Central Iowa Power Cooperative

POWER PLANT – RELAY REPLACEMENT DESIGN
FINAL REPORT

ISU Senior Design Group: Dec15-22

Dan Dye

Project Web Site:

http://dec1522.sd.ece.iastate.edu/

Project Sponsor: CIPCO

Project Advisor: Professor Mani Mina

Revised: 12/07/15

Table of Contents:

Figures and Diagrams:

Tables:

1. Introduction

This project is designed for and sponsored by Central Iowa Power Cooperative (CIPCO). The project is under the guidance of Terry Fett Manager of Engineering at CIPCO and Mani Mina the Engineering Advisor at Iowa State University.

Central Iowa Power Cooperative (CIPCO) is Iowa's largest cooperative energy provider serving 13 rural electric cooperatives and associations spanning 58 of Iowa's 99 counties. CIPCO's members serve a population of nearly 320,000 rural and urban residents and approximately 12,000 commercial and industrial accounts. CIPCO is a generation and transmission cooperative supplying power to its member distribution cooperatives covering a territory which stretches 300 miles diagonally across the state from the Mississippi River on the east to Shenandoah in the southwest.

CIPCO supplies all power requirements for its member cooperatives, and as their power provider, CIPCO is dedicated to delivering quality, safe, and reliable service at the lowest possible cost.

CIPCO locations include Cedar Rapids, Creston, Des Moines, Montpelier, and Wilton employing approximately 130 people.

This document includes the information to complete this project; design document, implementation details, testing process, support information, project difficulties, learning opportunities, and the deliverables.

2. Design Document

2.1. Project Statement

2.1.1. Project Description

There are three main parts to this project. First, due to age and condition the existing power plant electro-mechanical relay equipment will be retired and new microprocessor based relaying equipment will be installed. The senior design project will be responsible for the complete design of the relay replacement which includes all required schematics and wiring diagrams.

Second, the senior design project will complete arc flash calculations and analysis for the existing metal clad switchgear. Metal clad switchgear has been known in the industry to have a high potential for arc flash. Determining the potential of these issues allows the operator to be aware and use the proper amount of precaution and personal protective equipment.

Third, the senior design project will provide engineering solutions to operate the switchgear safely. By researching alternatives and analysis of the potential of arc flash, engineering solutions shall be provided to advice in choosing the proper safety precautions during operations.

2.1.2. Project Scope

2.1.2.1. Relay Replacement

The primary goal of this project is to replace four power plant electromechanical relays with microprocessor based SEL relays. A full set of for-construction drawings will be completed showing the remove and addition of equipment and wiring, including communication equipment. The drawings will be completed using existing drawings while following CIPCO drafting standards and design templates. Relay functions for this situation will be identified and described.

2.1.2.2. Arc Flash Calculations and Analysis

The second part of this project is to complete arc flash calculations and analysis. These will be used to show the potential of an arc flash on metal clad switchgear which are controlled by the relay equipment that will be replaced.

2.1.2.3. Safe Operation of Metal Clad Switchgear

The third part of this project will be to identify two engineering solutions to operate the metal clad switchgear and relay equipment safely. Cost estimates and benefits of both solutions will be reviewed.

2.1.3. Excluded From the Project

2.1.3.1. Design Simulation and Testing

While all due diligence will be given during the design of this project, simulation and testing will not be completed as part of this project. Verification of design documentation will be completed during design review meetings at CIPCO.

2.1.3.2. Relay Settings

Relay settings will not be included as part of the relay replacement. Identification of suggested relay functions will be included.

2.1.3.3. Relay Testing

Microprocessor based relays require very precise testing due to the amount of features and internal programming. Relay tests or system check out procedure will not be provided as part of this senior design project.

2.1.3.4. Procurement

Equipment and materials will not be procured for this project. A bill of materials and cost estimate will be provided.

2.1.4. Project Deliverables

The following list of requirements were established with CIPCO and in accordance with CIPCO document "Project Scope" included under section design documents. The template for the CIPCO Project Scope was provided by CIPCO. These deliverables will be included in the form of for construction drawings, a document called Arc Flash, and document called Safe Operation of Metal Clad Switchgear.

Spring Semester 2015 Deliverables

Relay Replacement

- Relay one line diagram
- Elementary diagram / current schematic
- Control schematic
- Panel wiring
- Communication processor wiring

- Drafting and review

Arc Flash Calculation

- Calculation per OSHA (Occupational Safety & Health Administration)

Safe Operation of Metal Clad Switchgear

- Research and identify two possible engineering solutions
- Pros and cons of both solutions

Fall Semester 2015 Deliverables

Relay Replacement

- For construction package
- Relay functions

Arc Flash Analysis

- Calculation analysis
- Compliance regulations

Safety Operation Solutions

- Compliance regulation
- Cost estimates
- Operation guides

2.1.5. Design Specifications and Standards

As stated, the existing electro-mechanical relays are being replaced due to age and condition. The new SEL 351 relays are microprocessor based which have many benefits over electro-mechanical style relays:

- Higher level of flexibility of protection schemes
- More inputs and outputs for greater control and room for expansion
- Faster and more precise relay testing
- Communication to monitor and gather data

The new SEL relays give overall flexibility and room to grow as protection needs and technology change.

2.1.5.1. Operating Environment

The operating environment will be considered for each part of the project due to the harsh power plant environment. The environment can have large temperature changes along with dust, vibration, audio and electrical noise. These, among other operating constraints, will be considered during the design of this project.

2.1.5.2. Compliance Standards

Compliance standards play a large part in all aspects of the electric utility business and operation. These compliance standards will be ever present in all aspects of this project.

OSHA

Occupational Safety and Health Administration (OSHA) standard 29 CFR Parts 1910 & 1920 Electric Power Generation, Transmission, and Distribution. This standard helps setup rules and standards to promote safety in the electric utility industry.

NERC

North American Electric Reliability Corporation (NERC) standards are in place to help protect the reliability of the electric system. These standards are highly important and full compliance is required.

2.1.5.3. Standards

Design and CAD standards

CIPCO design and CAD standards will be followed during the design of this project. These design standards are in place to insure the equipment is designed properly, and to help prevent field installation problems, and ease of design and checkout.

2.1.5.4. Risk

This project involves many areas of risk. While designing this project the designer will have to take into account these risks and design around them. Some of these areas of risk are operating environment, complying with compliance standards, budgetary constraints, and meeting project deadlines. During the design, the designer will need to build in protection from these risks.

2.2. System Level Design

This project consists of relay replacements on 4 sets of metal clad switchgear on panel units 6,7,8, and 9. The existing electromechanical relays are to be replaced with SEL 351 relays. Arc Fault calculations and engineered safety operation alternatives will be determined to operate the switchgear. The calculations will follow OSHA 29 CFR 1910.269 standard.

2.2.1. System Requirements and Functional Decomposition

2.2.1.1. Function Requirements

Due to the properties of this project, there will be no physical deliverables to test the functionality. The project will be designed to meet the main project requirements while adhering to CIPCO and regulatory standards. That being said, the reviews completed by the project sponsor will help insure that the designer is working towards producing a proper design that will function as required after implementation. Therefore, the following are considered functional requirements of this design project:

- Development of engineering for construction drawing package in AutoCAD format for relay replacement including the following:
  - Relay one line diagram
  - Elementary diagram / current schematic
  - Control schematic
  - Panel wiring
  - Communication processor wiring
  - All required drafted
  - Proposed relay functions
- Arc flash calculations and analysis
  - Per OSHA standard 29 CFR 1910.269
  - Calculation analysis and safety recommendations

- Safe operation of metal clad switchgear
  - Two possible engineering solutions to safely operated switchgear
  - Analysis of compliance regulation
  - Cost estimates
  - Operations guides for solutions

2.2.1.2. Non-Functional Requirements

Due to this project being a design without implementation, there are no non-functional requirements. This is primarily due to the project exceptions of relay modeling and testing. The project will be designed to meet all standards to insure the equipment will function as required when installed and tested. The functionality and relay settings will be tested at installation and is out of scope for this project.

2.2.2. System Analysis

2.2.2.1. Block Diagram of the Concept

To help stay organized, produce a high quality product, and keep on track the relay replacement design has been broken down into several parts. Each step has a review process with the Terry Fett, the Project Sponsor from CIPCO and the Supervisor of the Engineering Department, to insure the right approach has been taken with the design. During the review process, drawings will be delivered to Terry Fett. He will review and comment on the drawings. The drawings will then be delivered back to the designer for corrections. This process continues until Terry has deemed the design correct and then the designer can move on to the next step. This approach prevents mistakes from being carried throughout the project making corrections far more complicated, time consuming, and costly. This review process follows closely how CIPCO operates with internal and external design consultants.

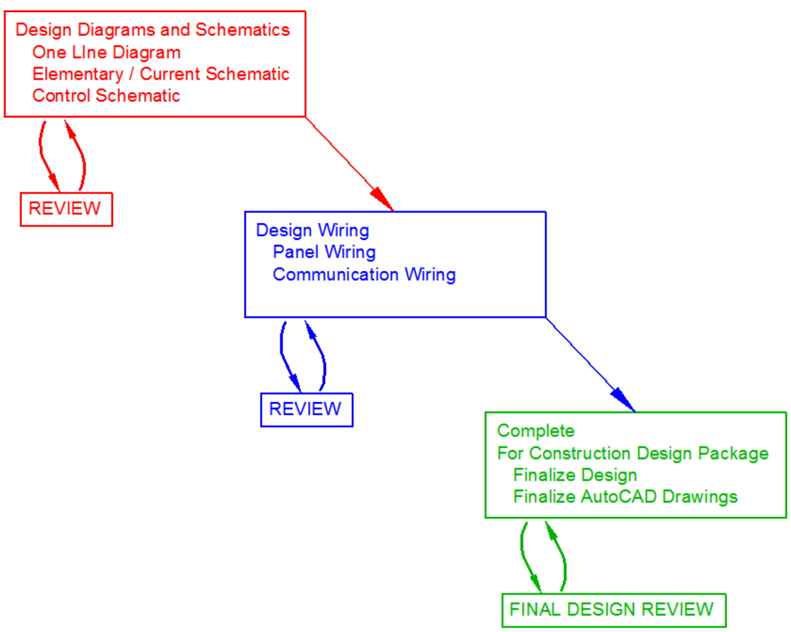

Figure 1: Concept Block Diagram

2.3. Design Description

The electromechanical relays to be replaced are on four different units, controlling four different switchgear, and powering different power plant equipment.

2.3.1. System input/output Analysis

2.3.1.1. System Inputs

The inputs to the new relay equipment will be very similar to the existing relays. AC line currents, AC bus voltages, 125VDC to power the relay, alarms, and breaker status will be brought into the SEL relay. The relay will use its programming to determine multiple functions and actions including tripping or closing the switchgear.

2.3.1.2. System Outputs

The outputs are similar to the relay inputs in that they will remain similar to the existing relay equipments outputs. The outputs will be switchgear trip and close, relay alarm, and communications.

2.3.2. User Interface Specifications

The primary software used for this project is AutoCAD. The CAD files will be prepared in accordance with the CIPCO CAD standard. These will be saved as .dwg file types and printed to .pdf. Fonts, layering, colors, title blocks, and additional items are covered in the CAD standard. The design review will cover both the electrical design as well as the drafting details.

2.3.3. Hardware/software Specifications

This project is software based, in that no physical product will be delivered. The project will be primarily designed in AutoCAD software. Other software used will be Microsoft products and Adobe Acrobat. No specialized software will be required and all CIPCO CAD standards will be followed.

2.3.4. Simulations and Modeling

All design drawings will be completed in AutoCAD and printed to pdf for review and for final construction drawings. These reviews will act as our testing grounds to produce a theoretical functioning design that meets industry standards. Arc flash calculations will be completed in Excel for ease of use and repeatability. Simulations and relay testing are out of scope for this project.

2.3.5. Implementation Issues and Challenges

There are many challenges to this project. Some are based on lack of experience with this type of equipment and the environment that it is operated in. Other challenges are schedule conflicts and meeting required deadlines. Also, challenges could be to balance cost versus benefit of the particular solution. All challenges will be met with a tenacious determination and a wiliness to learn.

2.3.6. Testing, Procedures and Specifications

No formal testing or simulations will be completed during this project and are considered out of scope. This design will be heavily reviewed to insure all industry standards, and regulations will be met and followed.

2.4. Design Decisions and Justifications

Standard drawings will be used and provided by CIPCO to help progress the project and understanding of the equipment.

2.4.1. One Line Diagram

The one line diagram is a simplified representation of the entire system. It uses industry standard symbols and IEEE device numbers to convey the equipment and the function of the equipment.

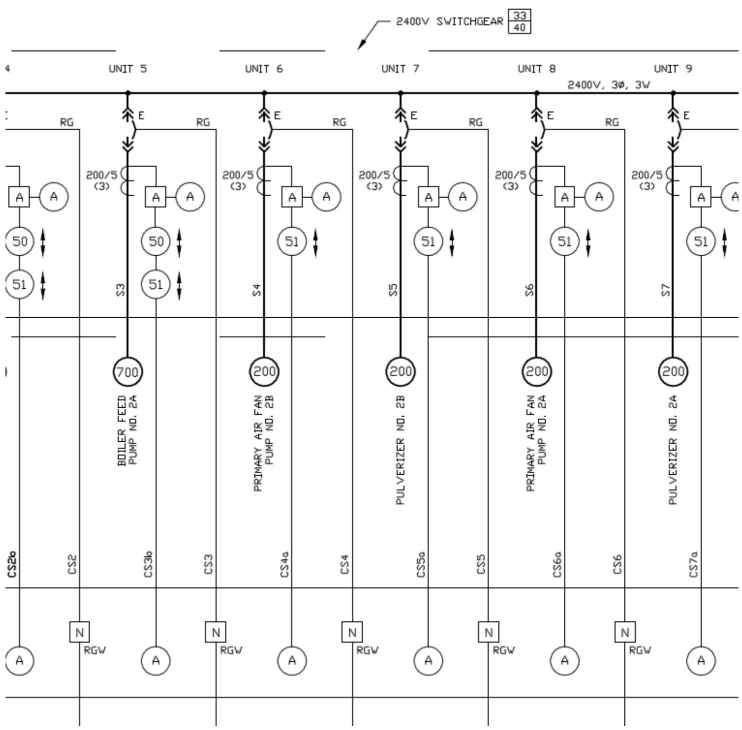

Figure 2: One Line Diagram

2.4.2. Elementary / Current Diagram

The elementary / current diagram is a simplified representation of the switchgear. The diagram show primarily how the current transformer is connected to the protective relaying, metering equipment, and phasing.

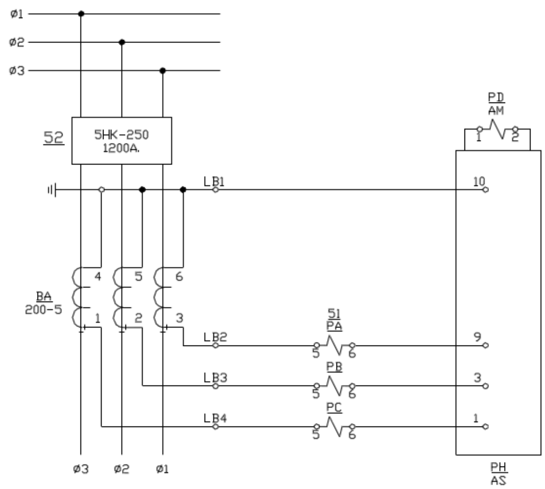

Figure 3: Elementary / Current Diagram

2.4.3. Control Diagram

The control diagram shows how the switchgear and relay equipment work together in a simplified diagram demonstrating its function. The diagram shows inputs and outputs of the relay, contacts of the breaker, and the close and trip portions of the control circuit. In general, it gives an overall picture of the workings between the equipment and a general understanding of how the equipment operates.

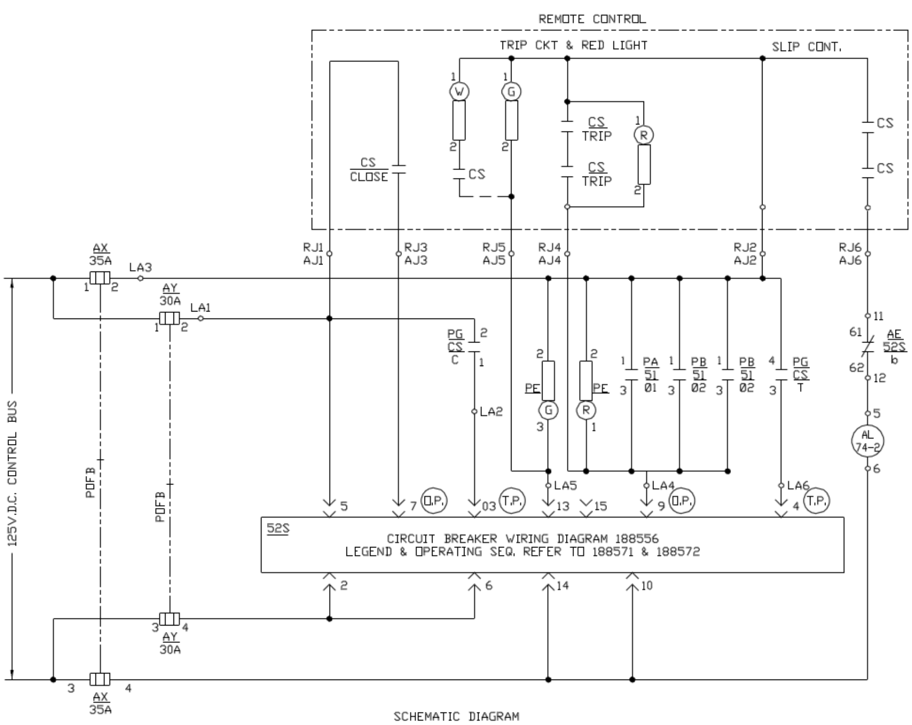

Figure 4: Control Diagram

2.4.4. Panel Wiring

Panel wiring is a diagram of how and where the equipment is wired together. The wiring should follow the functional representation shown in the control diagram and the other schematics.

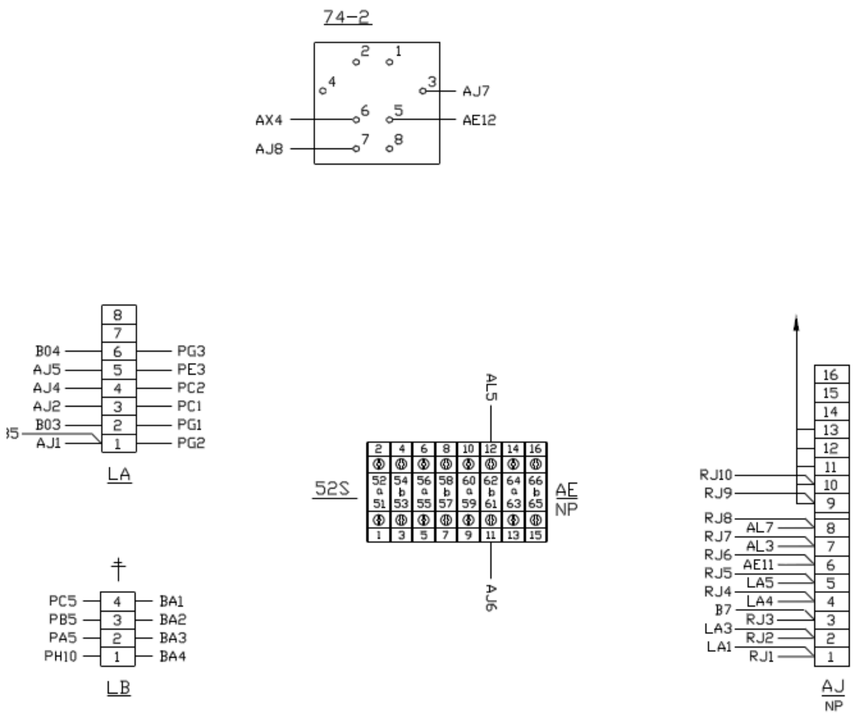

Figure 5: Panel Wiring

2.4.5. Communication Wiring

Communication wiring helps show what and how equipment is wired together. Some systems have functional schematics demonstrating how the equipment works together.

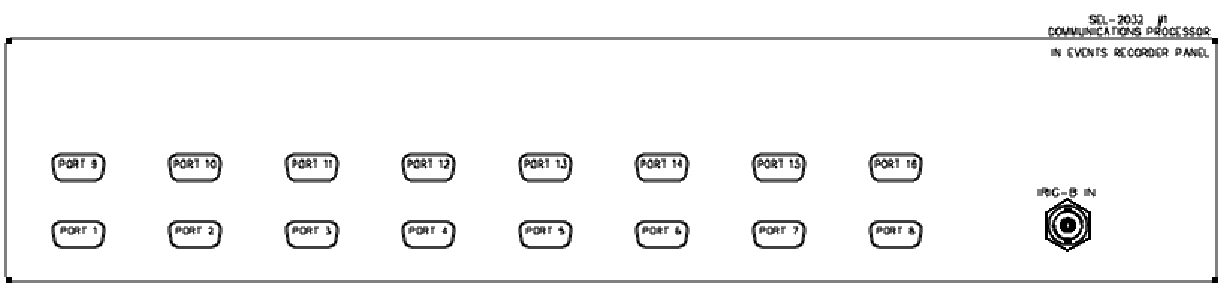

Figure 6: Communication Wiring

2.5. Work Plan

Power Plant - Relay Replacement

Iowa State EE Senior Design - December 2015
Group: Dec15-22
Dan Dye - 4/25/15

Key Activities Spring	Weeks - Spring 2015 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Develop Project Scope	■	■	■	■											
Develop Project Plan				■	■	■									
Develop Man-hour Budget						■									
Gantt Chart						■									
Design Relay One Line Diagram						■	■								
Design Elementary Diagram / Current Schematic							■	■							
Design Control Schematic							■	■							
Design Panel Wiring									■	■					
Design Communication processor Wiring									■	■					
Design Review											■				
Arc Flash Calculation									■	■					
Arc Flash Design Review											■				
Safe Operation Engineering Solutions										■	■				
Safe Operation Engineering Solutions Design Review											■	■			
Compleation of Project Report													■	■	
Presentation Practice / Presentation														■	■

Key Activities Fall	Weeks - Fall 2015 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Design Elementary Diagram / Current Schematic	■	■	■	■											
Design Control Schematic	■	■	■	■											
Design Panel Wiring	■	■	■	■											
Design Review					■	■									
Relay Replacement Deisgn Construction Package							■	■							
Relay Replacement Deisgn Function							■	■							
Arc Flash Calcuation Analysis					■	■	■								
Arc Flash Calcuation Compliance Regulations								■	■						
Arc Flash Analysis Review										■					
Safety Operation Solutions Compliance Regulations								■	■						
Safety Operation Solutions Cost Estimates									■	■					
Safety Operation Solutions Operation Guild									■	■					
Safety Operation Review											■				
Compleation of Final Project Report												■			
Design of Project Poster													■		
Presentation Practice														■	■
Presentation															■

Table 1: **Work Schedule - Gantt chart**

2.6. Engineering Diagrams

2.6.1. Switchgear Diagrams

2.6.1.1. One Line Diagram

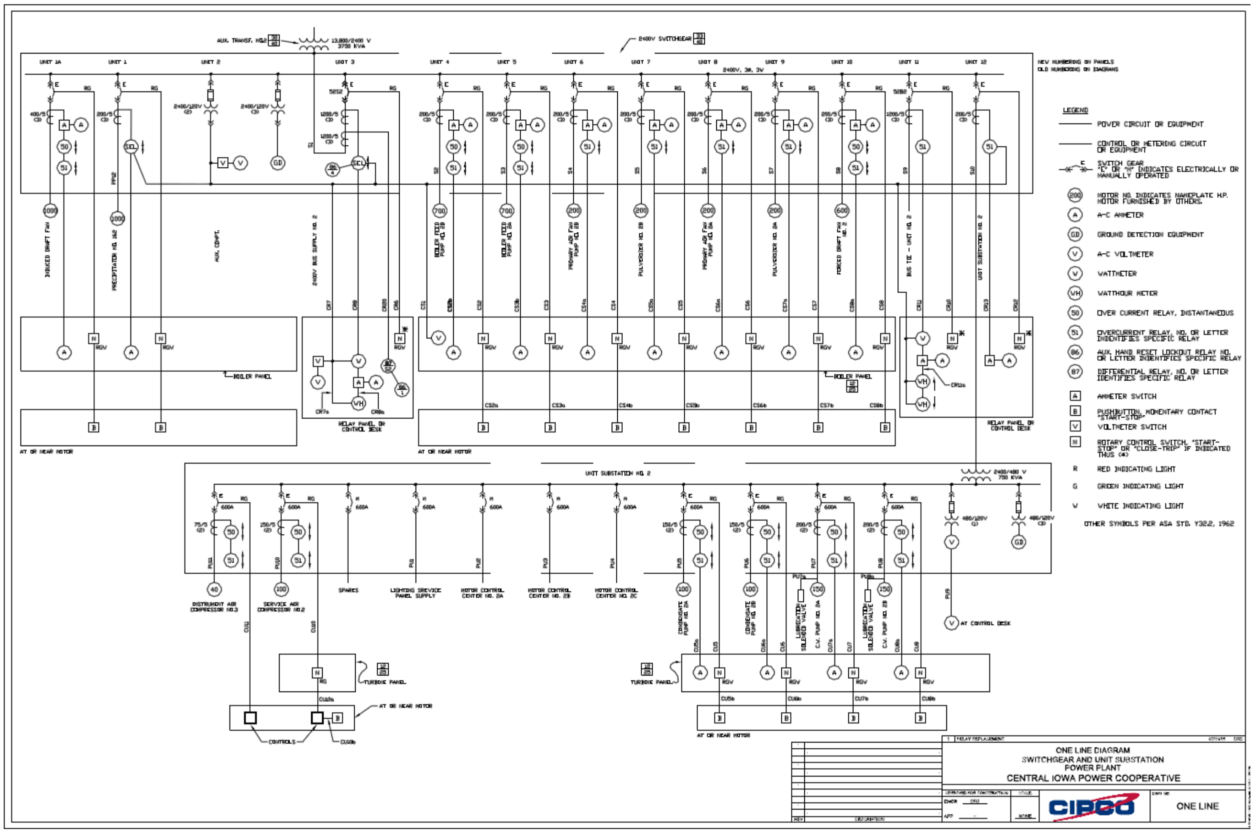

Figure 7: One Line Diagram

2.6.1.2. Power Plant – Unit #6 Diagram

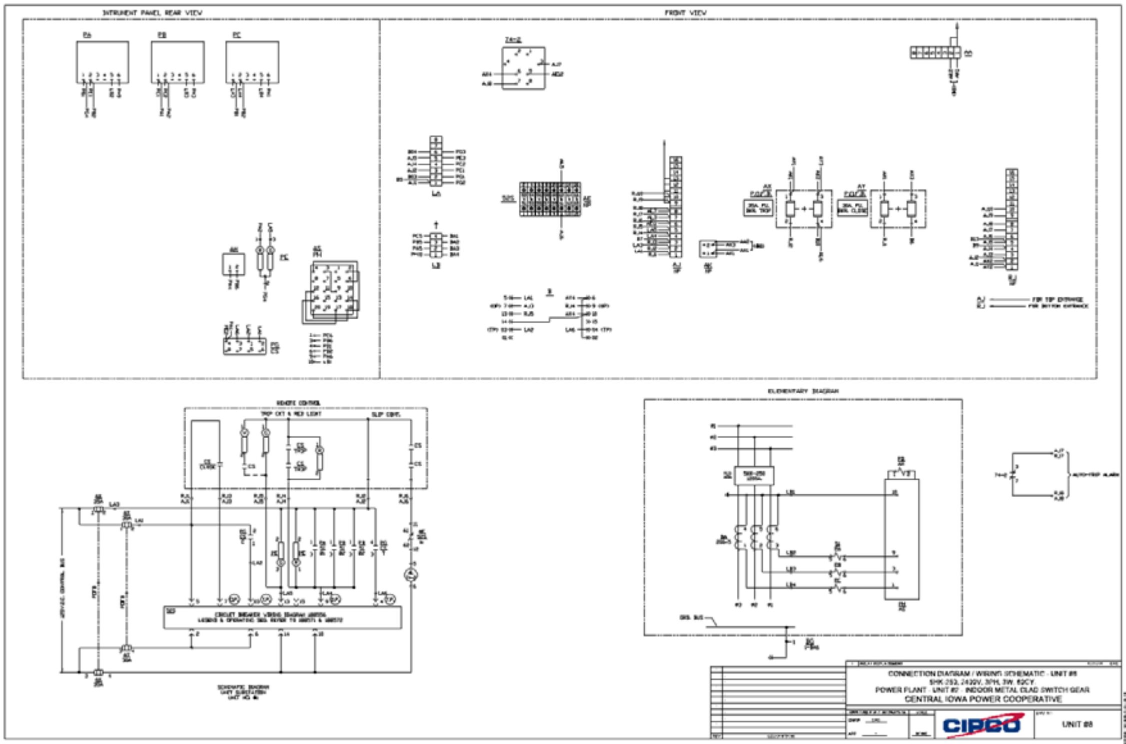

Figure 8: Connection Diagram / Wiring Schematic

2.6.2. Standard Drawings

2.6.2.1. Title Block

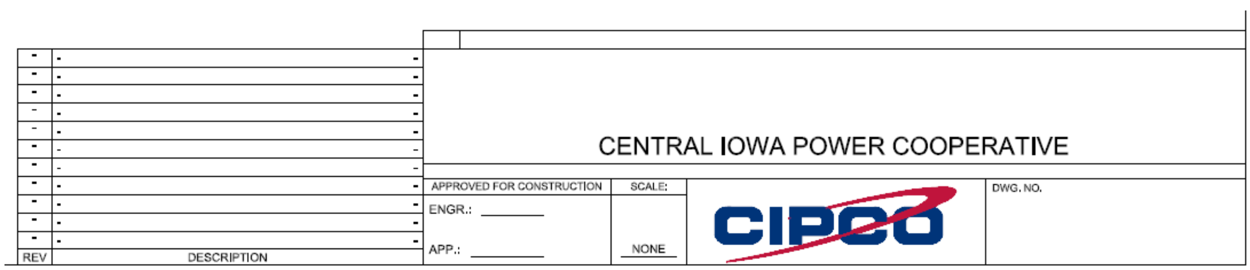

Figure 9: Standard Title Block

2.6.2.2. Standard Relay Wiring Diagram

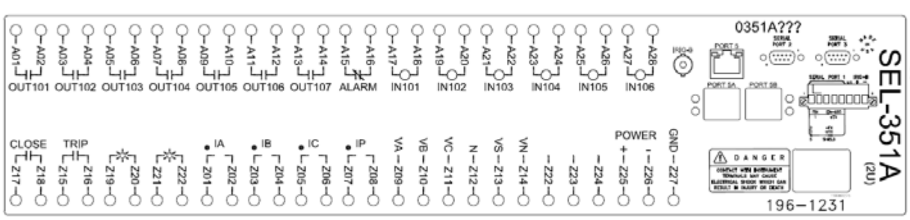

Figure 10: Standard Relay Wiring Diagram

2.6.2.3. CIPCO AutoCAD Standard Summary

The CIPCO AutoCAD standard is too detailed for this document. The purpose of the standard is to define information and procedures to assure the accurate and consistent work. The standard details items like drawing numbers, file naming, line types, title block, and construction drawings. These standards will be adhered to while completing this project.

3. Implementation

Implementation could be broken down into two parts. One part could be considered the design implementation and the other could be the physical implementation. This project falls into design implementation due to project considerations and exceptions. The design implementation was over seen by the client CIPCO, Engineering Manager and Project Sponsor, Substation Engineers, and Manager of Health and Safety. Their feedback helped guide the design as well as help my understanding.

As earlier stated, the physical implementation is not part of the project. This is primarily due to the exceptions of relay modeling and testing. CIPCO does not have a test lab to test the functionality of the equipment before the physical implementation. The design was reviewed to ensure the equipment will function as required when installed and tested at checkout. The functionality of the relay primarily comes from the relay setting and is out of scope for this project and was not included.

For the relay replacement, as shown in the diagram below identified with the blue arrow, the design was broken into sections as seen below. Moving from left to right, the drawings for the relay replacement we completed first. The order of the drawings follows Figure 1 the Concept Block Diagram and the Work Plan Gantt Chart. The drawings started with the one line diagram, and then moved to control schematics, and lastly the panel and communication wiring. Next the project documentation was completed such as the bill of materials and cost estimate. Lastly, the for construction package was completed by putting all of the drawing and documentation together and ready for construction.

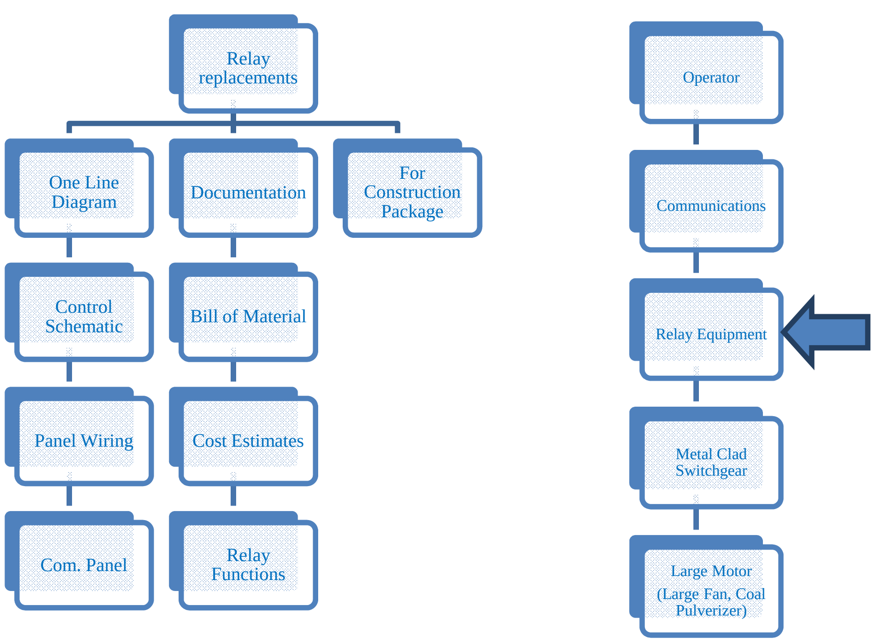

Figure 11: Relay Design Implementation

For the arc flash design implementation, a similar process was followed. The OSHA calculation was broken in to the phase to phase and phase to ground. The full IEEE calculation was also looked at as an design alternative. After the calculations were completed and reviewed by the client, I moved on to analysis of the calculation. Areas of interest were how does this the minimum approach distance affect the worker, what personal protective equipment is needed, and how does this work with CIPCO's standards. We also looked at the compliance and regulation and how these finding and CIPCO's safety standards work together.

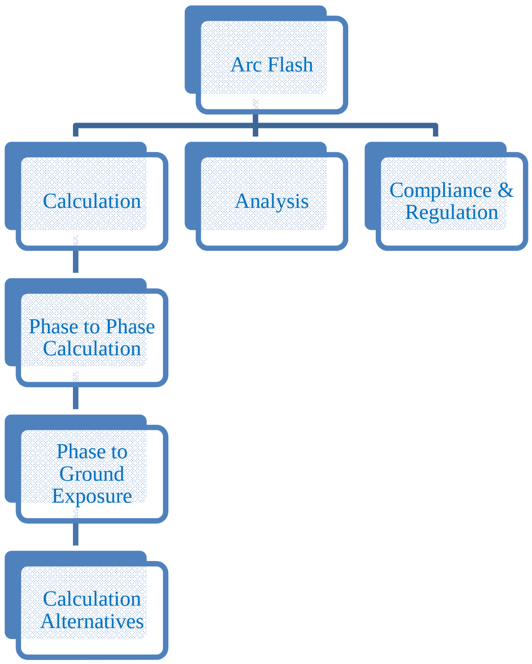

Figure 12: Arc Flash Design Implementation

For the safe operation design implementation, three viable solutions were proposed to CIPCO and two were chosen to investigate farther. The two solutions chosen were the remote control option using the new SEL relays and a timed control switch. Both solutions followed a similar design and review path. Areas covered by the design process were pros and cons were of each solution identified, bill of materials and cost estimates, basic operational guides were created, and how the solution worked with CIPCO and OSHA regulatory and compliance standards. All of this information went into the assessment of the engineering solution and was reviewed at length with the CIPCO and the project sponsor. Below is a diagram outlining the safe operation design implementation process.

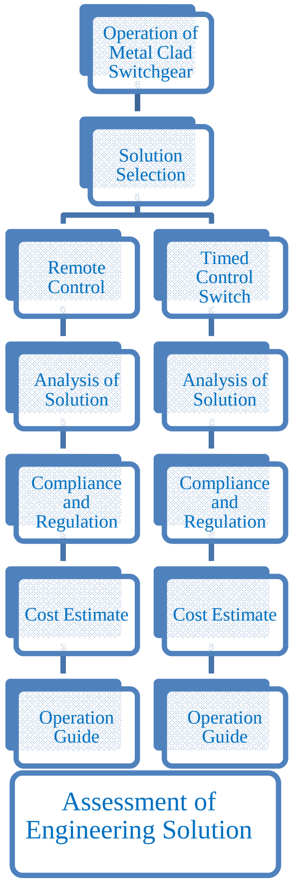

Figure 13: Safe Operation of Metal Clad Switchgear Design Implementation

4. Review Process

During the multiple reviews with the Project Sponsor, Substation Engineers, and Manager of Health and Safety the review process changed overtime. Originally the design process was break down the tasks into several parts and complete reviews on each section in order to help keep organized and to produce a high quality product. This process was used with outside contractors and was proven to work. As the project was designed the review process changed to more of a circle. As seen below.

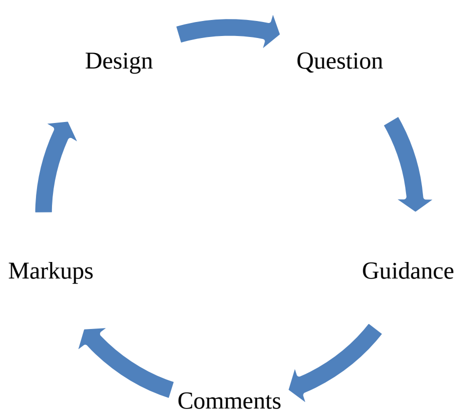

Figure 14: Review Process

The review process would start with me asking questions to one of the CIPCO staff such as the Project Sponsor. They would provide guidance and sometimes direction. I would use their comments to make markups or sometimes the Sponsor would provide comment and markups. With the markups the design process would continue until I had additional questions. I think the review process changed due to busy schedules or conflicting schedules.

5. Demonstration

With this project being theoretical in nature due to testing and modeling being out of scope, the demonstration is limited by the deliverables. All deliverables are attached to this document as appendixes and broken into three parts for this project. Below is a summary of findings.

Starting with the relay replacement design, the relay design drawings identify equipment or wiring that is to be removed or added. This is done by following the CIPCO drafting standards by using colors "Green – Out / Red – In" method. Each drawing also uses the CIPCO title block which was added during drafting. The project title bar was added on the left side of each print identifying what project the drawing is for as well as a drawing identifier on the right corner signaling if it is a remove or add drawing. The complete set of design drawings can be found in the appendixes at the end of this report.

Besides using CAD standards and being required to use design templates, many items were needed to be identified in the panels before the new equipment could be added in. For the new relay equipment AC and DC voltages as well as line currents needed to located and identified. For instance, the bus voltage required by the new relays was thought to be needed to be brought into each panel, but upon further review and field verification it was found that the bus voltage had already been distributed though each panel and had not been recorded on the drawings. Other wiring items that differentiate from the electromechanical relays are alarms and communications. The existing relay did not have either in place and these were added to the new equipment in each panel. Test switches were also added to the panels to help with checkouts and future relay testing needs. In short, the new relay equipment posed many challenges during the relay replacement design and was certainly not a plug and play device. Some of these difficulties are covered in the Difficulties and Learning Opportunities section.

The OSHA arc flash calculations determine the minimum approach distance. This distance must be maintained while working on energized equipment. The calculation is based on the level of voltage of the energized equipment. The OSHA calculation sets the standard for working around energized equipment. In order to work with in the MAD, the qualified employee would require the correct PPE for the voltage involved. The calculations use the OSHA table R-3-AC Live Line and R-6 Alternate Approach Distance. In both cases the phase to phase and phase to ground MAD distance was calculated to be 2.07 feet due to the metal clad switch voltage of 2400 VAC. In this situation the minimum approach distance is not very large (2.07 feet) and workers would be compliant staying outside the calculated distance. As for most company safety rules and regulations, CIPCO's are more conservative than the industry standard. This is for general safety purposes and ease of complying. CIPCO tries to complete all work on de-energized equipment with visual disconnects such as open switches. This allows the work to be completed in a much safer environment by eliminating the electrical hazard.

The safe operation of the metal clad switchgear was an assessment of two proposed options. Multiple areas of interest were considered when completing the assessment, but cost and the learning curve of new equipment were ultimate deciding factors when choosing a best engineering solution. A full project cost estimate was completing reviewing each option including additional labor associated with the additional equipment. This paired with the operation guide gave the project sponsor enough information to choose. Other information such as the listed pros and cons, but it came back to cost and ease of installation and use.

6. Difficulties and Learning Opportunities

While working on this project there were many difficulties which often lead to great learning opportunities. Throughout the three parts of the project there was a large learning curve. By researching items from relay functions to sifting through information on the OSHA website, to asking CIPCO questions about general functions to how they accomplished their Iowa State Senior Design project, I relied on research and the engineering team at CIPCO to overcome the learning curve.

The relay replacement was particularly difficult because of my lack of experience with this type of equipment and working with the drawings. I had issues determining what was existing and how it would work with the new equipment. Which was simplified after looking at manufacturing diagrams for the existing equipment. There were challenges with the existing drawings. There drawing inaccuracies due to items being added to the panels without it being documented on the drawings. The bus voltages and relay alarm were found out to be this way. One of the funniest and frustrating issues was when it was determined that the panel numbers were off by one number on many of the drawings which created confusion and extra work. The progress that was made on one panel was voided due to it being wrong number and not part of the project. It was confirmed that a panel had been added and some of the drawings were update, but not all of them.

Something that was simple but different was the use of IEEE device numbers on the one line diagram. The existing relays were listed as 51 which is listed as an AC time over current relay. The new microprocessor relay equipment could be listed as multiple IEEE identification numbers due to the equipment having multiple available functions. Another option could to list the equipment as a number 11 device which is considered a multifunction device under the IEEE device list. Whereas either way could be considered right, but the preference of CIPCO was to show it as SEL. SEL represents the manufacture Schweitzer Engineering Laboratories. This simple task gave an opportunity to learn.

OSHA standards were a very large part of the arc flash calculations and this project. A large challenge working with compliance standards is finding newest version of the standard and deciphering it correctly. Standards change over time and finding the correct version is important to maintain compliance. Reading the standard and interrupting it and then comparing it to the company standards and safety procedures were a challenge, but was completed with help and guidance. The searching and interpretation needs not to stand in the way of safety because at the end of the day you need to right because it is a safety issue and a top priority for the client

While working on the engineering solution to operate the metal clad switchgear the biggest challenge was the steep learning curve of the equipment. Both the existing equipment and new equipment were looked at and in particular how they functioned. This helped determine the equipment or process alternatives that would keep people out of harm’s way during operation. Research into the equipment helped expand my knowledge base quickly along with information from the senior engineers.

7. Design Alternatives

Multiple options were considered during the project design and each option was reviewed. Below are a few examples of options what were considered.

During the relay replacement, known environmental issues were considered. One of the largest issues considered was the problem with electrical interference called noise. This could lead to inaccurate communications between the relay and the communication processor. To remedy this, fiber communication cable was considered. The cost of both the fiber and Ethernet was provided to the client and after review fiber was chosen to replace the less expensive but potentially more noisy copper cable.

While working on the arc flash calculation part of the project, the main consideration was compliance with OSHA, but the OSHA calculation method is based on the IEEE method. The IEEE method was reviewed, but deemed not necessary due to its complexity and not all of the equipment data was easily accessible to complete the calculation. It is generally thought that the OSHA calculation if followed is a compliant, but leads to potentially more conservative results.

Additional engineering safety solutions were considered during the safe operation portion of the project. These two options that were not adopted, were moving the control switch, and using a remote switch with long cable. The option of moving the control switch to a different panel away from the potentially hazardous equipment was deemed infeasible due to limited space. There was not enough room to add additional panels or clutter existing panels with new equipment. The other approach was deemed infeasible right away due to the client knowing its employees and general human behavior. This option was not adopted because the switch with remote wire would most likely be lost or broken between uses.

The overall challenge for this project was time. Scheduling time to work on the project was tough with all of the other things going on in both my professional and private life. Time management was the key to complete the project. There were some late nights and early mornings, but the project was completed. I had a lot of help from my coworkers and family.

8. Team Support

The team support for this project comes from CIPCO. The engineering department at CIPCO is not very large and each one of the five engineers had helped answer questions from the inner workings of relays to how to get the web site to post on the Iowa State page. In the engineering department there are two senior substation engineers and three licensed professional engineers. Terry Fett is the manager and sponsor for this project and helped me immensely. I also had help from the Manager of Health and Safety for all of the compliance and safety questions due to his expertise in that field of study. I also had help from people outside of CIPCO. You could say they were a secondary support team. A friend in the quality field helped review my work. My family helped as well from assistance in childcare to house work. They provided me quite time to work on this project. I am very grateful for all of the help I received on this project.

9. Bring it Together

As this project was concluding, it became apparent on how all three parts of the project came together for one common goal. That common goal is safety. The new relay equipment protects the heavy motors and fans by operating the switchgear under fault conditions. The new relay equipment will be used to remotely operate the switchgear keeping people out of harm’s way. The arc flash calculations help identify hazards and help keep people out of the hazardous areas. Each part of this project goes back to safety, wither it is safety for employees or equipment.

10. Conclusion

Holding to tradition of breaking large projects into small parts, the relay replacement part of the senior design project has helped me improve my knowledge significantly in the area of relay design and functionality. Combining electrical design with project management topics such as budgets and cost benefits has improved my overall understand of the requirements and the amount of detail that goes into engineering projects.

The arc flash part of my senior design project has helped me improve my knowledge significantly in the area of arc flash analysis and compliance. Looking at real life examples has improved my overall understanding of the arc flash hazard, importance compliance, and most important of all worker safety.

Safe operation of metal cad switchgear part of my senior design project has helped me improve my knowledge significantly in the area of equipment operation and safety controls. Combining these elements with project management topics such as budgets and cost benefits has improved my overall understand of the requirements and the amount of detail that goes into engineering projects.

The review process helped immensely. Having completed multiple reviews gave me a chance to ask questions and learn from the review comments. The review process was also setup to help catch mistakes before they were carried though out the design which help keep the project on schedule. The CIPCO team really helped me grow in these three areas and I am thankful for the opportunity to work on this project.

POWER PLANT – RELAY REPLACEMENT
DELIVERABLE
RELAY REPLACEMENT DOCUMENTATION

ISU Senior Design Group: Dec15-22

Dan Dye

Project Web Site:

http://dec1522.sd.ece.iastate.edu/

Project Sponsor: CIPCO

Project Advisor: Professor Mani Mina

Revised: 12/07/15

Table of Contents:

Tables:

1. SUMMARY

This project is part of the Power Plant – Relay Replacement senior design project. This document is to clearly demonstrate the required deliverables as stated in the Project Plan and Design Document.

Due to age and condition the existing power plant electro-mechanical relay equipment will be retired and new microprocessor based relaying equipment will be installed. The senior design project will be responsible for the complete design of the relay replacement which includes all required schematics and wiring diagrams.

2. PROJECT BRIEF

The main objective of this part of the project is to replace four power plant electromechanical relays with microprocessor based Schweitzer Engineering Laboratories (SEL) relays. A full set of for-construction drawings will be competed showing the removal and addition of equipment and wiring, including communication equipment. The drawings will be completed using existing drawings while following CIPCO drafting standards and design templates. Relay functions will be identified and described.

3. PROJECT REQUIREMENTS

The following list of requirements was established with CIPCO and in accordance with the CIPCO document "Project Scope" included under section design documents. The template for the CIPCO Project Scope was provided by CIPCO.

3.1. SPRING SEMESTER 2015 DELIVERABLES

- Relay one line diagram
- Elementary diagram / current schematic
- Control schematic
- Panel wiring
- Communication processor wiring
- Drafting and review

3.2. FALL SEMESTER 2015 DELIVERABLES

- For construction package
- Bill of material
- Cost estimates
- Relay functions

4. FOR CONSTRUCTION PACKAGE

The For Construction Package will follow CIPCO guidelines and contain the following:

- Project memo to the installation crew showing what is included in the construction package
- Bill of material for the equipment and material
- Drawing list
- All required drawings to complete the project

See Appendix A – For Construction Package

5. BILL OF MATERIAL

Bill of material is defined by Business Dictionary as "A list of raw materials, parts, intermediates, subassemblies, etc., (with their quantities and description) required to construct, overhaul, or repair something". This material list is particularly important for planning the project, estimating cost, and purchasing the material.

The table below shows what equipment and material will be required for the relay replacement.

Bill of Material
Power Plant - Relay Replacement

Required Material			
Material Description	**Manufacturer**	**Model**	**Qty**
Microprocessor relay	SEL	351A	4
Test switch 10 position	ABB	129A501G01	4
Test switch 14 position	ABB	129A514G01-6C	4
6 Amp fuse, 600V, medium time lag	Littelfuse	G-Class	8
Fuse holder - 2 pole - panel mount	Square D	9080FB2	4
Fiber-Optic transceiver/modem	SEL	2800	8
Fiber-Optic cable	SEL		4x500'

Table 1: Bill of Material

6. COST ESTIMATES

A cost estimate should include all material, equipment, and labor to complete the project. Budgetary bids can be requested from vendors to get current material cost and lead times. Cost estimates and lead times can help with project budget planning and scheduling. Estimates can also help determine the most economical choice to fit budgets and project requirements.

The below cost estimate shows multiple options. This is to help weigh the benefits versus the cost of the addition equipment or labor cost. For instance, you could use fiber-optic cable instead of standard communication cable. There is an additional cost to the more expensive option, but if you have lots of electrical noise this could be a better option.

PROJECT COST ESTIMATE					
Power Plant - Relay Replacement					
Required Material					
Material Description	**Manufacturer**	**Model**	**Qty**	**Unit Cost**	**Total**
Microprocessor relay	SEL	351A	4	$2,380.00	$9,520.00
Test switch 10 position	ABB	129A501G01	4	$56.00	$224.00
Test switch 14 position	ABB	129A514G01-6C	4	$64.00	$256.00
6 Amp fuse, 600V, medium time lag	Littelfuse	G-Class	8	$7.00	$56.00
Fuse holder - 2 pole - panel mount	Square D	9080FB2	4	$12.00	$48.00
Communication cable	MonoPrice	CAT6	4x500'	$0.094	$188.000
				sub total	$10,292.00
Optional Equipment					
Fiber-Optic transceiver/modem	SEL	2800	8	$102.00	$816.00
Fiber-Optic cable	SEL		4x500'	$1.98	$3,960.00
(for communication line interference)				**sub total**	$4,776.00
Control switch with time delay	Electroswitch	TD-CSR	4	$1,573.00	$6,292.00
(Arc flash safety switch option)				**sub total**	$6,292.00

Installation Cost				
Labor Description	Hours per Unit	Hours for 4 units	Cost per Hour	Total Cost
Relay installation	8	32	$160.00	$5,120.00
Checkout and testing	3	12	$160.00	$1,920.00
			sub total	$7,040.00
Optional Equipment Installation Cost				
Control Switch with time delay	1	4	$160.00	$640.00
(Arc flash safety switch option)			**sub total**	$640.00

TOTAL COST	
Standard Equipment option - Total	**$17,332.00**
Fiber-Optic Cable option - Total	**$21,920.00**
Arc Flash and Fiber-Optic Cable option - Total	**$28,852.00**

Table 2: Project Cost Estimate

7. RELAY FUNCTIONS

In power systems, a protective relay is a device designed to trip a circuit breaker, or in our case a metal-clad switchgear, when a fault or other undesirable operating conditions are detected. The original protective relays were electromechanical devices that relied on coils and moving parts to provide detection of abnormal operating conditions. Microprocessor-based protective relays use software base protection algorithms and circuitry for detection of electrical faults.

Electromechanical relays were limited to the purpose and function they were created for. Microprocessor based relays are essentially limited by the software and programing. This allows the microprocessor relay to have many functions that were not available in electromechanical relays. The software uses inputs from the system such as line voltage and line current to determine unstable or unsafe electrical conditions. The following are functions that would be considered for this project:

- Overcurrent protection
  - Over current protection would guard against damage resulting from excessive current by opening the metalclad switchgear at a set level of current.
- Fault detection
  - An electrical fault is any abnormal electric current. Fault detection would be determined by use of the relays inputs and software calculations.
- Ground time-overcurrent elements
  - Ground time-overcurrent relays measure the summation of the currents from the current transformer devices. The summation should add up to zero unless under fault conditions. These use a set "pick up" value and the operating time is inversely related to the operating current which helps with protection coordination. This relay protection device helps protect equipment from ground faults.
- Over/under frequency elements
  - Either over or under electrical frequency can lead to equipment damage.
- Measure and record MW, MVAR, MWh, MVARh, Power Factor, instantaneous and/or peak demand
  - These items can be measured and recorded to help determine system and equipment loading.

8. DESIGN CHANGES

Very few design changes were made during the design and review process. One important change was made to account for the harsh operating environment. Due to the high probability of electrical noise between the relay and the communication processor, the connection will be made using fiber instead of cat6 communication copper wire. The electrical noise is fluctuation in the electrical signal. These fluctuations can happen in the power plant environment due to the high voltage equipment, large motors, switching gear, and high current sources. Noise on the communication cable could cause loss of signal between he equipment which is not a desired condition. This determination to go with fiber was made by CIPCO in hopes of preventing future communication problems and was a weighted cost verses benefit decision. The additional cost is shown in the project cost estimate.

9. CONCLUSION

This senior design project has helped me improve my knowledge significantly in the area of relay design and functionality. Combining electrical design with project management topics such as budgets and cost benefits has improved my overall understand of the requirements and the amount of detail that goes into engineering projects. The review process helped immensely. Having completed multiple reviews gave me a chance to ask questions and learn from the review comments. The review process was also setup to help catch mistakes before they were carried though out the design which help keep the project on schedule.

10. REFERENCES

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https://www.businessdictionary.com
<http://www.businessdictionary.com/definition/bill-of-materials-BOM.html>

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Industry Applications, IEEE Transaction (Volume:40, Issue:1)
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Report # Smarts-Lab-2011-003
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5kV and 15kV Metal-clad Switchgear, June 16, 1999
www.controlledpower.com/CPC5Kv15KvMetalClad.pdf

MEMORANDUM

To: Installation Crew

From: Dan Dye

Date: August 1st, 2015

Subject: Power Plant – Relay Replacement Project

Attached for your use during the Power Plant – Relay Replacement project are the following:

Drawing List
Bill of material
For construction drawing set

Upon completion of the project, please return the field mark up drawings to me to start the as built process.

If you have any questions or concerns, please call Dan Dye (319) 734-4363.

cc: Terry Fett
File

Bill of Material
Power Plant - Relay Replacement
Rev 7-27-14

Required Material

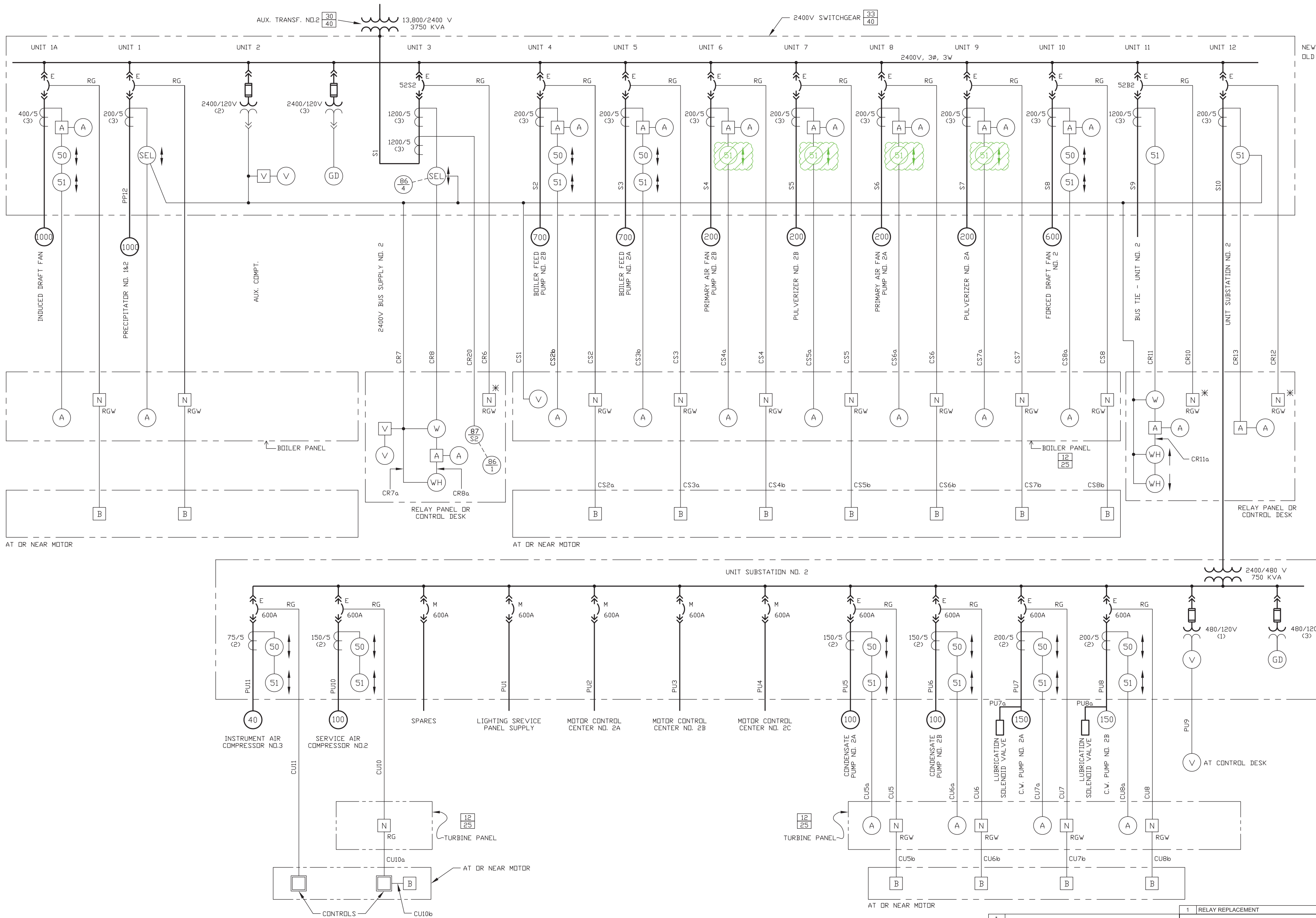
Material Description	**Manufacturer**	**Model**	**Qty**
Microprocessor relay	SEL	351A	4
Test switch 10 position	ABB	FT series	4
Test switch 14 position	ABB	FT series	4
6 Amp fuse, 600V, medium time lag	Littelfuse	G-Class	8
Fuse holder - 2 pole - panel mount	Square D	9080FB2	4
Fiber-Optic transceiver/modem	SEL	2800	8
Fiber-Optic cable	SEL		4x500'

DRAWING LIST
POWER PLANT RELAY REPLACEMENT

Project Drawings:

		For Construction	
Drawing Number	**Drawing Title**	**Remove**	**Add**
ONE LINE	One Line Diagram Switchgear and Unit Substation	Remove	Add
UNIT #6	Connection Diagram / Wiring Schematic – Unit #6	Remove	Add
UNIT #7	Connection Diagram / Wiring Schematic – Unit #7	Remove	Add
UNIT #8	Connection Diagram / Wiring Schematic – Unit #8	Remove	Add
UNIT #9	Connection Diagram / Wiring Schematic – Unit #9	Remove	Add
COMMUNICATION	Schematic Power Plant Communication	Existing	Add

POWER PLANT RELAY REPLACEMENT



NEW NUMBERING ON PANELS
OLD NUMBERING ON DIAGRAMS

LEGEND

- POWER CIRCUIT OR EQUIPMENT
- CONTROL OR METERING CIRCUIT OR EQUIPMENT
- SWITCH GEAR "E" OR "M" INDICATES ELECTRICALLY OR MANUALLY OPERATED
- (200) MOTOR NO. INDICATES NAMEPLATE H.P. MOTOR FURNISHED BY OTHERS.
- (A) A-C AMMETER
- (GD) GROUND DETECTION EQUIPMENT
- (V) A-C VOLTMETER
- (W) WATTMETER
- (WH) WATTHOUR METER
- (50) OVER CURRENT RELAY, INSTANTANEOUS
- (51) OVERCURRENT RELAY, NO. OR LETTER INDENTIFIES SPECIFIC RELAY
- (86) AUX. HAND RESET LOCKOUT RELAY NO. OR LETTER INDENTIFIES SPECIFIC RELAY
- (87) DIFFERENTIAL RELAY, NO. OR LETTER IDENTIFIES SPECIFIC RELAY
- [A] AMMETER SWITCH
- [B] PUSHBUTTON, MOMENTARY CONTACT "START-STOP"
- [V] VOLTMETER SWITCH
- [N] ROTARY CONTROL SWITCH, "START-STOP" OR "CLOSE-TRIP" IF INDICATED THUS (*)
- R RED INDICATING LIGHT
- G GREEN INDICATING LIGHT
- W WHITE INDICATING LIGHT

OTHER SYMBOLS PER ASA STD. Y32.2, 1962

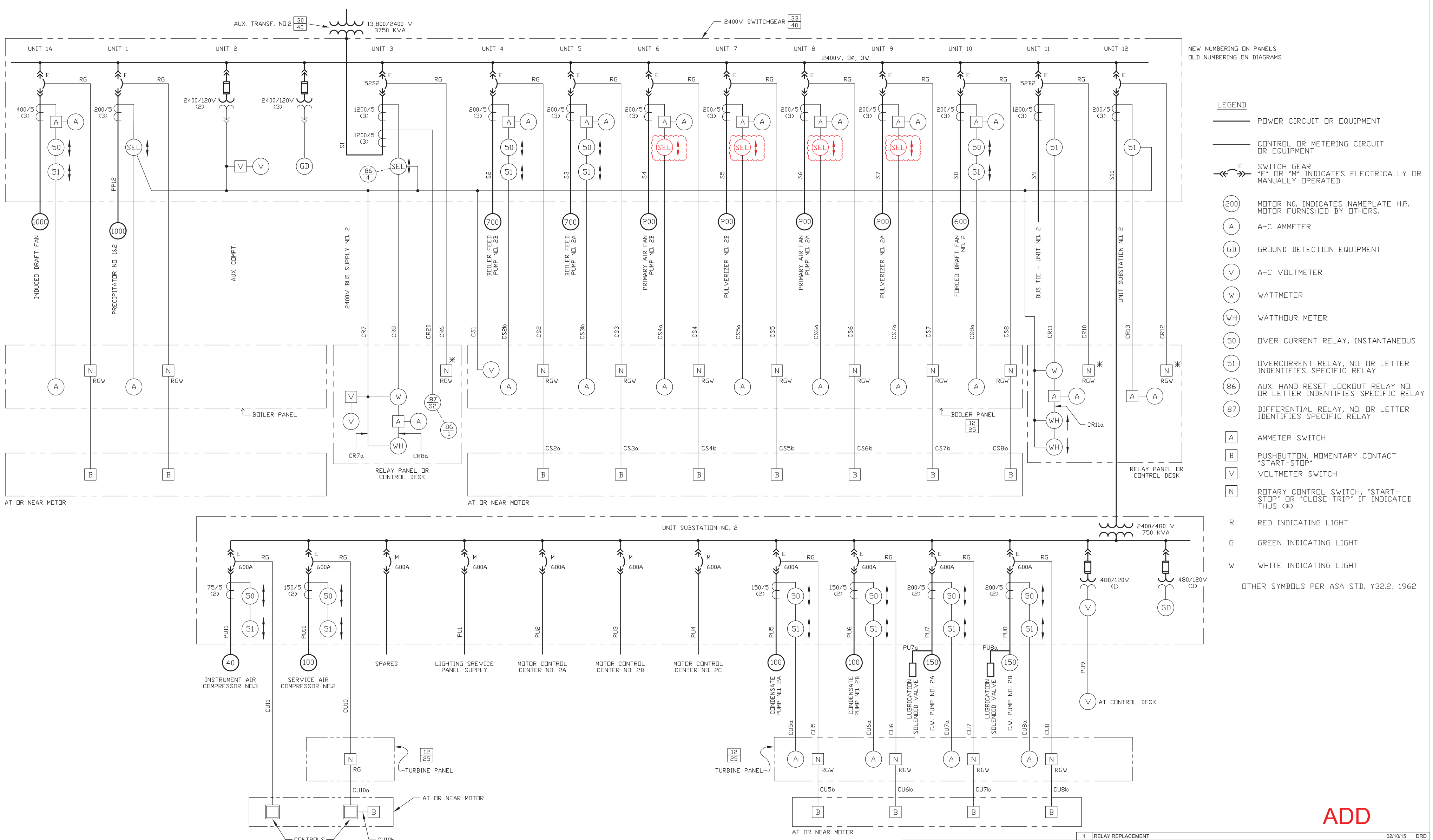
REMOVE

REV	DESCRIPTION		
1	RELAY REPLACEMENT	02/10/15	DRD

ONE LINE DIAGRAM
SWITCHGEAR AND UNIT SUBSTATION
POWER PLANT
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: -
SCALE: NONE
CIPCO
DWG. NO. ONE LINE

POWER PLANT RELAY REPLACEMENT



REV	DESCRIPTION		
1	RELAY REPLACEMENT	02/10/15	DRD

ONE LINE DIAGRAM
SWITCHGEAR AND UNIT SUBSTATION
POWER PLANT
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: ~
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DWG. NO. ONE LINE

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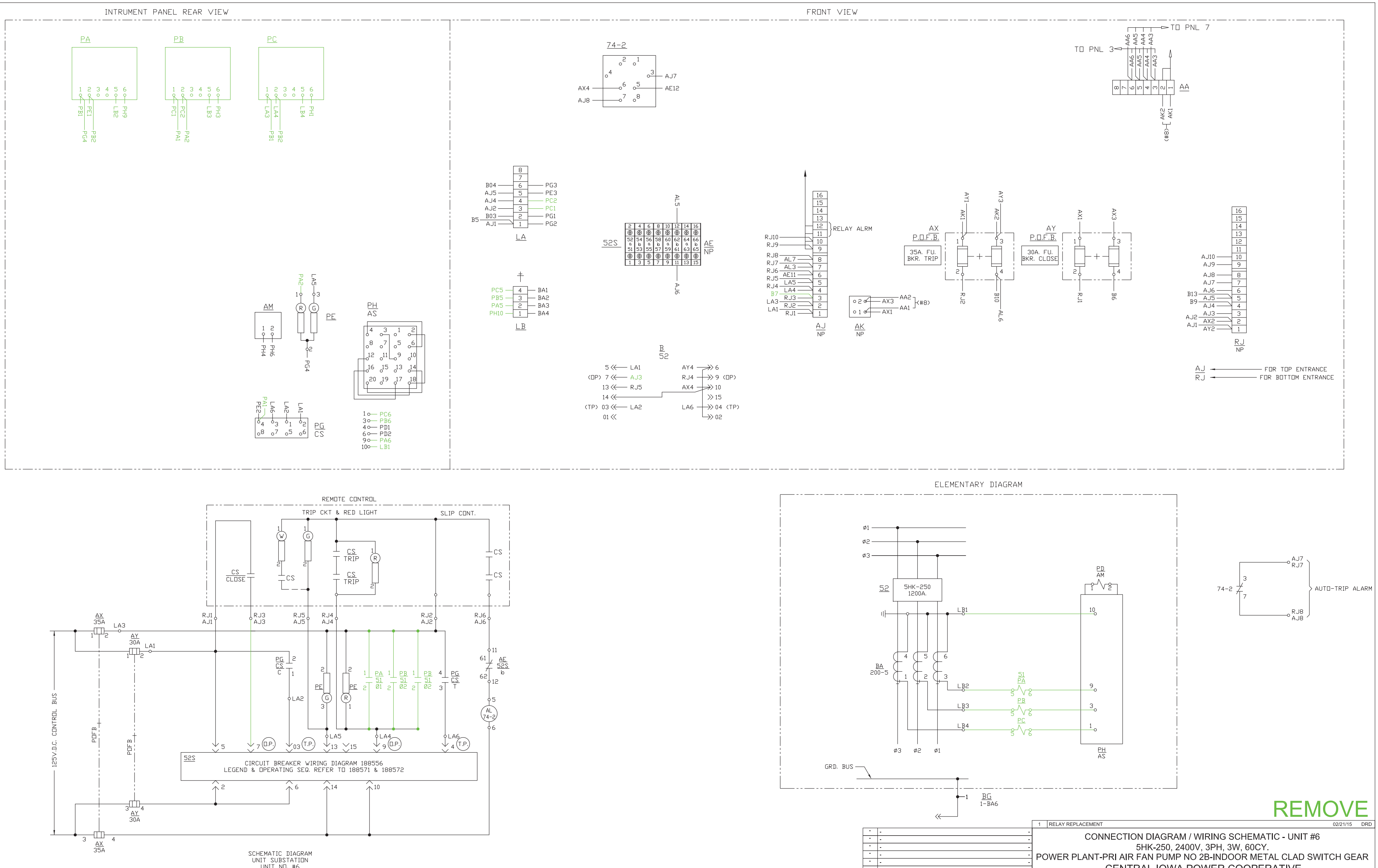

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CONNECTION DIAGRAM / WIRING SCHEMATIC - UNIT #6
5HK-250, 2400V, 3PH, 3W, 60CY.
POWER PLANT-PRI AIR FAN PUMP NO 2B-INDOOR METAL CLAD SWITCH GEAR
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: -
SCALE: NONE
DWG. NO. UNIT #6

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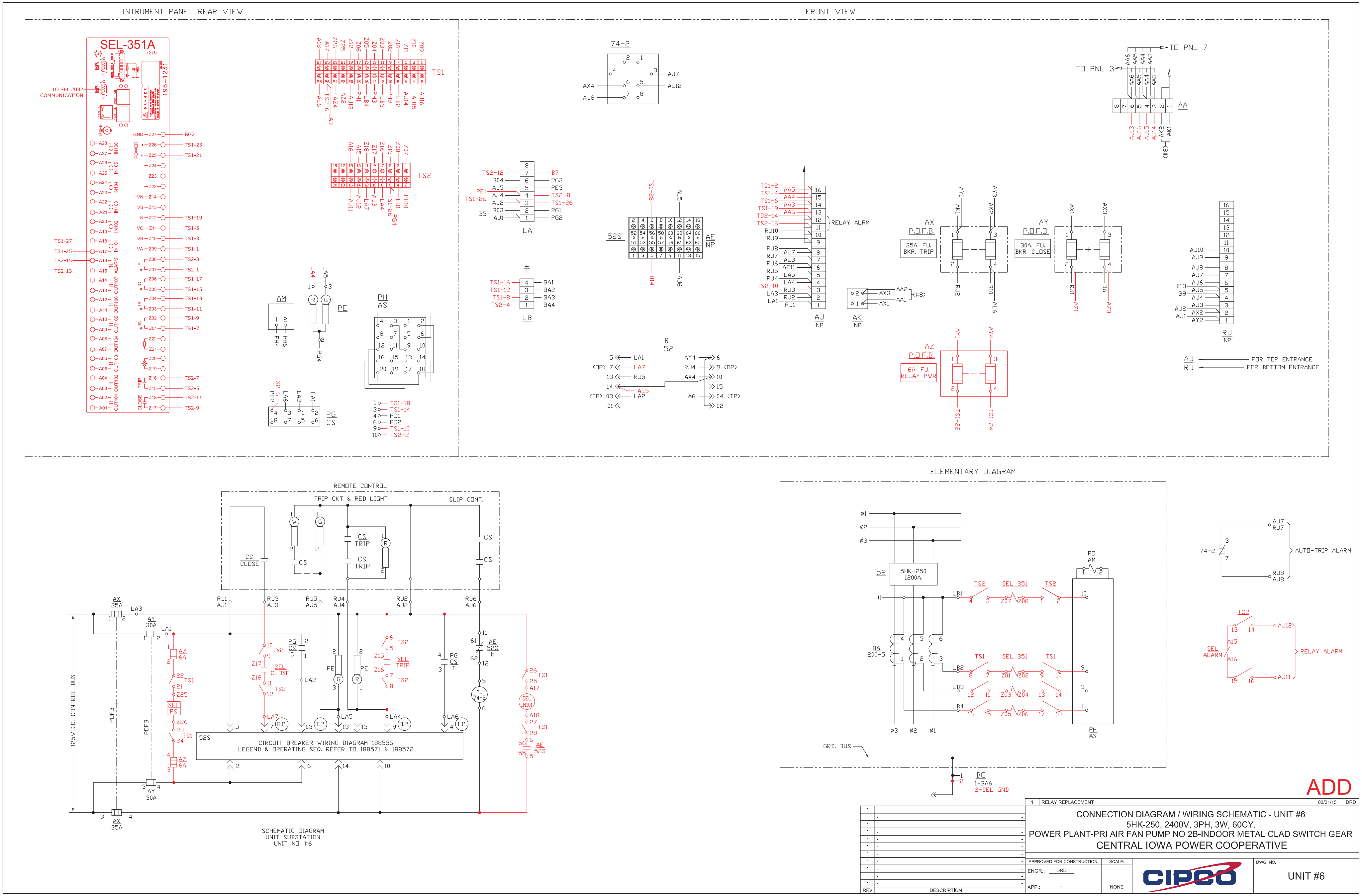

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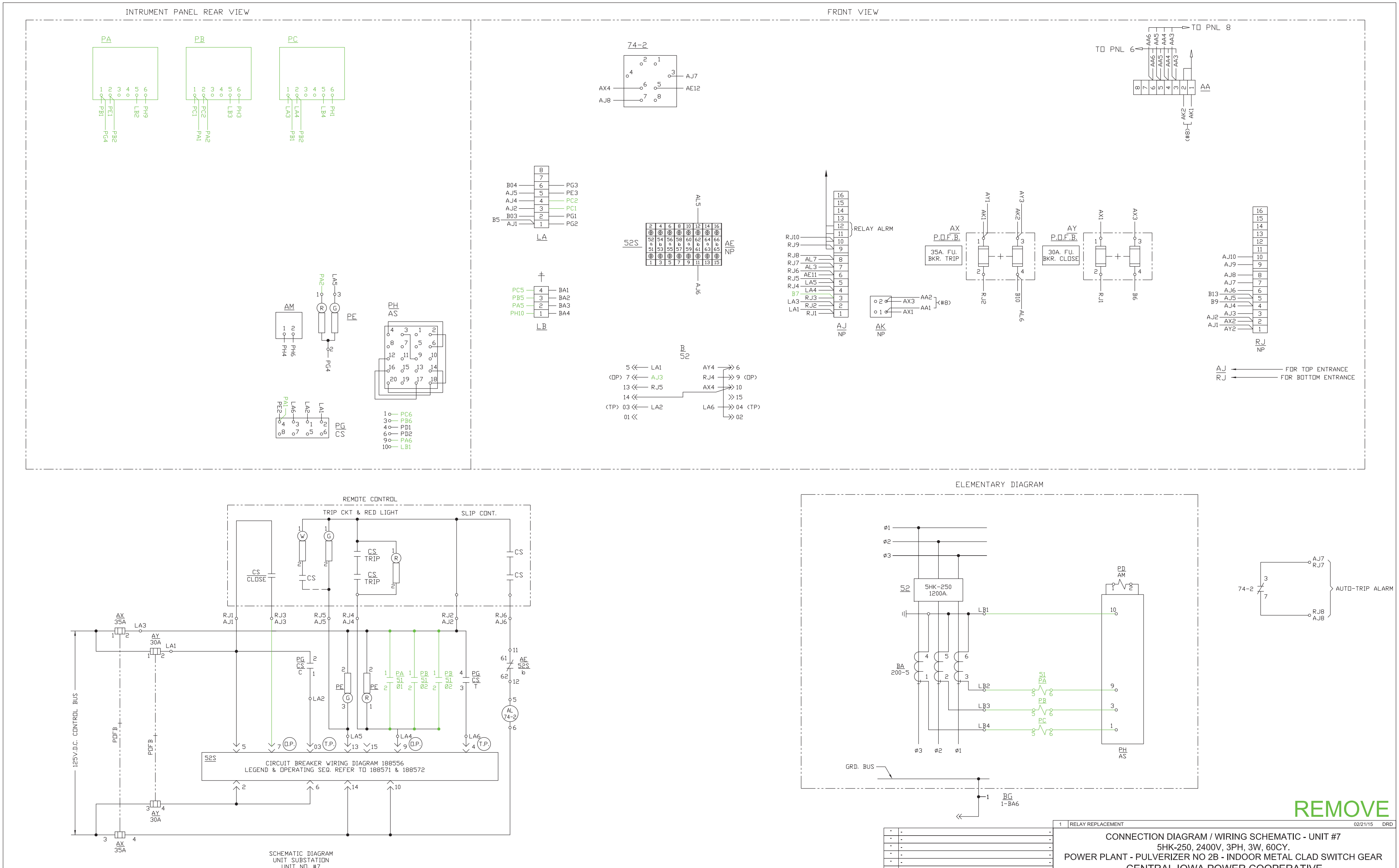

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REV	DESCRIPTION
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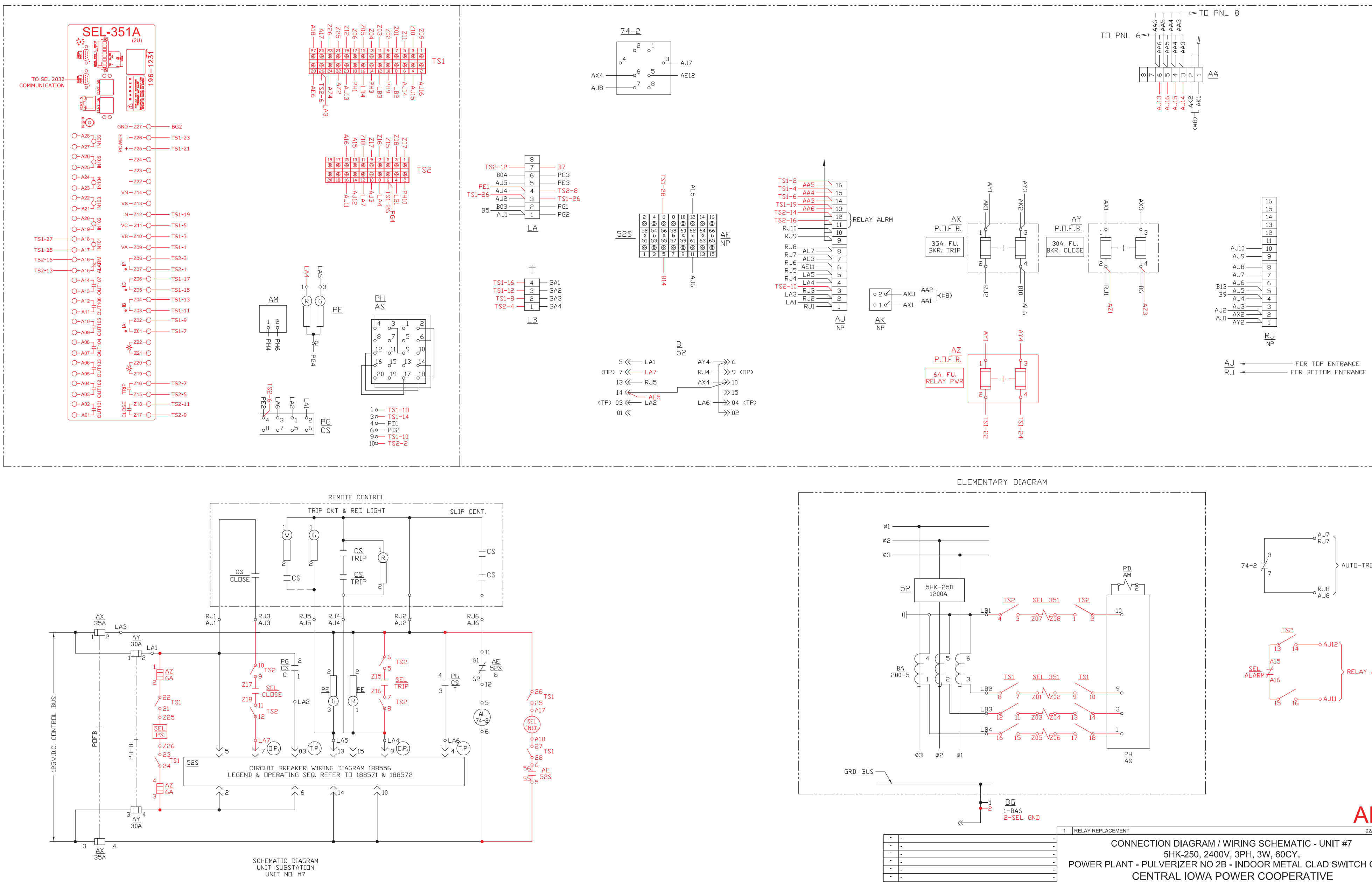
POWER PLANT - PULVERIZER NO 2B - INDOOR METAL CLAD SWITCH GEAR
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: -
SCALE: NONE
CIPCO
DWG. NO. UNIT #7

POWER PLANT - RELAY REPLACEMENT



REV	DESCRIPTION
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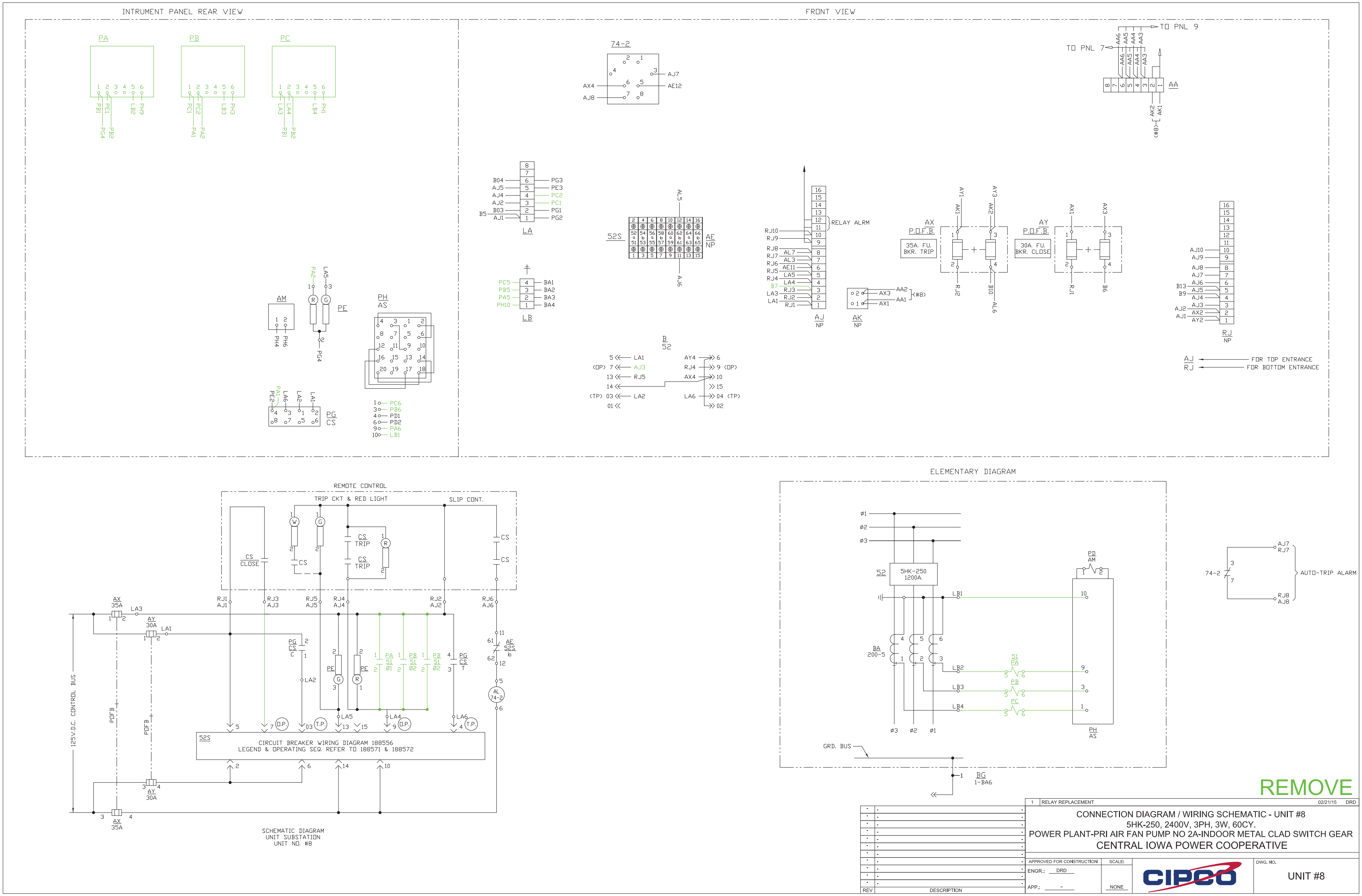
CONNECTION DIAGRAM / WIRING SCHEMATIC - UNIT #7
5HK-250, 2400V, 3PH, 3W, 60CY.
POWER PLANT - PULVERIZER NO 2B - INDOOR METAL CLAD SWITCH GEAR
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: ~
SCALE: NONE
DWG. NO. UNIT #7

POWER PLANT - RELAY REPLACEMENT



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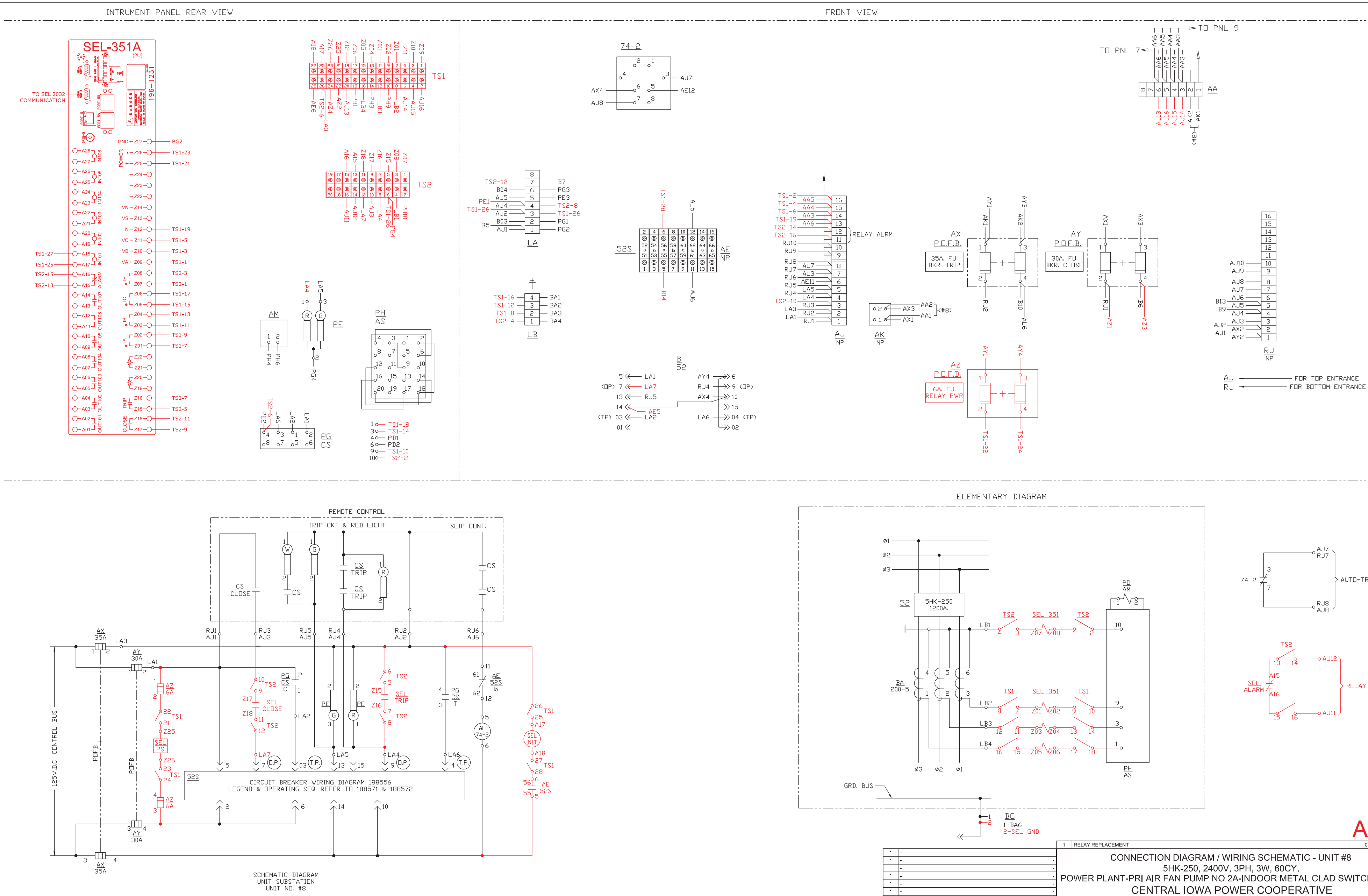

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CONNECTION DIAGRAM / WIRING SCHEMATIC - UNIT #8
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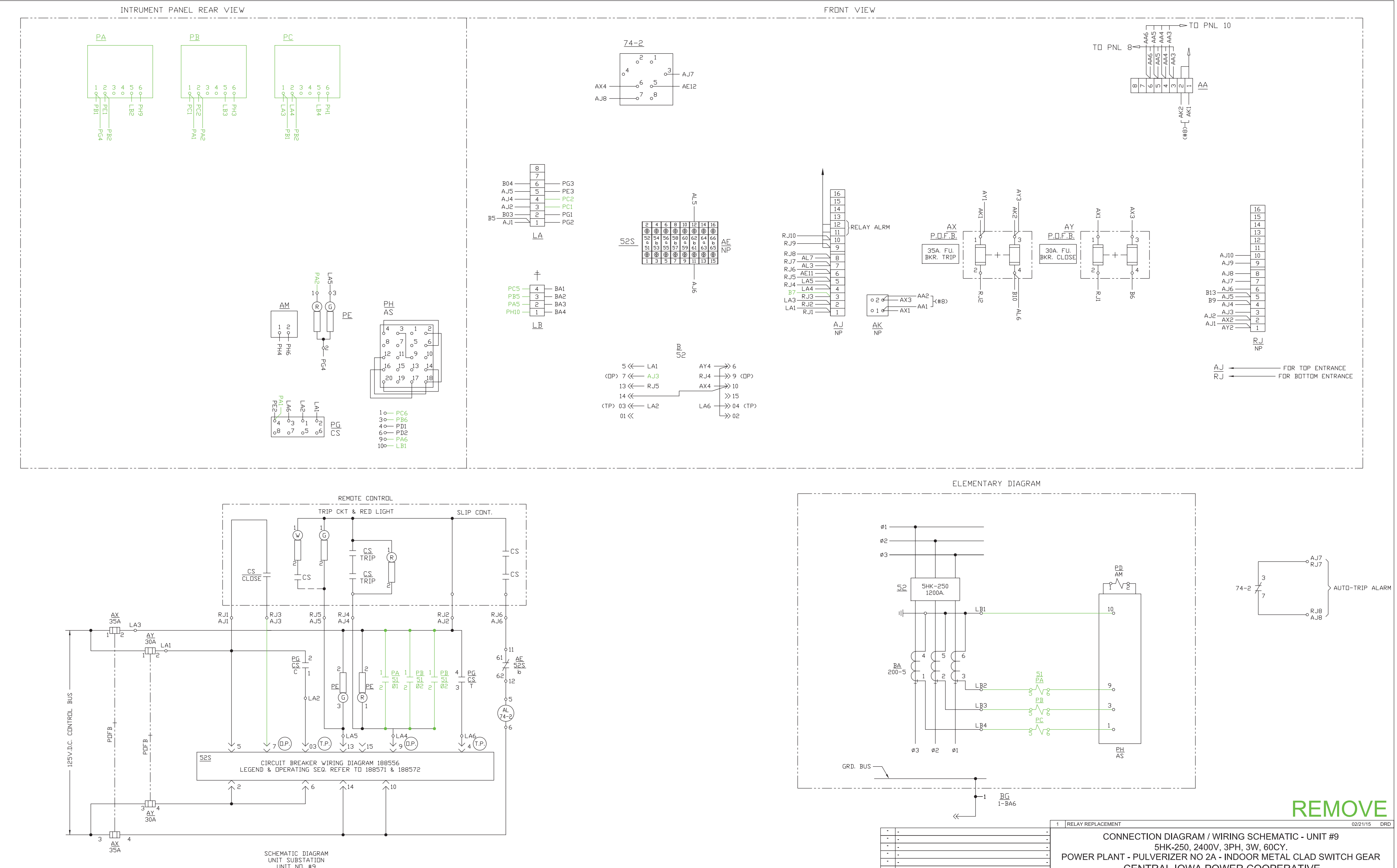
POWER PLANT-PRI AIR FAN PUMP NO 2A-INDOOR METAL CLAD SWITCH GEAR
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: ~
SCALE: NONE
CIPCO
DWG. NO. UNIT #8

POWER PLANT - RELAY REPLACEMENT



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REV	DESCRIPTION
1	RELAY REPLACEMENT 02/21/15 DRD

CONNECTION DIAGRAM / WIRING SCHEMATIC - UNIT #9
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POWER PLANT - PULVERIZER NO 2A - INDOOR METAL CLAD SWITCH GEAR
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
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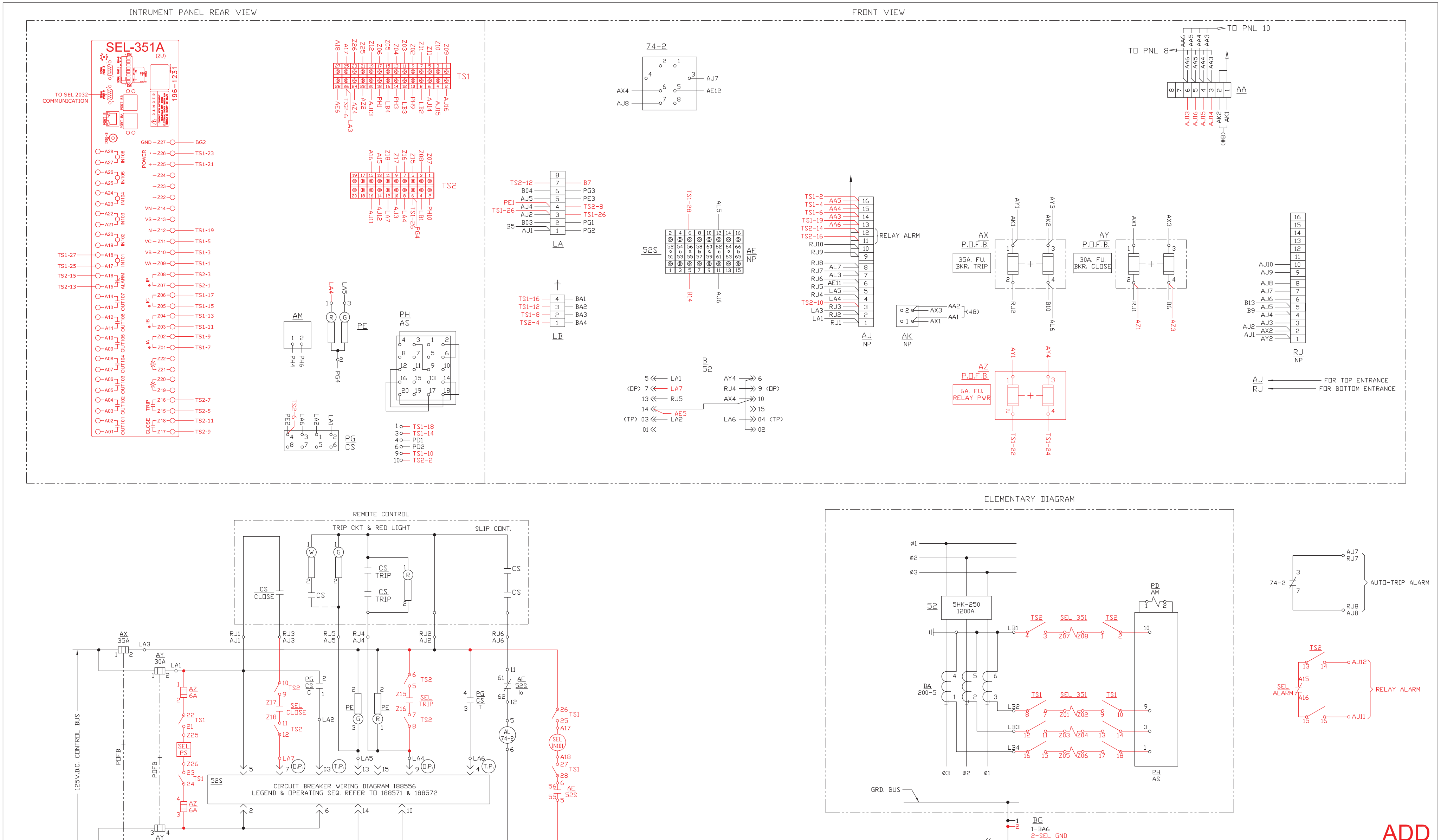
CIPCO
DWG. NO. UNIT #9

POWER PLANT - RELAY REPLACEMENT



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REV	DESCRIPTION	
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CONNECTION DIAGRAM / WIRING SCHEMATIC - UNIT #9
5HK-250, 2400V, 3PH, 3W, 60CY.
POWER PLANT - PULVERIZER NO 2A - INDOOR METAL CLAD SWITCH GEAR
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: ~
SCALE: NONE
CIPCO
DWG. NO. UNIT #9

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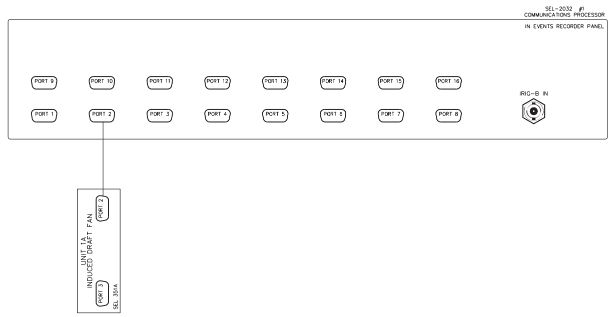

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REV	DESCRIPTION
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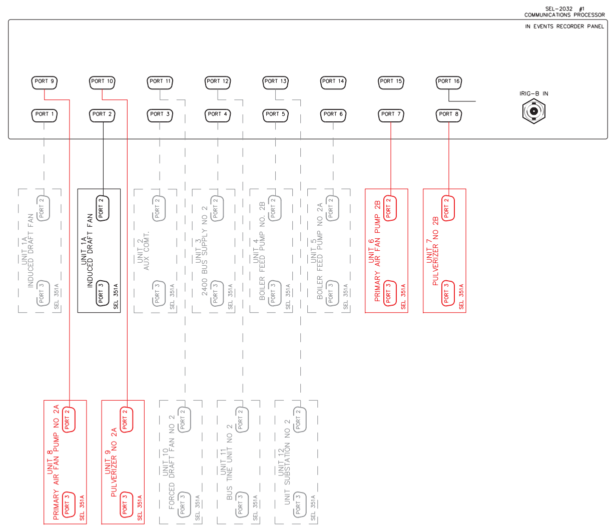
SCHEMATIC
POWER PLANT COMMUNICATION
POWER PLANT
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: ~
SCALE: NONE

CIPCO

DWG. NO.
COMMUNICATION



POWER PLANT RELAY REPLACEMENT

ADD

REV	DESCRIPTION
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SCHEMATIC
POWER PLANT COMMUNICATION
POWER PLANT
CENTRAL IOWA POWER COOPERATIVE

APPROVED FOR CONSTRUCTION
ENGR.: DRD
APP.: ~
SCALE: NONE

CIPCO

DWG. NO. COMMUNICATION

POWER PLANT – RELAY REPLACEMENT
DELIVERABLE
ARC FLASH

ISU Senior Design Group: Dec15-22

Dan Dye

Project Web Site:

http://dec1522.sd.ece.iastate.edu/

Project Sponsor: CIPCO

Project Advisor: Professor Mani Mina

Revised: 12/07/15

Table of Contents:

Tables:

1. SUMMARY

This project is part of the Power Plant – Relay Replacement senior design project. This document is to clearly demonstrate the required deliverable as stated in the Project Plan and Design Document.

This part of the senior design project will apply arc flash calculations and analysis for the existing metal clad switchgear to determine the minimum approach distance (MAD). Metal clad switchgear has been known in the industry to have a high potential for arc flash. Determining the potential of these issues allows the operator to be aware and use the proper amount of precaution and personal protective equipment.

2. PROJECT BRIEF

The arc flash calculations will follow the guidance of the Project Sponsor and the Safety Manager and will meet the OSHA (Occupational Safety & Health Administration) requirements. Both the Project Sponsor and Safety Manager will review the work and determine if it complies with OSHA and CIPCO standards.

3. DEFINITIONS AND EXPLANATIONS

In order to help the understanding some items will need to be defined with explanation to the importance for this project.

OSHA (Occupational Safety & Health Administration)
OSHA was created in 1970 by Congress to assure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance. There web site can be found at: www.osha.gov

Arc Flash
Per OSHA Workplace Safety Awareness Council paper on Understanding "Arc Flash"; an arc flash is a phenomenon where a flashover of electric current leave its intended path and travels through the air from one conductor to another, or to ground. The results are often violent and when a human is in close proximity to the arc flash, serious injury and even death can occur. Arc flash can be caused by many different things including dust, debris, non-insulated tools, accidental contact, moisture, material or equipment failure, and corrosion. Results from an arc flash can be burns, fire, flying molten metal, intense pressure wave (2,000 lbs. per square foot), intense sound (140 dB), and intense heat up to 35,000 degrees Fahrenheit. There are three factors that govern the level of an arc flash injury; proximity to the arc flash, temperature, and time.

MAD (minimum approach distance)
OSHA defines MAD (minimum approach distance) in standard table R-6 1910.268 as the minimum approach distance that must be maintained, based on voltage involved, by unprotected qualified employees when exposed to energized parts. In order to work within a MAD, the qualified employee must use proper work techniques, equipment, and PPE. The table R-6 and definition can be found at: www.osha.gov/SLTC/etools/electric_power/energized_mad.html

4. PROJECT REQUIREMENTS

The following list of requirements was established with CIPCO and in accordance with CIPCO document "Project Scope" included under section design documents. The template for the CIPCO Project Scope was provided by CIPCO.

4.1. SPRING SEMESTER 2015 DELIVERABLES

- Calculation per OSHA. (Occupational Safety & Health Administration)

4.2. FALL SEMESTER 2015 DELIVERABLES

- Calculation analysis
- Compliance regulations

5. CALCULATION REVIEW

The calculation will be completed adhering to regulatory and the CIPCO requirements. The calculation and analysis will be reviewed by both the Project Sponsor and CIPCO's Manager of Environmental & Safety.

6. CALCULATION

OSHA MAD documentation and the R-3-AC Live-Line table can be found on the OSHA website. The web address is below and can in the reference section.
https://www.osha.gov/dsg/mad_calculator/tables.html

6.1. PHASE TO PHASE CALCULATION

The phase to phase calculation follows the OSHA Table R-3-AC Live-Line Work Minimum Approximant Distance for 2400 VAC. The variable definitions can be found on the table, but "M" is the inadvertent movement factor and "D" is the electrical component of the minimum approach distance.

MAD (Minimum Approach Distance) = M + D = 0.02 + 0.61 = 0.63 Meters (2.07 feet)

For phase-to-phase system voltages of 301 V to 5 kV: [1]	
MAD = M + D, where	
D = 0.02 m	the electrical component of the minimum approach distance.
M = 0.31 m for voltages up to 750 V and 0.61 m otherwise	the inadvertent movement factor.

Table 1: Partial OSHA Table R-3-AC Live-Line Work Minimum Approach Distance

6.2. PHASE TO GROUND EXPOSURE CALCULATION

The phase to ground calculation follows the OSHA Table R-6-Alternative Minimum Approach Distances For Voltages of 72.5 kV and Less. Per the table below the phase to ground exposure for the metal clad switchgear would be .63 meters (2.07 ft).

TABLE R-6-ALTERNATIVE MINIMUM APPROACH DISTANCES FOR VOLTAGES OF 72.5 KV AND LESS [1]

Nominal voltage (kV) phase-to-phase	Distance			
	Phase-to-ground exposure		Phase-to-phase exposure	
	m	ft	m	ft
0.50 to 0.300 [2]	Avoid Contact		Avoid Contact	
0.301 to 0.750 [2]	0.33	1.09	0.33	1.09
0.751 to 5.0	0.63	2.07	0.63	2.07
5.1 to 15.0	0.65	2.14	0.68	2.24
15.1 to 36.0	0.77	2.53	0.89	2.92
36.1 to 46.0	0.84	2.76	0.98	3.22
46.1 to 72.5	1.00	3.29	1.20	3.94

[1] Employers may use the minimum approach distances in this table provided the worksite is at an elevation of 900 meters (3,000 feet) or less. If employees will be working at elevations greater than 900 meters (3,000 feet) above mean sea level, the employer shall determine minimum approach distances by multiplying the distances in this table by the correction factor in Table R-5 corresponding to the altitude of the work.

[2] For single-phase systems, use voltage-to-ground.

Table 2: OSHA Table R-6-Alternative Minimum Approach Distance For Voltages of 72.5kV and Less

6.3. CALCULATION ALTERNATIVES

Minimum approach distance (MAD) calculations can be completed different ways and still be compliant per OSHA. You can follow OSHA Tables or you can complete a full IEEE 1584 calculation. The OSHA tables are convenient for quick guidelines where some of the system information might not be available for reference to complete full IEEE calculations. The MAD figures in the OSHA tables are typically more conservative than results of actual calculations. Below is part of the full IEEE calculation.

Normalized incident energy can be found using the equation below:

$$lg\, E_n = K_1 + K_2 + 1.081 * lgI_a + 0.0011 * G$$

Equation 1

where,

E_n - incident energy in J/cm^2 normalized for time and distance. The equation above is based on data normalized for a distance from the possible arc point to the person of 610 mm. and an arcing time of 0.2 sec

K_1 = -0.792 for open configurations, and is -0.555 for box configurations / enclosed equipment

K_2 = 0 for ungrounded and high resistance grounded systems, and equals -0.113 for grounded systems

G - gap between conductors in millimeters

I_a - predicted three phase arcing current in kA. It is found by using Equations 2 a) or b) so the operating time for protective devices can be determined.

Table 3: Partial IEEE 1584 Arc Flash Calculation

The IEEE 1584 Arc Flash calculations is the combination of several equations. In total there are five steps to complete the calculation. First the arcing current is found using information such as the bolted fault current for three-phase faults, system voltage, and gap between conductors. Second, you would normalize the arching current. Third, the incident energy is calculated depending on if the systems configuration and grounding. Fourth, normalize the incident energy for distance and time. Last, calculate the incident energy using arcing time, distance from arc to person, and incident energy.

These calculations can be simplified by using or creating Excel templates to complete the calculation, but it can be cumbersome to complete by hand. Due to the complexity of the equations there are areas that can lead to confusion and errors which is why OSHA simplified the process by providing R-6 table for fast and compliant analysis.

7. ARC FLASH ANALYSIS

The Minimum Approach Distance (MAD) was calculated per direction of the CIPCO's Manager of Environmental & Safety, CIPCO's Substation Engineer, and per OSHA Table R-3-AC Live-Line Work. The distance calculated is 0.63 meters or 2.07 feet. This calculation matched the OSHA Table R-6-Alternative Minimum Approach Distance for Voltages of 72.5kV and less. For higher voltages the MAD formula would change by considering voltage, altitude correction factor, inadvertent movement factor, and the electrical component of the minimum approach distance. This calculation and the additional tables can be seen in the full OSHA Table R-6 (table 2 this document) and located on the OSHA website.

8. COMPLIANCE REGULATIONS

Compliance is also discussed under the Safe Operation of Metal Clad Switchgear Deliverable document. Both parts of this project are required to be compliant with regulators, meet industry standards, and most of all keep workers and equipment safe.

In this situation the minimum approach distance is not very large (2.07 feet) and workers would be compliant staying outside the calculated distance. As for most company safety rules and regulations, CIPCO's are more conservative than the industry standard. This is for general safety purposes and ease of complying. CIPCO tries to complete all work on de-energized equipment with visual disconnects such as open switches. This allows the work to be completed in a much safer environment by eliminating the electrical hazard. When equipment cannot be completely de-energized, the CIPCO Safety Manual will be followed. The approach distance is different for different equipment, voltages, and the level employee training dealing with energized equipment. For 2400 VAC equipment, the minimum distance for qualified worker is 3 feet. This approach distance covers voltages between 480V<34.5kV.

Whenever work will be performed within the approach distance the qualified worker shall wear all required arc-rated Flame Retardant (FR) clothing and personal protective equipment (PPE). The level of FR and PPE is determined by the amount of exposure as listed in the Safety Manual. For this case, if a qualified worker had to perform within the minimum approach distance, the worker would be required to wear arc-rated flame-retardant long-sleeve shirt, arc-rated flame-retardant pants, hard hat, safety glasses, leather gloves over rated rubber gloves, arc-rated face shield, and leather work shoes with toe protection.

Safety is a top priority for CIPCO and by following the CIPCO Safety Manual, OSHA compliance rules and standards, work can be completed safely.

9. CONCLUSION

This part of my senior design project has helped me improve my knowledge significantly in the area of arc flash analysis and compliance. Looking at real life examples has improved my overall understanding of the arc flash hazard, importance compliance, and most important of all, worker safety. The review process helped immensely. Having completed multiple reviews gave me a chance to ask questions and learn from the review comments and from the experts I was working with. The review process was also setup to help catch mistakes before they were carried though out the design which help keep the project on schedule.

1. REFERENCES

Table 1:
OSHA, Regulations (Standards – 29 CFR) 1910-269(1)(12)(ii) - Table R-3-AC Live-Line Work Minimum Approach Distance
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Table 2:
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<https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9868>

Table 3:
Arc Advisor, IEEE 1584 Calculation Procedure Example
Procedure of IEEE arc flash calculations
<http://archadvisor.com/faq/ieee-1584-calculation-procedure>

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CIPCO Safety Manual
Appendix 2: Arc Flash Protection Program

POWER PLANT – RELAY REPLACEMENT
DELIVERABLE
SAFE OPERATION OF METAL CLAD SWITCHGEAR

ISU Senior Design Group: Dec15-22

Dan Dye

Project Web Site:

http://dec1522.sd.ece.iastate.edu/

Project Sponsor: CIPCO

Project Advisor: Professor Mani Mina

Revised: 12/07/15

Table of Contents

Figures:

Tables:

1. SUMMARY

This project is part of the Power Plant – Relay Replacement senior design project. This document is to demonstrate clearly the required deliverable as stated in the Project Plan and Design Document.

This part of the senior design project will provide engineering solutions to operate the switchgear safely. By researching alternatives and analysis of the potential of arc flash, engineering solutions shall be provided to advise the choosing of safety precautions during operations.

2. PROJECT BRIEF

The main objective is to provide two engineering solutions to operate metal clad switchgear safely. The following will be included as part of this project: Evaluation of both solutions, compliance regulation, cost estimate, bill of material, and operational guides.

3. PROJECT REQUIREMENTS

The following list of requirements was established with CIPCO and in accordance with the CIPCO document "Project Scope" included under section design documents. The template for the CIPCO Project Scope was provided by CIPCO.

3.1. SPRING SEMESTER 2015 DELIVERABLES

- Research and identify two possible engineering solutions
- Evaluation of both solutions

3.2. FALL SEMESTER 2015 DELIVERABLES

- Compliance regulation
- Bill of material
- Cost estimates
- Operation guides

4. ENGINEERING SOLUTIONS

I researched and discussed with CIPCO staff, two engineering solutions that would meet the requirements of the project. A remote controlled option and a time controlled option to meet the needs of CIPCO and fulfilled the project requirements. Both options allow the operator to operate the equipment at a safe distance from the arc flash area.

4.1. REMOTE CONTROL

The remote control option would utilize the capability and functionality of the newly installed Schweitzer Engineering Laboratories (SEL) microprocessor-based relay. One large benefit of upgrading the relays from electromechanical to microprocessor-based is the new SEL relays are capable of remote control through the hardware and software.

This remote control could allow an operator to control the metal-clad switchgear at a safe distance from the arc flash area. This location could be in the same facility or across the country. Below are pros and cons of controlling the equipment this way.

4.1.1. PROS & CONS OF SOLUTION

The remote control option would utilize the capability and functionality of the newly installed microprocessor.

- Pros
  - Equipment can be operated with people far away from energized or operating equipment.
  - Human control – people control the equipment operation even when operated remotely.
  - Limited cost due to using new capacity of relay equipment.

- Cons
  - No direct view of equipment by remote operator which could be a safety issue; would still require on-site technician to confirm closure.
  - Relying on equipment to function correctly during operation.
  - Potential latency between the equipment and the remote operator.

4.2. TIMED CONTROL SWITCH

The time control option would utilize a replacement control switch for the metal-clad switchgear. This control switch is currently a manually-operated switch to trip or close the switchgear. A replacement switch built by Electroswitch model TS-CSR includes features that would meet project requirements. This switch utilizes two front panel mounted push buttons integrated into the nameplate. These push buttons provide the ability to manually initiate a time-delayed breaker trip or close operation with a factory preset time delay. This time delay should allow appropriate time to evacuate the arc flash area. Below are pros and cons of controlling the equipment this way.

Figure 1: Electroswitch Time Delay Control Switch Relay (TD-CSR)

4.2.1. PROS & CONS OF SOLUTION

The time-delayed option would utilize the capability and functionality of a new manually-indicated time delay switch.

- Pros
  - Direct view before and after operation.
  - Human control – people control equipment operation.

- Cons
  - Additional cost for new equipment.
  - Additional cost for new installation
  - Additional training.

5. COMPLIANCE AND REGULATION

Compliance is also discussed under the Arc Flash Deliverable document. Both parts of this project are required to be compliant with regulators, meet industry standards, and most of all keep workers and equipment safe.

In this situation the minimum approach distance is not very large and workers would be compliant staying outside the calculated distance. As for most company safety rules and regulations, CIPCO's are more conservative than the industry standard. This is for general safety purposes and ease of complying. CIPCO tries to complete all work on de-energized equipment with visual disconnects such as open switches. This allows the work to be completed in a much safer environment by eliminating the electrical hazard. When equipment cannot be completely de-energized, the CIPCO Safety Manual will be followed. The approach distance is different for different equipment, voltages, and employee training. For instance, unqualified individuals will maintain a boundary of at least 10 feet during energized work. For 2400 VAC equipment, the minimum distance for qualified worker is 3 feet. This approach distance covers voltages between 480V<34.5kV.

Whenever work will be performed within the approach distance the qualified worker shall wear all required arc-rated flame-retardant (FR) clothing and personal protective equipment (PPE). The level of FR and PPE is determined by the amount of exposure as listed in the Safety Manual. For this case, if a qualified worker had to perform within the minimum approach distance, the worker would be required to wear arc-rated flame-retardant long-sleeve shirt, arc-rated flame-retardant pants, hard hat, safety glasses, leather gloves over rated rubber gloves, arc-rated face shield, and leather work shoes with toe protection.

Safety is a top priority for CIPCO and by following the CIPCO Safety Manual, OSHA compliance rules and standards, work can be completed safely.

6. COST ESTIMATES

A cost estimate should include all material, equipment, and labor to complete the project. Budgetary bids can be requested from vendors to get current material cost and lead times. Cost estimates and lead times can help with project budget planning and scheduling. Estimates can also help determine the most economical choice to fit budgets and project requirements. Below is the project cost estimate for using a timed control switching device.

PROJECT COST ESTIMATE
Power Plant - Relay Replacement

Required Material					
Material Description	**Manufacturer**	**Model**	**Qty**	**Unit Cost**	**Total**
Microprocessor relay	SEL	351A	4	$2,380.00	$9,520.00
Test switch 10 position	ABB	129A501G01	4	$56.00	$224.00
Test switch 14 position	ABB	129A514G01-6C	4	$64.00	$256.00
6 Amp fuse, 600V, medium time lag	Littelfuse	G-Class	8	$7.00	$56.00
Fuse holder - 2 pole - panel mount	Square D	9080FB2	4	$12.00	$48.00
Communication cable	MonoPrice	CAT6	4x500'	$0.094	$188.000
				sub total	$10,292.00

Optional Equipment					
Fiber-Optic transceiver/modem	SEL	2800	8	$102.00	$816.00
Fiber-Optic cable	SEL		4x500'	$1.98	$3,960.00
(for communication line interference)				**sub total**	$4,776.00
Control switch with time delay	Electroswitch	TD-CSR	4	$1,573.00	$6,292.00
(Arc flash safety switch option)				**sub total**	$6,292.00

Installation Cost				
Labor Description	Hours per Unit	Hours for 4 units	Cost per Hour	Total Cost
Relay installation	8	32	$160.00	$5,120.00
Checkout and testing	3	12	$160.00	$1,920.00
			sub total	$7,040.00

Optional Equipment Installation Cost				
Control Switch with time delay	1	4	$160.00	$640.00
(Arc flash safety switch option)			**sub total**	$640.00

TOTAL COST	
Standard Equipment option - Total	**$17,332.00**
Fiber-Optic Cable option - Total	**$21,920.00**
Arc Flash and Fiber-Optic Cable option - Total	**$28,852.00**

Table 1: Project Cost Estimate

7. OPERATION GUIDES

Both solutions would need basic instructions to operate the metal clad switchgear in a safe manner.

7.1. REMOTE CONTROL OPERATIONAL GUIDE

The operator could control the equipment remotely though Supervisory Control and data Acquisition (SCADA). SCADA communicates with the 2032 SEL communication processor, which in turn communicates with the microprocessor relay. The communication between the relay and the communication processor is SEL protocol communication logic. SEL protocol was developed by SEL and is a proprietary communication protocol. The connection between the 2032 and the SCADA controller is fiber with Distributed Network Protocol (DNP). DNP is becoming the standard SCADA communication protocol for the electrical utility industry. With this communication path, SCADA can send and receive many types of data depending on the attached equipment, settings, and desired information. The operator can trip or close the switchgear from a remote location and far from harm's way. This control is typical for other equipment such as line relays and substation circuit breakers.

7.2. TIME CONTROL SWITCH OPERATIONAL GUIDE

The time controlled operation would utilize the time controlled switch in place of the existing control switch. The operator would select delay trip or close and then turn the switch to the desired position. The operator would then move away to a safe distance before the switchgear operates. The delay is factory set and would need to give the operator enough time to reach the safe area.

8. ASSESSMENT OF ENGINEERING SOLUTION

After taking into consideration cost and the learning curve of new equipment, the engineering solution best suited for CIPCO needs will be the remote control option. This option utilizes current equipment and operation. This solution would save money by eliminating the need to purchase new equipment or engage in training associated with it.

9. CONCLUSION

This senior design project has helped me improve my knowledge significantly in the area of equipment operation and safety controls. Combining these elements with project management topics such as budgets and cost benefits has improved my overall understand of the requirements and the amount of detail that goes into engineering projects. The review process helped immensely. Having completed multiple reviews gave me a chance to ask questions and learn from the review comments. The review process was also setup to help catch mistakes before they were carried though out the design which help keep the project on schedule.

10. REFERENCES

Figure 1:
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