POWER QUALITY & RELIABILITY SEMINAR

10:30 a.m. - 11:30 a.m.: The Electrical Environment: Common Levels of Power Quality

Noon-1p.m.: Case Studies

Alden Wright, PE, CEM, CP EnMS
EPRI Industrial PQ and EE Group
The Electrical Environment: Common Levels of Power Quality

▪ What level of PQ performance is “normal” for various power systems? How does the power system performance vary by voltage class?

▪ This session will cover:
  – Benchmarking studies and look at how to apply the results of the study to better understand common Power Quality levels
  – Relevant power quality standards and the need for cooperation between the utility and the end user to solve power quality issues
  – Susceptibilities of various commercial and industrial equipment to voltage sags and various solution approaches will be presented including embedded, control, machine, process, and plant level.
  – Example Mitigation Solutions
# Power Quality

(IEEE 1159 Defines)

- **Transients**
  - Impulse
  - Oscillatory
  - Irregular

- **Short Duration Variations**
  - Sags/Swells
  - Interruptions

- **Long Duration Variations**
  - Under voltage
  - Overvoltage
  - Interruptions

- **Unbalance**

- **Waveform Distortion**
  - Harmonics

- **Voltage Fluctuations**
Sustained Interruption (Outage)

Typical Duration: > 1 Minute

Typical Magnitude: 0.0 pu

pu = per unit (1 pu = nominal)
Momentary Interruption

Typical Duration:  0.5 cycles – 3 s (180 cyc.)
Typical Magnitude:  < 0.1 pu

HIOKI 3196 Event Data, 3 cycle Interruption

SAMPLE03  April 22, 1994 at 09:32:13 PQNode Local
Phase C Voltage
RMS Variation

Duration
5.167 Sec
Min 0.141
Ave 5.273
Max 100.5
Ref Cycle 26553
# Voltage Sag Common Depths and Durations

<table>
<thead>
<tr>
<th></th>
<th>Typical Duration</th>
<th>Typical Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instantaneous</strong></td>
<td>0.5 – 30 cycles</td>
<td>0.1 - 0.9 pu</td>
</tr>
<tr>
<td><strong>Momentary</strong></td>
<td>30 cycles - 3 s</td>
<td>0.1 - 0.9 pu</td>
</tr>
<tr>
<td><strong>Temporary</strong></td>
<td>3 s - 1 min</td>
<td>0.1 - 0.9 pu</td>
</tr>
</tbody>
</table>

**HIOKI 3196 Event Data**
- 3 cycle, 0.8 pu
- 3 cycle, 0.5 pu
Why Voltage Sags Occur...

- Line-to-Ground/Line-to-Line Faults Occur on the Utility System due to:
  - Weather
  - Trees
  - Public Interference
- Internally induced plant events (starting of large high inrush load)
- Although the utility can reduce the number of events (tree trimming, root cause analysis), it is impossible to eliminate all voltage Sags.
Voltage Sag Caused by Starting a Large Motor
Voltage Sags Caused by Faults

![Diagram showing voltage sags caused by faults]

- **F**: Voltage source
- **M1**: Fault location
- **M2**: Fault cleared
- **K**: Fault impedance
- **Large Fault Current**: Current during fault
- **70% Sag**: Voltage sag at 70% of nominal voltage
- **50% Sag**: Voltage sag at 50% of nominal voltage

**Line Segment Impedance**: Impedance along the线路 segment

**Source Impedance**: Impedance from the source

**Return Impedance**: Impedance returning to the source

**Distance from Voltage Source (miles)**: Measurement of distance along the lines.
Graduation Mylar Balloons

Can be Seasonal

Bird Migration
Locations Where Animal Faults Occur

Data source: EPRI TE-114915

- Transformers
- Phase-to-neutral contacts
- Jumper wires contacts
- Reclosers
- Surge arresters
- Cutouts
- Phase-to-phase conductor contacts
- Potheads at riser locations
- Pole-top ground wires
- Regulators
- Grounded pole-top hardware
- Insulator contamination
- Switchgear
- Breakers
- Conductor jumping
- Capacitors
- Sectionalizers
- Unknown
- Structural failure

Percentage of utilities listing the item as a top-five outage-frequency problem
RMS Variation Event Rate Duration—System-wide All Sites, One-minute Temporal Aggregation, Events per Site per 30 Days

RMS Event Rate Duration Column Chart - System Wide
From 1/1/2009 through 12/31/2012

<table>
<thead>
<tr>
<th>Duration</th>
<th>Events per Site per 30 Days</th>
<th>Cumulative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 1 c</td>
<td>1 to 2 c</td>
</tr>
<tr>
<td>Events</td>
<td>0.018</td>
<td>0.497</td>
</tr>
<tr>
<td>site per</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative Frequency</td>
<td>0.005</td>
<td>0.127</td>
</tr>
</tbody>
</table>
RMS Variation Event Rate Magnitude—System-wide All Sites, One-minute Temporal Aggregation Events per Site per 30 Days

RMS Event Rate Voltage Magnitude Column Chart - System-Wide
From 1/1/2009 through 12/31/2012

<table>
<thead>
<tr>
<th>Voltage Magnitude (%)</th>
<th>Events per Site per 30 Days</th>
<th>Cumulative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0.05</td>
<td>0.09</td>
<td>2%</td>
</tr>
<tr>
<td>0.05 to 0.10</td>
<td>0.22</td>
<td>7%</td>
</tr>
<tr>
<td>0.10 to 0.15</td>
<td>0.03</td>
<td>8%</td>
</tr>
<tr>
<td>0.15 to 0.20</td>
<td>0.03</td>
<td>9%</td>
</tr>
<tr>
<td>0.20 to 0.25</td>
<td>0.04</td>
<td>10%</td>
</tr>
<tr>
<td>0.25 to 0.30</td>
<td>0.05</td>
<td>11%</td>
</tr>
<tr>
<td>0.30 to 0.35</td>
<td>0.05</td>
<td>12%</td>
</tr>
<tr>
<td>0.35 to 0.40</td>
<td>0.06</td>
<td>13%</td>
</tr>
<tr>
<td>0.40 to 0.45</td>
<td>0.08</td>
<td>15%</td>
</tr>
<tr>
<td>0.45 to 0.50</td>
<td>0.10</td>
<td>17%</td>
</tr>
<tr>
<td>0.50 to 0.55</td>
<td>0.11</td>
<td>19%</td>
</tr>
<tr>
<td>0.55 to 0.60</td>
<td>0.13</td>
<td>22%</td>
</tr>
<tr>
<td>0.60 to 0.65</td>
<td>0.15</td>
<td>25%</td>
</tr>
<tr>
<td>0.65 to 0.70</td>
<td>0.20</td>
<td>29%</td>
</tr>
<tr>
<td>0.70 to 0.75</td>
<td>0.28</td>
<td>33%</td>
</tr>
<tr>
<td>0.75 to 0.80</td>
<td>0.38</td>
<td>40%</td>
</tr>
<tr>
<td>0.80 to 0.85</td>
<td>0.65</td>
<td>50%</td>
</tr>
<tr>
<td>0.85 to 0.90</td>
<td>1.39</td>
<td>66%</td>
</tr>
</tbody>
</table>

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Sag and Interruption Rates per 365 Days
Sag to Interruption Ratio

Events at Various Voltage Sag Ranges for Each Voltage Classification

<table>
<thead>
<tr>
<th>Voltage Classifications</th>
<th>Count Per Site Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>45</td>
</tr>
<tr>
<td>Trans</td>
<td>23</td>
</tr>
<tr>
<td>Sub-T</td>
<td>41</td>
</tr>
<tr>
<td>Distr</td>
<td>52</td>
</tr>
<tr>
<td>Low V</td>
<td>53</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>365 Days</th>
<th>All Voltages</th>
<th>Voltage Classifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranges</td>
<td>Overall</td>
<td>Trans</td>
</tr>
<tr>
<td>V&lt;10%</td>
<td>3.4</td>
<td>3.0</td>
</tr>
<tr>
<td>10%&lt;V&lt;90%</td>
<td>45.0</td>
<td>23.0</td>
</tr>
<tr>
<td>V&lt;90%</td>
<td>48.5</td>
<td>26.0</td>
</tr>
<tr>
<td>Sag/Int Ratio</td>
<td>13</td>
<td>8</td>
</tr>
</tbody>
</table>
SARFI

- System Average RMS (Variation) Frequency Index
- Typically normalized to per site/per year data
- Basically a count of how many events fall below a threshold over a period
- Provides a benchmarking measure to understand power quality performance at a site

\[
SARFI_x = \frac{\sum N_i}{N_T}
\]
# TPQ-DPQ III SARFI Results

<table>
<thead>
<tr>
<th>TPQ-DPQ III</th>
<th>SARFI-CBEMA</th>
<th>SARFI-ITIC</th>
<th>SARFI-SEMI</th>
<th>SARFI-90</th>
<th>SARFI-70</th>
<th>SARFI-50</th>
<th>SARFI-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trans</td>
<td>10.7</td>
<td>8.4</td>
<td>6.6</td>
<td>22.8</td>
<td>6.4</td>
<td>4.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Sub-T</td>
<td>14.6</td>
<td>9.9</td>
<td>7.0</td>
<td>35.3</td>
<td>9.1</td>
<td>5.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Dist</td>
<td>23.3</td>
<td>17.4</td>
<td>11.6</td>
<td>52.2</td>
<td>16.2</td>
<td>8.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Low V</td>
<td>29.8</td>
<td>24.8</td>
<td>18.2</td>
<td>53.0</td>
<td>23.3</td>
<td>14.4</td>
<td>5.9</td>
</tr>
</tbody>
</table>
How Common are Sags and Interruptions?

**Key Results of EPRI TPQ-DPQ III Study**

- The ratio of sags to interruptions found in the DPQ III study based upon circuit type:
  - Transmission: 8 to 1 (high – due to Bad Weather in 2009-2012 time frame)
  - Sub-Transmission: 20 to 1
  - Distribution: 15 to 1
  - Low Voltage: 8 to 1
- Average distribution fed customer site is 15 times more likely to experience a voltage sag than a sustained interruption or momentary interruption.
How many phases “sag”?

Number of Phases Below 90% - System Wide
in percent of total number 60-second aggregate sag and interruption events

- Three Phases: 20%
- Two Phases: 27%
- One Phase: 53%

Ref: EPRI TPQ-DPQ III Study, June 2014
Effects of Voltage Sags

- Lights may or may not flicker
- Equipment shutdown or malfunction
- Can result in production downtime and/or product loss

For every 1 momentary interruption a customer will see 8 to 20 voltage sags (EPRI TPQ-DPQ III Study)
Who’s “Fault” is it?

Tolerance and Protection Curves with PQ Data Overlay

EPRI

PQ Investigator

Potter & Brumfield, KRPA, KRPA-14AN-120, 120 VAC, 60Hz

Allen Bradley, PLC 5/11, 1765-L115/E, 120 Volts Nominal, 60Hz

Site - 5 Min Aggregation, 5 Min Aggregation [8/22/2009 9:32:00 AM - 10/28/2010 3:40:23 AM]
Why is PQ Important - Impacts

- What happens to a manufacturing process when a power quality problem occurs?
- Who is to blame?
- How do we work together to fix the problems?
### Example Reported Per Event Cost of PQ Disturbance

<table>
<thead>
<tr>
<th>No.</th>
<th>Process</th>
<th>Reported Cost</th>
<th>Service Voltage</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Semiconductor</td>
<td>$1,500,000</td>
<td>69 kV</td>
<td>25 MW</td>
</tr>
<tr>
<td>2</td>
<td>Semiconductor</td>
<td>$1,400,000</td>
<td>161 kV</td>
<td>30 MW</td>
</tr>
<tr>
<td>3</td>
<td>Semiconductor</td>
<td>$700,000</td>
<td>12.5 kV</td>
<td>10 MW</td>
</tr>
<tr>
<td>4</td>
<td>Metal Casting</td>
<td>$200,000</td>
<td>13.8 kV</td>
<td>16 MW</td>
</tr>
<tr>
<td>5</td>
<td>Chemical Plant</td>
<td>$160,000</td>
<td>12.5 kV</td>
<td>5 MW</td>
</tr>
<tr>
<td>6</td>
<td>Pulp and Paper Mill</td>
<td>$110,000</td>
<td>161 kV</td>
<td>100 MW</td>
</tr>
<tr>
<td>7</td>
<td>Aerospace Engine Machining</td>
<td>$100,000</td>
<td>13.8 kV</td>
<td>10 MW</td>
</tr>
<tr>
<td>8</td>
<td>Food and Beverage</td>
<td>$87,000</td>
<td>12.5 kV</td>
<td>5 MW</td>
</tr>
<tr>
<td>9</td>
<td>Chemical Plant</td>
<td>$75,000</td>
<td>66 kV</td>
<td>3 MW</td>
</tr>
<tr>
<td>10</td>
<td>Chemical Plant</td>
<td>$75,000</td>
<td>66 kV</td>
<td>5 MW</td>
</tr>
<tr>
<td>11</td>
<td>Electronic Components</td>
<td>$75,000</td>
<td>12.5 kV</td>
<td>5 MW</td>
</tr>
<tr>
<td>12</td>
<td>Crystal Growth</td>
<td>$60,000</td>
<td>12.5 kV</td>
<td>1 MW</td>
</tr>
<tr>
<td>13</td>
<td>Chemical Plant</td>
<td>$46,175</td>
<td>66 kV</td>
<td>30 MW</td>
</tr>
<tr>
<td>14</td>
<td>Wiring Manufacturing</td>
<td>$34,000</td>
<td>12.5 kV</td>
<td>2 MW</td>
</tr>
<tr>
<td>15</td>
<td>Chemical Plant</td>
<td>$18,000</td>
<td>12.5 kV</td>
<td>2 MW</td>
</tr>
<tr>
<td>16</td>
<td>Fibers Plant</td>
<td>$15,000</td>
<td>12.5 kV</td>
<td>1 MW</td>
</tr>
<tr>
<td>17</td>
<td>Paper and Packaging</td>
<td>$10,000</td>
<td>12.5 kV</td>
<td>4 MW</td>
</tr>
<tr>
<td>18</td>
<td>Plastic Bag Manufacturing</td>
<td>$10,000</td>
<td>480 V</td>
<td>4 MW</td>
</tr>
<tr>
<td>19</td>
<td>Plastics</td>
<td>$7,500</td>
<td>12.5 kV</td>
<td>4 MW</td>
</tr>
<tr>
<td>20</td>
<td>Stainless Steel Manufacturing</td>
<td>$5,500</td>
<td>12.5 kV</td>
<td>2 MW</td>
</tr>
</tbody>
</table>
Important Realization

▪ Utilities Share Responsibility
  – Tree Trimming, Lighting Arrestors, Grounding, Maintenance, Provide PQ information to industrials, etc
  – Circuit patrols, Reviewing customer complaints and device operations, line device settings.

▪ Industrials Share Responsibility
  – Understanding Equipment Vulnerability, Implementing PQ Standards in Purchase Specifications, Power Conditioning, Proper Wiring/Grounding, etc

▪ Most effective solutions are reached when both sides work together to see what can be done
PQ Solution: Specify Voltage Sag Standards in Purchase Specs

- Example Specs
  - SEMI F47
    - From Semiconductor Industry
    - Most control OEMs have compliant hardware
  - IEC 61000-4-11/34
    - Class 3
  - IEEE P1668
IEEE Std. 1668

Recommended Practice for
Voltage Sag and Short
 Interruption Ride-Through
 Testing
 for End-Use Electrical
 Equipment Rated Less than
 1000 V
IEEE Std. 1668 – What is its Purpose?

- IEEE Std. 1668 Recommended Practice for Voltage Sag and Short Interruption Ride-Through Testing for End-Use Electrical Equipment Rated Less than 1000 V
  - Non-industry-specific document
  - All electrical/electronic equipment may be evaluated
    - Response to supply voltage reductions up to 2 seconds
  - Standard provides/defines
    - Clearly defined testing procedures and test equipment requirements for single-phase, two-phase, and three-phase balanced and unbalanced voltage sags
    - Certification and test reporting requirements, including voltage-sag ride-through equipment characterization
IEEE Std. 1668 – Why is it necessary?

- Industrial Process Sensitivity
  - IEEE Std 1157
    - Instantaneous event
  - Momentary event
  - Temporary Event
IEEE Std. 1668 – Why is it necessary?

- Industrial Process Sensitivity
  - IEEE Std 1668
    - Instantaneous event
    - Momentary event
    - Temporary Event

IEEE Std. 1668 – Why is it necessary?

- Industrial Process Sensitivity
  - IEEE Std 1668
    - Instantaneous event
    - Momentary event
    - Temporary Event
IEEE Std. 1668 – Why is it necessary?

- Voltage Sags and brief interruptions disrupt industrial processes
  - Production is interrupted
    - In-process product may become scrap
  - Process equipment may be damaged
  - Downtime may be measured in hours, entire shifts, or days.
    - Monthly production goals and profitability at risk
    - One estimate put losses at $7,000 per MW
IEEE Std. 1668 – Why is it necessary?

- Lights blink → Power Loss!
  - 90% to 10% = Voltage Sag
  - 10% to 0% = Interruption
- Voltage sags → one-, two-, or all three-phases
IEEE Std. 1668 – Why is it necessary?
IEEE Std. 1668 – Why is it necessary?

- IEEE 1668 Draws a “Line in the Sand” for Industries, Electrical Product Manufacturers, and Utility Suppliers

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**Figure 22**—Recommended Type I & Type II test levels

**Figure 23**—Recommended Type III test levels
IEEE Std. 1668 – What is in it?

- 90 Pages front to back.
- Contains a significant amount of newly created content from working group members.
- References existing work from ANSI, CIGRE, EPRI, IEC, IEEE, and SEMI.
- In-depth voltage sag primer included
- Voltage sag characteristics and descriptions built on findings from CIGRE C4.110 working group.
- Voltage sag test levels an extension of SEMI F47 (Type I and Type II) and includes 3-phase (Type III) sags.
- Test Procedures and Guidelines thoroughly documenting various test methodologies and approaches.
- Defines test equipment requirements.
- Defines certification and test report requirements.

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What does IEEE Std. 1668 Accomplish?

- IEEE 1668 provides a Primer On Voltage Sags (Section 4)
- Provides Recommended Voltage Sag Test Levels
  - Users may understand
    - Voltage sags
    - Causes
    - How to assess voltage sag sensitivity
  - How to test and certify equipment
What does IEEE Std. 1668 Accomplish?

- IEEE 1668 provides test vectors to be used in voltage sag testing
  - Type I voltage sags
    - Single phase affected
  - Type II voltage sags
    - Two phases affected
  - Type III voltage sags
    - Three phases affected

### Table 8—Recommended Type I, II, and III voltage-sag classifications [B1]

<table>
<thead>
<tr>
<th>Voltage-sag type</th>
<th>Description[^1]</th>
<th>Vector diagram</th>
<th>Waveform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>This is a voltage sag in which a drop in voltage takes place mainly in one of the phase-to-ground voltages.</td>
<td><img src="image1" alt="Type I Vector Diagram" /></td>
<td><img src="image2" alt="Type I Waveform" /></td>
</tr>
<tr>
<td></td>
<td>( U_a = P )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( U_b = -\frac{1}{2}P - \frac{1}{2}jE \sqrt{3} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( U_c = -\frac{1}{2}P + \frac{1}{2}jE \sqrt{3} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type II</td>
<td>This is a voltage sag in which a drop in voltage magnitude takes place mainly in one of the phase-to-phase voltages.</td>
<td><img src="image3" alt="Type II Vector Diagram" /></td>
<td><img src="image4" alt="Type II Waveform" /></td>
</tr>
<tr>
<td></td>
<td>( U_a = E )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( U_b = -\frac{1}{2}E - \frac{1}{2}jF \sqrt{3} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( U_c = -\frac{1}{2}E + \frac{1}{2}jF \sqrt{3} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type III</td>
<td>This is a voltage sag in which there is a drop in voltage magnitude that is equal for the three voltages.</td>
<td><img src="image5" alt="Type III Vector Diagram" /></td>
<td><img src="image6" alt="Type III Waveform" /></td>
</tr>
<tr>
<td></td>
<td>( U_a = F )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( U_b = -\frac{1}{2}F - \frac{1}{2}jF \sqrt{3} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( U_c = -\frac{1}{2}F + \frac{1}{2}jF \sqrt{3} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[^1]: Where: \( P \) — characteristic voltage of the sag event, \( E \) — pre-sag voltage, and \( U_a, U_b, U_c \) — phase-to-neutral voltages.

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What does IEEE Std. 1668 Accomplish?

- Voltage-sag immunity characterization
  - reveals equipment’s ride-through ability for voltage sags.

- The “voltage-sag tolerance curve”
  - an important tool to understand
    - the equipment and the electric power supply compatibility
What does IEEE Std. 1668 Accomplish?

- IEEE 1668 provides three approaches to characterizing the sensitivity of the Equipment under test (EUT).
  - Top-down Method
  - Left-right Method
  - Box-in Method
    - Typically quickest

- Thus equipment sensitivities may be identified
Use IEEE Std. 1668 in Procurement!

- User may specify the desired equipment immunity in a purchase requisition
  - Specification sheet provided in Table 12 and Table 13 for purchasing three-phase or single-phase equipment
  - Specify equipment immunity
How may IEEE Std. 1668 be used in Procurement?

- Equipment buyer can specify to a system integrator/OEM requirements for voltage-sag immunity.
- System integrator/OEM can use this document to specify voltage-sag immunity requirements to their subsystem and component suppliers.
- More stringent requirements may be referenced from other documents.
How may IEEE Std. 1668 be used in Procurement?

- Equipment, subsystems, components orders should specify:
  - This recommended practice document number and date of publication
  - The requirement for a certificate per Annex C of this document (optional)
  - The requirement for a test report per Annex C of this document (optional)
  - Whether a third-party certificate is required, or whether self-certification is acceptable (optional)
How may IEEE Std. 1668 be used in Procurement?

- Example language:
  - (not part of 1668)

Example Purchase Spec Language*

The equipment provider (Seller) shall provide documentation that proves that the provided equipment is compliant with the IEEE Std. P1668-2017 Recommended Practice for Voltage Sag and Short Interruption Ride-Through Testing for End-Use Electrical Equipment Rated Less than 1000 V. The qualification testing shall be conducted and completed prior to the first scheduled shipment of new products to Buyer. If Seller has conducted the required testing before and can provide a test report to prove compliance, then retesting shall not be required. Such testing shall occur, at the option of Buyer, either at Seller’s facility or on the premises of Buyer and shall be at the expense of the Seller. Qualification testing shall determine the acceptability of the equipment in accordance with the IEEE 1668 specifications and shall be conducted in accordance with the procedures outlined in the standard. In addition to the test results, the Seller must clearly document the test method and test equipment used for creating voltage sags per Annex C of IEEE 1668. Upon written agreement of Seller and Buyer that the qualification tests have been successfully completed, the initial deliveries of production unit(s) of the equipment shall commence in accordance with the scheduled shipment established by issued Purchase Orders.

* Not part of IEEE Std. 1668 – Offered here as an Example
How may IEEE Std. 1668 be used in Procurement?

- Example language:
  - (not part of 1668)

Example Purchase Spec Language*

Requirements for Single-Phase Equipment from Seller: Single-phase powered equipment shall comply with the Type I voltage sag immunity requirements defined by IEEE 1668 shown in Figure 1. The acceptable pass/fail criteria for single-phase equipment shall be “Full Operation”.

* Not part of IEEE Std. 1668 – Offered here as an Example
How may IEEE Std. 1668 be used in Procurement?

- Example language:
  - (not part of 1668)

**Example Purchase Spec Language**

*Requirements for Three-Phase Equipment from Seller:* Three-phase powered equipment shall comply with the single-phase (Type I) and two-phase (Type II) voltage sag immunity requirements defined by IEEE 1668 as shown in Figure 2. The acceptable pass/fail criteria for the Type I and Type II tests on the equipment shall be “Full Operation”. The equipment shall also comply with the three-phase (Type III) voltage sag immunity requirements with a minimum Pass/Fail criterion of “Self-Recovery”**.

**Note:**
User could specify “full operation” for Type III if desired. This may or may not require stored energy to achieve.

*Not part of IEEE Std. 1668 – Offered here as an Example*
IEEE Std. 1668 Summary

- IEEE Std. 1668 Recommended Practice for Voltage Sag and Short Interruption Ride-Through Testing for End-Use Electrical Equipment Rated Less than 1000 V
  - Non-industry-specific document
  - All electrical/electronic equipment may be evaluated
    - Response to supply voltage reductions to 2 seconds
  - Standard provides/defines
    - Clearly defined testing procedures and test equipment requirements for single-phase, two-phase, and three-phase balanced and unbalanced voltage sags
    - Certification and test reporting requirements, including voltage-sag ride-through equipment characterization
2.0 Effects of Voltage Sags on Industrial Equipment, and Susceptibilities

Alden Wright, PE, CEM, CP EnMS
EPRI Industrial PQ and EE Group
Interrelated Processes

Is Compressed Air Present?

Is Process Cooling Water Present?

Are the Exhaust Systems Running?

Is Power Present?

Is Interlocked Process Running?

Ok to Run Automated Process

CONTINUALLY REPEATED

Stop Automated Process
“Extending the operating envelope” of equipment means that we have to reduce the area of equipment malfunctions by enabling the equipment to ride through deeper and longer voltage sags.
Voltage Sag Test Equipment Pioneers: EPRI Porto-Sag

As featured in Plant Engineering Magazine, August 8, 2002
Versions of the Porto-Sag EPRI Built

Patented Tri-Mode
Model PS200-3P-T-TM

Sag Types Per IEEE 1668

- Type I
- Type II
- Type IIA.1
- Type IIA.2
- Type III
Sample Output Waveform

Source: EPRI Porto-Sag Generator
Porto-Sag Software Interface

- **Load voltage**
- **Load current**
- **Ch 10: 135V DC supply**
- **Ch 11: 48V DC supply**
- **Ch 12: Control Relay**

**Sag Duration (cycles)**: 12.00

- **Points per cycle**: 166.65
- **Sampling rate (kHz)**: 10.0
- **Points in wfm**: 4667
- **Line frequency**: 60 Hz

**Reference**: control power
Single-Phase Sag Generators (Portable)

Voltage Sag Generator
1-Phase 20A 120/240V 50/60Hz

Omniverter offers a new diagnostic tool to industry, business and electric utilities who wish to perform voltage sag testing to IEC61000-4-11, IEEE1688 and to SEMI F47

Unique features to improve accuracy
Voltage compensation for line test voltage.
User can select standard or custom test sequence

The Voltage Sag Generator provides investigators a quick way to identify weak links in a process by injecting voltage sags of known, controlled magnitude and duration, while monitoring the response of the process. The Voltage Sag Generator helps engineers quickly characterize process components from a simple relay to complex programmable logic controllers and equipment in industrial facilities. Its built-in data acquisition system automatically captures voltage, current and other user connected signals during induced sag events.

Includes
- Main unit and all necessary interconnecting cables
- Built-in 8-channel data acquisition system
- Voltage probe accessory kit
- User manual and Voltage Sag Generator software

Available Option
- Notebook computer pre-loaded and tested with Voltage Sag Generator software.

Features
- Connects in series between the utility supply and load using simple input and output connections
- Test voltages (100–240V, 50 or 60 Hz)
- Creates sags by switching momentarily to adjustable transformer
- Easy setup for single or split phase loads
- Motorized Transformer to select sag levels
- Sag depth 100% to 0% in 3% steps
- Voltage sag durations ranging from 1/8 cycle to 30 seconds full load, (60 sec. half load) in 1/8 cycle increments
- 360-degree point-on-wave control
- Built-in start/stop circuit
- Built-in current transformer to monitor load current
- Captured waveforms can be saved in any of several formats including CSV, bitmap, .jpeg
- Software runs under Microsoft® Windows™ 7 64 bit is provided.

Specifications

Electrical
- Control voltage: Either 120VAC or 220VAC
- Operating frequency: 50 or 60 Hz, automatic detection
- Test voltage range: 100–240V Phase-to-Neutral, or split phase
- Max load current: 20A
- Max load inrush current: 60A
- Input configuration: 1-phase Y + N or Split phase + G
- Output configuration: 1-phase Y + N or Split phase + G
- Monitoring points: Phase A-N, or L-L2

Sag Control
- Sag duration: 1/8 cycle to 30 sec. in 1/8-cycle steps at full load (60 sec. at half load)
- Sag magnitude: 3% to 100% in 3% steps
- Point-on-wave: 360° in 1° increments
- Trigger output: TTL compatible

Data Acquisition
- Sampling rate: 10 kHz
- Resolution: 16 bits
- Max input voltage: 3 channels ±10 Vpeak AC or DC
- 3 channels ±350 Vpeak AC or DC (approx 240 Vrms)

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Markham, Ontario
L3R 0G7
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Fax: 416-845-2299
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www.omniverter.com

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Sag Generators – PSL Industrial Power Corrupter

- The IPC create sags/dips, swells, interruptions on 100 V – 480 V systems, at up to 480 volts and up to 200 Amps continuous
- Portable
- Connects to All three Phases
- Can create a sag across a selected phase-neutral or phase-to-phase vector – Only one tapped transformer
- Measure energy consumption at all stages of a process or cycle
- Fully compliant with SEMI F47, IEC 61000-4-34, IEC 61000-4-11
  - Can do IEEE Std. 1668 testing for single phase loads.
  - Can do one Mode of Type II testing per IEEE Std. 1668 Type IIA.1.
  - Not able to do Type III tests per with IEEE Std. 1668-2018 for three-phase loads – can only generate three-phase interruption.
Sag Generator – Omnivert 3-Phase

Enables:
- IEC 61000-3-11 & 61000-3-34 testing.
- IEEE Std. 1668 (All test Modes)
- SEMI F47 Testing

<table>
<thead>
<tr>
<th>Type</th>
<th>Voltage Sag Description</th>
<th>Other Common Designators</th>
<th>IEC 61000-4-34 Reference Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Single-Phase</td>
<td>Type I</td>
<td>Figure 3A</td>
</tr>
<tr>
<td>B</td>
<td>Phase to Phase Alternative 1</td>
<td>Type II A1</td>
<td>Figure 3B</td>
</tr>
<tr>
<td>C</td>
<td>Phase-to-Phase</td>
<td>Type II</td>
<td>Figure 3C</td>
</tr>
<tr>
<td>D</td>
<td>Phase to Phase Alternative 2</td>
<td>Type II A2</td>
<td>Figure 3D</td>
</tr>
<tr>
<td>E</td>
<td>Unbalanced Three-Phase</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>F</td>
<td>Balanced Three-Phase</td>
<td>Type III</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Voltage Tolerance Curve: Ice Cube Relay

How many potential shutdown events would be caused by the relays?
Voltage Tolerance Curve: Small Contactor

What happens during a voltage sag down to 50% of nominal for 5 cycles?
Voltage Tolerance Curve of Motor Starters

Which motor starters are the most susceptible to voltage sags?
Emergency Off (EMO) Circuit

Q1. What happens if the EMO relay or Main Contactor are extremely vulnerable to voltage sags?
Q2. What if the plant voltage is low?
Q3. What if the transformer rated output voltage does not match the relay and contactor?
Master Control Relay Example

What happens when an operator hits the E-Stop?

What happens if 1CRM1 is a sensitive relay?

Diagram of a master control relay circuit.
DC Power Supplies

- DC Power supplies range from single-phase linear to switch-mode designs and are used to power user interface PCs, tool controllers, and instrument I/O applications.
- The voltage sag ride-through of most power supplies designed for PC, tool controllers, and instrument I/O applications is directly related to the amount of stored energy and power and/or topology.
- PQ Performance Varies based on topology and loading
- An example is 120 volts to 24Vdc. The "secondary" voltage is a lower, control level voltage.
DC Power Supply Susceptibility Example 1: Single-Phase 120Vac Input Switch Mode

- **Heavily Loaded Power Supplies** will typically have less immunity to voltage sags than lightly loaded supplies.

![Diagram of Astrodyne SCN-600-12 Voltage Sag Ride Through Curve](image)

- **Input:** 120Vac
- **Duration (in seconds)**
- **Voltage (% of Nominal):**
  - 30%
  - 35%
  - 40%
  - 45%
  - 50%
  - 55%
  - 60%
  - 65%
  - 70%

- **Load Levels:**
  - 48% Load
  - 72% Load
  - 94% Load
DC Power Supply Susceptibility Example 2: Universal Input Types

Idec PS5R-A12, 7.5W

Vin=208Vac
Vin=120Vac

CM50 (208 Volts)

100% Load SEMI F47
PLC Based Control Systems

- Power Supply
- Discrete Input Modules
- Central Processing Unit
- Discrete Output Modules
- Spacer
- Analog Output Module
- Analog Input Module

---Select Manufacturer---
- Allen Bradley/Rockwell Automation
- GE
- GE Fanuc
- Giddings and Lewis
- HoneyWell
- Institute of Electrical and Electronics Engineers
- Modicon
- Omron
- OPTO
- Sharp
- Siemens
- Square D / Schneider / Telemecanique
How PLC I/O Is Typically Powered?

PLC POWER SUPPLY:

• CPU
• I/O CARD (LOGIC SIDE)
• ANALOG OUTPUT CARDS (SOME MANUFACTURERS)

EXTERNAL POWER REQUIRED FOR:

• DISCRETE INPUTS (120 Vac, 24 Vdc, etc.)
• DISCRETE OUTPUTS (120 Vac, 24 Vdc, etc.)
• ANALOG INPUTS (FIELD CURRENT/ VOLTAGE SOURCE)
• ANALOG OUTPUTS (SOME MANUFACTURERS)
AC Powered PLC Power Supply

From Typical PLC Literature:

Each ac-input power supply generates a shutdown signal on the backplane whenever the ac line voltage drops below its lower voltage limit, and removes the shutdown signal when the line voltage comes back up to the lower voltage limit. This shutdown is necessary to ensure that only valid data is stored in memory.

What that means to you:
- Oversensitive Power Supply
- Process Shutdown due to voltage Sags

What can be done about this?
Suitcase Demo PLC
Example Voltage Sag Ride-Through of AC Powered PLCs
Adjustable Speed Drives
AC PWM Drive

INPUT SECTION
Rectifier
Diode Bridge
Source Voltage

ENERGY STORAGE SECTION
DC Bus
Capacitor
DC Bus Voltage

OUTPUT SECTION
IGBT
Inverter
Motor Input Voltage

AC MOTOR
Voltage Sag Impact on ASD

Drive Trips on Undervoltage
Example Drive Response

Test Curves

- SEMI F47
- ITIC (Lower)
- Single-Phase Sag Results

Two-Phase Sag Results
Three-Phase Sag Results

% of Nominal Voltage

Duration (Seconds)
Line-Side and Motor-side Contactors
ASD Enable/Run Signal

Line

Neutral

120 V_{ac}

Contact on

120 V AC relay

ASD I/O Control Module

- Com
- Drive
- Enable/Run
- Motor Thermo
- Stop
- Ext Fault
Mitigation Solutions
PQ Solution – Add Mitigation

Where Possible
Avoid
Battery Based
Solutions!
Uninterruptible Power Supply (UPS)

For Control Loads

Small 500Va to 3kVA

UPS Systems are sometimes Used

Battery Based UPS Are Often “Overkill”

“Abandoned in Place” UPS Systems
Mitigation Levels

- Utility Solutions
  - Protect Entire Facility

- Whole Plant Solution
  - Protect Entire Facility

- Panel Feeder Solution
  - Protect Feeder or Group of Machines

- Machine Solutions
  - Protect Whole Machine or Machine Control Circuits

- Control Level Solutions
  - Small Power Conditioners, More Robust Relays, Power Supplies, Contactors, Sensors, etc.

- Embedded Solutions

Knowledge of Equipment Sensitivity

Relative Cost of Solution

10^6

10^5

10^4

10^3

10^2
Example Comparison of Large Scale Technologies for Plant PQ and Reliability Improvements

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Sag RT</td>
<td>OmniVerter AVC\textsubscript{2}</td>
<td>99%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Low</td>
<td>None</td>
<td>7</td>
<td>12</td>
<td>None</td>
<td>No</td>
<td>200%</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sag RT + 15s Interruption</td>
<td>OmniVerter AVC\textsubscript{RTS} - Battery (30s)</td>
<td>99%</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
<td>5</td>
<td>5</td>
<td>12</td>
<td>None</td>
<td>30</td>
<td>200%</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>CAT UPS 900Z</td>
<td>CAT UPS 900Z</td>
<td>99%</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
<td>5</td>
<td>5</td>
<td>12</td>
<td>None</td>
<td>30</td>
<td>200%</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Bridge Power + Gen Sets</td>
<td>OmniVerter AVC\textsubscript{RTS} - Battery (30s) + Generator</td>
<td>99%</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>None</td>
<td>30 s + Gen</td>
<td>200%</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CAT UPS + Generator</td>
<td>CAT UPS + Generator</td>
<td>98%</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>High</td>
<td>None</td>
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<td>10</td>
<td>4</td>
<td>16</td>
<td>200%</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Bridge Power + Alternate Feed</td>
<td>OmniVerter AVC\textsubscript{RTS} - Battery + MV Feed</td>
<td>99%</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Low</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>None</td>
<td>30 s + MV Feeder</td>
<td>200%</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CAT UPS + MV Feed</td>
<td>CAT UPS + MV Feed</td>
<td>98%</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Med</td>
<td>None</td>
<td>None</td>
<td>10</td>
<td>4</td>
<td>16 s + MV Feeder</td>
<td>200%</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Full Load Battery plus Alternate Feed</td>
<td>8 MW UPS Battery System + MV Standby Feed</td>
<td>98%</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Low</td>
<td>Included in warranty (Typically 10 years)</td>
<td>None</td>
<td>15 s + MV Feeder</td>
<td>110%</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Pro**, **Neutral**, and **Con**
Method 1: Design with DC Power

- One of the best methods of increasing the tolerance of control circuits is to use direct current (DC) instead of alternating current (AC) to power control circuits, controllers, input/output devices (I/O), and sensors.
- DC power supplies have a “built-in” tolerance to voltage sags due to their ripple-correction capacitors, whereas control power transformers (CPTs) and AC components do not have inherent energy storage to help them ride through voltage sags.
- Many OEMs are moving in this direction to harden their equipment designs.

DC Powered Emergency Off Circuit
Demonstration Time – PLC using DC Power Supply Rather Than CPT

- How Much Better is the DC solution?
  - Depth of Sag
  - Duration of Sag
- What other benefits does DC have?
- What are some design considerations with DC?

**PLC DC P/S On, AC P/S OFF**

Sequence State Set to “0”

**DC Powered PLC Circuit**

**Video Link**
DC Powered PLC System in Weld Shop

(3) Three phase input Siemens SITOP DC Power Supplies

AB SLC-5/0 PLC with DC I/O

Duration (cycles)

Magnitude (Percentage of Pre-Sag Voltage)
Summary of Robust Power Supply Strategies

**Single-Phase**
- **Switch-Mode DC Power Supply**
  - Loaded 50%
  - Most relevant to single-phase circuits. In order to ensure robustness, design for 50% loading.

**Two-Phase**
- **Universal Input DC Power Supply Connected Phase-to-Phase**
  - Most relevant to 208-VAC, three-phase systems. Input voltage ranges from 85 VAC to 264 VAC connected phase-to-phase. Will maintain output down to 41% nominal input voltage even at 100% load.

**Three-Phase**
- **Three-Phase DC Power Supply**
  - Most relevant to 480-VAC, three-phase systems. Power supply is impervious to single-phase voltage sags and momentary interruptions.
Summary of Robust Power Supply Strategies: Relative Power Supply Response at 100% Loading

Ride-Through for Single-Phase Voltage Sags
24Vdc Energy Storage Options

The PQI now has two 24Vdc Energy Storage Options that can harden 24Vdc Based Controls.
PULS DC BUFFER Module

Buffering: Electrolytic caps.

SLV20.200

- Buffering for 24V loads
- Minimum hold-up time: 0.2s/20A (max. buffer time depends on load)
- Fit for industrial use: Energy storage in electrolytic caps, no accumulators
- Clear status indication by Status LED and signalling terminals

Ref: PULSE Buffer module SLV.20.200 data sheet

DEMO:
Sequence “0”
PLC DC P/S “ON”
Connect Buffer Module to 24VDC
ABB Ucap DC Power Supply Buffer Module

- DC Buffer modules are devices that are installed in parallel with the output of DC power supplies to offer extended voltage sag ride through protection.
- There are several manufacturers of DC voltage buffers.
- Most manufacturers assert that buffers may be used in parallel to supply more energy.
- These modules can supply power up to 38 seconds at full load current in the event of an interruption of DC power.

### DEMO:
Sequence “0”
PLC DC P/S “ON”
Connect Buffer Module to 24VDC

### Table: DC Buffer Module Options

<table>
<thead>
<tr>
<th>Select</th>
<th>Model</th>
<th>Manufacturer</th>
<th>Part Number</th>
<th>Description</th>
<th>Cost USD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24Vdc Ultracap Buffer Module</td>
<td>ABB</td>
<td>CP-B 24/3.0 1SVR 427 060 R0300</td>
<td>DC Ucap Buffer - 1000 Ws, 24Vdc, 3A, 13s Outage Coverage at Full Load</td>
<td>870</td>
</tr>
<tr>
<td></td>
<td>24Vdc Ultracap Buffer Module</td>
<td>ABB</td>
<td>CP-B 24/10.0 1SVR 427 060 R1000</td>
<td>DC Ucap Buffer - 10000 Ws, 24Vdc, 10A, 38s Outage Coverage at Full Load</td>
<td>2500</td>
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<tr>
<td></td>
<td>24Vdc Ultracap Buffer Module</td>
<td>ABB</td>
<td>CP-B 24/20.0 1SVR 427 060 R2000</td>
<td>DC Ucap Buffer - 8000 Ws, 24Vdc, 20A, 15s Outage Coverage at Full Load</td>
<td>2600</td>
</tr>
</tbody>
</table>
Method No. 2: Utilize Sag Tolerant Components

- If AC Relays and Contactors are used in the machine design, then utilize compliant devices.
- Consider response at both 50 and 60 Hz.
- We have certified a many relays and contactors to SEMI F47.
Example Robust Contactor

Tolerance and Protection Curves

Percent of Nominal

Seconds

EPRI

PQ Investigator

Square D / Schneider / Telemecanique, D line, LC1D11500F7, 110VAC, 60Hz

Semiconductor Equipment and Materials International, SEMI-F47-0706 Standard, 60Hz
Example Voltage Sag Response of Motor Controls Based on Robustness of Components
New Solution for an Old Problem: “Nice Cube”

Concept

Original “AC Ice Cube”
Drop out ~70% Vnom

Remove “AC Ice Cube” Insert
“Nice Cube” Puck Into Base

Insert “DC Ice Cube”
Drop Out ~ 25-30% Vnom
Nice Cube Relay

### General Specifications

<table>
<thead>
<tr>
<th>Contact Characteristics</th>
<th>Units</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number and type of Contacts</td>
<td>A</td>
<td>DPDT</td>
</tr>
<tr>
<td>Contact materials</td>
<td>V</td>
<td>Silver Alloy</td>
</tr>
<tr>
<td>Thermal (Carrying) Current</td>
<td>16A</td>
<td>277V 50/60Hz</td>
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<tr>
<td>Maximum Switching Voltage</td>
<td>16A</td>
<td>120V 50/60Hz</td>
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<tr>
<td>Switching Current @ Voltage</td>
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<td>28V</td>
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<tr>
<td>Pilot Duty</td>
<td>HP</td>
<td>1/3 @ 120VAC</td>
</tr>
<tr>
<td>Minimum Switching Requirement</td>
<td>mA</td>
<td>3 @ 150VDC</td>
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</table>

### Coil Characteristics

| Voltage Range | V | 6...240 |
| Operating Range | % of Nominal | 85% to 110% |
| Average consumption | VA | 3 |
| Drop-out voltage threshold | W | 1.4 |

### Performance Characteristics

| Electrical Life (UL508) | Operations @ Rated Current | (Resistive) | 100,000 |
| Mechanical Life | Unpowered | 5,000,000 |
| Operating time (response time) | ms | 20 |
| Dielectric strength | Between coil and contact | Yrms | 1500 |
| Between poles | Yrms | 1500 |
| Between contacts | Yrms | 1500 |

### PQSI VNC 120Vac and 24Vac Models

<table>
<thead>
<tr>
<th>PQSI NiceCube Models</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiceCube VNC 120Vac Input</td>
<td>UL/CSA Compliant File #255764</td>
</tr>
<tr>
<td>NiceCube VNC 24Vac Input</td>
<td>UL/CSA Compliant File #255764</td>
</tr>
</tbody>
</table>

MitigatorModel | Manufacturer | Mfr Part Number | MitigatorDescription | Mitigator Cost ($)
---|---|---|---|---
Nice Cube Relay 120Vac | Power Quality Solutions Inc. | VNC-120Vac | Nice Cube, 120Vac Unit, 50/60Hz | 85
Nice Cube Relay 24Vac | Power Quality Solutions Inc. | VNC-24Vac | Nice Cube, 24Vac Unit, 50/60Hz | 85

A typical NiceCube weighs approximately 7 oz. (0.2 kg) and measures 5”H x 1.625”W x 2.25”L.
Method 3: Apply Custom Programming Techniques – Delay Filters

- **Delay filters** can verify the presence of power and work as a “de-bounce” mechanism for when components drop out due to a voltage sag. The PLC motor-control circuit shown demonstrates how this method can be applied.

- The program is designed to detect whether the auxiliary contact is open for more than 250 milliseconds.

- If the contact is open for more than that preset time, then the “Timer On Delay Coil” in Rung 2 will be set and un latch the previous rung to remove voltage from the motor starter.
Method 3: Apply Custom Programming Techniques – State Machine Programming

- State Machine Programming is based on the idea that manufacturing processes are comprised of a number of steps with the goal of producing and moving a product.

- Therefore, machine-state programming keeps track of every sequential process state and associated variables by writing variables to non-volatile memory in the event power is lost.

- When power returns, the processing step number and variables can be recalled so that the machine can continue from where it stopped.

Machine-state programming uses coding, such as shown below, to store and retrieve data as needed:

1. IF PE_COUNT AND PUSH_COUNT EQUAL 0, THEN TURN M1 ON
2. WHEN PHOTO-EYE COUNT (PE_COUNT) EQUALS 3, STOP CONVEYOR
3. IF PE_COUNT EQUALS THREE AND M1 IS STOPPED, MOVE SOL1 TO LS1 AND INCREMENT PUSH_COUNT
4. IF PUSH_COUNT EQUALS 1 AND SOL1 IS HOME, TURN M1 ON
5. IF PE_COUNT IS EQUAL TO 6 AND M1 IS STOPPED, MOVE SOL1 TO LS2 AND INCREMENT PUSH_COUNT
6. IF PUSH_COUNT EQUALS 2 AND SOL1 IS HOME, MOVE SOL2 TO LS3 AND INCREMENT PUSH_COUNT
7. IF PUSH_COUNT EQUALS 3 AND SOL2 IS HOME, EXTEND SOLENOID 2 FOR 5 SECONDS
8. IF SOL3 TIMER IS DONE, TURN M2 ON FOR 5 SECONDS AND RESET ALL COUNTERS AND TIMERS (PE_COUNT AND PUSH_COUNT)
YMCA BOT Demo State Machine Programming Using Volatile vs. Non-Volatile Memory

- By writing the process step into non-volatile memory, the YMCA Bot is able to remember which letter it was doing before it shutdown and pick up afterwards.

```c
/*
Address = 0 / EEPROM Address for state variables

State=0  No state
State=1  Hands by side
State=2  Y
State=3  M
State=4  C
State=5  A
*/

// Next upon first scan of program (start=0), recover info to pick up process state and servo positions
if (start==0) {
    // recover robot after power loss/voltage sag shutdown
    // Read info back from non-volatile memory area from EEPROM

    state = EEPROM.read(address); // recover state of robot prior to PQ Induced Shutdown
    LS_Angle = EEPROM.read(address+1); // Recover Left Shoulder Angle
    LE_Angle = EEPROM.read(address+2); // Recover Left Elbow Angle
    RS_Angle = EEPROM.read(address+3); // Recover Right Shoulder Angle
    RE_Angle = EEPROM.read(address+4); // Recover Right Elbow Angle
    delay(100);

    // Write Recovered angles to servos

    LeftShoulder.write(LS_Angle);
    LeftElbow.write(LE_Angle);
    RightShoulder.write(RS_Angle);
    RightElbow.write(RE_Angle);
}
```
YMCA BOT Demo State Machine Programming Using Volatile vs. Non-Volatile Memory

“YMCA” States Written to Volatile Memory

“YMCA” States Written to Non-Volatile Memory
Method 3: Apply Custom Programming Techniques – Programming Using Phase/Voltage Sensing Relay

- A phase monitor or voltage sensing relay, used in conjunction with programming, can also protect against the effects of voltage sags.
- The relay contacts can be used to run a check on the system, retrieve past information stored in memory, or hold control parameters constant until the event is over.

Potential Sensing Devices For Voltage Sags
(Left to Right)
- Phase Monitoring Relay
- PQ Relay
- “Original” PQ Relay (AC Ice Cube)
Method 4 – Examine Configuration Settings

- A low-cost or perhaps no-cost method of increasing the tolerance of AC and DC motor drives to voltage sags is through software configuration settings.
- This method applies to all types of drives, including, but not limited to, AC pulse-width modulation (PWM), direct-current, AC-pulse, stepper, and servo drives.
Video: Visualizing PQ Drive Parameters for Improved Voltage Sag Ride-Through
Method 5 – Select Appropriate Trip Curves for Circuit Breakers

- Some equipment, especially equipment with AC-to-DC converters, may respond to a voltage sag by drawing inrush current when the voltage supply returns to normal.

- During a voltage sag, the AC-to-DC converter capacitors discharge. At the end of the sag, the sudden presence of full voltage causes the discharged capacitors to rapidly recharge.

- The magnitude of this inrush of current depends on the depth and duration of the voltage sag. The resulting current transient may be large enough to trip circuit breakers that have a quick response time.

- Process machines with any type of AC-to-DC converter—such as DC power supplies, AC or DC variable-speed drives, and servo drives—can not only cause such transients but may also be susceptible to breaker trips caused by the transients.
Method 6: Control Power Transformer Tap Adjustments

- If CPT output voltage is not at rated output:
  - Adjust CPT taps up (if available on transformer)
    - 1) Lower Input Tap (i.e. from 460/480 to 440/460)
    - 2) Raise Output Tap (i.e. from 110/115 to 115/120)
  - Lowers susceptibility of control components to voltage sags by raising the nominal voltage.
  - Check against unloaded condition to insure you do not overvoltage the control power
Method 7: Coordinate Control Power Transformer Wiring Adjustments

- Within a process line with multiple control cabinets, the Control Power Transformers (CPTs) may be derived from various phase-to-phase combinations and be at various output voltages.
- A voltage sag on most any phase combination will cause the line to trip somewhere.
Method 7: Coordinate Control Power Transformer Wiring Adjustments (2)

- Coordinating which phases the CPT wiring is derived from within a line can make it less apt to drop out during a sag on a specific phase or phases.
- In this case a phase C, A-C, B-C voltage sag is less likely to cause the line to drop out.
Method 7: Coordinate Control Power Transformer Wiring Adjustments (3)

- Coordinating between will raise the chances that some lines may ride-through an event.
- What lines are likely to ride-through for:
  - A sag on line A-B?
  - A sag on line C?
- Probability Game!
Method 8 – Specify a Voltage Sag Recommended Practice for OEMs!

- A new recommended practice for voltage sag immunity was published by IEEE in the fall of 2014.
- IEEE P1668 is based on SEMI F47 but includes requirements for three phase voltage sags.
- This recommended practice defines test requirements and test criteria.
IEEE P1668 – User Specs Desired Machine Response

- **Full (normal) operation** – equipment performs as expected or intended and all of its relevant parameters are within technical specification or within allowed tolerance limits. Equipment performance should be expressed and measured against the set of relevant/critical “equipment outputs” (e.g. speed, torque, voltage level, etc.), which have to be defined as per the process requirements.

- **Self-recovery** – equipment does not perform intended functions, or its outputs vary outside the technical specification/limits, but equipment is able to automatically recover after the end of voltage sag event without any intervention from the user.

- **Assisted-recovery** – equipment does not perform intended functions, or its outputs vary outside the technical specification/limits, and equipment is not able to automatically recover after the end of voltage sag event. Assisted-recovery criteria should be applied only when there are dedicated and/or trained personnel/staff, who either operate the equipment, or are responsible for supervising the equipment at all times when equipment is in use. If some external control circuit is applied for automatic restarting of equipment, this should be treated as a self-recovery criterion.
4.0 Embedded Solutions through targeted power conditioning

Alden Wright, PE, CEM, CP EnMS
EPRI Industrial PQ and EE Group
Example Cost vs. Coverage

Example Cost per Option

- Most Equipment Level
- Control Level
- Relay Level
- Least

- Small Power Conditioner: $1500 - $3,000
- Replace Relay $25
- Coil Lock $130

Cost (USD)

Minimum: $20K - $40K
Maximum: $80K - $100K

Equipment Level: $25K to $88K
## Typical PQ Mitigation Devices

### Comparison of Power Conditioning Devices

<table>
<thead>
<tr>
<th>Application</th>
<th>Device</th>
<th>Coverage (Vnom) / Duration</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1φ</td>
<td>φ - φ</td>
</tr>
<tr>
<td>3φ</td>
<td>ProDySC</td>
<td>0% / 2 sec.</td>
<td>30% / 2 sec.</td>
</tr>
<tr>
<td>3φ</td>
<td>AVC (two rated models)</td>
<td>45% / 30 sec.</td>
<td>45% / 30 sec.</td>
</tr>
<tr>
<td>1φ Ctrl Ckt</td>
<td>PowerRide RTD</td>
<td>0% / 2+ sec.</td>
<td>0% A-B, B-C; 70-80% C-A / 2+ sec.</td>
</tr>
<tr>
<td>1φ Ctrl Ckt</td>
<td>MiniDySC</td>
<td>0% / 0.05 sec.</td>
<td>50% / 2 sec.</td>
</tr>
<tr>
<td>1φ Ctrl Ckt</td>
<td>CVT</td>
<td>40-50% / 2+ sec.</td>
<td>n/a</td>
</tr>
<tr>
<td>1φ Ctrl Ckt</td>
<td>VDC (6T Model)</td>
<td>37% / 2+ sec.</td>
<td>n/a</td>
</tr>
<tr>
<td>1φ Ctrl Ckt</td>
<td>Coil Hold-in (CoilLock and KnowTrip)</td>
<td>25% / 2+ sec.</td>
<td>n/a</td>
</tr>
<tr>
<td>1-phase</td>
<td>Supercapacitor UPS</td>
<td>0% /15 sec.</td>
<td></td>
</tr>
</tbody>
</table>
“Selective” Conditioning

The Premise:
All equipment power users are not ultra-sensitive.

The Plan:
To prop up the single-phase “weak links” only.

The Weak Links:
Small, single-phase 100Vac-230Vac, typically power supplies, sensors and controls.

The Benefit: Lower Cost than Macro Solutions.
Industrial UPS Example: SDU DIN Rail DC UPS Series

- **Features**
  - Modular, rugged industrial grade design
  - Microprocessor based controls
  - **Automatic self-test feature for UPS function and battery management check**
  - Power module wide operation temperature range (-20 to +50°C)
  - Flexible batteries back-up expansion capabilities
  - Overload protection in normal and battery modes
  - User replaceable batteries
  - Both power and battery modules are UL508 Listed
  - IP-20 rated input and output screw terminals
  - No internal fan, no extra cooling required
  - Sturdy, reliable all metal DIN Rail mounting connector
  - LED Status Indicators
  - **Universal Dry Contact Relay terminals provide remote signaling**
  - **Monitoring, diagnostics, and remote turn-on and shut-off capabilities**
  - Limited two-year warranty

Cost/Unit ~$500 USD
Supercapacitor UPS

- New Product from Marathon Power
- “Batteryless” UPS
- Supercapacitors store energy
- 3kVA, 2100 W
- 120V, 208V, 230V models

Interruption Coverage:
- 15 seconds at full load
- 45 seconds at ½ load
Marathon Power Supercapacitor UPS Product Matrix

Marathon Power, SuperCap UPS, Supercapacitor UPS

Applied To: Control Circuit

Mitigated Circuit: 1T (CPI) 1.5kVA - 480/120 Vac

Sizing Notes:
The Marathon Power Supercapacitor UPS System can allow the sensitive load to ride-through voltage sags and outages lasting up to 15 seconds and full load and 45 seconds at half load. Size unit based on desired voltage (120 or 220Vac) and the required load. The unit comes in a 1kVA/700W and a 3kVA/2100W size. Measure amps and power factor of load to determine real watt requirements and kVA.

Reference

Mitigator List:

<table>
<thead>
<tr>
<th>Select</th>
<th>Model</th>
<th>Manufacturer</th>
<th>Part Number</th>
<th>Description</th>
<th>Cost USD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Supercapacitor</td>
<td>Marathon</td>
<td>ARTE-1000-01 +</td>
<td>1000RT UPS Electronics + Cap Pack, 1kVA, 120V, 700W, 8.3A, 50/60Hz</td>
<td>2650</td>
</tr>
<tr>
<td></td>
<td>UPS Power</td>
<td>Power</td>
<td>ACPR-0458-36</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Supercapacitor</td>
<td>Marathon</td>
<td>ARTE-3000-01 +</td>
<td>3000RT UPS Electronics + Cap Pack, 3kVA, 120V, 2100W, 25A, 50/60Hz</td>
<td>5000</td>
</tr>
<tr>
<td></td>
<td>UPS Power</td>
<td>Power</td>
<td>ACPR-1058-96</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supercapacitor</td>
<td>Marathon</td>
<td>ARTE-1000-02 +</td>
<td>1000RT UPS Electronics + Cap Pack, 1kVA, 220V, 700W, 4.5A, 50/60Hz</td>
<td>2650</td>
</tr>
<tr>
<td></td>
<td>UPS Power</td>
<td>Power</td>
<td>ACPR-0458-36</td>
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<tr>
<td></td>
<td>Supercapacitor</td>
<td>Marathon</td>
<td>ARTE-3000-02 +</td>
<td>3000RT Electronics + Cap Pack UPS, 3kVA, 220V, 2100W, 13.6A, 50/60Hz</td>
<td>5000</td>
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<tr>
<td></td>
<td>UPS Power</td>
<td>Power</td>
<td>ACPR-1058-96</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Constant Voltage Transformer (CVT)
CVT Application & Features

- On-line Device. In-Rush Current of load(s) MUST be considered in sizing.
- Output of CVT can collapse when in-rush current gets close too high (around 4 x rated size).
- Sub-Cycle Response.
- Should be oversized to at least 2 times nominal of load to increase ride-through.
- Acts as an isolation transformer and protects against voltage sags.
Example Control Level Solution Application

- The CVT is protecting only the AC control components means that the selected power conditioner will be more affordable than one that could protect the entire machine.
- The ride through of the AC drives in this example can be enhanced by modifying their programming, thus eliminating the need for a large power conditioner.
- However, “run” signal to drives must be maintained
Sizing Notes for CVT

- In order to get the best voltage sag ride-through, size a CVT to 2.5 X Nominal Load VA.
  - This does not always mean just doubling the CPT size. If you are specifying a CVT > 3KVA look at the application closely. These units get very large and require significant mounting brackets.

- Also make sure that the load inrush is less than 1/2 Max Inrush of chosen CVT.
  - If it exceeds that value, upsize such that the chosen CVT VA size is at least 1/2 Max Inrush.

- Remember since the CVT has multiple taps, if the application as a Control Power Transformer (CPT), it may be possible to replace the CPT with the CVT. Otherwise, tap it in a 1:1 input/output configuration.
## CVT Typical Costs ($USD)

(Sola/Hevi-Duty. Ph: 1-800-377-4384, [www.sola-hevi-duty.com](http://www.sola-hevi-duty.com))

<table>
<thead>
<tr>
<th>Catalog Number</th>
<th>VA</th>
<th>Voltage Input</th>
<th>Voltage Output</th>
<th>Newark Price</th>
<th>Allied Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>63-23-112-4</td>
<td>120</td>
<td>120, 208, 240, 480</td>
<td>120</td>
<td>$465.43</td>
<td>$437.35</td>
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<tr>
<td>63-23-125-4</td>
<td>250</td>
<td>120, 208, 240, 480</td>
<td>120</td>
<td>$595.62</td>
<td>$559.68</td>
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<tr>
<td>63-23-150-8</td>
<td>500</td>
<td>120, 208, 240, 480</td>
<td>120, 208, 240</td>
<td>$887.54</td>
<td>$833.98</td>
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<tr>
<td>63-23-175-8</td>
<td>750</td>
<td>120, 208, 240, 480</td>
<td>120, 208, 240</td>
<td>$1,113.87</td>
<td>$1,046.63</td>
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<tr>
<td>63-23-210-8</td>
<td>1000</td>
<td>120, 208, 240, 480</td>
<td>120, 208, 240</td>
<td>$1,349.39</td>
<td>$1,248.74</td>
</tr>
<tr>
<td>63-23-215-8</td>
<td>1500</td>
<td>120, 208, 240, 480</td>
<td>120, 208, 240</td>
<td>$1,816.80</td>
<td>$1,681.30</td>
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<tr>
<td>63-23-220-8</td>
<td>2000</td>
<td>120, 208, 240, 480</td>
<td>120, 208, 240</td>
<td>$2,298.13</td>
<td>$2,126.74</td>
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<td>63-23-230-8</td>
<td>3000</td>
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<td>120, 208, 240</td>
<td>$3,285.84</td>
<td>$3,040.79</td>
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<tr>
<td>63-23-250-8</td>
<td>5000</td>
<td>120, 208, 240, 480</td>
<td>120, 208, 240</td>
<td>$5,138.80</td>
<td>$4,927.80</td>
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<tr>
<td>63-28-275-8</td>
<td>7500</td>
<td>208, 240, 480</td>
<td>120, 208, 240</td>
<td>$6,737.18</td>
<td>$6,234.73</td>
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<td>63-28-310-8</td>
<td>10000</td>
<td>208, 240, 480</td>
<td>120, 208, 240</td>
<td>N/A</td>
<td>$8,650.97</td>
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<tr>
<td>63-28-315-8</td>
<td>15000</td>
<td>208, 240, 480</td>
<td>120, 208, 240</td>
<td>$12,652.23</td>
<td>$11,708.64</td>
</tr>
</tbody>
</table>
CVT Coverage vs. Sample Historical Data

Tolerance and Protection Curves with PQ Data Overlay

FPR1

PO Investigator

Semiconductor Equipment and Materials International, SEMI, F47-0706, Standard, 60Hz

SOLA-Hevi-Duty, CVS, Hardwired, CVT, 50% Loaded


Watch Video
Example CVT Application to **Avoid**: 400VA control power transformer and a NEMA type 6 starter

<table>
<thead>
<tr>
<th>CVT Circuit or Load</th>
<th>Measured Steady-State RMS Current</th>
<th>Measured Peak Inrush Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CVT Sizing Worksheet (Recommended Minimum Size: 500 VA)

\[
\text{Sum of Steady-State RMS Currents} \leq \frac{3.3}{120} \times 400 \times 2.5 = 1000
\]

\[
\text{Circuit Voltage} \times \frac{40.5}{120} \times 4860 \times 0.5 = 2,430
\]

3kVA Closest Size

$3,300 List
# UPPI PowerRide RTD: CVT on STEROIDS

No need to oversize by factor of 2.5
Apply same Inrush caution as with Standard CVT.

<table>
<thead>
<tr>
<th>Power Anomaly</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of Phase A</td>
<td>Output remains constant</td>
</tr>
<tr>
<td>Loss of Phase B</td>
<td>Output remains constant</td>
</tr>
<tr>
<td>Loss of Phase C</td>
<td>Output remains constant</td>
</tr>
<tr>
<td>Loss of Phase A and B - 33% sag on remaining phase</td>
<td>Output remains constant</td>
</tr>
<tr>
<td>Loss of Phase B and C - 33% sag on remaining phase</td>
<td>Output remains constant</td>
</tr>
<tr>
<td>Loss of Phase A and C</td>
<td>Output goes to 0</td>
</tr>
<tr>
<td>Loss of A and 33% Sag on C</td>
<td>Output remains constant</td>
</tr>
<tr>
<td>Loss of C and 33% Sag on A</td>
<td>Output remains constant</td>
</tr>
<tr>
<td>37% Sag on A and C</td>
<td>Output remains constant</td>
</tr>
</tbody>
</table>
Power Ride RTD Coverage vs. Sample Historical Data

Tolerance and Protection Curves with PQ Data Overlay

- Semiconductor Equipment and Materials International (SEM), F47-07/06, Standard, 60Hz
- Uninterruptible Power Products, Inc., PowerRide RTD, PowerRide RTD, Phase A-B and B-C Sag Response
- PQ Data, AKZO All Events (9/1/2008 5:13:27 AM - 9/2/2013 3:05:56 AM)
UPPI PoweRide RTD: Example Suggested List Price

Contact UPPI for accurate Pricing

No need to oversize by factor of 2.5
Apply same Inrush caution as with Standard CVT.

<table>
<thead>
<tr>
<th>Mfr Part Number</th>
<th>Mitigator Description</th>
<th>Mitigator Cost ()</th>
</tr>
</thead>
<tbody>
<tr>
<td>500VA 500W</td>
<td>0.5kVA, Input 208, 480,380,400,415 Wye/Del Or 240,480,200 del, Output 1ph, Any Input V Lvl, 10A, 60Hz</td>
<td>1000</td>
</tr>
<tr>
<td>1kVA 1kW</td>
<td>1kVA, Input 208, 480,380,400,415 Wye/Del Or 240,480,200 del, Output 1ph, Any Input V Lvl, 10-15A, 60Hz</td>
<td>1400</td>
</tr>
<tr>
<td>2kVA 2kW</td>
<td>2kVA, Input 208, 480,380,400,415 Wye/Del Or 240,480,200 del, Output 1ph, Any Input V Lvl, 20-35A, 60Hz</td>
<td>2400</td>
</tr>
<tr>
<td>3kVA 3kW</td>
<td>3kVA, Input 208, 480,380,400,415 Wye/Del Or 240,480,200 del, Output 1ph, Any Input V Lvl, 15-50A, 60Hz</td>
<td>3200</td>
</tr>
<tr>
<td>5kVA 5kW</td>
<td>5kVA, Input 208, 480,380,400,415 Wye/Del Or 240,480,200 del, Output 1ph, Any Input V Lvl, 20-80A, 60Hz</td>
<td>4900</td>
</tr>
<tr>
<td>7.5kVA 7.5kW</td>
<td>7.5kVA, Input 208, 480,380,400,415 Wye/Del Or 240,480,200 del, Output 1ph, Any Input V Lvl, 30-125A, 60Hz</td>
<td>5300</td>
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<tr>
<td>10kVA 10kW</td>
<td>10kVA, Input 208, 480,380,400,415 Wye/Del Or 240,480,200 del, Output 1ph, Any Input V Lvl, 40-175A, 60Hz</td>
<td>8300</td>
</tr>
</tbody>
</table>
Dip Proofing Inverter

- Electrolytic Capacitor Based UPS
- Square-Wave Output
- Sizing:
  1. Determine Control Voltage Requirement
  2. Determine Overall KVA/Current Requirements of Load
  3. Measure Real Power Load Requirements (Watts)
  4. Select Matching from of Product Matrix and note “Joules” of energy available
  5. Calculate to determine ride-through time in seconds…
    \[
    \text{Ride-Through Time} = \frac{\text{Joules Available}}{\text{Control Load Watts}}
    \]
  6. If sufficient, you are done.*
  7. If more ride-through desired, select next largest kVA product and redo steps 4-6.

*Note: You can adjust
  - Ride-Through Time Down by changing dip switch settings.
  - Transfer Level from 50 to 80%, 90% special order
DPI Output

Square Wave not compatible with some PLC AC Input Cards.

• 1-3 second ride-through based on real power required and sizing.
DPI Coverage vs. Sample Historical Data

Tolerance and Protection Curves with PQ Data Overlay

- EPRI
- PQ Investigator

- Semiconductor Equipment and Materials International, SEMI, F47-0706, Standard, 60Hz
- Dip-Proofing Technologies Inc., Dip Proofing Inverter, DPI, Inductive Load (p.f. < 0.25)

Watch Video
## DPI Product Matrix

<table>
<thead>
<tr>
<th>Mitigator Model</th>
<th>Manufacturer</th>
<th>Mfr Part Number</th>
<th>Mitigator Description</th>
<th>Mitigator Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S6.6mF120V2A</td>
<td>DPI, 0.25kVA, 120V, 2A, 31J, 50/60Hz</td>
<td>1500</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S13.2mF120V4A</td>
<td>DPI, 0.5kVA, 120V, 4A, 68J, 50/60Hz</td>
<td>1900</td>
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<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S19.8mF120V6A</td>
<td>DPI, 0.75kVA, 120V, 6A, 103J, 50/60Hz</td>
<td>2400</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S39.6mF120V8A</td>
<td>DPI, 1kVA, 120V, 8A, 217J, 50/60Hz</td>
<td>2800</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI54L33mF120V25A</td>
<td>DPI, 3kVA, 120V, 25A, 181J, 50/60Hz</td>
<td>3200</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI54L66mF120V25A</td>
<td>DPI, 3kVA, 120V, 25A, 371J, 50/60Hz</td>
<td>3800</td>
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<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI54L99mF120V25A</td>
<td>DPI, 3kVA, 120V, 25A, 556J, 50/60Hz</td>
<td>4200</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S2.04mF120V2A</td>
<td>DPI, 0.46kVA, 208 or 230V, 2A, 910J@230V, 50/60Hz</td>
<td>1500</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S4.08mF120V4A</td>
<td>DPI, 0.92kVA, 208 or 230V, 4A, 1820J@230V, 50/60Hz</td>
<td>1900</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S6.120mF230V6A</td>
<td>DPI, 1.38kVA, 208 or 230V, 6A, 273J@230V, 50/60Hz</td>
<td>2400</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI53S12.24mF230V8A</td>
<td>DPI, 1.84kVA, 208 or 230V, 8A, 584J@230V, 50/60Hz</td>
<td>2800</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI54L15mF230V25A</td>
<td>DPI, 5.75kVA, 208 or 230V, 25A, 373J@230V, 50/60Hz</td>
<td>3200</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI54L30mF230V25A</td>
<td>DPI, 5.75kVA, 208 or 230V, 25A, 746J@230V, 50/60Hz</td>
<td>3800</td>
</tr>
<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI54L45mF230V25A</td>
<td>DPI, 5.75kVA, 208 or 230V, 25A, 1.2kJ@230V, 50/60Hz</td>
<td>4200</td>
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<tr>
<td>DPI</td>
<td>Dip Proofing Technologies</td>
<td>DPI54L90mF230V25A</td>
<td>DPI, 5.75kVA, 208 or 230V, 25A, 2.2kJ@230V, 50/60Hz</td>
<td>5900</td>
</tr>
</tbody>
</table>
Supercapacitor UPS
- New Product from Marathon Power
- “Batteryless” UPS
- Supercapacitors store energy
- 3kVA, 2100 W
- 120V, and 220V models
- Interruption Coverage:
  - 15 seconds at full load
  - 45 seconds at ½ load

15 to 45 Seconds @ Full Load
Voltage Dip Compensator (Vdc)

- No batteries; no maintenance.
- Fast compensation.
- Able to withstand high inrush currents.
- Small footprint, easy to retrofit.
- Support exceeds SEMI F47 standard requirements.
- Handles inductive and low power factor loads.
- 120Vac and 208Vac Models
VDC Output

AC Output is a Sine Wave instead of a Square Wave

Product by Dip Proofing Technologies

www.dipproof.com
www.measurlogic.com
VDC Coverage (4T Model) vs. Sample Historical Data

Tolerance and Protection Curves with PQ Data Overlay

- EPRI
- PQ Investigator
- Semiconductor Equipment and Materials International SEMI F47-0700 Standard, 60Hz
- Dip-Prooing Technologies Inc., Voltage Dip Compensator, VDC 4T Model
- Dip-Prooing Technologies Inc., Voltage Dip Compensator, VDC 6T Model
## VDC Sizing

### Technical Specifications

<table>
<thead>
<tr>
<th>MODEL</th>
<th>120V</th>
<th>208V*</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDC S1X120</td>
<td>120V</td>
<td>208V</td>
</tr>
<tr>
<td>VDC S2X250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC LA1X30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC S2X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC S4X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC L6X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC S4X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC L6X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC S4X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC L6X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC L8X120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDC L8X120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### AC INPUT SUPPLY

<table>
<thead>
<tr>
<th></th>
<th>120V</th>
<th>208V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single phase supply voltage:</td>
<td>120V</td>
<td>208V</td>
</tr>
<tr>
<td>Maximum input voltage:</td>
<td>+10%</td>
<td></td>
</tr>
<tr>
<td>Minimum input voltage:</td>
<td>-50%</td>
<td>-50%</td>
</tr>
<tr>
<td>Full load current:</td>
<td>8.5A</td>
<td>4.6A</td>
</tr>
<tr>
<td>Maximum surge current for 3 cycles duration:</td>
<td>55G</td>
<td>24A</td>
</tr>
</tbody>
</table>

### AC OUTPUT

<table>
<thead>
<tr>
<th></th>
<th>120V</th>
<th>208V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal output voltage:</td>
<td>120V</td>
<td>208V</td>
</tr>
<tr>
<td>Voltage fluctuations over full operating range:</td>
<td>± 10%</td>
<td></td>
</tr>
<tr>
<td>Nominal load current:</td>
<td>8.5A</td>
<td>4.6A</td>
</tr>
<tr>
<td>Power factor range:</td>
<td>cos φ from 1 to 0</td>
<td></td>
</tr>
<tr>
<td>Wave shape:</td>
<td>Sinusoidal</td>
<td></td>
</tr>
<tr>
<td>Nominal load (VA):</td>
<td>1000</td>
<td>5000</td>
</tr>
<tr>
<td>Maximum up-time (sec):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timer Control:</td>
<td>0.05 to 3.15s in 0.05s steps</td>
<td></td>
</tr>
<tr>
<td>PFC Control:</td>
<td>Provides extended ride-through time (see user manual for details)</td>
<td></td>
</tr>
<tr>
<td>Overload current Limit (A RMS):</td>
<td>12A</td>
<td>12A</td>
</tr>
<tr>
<td>Short circuit current Limit (A RMS):</td>
<td>30A</td>
<td>30A</td>
</tr>
</tbody>
</table>

---

General Sizing Rule up to existing CPT size.

- **120Vac Sizes** – 1kVA, 3kVA
- **208Vac Sizes** – 1kVA, 5kVA
# VDC Product Matrix in PQI

<table>
<thead>
<tr>
<th>Mfr Part Number</th>
<th>Mitigator Description</th>
<th>Mitigator Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDC S4T1K 120</td>
<td>VDC, 1kVA, 120V, Output, 8.5A, 50/60Hz,</td>
<td>1900</td>
</tr>
<tr>
<td>VDC L4T3K 120</td>
<td>VDC, 3kVA, 120V, Output, 24A, 50/60Hz</td>
<td>3000</td>
</tr>
<tr>
<td>VDC S4T1K 208</td>
<td>VDC, 1kVA, 208V, Output, 4.8A, 50/60 Hz</td>
<td>1900</td>
</tr>
<tr>
<td>VDC L4T5K 208</td>
<td>VDC, 5kVA, 208V, Output, 24A, 50/60Hz</td>
<td>3800</td>
</tr>
</tbody>
</table>
Dynamic Sag Corrector

- Draws power from remaining sagged voltage down to 50% of nominal voltage, and injects a series voltage to regulate a sinusoidal output voltage
- Below 50%, draws power from internal storage capacitors
- Mega and Pro DySC have on board event logging.

MegaDySC
Three-Phase Protection
400-3200Amps

ProDySC
Three-Phase Protection
25-200Amps

MiniDySC
Single-Phase Protection
1-50 Amps
Example DySC Output

Input Voltage (Van)

Missing Volts

DySC Output Voltage
Single Phase DySC Topology

**Static Bypass Switch**
- On under normal conditions
- Highly efficient (>99%)

**Voltage-doubling Rectifier**
- Each dc capacitor charged to peak of AC source voltage
- Idle under normal conditions
- Supplies power to inverter at dc bus during sag correction

**Half-bridge Inverter**
- Idle under normal conditions
- Sinusoidal 12 kHz PWM switching during sag correction
- Acts as an AC voltage source between points A and B, supplying only the missing voltage

**Notes**
- The unique DySC circuit utilizes the same capacitors for two functions: rectifier and inverter
- More “ER” dc capacitors can be added for longer run time when input voltage <50%.
- Series connected inverter requires current path through AC source.
DySC Operation

**Normal Conditions:**
- Capacitors remained fully charged, idle, with no ripple current heating
- Output (load) voltage is continuously monitored
- Output voltage phase and frequency are tracked

**Sag Condition:**
- A voltage sag is detected at the output of the DySC
- Inverter IGBTs apply a reverse voltage to the conducting SCR to quickly force it off (commutate it)
- Inverter regulates the DySC output voltage to produce a sinusoidal output voltage
- When input line rms voltage is restored to >90% for one cycle, the SCRs are turned on and the inverter is shut off
- Capacitors recharge to normal condition within a few cycles
Example: MiniDySC 60% sag correction

Voltage sag Correction

• DC voltage is sufficient to correct voltage sags if input line voltage remains ≥ 50%.
• Stored Energy in capacitors is not needed unless input drops below 50%.
• Correction for up to 5 seconds or 2 seconds cumulative every minute (design limits).

Example: voltage sag to 60% remaining voltage, at full load

• Power in = Power out = Load power (determined by load) = (voltage) x (current)
• Load voltage remains 100%, load current remains 100%
• Input voltage dip to 60% causes input current 167% of load
• Load energy comes from the AC source, not capacitors
Mini-DySC Ride-Through Capability

- **Ride-Through Times**: (Based on 100% load, 0.7PF at 60Hz line frequency)
- **Standard Runtime (SR)** is 5 seconds for sags from 87% to 50% of nominal voltage every 60 seconds
- **3 cycles** for Standard Outage units from 50%-100% (zero voltage remaining)
- **12 cycles** for Extended Ride-Through (ER) units from 50%-100% (zero voltage remaining)
MiniDySC Coverage vs. Sample Historical Data

Tolerance and Protection Curves with PQ Data Overlay

Static Series Compensator with Stored Energy Supply

Coverage out to 5 seconds

WATCH VIDEO

Semiconductor Equipment and Materials International, SEMI F47-0706, Standard 60 Hz

Softswitching Technologies, DySC, MiniDySC, Standard

Softswitching Technologies, DySC, MiniDySC, Extended

MiniDySC Product Matrix

http://ab.rockwellautomation.com/Power-Supplies/Voltage-Sag-Protector

Size to CPT or if fed from CB or Fuse:
(Rated Voltage x Fuse/CB Size) x 0.8.

Pay careful attention to load inrush for units 6A and Below.
Coil Hold-in Devices

- Designed to “Prop Up” individual relays and contactors. Available at 120, 230 and 480Vac.
- Holds in down to 10 to 20% of %Vnominal.
- Ideal for Motor Control Center Applications.
- Size Based on Voltage and Coil Resistance.
- **Cost:** less than $130 per unit

![Coil Lock Diagram](image)

**Figure 2.**
Coil Hold-In Device Ride-Through Curve

Tolerance and Protection Curves with PQ Data Overlay

- SEMI F47

Demo
PLC DC Powered
Sequence Set to "1"
8 cycle sag, 40%
## Coil Hold-In Device Costs

### PQSI Coil Lock

<table>
<thead>
<tr>
<th>Model Number</th>
<th>Coil Resistance Measured with DC Ohmmeter</th>
<th>Comments</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000-120V</td>
<td>801 to 4.5k Ohms [1] UL Compliant File E255764</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>1001-120V</td>
<td>201 to 800 Ohms [1] UL Compliant File E255764</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>1002-120V</td>
<td>8 to 200 Ohms [1] UL Compliant File E255764</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>1002-120V-CE</td>
<td>8 to 200 Ohms [1] UL &amp; CE Compliant (50 ma no load, 0.4 Amp w/8 Ohm Coil)</td>
<td></td>
<td>140</td>
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<tr>
<td>1003-120V</td>
<td>3 to 7.9 Ohms [1] UL Compliant File E255764</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>1001-240V</td>
<td>601 to 17.5k Ohms [2] UL Compliant File E255764</td>
<td></td>
<td>140</td>
</tr>
<tr>
<td>1002-240V</td>
<td>155 to 600 Ohms [2] UL Compliant File E255764</td>
<td></td>
<td>140</td>
</tr>
<tr>
<td>1003-240V</td>
<td>20 to 154 Ohms [2] UL Compliant File E255764</td>
<td></td>
<td>140</td>
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</table>

### Know Trip

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>PART NUMBER</th>
<th>LIST PRICE</th>
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</thead>
<tbody>
<tr>
<td>MODEL 120 8.0 - 35 OHMS</td>
<td>MODEL 120</td>
<td>$268</td>
</tr>
<tr>
<td>MODEL 120-8.5 36 - 200 OHMS</td>
<td>MODEL 120-8.5</td>
<td>$268</td>
</tr>
<tr>
<td>MODEL 120A 201 - 800 OHMS</td>
<td>MODEL 120A</td>
<td>$268</td>
</tr>
<tr>
<td>MODEL 120B 801 OHMS and UP</td>
<td>MODEL 120B</td>
<td>$268</td>
</tr>
<tr>
<td>MODEL 120HP .5 - 7.9 OHMS</td>
<td>MODEL 120HP</td>
<td>$696</td>
</tr>
<tr>
<td>MODEL 240 151 OHMS and UP</td>
<td>MODEL 240</td>
<td>$417</td>
</tr>
<tr>
<td>MODEL 240A 5 - 35 OHMS</td>
<td>MODEL 240A</td>
<td>$1,006</td>
</tr>
<tr>
<td>MODEL 240B 36 - 150 OHMS</td>
<td>MODEL 240B</td>
<td>$1,006</td>
</tr>
<tr>
<td>MODEL 480 151 OHMS and UP</td>
<td>MODEL 480</td>
<td>$423</td>
</tr>
<tr>
<td>MODEL 480 and RC4 40 - 150 OHMS</td>
<td>MODEL 480 &amp; RC4</td>
<td>$615</td>
</tr>
</tbody>
</table>
Some of you have asked “how do I know what type of mitigation technique to use?”

EPRI’s team has learned how to do this because we are constantly conducting PQ Audits and making these decisions.

A simplified approach for selecting a general strategy is presented in this example to help you determine what approach makes sense against the goals of the site, the PQ Data, and the equipment/components to be supported.

PQ Data from 5 example Sites.
How do I decide what mitigator would work best???
Control Level Mitigation Decision Tree

1. **Power Conditioning Process Start**
   - Chiller or Air Compressor Control Panel?
     - YES → Is goal to ride through Sags / Outages?
     - NO → SAGS + OUTAGES

2. **SAGS**
   - Only AC Relays, Contactors, or Motor Starter?
     - YES → Consider DPDT 8 Pin OCTAL SOCKET?
     - NO → Consider DPDT Nice Cubes Relay from PQSI
       - YES → Is there 3-Phase Voltage in the Cabinet?
       - NO → YES
       - NO → Using More than 2 Poles on Relay?
         - YES, 120Vac Relay Only
           - Option 1
           - Option 2
         - NO → Consider Coil Hold-in Device Technology:
           - Size Based on Voltage and Coil Resistance
           - SCR Controls’ Knowtrip

3. **Consider Coil-Lock (120Vac and 240Vac)**
   - YES

4. **Consider Voltage Dip Compensator (VDC) from Dip Proofing Technologies**
   - NO → Consider 2 x Oversized CVT (Sola MCR Series or Equivalent)
   - YES → Consider Standard Outage Rockwell MiniDySC < ¼ Loaded

5. **Consider Extended Outage Rockwell MiniDySC < ¼ Loaded**
   - NO or IDK

6. **Consider UPPI PowerRide RTD 3-Phase CVT**
   - YES → Is Adjacent Feeder Recloser Instantaneous or Hydraulic?
     - YES → YES/NO → Quick (≤0.5 to 2 sec) Back to Back Sags Possible
     - NO → Large Starter, High Inrush in Control Load?
       - YES → Consider 2 x Oversized CVT (Sola MCR Series or Equivalent)
       - NO → Consider Voltage Dip Compensator (VDC) from Dip Proofing Technologies

7. **Consider Square Wave Compatible Controls?**
   - YES → NO
   - NO → Consider Marathon SuperCap UPS

8. **Consider On-Line Battery-Based UPS Solution**
   - YES → Consider Dip Proofing Inverter (DPI) from Dip Proofing Technologies
Together…Shaping the Future of Electricity