POWER PLANT – RELAY REPLACEMENT
DELIVERABLE
ARC FLASH

ISU Senior Design Group: Dec15-22

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Project Web Site:

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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
https://www.osha.gov
<https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9868>

Table 2:
OSHA, Regulations (Standards – 29 CFR) 1910-269(1)(12)(i) - Table R-6-Alternative Minimum Approach Distances For Voltages of 72.5kV and Less
https://www.osha.gov
<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>

National Fire Protection Association
NFPA 70E: Standard for Electrical Safety in the Workplace
www.nfpa.org
<http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70e>

CIPCO Safety Manual
Appendix 2: Arc Flash Protection Program