations will be considered for an 8 hour outage. It is assumed that the substation would have on-site engineers capable of quick service and repair. This means that an 8 hour window to get the system back up and running without a major reset of the system is a reasonable goal.

NOTE: Due to the time constraints of this project, the design will only look at the relays from the one-line diagram and define an assumption for an 115kV amp load for a 125Vdc station battery design.

The first step is to calculate the discharge rate. For the purpose of this calculation a discharge rate of 1-min is assumed. In the basic one-line diagram, there are 10 major relaying equipment pieces to service during an outage. Under maximum conditions and for safety, we are assuming each relay demands a maximum of 25 watts.
(Total list of Relays from one-line: SEL-321 (2), SEL-352 (3), SEL-311B (2), SEL-311L (2), SEL-351A (1).

$$25 \times 10 = 250W$$
$$\frac{250W}{125Vdc} = \mathbf{2\ amps}$$

125VDC Load	Quantity	Current(A)	Subtotal(A)
115kV Substation Relays	10	.2	2
Assumption: 115kV Substation Circuit Switches, breakers, switchgear indicating lights.	20	5.6	112
Total System Load			**114 Amps**

The following values of 0.8 battery aging factor and 0.85 design factor is based off of a CH2M HILL, Inc.[i] research study on batteries and their models of N-C battery types. The required ampere-hour rate for a hypothetical 115kV substation load is calculated out to be 25Ah.

$$\frac{114\ amps}{0.8\ (battery\ aging\ factor)} = 142.5amps \quad \frac{142.5}{.85\ (design\ factor)} = \mathbf{167.64\ amps}$$

The rate of discharge under the assumed load condition for the substation is 167.4 amps.

Next is to calculate the ampere-hour (Ah) rate. 115kV substation 35 = Ah, 77 degrees ambient room temperature factor of 0.8. (CH2M HILL, Inc.)

$$\frac{35Ah}{0.8} = \mathbf{43.75Ah}$$

From the provided studies of CH2M Hill, Inc. our team has chosen battery Model A, which has a 1-minute, 177A discharge rate with an 8-hour Ah rate of 180 amps, which is plenty to cover our load for the 115kV substation because we measured at the maximum load with a little extra for safety room.

The Iowa State Substation 125Vdc battery bank would then consist of **92, Nickel-Cadmium Battery Cells,** which will also allow for future expansion and growth for the substation.

4.5.2 Discussion of Options

The battery selected was a Vented Nickel-Cadmium (N-C) with an expected life of 20-25 years. This specific kind of battery has a low risk priority number (RPN), which is calculated by the ease of detection, occurrence of failure, and how severe the failure.[ii] The (N-C) battery degrades linearly over its lifespan and is able to provide tripping duty until the battery is no longer able to hold a charge. Other positives to the N-C battery bank, is the ability to maintain performance under rapid high and low temperature changes (typical for Iowa climate), and low water consumption over the lifespan. We have chosen these to be important measures at the cost of reliability and safety for the campus and surrounding services.

4.5.3 Discussion of Future Maintenance and Testing

Part of a comprehensive contracting package includes considering the maintenance and testing required when installing a component, in this case, a 125V DC battery supply. For ease of testing, the batteries will have a circuit breaker and its own connection ports and switches to allow a place for connecting a discharge load. Each battery will be wired in series yet isolated from the rest of the system to allow tying in new batteries as well as capacity tests during maintenance. Another reason for individual isolation, is for the system to be ready for future expansion. The batteries will be configured as an auxiliary power system and rated to handle the full load of the system. This is to undergo contingencies; the backup auxiliary DC supply will be able to handle even the heaviest bus load.

In accordance with supplying power to the distributed bus loads, the battery charger must also be able to supply a continuous load and recharge the system during the power outage time frame. The system has been designed to handle a power outage within a 24-hour power outage. To help determine the time frame, the IEEE standard given in the IEEE Std. 946-2004 was referenced, which is the recommended practice for the design of a DC auxiliary power system for substations.

The monitoring system installed will be able to determine the voltage level of each battery as well as at each bus delivery point. This helps to ensure proper distribution of power during the outage. Another key component to the battery design is the redundancy to each battery connection so that there is not a single point of failure. Further prevention of faults will be monitored through an internal relay and breaker system to ensure the battery bank is safe from faults, and operates under high current levels yet maintains a safe and operable system.

5 Design Assessment

5.1 Risk Assessment/Technical Challenges

There are no true risks associated with this project. This is due to the fact that the project is intended for educational purposes only. However, there were risks associated with completing this project that exist in the form of bottlenecks. Bottlenecks on this project include:

- Learning curve associated with learning the two software packages associated with this project: WinIGS and AutoCAD
- Learning and becoming familiar with Burns and McDonnell, as well as industry safety standards
- Learning Burns and McDonnell symbology
- Ensuring a correct one-line diagram
- Finding resources to confer with on the design

5.2 Design Verification

As no formal testing is required for this project, the team will verify the design by conducting numerous design review meetings with experts in the field. Not only will the team advisor, Professor Ajjarapu, be supervising the design, the team will be consulting with engineers at the client company, Burns and McDonnell. This reflects the current internal review process utilized by Burns and McDonnell.

6 Work Plan

6.1 Scheduling: Jan 14, 2013 - Dec 10, 2013

Please see attached GANNT chart.

6.2 Work Breakdown Structure

Review Materials	Responsible Party	Details
Understand Requirements and Specification	Entire Team	Substation Design Manual
	Entire Team	Scope Document
Project Documents	Jane Peters	Draft Project Plan
	Jane Peters, Jared Jasper	GANNT Chart
	Matt Murphy	Draft Design Document
	Jane Peters	Final Project Plan
	Jane Peters, Matt Murphy	Final Design Document
	Jared Jasper	Legend of Symbols
	Muzi Li	Bill of Materials
	Jane Peters, Matt Murphy, Jared Jasper	Project Poster
Calculations	Muzi Li	Bus calculation
	Jane Peters, Jared Jasper	Identify System Load
	Matt Murphy	Grounding Conductor Sizing
	Supplied	Fault Current Verification
Detailed Physical Design	Jared Jasper, Jane Peters	Site Design
	Muzi Li	Foundation Design
	Matt Murphy	Grounding Plan
	Muzi Li	Raceway
	Muzi Li	Bus and Insulator Sizing

	Matt Murphy	Service Station Transformer
	Jane Peters, Jared Jasper	Drawing for Circuit Breakers
Detailed Protection & Control Design	Matt Murphy	Relaying and Controls
	Riley Groves	125V DC Station Battery Design
	Jane Peters, Jared Jasper	Control Building Conduit Trench
Layout	Jane Peters, Riley Groves, Matt Murphy	One-line Diagram
	Jared Jasper, Jane Peters	Physical Layout (Substation)
	Jane Peters, Jared Jasper	Section Cut Drawing
	Muzi Li	Foundation Plan
	Matt Murphy	Grounding Layout
	Jane Peters, Jared Jasper	Control Building Sizing

6.3 Resource Allocation

Resource Allocation	
Software	AutoCAD, WinIGS T&D Toolkit
Hardware	ECpE Lab Resources
ECpE Faculty	Dr. Ajjarapu, Venkataramana
Burns &McDonnell Project Contacts	Brad Jensen Nathan G. Schares
Senior Design Funds	Diagram printing Travel cost to local substation

Personal Roles	
Groves, Riley	Communications Coordinator
Jasper, Jared	Webmaster
Peters, Jane	Project Coordinator
Li, Muzi	Materials Analyst
Murphy, Matthew	Primary Drafter

7 Revision History

REVA: Draft of project report completed 2/22/2013.
REVB: Update Project Plan 4/9/2013.
REVC: Update Final version of project report for the first semester 4/27/2013.
REVD: Update Project Plan to reflect changes to scope. 10/15/2013.