DC Arc Flash Working Group

EFCOG ESSG
Brookhaven National Lab
October 4-8, 2010
DC Arc Flash WG Tasks

- Review Research and Development
  - Empirical Data – Bruce Power, Kinectrics
  - Models – Ammerman, Sen
- Review Applications
  - Large UPS battery banks – 500kW PNNL, 1.5MW Hanford-LM
  - Future IT power distribution may be 250-350 Vdc
- Station Power
  - Safety-Class DC motors, switch & battery bank - ORNL
- Power for portable devices
  - Proprietary Data Electric & Hybrid (PHEV) Car
  - DOD sponsored topics
  - Large R&D DC power supplies
    - Cryogenic Energy store – 10 at LANL at thousands of amps, 10s of MJ
- 2012 NFPA 70E
  - Proposals
  - Status
DC Arc Flash WG Deliverables

- Best Practices
  - DOE Handbook – R&D
  - Station Power – 125Vdc

- Research Recommendations
  - Field Measurements on existing systems
  - Skunk Works

- New Proposals for NFPA 70E
## DC Applications

<table>
<thead>
<tr>
<th>Company</th>
<th>Model</th>
<th>Voltage</th>
<th>Power [kW]</th>
<th>Energy [kWh]</th>
<th>Weight [kg]</th>
<th>Type</th>
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<tr>
<td>GM</td>
<td>Volt</td>
<td>365</td>
<td>111</td>
<td>16</td>
<td>181</td>
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<tr>
<td>GM</td>
<td>EV1</td>
<td>312</td>
<td>105</td>
<td>16</td>
<td>450</td>
<td>Lead acid</td>
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<td>Toyota</td>
<td>Prius</td>
<td>202</td>
<td>37.9</td>
<td>1.31</td>
<td>29.1</td>
<td>Nickel-metal Hydride</td>
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<tr>
<td>Nissan</td>
<td>Leaf</td>
<td>408</td>
<td>90</td>
<td>28.8</td>
<td>300</td>
<td>Lithium Ion</td>
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<td>Tesla</td>
<td>Roadster</td>
<td>375</td>
<td>185</td>
<td>53</td>
<td>450</td>
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<tr>
<td>Mercedes</td>
<td>SLS Ecell</td>
<td>400</td>
<td>480</td>
<td>48</td>
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<td>Lithium Ion</td>
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<tr>
<td>TEPCO</td>
<td>Level III</td>
<td>500</td>
<td>50</td>
<td></td>
<td></td>
<td>EV charger connector</td>
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<td>USN</td>
<td>Albacore</td>
<td>710</td>
<td>11190</td>
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<td>Silver Zinc</td>
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</table>
Arc Flash Calculations for Exposures to DC Systems-ESW2007-19

Duke Power-Kinectrics testing had difficulty in establishing and maintaining an arc in excess of 0.5 in at 130V and 2.0 in at 260V. Isc was > 20kA at 230V.

\[ IE_{\text{max}} \text{ power} = 0.005 \times \left( \frac{V_{\text{sys}}^2}{R_{\text{sys}}} \right) \times \frac{T_{\text{arc}}}{R^2} \]

Examples

- UPS
- Substation battery
- Electrochemical cell

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Isc</th>
<th>Iarc</th>
<th>Tarc [s]</th>
<th>IEmax</th>
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<tr>
<td>350</td>
<td>10k</td>
<td>5k</td>
<td>0.2 - fuse</td>
<td>1.2</td>
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<tr>
<td>135</td>
<td>1.34k</td>
<td>669</td>
<td>2.0 - no OL</td>
<td>0.9</td>
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<tr>
<td>250</td>
<td>45k</td>
<td>22.5k</td>
<td>0.5 - CB</td>
<td>7.5</td>
</tr>
</tbody>
</table>
DC Arc Flash WG Members

- Cliff Ashley, Andrew Burbelo, Sjef Bennink, Todd Bischoff, Jeremy Bynum, Douglas Coffland, Gary Dreifuerst, Jim Durnan, Lloyd Gordon, Kurt Kranz, Jerry Lane, Mark Mathews, Bert Manzlak, Troy McCuskey, Jacqueline Mirabal, Earl Myott, Thomas Nehring, Sanjay Sanan, Joshua Siems, Bobby Sparks, Richard Waters
AC Faults with DC Effects

- Three Phase Faults may have currents that excite the Arc Flash Plasma with the same non-zero crossing waveforms that are characteristic of DC Faults.
- A voltage (current) zero-crossing exists for all single phase faults, this includes:
  - LL, LN, LG, LLG (Va, Vb, Vc, Vab)
- No voltage (current) zero-crossing exists for the LLL fault.
  - LLL (Vpn) See Vpn on the next slide
AC Fault Waveforms

Three Phase Power

- $V_a$
- $V_b$
- $V_c$
- $V_{pn}$
- $V_{ab}$

Voltage

Phase Angle [deg]
NFPA 70E – 2012 ROP

- NFPA 70E 2012 DC Hazards Task Group whose members include:
  - Tom Carpenter, Jim Coady, Gary Dreifuerst, Dan Doan, Lloyd Gordon, Bobby Gray, Mike Hittel, Hugh Hoagland, Greg Leask, Mark Ode, and PK Sen.
**NFPA 70E – 2012 ROP**

- NFPA 70E 2012 DC Hazards Task Group

**Proposal Status**

<table>
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<th>Identification</th>
<th>Result</th>
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<tr>
<td>70E-206 Log #527 EEW-AAA</td>
<td>Accept</td>
</tr>
<tr>
<td>70E-212 Log #530 EEW-AAA</td>
<td>Accept</td>
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<tr>
<td>70E-214a Log #CP11 EEW-AAA</td>
<td>Accept</td>
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<td>70E-230 Log #528 EEW-AAA</td>
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<td>70E-239 Log #531 EEW-AAA</td>
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<td>70E-242 Log #532 EEW-AAA</td>
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<td>70E-243 Log #533 EEW-AAA</td>
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<td>70E-347a Log #CP12 EEW-AAA</td>
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</tr>
<tr>
<td>70E-517a Log #CP16 EEW-AAA</td>
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</table>
The shock protection boundaries identified as Limited, Restricted, and Prohibited Approach Boundaries are applicable to the situation in which approaching personnel are exposed to energized electrical conductors or circuit parts. See Table 130.2(C)(1) for the distances associated with various ac system voltages. Table 130.2(C)(2) shall be used for the distances associated with various dc system voltages.

Currently, the requirement to complete a Shock Hazard Analysis directs the user to Table 130.2(C) to determine the approach distances and appropriate PPE. Table 130.2(C) is not applicable to dc sources since the voltage ranges are listed Phase-to-Phase and phase-to-ground. This proposal will provide the user with another table established by a companion proposal for determination of the appropriate approach boundary for work with exposure to de shock hazards. Existing language is changed to comply with manual of style and readability.
70E-212 Log #530 EEW-AAA Accept

(Table 130.2(C))

Revise text to read as follows:

Table 130.2(C)(1) Approach boundaries to Energized Electrical Conductors or Circuit Parts for Shock Protection For AC Systems (All dimensions are distance from energized electrical conductor or circuit part to employee.)

[Remainder of table unchanged.]

Currently, the requirement to complete a Shock Hazard Analysis directs the user to Table 130.2(C) to determine the approach distances and appropriate PPE. Table 130.2(C) is not applicable to DC sources since the voltage ranges are listed Phase-to-Phase or phase-to-ground. This proposal will provide new numbering for the table as a second table is introduced with a companion proposal and clarifies that is for AC systems. This proposal is companion to other proposals on this subject.
NFPA 70E – 2012 ROP

- 70E-214a Log #CP11 EEW-AAA Accept
- (Table130.2(C)(2) NEW)
- Add a new Table 130.2(C)(2).
- Currently, the requirement to complete a Shock Hazard Analysis directs the user to Table 130.2(C) to determine the approach distances and appropriate PPE. Table 130.2(C) is not applicable to dc sources since the voltage ranges are listed as Phase-to-Phase. This proposal will provide a table for dc sources that have a technical basis described in the paper: “A COMPLETE ELECTRICAL HAZARD CLASSIFICATION SYSTEM AND ITS APPLICATION” by LB Gordon and L Cartelli. The paper was presented at the 2009 IEEE IAS Electrical Safety Workshop. This proposal is a companion to others on the same subject.
- Note: Supporting material is available for review at NFPA headquarters.
Exception No.1: An arc flash hazard analysis shall not be required where all of the following conditions exist:

1. The circuit is rated 240 volts or less.
2. The circuit is supplied by one transformer or dc power source.
3. The transformer or dc power source supplying the circuit is rated less than 125 kVA.

Currently, the exception to conduct an arc flash hazard analysis applies only to AC systems. This proposal will expand the application to DC systems as well.
70E-239 Log #531 EEW-AAA    Accept

(130.3(A)(1))

AC Voltages Levels Between From 50 Volts and Through 600 Volts

Revise text to read as follows:

[Remainder of section unchanged.]

Currently, the requirement to complete an Arc Flash Hazard Analysis using 130.3(A) is not adequate for dc systems. The calculations to determine the Arc Flash Protection Boundary are based on the product of bolted fault current and clearing time in cycles. The evaluation has a basis in the techniques described in Annex D, which are all ac system evaluations. This proposal specifies the application is for ac systems and is companion to other proposals that will provide specific criteria related to dc arc flash exposure. Existing language changed to comply with manual of style and readability.
70E-242 Log #532 EEW-AAA  Reject

DC Voltages Levels Above 50 Volts Through 600 Volts

(1) New 130.3(A)(2) to read as follows:
DC Voltage Levels Above 50 Volts Through 600 Volts. In those cases where detailed arc flash
test analysis calculations are not performed for systems that are above 50 volts through 600
volts, the Arc Flash Protection Boundary shall be 4.0 ft, based on the product of an arc duration
of 0.25 sec with an available bolted fault current of 25 kA or any combination not exceeding 6250
ampere-seconds. Where the product of the clearing time and bolted fault current exceeds 6250
ampere-seconds, the Arc Flash Protection Boundary shall be calculated.

Informational Note No.1: DC arc flash is a recognized hazard that is difficult to analyze.
Researchers are working on this hazard, and up to date information can be obtained at the

Informational Note No.2: See Annex D for best available methods of calculation.

(2) Renumber existing 130.3(A)(2) to 130.3(A)(3)
Currently, the requirement to complete an Arc Flash Hazard Analysis using 130.3(A) is not
adequate for dc systems. As a technical substantiation, this proposal uses information contained
in the attached papers:
by DR Doan; by RF Ammerman et. al.; and by C. Keyes and C. Maurice.

This approach to DC arc flash analysis is used currently in Canada to establish protection schemes
for workers potentially exposed to DC arc flash hazards. The informational notes will provide an
explanation that until more accurate testing can be accomplished, the best available theoretical
modeling is provided to aid the user in attempting to protect the worker adequately. A companion
proposal will place alternate calculation methods in Annex D.
AC and DC Voltage Levels above 600V [Remainder of section unchanged.]

Currently, the requirement to complete an Arc Flash Hazard Analysis using 130.3(A) is not adequate for dc systems. The calculations to determine the Arc Flash Protection Boundary are based on the product of bolted fault current and clearing time in cycles. The evaluation has a basis in the techniques described in Annex D, which are all ac system evaluations. This proposal specifies the application is for ac systems and is companion to other proposals that will provide specific criteria related to dc arc flash exposure.

The committee action on Proposal 70E-237 has removed the voltage based provision for arc flash calculation.
NFPA 70E – 2012 ROP

- 70E-347a Log #CP12 EEW-AAA Accept
- (Table 130.7(C)(9)(2) New)
- Renumber existing Table 130.7(C)(9) as Table 130.7(C)(9)(1) and add a new Table 130.7(C)(9)(2)
- There is no information for dc hazards in the standard which gives usable guidance. This proposal provides tasks associated with dc hazards using the best available technical information as shown in referenced documents. This following technical papers were used in developing this table:
  - 1. DC Arc Models and Incident Energy Calculations Copyright Material IEEE Paper No. PCIC-2009-7
  - 3. DC Arc Hazard Assessment Phase II Copyright Material Kinectrics Inc. Report No. K-012623-RA-0002-R00
 NFPA 70E – 2012 ROP

- 70E-517a Log #CP16 EEW-AAA Accept
- (Annex D.10 New)
- Add a new Annex D.10: DC Incident Energy Calculations
- There is no information for dc hazards in the standard which gives usable guidance. This proposal provides tasks associated with dc hazards using the best available technical information as shown in referenced documents. This following technical papers were used in developing this table:
  - 1. DC Arc Models and Incident Energy Calculations Copyright Material IEEE Paper No. PCIC-2009-7
  - 3. DC Arc Hazard Assessment Phase II Copyright Material Kinectrics Inc. Report No. K-012623-RA-0002-R00