DC Arc Flash

Lesley Varga, P.E.
President
Quality Standby Services, LLC
E-mail: lesley@qualitystandbyservices.com
Agenda

- Where are we on DC Arc Flash?
- How to Calculate DC Arc Flash (NFPA 70E 2018)
- A Technique for Analyzing Hazards and Risks
NFPA 70E-2018

- NFPA 70E: Standard for Electrical Safety in the Workplace
  - “best practices”
- Article 130 covers arc flash hazards (AC and DC)
- Article 320 Safety Requirements Related to Batteries and Battery Rooms
- Annex D Incident Energy and Arc Flash Boundary Calculation Methods
  - D.5 Direct Current Incident Energy Calculations
Article 130.4 Shock Risk Assessment
  ◦ >50 VDC per Table 130.4(D)(b)

Article 130.5 Arc Flash Risk Assessment
  ◦ Likelihood of occurrence
  ◦ Assess arc flash using tables (category) or calculation method (either not both)
  ◦ Frequency
    ◦ Assess when new
    ◦ Every major upgrade or every 5 years
  ◦ Labeling requirements (also see Article 320)
Article 130.7 Personal and Protective Equipment

- PPE Category Method
- Determine likelihood of occurrence, Table 130.5(C)
- Determine Arc Flash Category & Boundary, Table 130.7(C)(15)(b)
  - Battery voltage and SS current must be in the table
  - If not, use IE calculation Annex D method
- If above tables are utilized, can use Table 130.7(C)(15)(c) for PPE Selection
  - Otherwise perform the IE calculation Annex D and use Table 130.5(G) for PPE selection
NFPA 70E–2018 (Continued)

- Article 320
  - Signage
    - Arc Flash
    - Shock
    - Thermal
    - Chemical
  - Electrolyte Safety
    - If not handling electrolyte – Safety Glasses only
Annex D

- Calculations for DC arc flash
- Very conservative
- Based on worst case theory
Battery related arc flash

- Not traditionally an issue
- Documented cases?
  - Confusion with large shorts resulting in molten metal
- Many users ignore risk completely
- Users who abide by NFPA 70E often overprotect which results in other safety issues
- Guidance in NFPA 70E is very conservative
  - Limited test data available
PPE Flow Chart for Battery Work proposed by Stationary Battery Committee

Notes:
1. Arc flash and shock PPE may be required to put the battery in a segmented state. The battery must also be isolated from the system.
2. This only applies if the technician cannot reasonably reach across more than 100 volts or if the exposed parts are protected so the technician cannot touch across more than 100 volts.
3. If the battery terminals are more than 6 feet apart, or if at least one of the terminals is protected, arc flash hazard PPE is not required with respect to the battery terminal risk.
4. There may be additional procedures that can be implemented that would further reduce the arc flash hazard and required PPE.

From IEEE Std. 1187–2013
IEEE Std. 1657–2018
70E Annex D.5 DC Incident Energy Calculation

Arc Flash Calculations for Exposures to DC Systems
Copyright Material IEEE
Paper No. ESW2007-19

Daniel R. Doan, PE
Sr. Member IEEE
DuPont Engineering
PO Box 80723
Wilmington, DE 19880 USA
doan@ieee.org

Abstract – Electrical systems with AC voltage have been shown to exhibit arc flash incident energy during faults. Are there arc flash hazards related to DC systems, such as battery banks for UPS or drives, or DC buses used in chemical processes? Methods are available to estimate arc flash energy of AC exposures, but not DC. This paper will show the basic equations for maximum power from a DC arc, and the resulting estimated arc flash incident energy. Research is required to find accurate values, but until research is completed, these equations can help the engineer provide a preliminary estimate of the thermal energy values for applying protective clothing for these exposures.

environment. All these variables make it difficult to estimate the true arc flash energy exposure for a worker.

II. BASIC EQUATIONS

A DC system can be modeled as shown in Figure 1. The source can be simply modeled as a system voltage and impedance. To begin an estimate, it is necessary to make some assumptions. During the arc we can work under the assumption of a steady state of current, so that we can use the resistance of the system and the resistance in the arc for calculations. Any inductance in the system would tend to
Maximum Power Method:

- This method is based on the concept that the maximum power possible in a dc arc will occur when the arcing voltage is \( \frac{1}{2} \) the system voltage.
- Applies to dc systems up to 1000V.
- “…this calculation is conservatively high in estimating the arc flash value.”
DC Arc Flash Incident Energy

\[ IE = 0.01 \times V_{sys} \times I_{arc} \times T_{arc}/D^2 \]

- \( V_{sys} \) = system voltage, nominal
- \( I_{arc} = 0.5 \times I_{bf} \)
  - \( I_{bf} \) = bolted fault current = battery short circuit
- \( T_{arc} \) = arcing time; 2 sec, Table 130.7(C)(15)(b)
- \( D \) = working distance, cm; 18”, Table 130.7(C)(15)(b)
- Note: for battery cabinets/enclosures multipliers are used (e.g. 3x)
Short Circuit Current

- Obtain the battery short circuit current from the battery manufacturer
- Annex D.5.3: A conservative approach...is to assume the maximum short circuit current is 10 X the 1 minute rate (to 1.75 vpc at 25 °C) of the battery

\[ I_{arc} = 0.5 \times I_{ss} \ (I_{bf}) \]
DC ARC FLASH: 125V, 1300 AMP-HOUR BATTERY

DATE: May 11, 2017
REPORT NO.: TEST-17-051

AUTHOR: J. G. Hildreth – TEST-MODA

Assisted By:
D.J. Fujita – TEST-MODA
D.J. Mullen – TEST-MODA
P.C. Anderson – TEST-MODA

REVIEWED BY:
S. Khem – TEST-MODA
Safety Switch w/Fuses

Battery Voltage Measurement

Shunt O'scope Current Measurement

Recloser used to initiate Fault

800A Main CB, shunt trip to interrupt fault

Added Inductance

High speed camera

Arc Voltage Measurement

Arc in a Box Set up

Calorimeters to measure Incident Energy

Battery Bank, 125VDC, 1300 Ah

From Bonneville Power Authority
Test -17-051
DC Arc Flash

Figure 1 – Arc Flash Circuit Configuration.
Battery
The power source for this series of tests consists of a battery bank made up of flooded lead acid batteries. The battery, one of the largest used at BPA, was removed from service at Raver substation. It has a rating of 125V and 1,300 ampere-hours. Its short circuit capacity is 11,000A. The manufacturer is C&D. The battery was installed in a standard 40-foot shipping container equipped with active ventilation and a hydrogen gas monitor.
## Table 1 - (continued) – Summary of Test Results

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Description</th>
<th>Voltage (Vdc)</th>
<th>Gap (inch)</th>
<th>No-Ox</th>
<th>Fuse Wire</th>
<th>Duration (s)</th>
<th>Self Extinguish</th>
<th>Peak Current (A)</th>
<th>Mean Arcing Current (A)</th>
<th>Energy (Cal/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Vertical Rod-to-Rod Gap</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Arc between copper rods</td>
<td>125</td>
<td>0.25</td>
<td>N</td>
<td>4 #24</td>
<td>0.338</td>
<td>Y</td>
<td>5344</td>
<td>3098</td>
<td>0.46</td>
</tr>
<tr>
<td>39</td>
<td>Arc, Repeat with 2 fuse wires</td>
<td>125</td>
<td>0.25</td>
<td>N</td>
<td>2 #24</td>
<td>0.165</td>
<td>Y</td>
<td>?</td>
<td>?</td>
<td>0.18</td>
</tr>
<tr>
<td>40</td>
<td>Arc, same as #39</td>
<td>125</td>
<td>0.25</td>
<td>N</td>
<td>2 #24</td>
<td>0.249</td>
<td>Y</td>
<td>4606</td>
<td>3336</td>
<td>0.35</td>
</tr>
<tr>
<td>41</td>
<td>Arc, same as #39</td>
<td>125</td>
<td>0.25</td>
<td>N</td>
<td>2 #24</td>
<td>0.267</td>
<td>Y</td>
<td>4493</td>
<td>3269</td>
<td>0.35</td>
</tr>
<tr>
<td>42</td>
<td>Arc, same as #39</td>
<td>125</td>
<td>0.25</td>
<td>N</td>
<td>2 #24</td>
<td>0.274</td>
<td>Y</td>
<td>4645</td>
<td>3275</td>
<td>0.43</td>
</tr>
<tr>
<td>43</td>
<td>Arc, added no-ox, #22 wire</td>
<td>125</td>
<td>0.25</td>
<td>Y</td>
<td>2 #22</td>
<td>0.004</td>
<td>Y</td>
<td>3480</td>
<td>1912</td>
<td>0.00</td>
</tr>
<tr>
<td>44</td>
<td>Arc, same as #43</td>
<td>125</td>
<td>0.25</td>
<td>Y</td>
<td>2 #22</td>
<td>0.026</td>
<td>Y</td>
<td>4094</td>
<td>1800</td>
<td>0.04</td>
</tr>
<tr>
<td>45</td>
<td>Arc, single #16 fuse wire</td>
<td>125</td>
<td>0.25</td>
<td>Y</td>
<td>1 #16</td>
<td>0.054</td>
<td>Y</td>
<td>6064</td>
<td>2998</td>
<td>0.07</td>
</tr>
<tr>
<td>46</td>
<td>Arc, same as #45</td>
<td>125</td>
<td>0.25</td>
<td>Y</td>
<td>1 #16</td>
<td>0.297</td>
<td>Y</td>
<td>6156</td>
<td>3234</td>
<td>0.24</td>
</tr>
<tr>
<td>47</td>
<td>Arc, same as #45</td>
<td>125</td>
<td>0.25</td>
<td>Y</td>
<td>1 #16</td>
<td>0.308</td>
<td>Y</td>
<td>6098</td>
<td>3151</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td><strong>Bolted Fault</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>Bolted Fault</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.015</td>
<td>N/A</td>
<td>7814</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>49</td>
<td>Bolted Fault</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.015</td>
<td>N/A</td>
<td>7850</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td><strong>Installed Actual DC Panel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Arc, smallest gap (0.9&quot;)</td>
<td>125</td>
<td>0.9</td>
<td>N</td>
<td>1 #16</td>
<td>0.011</td>
<td>Y</td>
<td>6177</td>
<td>3223</td>
<td>0.00</td>
</tr>
<tr>
<td>51</td>
<td>Arc, repeat #50</td>
<td>125</td>
<td>0.9</td>
<td>N</td>
<td>1 #16</td>
<td>0.009</td>
<td>Y</td>
<td>6124</td>
<td>3590</td>
<td>0.00</td>
</tr>
<tr>
<td>52</td>
<td>Arc, repeat #50</td>
<td>125</td>
<td>0.9</td>
<td>N</td>
<td>1 #16</td>
<td>0.020</td>
<td>Y</td>
<td>6091</td>
<td>1977</td>
<td>0.00</td>
</tr>
<tr>
<td>53</td>
<td>No Arc, steel plate bolted one end</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Steel</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>54</td>
<td>Arc, steel plate bolted one end</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Steel</td>
<td>0.171</td>
<td>Y</td>
<td>6714</td>
<td>4003</td>
<td>0.55</td>
</tr>
<tr>
<td>55</td>
<td>Arc, repeat #54</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Steel</td>
<td>0.162</td>
<td>Y</td>
<td>7375</td>
<td>4470</td>
<td>0.23</td>
</tr>
<tr>
<td>56</td>
<td>Arc, wrench bolted one end</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Wrench</td>
<td>0.342</td>
<td>Y</td>
<td>7231</td>
<td>4813</td>
<td>0.21</td>
</tr>
<tr>
<td>57</td>
<td>Arc, repeat #56</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Wrench</td>
<td>0.266</td>
<td>Y</td>
<td>7231</td>
<td>4813</td>
<td>0.21</td>
</tr>
<tr>
<td>58</td>
<td>Arc, repeat #56</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Wrench</td>
<td>0.518</td>
<td>Y</td>
<td>7216</td>
<td>5298</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>arc re-established itself</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.114</td>
<td>Y</td>
<td>5827</td>
<td>3442</td>
<td>0.03</td>
</tr>
<tr>
<td>59</td>
<td>Arc, screws between bus bars ar</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Screws</td>
<td>0.064</td>
<td>Y</td>
<td>3025</td>
<td>1580</td>
<td>0.03</td>
</tr>
<tr>
<td>60</td>
<td>Arc, repeat #59, bigger screws</td>
<td>125</td>
<td>N/A</td>
<td>N/A</td>
<td>Screws</td>
<td>0.285</td>
<td>Y</td>
<td>7337</td>
<td>4199</td>
<td>0.09</td>
</tr>
</tbody>
</table>
In tests with the actual DC panel, the tool was fixed to one bus bar such that it was touching the other. Once the arc was established, it burned away the bus bar and the end of the tool until there was a sufficient gap to extinguish the arc. The maximum incident energy from this configuration was 0.32 Cal/cm².

**Figure 17** – Wrench Fixed to a Bus Bar in the Panel, Before and After Arc.
The following assumptions are made when estimating the incident energy using Equation 1:

- The distance is 18-inches (45.7 cm)
- System bolted fault current is the maximum short circuit current of the battery, 10.747 A
- Arcing current is 50% of the bolted fault current (maximum power transfer theorem)
- System voltage is the nominal 125 Vdc
- Arcing time is 2 seconds
- A multiplier of 1.6 is applied to the calculated incident energy to account for the enclosure’s tendency to direct the energy.

The resulting incident energy for the above assumptions is 10.3 Cal/cm².
Test Results vs Calculated IE

Figure 3 – Measured Incident Energy versus NFPA Calculated Value
A Technique for Analyzing Hazards and Risks Associated with Battery Systems
Analyzing Hazards and Risks

- Battery System Hazards and Risk Ranking
  - A technique to highlight operations of high hazard and high risk

- Job Hazard Analysis / Job Safety Analysis
  - Assigns hazards and risks rankings for basic steps
  - Identifies steps of highest concern
  - Identifies required PPE

- Examples
Battery Installations: What are the Risks?

- **Shock hazard:**
  - For strings operating at >50 VDC nominal, under normal conditions:
    - It should be presumed that there is an unacceptable risk of injury from shock or thermal hazards (arc flash, electrical burn, or thermal burn) from exposure to energized conductors and circuit parts operating at greater than or equal to 50 volts.

- **Arc flash hazard:**
  - Dependent upon the task
  - The battery positive and negative terminal location
  - Is the string/system grounded
Battery Installations: What are the Risks?

- Chemical hazard
  - Handling of electrolyte (water and sulfuric acid)

- Thermal hazard
  - A burn as a result of a short

- Lifting and handling hazards
  - Material handling equipment and manual efforts
120V Utility Battery System Shock Hazard

Do not connect until final step

Including the bottom tier: 16 cells + 14 cells = 30 cells x 2 VDC = 60VDC

Including the back rack bottom tier = 44 cells total x 2 = 88 VDC

14 cells x 2 V = 28 VDC
240 Cell UPS Wet Cell Battery

8 units x 4 cells = 32 cells x 2V = 64V
Biggest Risk at Positive and Negative
Organize the job tasks

- For each step, identify the hazard that may be encountered
- For each hazard,
  - determine the severity of the hazard
  - determine the risk or likelihood of occurrence
  - determine the PPE required, tools and equipment needed, and other mitigation techniques
## Hazard and Risk Rankings

<table>
<thead>
<tr>
<th>HAZARD SEVERITY RANKING</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Low hazard</td>
<td>Can cause local/temporary irritation</td>
</tr>
<tr>
<td>2 Low to moderate</td>
<td></td>
</tr>
<tr>
<td>3 Moderate hazard</td>
<td>Can cause minor injury, local aid sufficient</td>
</tr>
<tr>
<td>4 Moderate to high</td>
<td></td>
</tr>
<tr>
<td>5 High hazard</td>
<td>Can cause major injury, professional aid required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RISK PROBABILITY RANKING</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Low risk</td>
<td>Unlikely to occur</td>
</tr>
<tr>
<td>2 Low to moderate</td>
<td></td>
</tr>
<tr>
<td>3 Moderate risk</td>
<td>Possible to occur without mitigation</td>
</tr>
<tr>
<td>4 Moderate to high</td>
<td></td>
</tr>
<tr>
<td>5 High risk</td>
<td>Likely to occur without mitigation</td>
</tr>
</tbody>
</table>
### Hazard and Risk Ranking Table

<table>
<thead>
<tr>
<th>Hazard Ranking</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Ranking</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined Ranking</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>16</td>
<td>25</td>
</tr>
</tbody>
</table>

- Combined ranking 1 = low hazard + low risk
- Combined ranking 9 = moderate hazard + moderate risk
- Combined ranking 25 = high hazard + high risk
## Hazard and Risk Ranking Table

<table>
<thead>
<tr>
<th>Battery installation</th>
<th>Hazard ranking</th>
<th>Risk ranking</th>
<th>Combined ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical hazard - electric shock</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Heavy lifting - physical injury</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Drop hazard - physical injury</td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Equipment hazard - forklift safety</td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Equipment hazard - ladder safety</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Electrical hazard - arc flash incident</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Chemical hazard - acid spill in eyes</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Chemical hazard - acid spill on skin</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
A Job Hazard Analysis, "JHA" is a process of taking a critical look at the basic steps of a job to identify the hazards. Once the hazards are identified, implement methods to eliminate or reduce to an acceptable risk level.
Basic Process of JHA

- Step One: Select the job/ task
- Step Two: Breakdown the job into successive basic steps
- Step Three: Identify the hazards and likelihood of occurrence in each step
- Step Four: Eliminate or reduce the hazards
EXAMPLE VLA (Wet Cell) 120VDC, 60 Cell Installation

470 AH battery
Short circuit = 5,620 Amps
Arc Flash PPE – Calculation

- 120VDC, 470 Ampere hour battery system
  - Short circuit provided by the manufacturer: 5,620 amps

- The Job is installing a new string, while this task is not directly listed in NFPA 70E Table 130.5 (C), it can be assumed there is a potential risk of arc flash

- Using PPE Category Method:
  - Table 130.7(C)(15)(b) shows Arc Flash PPE category 2 is required
  - Table 130.7(C)(15)(c) shows category 2 = 8 cal/cm²
DC Incident Energy (IE) Calculation

- Battery short circuit current: 5,620 amps
- \( I_{sc} = 5,620 \text{ amps} \), where \( I_{arc} = I_{sc}/2 = 2,810 \text{ Amps} \)
- \( V_{sys} = 120 \text{ VDC} \)
- \( D = 18" \text{, 45.72 cm} \)
- \( T = 2 \text{ sec} \)

\[
IE = 0.01 \times V_{sys} \times I_{arc} \times T_{arc}/D^2
\]

\[
IE = .01 \times 120 \times 2,810 \times .0009567 = 3.2 \text{ cal/cm}^2
\]
**DC Incident Energy (IE) Calculation**

- Using Battery 1 Minute Rate (594A) to 1.75vpc =
  - 5,940 amps
- $I_{sc} = 5,940$ amps, where $I_{arc} = I_{sc}/2 = 2,970$ Amps
- $V_{sys} = 120$ VDC
- $D = 18", 45.72$ cm
- $T = 2$ sec
- $IE = 0.01 \times V_{sys} \times I_{arc} \times T_{arc}/D^2$

$IE = 0.01 \times 120 \times 2,970 \times 0.0009567 = 3.4$ cal/cm²
Arc Rated Clothing and PPE

- Per Category Method, Table 130.7(C)(15)(c) specifies minimum arc rated clothing of 8 cal/cm².

- Per IE Analysis Method, Table 130.5(G), select: 1.2 to 12 cal/cm² section:

- Arc rated clothing and equipment greater or equal to the determined incident energy (≥ 3.2 cal/cm²).
Standard PPE

- Safety glasses with side shields
- Safety shoes
- Eye wash device or station
- Acid neutralizer
- Insulated tools
- Leather gloves
- FR long sleeve shirt and pants
- Calibrated instruments
Electrically rated gloves and blankets when shock hazard exists
Proper arc flash rated PPE when arc flash hazard exists
Acid resistant apron and gloves, face shield and/or goggles when chemical hazard exists
VLA (Wet Cell) 120VDC, 60 Cell Installation

Job Hazard Analysis Basic Steps:

- Receive battery and rack
- Transport to installation location
- Assemble rack
- Load cells onto rack
- Assemble battery hardware
- Terminate charger to battery
- Data gather for initial installation
## Receive battery and rack

<table>
<thead>
<tr>
<th>Basic steps</th>
<th>Potential Hazards</th>
<th>Hazard Ranking (how bad)</th>
<th>Risk Ranking (how likely)</th>
<th>Combined Ranking</th>
<th>Safe job procedures, Mitigation &amp; PPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unload delivery truck/pallet movement</td>
<td>Injury due to forklift or pallet jack</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>Forklift and/or pallet operating safety training, spill response kit/means available, Std. PPE</td>
</tr>
<tr>
<td>Inspection of equipment</td>
<td>Trip hazard</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Precautions based upon any visible damage, Std. PPE</td>
</tr>
<tr>
<td></td>
<td>chemical hazard from leaking electrolyte</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>+ Chemical PPE if needed</td>
</tr>
</tbody>
</table>
## Complete Rack & Load Cells

<table>
<thead>
<tr>
<th>Basic steps</th>
<th>Potential Hazards</th>
<th>Hazard Ranking (how bad)</th>
<th>Risk Ranking (how likely)</th>
<th>Combined Ranking</th>
<th>Safe job procedures, Mitigation &amp; PPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground rack</td>
<td>Airborne particles</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Utilize dust mask for buffing paint (at rack ground location), proper tool use, Std. PPE</td>
</tr>
<tr>
<td>Unpack cells &amp; prep for install</td>
<td>Injury due to mechanical hazards</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>Maintain body positioning and footing; maintain awareness of surrounding, Std. PPE, spill response available</td>
</tr>
<tr>
<td>Install/load new cells onto rack</td>
<td>Injury due to drop and lifting</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>Maintain body positioning and footing; verify lifting equipment is of adequate rating and maintained; follow manufacturer’s instructions, Std. PPE</td>
</tr>
<tr>
<td></td>
<td>Chemical hazard due to electrolyte</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>+ Chemical PPE, spill response available</td>
</tr>
</tbody>
</table>
## Installation of Cells

<table>
<thead>
<tr>
<th>Basic steps</th>
<th>Potential Hazards</th>
<th>Hazard Ranking (how bad)</th>
<th>Risk Ranking (how likely)</th>
<th>Combined Ranking</th>
<th>Safe job procedures, Mitigation &amp; PPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean cell posts, apply no-ox grease</td>
<td>Chemical exposure</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Follow manufacturer’s instructions, see no-ox-id grease Safety Data Sheet (SDS), Std. PPE + Chemical PPE, appropriate gloves</td>
</tr>
<tr>
<td>Install new battery connectors and hardware</td>
<td>Electrical hazard: shock and/or thermal</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>Follow mfg. instructions, Std. PPE, work on cell groups &lt;50VDC, appropriate gloves. Leave connection open between cell groups.</td>
</tr>
<tr>
<td>Torque the connections</td>
<td>Electrical hazard: shock and/or thermal</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>Utilize insulated tools, follow mfg. instructions, Std. PPE, work on cell groups &lt;50VDC</td>
</tr>
<tr>
<td>Terminate and torque the inter-tier and inter-rack cables &amp; connectors</td>
<td>Electrical hazard: shock and arc flash</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>Required PPE per IE calculation (arc rating $\geq 3.2 \text{ cal/cm}^2$), utilize protective blankets to terminate one connection at a time</td>
</tr>
</tbody>
</table>
# Terminate Battery to Charger

<table>
<thead>
<tr>
<th>Basic steps</th>
<th>Potential Hazards</th>
<th>Hazard Ranking (how bad)</th>
<th>Risk Ranking (how likely)</th>
<th>Combined Ranking</th>
<th>Safe job procedures, Mitigation &amp; PPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obtain connection resistance readings to verify proper torque</td>
<td>Electrical hazard: shock</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>Follow instructions, proper use of digital low resistance ohmmeter (DLRO), Std. PPE, appropriate gloves</td>
</tr>
<tr>
<td>Obtain open circuit voltage of each cell</td>
<td>Electrical hazard: Shock</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>Proper use of DMM, Std. PPE, appropriate gloves</td>
</tr>
<tr>
<td>Terminate positive and negative cables (feeders) from charger</td>
<td>Electrical hazard: shock and arc flash</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>Verify LOTO on de-energized charger, verify DC output breaker of charger open, verify voltage polarity, PPE per IE calculation (arc rating &gt; 3.2 cal/cm², utilize protective blankets</td>
</tr>
</tbody>
</table>
Conclusion

- Stationary batteries are used throughout our industrial world
- There are hazards associated with stationary batteries
- Every installation should be evaluated for potential hazards, risks and likelihood of occurrence
- Information concerning the risks should be provided and/or posted with the battery installation
- Work on battery systems should be performed by knowledgeable personnel with proper training, tools and PPE
Thank you

Lesley Varga, P.E.
President
Quality Standby Services, LLC
Standby Power Products for the Telecom, UPS and Utility Applications

Engineer and Furnish
- All battery types
- Chargers and ancillary equipment
- Battery Monitors

Application and System Design
- Registered Electrical PE
- Electrical Contractor License

Field Services
- Installation Services
- Start-up Service and Inspection
- Battery Testing
- Maintenance Contracts
- Battery Disposal
- 24 Hour Emergency Service