A Guide to Establish an Arc Flash Safety Program for Electric Utilities

by

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Abstract

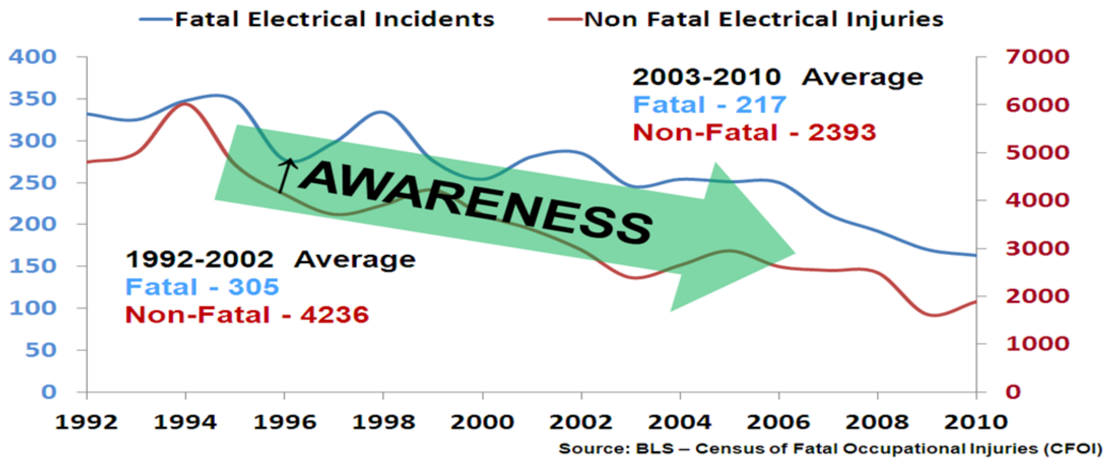
Most of the utility companies have already performed arc flash assessments or studies due to the NESC requirements established in 2007. The assessment is just one piece of the arc flash safety program. Arc flash mitigation, training of employees, equipment labeling, PPE maintenance, maintenance of protective devices, periodic review of arc flash calculations and maintaining the assessment to current standards are all essential parts of a successful arc flash safety program. The intent of this paper is to provide comprehensive guidelines for a utility company to establish and maintain an arc flash safety program at their facility.

Introduction

With electrical safety standards such as NESC and NFPA-70E containing detailed arc flash requirements in recent times, improved awareness of the arc flash hazard has become more and more prevalent. While the arc flash hazard has always been present, industry awareness in recent years has proved vital to the safety of electrical workers. From 1980 to 1995, electrical injuries were the fifth largest cause of fatal injuries in the workplace, averaging 1-2 fatalities per day and a non-fatal injury every 2-3 hours; currently electrical injuries are the seventh largest cause of fatal injuries [1]. When comparing the number of incidents from 1992-2002 and 2003-2013, considerable decrease is observed for both fatal and non-fatal injuries (see Figure 1). Requirements in both electrical safety standards mentioned for completing an arc flash survey, along with those for training and industry regulation can be attributed to the favorable trend with incident rates.

In a study conducted from 1995-2004 on thermal burn and electrical injuries among utility workers, there were a total of 872 injuries from thermal burn and shock reported across 15 utilities whose injury statistics were considered. Electric burns accounted for 399 injuries (45.8%), totaling the largest percentage of burn injuries, where seven of the injuries involved fatalities. Male workers in their thirties and forties were found to have the highest injury rates for burns, with line workers having the highest injury rate for flashburn/electric shock/electrocution injuries. Burn injuries are found to be less common than other occupational injuries, but more serious and result in higher loss of productivity. Medical costs for injuries caused by flashburn/electric shock/electrocution averaged $14,121 [2]. The study quantifies the reality of arc flash hazard in the utility industry and effects felt by several utility companies. In response to results seen in this study and others similar, measures have been taken by many utility companies to develop arc flash safety programs in recent years.

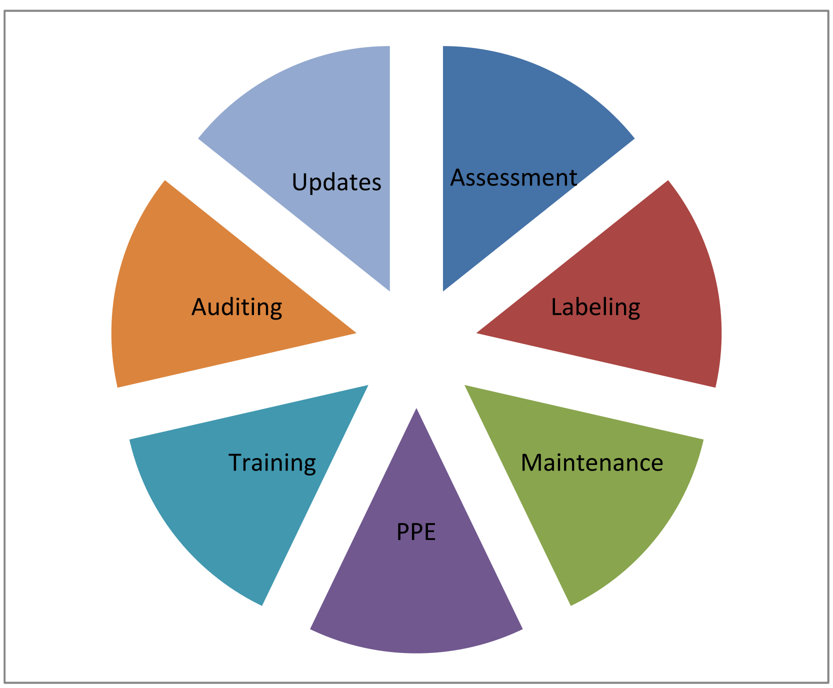
Figure 1: Electrical Incident Statistics



Arc Flash Safety Program

A written program should be in place to provide guidelines for equipment labeling, maintenance of protective devices, PPE, training, auditing, and updating the arc flash calculations. The program should be written around the results of the arc flash assessment performed and be part of the company's overall electrical safety program. All parts of the program should come together to form a successful arc flash safety program (see Figure 2). Affected employees should be knowledgeable on the program requirements and understand how to apply them in practical situations encountered.

Figure 2: Arc Flash Safety Program



Arc Flash Assessment

Utility systems can be broken into two categories for arc flash assessment considerations: 1) Generation facilities 15 kV and below, and 2) Transmission and Distribution systems 15 kV and above. For Generation facility systems 15 kV and below, IEEE-1584 is the industry preferred standard for arc flash calculations; for Transmission and Distribution systems 15 kV and above, the NESC table method is commonly applied. Each arc flash assessment method will be described.

IEEE-1584 Method Steps

1. Collect the system and installation data.
2. Determine the system modes of operation.
3. Determine the bolted fault currents.
4. Determine the arc fault currents.
5. Find the protective device characteristics and the duration of the arcs.
6. Document the system voltages and classes of equipment.
7. Select the working distances.
8. Determine the incident energy for all equipment.
9. Determine the flash-protection boundary for all equipment.

Step 1 involves gathering pertinent system information such as available fault current and X/R ratios from the utility, cable data, circuit breaker ratings and settings, etc. Step 2 requires a determination of the system switching configurations during normal, emergency, and alternative operation. Step 3 will necessitate a complete short circuit study to be performed for all equipment locations to be included in the analysis. Both maximum and minimum short circuit scenarios should be considered. In Step 4 the calculations in Step 3 will be used to determine the arcing fault currents at each location. The arcing fault current will typically be less than the bolted fault current, with lesser values for low voltage systems in comparison to medium voltage systems. In Step 5 calculated arcing fault current will be compared to manufacturer published time-current curves for determination of the arcing duration. Consideration will need to be given to total opening times for time-current curves which don't represent the total clearing time of the device (i.e. protective relays which trip medium voltage circuit breakers). In Step 6 system voltage and equipment classes (i.e.15 kV switchgear) are determined for correct input into the 1584 model equations. Step 7 will use the results of Step 6 to select the correct working distance for arc flash calculations. Step 8 is done to calculate the arc flash incident energy based on all the information compiled and calculated in the previous steps. In Step 9 the flash-protection boundary will be calculated for the distance the onset of a second degree burn can occur [3]. Application of the IEEE-1584 method for arc flash calculations is commonly performed with commercially available software.

NESC Table Method Steps for Voltages 50 V to 1000 V

1. Determine equipment type.
2. Determine nominal voltage of equipment.
3. Use Table 410-1 to determine the effective arc rating of the clothing.

Step 1 requires the equipment type to be determined. In Step 2 the nominal voltage of the equipment will need to be determined. Table 410-1 specifies ranges of 50 V to 250 V, 251 V to 600 V, and 601 V to 1000 V for each equipment type found in the table. Step 3 allows the effective arc rating of clothing to be determined based on the equipment type and nominal voltage of the equipment. For 251 V to 1000 V network protectors and three-phase panelboards greater than 100 A, the notes at the end of Table 410-1 require a detailed arc flash hazard analysis to be performed [4].

Table 1: Table 410-1 (NESC 2012)

Equipment type	Nominal voltage range and cal/cm²		
	50 V to 250 V	251 V to 600 V [14]	601 V to 1000 V
Self-contained meters / cabinets	4 [2]	20 [4]	30 [8]
Pad-mounted transformers	4 [9]	4 [9]	6 [8]
CT meters and control wiring	4 [2]	4 [5]	6 [8]
Metal-clad switchgear / motor control centers	8 [3]	40 [6]	60 [8]
Pedestals / pull boxes / hand holes	4 [2]	8 [7]	12 [8]
Open air (includes lines)	4 [2]	4 [7]	6 [8]
Equipment type	**Nominal voltage range and cal/cm²**		
	50 V to 250 V	**251 V to 600 V [14]**	**601 V to 1000 V**
Network protectors	4 [10]	[11]	[11]
Panel boards—single phase (all) / three phase (≤100 A)	4 [2]	8 [12]	12 [8]
Panel boards—three phase (>100 A)	4 [2]	[13]	[13]

NESC Table Method Steps for Voltages 1.1 kV to 800 kV

1. Collect the system and installation data.
2. Determine the system modes of operation.
3. Determine the bolted fault currents.
4. Find the protective device characteristics and maximum clearing time.
5. Use Table 410-2 and 410-3 to determine the effective arc rating of the clothing.

Step 1 involves gathering pertinent system information such as available fault current and X/R ratios from connecting utilities, overhead line data, circuit breaker/protective relay ratings and settings, etc. Step 2 requires a determination of the overall system switching configurations during normal, emergency, and alternative operation. Step 3 will necessitate a complete short circuit study to be performed for all arc flash locations to be included in the analysis. Both maximum and minimum short circuit scenarios should be considered. In Step 4 the calculations in Step 3 will be used to determine the arcing fault currents at each location. Note the phase-to-ground bolted fault current in open air is used for comparison. In Step 5 the phase-to-phase voltage, calculated line-to-ground fault current, and maximum protective device clearing time will be compared to Table 410-2 to determine the effective arc rating of clothing to be worn. The tables allow selection based on a 4-cal, 8-cal, or 12-cal system. Note the arc distance to the electrical worker and arc gap is derived differently for Table 410-2 and Table 410-3 [4]. The notes at the end of each table should be referenced for clarification.

Table 2: Table 410-2 (NESC 2012)

Phase-to-Phase Voltage (kV)	Fault Current (kA)	4-cal System	8-cal System	12-cal System
		Maximum Clearing Time (cycles)	Maximum Clearing Time (cycles)	Maximum Clearing Time (cycles)
1.1 to 15	5	46.5	93.0	139.5
	10	18.0	36.1	54.1
	15	10.0	20.1	30.1
	20	6.5	13.0	19.5
15.1 to 25	5	27.6	55.2	82.8
	10	11.4	22.7	34.1
	15	6.6	13.2	19.8
	20	4.4	8.8	13.2
25.1 to 36	5	20.9	41.7	62.6
	10	8.8	17.6	26.5
	15	5.2	10.4	15.7
	20	3.5	7.1	10.6
36.1 to 46	5	16.2	32.4	48.6
	10	7.0	13.9	20.9
	15	4.3	8.5	12.8
	20	3.0	6.1	9.1

Method Comparison

The IEEE-1584 method for arc flash calculations uses an empirically derived model based on statistical analysis and curve fitting programs. The model is applicable to systems 208 – 15,000 V, bolted fault currents 700 – 106,000 A, and three phase faults. Equations are provided to calculate the predicted arcing fault current, available incident energy, and arc flash boundary for system configurations within the range of the model parameters described. The theoretically derived Lee model is included for system configurations which fall outside the range of the model, including open air substations and overhead lines, and single phase systems [3].

The NESC 2007 (IEEE C2-2007), Rule 410.A.3, required utilities perform an assessment to determine potential arc flash exposure for employees who work on or near energized electrical equipment, effective January 1, 2009. This required a PPE system to be worn which exceeded the level of arc energy calculated for employee exposure greater than 2 cal/cm^2. Tables 410-1 and 410-2 were provided to allow an appropriate PPE system to be selected in accordance with the voltage level, fault current, and protective device clearing time for locations 1000 V and above [5].

The NESC 2012 (IEEE C2-2012), Rule 410.A.3, was revised to include secondary systems 1000 V and below. New Table 410-1 was provided to allow an appropriate PPE system to be selected for equipment from 50 V to 1000 V based on equipment type and voltage. Tables 410-1 and 410-2 from the 2007 standard have become Tables 410-2 and 410-3, respectively. Table 410-2 now includes voltages from 1.1 kV to 46 kV, but the rest of the table remained the same. Table 410-3 on the other hand included significant changes to the maximum clearing times tabulated and notes at the end of the table [4].

Table 3: Table 410-3 (NESC 2012)

Phase-to-Phase Voltage (kV)	Fault Current (kA)	4-cal System Maximum Clearing Time (cycles)	8-cal System Maximum Clearing Time (cycles)	12-cal System Maximum Clearing Time (cycles)
46.1 to 72.5	20	8.5	17.0	25.5
	30	5.3	10.5	15.8
	40	3.7	7.3	11.0
	50	2.8	5.5	8.3
72.6 to 121	20	8.2	16.5	24.7
	30	4.7	9.4	14.1
	40	3.1	6.2	9.3
	50	2.2	4.4	6.6
138 to 145	20	9.8	19.5	29.3
	30	5.6	11.2	16.8
	40	3.7	7.4	11.1
	50	2.6	5.3	7.9
161 to 169	20	9.3	18.6	27.9
	30	5.7	11.5	17.2
	40	4.0	8.0	12.0
	50	3.0	6.0	9.0
230 to 242	20	10.4	20.9	31.3
	30	6.4	12.9	19.3
	40	4.5	9.0	13.5
	50	3.4	6.8	10.1
345 to 362	20	22.6	45.3	67.9
	30	14.0	28.1	42.1
	40	9.8	19.6	29.4
	50	7.4	14.7	22.1
500 to 550	20	18.9	37.8	56.7
	30	11.7	23.3	35.0
	40	8.1	16.3	24.4
	50	6.1	12.2	18.3
765 to 800	20	43.6	87.3	130.9
	30	27.0	53.9	80.9
	40	18.9	37.8	56.7
	50	14.2	28.4	42.6

Both IEEE-1584 and NESC have applications in a utility company's arc flash assessment methodology. 1584 calculation methods are based on extensive testing done for the range of the model which the calculations can be applied. NESC Table 410-1 is based on testing done by two utility companies and a research institute for the calculations provided; whereas Table 410-2 and 410-3 are based on calculations using a commercial software program. The 1584 standard is commonly applied within generation facilities where the range of the model applies to the majority of the equipment locations. The NESC table method, using Tables 410-2 and 410-3, is commonly applied to distribution and transmission lines where the table calculations are based on open air phase-to-ground arcs. NESC Table 410-1 can also be applied to equipment 1000 V and less within generation facilities, and offers the advantage of the table calculations being based on equipment type and voltage range. Important to note is the 1584 standard provides a calculation for the arc flash boundary, where the NESC table method does not. When considering which calculation methodology to apply, the utility company must consider the how each calculation method applies to the equipment being analyzed.

Arc Flash Improvements, Labeling, Protective Device Maintenance, and Assessment Updates

After the assessment is complete, considerations for arc flash mitigation techniques to be applied should be given to any locations where the calculated incident energy exceeds desired levels and should be evaluated on a case by case basis. Equipment labeling details should be outlined in the safety program and understood by the affected electrical workers. Protective device settings should be set to match the recommended settings provided in the assessment, as well as any overdutied equipment locations being upgraded to exceed the calculated available short circuit for each location. In order to keep the assessment up-to-date, an update should be made when revisions to any of the industry standards for which the calculations were performed take place or when any system upgrades/changes are done.

Arc Flash Mitigation

Arc flash mitigation techniques involve changing at least one of three factors: 1) Distance from the electrical worker to the arc source, 2) Protective device clearing time for which the arc flash calculation is based, or 3) Fault current at the arc flash location. The majority of practical solutions available typically involve the first two. The mitigation process can be done in two phases: 1) Identifying all locations with unacceptable incident energy levels and developing solutions to lower the calculated values, and 2) Implementing the changes and updating the arc flash calculations.

A good starting point for locations to consider lowering the incident energy level is above 40 cal/cm^2. Consideration of the level of arc flash PPE to be worn by the electrical workers should also be given to ensure the mitigation being applied goes hand in hand with the arc flash safety program PPE requirements. With many companies selecting a two clothing arc flash PPE program and wanting to require particular levels to be worn for similar type locations, the incident energy calculations for all locations which exceed wanted levels should be reviewed. Common incident energy levels to reach are below 4, 8, or 12 cal/cm^2 to meet the lower level of PPE required and 40 cal/cm^2 for the higher level of required PPE.

Several solutions to lower incident energy calculations to desired levels are available, many of which are straightforward and simplistic for use by the qualified electrical worker with proper training. Protective relays with multiple setting groups can be applied to use one group as a "maintenance" or "arc flash reduction" mode which will incorporate lower settings than used for normal system operation, making the overall clearing time lower than before and in turn reducing the incident energy level calculated. Remote circuit breaker racking and switching devices can be applied to create distance between the electrical worker and equipment which results in a lower incident energy level seen by the worker.

After the locations which require mitigation have been determined and solutions provided, the decision to implement system changes must be made. For any locations affected by the system changes, the arc flash calculations should be updated. The calculations should include a detailed analysis of all possible operational scenarios and switching configurations to ensure a high degree of certainty in the lower calculations provided. Any areas which involve new technology will require the affected electrical workers to be trained on the operation and maintenance techniques to be applied.

Equipment Labeling

A decision needs to be made for what information is to be shown on the arc flash label. Incident energy calculated at the specified working distance, minimum arc rating of PPE, hazard/risk category for the equipment location, arc flash boundary, nominal system voltage, shock boundaries, and ANSI signal wording and coloring are all relevant items for inclusion. The goal with the label presentation should be to accurately convey the hazard present and provide the electrical worker with enough information to determine the appropriate PPE to wear to be in compliance with the arc flash safety program guidelines [6]. NFPA 70E-2012, 130.5(C), provides guidance for the information to be presented on the arc flash label [7]. Reference to the appropriate arc flash PPE to be worn based on incident energy level determined should be included in the arc flash safety program.

Protective Device Maintenance

For arc flash calculations which use arcing time in the formula, protective device clearing time is a key component of the calculation. Both the IEEE-1584 method and NESC table method (for equipment above 1000 V) utilize protective device clearing time in their calculations to determine incident energy levels. A high degree of confidence protective devices used to determine arc flash calculations will operate within expected manufacturer published tolerances is necessary for the validity of any calculations performed. Manufacturer recommendations for maintenance of fuses, circuit breakers, protective relays, and reclosers should be followed to ensure correct operation under overload and fault conditions. Many types of components are recommended to be tested every 1-3 years for correct operation. Any devices found to be not operating within tolerance should either be corrected or replaced. A regular maintenance schedule is an important part of any arc flash safety program. IEEE Std. 902-1998 [8], IEEE Std. 141-1993 [9], and IEEE Std. 242-2001 [10], along with manufacturer and NETA published documents, contain helpful guidelines for maintenance considerations.

Protective device maintenance is closely linked equipment failure and proper operation. Maintenance quality and frequency are good indicators of failure (see Table 4 and Table 5). Poor quality of maintenance and prolonged periods between scheduled maintenance are shown to contribute to increased equipment failures. Environmental and operational conditions such as dust, dirt, short circuits, high duty cycles, loose connections, etc. can all contribute to failures. A sound protective device maintenance program is important to minimize equipment failures and provide a high degree of reliability of electrical system components [11].

Table 4: Table 5-1 (IEEE Std. 493-2007)

Maintenance quality	**Number of failures**		**Percent of failures due to inadequate maintenance (%)**
	All causes	**Inadequate maintenance**	
Excellent	311	36	11.6
Fair	853	154	18.1
Poor	67	22	32.8
None	238	28	11.8
Total	1469	240	16.3

Table 5: Table 5-2 (IEEE Std. 493-2007)

Failure (months since maintained)	All electrical equipment classes combined (%)	Circuit breakers (%)	Motors (%)	Open wire (%)	Trans-formers (%)
Less than 12 months ago	7.4	12.5[a]	8.8	0[a]	2.9[a]
12 to 24 months ago	11.2	19.2	8.8	22.2[a]	2.6[a]
More than 24 months ago	36.7	77.8	44.4	38.2	36.4
Total	16.4	20.8	15.8	30.6	11.1

[a]Small sample size; less than seven failures caused by inadequate maintenance.

Arc Flash Calculation Updates

It's widely recognized arc flash calculation methodology is ever-changing, with much testing being performed to simulate real-world conditions by different parties and associated electrical safety standards being updated every 3-5 years with new or revised information being presented. Maintaining the assessment calculations to current standards, such as IEEE-1584, NFPA 70E, and NESC, is a critical part of the arc flash safety program. With more and more data becoming available, along with different equipment configurations and system conditions being tested, calculations will follow with more accuracy as more arc flash knowledge is gained by the industry. As new and improved calculation methods are developed, arc flash assessment results should be reevaluated and compared to those existing for inclusion into the safety program guidelines. In addition, any electrical system changes, such as those involving equipment upgrades/additions, alternate switching configurations, or system impedance changes, require the arc flash calculations to be reevaluated. Periodic update of the arc flash calculations should be done to ensure all are up-to-date.

PPE, Auditing, and Training

A successful Arc Flash Safety Program is dependent on all of its individual components. While PPE should be considered the last line of defense against a hazard, its proper selection and maintenance are important to the safety of electrical workers in the event all other safety measures fail. Auditing provides assurance the safety program is headed in the right direction and allows for a way to continuously improve. Regularly scheduled training keeps employees up-to-date on the safety program and safe work processes to be followed.

Arc Flash PPE

Different methods and processes for selecting arc flash PPE are available, but selecting a system which exceeds the determined incident energy is common to all. NFPA 70E-2012, Annex H, provides guidance on selecting PPE and outlines different available methods, whereas NESC 2012 only requires the PPE system to exceed the expected level of incident energy. Selecting PPE should be based upon the results of the arc flash assessment (or improved results after mitigation has been implemented) to ensure electrical workers have appropriate protection available regardless the work location encountered. A two-level approach to PPE selection provides the electrical worker with the flexibility to utilize lower rated attire for locations where the incident energy calculated is below a certain cutoff (i.e. maybe 8 or 12 cal/cm^2), whereas higher rated dress is used for locations which exceed the lower level cutoff selected but fall within the highest incident energy level where work is allowed to be performed per the arc flash safety program (i.e. 40 or 60 cal/cm^2). The advantage of the two-level system is workers aren't exposed to additional hazards created by wearing too much PPE and the vast majority of locations will fall into one of the levels of dress required.

Recommended PPE maintenance and replacement procedures set forth by manufacturers are to be followed. Instructions for washing and drying arc rated clothing, insulated glove testing on regular time intervals, and repair/replacement of equipment found to be deficient are all part of maintaining arc flash PPE correctly. Clothing manufacturers will specify the number of washes the clothing is capable before its ATPV ratings are no longer valid; certified labs which test gloves will indicate locations on the glove which fail the tests performed and recommend replacement for those which don't pass; clothing with visible holes and damage should either be sent back the manufacturer for repair or in many cases simply replaced with a new item meeting the criteria previously determined. Maintaining PPE adequately is equally as important as applying its ratings correctly for the work location at hand. All PPE should be inspected by the electrical worker thoroughly before each use.

Auditing

Auditing is an important part of any safety program. Both internal and external audits should be conducted on a periodic basis. The results of the audits are used to determine which parts of the safety program are working well, as well as identifying gaps in the program where changes are needed to meet applicable regulations and standards. The major elements of an audit are 1) Pre-audit activities, 2) On-site audit activities, and 3) Post-audit activities. Pre-audit activities involve selecting personnel to conduct the audit, deciding the scope of the audit, determining how the results will be reported, identifying protocols and criteria, and developing a detailed plan of attack prior to the on-site audit; on-site audit activities involve a kick-off meeting between the auditors and facility management, reviewing the facility for compliance with internal and external standards, assigning each member of the audit team specific topics of responsibility, and reviewing documented procedures/work practices and physical condition of facility components; post-audit activities involve creating a final audit report, developing a corrective plan of action for deficiencies found, and executing the corrective plan . A final audit report should be issued with each audit conducted which contains the strengths and weaknesses of the program, as well as recommendations for corrective action items. Internal audits are recommended to be done yearly and external audits at least every three years. With the goal of increasing safety performance, auditing will increase standard and regulatory compliance if performed correctly [12].

Training

Yearly safety training should be conducted for all workers exposed to energized lines and parts, as required by NESC Section 41, 410.A.2. Review of the assessment report results, as well as any maintenance/operation procedures necessary to achieve reduced calculations should be understood. Utility company PPE guidelines and application for all work locations should be reviewed. Training should be consistent across all work shifts and groups. Monthly safety meetings should be conducted to review any "near misses" encountered, along with covering safety topics and addressing any questions about the safety program. All training should be documented and retraining done on a periodic basis to ensure proficiency.

Conclusion

Maintaining a successful arc flash safety program for a utility company will require a continual effort. Both employers and employees must work together to achieve a zero incident safety culture. With multiple industry standards covering arc flash safety guidelines and different calculation methodologies being applied to various classifications of equipment, maintaining the program to current best practices is a challenge. To achieve success and the overall goal of a safer workplace for electrical workers, program goals and guidelines must align from the top to the bottom of the organization.

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