EPRI Power Quality Webinar

Presented by:
Mark Stephens, PE, CEM, CP EnMs
Principal Project Manager
EPRI Industrial PQ and EE Group
Thursday, October 22, 2015
11:00 AM Eastern Time

Sponsored by
Introduction

- Tired of your equipment shutting down when the lights blink in your facility?
- In this webcast, EPRI will discuss the challenges and solutions for making equipment “ride-through” events on the electrical system without shutting down.
- This presentation will review what you can expect from the typical electrical environment and present the technologies that can enable ride-through.
- The webinar will discuss low cost mitigation technologies that can be used to increase the ride-through and uptime of your operations.
Follow On Learning Opportunity

Following today’s webcast, you are invited to view training videos to help further solidify the concepts that were discussed.

These videos demonstrate some of the key concepts discussed during the webinar and can be viewed at your leisure.

Videos feature recorded conceptual demos including:

- Visualizing PQ Drive Parameters for Improved Voltage Sag Ride-Through
- Understanding PLC Voltage Sag Ride-Through: AC and DC Powered Systems
- Power Conditioning to Enhance Control System Voltage Sag Ride-Through: The Constant Voltage Transformer

http://mypq.epri.com/
PQ & EE On-Site Assessment Team

Mark Stephens, PE, CEM, CP EnMS
Principal Project Manager

Bill Howe, PE, CEM
PQ Program Manager
Team Advisory Role

Scott Bunton, CEM, CPQ
Technical Lead
PQ Proposals & Assessments

James Owens, CEM, CPQ
PQ and EE Team Member
Logistics, Scheduling, Process

Alden Wright, PE, CEM, CP EnMS
Technical Lead, PQ & EE Assessments

Baskar Vairamohan, PE, CEM
Specialists: Project Management, & Industrial Process Heating

Jason Johns, Technologist
PQ Monitoring & Assessments

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EPRI’s Industrial Energy Efficiency and Power Quality Work

- Headed up primarily from Knoxville, we specialize in solving EE & PQ Problems In all Manufacturing Sectors
- Our Primary mission is to Focus on Reducing End Use Customer Losses by improving process Energy Efficiency and PQ through:
  - Energy Efficiency Assessments
    - Traditional Areas
    - Process Heating
    - Energy Management
  - Power Quality Assessments
    - Voltage Sags
    - Harmonics
    - Flicker
    - Wiring and Grounding
  - Common Areas to PQ and EE
    - Testing (lab and field)
    - Consulting with OEMs
    - Training
### EPRI Industrial Site Assessments 1996-2014

<table>
<thead>
<tr>
<th>Industry</th>
<th>Sites</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Semiconductor</td>
<td>29</td>
<td>13%</td>
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<tr>
<td>Plastics</td>
<td>28</td>
<td>13%</td>
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<tr>
<td>Food &amp; Beverage</td>
<td>25</td>
<td>11%</td>
</tr>
<tr>
<td>Automotive</td>
<td>21</td>
<td>9%</td>
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<tr>
<td>Paper/Printing</td>
<td>17</td>
<td>8%</td>
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<tr>
<td>Machining</td>
<td>12</td>
<td>5%</td>
</tr>
<tr>
<td>Aviation/Aerospace</td>
<td>11</td>
<td>5%</td>
</tr>
<tr>
<td>Fibers/Textile</td>
<td>11</td>
<td>5%</td>
</tr>
<tr>
<td>PetroChem/Nat Gas</td>
<td>9</td>
<td>4%</td>
</tr>
<tr>
<td>Chemical</td>
<td>8</td>
<td>4%</td>
</tr>
<tr>
<td>Commercial</td>
<td>8</td>
<td>4%</td>
</tr>
<tr>
<td>General</td>
<td>7</td>
<td>3%</td>
</tr>
<tr>
<td>Glass</td>
<td>7</td>
<td>3%</td>
</tr>
<tr>
<td>Heavy Ind</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td>Metals/Wire</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td>Govt</td>
<td>5</td>
<td>2%</td>
</tr>
<tr>
<td>Electronic</td>
<td>4</td>
<td>2%</td>
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<tr>
<td>Medical/Hospital</td>
<td>4</td>
<td>2%</td>
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<tr>
<td>Pharma</td>
<td>4</td>
<td>2%</td>
</tr>
<tr>
<td>Power Gen</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total Sites</strong></td>
<td><strong>223</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Average/Year</strong></td>
<td><strong>13</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Mid Year 2015: Paper, Semi, Auto, Food & Bev, Textile, & 10 Hospital/Research Sites**
Why is PQ Important?

- 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?
Interrelated Processes

Is Power Present?
- NO
- YES

Is Compressed Air Present?
- NO
- YES

Is Process Cooling Water Present?
- NO
- YES

Are the Exhaust Systems Running?
- NO
- YES

Is Interlocked Process Running?
- NO
- YES

Ok to Run Automated Process

CONTINUALLY REPEATED
Outage or Sag?

Diagram:
- Utility Substation
- Customer A (Sag)
- Customer B (Outage)
- Fault

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Typical Recloser Screens

Faulted Feeder “A”

Initial Fault
TD 1
Reclose Attempt 1
TD 2
Reclose Attempt 2
TD 3
Reclose Attempt 3

Time

RMS Voltage

Adjacent Feeder “B”

Sag Event
TD 1
Sag Event
TD 2
Sag Event
TD 3
Sag Event

From Initial Fault
Reclose Attempt 1
Reclose Attempt 2
Reclose Attempt 3

Time

RMS Voltage
Targeting by Cause

Northwest US

By Occurrence
- Equipment Failure (29%)
- Foreign Interference (16%)
- Tree Contacts (13%)
- Unknown (9%)
- Weather (9%)

By Hours Out
- Tree Contacts (27%)
- Weather (21%)
- Equipment Failure (18%)
- Foreign Interference (14%)
- Unknown (6%)

EPRI Fault Study

- Lightning
- Tree contact
- Equipment failure
- Animal
- Wind
- Dig-in
- Vehicle accident
- Ice/snow
- Vandalism
- Construction activity
- Other

Percent of faults by cause

FIGURE 7.1
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)
How many phases “sag”?

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

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

Ref: EPRI TPQ-DPQ III Study, June 2014
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.
Rural Site 5 Minute Aggregation, 14 Months of Data

Tolerance and Protection Curves with PQ Data Overlay

EPRI

PQ Investigator

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## Rural Site Summary of Events

<table>
<thead>
<tr>
<th>Intermittent Events</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled outages</td>
<td>2</td>
</tr>
<tr>
<td>Station Breaker outage, Bird contact pole fire near Site</td>
<td>1</td>
</tr>
<tr>
<td>Station Breaker operated, Weather lightning, tree contact</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage Sags</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Storm</td>
<td>6</td>
</tr>
<tr>
<td>Weather Lightning Storm</td>
<td>6</td>
</tr>
<tr>
<td>No Trouble Tickets/operations</td>
<td>26</td>
</tr>
<tr>
<td>Blown transformer fuse due to squirrel</td>
<td>10</td>
</tr>
<tr>
<td>TOR outage beyond protective Device</td>
<td>10</td>
</tr>
<tr>
<td>TOR outage beyond protective Device</td>
<td>15</td>
</tr>
<tr>
<td>Failed equipment</td>
<td>5</td>
</tr>
<tr>
<td>Blown fuse at Adjacent Industrial</td>
<td>2</td>
</tr>
<tr>
<td>Adjacent Industrial Substation Fire</td>
<td>1</td>
</tr>
<tr>
<td>Vehicle accident</td>
<td>1</td>
</tr>
</tbody>
</table>

**Note:**
- TOR – Tree Outside of Right-Of-Way
- TIR – Tree Inside Right-Of-Way
Is it the Plant Equipment’s Fault?

Tolerance and Protection Curves with PQ Data Overlay

- Potter & Brumfield, KRPA, KRPA-14Al-120, 120 VAC, 60Hz
- Allen Bradley, PLC 5/11: 1765-L11B/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)
Goal – Extending the Operating Envelope

“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.
Important Realization

- **Utilities Share Responsibility**
  - Tree Trimming, Lighting Arrestors, Grounding, Maintenance, Provide PQ information to industrials, etc

- **Industrials Share Responsibility**
  - Understanding Equipment Vulnerability, PQ Specifications, Power Conditioning, Proper Wiring/Grounding, etc

- **Most effective solutions are reached when both sides work together to see what can be done**
Voltage Sags and Solutions
Common Weak Links – AC Powered Relays, Contactors, Motor Starters, PLCs

Figure 1. A rack-mounted PLC power supply that requires AC voltage (120/208-240 volts)

Figure 5. Composite Low-Voltage Tolerance of Relays
AC Circuits that can be Sensitive
Another Example Weak Link - Drive Interfacing Circuits

- AB Power Flex 700
- Drive is compliant to SEMI F47
- Utilizes Run Relay and Stop Interposing Relays ("ice cubes").
- Powered from 500VA CPT in cabinet, circuit goes to field start and stop pushbuttons and back to relays in drive cabinet
PQ Investigator Tool

- EPRI has developed a tool called PQ Investigator.
- This tool allows for look up of hundreds of device ride-through curves.
- SCE&G has the software and can help you understand your equipment sensitivities to voltage sags.
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 1668
    - Trial Use Recommended Practice
    - Applicable to General Industry
IEEE 1668 Excerpt

- 1, 2, & 3 phase voltage sag requirements
- Comprehensive document:
  - Primer on Voltage Sags
  - Recommended test requirements
  - Test Procedures & Guidelines
  - Test Equipment Requirements
  - Certification and Test Report Requirements

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Table 12 — IEEE 1688™ voltage-sag equipment-immunity specification sheet (for use with three-phase equipment)

**Immunity Curve for Type I & Type II Sags**

- Duration [ms]
- Voltage [%]

**Immunity Curve for Type III Sags**

- Duration [ms]
- Voltage [%]

**Type I and II voltage-sag test points:**
- 80% for 2 s
- 70% for 500 ms
- 50% for 200 ms

Repeat for test points for each phase-neutral and phase-to-phase combination.

**Testing for Type III voltage-sag required:**
- 80% for 2 s
- 70% for 100 ms
- 50% for 50 ms

<table>
<thead>
<tr>
<th>Desired Type II Test Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type II</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pass/Fail Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Operation</td>
</tr>
<tr>
<td>Full Operation</td>
</tr>
</tbody>
</table>

Testing Procedure Requirements: IEEE 1668
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.
Summary of Robust Power Supply Strategies: Relative Power Supply Single Phase Sag Response

All of these units will perform even better if Half Loaded or Less!
AC Versus DC Input for PLCs

Figure 1. A rack-mounted PLC power supply that requires AC voltage (120/208-240 volts)

Figure 2. External power supply that provides 24 volts DC to the rack-mounted PLC power supply.

Related Follow on Learning Opportunity at http://mypq.epri.com

Video 2: Understanding PLC Voltage Sag Ride-through: AC and DC Powered Systems
This video demonstrates the differences in voltage sag ride-through between an AC powered PLC system and a DC Powered PLC system.
Utilize Sag Tolerant Components

- IF AC Relays and Contactors are used in the semiconductor tool design, then utilize compliant devices.
- Consider response at both 50 and 60 Hz.
- Many components have been certified to SEMI F47.
Examine Drive Configuration Settings

- In most cases, drive manufacturers give users access to basic microprocessor program parameters so that the drive can be configured to work in the user’s particular application.

- An AC drive’s programming parameters associated with reducing the effect of voltage sags are typically in the drive manual.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic Reset</td>
<td>This parameter allows the drive to automatically reset some fault conditions, such as DC link undervoltage or overvoltage, without the need for operator/user intervention. This feature is used in conjunction with Automatic Restart.</td>
</tr>
<tr>
<td>Automatic Restart</td>
<td>This parameter defines the method in which the drive automatically restarts after a fault condition is over. Automatic Restart operations may only be used as outlined in NFPA 79. Equipment damage and/or personal injury may result if the Automatic Restart parameter is used in an inappropriate application.</td>
</tr>
<tr>
<td>Kinetic Buffering</td>
<td>When the drive senses a DC link low-voltage condition, the drive uses the combined motor-load inertial energy to maintain a factory-programmed DC link voltage inside the drive by applying a braking force to the motor. This feature does not create a potential for extreme current or torque transients.</td>
</tr>
<tr>
<td>Motor Voltage Compensation</td>
<td>When the drive senses a DC link low-voltage condition, the drive’s controller changes the inverter firing timing sequences to compensate for a reduced DC link voltage. The objective is to maintain as close as possible the desired output voltage for operating the motor and load.</td>
</tr>
<tr>
<td>Controlled Deceleration and Acceleration</td>
<td>When the drive senses a DC link undervoltage condition, the drive begins to decelerate the motor at a user-defined rate. When the undervoltage condition ends, the drive reaccelerates the motor back to the desired operating point. This feature is often used in processes with multiple drives operating in succession, where all drives are expected to operate in unison to maintain process quality. This feature works well for common DC bus drive systems.</td>
</tr>
</tbody>
</table>


Video 1: Visualizing PQ Drive Parameters for Improved Voltage Sag Ride-Through

This video demonstrates the voltage sag susceptibility of AC drive systems and how to improve the drive’s robustness through parameter changes.
Other Considerations

- Make sure the device rated voltage matches the nominal voltage. Mismatches can lead to higher voltage sag sensitivities (for example 208Vac fed to 230Vac rated component).
- Consider Subsystem performance. Vendor subsystems must be robust for the entire system to be robust. Otherwise, power conditioning may be required for the subsystem.
- Consolidate Control Power Sources. This will make the implementation of any required power conditioner scheme much simpler and cost effective.
- Use a targeted voltage conditioning approach as the last resort. Apply Batteryless power conditioner devices where possible.
Example Power Conditioning Approaches

Machine or Subsystem Level
Power Conditioning

Control Level
Power Conditioning
(1/10th to 1/20th of Machine Level Power Conditioner Cost)

Control Level
Embedded DC Solution
(Best done by OEM in design phase)
Solution Application Points

• Voltage Sags may be mitigated at a variety of locations
• Service Entrance, Panel Feeder, Panel, Machine, and Control Levels.

Example Network:
Machine and Panel Level Solutions
Generalized Example: Control Level to Equipment Level Cost vs. Coverage

Example Cost per Option

Cost (USD)

Most Equipment Level
Level
Control Level
Relay Level
Least

Minimum $20K
$40K
$60K
$80K
$100K+

Maximum

Equipment Level
$25K to $88K+

Small Power Conditioner $1500 - $3000
Replace Relay $25
Coil Lock $130
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: A Common Problem
Common Power Conditioners for Control Level Voltage Sag Mitigation

- **CVT (Constant Voltage Transformer)**
- **VDC (Voltage Dip Compensator)**
- **DPI (Dip Proofing Inverter)**
- **MiniDySC (Mini Dynamic Sag Corrector)**

*Typical Cost $1500-$3000 Per Application*
Common Power Conditioners for Control Level Voltage Sag Mitigation

CVT

Constant Voltage Transformer

Related Follow on Learning Opportunity at http://mypq.epri.com
Video 3: Power Conditioning to Enhance Control System Voltage Sag Ride-Through: The Constant-Voltage Transformer
This video shows how a CVT can be utilized to harden the voltage sag response of an automated control system.
Coil Hold-In Device Ride-Through Curve

- Designed to “Prop Up” individual relays and contactors. Available at 120, 230 and 480Vac.
- Ideal for Motor Control Center Applications.
- Size Based on Voltage and Coil Resistance.
- Cost: $130 per unit
Nice Cube “Assembly”

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

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

Insert “DC Ice Cube”
Drop Out ~ 25-40% Vnom
Typical AC “ice cube” Vs. PQSI “Nice Cube” Assembly

Tolerance and Protection Curves

Cost: $85 per unit
Mitigation Coverage and PQ Events

- Example AC “Ice Cube” Relay/Sensitive PLC
  - The blue line indicates the coverage area for the MiniDySC Power Conditioner.
    - www.softswitch.com

- The green line indicates the coverage area for the CVT when ½ loaded.
  - www.emersonindustrial.com

- The brown line indicates the coverage for Nice Cube.
  - www.pqsi.com
Example Problem – Multiple Cabinets Fed from Centralized Control Power Panels

- **AB PLC 5**
  - 78% Vnom
  - Remote rack – 72% Vnom

- **Idec RY4S – ac “Ice Cube” relays**
  - ~70% Vnom
Example Solution: Distribution Panel Level Mitigation

- Remove abandoned UPS and use UPS bypass switch already in place

- Four distribution panels in room for Extruder lines plus one additional for other related control loads (5 total)
**Another Distribution Panel Example**

- Sometimes the most effective solution is to provide conditioned power for the entire IPP Panel. Advantages of this approach include:
  - Simplified Cut Over/Fewer Touch Points
  - Single Power Conditioner for many loads
  - When sized to support kVA of transformer, this approach will support future expansion in panels
Feeder Level Mitigation Scenarios

- Multiple very large sag mitigation devices
  - Fewer installation points, less wiring, conduit, & labor
  - Higher Equipment Costs
  - More Comprehensive Coverage
- Some Typical Voltage Sag Solutions
  - Omniverter AVC
  - Softswitching DySC
Conclusions

- It’s a team effort to solve these problems, the utility, industrial/commercial, and consultants need to come together.
- Understanding why your equipment is vulnerable is paramount. You can’t fix a problem without understanding the true cause.
- Moving forward you can make industrial systems more robust… sometimes with simple modifications.
- Don’t assume battery based systems are required.
- Be sure to include PQ standards in your purchase specifications (SEMI F47, IEEE 1668, etc.)