Arc Flash Study

Prepared for:

ABC
City, State

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October 3, 2017

ABC—City, State - Five Year Review of DC Arc Flash Study

Jim,
Thank you for the opportunity to perform the five (5) review of the Arc Flash Study for your electrical distribution system and to provide an Arc Flash Study of the direct current (DC) electrical distribution system for the company Center facility near City, SC.

The current version (v7.0) of SKM Power Tools Arc Flash modeling, equipment evaluation, short circuit current analysis and over current device coordination software programs were used to determine Arc Flash incident energy levels for this project. IEEE Standard 1584 modeling software and NFPA 70E 2018 edition was used for verification.

We have documented the results of the calculations and models on one (1) drawing based for the facility direct current (DC) systems. The calculations and analysis have been based on data collected by me during my on-site visit on October 3, 2017.

The results contained in this report are based on the design and information available at the time this report was completed. Any changes made to equipment settings or system configuration will invalidate the results contained in this report and may result in a more hazardous condition thus, necessitating a follow-up review of this arc flash study.

The results of the Five-Year Review of the previous Arc Flash Study and the DC Arc Flash Study are provided below:

Review of AC Arc Flash Study
The Short Circuit, Protective Device Coordination and Arc Flash Hazard Study for Calpine company dated October 2009 (2009 Study) that was completed by Eaton Electrical Services and Systems was reviewed and found to be current with and representative of the site electrical distribution system as found during the on-site inspection and data collection visit on October 3, 2017.

A. The current version (v7.0) of SKM Power Tools was utilized to evaluate various scenarios and these results were compared with the 2009 Study report. No significant differences, variances, or anomalies were identified.
B. The recommended changes in protective device trip settings to improve coordination in the 2009 Study that have been implemented by the site have resulted in the improvements expected.
C. No significant additions or modifications have been made to the electrical distribution system addressed by the 2009 Study.
D. Routine testing and inspection of electrical distribution equipment is performed by the site.
E. The 2009 Study did not evaluate the battery supplied direct current systems utilized on site. A direct current (DC) system arc flash study has been performed as part of this project and the results of it are documented in the “Direct Current (DC) System Arc Flash Study” section of this report.
Direct Current (DC) System Arc Flash Study

The DC Incident Energy Summary Report and Model Drawing provide the detailed results however; the highlights of the DC Arc Flash Study are summarized as follows:

1. **Analysis Methods Utilized**
   For each of the battery systems, three analysis methods were used to determine the worst-case scenario. The three analysis methods were based on three types of ratings provided by the battery manufacturer; the eight (8) hour performance rating, the one (1) minute performance rating, and, the maximum short circuit current rating. Typically, all three of these rating result in similar incident energies for the battery system bus. All three are shown on the model drawing for each battery system. The rating resulting in the worst-case (highest) incident energy level for the battery system bus was then selected for analysis of the DC distribution system fed by the respective battery system bus.
   - For the CTG-1 and CTG-2 Battery Systems the 8 Hour Rating of 82.5A was used
   - For the Main Plant Battery System, the 8 Hour Rating of 444A was used
   - For the Switchyard Battery System, the 1 Minute Rating of 222A was used

2. **System Mis-coordination**
   A few areas of overcurrent device mis-coordination are indicated in the DC Incident Energy Summary Report (see the (*N5) notations). In an industrial power system though, mis-coordination is not an uncommon situation to find and it typically works in your favor relative to arc flash as the speed of the upstream protective device reduces the incident energy exposure. These upstream protective devices function in this manner only in an overload condition. A detailed system analysis could be considered although, it should be noted that this power system device coordination analysis could consume significant engineering and field monitoring cost.

3. **Equipment Labeling**
   The switchboard, motor control center (MCC) sections, and panel boards must be labeled to the actual incident energy levels per the requirements of IEEE 1584 and NFPA 70E for testing, troubleshooting and interacting with the device with exposed energized parts. All disconnects that could require maintenance, testing or troubleshooting will be labeled to the requirements of NFPA 70E 130.5(D); extracted text from provided next.

NFPA 70E, 2015 Edition (Pg. 28)

130.5 (D) Equipment Labeling. Electrical equipment such as switchboards, panel boards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling units and that are likely to require examination, adjustment, servicing, or maintenance while energized shall be field-marked with a label containing all the following information:
   - (1) Nominal system voltage
   - (2) Arc flash boundary
   - (3) At least one of the following:
a. Available incident energy and the corresponding working distance, or the arc flash PPE category in Table 130.7(C)(15)(A)(b) or Table 130.7(C)(15)(B) for the equipment, but not both
b. Minimum arc rating of clothing
c. Site-specific level of PPE

Exception: Labels applied prior to September 30, 2011 are acceptable if they contain the available incident energy or required level of PPE.

The method of calculating and the data to support the information for the label shall be documented. Where the review of the arc flash hazard risk assessment identifies a change that renders the label inaccurate, the label shall be updated.

The owner of the electrical equipment shall be responsible for the documentation, installation, and maintenance of the field-marked label.

4. Operation of Electrical Equipment
The motor control centers and distribution panels are typical lockout points. The calculated energy levels as indicated on the drawings are often in excess of 1.2 calories/cm² and as such would require some level of arc rated PPE. The extracted text from NFPA 70E 2015 edition regarding this situation is provided next:

NFPA 70E, 2015 Edition (Pg. 24)
130.2 Electrically Safe Working Conditions
(A) Energized Work

(4) Normal Operation. Normal operation of electric equipment shall be permitted where all of the following conditions are satisfied:

(1) The equipment is properly installed.
(2) The equipment is properly maintained.
(3) The equipment doors are closed and secured.
(4) All equipment covers are in place and secured.
(5) There is no evidence of impending failure.

Informational Note: The phrase properly installed means that the equipment is installed in accordance with applicable industry codes and standards and the manufacturer’s recommendations. The phrase properly maintained means that the equipment has been maintained in accordance with the manufacturer’s recommendations and applicable industry codes and standards. The phrase evidence of impending failure means that there is evidence such as arcing, overheating, loose or bound equipment parts, visible damage, or deterioration.
**NFPA 70E, 2015 Edition (Pg. 35)**

Table 130.7(C)(15)(A)(a) Arc Flash Hazard Identification for Alternating Current (ac) and Direct Current (dc) Systems

<table>
<thead>
<tr>
<th>Task</th>
<th>Equipment Condition*</th>
<th>Arc Flash PPE Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td></td>
<td></td>
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</tbody>
</table>
| Normal operation of a circuit breaker (CB), switch, contactor, or starter | All of the following:  
The equipment is properly installed  
The equipment is properly maintained  
All equipment doors are closed and secured  
All equipment covers are in place and secured  
There is no evidence of impending failure | No |
| | One or more of the following:  
The equipment is not properly installed the equipment is not properly maintained  
Equipment doors are open or not secured  
Equipment covers are off or not secured  
There is evidence of impending failure | Yes |

Additionally, while for DC systems, work on energized electrical conductors and circuit parts of series-connected battery cells, including voltage testing requires arc flash PPE, these conditions for Normal Operation apply specifically to voltage testing on individual battery cells or individual multi-cell units and removal of battery inter-cell connector covers as outlined in Table 130.7(C)(15)(A)(a). The calculated energy levels as indicated on the drawings are often in excess of 1.2 calories/cm² and as such would require some level of arc rated PPE. The extracted text from NFPA 70E 2015 edition regarding this situation is provided next:

**NFPA 70E, 2015 Edition (Pg. 35)**

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| Voltage testing on individual battery cells or individual multi-cell units or Removal of battery inter-cell connector covers | All of the following:  
The equipment is properly installed  
The equipment is properly maintained  
All equipment covers are in place and secured  
There is no evidence of impending failure | No |
One or more of the following:

- The equipment is not properly installed
- The equipment is not properly maintained
- Equipment doors are open or not secured
- Equipment covers are off or not secured
- There is evidence of impending failure

Yes

NFPA 70E makes it very clear the determination of this condition can only be made by the responsible person in charge of the facility. If the facility has evidence and documentation as per the requirements of NFPA 70E 205.3, 205.4 and 210.5 that all five conditions are met, then no arc rated PPE would be required to operate disconnects with the doors properly closed and latched. "In our experience, it is very rare that equipment is maintained to the exact specifications of the manufacturer". For reference see NFPA extracts listed below.

A safer approach could be taken. Other facilities with similar situations provide an appropriate Arc Rated switchers coat, face shield and leather gloves in each of the MCC rooms and then instruct the task qualified workers when performing the lock out procedure to wear the coat, hard hat, face shield and gloves to interact with the disconnect in question. If this approach is taken, the under-layer clothing shall be 100% natural fiber non-melting clothing per NFPA 70E. After the disconnect switch is operated to the “off” position, then lock out procedures can be performed without any arc rated PPE.

NFPA 70E, 2015 Edition (Pg. 44 & 45)

205.3 General Maintenance Requirements. Electrical equipment shall be maintained in accordance with manufacturers’ instructions or industry consensus standards to reduce the risk associated with failure. The equipment owner or the owner’s designated representative shall be responsible for maintenance of the electrical equipment and documentation.

Informational Note: Common industry practice is to apply test or calibration decals to equipment to indicate the test or calibration date and overall condition of equipment that has been tested and maintained in the field. These decals provide the employee immediate indication of last maintenance date and if the tested device or system was found acceptable on the date of test. This local information can assist the employee in the assessment of overall electrical equipment maintenance status.

205.4 Overcurrent Protective Devices. Overcurrent protective devices shall be maintained in accordance with the manufacturers’ instructions or industry consensus standards. Maintenance, tests, and inspections shall be documented.

210.5 Protective Devices. Protective devices shall be maintained to adequately withstand or interrupt available fault current.

Informational Note: Improper or inadequate maintenance can result in increased opening time of the overcurrent protective device, thus increasing the incident energy.

The calculations in this study and resultant incident energy levels are based upon the overcurrent devices (overcurrent relays, circuit breakers, and fused disconnects) operating as designed and being properly
maintained. Maintenance intervals should be based on the manufacturer’s recommendations or industry consensus testing standards. This is typically a 3 to 5 year interval based on the conditions of the equipment. The InterNational Electrical Testing Association (NETA) provides guidance documents for adjusting these intervals based on location conditions.

It is important to note that in many cases, changing the trip settings of the equipment in place in the facility is relatively simple to do. Full-function circuit breakers and time overcurrent relay devices often have adjustable long-time, short-time and instantaneous (LSI) trip units that provide the unique ability to modify or change the trip settings with a small screwdriver. As any changes to the equipment settings may have a significant impact on the incident energy levels found in the electrical system, the facility should have a change management process in place to maintain the settings as found for this Arc Flash Study. Any change to the site distribution system or a change to your incoming service fault current could necessitate a review of this arc flash study.

Annex H of NFPA 70E provides guidance for a clothing system to 12 calories/cm² and as such on all the model drawings anytime there is a PPE Category 3 situation it will be indicated as such with the specific calories/cm² exposure. This can help you if your clothing supplier is providing 12 calories/cm² clothing. This needs to be verified to what level of protection your PPE uniform clothing provides. This can be your decision after verification of the ATPV of the clothing supplied, documented and communicated to the affected personnel.

Layering of Arc rated clothing is allowed as long as it has been tested as a system. This information is available on the clothing manufacturers’ websites as well as on ArcWear.com. As an example, Westex has tested their Indura Ultrasoft shirt with their T-shirt (typical rental company provided material) and the combination achieves 20 calories/cm². Tyndale’s 9 calories/cm² shirt has been tested with various other 4 calories/cm² T-shirts achieving slightly higher overall results when used together.

Any exposures greater than PPE Category 1 (> 4 calories/cm²) requires the use of an arc rated face shield and balaclava or an arc rated face shield hood assembly.

NFPA 70E requires the arc flash study to be reviewed every five years. If nothing has changed relative to your incoming service fault current and you have not changed anything in your distribution system on site, then the review can be a very simple process of noting this fact every 5 years. A verification from the utility of the utility information found on the arc flash study document and also contained on the USB drive is all that would be required.

NFPA 70E requires initial qualified training and re-training every three years for your qualified electrical workers. We typically recommend electrical safety training after the labeling activity as this can provide a customized session for your specific equipment and what the labels require as far as proper work practices. Within the documentation binder for this study are copies of all the associated information; this summary report, the one-line drawings from SKM, the Arc Flash Evaluation reports, and the Equipment Evaluation report. All of the relative files in PDF, native Microsoft Office format and native SKM format are provided on an USB drive for file retention. It is recommended that these files be retained in a secure location within your organization. e-Hazard also retains the files backed up to a “secured cloud service”.

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I keep an exact duplicate of the documentation binder in my office so if there is ever a question, we can both look at the exact same piece of information at any time in the future. If I should be traveling, I have all the files on my laptop with me.

Please call John Aeiker, 251-581-1492 for any additional clarification relative to this report.

Thank you,

John Aeiker

john.aeiker@e-hazard.com
| A | B          | C    | D | E    | F    | G | H | I | J | K | L | M | N | O | P |
|---|------------|------|---|------|------|---|---|---|---|---|---|---|---|---|---|---|
|   | Bus Name   | Device | kV | Fault (kA) | Fault (kA) | Equivalent Resistance | Fault (kA) | Fault (kA) | Trip Delay Time | Opening Duration of Arc | Multiplier | Working Distance (in) | Boundary (in) | Flash Energy (cal/cm²) | PPE Level |
| 1 | 600A Main DC Bus @ 1 Minute | MaxTripTime | 0.125 | 7.088 | 3.544 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.0 | 18 | 4 | 2 | Level 2 (N2) (N9) |
| 2 | 600A Main DC Bus @ 8 Hour | Emergency Lube Oil Pump CB | 0.125 | 13.495 | 6.748 | 0.0093 | 3.332 | 1.666 | 2.000 | 0.000 | 2.000 | 1.0 | 18 | 47 | 8 | Level 3 (N2) (N9) |
| 3 | 600A Main DC Bus @ 9 Hour | Emergency Lube Oil Pump CB | 0.125 | 13.495 | 6.748 | 0.0093 | 3.830 | 1.915 | 2.000 | 0.000 | 2.000 | 1.0 | 18 | 47 | 8 | Level 3 (N2) (N9) |
| 4 | 600A Main DC Bus @ Max SC | MaxTripTime | 0.125 | 4.498 | 2.249 | 0.0276 | 0.000 | 0.000 | 2.000 | 0.000 | 2.000 | 1.0 | 18 | 27 | 2 | Level 1 (N2) (N9) |
| 5 | BOP SWBD 1B Bus | SWBD 1B Main FD | 0.125 | 16.316 | 8.159 | 0.077 | 16.316 | 8.159 | 1.086 | 0.000 | 1.086 | 1.0 | 18 | 38 | 5.3 | Level 5 |
| 6 | BOP SWBD 1B Bus | SWBD 1B Main FD | 0.125 | 16.316 | 8.159 | 0.077 | 15.640 | 7.820 | 1.485 | 0.000 | 1.485 | 1.0 | 18 | 44 | 7.3 | Level 2 |
| 7 | Control Power Cabinet | Control Power CB | 0.125 | 10.420 | 5.210 | 0.0120 | 10.420 | 5.210 | 0.020 | 0.000 | 0.020 | 1.0 | 18 | 4 | 0.06 | Level 0 (N2) |
| 8 | DC PNLBD Main Bus | Emergency Lube Oil Pump CB | 0.125 | 12.446 | 6.223 | 0.0100 | 3.067 | 1.534 | 2.000 | 0.000 | 2.000 | 1.0 | 18 | 45 | 7.4 | Level 2 (N2) (N9) |
| 9 | Emergency Seal Oil Pump FS | Emergency Seal Oil Pump CB | 0.125 | 8.777 | 4.389 | 0.0142 | 6.777 | 3.389 | 0.020 | 0.000 | 0.020 | 1.0 | 18 | 4 | 0.05 | Level 0 (N2) |
| 10 | Emergency Seal Oil Pump FS | Emergency Seal Oil Pump CB | 0.125 | 10.808 | 5.404 | 0.0116 | 6.808 | 3.404 | 0.017 | 0.000 | 0.017 | 1.0 | 18 | 4 | 0.05 | Level 0 (N2) |
| 11 | Emergency Lube Oil Pump FS | Emergency Lube Oil Pump CB | 0.125 | 10.808 | 5.404 | 0.0116 | 16.318 | 8.159 | 1.086 | 0.000 | 1.086 | 1.0 | 18 | 38 | 5.3 | Level 5 |
| 12 | SWBD 1A - AX-011A Emergency SWBD 1B - AX-011A CB | Normal | 0.125 | 16.073 | 8.036 | 0.0078 | 16.073 | 8.036 | 0.013 | 0.000 | 0.013 | 1.0 | 18 | 4 | 0.06 | Level 0 |
| 13 | SWBD 1A - AX-011A Normal SWBD 1A - AX-011A CB | Normal | 0.125 | 16.194 | 8.097 | 0.0077 | 16.194 | 8.097 | 0.013 | 0.000 | 0.013 | 1.0 | 18 | 4 | 0.06 | Level 0 |
| 14 | SWBD 1B - AX-011B Emergency SWBD 1B - AX-011B CB | Normal | 0.125 | 16.073 | 8.036 | 0.0078 | 16.073 | 8.036 | 0.013 | 0.000 | 0.013 | 1.0 | 18 | 4 | 0.06 | Level 0 |
| 15 | SWBD 1B - AX-011B Normal SWBD 1A - AX-011A CB | Normal | 0.125 | 16.073 | 8.036 | 0.0078 | 16.073 | 8.036 | 0.013 | 0.000 | 0.013 | 1.0 | 18 | 4 | 0.06 | Level 0 |
| 16 | SWBD 1B - Battery Charger 1B | Battery Charger 1B CB | 0.125 | 16.184 | 8.102 | 0.0077 | 16.184 | 8.102 | 0.013 | 0.000 | 0.013 | 1.0 | 18 | 4 | 0.06 | Level 0 |
| 17 | SWYD Battery Bus @ 8 Hour | SWYD 125V DP MLO | 0.125 | 0.035 | 0.018 | 3.5619 | 0.035 | 0.018 | 2.000 | 0.000 | 2.000 | 1.0 | 18 | 2 | 0.02 | Level 0 (N2) (N9) |
| 18 | SWYD Battery Bus @ 8 Hour | SWYD 125V DP MLO | 0.125 | 0.035 | 0.018 | 3.6402 | 0.034 | 0.017 | 2.000 | 0.000 | 2.000 | 1.0 | 18 | 2 | 0.02 | Level 0 (N2) (N9) |

Fault Thresholds:
- 0.0 - 1.2 cal/cm²: #Level 0 = 25 (%N2 ≤ 80% Cleared Fault Threshold)
- 1.2 - 4.0 cal/cm²: #Level 1 = 3 (%N5) - Miscoordinated, Upstream Device Tripped
- 4.0 - 8.0 cal/cm²: #Level 2 = 4 (%N8) - Max Arcing Duration Reached
- 8.0+ cal/cm²: #Level 3 = 5 (%N8) - Max Arcing Duration Reached

Legend:
- Level 0: Nonmelting or Untreated Fiber with Weight >= 4.5 oz/sq yd
- Level 1: Arc-rated shirt & pants or arc-rated coverall
- Level 2: Arc-rated shirt & pants or arc-rated coverall
- Level 3: Arc-rated shirt & pants or arc-rated coverall
- Level 4: Arc-rated shirt & pants or arc-rated coverall
- Level 5: Arc-rated shirt & pants or arc-rated coverall
- Level 6: Arc-rated shirt & pants or arc-rated coverall
- Level 7: Arc-rated shirt & pants or arc-rated coverall
- Level 8: Arc-rated shirt & pants or arc-rated coverall
- Level 9: Arc-rated shirt & pants or arc-rated coverall

Notes:
- *N2 = 80% Cleared Fault Threshold
- *N5 = 50% Cleared Fault Threshold
- *N8 = 25% Cleared Fault Threshold

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DC Incident Energy Summary Report
J.D. Aeker
| Level 3: Arc-rated shirt & pants + arc-rated coverall + arc-rated arc flash suit | 8.0 - 25.0 cal/cm² | Level 3 = 4 |
| Level 4: Arc-rated shirt & pants + arc-rated coverall + arc-rated arc flash suit | 25.0 - 40.0 cal/cm² | Level 4 = 0 |
| Level Dangerous!: DO NOT WORK | 40.0 - 999.0 cal/cm² | Danger = 0 DC Arc Flash (ANSI) |

For additional information refer to NFPA 70 E, Standard for Electrical Safety in the Workplace.

Level 5: Nonmelting or Untreated Fiber with Weight >= 4.5 oz/sq yd, Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Safety glasses, Non-melting or untreated natural fiber (cotton/wollayon/silk > 4.5 oz/sq yd), shirt (long-sleeve), pants (long), > 50V voltage rated tools + Class 0 (minimum) gloves, Dielectric shoes or insulating mat (step and touch potential).

Level 6: Arc-rated shirt & pants or arc-rated coverall, Hardhat + Arc-rated hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Leather Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield, 4 cal/sq cm, Arc-rated shirt (long-sleeve) plus Arc-rated pants (long), or Arc-rated coverall, plus arc-rated face shield or arc flash suit hood, Arc-rated rainwear as needed, > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash) as needed, Hearing protection, 8 cal/sq cm, Arc-rated shirt (long-sleeve) plus Arc-rated pants (long), or Arc-rated coverall, plus arc-rated flash suit hood or arc-rated face shield and arc rated balaclava, Arc-rated rainwear as needed, > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash), Leather shoes (flash) as needed, Dielectric shoes or insulating mat (step and touch potential).

Level 7: Arc-rated shirt & pants + arc-rated coverall + arc-rated arc flash suit, Hardhat + Arc-rated hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield, Hearing protection, 25 cal/sq cm, Arc-rated shirt (long-sleeve) plus Arc-rated pants (long) plus Arc-rated coverall, plus arc-rated arc flash suit jacket, pants, & hood, Arc-rated rainwear as needed, > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash), Leather shoes (flash) as needed, Dielectric shoes or insulating mat (step and touch potential).

Level 8: Arc-rated shirt & pants + arc-rated coverall + arc-rated arc flash suit, Hardhat + Arc-rated hard hat liner + Safety Glasses or Goggles + Ear Canal Inserts, Arc-rated Gloves, Leather work shoes, Safety glasses, electrically rated hard hat with hood and face shield, Hearing protection, 40 cal/sq cm, Arc-rated shirt (long-sleeve) plus Arc-rated pants (long) plus Arc-rated coverall, plus arc-rated arc flash suit jacket, pants, & hood, Arc-rated rainwear as needed, > 50V voltage rated tools + Class 0 (minimum) gloves and leather protectors (flash), Leather shoes (flash) as needed, Dielectric shoes or insulating mat (step and touch potential).

Level Dangerous!: DO NOT WORK ON LIVE!, DO NOT WORK ON LIVE!, DO NOT WORK ON LIVE!, DO NOT WORK ON LIVE!, No FR Category Found
Best Practices for Exposure up to: 1.2 cal/cm²

- Eye and Hearing Protection
  - Long sleeve Shirt
  - Long Pants Undergarments
  - ALL Clothing Made of Nonmelting or Untreated Natural Fiber

- Heavy Duty Leather Gloves

- Dielectric Shoes
  - Working under powerlines
  - High step-potential risk
  - Wet conditions

Are You Protected?

Check to be sure you have correct Arc-Rated PPE for the task.