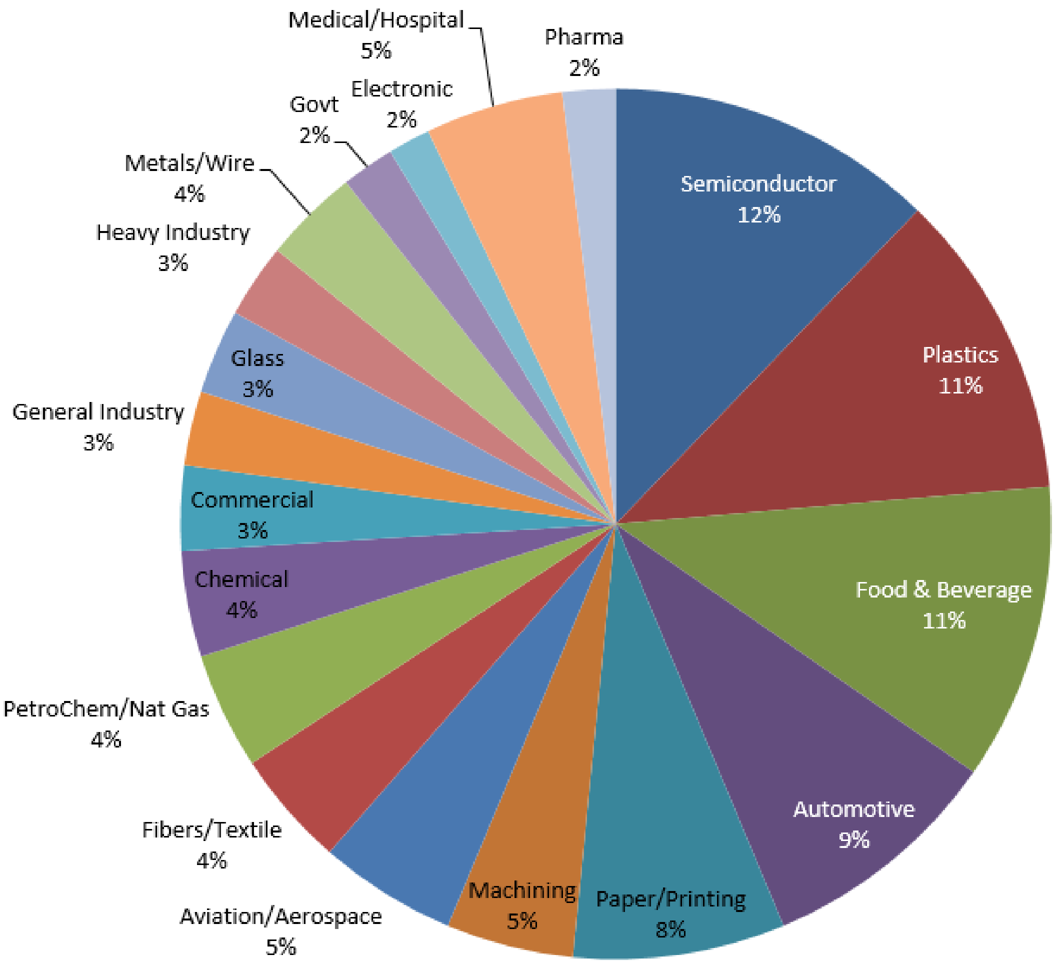
5.0 PQ Hot-Line Calls & Case Studies

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

EPRI Industrial Site Assessments 1996-2016

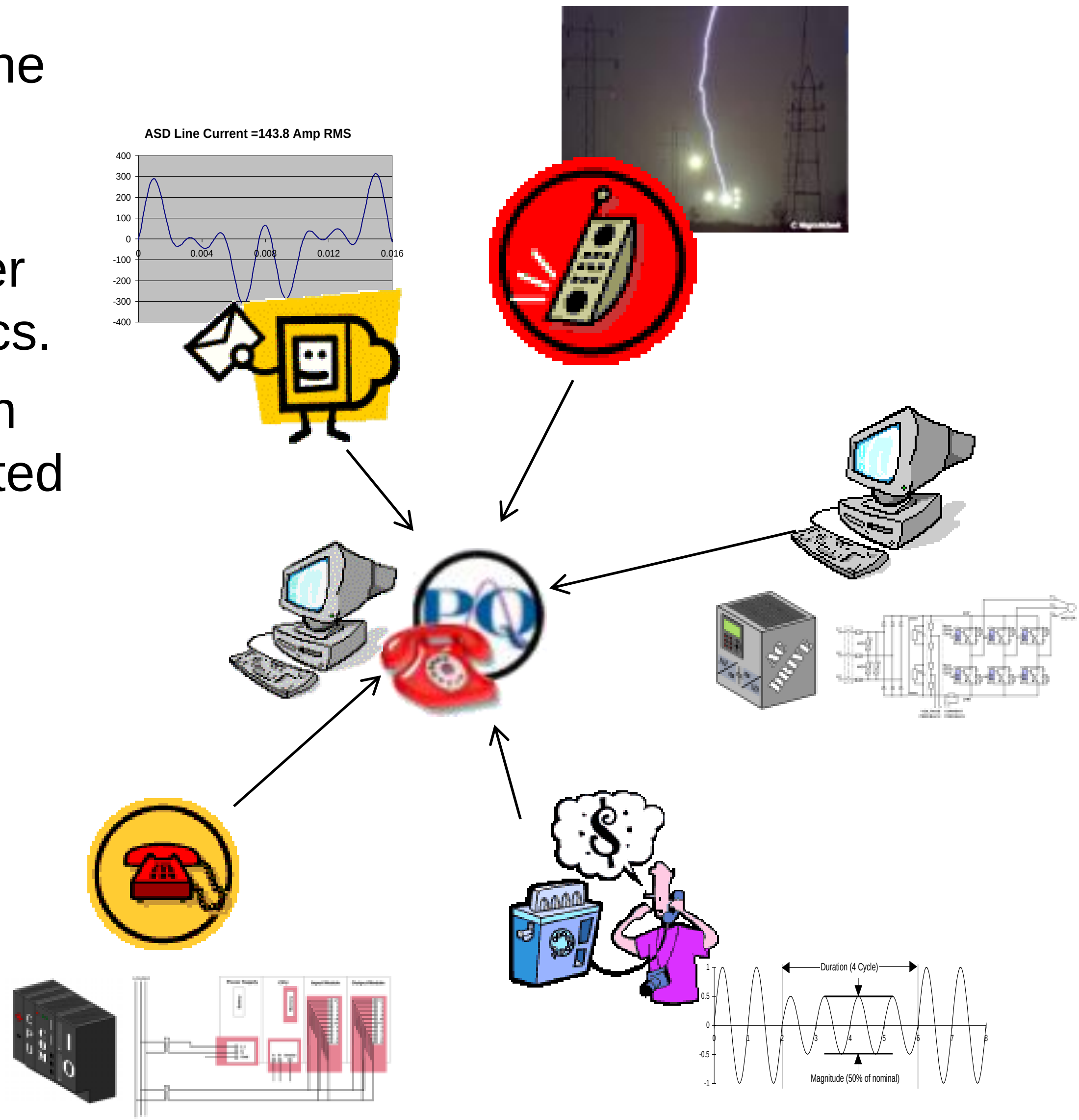


Site Investigations 1996-2016		
Industry	**Sites**	**Percentage**
Semiconductor	31	12%
Plastics	29	11%
Food & Beverage	28	11%
Automotive	23	9%
Paper/Printing	20	8%
Machining	12	5%
Aviation/Aerospace	13	5%
Fibers/Textile	11	4%
PetroChem/Nat Gas	11	4%
Chemical	10	4%
Commercial	8	3%
General Industry	7	3%
Glass	8	3%
Heavy Industry	7	3%
Metals/Wire	9	4%
Govt	5	2%
Electronic	4	2%
Medical/Hospital	13	5%
Pharma	5	2%
Power Gen	1	0%
Total Sites	***255***	
Average/Year	***13***	

13 Sites in 2016

PQ Hotline Calls-Of-The-Month

- This project directly benefits the utility and their customers.
- EPRI operates a hot-line for funding members to ask power quality questions from all topics.
- Each month, the best question and EPRI response is presented at the “Hot Line Call of the Month.”



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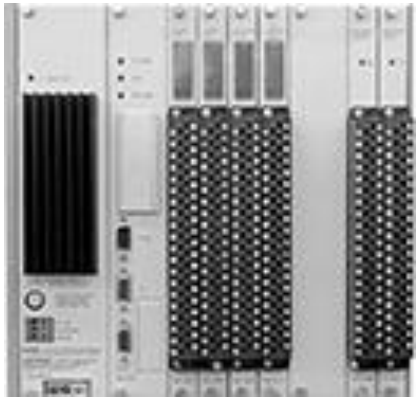
Hot Line Calls of the Month

PQ HOTLINE:
CALL-OF-THE-MONTH

January 2014: Understanding UPS Types and Their Ability to Harden Industrial Controls to Voltage Sags: Part 1

- **Question:** Via EPRI's PQ Knowledge (PQK) Power Quality Hotline, a PQK funder asked which is the best uninterruptible power supply (UPS) to use for protecting industrial processes?
- **Answer:** The answer, of course, is, "It depends," especially on the types of processes and industrial control loads that you are trying to protect.
- This first part of a two-part series on selecting the right UPS technology for your application discusses the three major UPS topologies.
- The second part will investigate a case study on the consequences of applying the wrong type of UPS.



Industrial process loads, such as relays and programmable logic controllers (PLCs) may be vulnerable to voltage sags.

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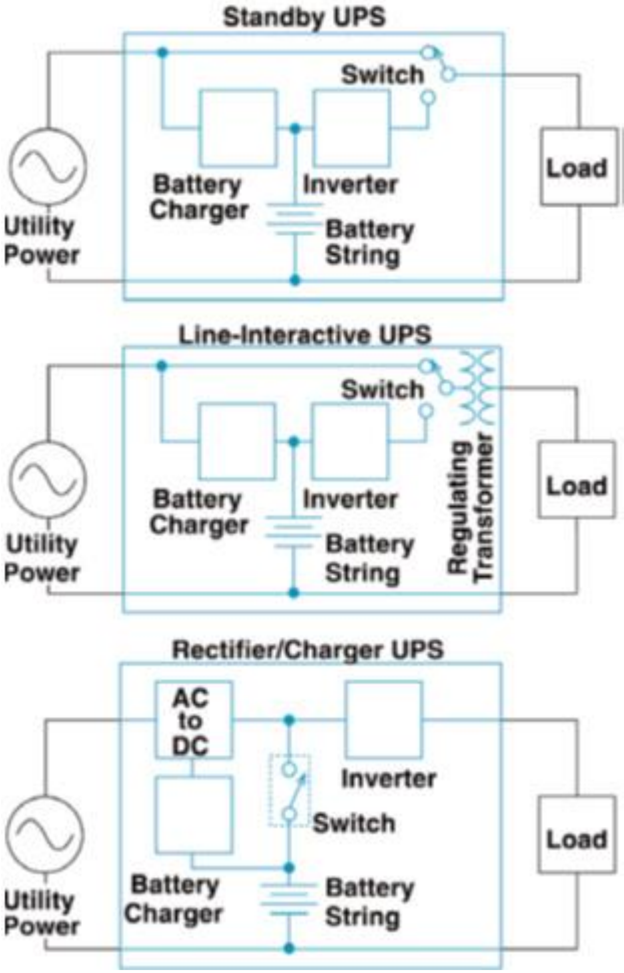
Background

- Occasionally, facility engineers attempt to mitigate voltage sags by installing an uninterruptible power supply (UPS) on critical process controls or individual components.
- Different UPS topologies with different strengths and weaknesses are available for purchase.
- If the wrong UPS topology is applied to industrial control components, it may not harden the process to voltage sags and may *<u>in fact make the ride-through performance of the industrial equipment worse.</u>*

Although uninterruptible power supplies are designed to protect sensitive loads, some topologies may not be suitable for sensitive industrial controls.

UPS Types

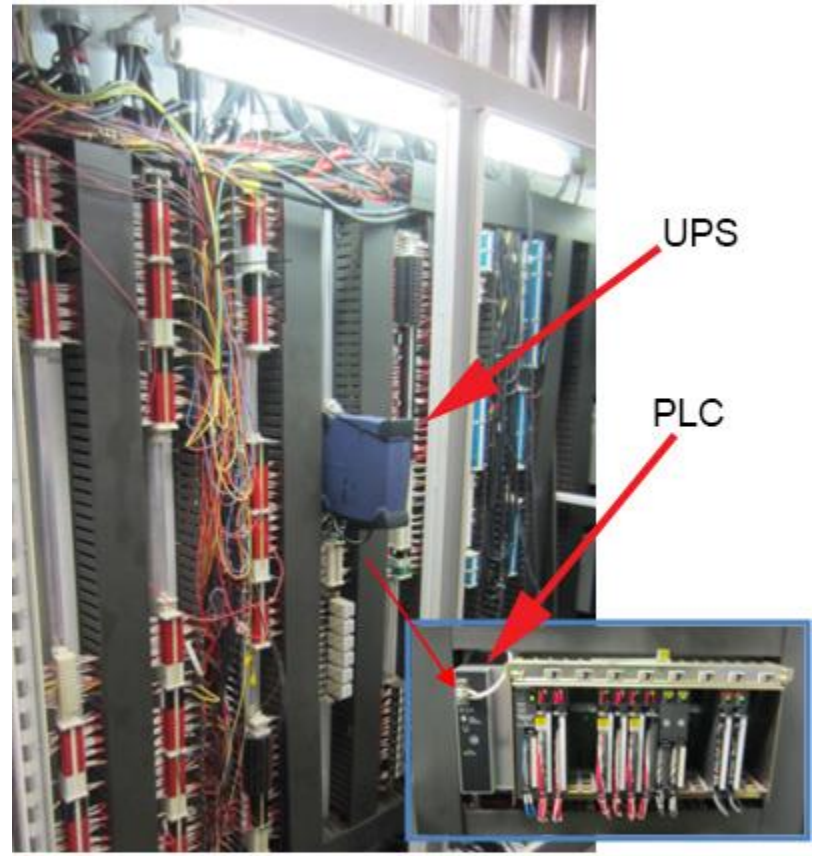
- **A Standby UPS** is the type often found at a local computer store intended to backup a desktop computer in the event of a power outage. This UPS is normally bypassed
- A **Line-interactive UPS** is very similar to a standby UPS—the major difference between the two being that some kind of voltage-regulation transformer is located between the transfer contactor and the load. The regulation transformer is typically a fast-switching auto transformer or a constant voltage transformer.
- The **Online UPS design** is significantly different from the two topologies previously described. An online UPS rectifies the input voltage, converting it to DC, and recreates AC voltage for the load.



There are three basic UPS topologies.

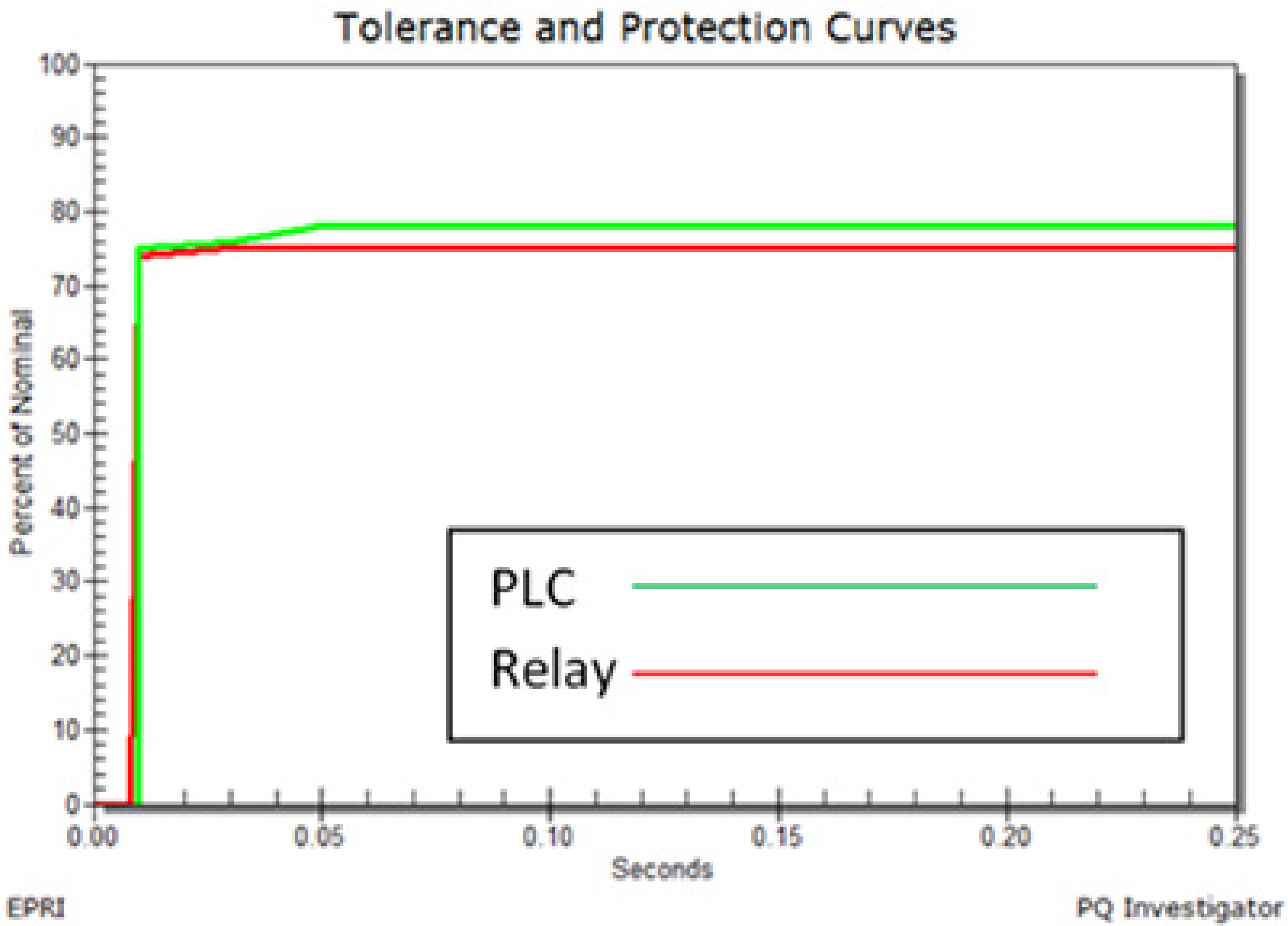
UPS Found in the Facility: Why a Standby UPS May Not Work for Industrial Control Applications

- The control cabinet used a standby UPS in several locations throughout the facility.
- The standby UPS technology has a switch between the line and the inverter output connection.
  – This switch is typically a relay or contactor. Relay contacts do not switch instantaneously; in fact, they may take more than a 60-Hz cycle (or 16 milliseconds) to accomplish the switching operation.
  – This single-cycle delay can cause sensitive loads to drop out.



A standby UPS was used to prop up a PLC at a food-processing facility

Sensitivity of Items in Control Cabinet



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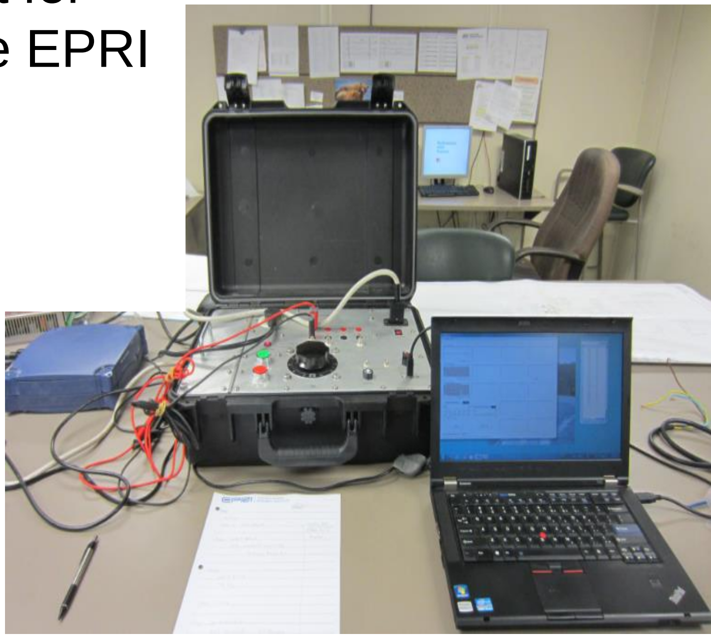
Discussion

- The response time of this UPS largely depends upon the response time of the relay used to switch from the source voltage to the inverter voltage, an action that, as described earlier, may take a full cycle.
- The two devices in the ride-through curve shown indicate that these loads trip due to a 10-millisecond interruption.
- Since the UPS must have time to detect an event before executing the transfer, the whole operation from detection to transfer may well exceed the voltage sag tolerances of these two devices.
- A standby UPS would typically work well with devices such as desktop computers but may not be the best choice for industrial components.
- The power supply inside a computer typically contains a significant amount of capacitance for DC bus filtering.
- These capacitors have a secondary effect in that they add some voltage sag ride-through capability that enables the computer to operate normally through the transfer stage of the standby UPS.

January 2014: Understanding UPS Types and Their Ability to Harden Industrial Controls to Voltage Sags: Part 2

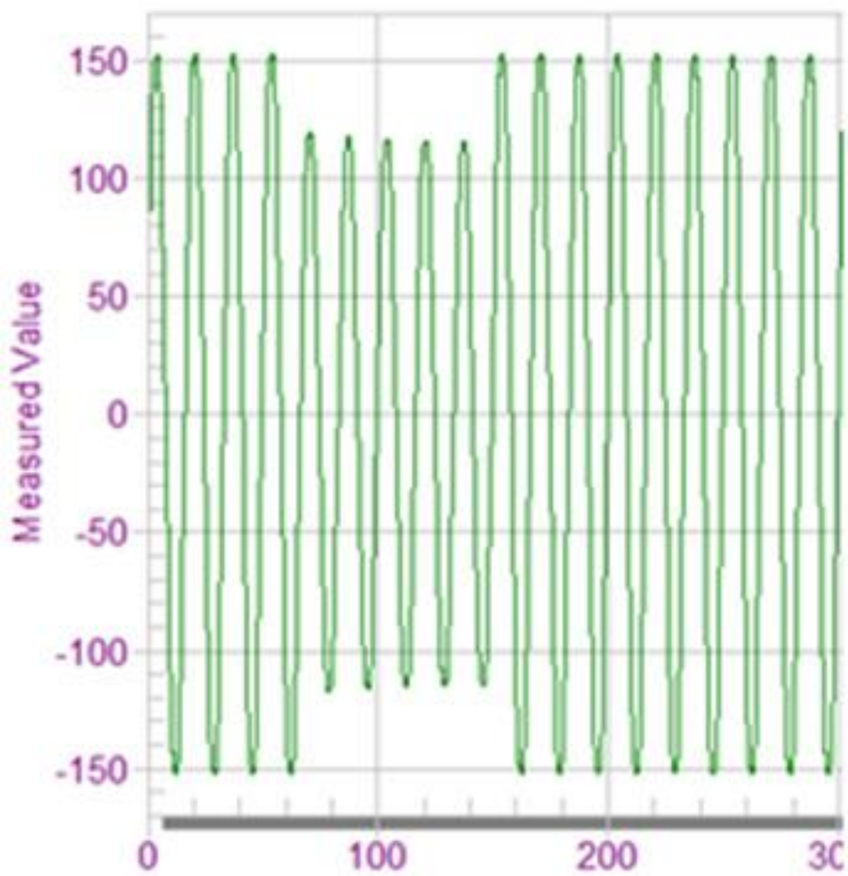
- When conducting power quality audits, EPRI engineers occasionally encounter a component for which a ride-through curve does not exist in the EPRI ride-through database.
- Various voltage sag generators designed by EPRI—ranging in size from 15 amperes (single-phase) to 200 amperes (three-phase)—can create voltage sags or swells from a quarter cycle to 3 seconds in increments of one-quarter cycle and from 120% to 0% of nominal voltage on demand.
- EPRI engineers may take the 15-A suitcase model called the Porto Sag to the PQ audit to test components that are not already in the EPRI database.



UPS Low-Voltage Detection Too Low

- The test demonstrated that the UPS did not attempt to transfer to the alternative source until the voltage dropped to 70% of nominal voltage.
- The figure shows the UPS output 5-cycle voltage sag to 75% of the nominal voltage.
- The waveform shows that the UPS did not transfer during that sag and indeed would have passed the sag to the PLC.
- The voltage sag ride-through of one of the typical PLCs in the facility was 1 cycle at 78% of nominal voltage.
- ***Therefore, this event would have shut down the PLC.***

A 5-cycle voltage sag to 75% of nominal voltage did not trigger the UPS to switch to its alternative source.



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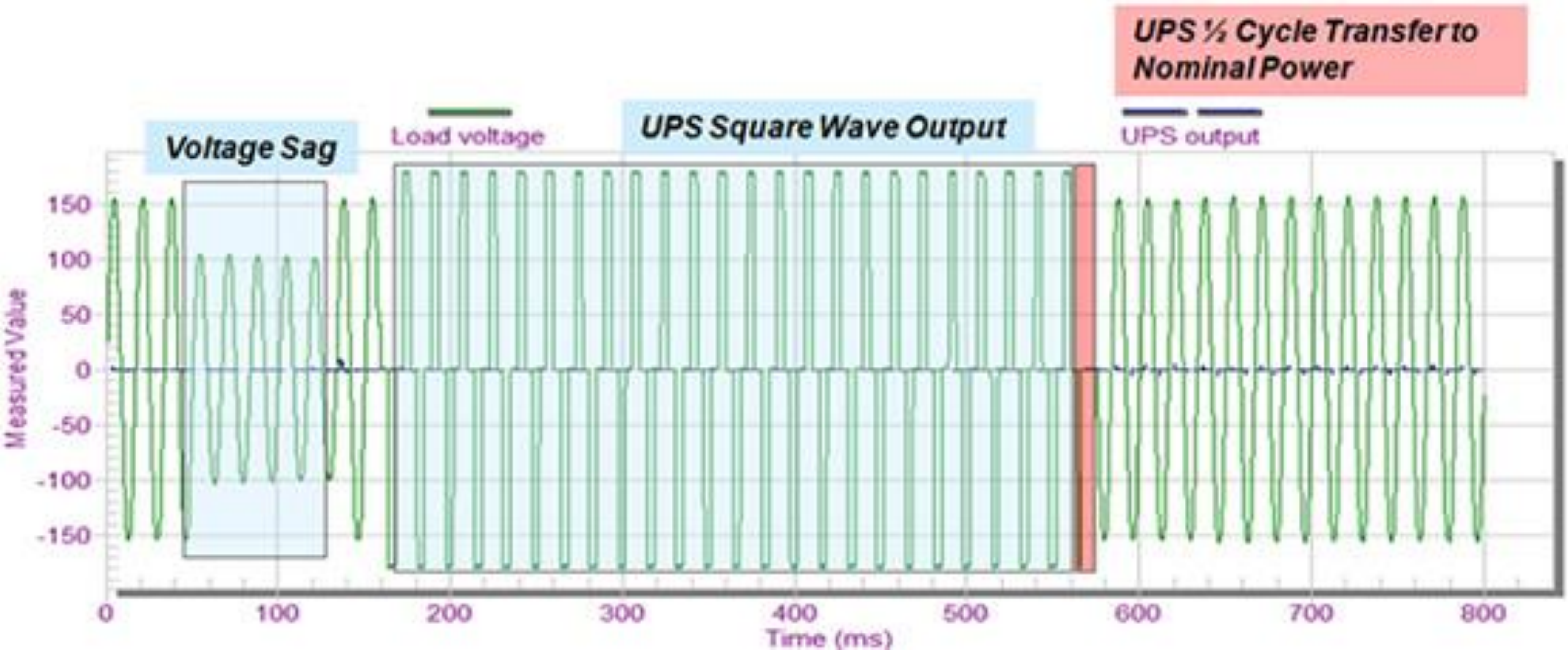
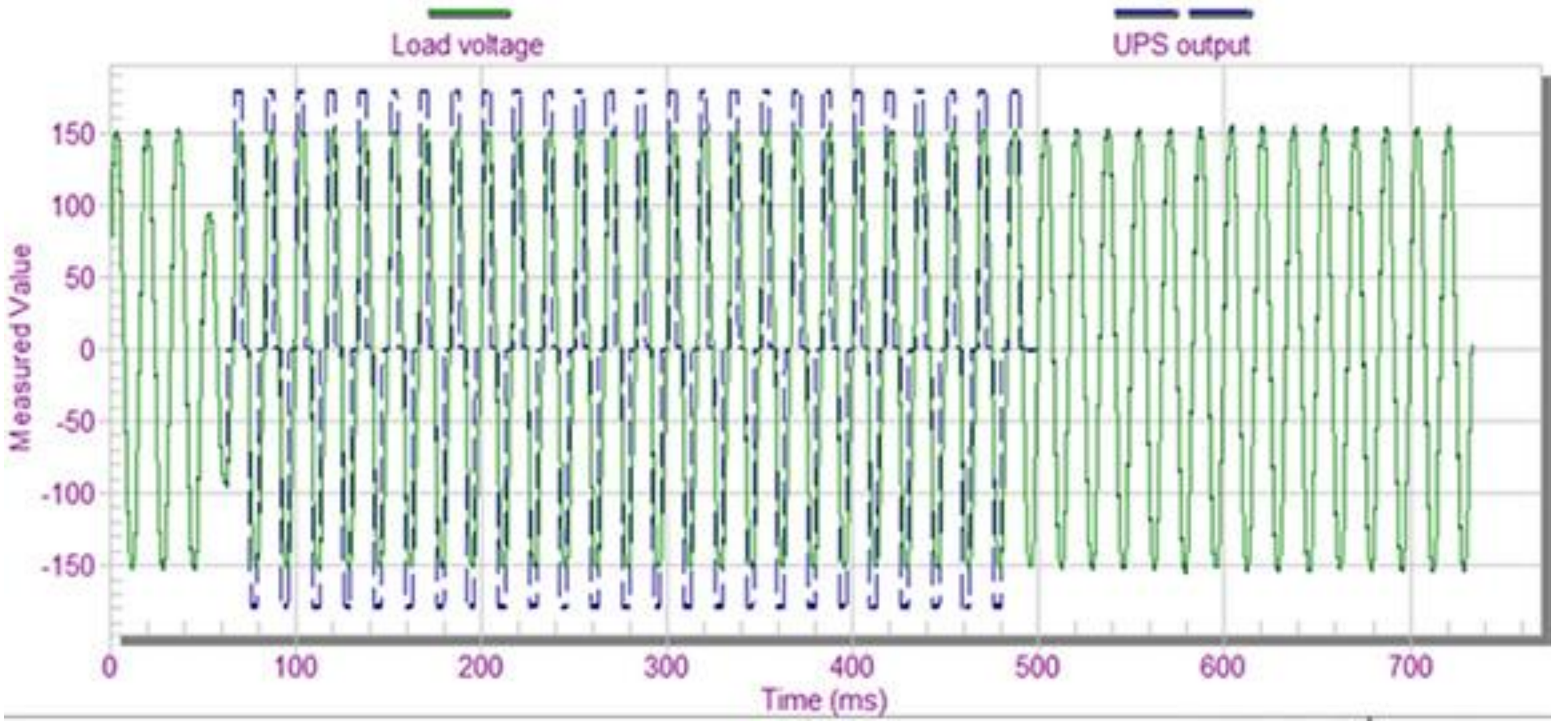
UPS Transfer Too Late



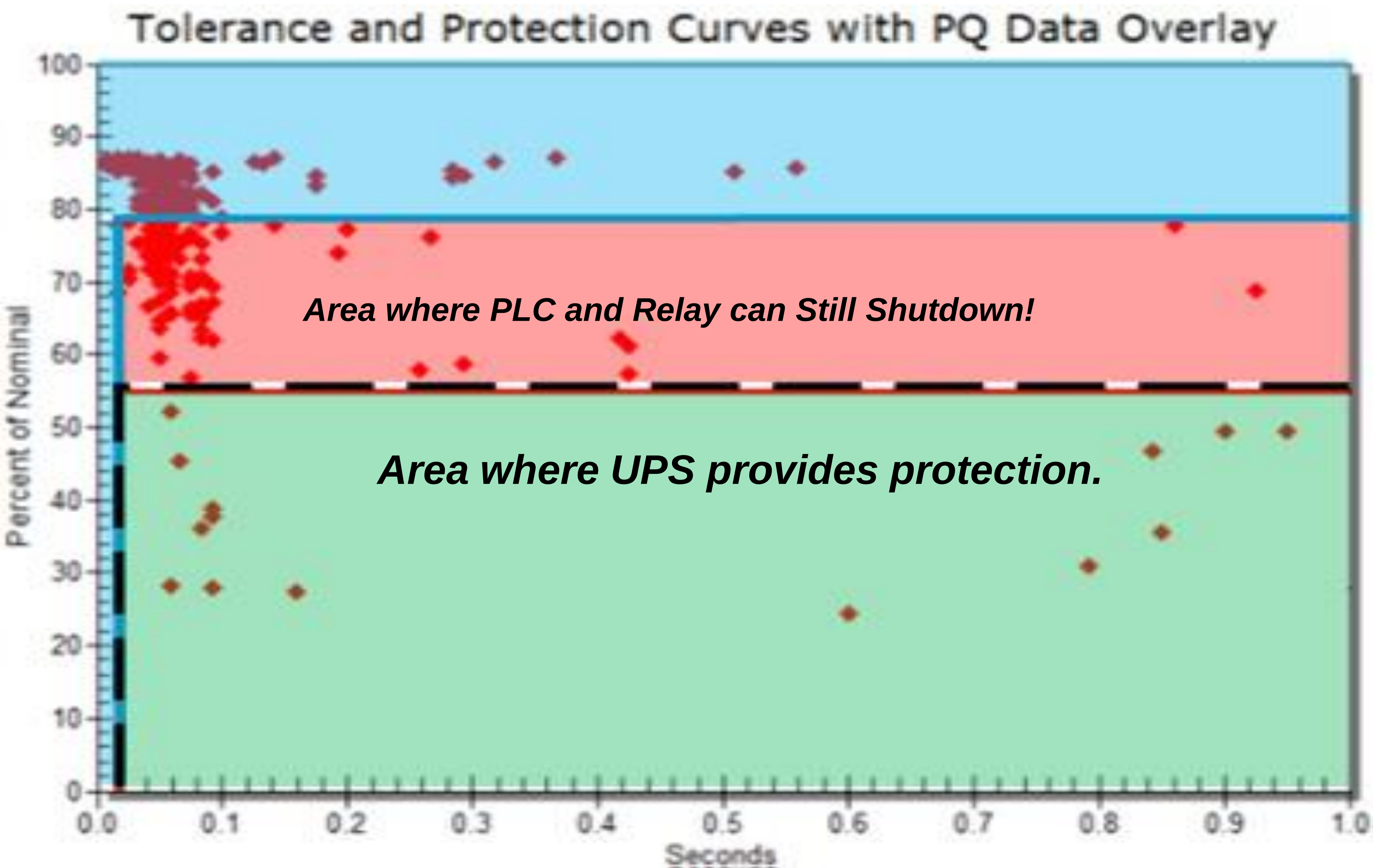
The UPS that was used in the food-processing facility exhibited intolerable latency when switching to and from alternative power.

Transfer Time Acceptable at Lower Sag Voltages



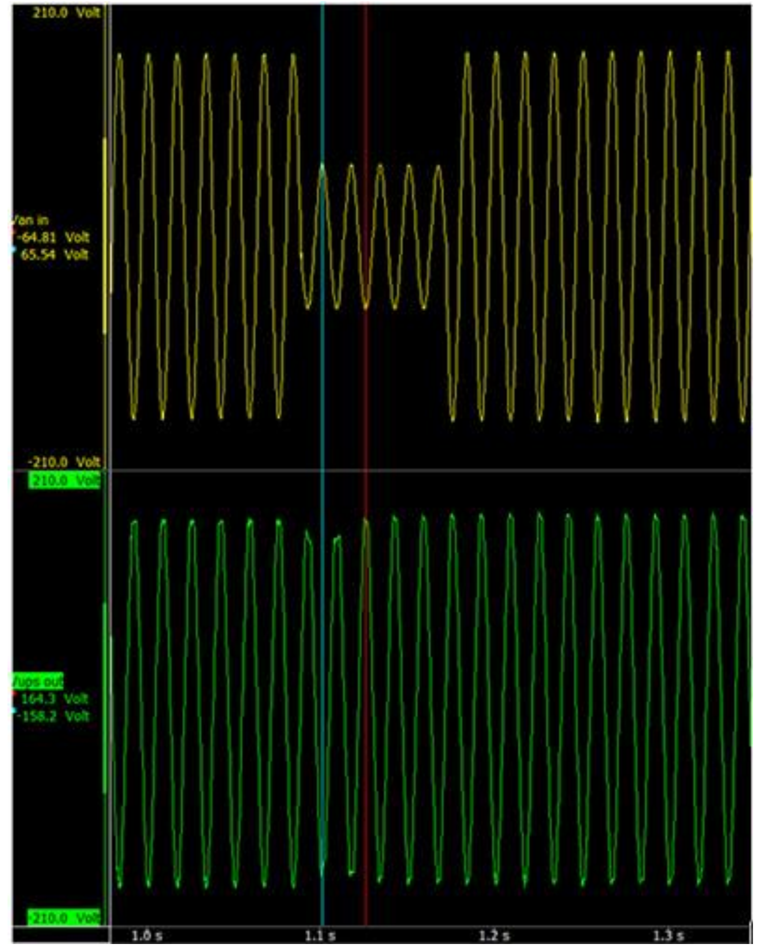
The UPS protected its load during a 1-cycle voltage sag to 55% of nominal voltage.

UPS Response against PQ Data



What Type of UPS for Industrial Applications?

- An online or "rectifier/charger" UPS would probably be the recommended UPS should a UPS be absolutely necessary to support industrial control loads.
- The reason that an online UPS may be a better choice than a standby UPS for mitigating the effects of voltage sags on industrial controls is that the *output voltage is continuous.*



The output of an ultracapacitor-based UPS is continuous and sinusoidal, even during deep voltage sags

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Other Considerations When Specifying a UPS

1. What is the type of output waveform? Some discrete PLC AC input cards tested at EPRI cannot render a 0 or 1 when the input signal is a square wave.
2. Is long-term coverage during voltage interruptions necessary? Battery-less mitigation devices can provide short-term coverage and require little to no maintenance.
3. If interruption coverage is necessary for industrial controls, does the maintenance staff understand that it must support the batteries reliably in multiple units? A large distributed UPS approach to centralize the battery maintenance may be preferable.
4. How may the charge level of a battery and the battery's condition be monitored? Specify a UPS that provides a battery health contact that may be monitored by a PLC or other monitoring device. Knowing the health of the battery is good insurance that the UPS is going to support its load during the next voltage sag.

Conclusion

- When applying UPS technology to industrial control circuits, the person in charge of specifying the UPS must understand the different types of UPS technology and the effects that they may have on industrial controls.
- The UPS that EPRI engineers discovered in the food-processing facility discussed in this Hotline Call of the Month was the wrong choice to support industrial controls for two main reasons:
  - The low voltage transfer setting of the UPS was below the susceptibility of the industrial control loads.
  - Occasionally, the transfer between normal power to the inverter was too long to support the sensitive loads.

Conclusion (cont.)

- When specifying power conditioning for industrial control loads, interruption coverage for the process controls may not be necessary.
- If long-term voltage interruption coverage is not necessary—as in this case—battery-less solutions for voltage sags, such as the ultracapacitor-based UPS, Dynamic Sag Corrector (DySC), or constant-voltage transformer (CVT), may provide effective mitigation against voltage sags, without battery maintenance.
- Should a battery-based UPS be necessary for multiple control cabinets, a central UPS providing mitigation for all cabinets may minimize battery maintenance.
- Specifying an appropriate UPS for a specific application is not difficult when the engineer understands the available UPS topologies and the potential effects that their voltage output may have on the end-use equipment.

HealthCare Facilities

PQ Characteristics

- Healthcare PQ
  - Same as for anyone else
- Standards
  - The IEEE Standard 602 (*White Book*), and
  - IEEE Standard 1100 (*Emerald Book*)
    - excellent technical resources
    - power quality in healthcare facilities and medical clinics
    - powering and grounding sensitive electronic equipment during facility construction

Categories			Typical Duration	Typical Spectral Content	Typical Voltage Magnitude	Method of Characterizing	Typical Causes	Example of Power Conditioning Solutions
Transients	Impulsive	Nanosecond	> 50 nanoseconds	5 ns rise		Peak Magnitude, Rise Time, Duration	Lightning, Electro-Static Discharge, Load Switching, Capacitor Switching	Surge Arresters, Filters, Isolation Transformers
		Microsecond	50 nanoseconds to 1 millisecond	1 μ rise				
		Millisecond	> 1 millisecond	0.1 ms rise				
	Oscillatory	Low Frequency	0.3 milliseconds to 50 milliseconds	< 5 kHz	0 to 4 pu	Waveforms, Peak Magnitude Frequency Components	Line/Cable Switching, Capacitor Switching, Load Switching	Surge Arresters, Filters, Isolation Transformers
		Medium Frequency	20 microseconds	5 to 500 kHz	0 to 8 pu			
		High Frequency	5 microseconds	0.5 to 5 MHz	0 to 4 pu			
Short Duration Variations	Instantaneous 0.5 cycles to 30 cycles	Sag			0.1 to 0.9 pu	RMS vs. Time, Magnitude, Duration	Remote System Faults	Ferroresonant Transformers, Energy Storage Technologies, UPS
	Momentary 30 cycles to 3 seconds	Swell			1.1 to 1.8 pu			
	Temporary 3 seconds to 1 minute	Interruption			< 0.1 pu	Duration	System Protection (Breakers, Fuses), Maintenance	Energy Storage Technologies, UPS, Backup Generators
Long Duration Variations	Undervoltages		> 1 minute		.08 to 0.9 pu	RMS vs. Time, Statistics	Motor Starting, Load Variations, Load Dropping	Voltage Regulators, Ferroresonant Transformers
	Overvoltages		> 1 minute		1.1 to 1.2 pu			
Voltage Unbalance			steady state		0.5 to 2%			
Waveform Distortion	DC Offset		steady state		0 to 0.1%			
	Harmonics		steady state	0 to 100th H	0 to 20%	Harmonic Spectrum, Total Harm. Distortion, Statistics	Nonlinear Loads, System Resonance	Filters (active or passive), Transformers (cancellation or zero sequence components)
	Interharmonics		steady state	0 to 6 kHz	0 to 2%			
	Notching		steady state					
	Noise		steady state	broad-band	0 to 1%			
Voltage Fluctuations			Intermittent	< 25 Hz	0.1 to 7%			
Power Frequency Variations			> 10 seconds			Variation Magnitude, Frequency of Occurrence, Mod. Frequency	Intermittent Loads, Motor Starting, Arc Furnaces	Static Var Systems

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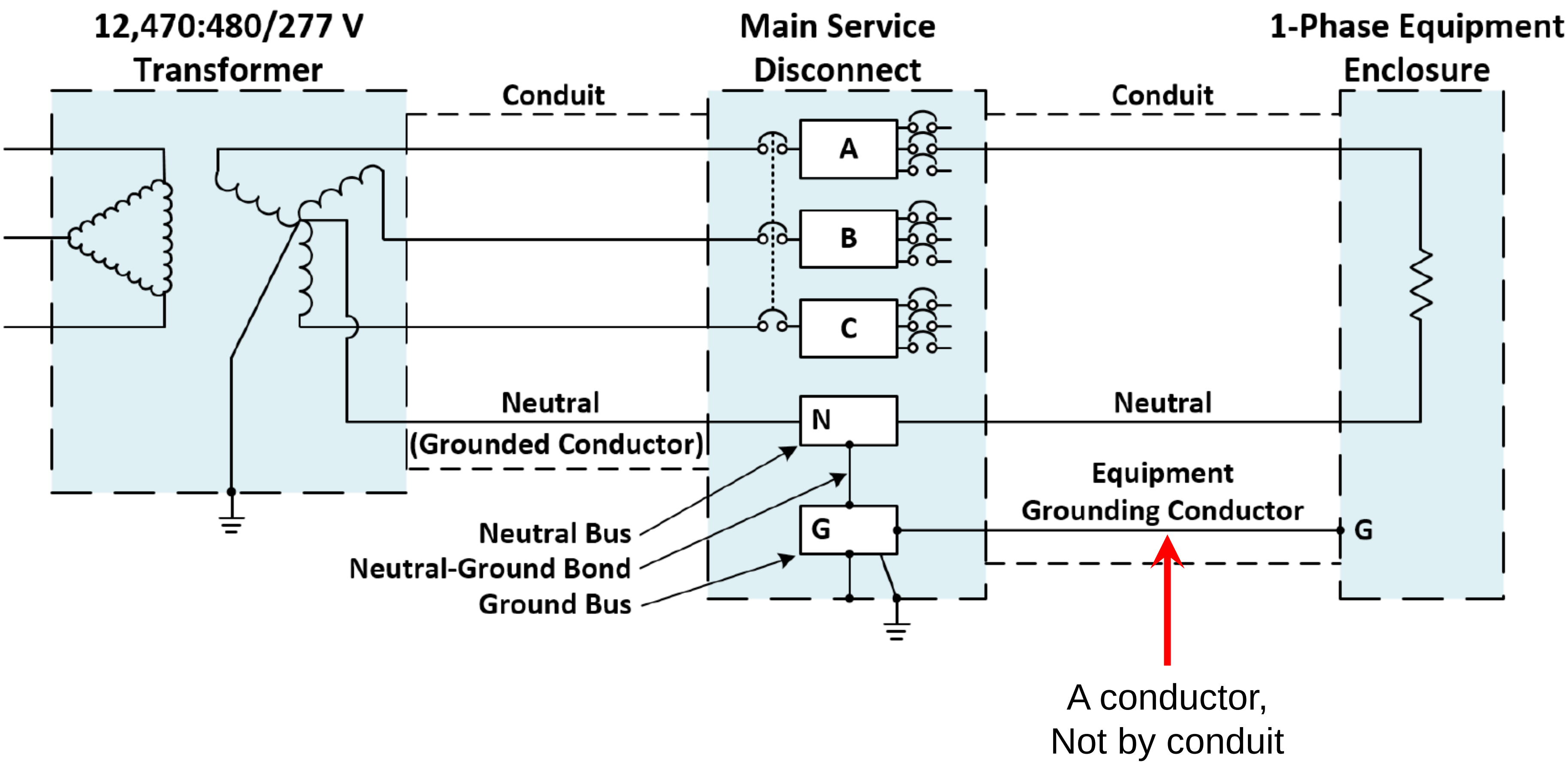
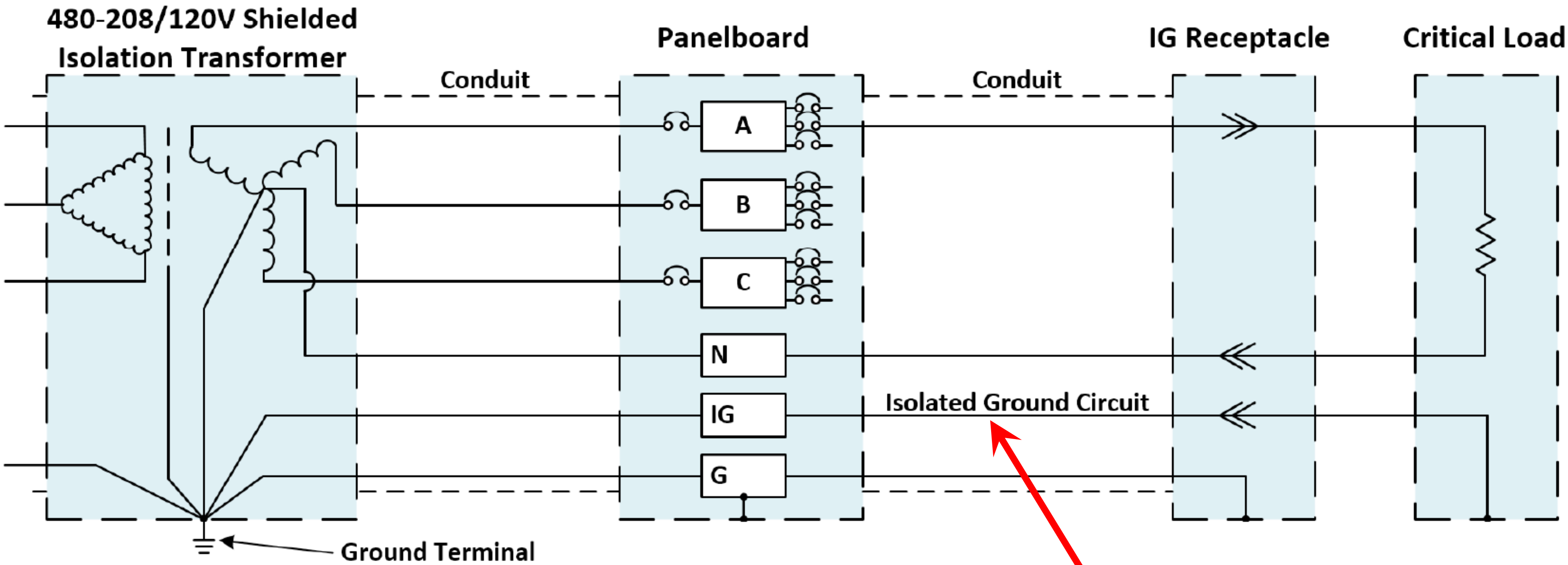
Service Ground



Isolated Ground



Only sensitive equipment and only to marked outlets

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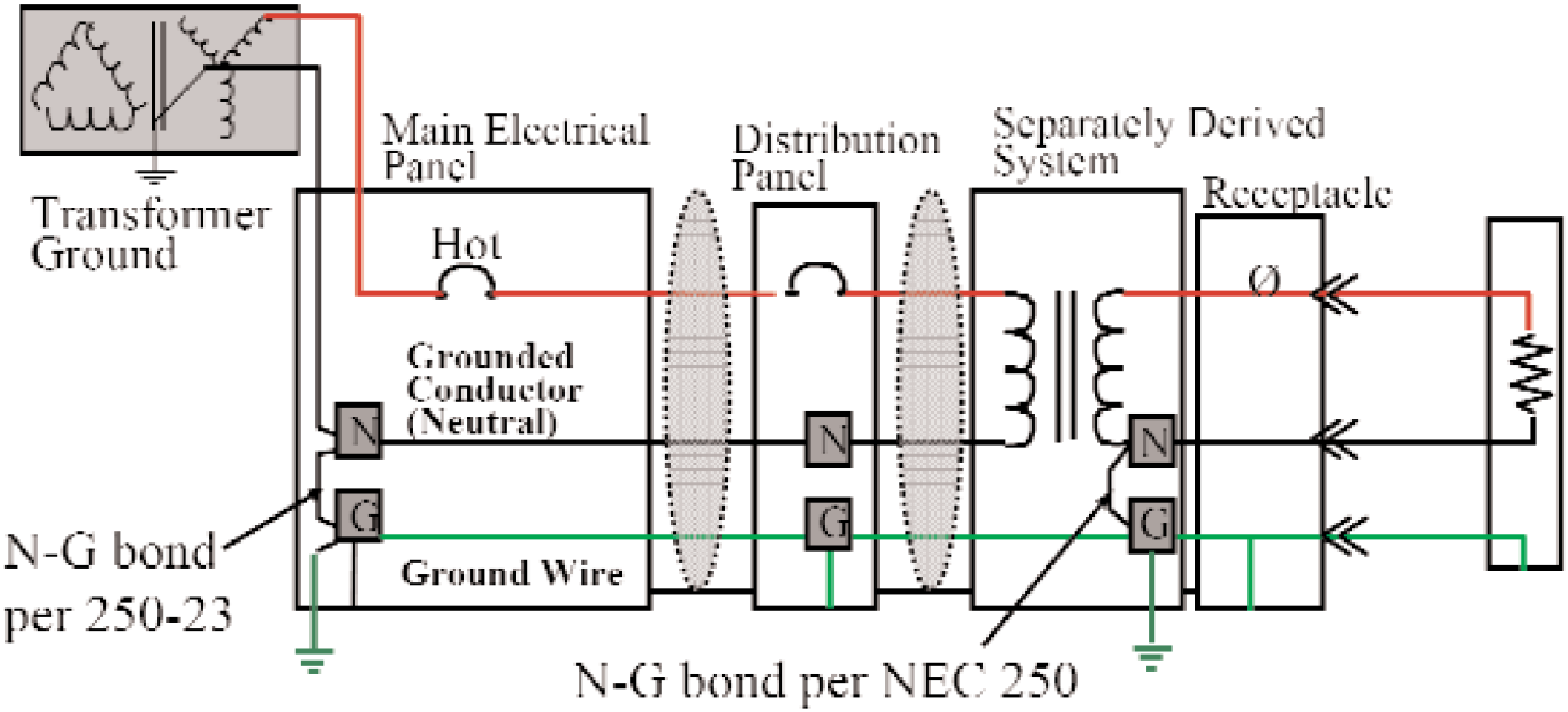
Separately-derived System

- Neutral to ground bonds are required at main service (NEC 250) and at any separately derived power sources (NEC 250 Supplemental grounding electrode OK if it is bonded to common bonding network) and shall not be made at any grounded circuit conductor (neutral) on the load side of the service disconnect



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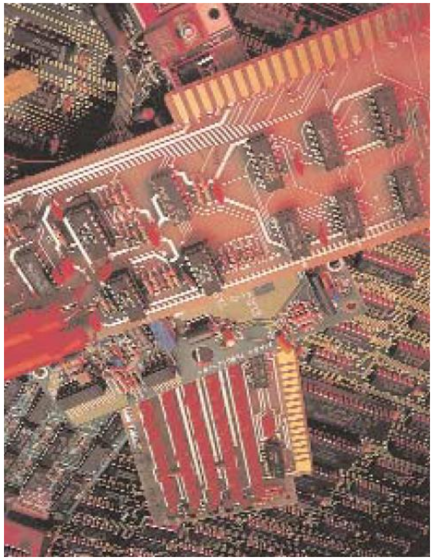
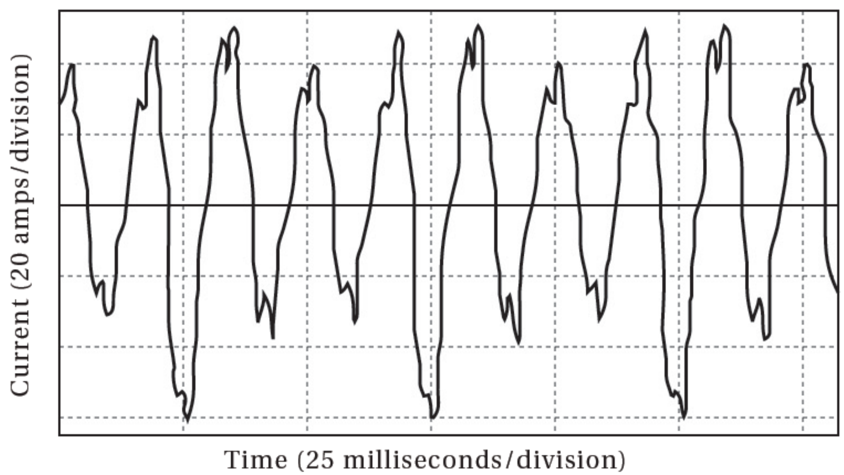
Wiring and Grounding: Artifacts in a CT Scan, 2006

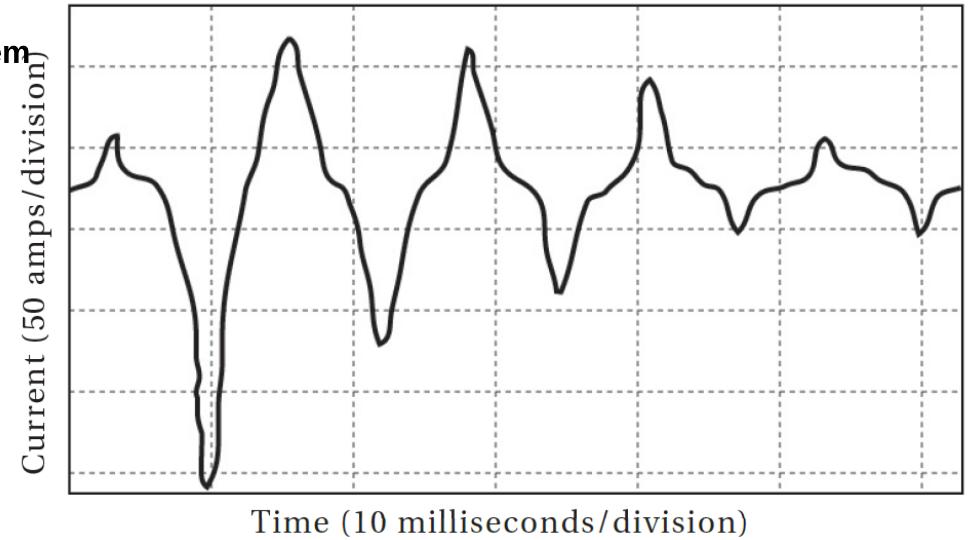
- Circuit boards are in medical equipment
  - Sensitive to PQ
- Some medical equipment causes PQ issues
  - Equipment locks up, must be restarted
  - Scans may have artifacts
    - Misdiagnoses possible



Non-linear (Harmonic-Rich) Load Current from an MRI System



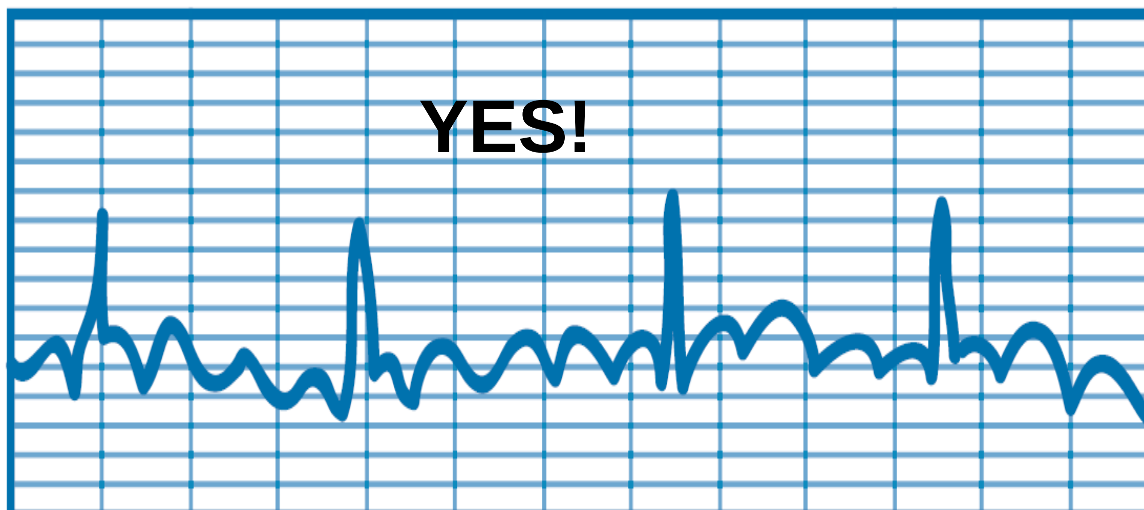
Non-linear (Harmonic-Rich) Load Current from a CT System



How Bad Could it Be?

- Artifact-infested electrocardiograph (top)
  - appears to match a textbook example of arrhythmia (bottom)
    - (reproduced from Capuano, 1993)
- 300 beats per minute or 5 hertz
  - accepted and diagnosed as arrhythmia, or atrial flutter
- Scan artifacts may resemble tumors

Arrhythmia?



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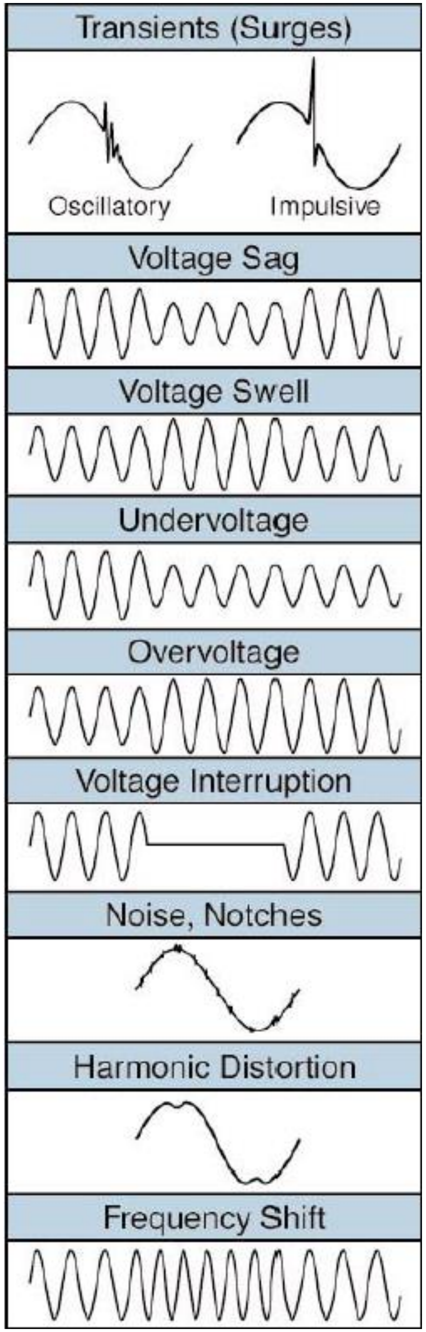
What Caused These Issues?

- Wiring and grounding problems
- Voltage Sags and momentary interruptions
- Overvoltages
- Harmonics propagating into sensitive equipment
- Etc.



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What Equipment Might be Sensitive?

- Anything from
  - a simple blood pressure monitor
  - to a complex medical imaging system
  - or a heart-lung bypass machine—
  - virtually all are susceptible to electrical and electromagnetic disturbances
  - Chiller system (heater contactor elsewhere)

What to Do?

- Examine grounding System and Facility Ground
- Install PQ meter
  - ~$2500 or less for the meter
- Maintain UPSs
  - Batteries last 3 years
  - Is it line-interactive or standby?
    - Double conversion is best
- Examine line isolation monitor (LIM) alarm for unintended grounds (thru patient)
  - Was 2 mA, now 5 mA
    - 10 mA can cause muscle contractions

Start Time	July 9, 2015 @ 5:28:06 PM CDT
Worst-Case RMS	57.6V (48.0%)
Nominal Voltage	120.0V
Duration	156ms (9.36 cycles)
IEEE Classification	Instantaneous Sag
Frequency	60.0 Hz

RMS Data

Channel	Min	Max	% Nominal
1	104.2V	120.9V	86.8%
2	93.7V	119.6V	78.1%
3	57.6V	119.0V	48.0%

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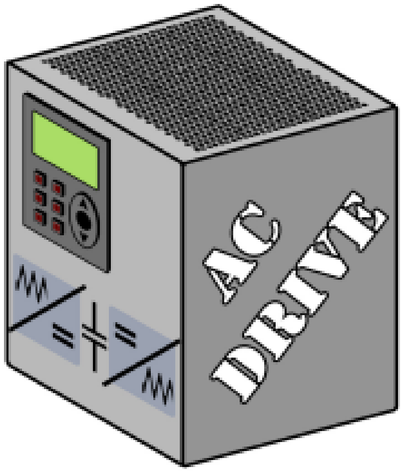
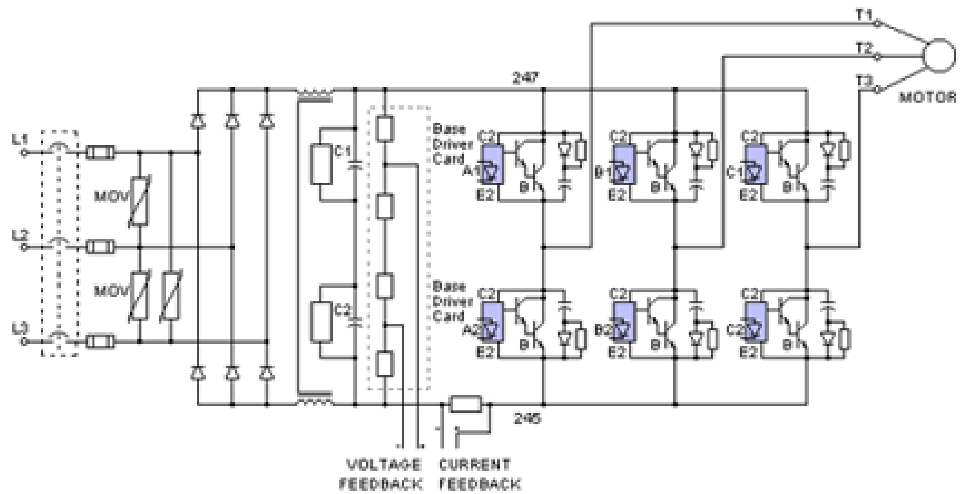
March 2010: OV fault tripping of ASD caused by Capacitor-Switching Transients





- **Question:** Via EPRI's PQ Knowledge (PQK) Power Quality Hotline, a PQK funder asked EPRI engineers about periodic nuisance tripping in its six-pulse adjustable-speed drives (ASDs).
- These nuisance trips seemed to correlate with a 34.5-kV capacitor bank being switched into service at the substation. The fault code on the drives was "Overvoltage."

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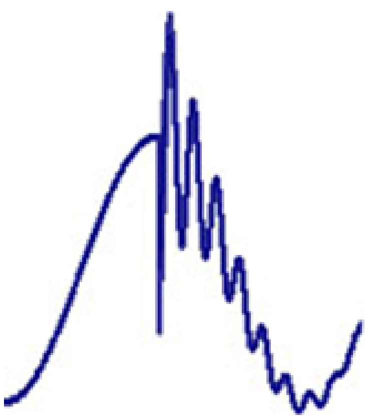
Problem Description

- Capacitor-switching operations are one of the most common causes of transient overvoltages on the power system.
- When a capacitor bank is energized, it interacts with the system inductance, causing a resonant condition.
- The transient overvoltage caused by a capacitor-switching event can be between 1.0 to 2.0 p.u., but is most commonly between 1.3 and 1.4pu, with frequencies between 250 and 1,000 Hz.
- One of the more common problems associated with a switching transient is the tripping off of electronically controlled loads such as ASDs, as in this case.



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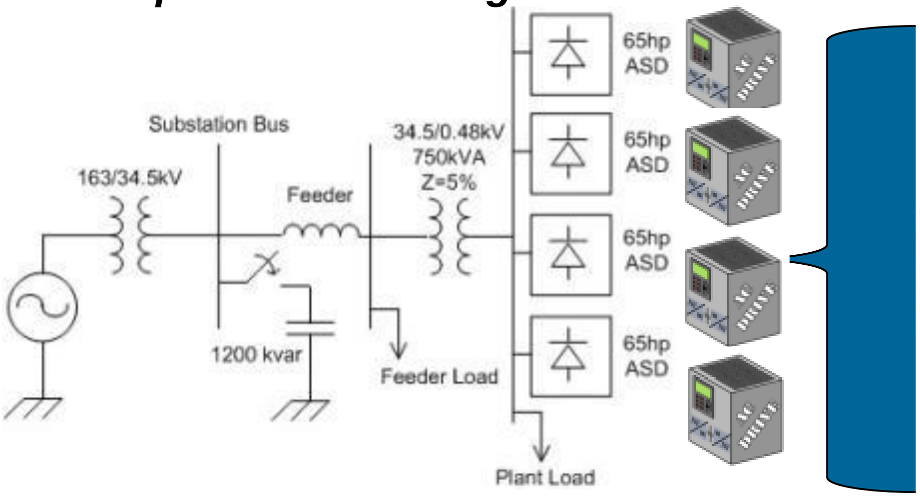
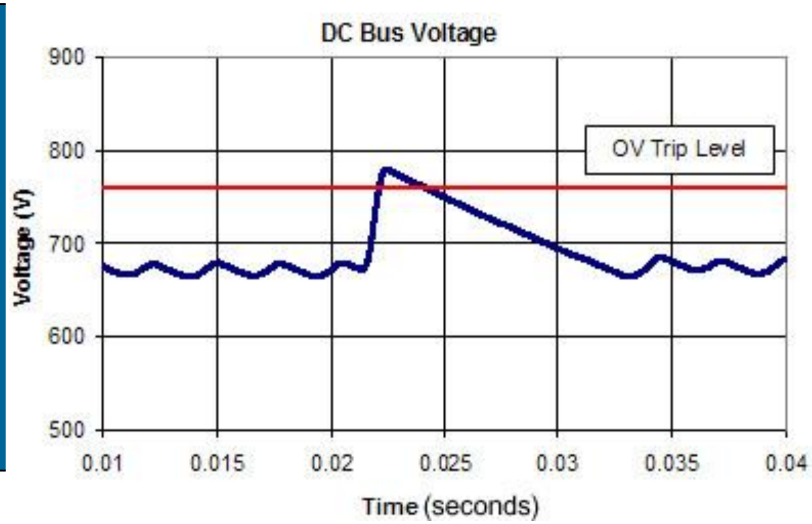
Analysis

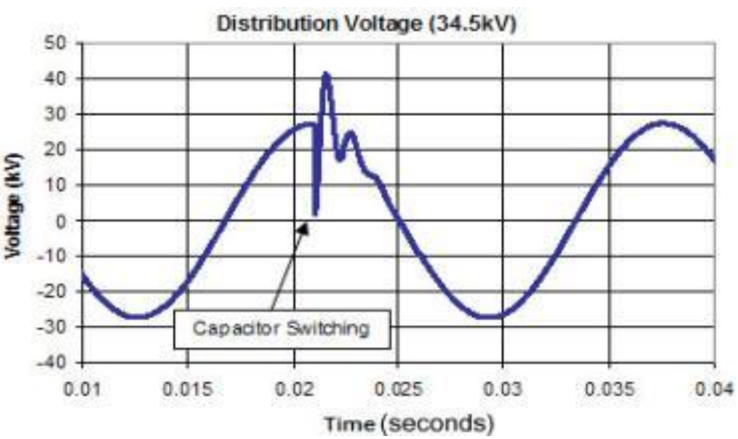
- When an ASD is exposed to a substantial transient overvoltage, the DC bus in the drive may exceed the overvoltage trip point, causing the ASD to trip offline due to "Overvoltage."
- When the ASD experiences this overvoltage, a fault code is typically shown on its LED front display that reads "OV," similar to that shown.
- An ASD overvoltage trip point may be as low as 1.2 p.u. on its DC bus (760 Vdc on a 480-Vac unit).

Capacitor Switching Transient

A Circuit Model Replicates a Capacitor-Switching Event







Switching on the Capacitor Bank Creates a Transient Overvoltage

The Transient Overvoltage Causes the DC Bus Voltage in the ASDs to Increase above Their Overvoltage Trip Point

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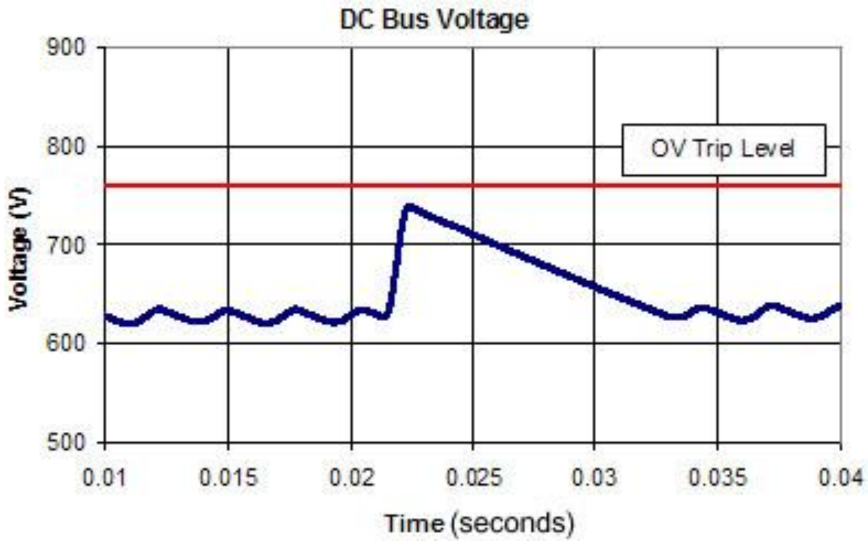
Reducing Service Transformer Tap Setting

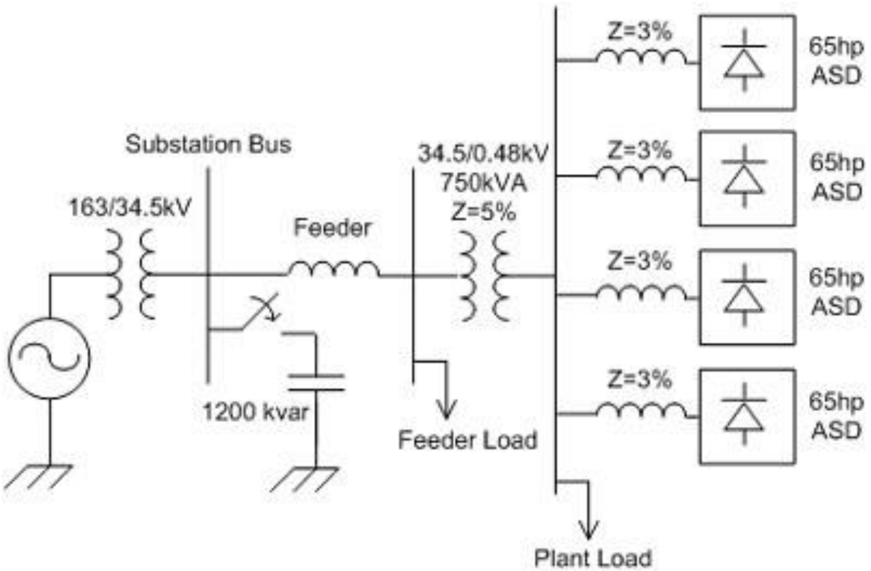
- If the tap setting on the plant's transformer is reduced from 1.05 to 0.975, it will lower the voltage magnitude of the DC buses in the ASDs.
- The reaction of a DC bus to the capacitor-switching event is shown after lowering the transformer tap.
- This may reduce the risk of ASDs tripping on overvoltage….
  - ***but it also exposes other plant loads to a lower service voltage, possibly increasing plant vulnerability to voltage sags.***



Reducing the Tap Setting of the Transformer Causes the ASD Bus Voltage to Stay Below its Overvoltage Trip Point during the Capacitor-Switching Event

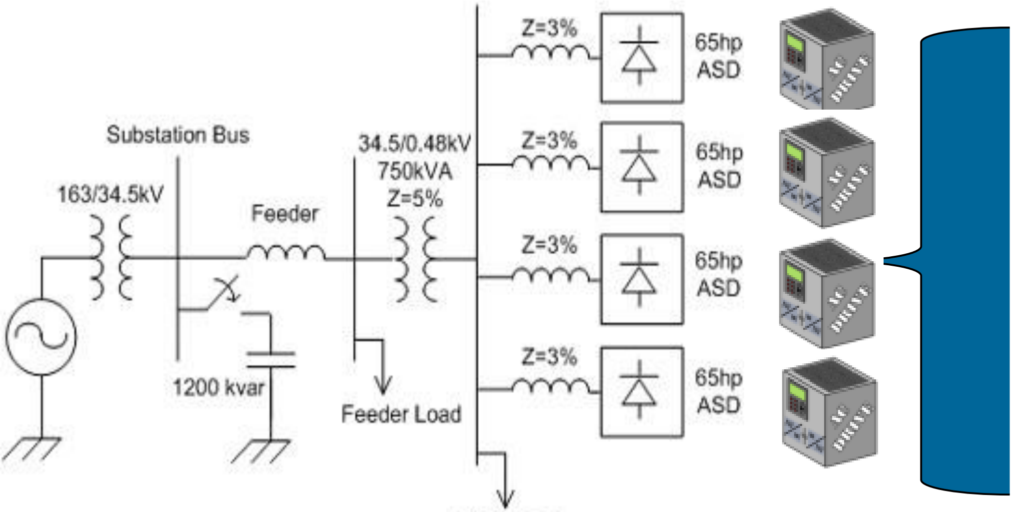
Installing AC Line Reactors or Isolation Transformers

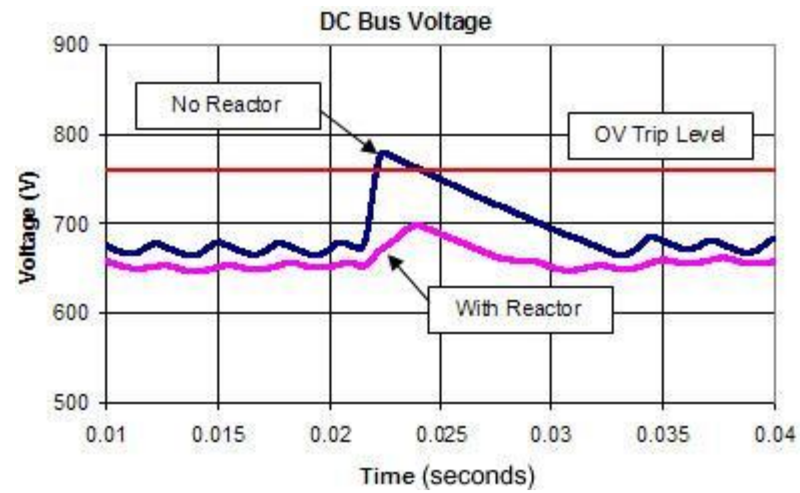
- One of most effective ways to eliminate nuisance tripping is to isolate an ASD from the power system with an AC-line reactor or an isolation transformer.
- The additional series inductance will reduce the magnitude of a transient overvoltage that appears at the input of an ASD.
- Determining how much inductance is required for a particular application usually requires a fairly detailed transient simulation; however, typical values are 3% of the ASD rating.



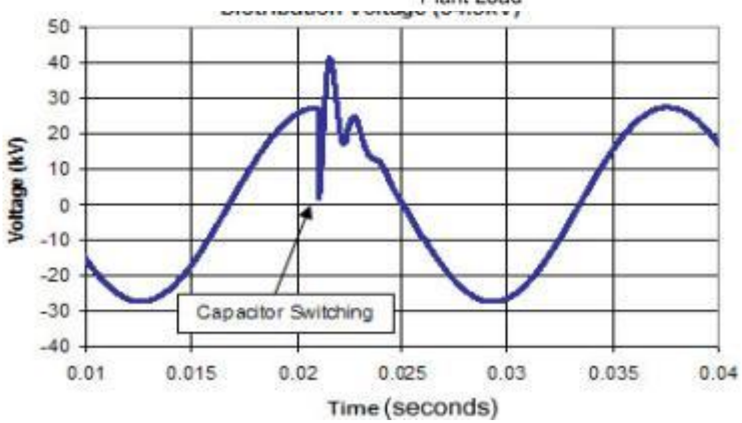
Isolating an ASD from the Power System by Adding an Input Reactor Can Reduce the Magnitude of the Transient Voltage That Appears at the ASD Input

Solution with Line Reactors





Adding the 3% Reactor Reduced the DC Bus Voltage to Well below the Overvoltage Trip Level

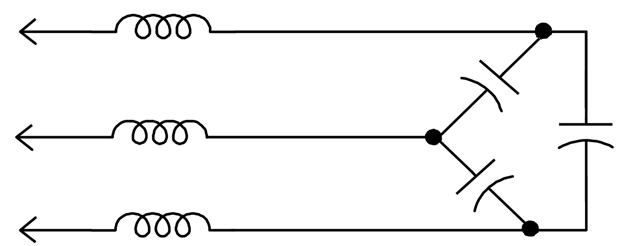


Switching on the Capacitor Bank Creates a Transient Overvoltage

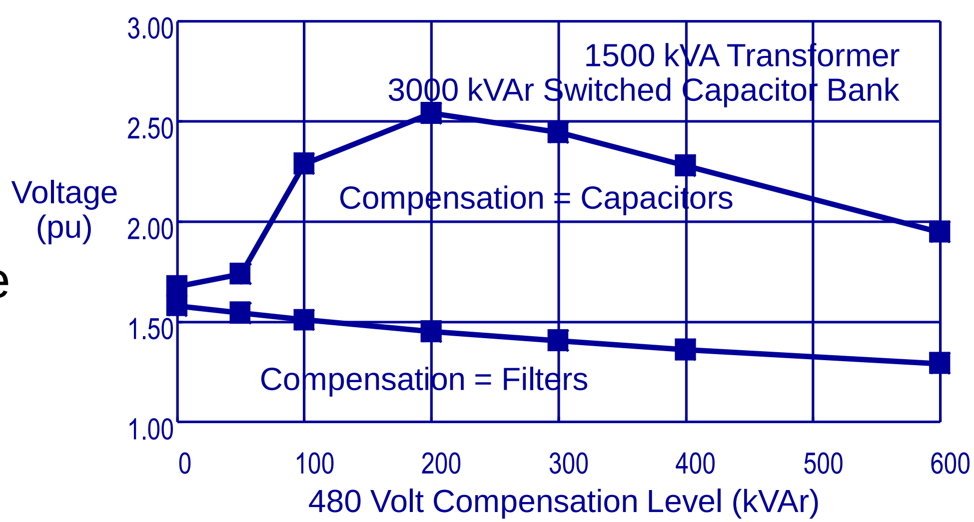
Adjust parameters on ASD if possible to ignore overvoltage for a period of time (time delay)

What about Local Power Factor Correction?

- If the plant has local power-factor correction on the 480-Vac side of the service transformer, another concern would be voltage magnification.
- In this case, voltage magnification may occur if the substation switching event excites a local resonance at the plant.
- This will make the transient high enough that isolation transformers or reactors may not work.
- In this case, the local power-factor-correction capacitors may need to be detuned by adding an inductance in series with the capacitor bank to decrease the transient voltage to an acceptable level.



Detuning Local PFC Caps with Inductors (Typically @ 4.7th Harmonic)



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Conclusion

- Capacitor-switching operations are a common cause of overvoltage transients.
- There are several options that may be used to limit the effect that these transient overvoltages have on ASDs.
- The solution may range from going to a lower tap on the service transformer (if available) or adjusting some protection parameters on the ASD itself (most ASDs do not have this feature).
- Or the solution may be a little more difficult, where isolation impedance may need to be added or de-tuning a capacitor in the facility is needed.

Here, Reactors Are Installed Next to ASDs

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Case Studies in PQ

Voltage Sag study at a Pharmaceutical Manufacturing Plant

Introduction

- Located in a rural area, a pharmaceutical manufacturing customer was experiencing voltage sag induced shutdowns of their critical fluid beds.
- The facility reported several PQ events from 2013 to 2015. The pharmaceutical manufacturing facility reached out to the Utility to assist in troubleshooting these PQ issues.
- Working in cooperation, the pharmaceutical company and the Utility brought in EPRI to review the electrical environment, the plant equipment, and offer possible solutions as to what could be done at the plant to maintain service during normal system conditions, which typically includes some level of voltage fluctuation.
- This paper presents a case study of the analysis, findings, and details the successful outcome of the work at the pharmaceutical manufacturing facility.

Pharmaceutical Plant Process & PQ Sensitivity

- The purpose of a fluid bed is to create a vortex in which raw chemicals used to make pharmaceutical drugs are levitated and liquid ingredients are systematically sprayed on to a circular placebo.
- This process occurs in a closed environment as shown in the example fluid bed.
- Any fluctuation in the power may cause this sensitive process to shut down.
- If the vortex stops the ingredients fall to the bottom of the chamber and coagulates.
- Such events can lead to:
  - Hours of downtime to cleanup and reclaim the ingredients
  - Catalog lost product and rectify with the FDA
  - After proof of reclamation more controlled ingredients may be purchased potentially resulting in weeks of lost production time.

Typical Fluid Bed

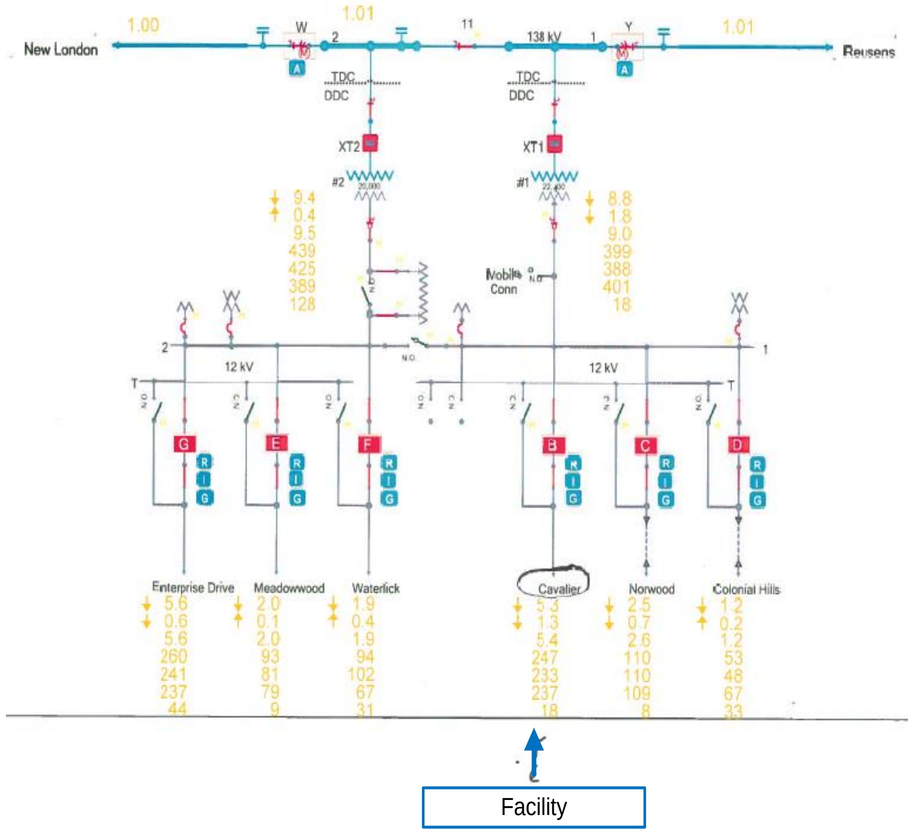
Why was this Audit Chosen as a Case Study?

- Sensitive controls found throughout the facility.
- Product loss and downtime costs at the facility prompted the customer to request:
  - voltage sag solutions
  - critical load coordinated shutdown
  - and 2MVA switchboard solutions
- Facility already has 1MW generator and various automatic transfer switches that may be used in a mitigation scheme.
- Initially the facility engineer assumed he could have no interruption of power.
  - Through collaboration with EPRI engineers, the facility engineer, and process engineer it was discovered that a controlled shut down solution is possible thus less expensive than providing protection for the whole switchboard.

Typical Fluid Bed

Power System Overview

- The facility is supplied 12kV power from the Utility's Substation.
  - The substation accepts power from the 138 kV system from one of two transformers.
- The facility is powered from XT1 22.4MVA transformer.
  - Transformer sources three circuits.
  - The branch lines are sourcing a mix of residential, commercial, and industrial loads.



Power System Overview

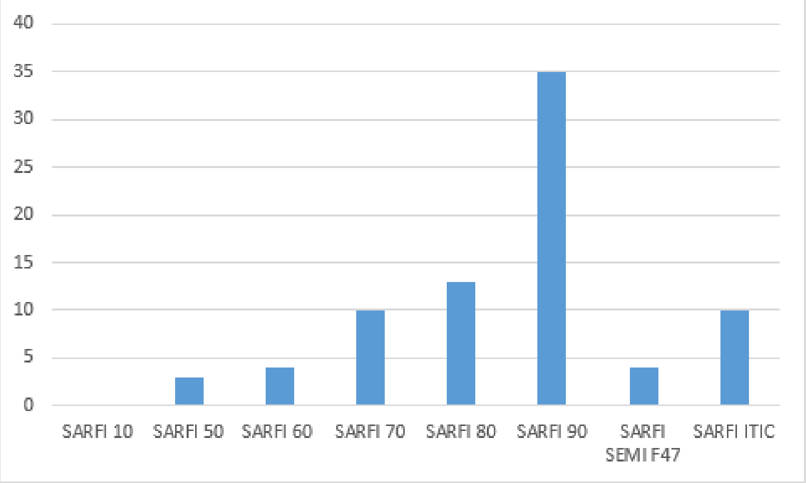
PQ Data & Analysis

(System Average RMS Variation Frequency Index)

Import Name	TEVA Pharmaceutical, Forest, VA (1/5/2015 - 10/17/2015)	
Event Count	35 total events	
Monitor Years	0.83 years	
Average Sag Magnitude (%)	75.40%	
Average Sag Duration (sec)	0.082 s	
Median Sag Magnitude (%)	82.10%	
Median Sag Duration (sec)	0.057 s	
	Normalized to 1 Year	**Raw Count**
SARFI 10	0	0
SARFI 50	3.6	3
SARFI 60	4.8	4
SARFI 70	12	10
SARFI 80	15.6	13
SARFI 90	42	35
SARFI SEMI F47	4.8	4
SARFI ITIC	12	10

This slide shows the Average Sag Magnitude is 75.4%, and the Average Sag Duration is 0.082 seconds.

Median Sag Magnitude and Duration are 82.1%, 0.057 Seconds.



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Utility Suggestion for circuit protection

- There is a new Sub-Division being constructed across the street from the facility. The contractors working in the subdivision have contacted the power cables while trenching on a couple of occasions thus resulting in the substation breaker to operate.
- **The utility investigated the issue and has taken the following action:**
  - **Removed the instantaneous fault response of the upstream breaker to allow for downstream primary tap line fuses to open.**
  - **This scheme should reduce the potential of momentary interruptions on the main Cavalier circuit due to faults on the branch feeds.**
  - **This will not eliminate station breaker operations.**

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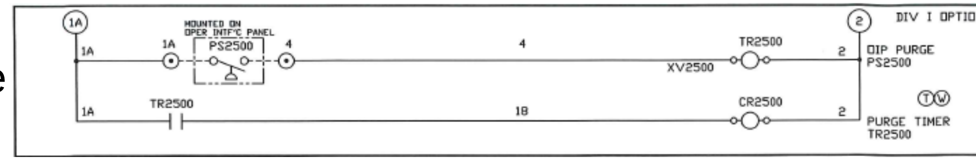
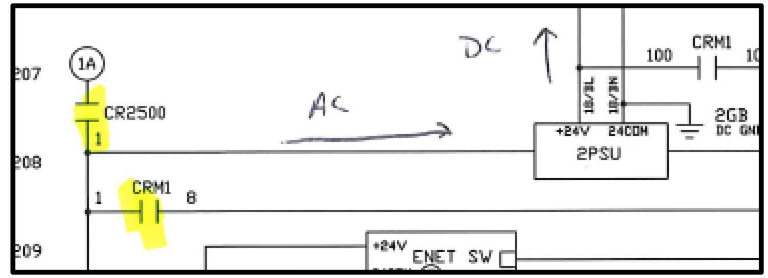
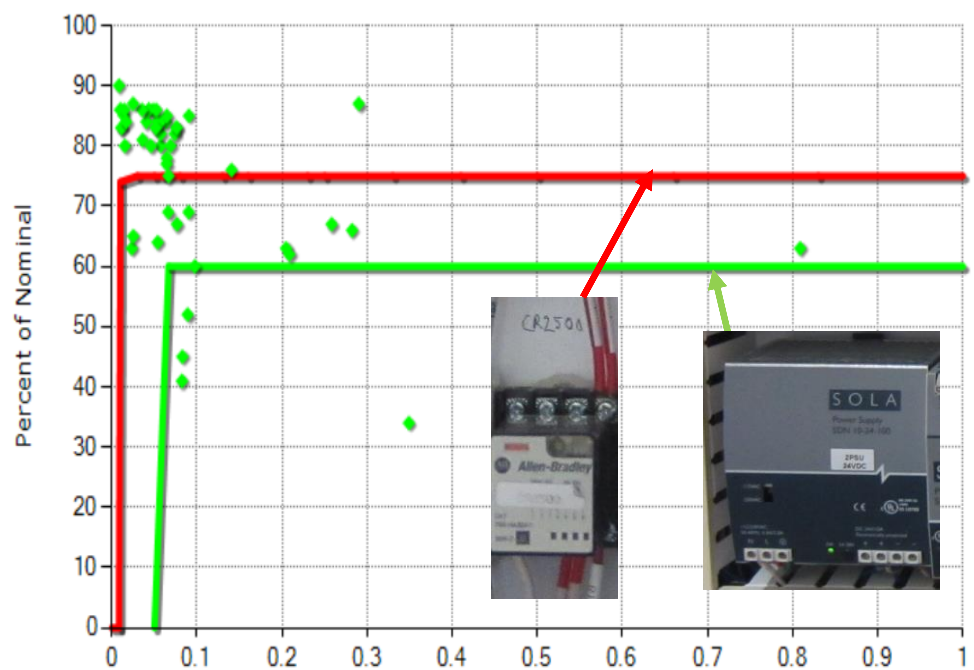
1st Key Finding from On-Site Audit

- All of the fluid bed control equipment in the facility has a purge timer before the system is allowed to operate.
  - This timer circuit is a delay on timer that closes an Ice Cube relay with a 120Vac Coil sensitive to voltage sags lower than 72% nominal.
  - The contacts of the relay supplies all 120Vac control power to the circuit.
  - Most of the controls are powered 24Vdc from a power supply that receives power from the 120V control power downstream of the Ice Cube relay.
  - The DC power supply was tested and found to trip for voltage sags 3cycles 60% nominal.
  - ***Therefore any voltage sag on the control power lower than 72% nominal will result in the loss of control power.***





Tolerance and Protection Curves with PQ Data Overlay



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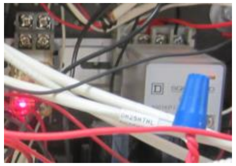
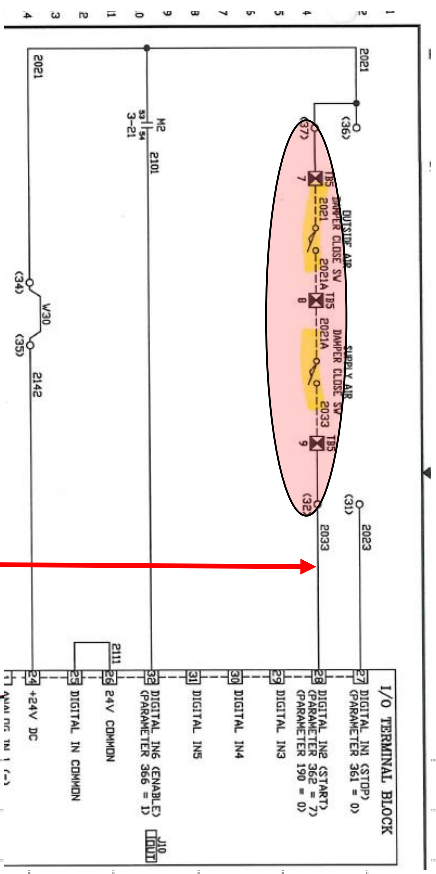
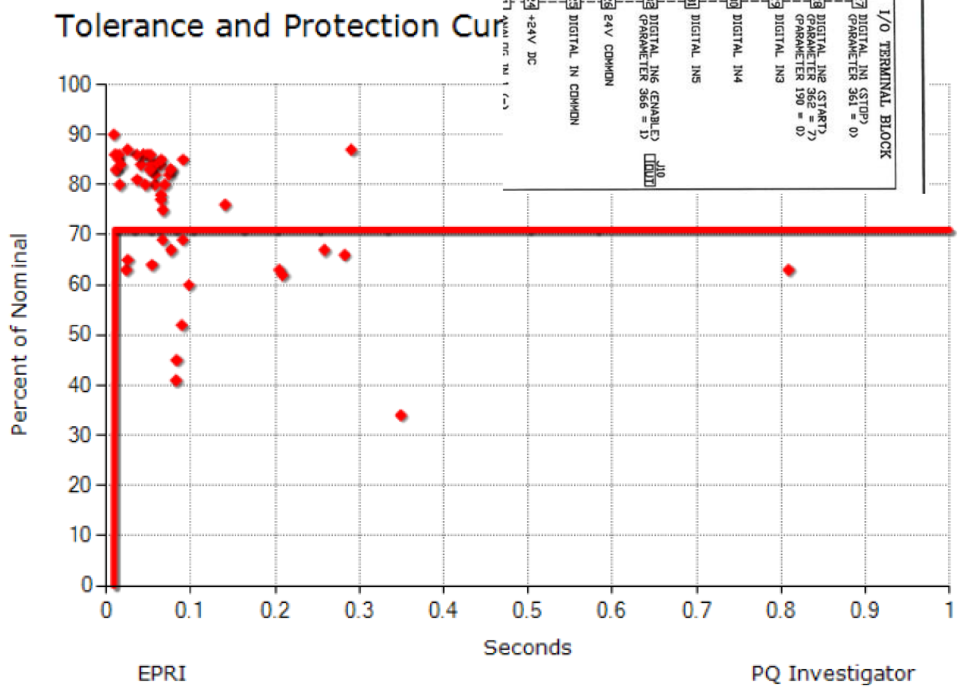
2nd Key Finding from On-Site Audit

- The facility air handler adjustable speed drives (ASDs) are known to be very robust to voltage sags, however:
  - The air handler ASD enable signal is complete when both input and output damper feedback switches are closed indicating they are fully open.
  - The damper actuator motors are controlled by the building automation system (BAS) through 24Vac Ice Cube Relays
  - If a voltage sag less than 72% nominal occurs these relays open removing power from the damper actuator motors causing them to close.
  - ***The end switches open causing the drive to trip.***





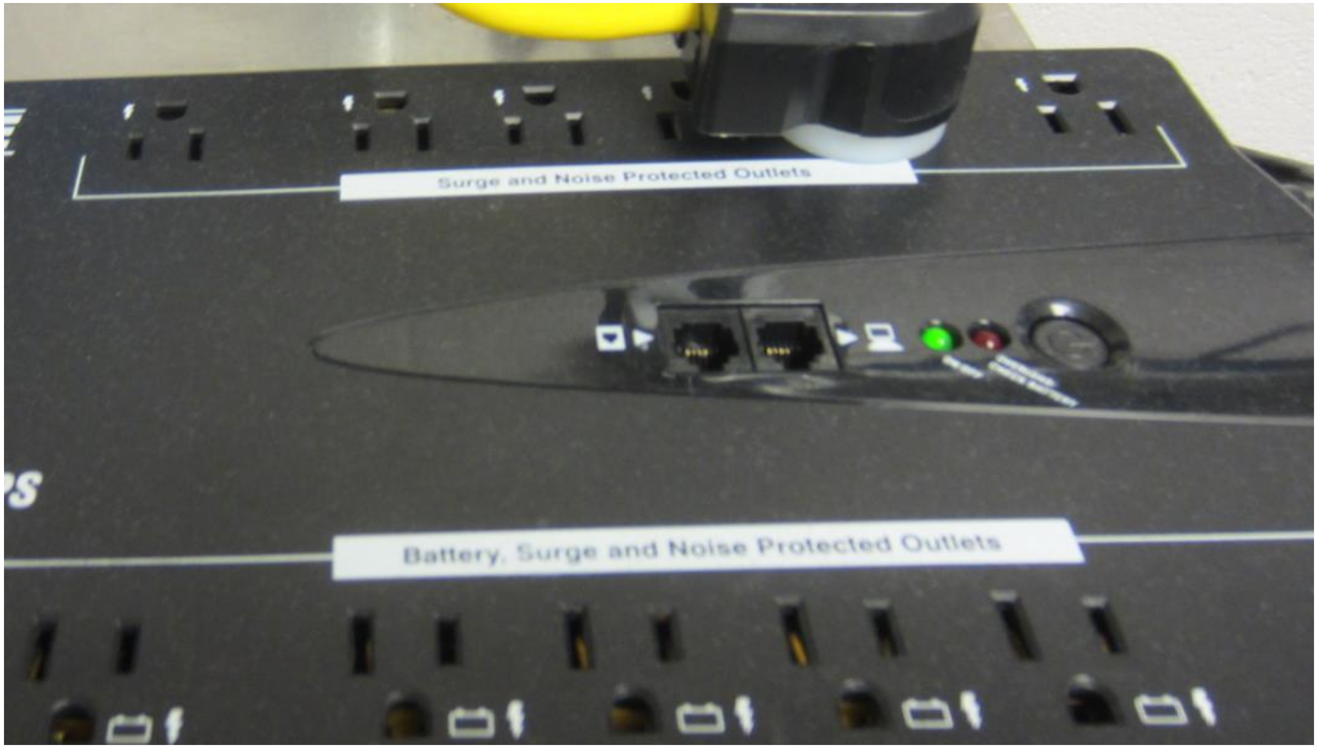


Allen Bradley,Bulletin 700-HB Square Base Relay,AB700-HB32-A24-1,Test Results,60Hz

PQ Data, TEVA Pharmaceutical All PQ Data (1/5/2015 10:18:00 AM - 10/17/20

3rd Key Finding from On-Site Audit

- During the audit we located a UPS in the facility whose load was plugged into a “Surge only” outlet.



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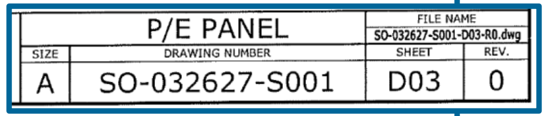
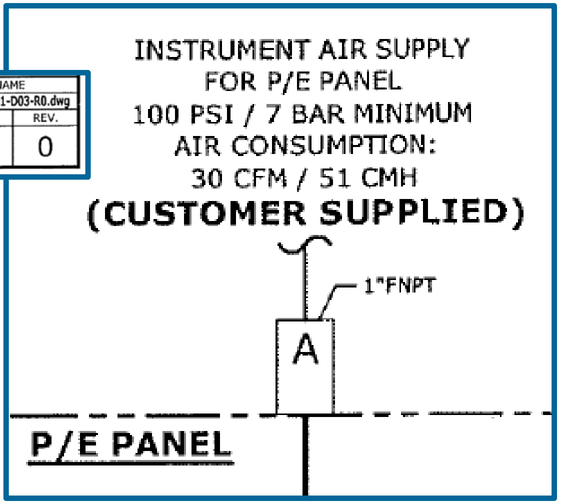
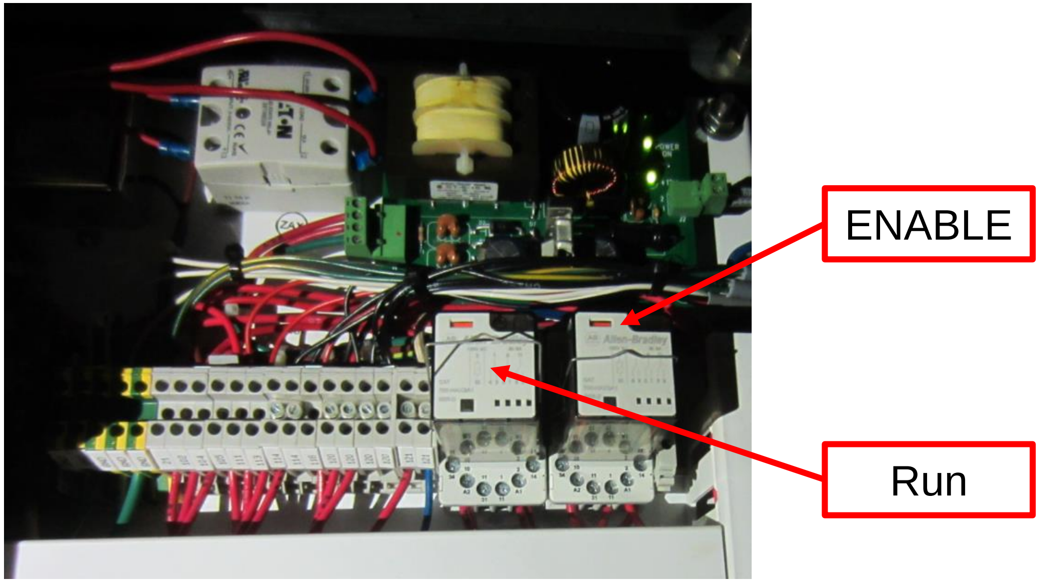
4th Key Finding from On-Site Audit

- During the drawing analysis we noticed that the pneumatic instrument air requirements for the FESTO system in Glatt 2 (seen in all other fluid beds as well) are
  - 100psi/7bar minimum
  - Air consumption is 30CFM
- The nominal air pressure at the facility is set to 116lb.
- The enable and run signals for the compressors are fed through the contacts of sensitive Ice Cube Relays.



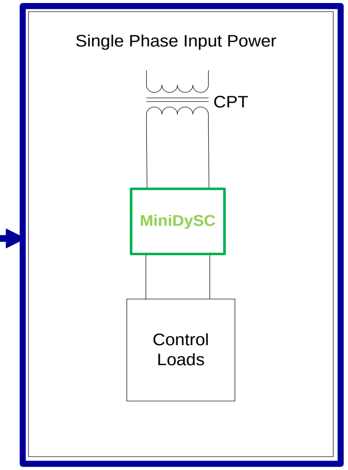




Types of Control Level Solutions Selected

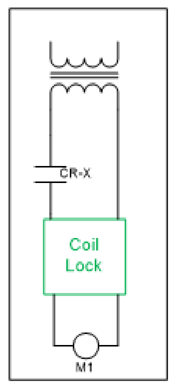
- MiniDySC
  - Control Circuit Mitigation
  - Static Series Compensator with Capacitor Storage
  - 50ms of voltage interruption (more time at reduced load)
  - 5 seconds of voltage sag protection to 50% nominal.

MiniDySC



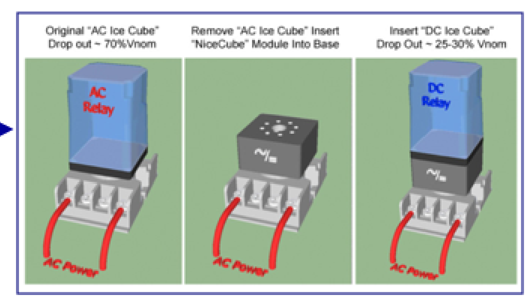
- Coil Lock
  - Relay Coil Solution
  - Size based upon coil resistance
  - 3 seconds of voltage sag protection to 25% nominal

Coil-Lock



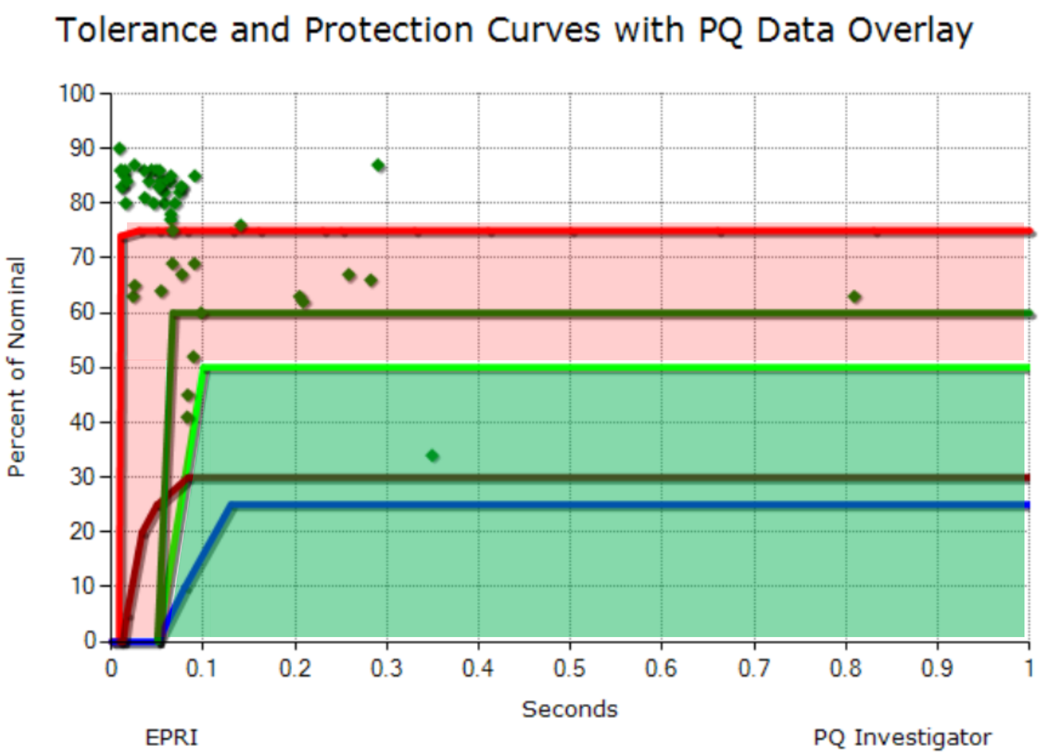
- Nice Cube
  - 8 pin octal Ice Cube Relay Solution
  - Direct replacement for 120Vac and 24Vac octal relays
  - 3 seconds of voltage sag protection to 30% nominal

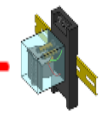
NICE Cube



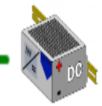
Control Level Solutions

* These solutions are designed to protect for voltage sags.
A generator with bridge power solution will be necessary for extended interruptions.*





Allen Bradley,Bulletin 700 Type H,700-HA32A1,120 Vac Test,60Hz

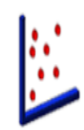


Sola,SDN,SDN-10-24-100,120V 60Hz Full Load,60Hz

Softswitching Technologies,DySC,MiniDySC,Standard

Power Quality Solutions Inc.,Coil-Lock,Coil-Lock,Protection Curve

Power Quality Solutions Inc.,Nice Cube,Nice Cube with DC Relay - 24Vdc - Magnecraft 750XBXM4L-24D,Mitigated Curve



PQ Data, TEVA Pharmaceutical All PQ Data (1/5/2015 10:18:00 AM - 10/17/20

Original Susceptibility of Controls

Susceptibility of Controls with MiniDySC

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Total Voltage Sag Mitigation Solution Costs

		Option 1	Option 2
All Areas	****Estimated Total***	***$12,172.58***	***$23,882.64***

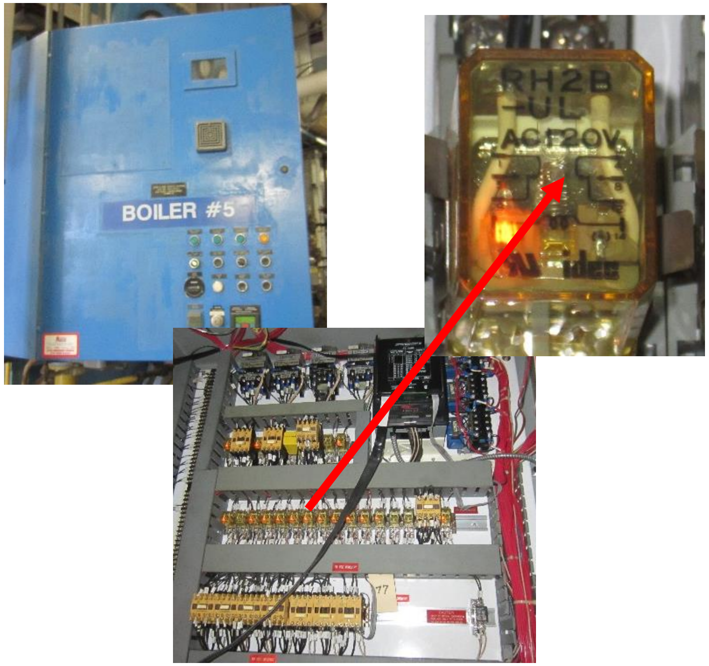
Option 1 recommendations are typically less expensive than Option 2. Option 2 recommendations often provide ridethrough for deeper and longer voltage sags.

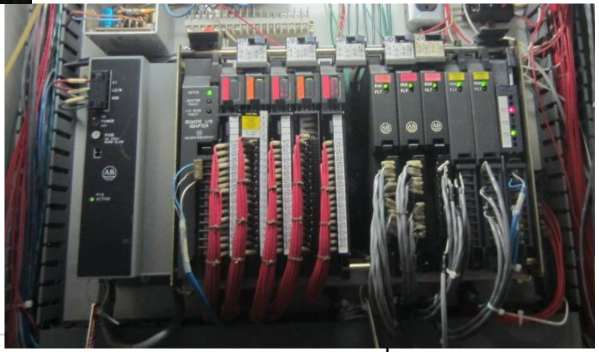
The customers indicated that they will implement all of the *Option 2* Recommendations.

Boiler Controls at a Food and Beverage Facility

Background

- Recently we had a PQ audit at a facility that had a room with two boiler units, their assorted controls cabinets, and a monitoring/control room.
- The control cabinets had several AC ice cube relays inside. The Monitoring/control room had some small UPSs for backup power.
- Some of the other stand alone control cabinets had AB PLC5s with AC I/O.





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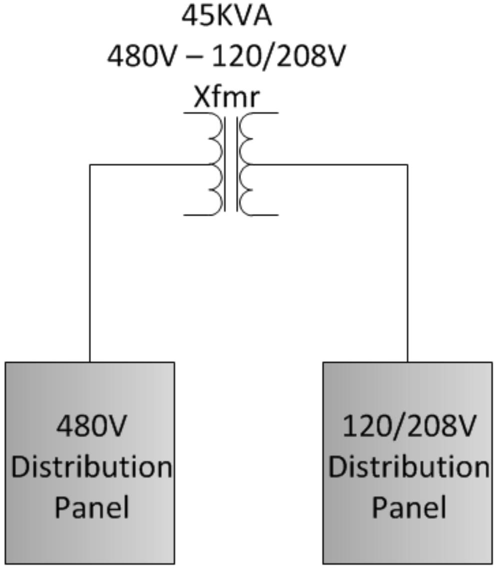
Analysis and Walkdown

- Where is the control power coming from?
- After reviewing their drawings, it was determined that most of the sensitive equipment was being powered from a distribution panel in the same area.
  - The panel was a 120/208V 3Ø, with a 150A main breaker.
- This distribution panel was being sourced from a 45kVA 480V – 120/208V Xfmr. The panel to the left of the distribution panel was the 480V panel sourcing the 45kVA Xfmr.



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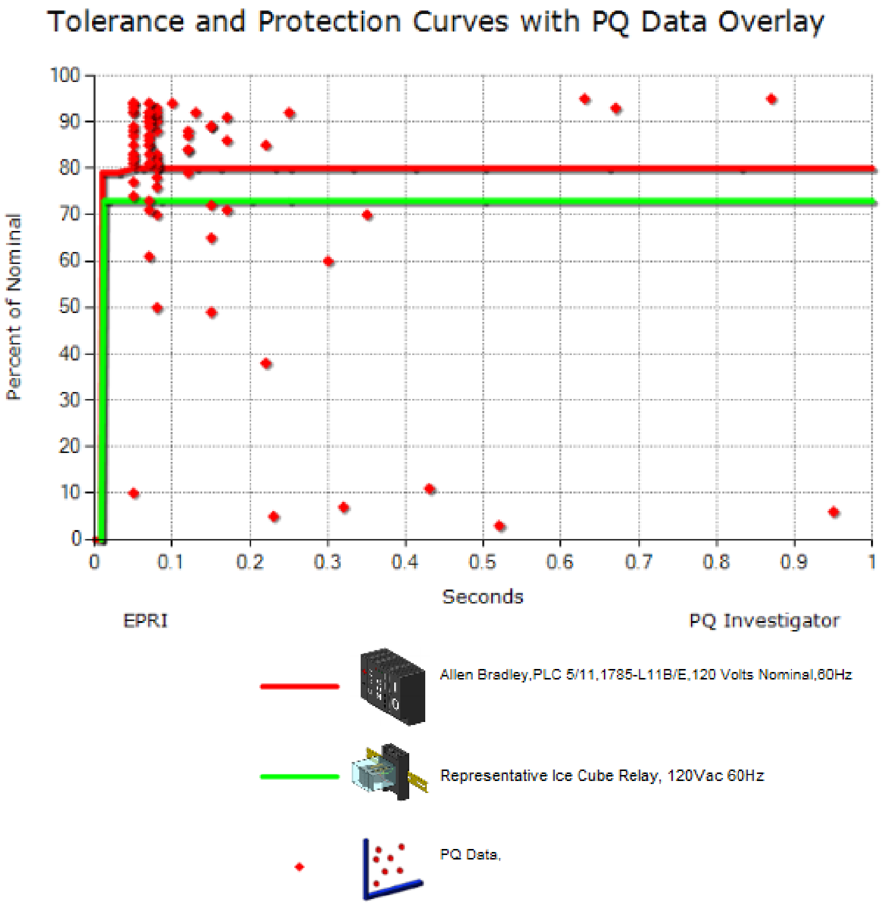
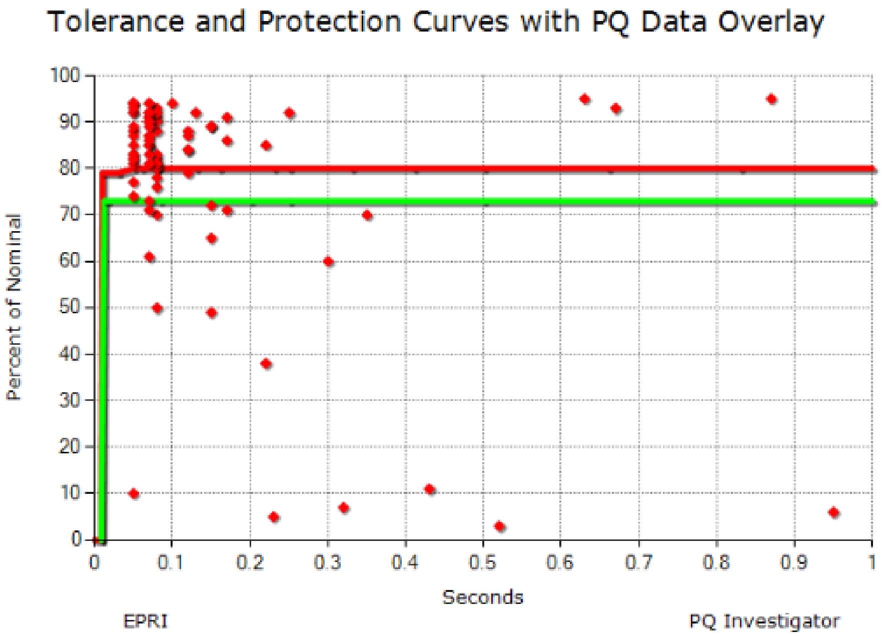
Analysis of the PQ Environment

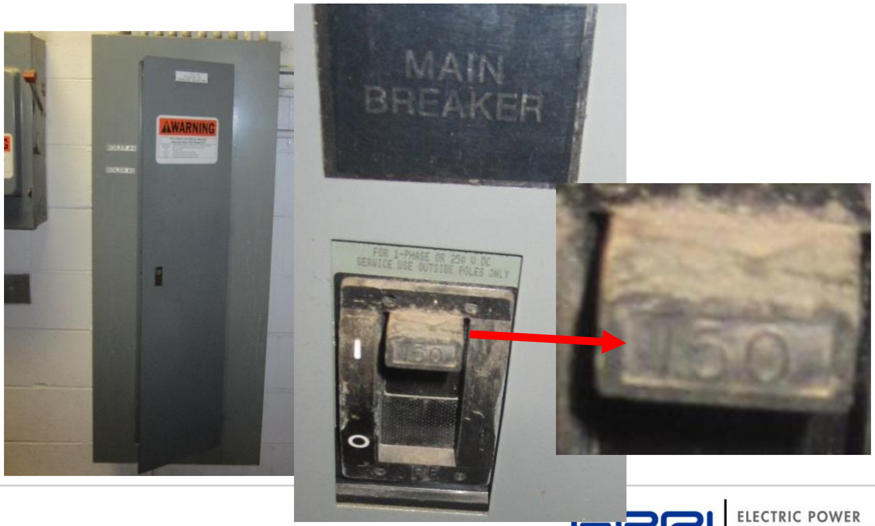
- What does the PQ environment look like?
- Based on the PQ events data, the PLC 5 and the AC ice cube relays are right in the area of most of the events this facility were seeing.
- What would be best option to mitigate these events and provide a wider area of protection?



Mitigating the Issue

- We chose to put our mitigate at the distribution panel level.
- Why would we do that?
  - Most of the equipment that needed protecting were not located close together.
  - Plus there were other pieces of equipment that needed to be protected that were being sourced from the distribution panel.
- But wait!! The panel has a 150A main breaker (120/208V).





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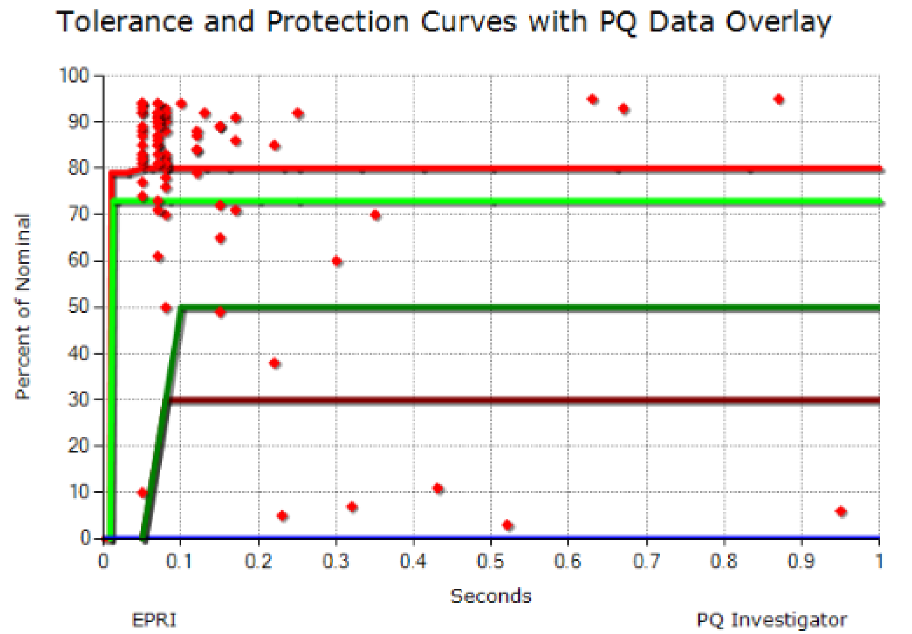
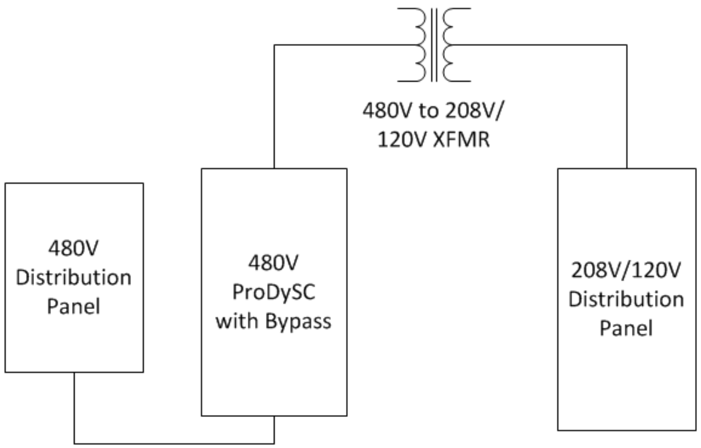
Solution

- The mitigation device chosen was an AB ProDySC rated at 100A for 480V.
- This was the cheapest option, and could be put up stream of the 45kVA 480V-120/208V Xfmr.
- This option would protect everything the 120/208V distribution panel, and allow some room to move a few other critical items over to the panel for protection as well.





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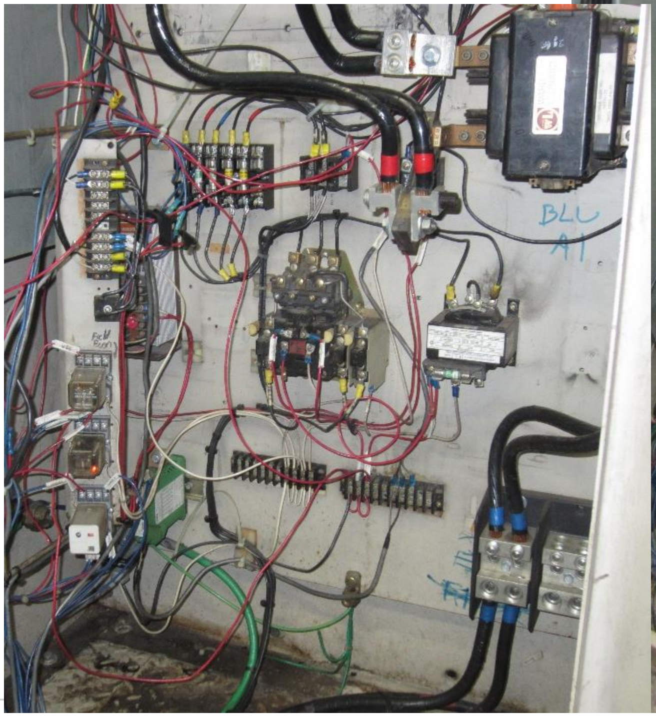
Plastic Extrusion Plant with PQ Issues

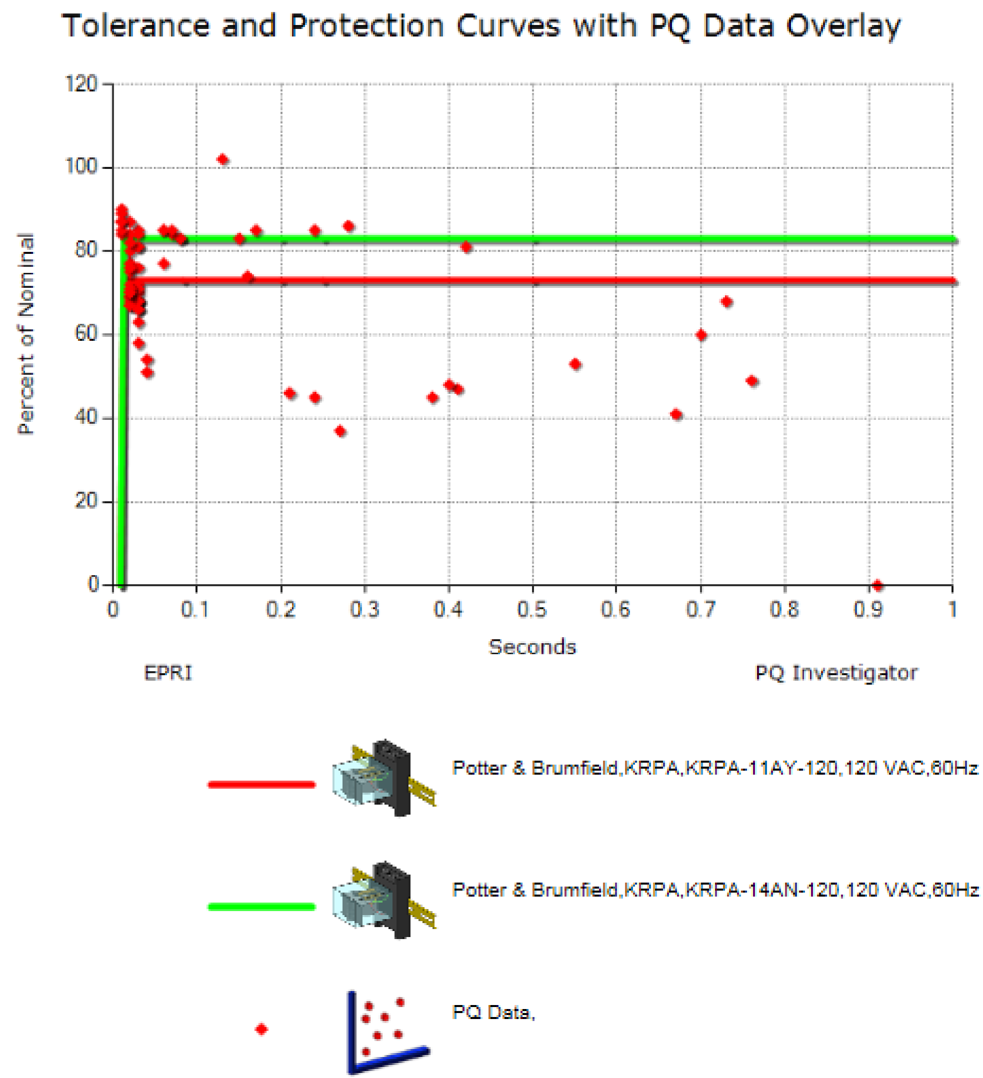
Extruders, Extruders, Extruders…..

- A plant utilized extruders to manufacture foam plates.
- The extruders were using DC drives; mostly older vintage and some newer models.
- They were using two extruders and drives for each line; Primary and Secondary.
- This particular line had two newer models, but this particular drives cabinet was still using older permissives for the controls.
  – Control Transformer (CPT) 75VA
  – AC Ice Cube Relays for Run, Field Run, and MX.



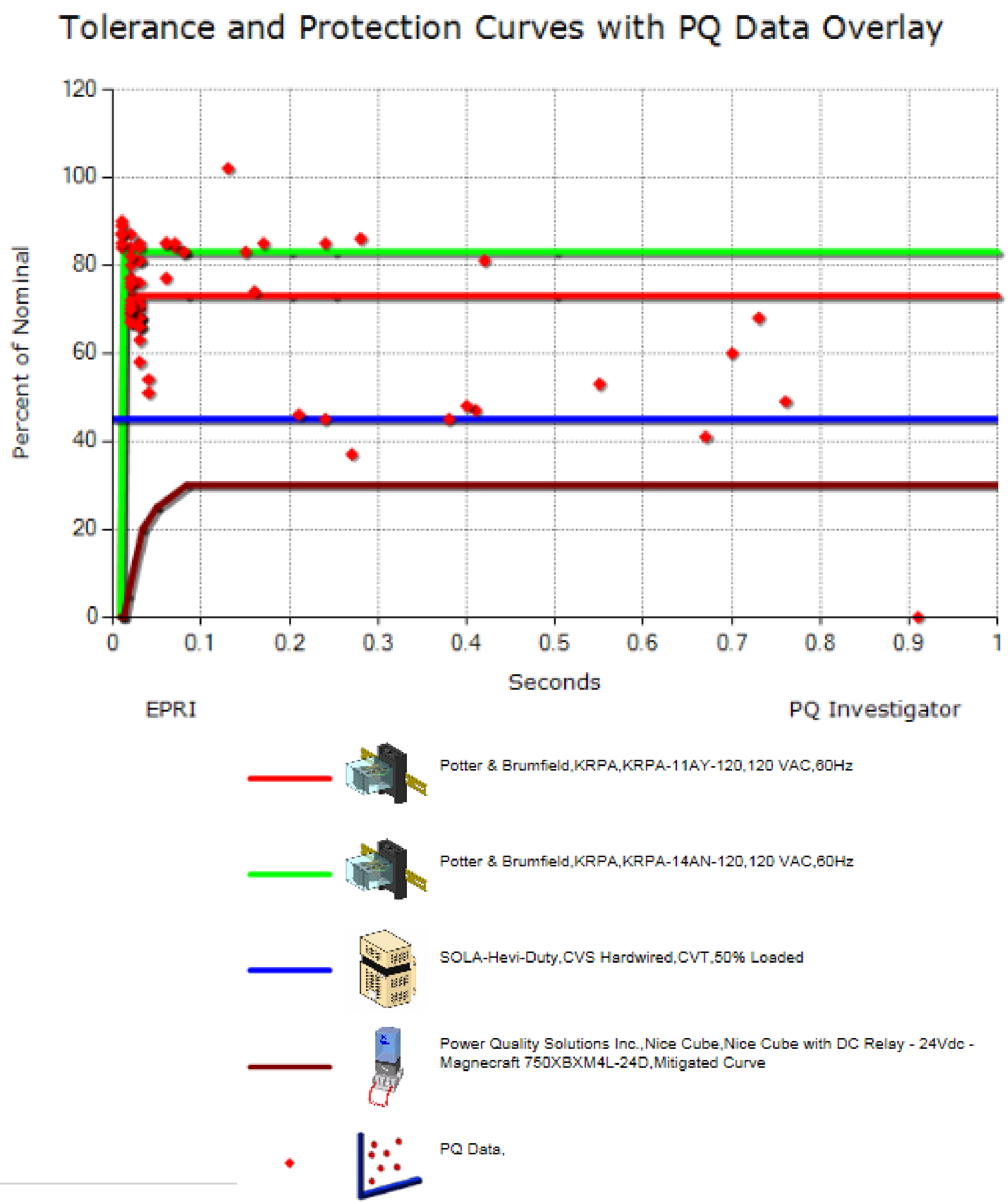
Examining the PQ Environment

- What did the PQ Environment look like?
- The permissive run signals from the AC ice cube relays are right in the area of the most events at this facility.
- This helped explain why these drives were shutting down during PQ events on the incoming power.
  - The facility keep complaining that it was the utilities fault that they were having lines tripped off line.
- So what do we do to mitigate this???



Solution

- How do we provide mitigation for this type of equipment?
- For this particular drive cabinet, we recommended the facility either replace the three AC ice cube relays with NICE cube relays or replace the CPT with a 50% loaded Constant Voltage Transformer (CVT).
- The DC drive was a newer design than some of the other much older ones that they were using, but the permissives were still using sensitive components.

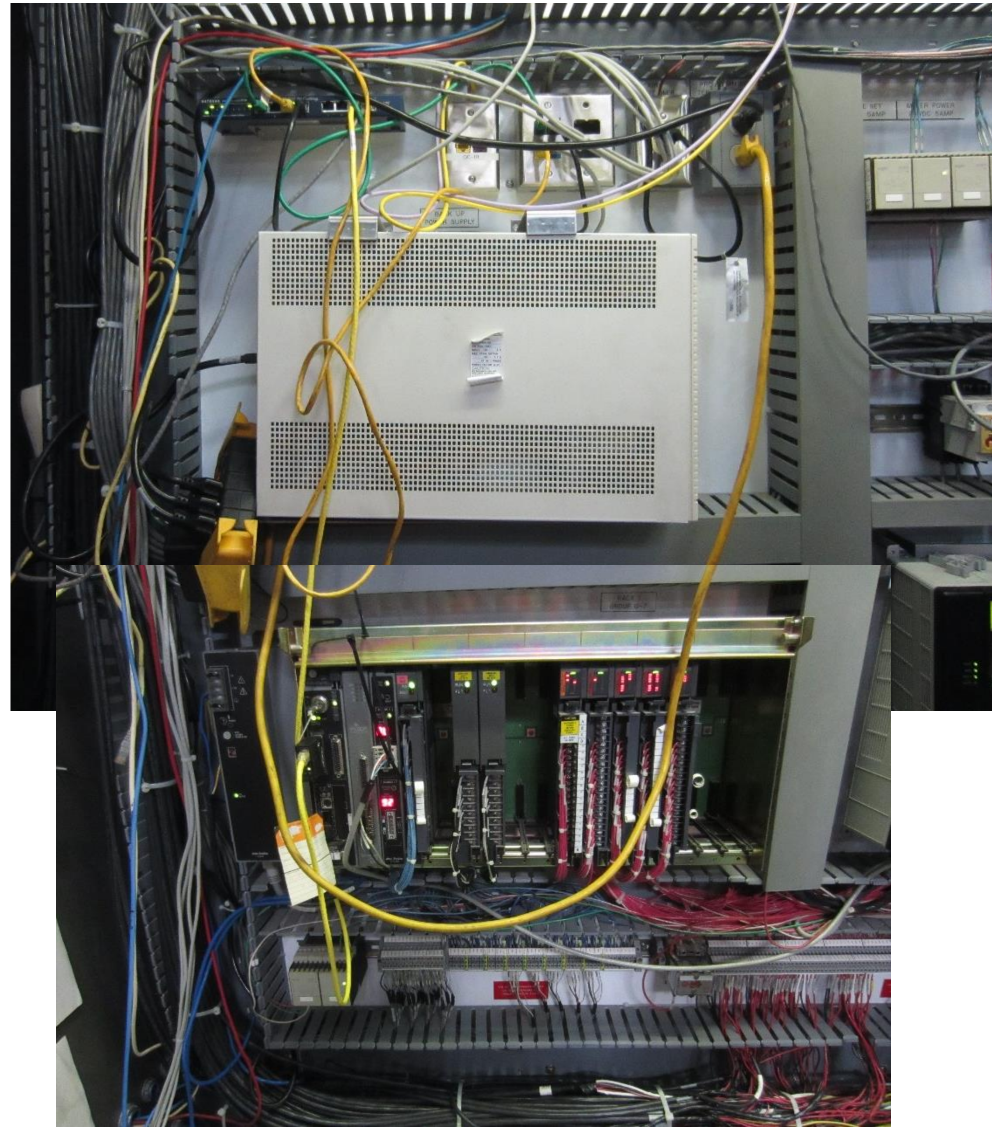


UPS Mayhem at a Soft drink Bottling Plant

James Owens, CEM, CPQ
EPRI

UPSs used for Protection of Critical Controls at a facility

- A PQ audit at a soda bottling facility was conducted.
- As part of our initial questions we asked if they had done any mitigation for their equipment.
  - They replied “We have UPSs sprinkled around the plant.”
  - We replied, “Ok, we’d like to see them when we are on-site.”
- What do you see????



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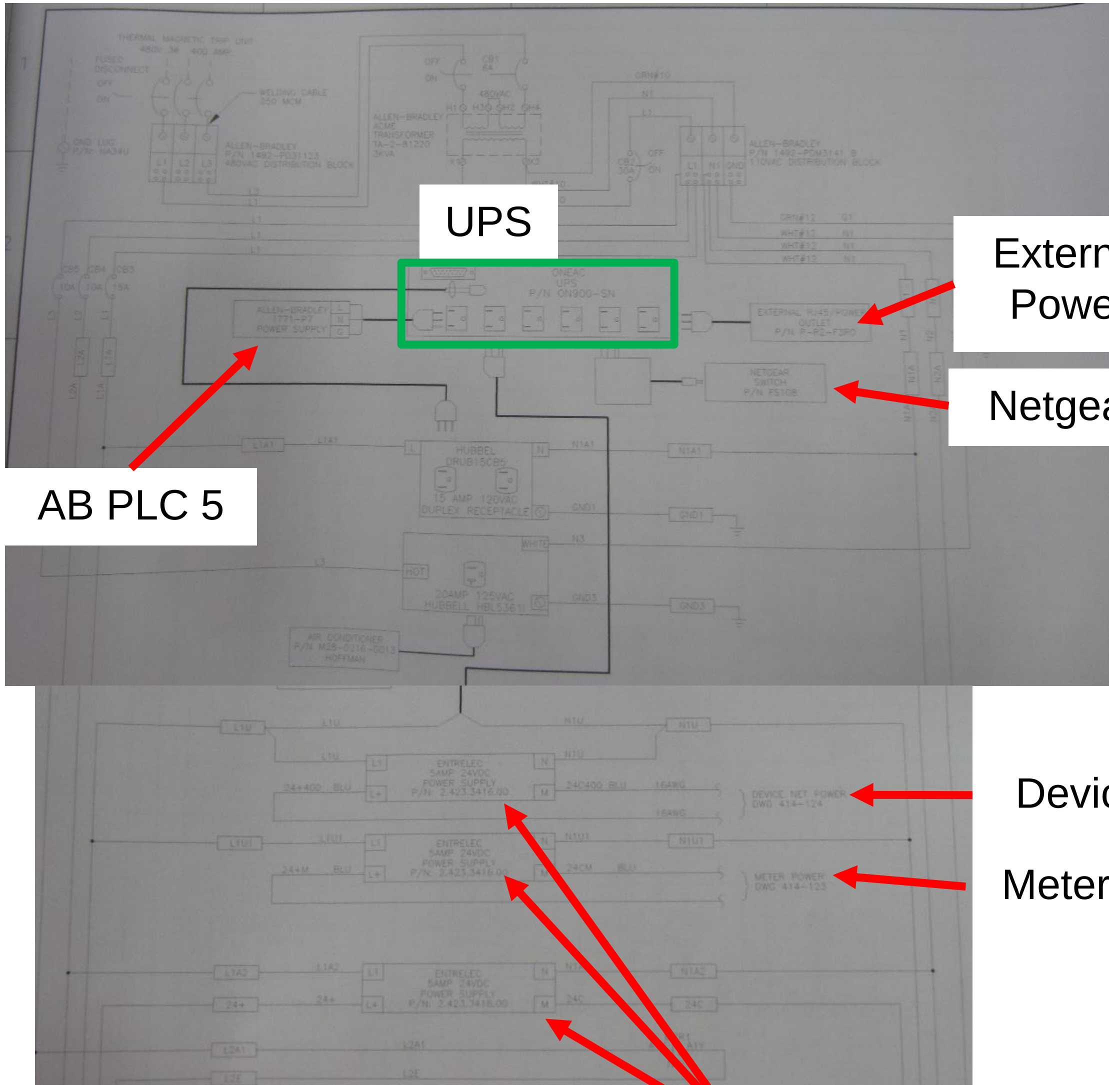
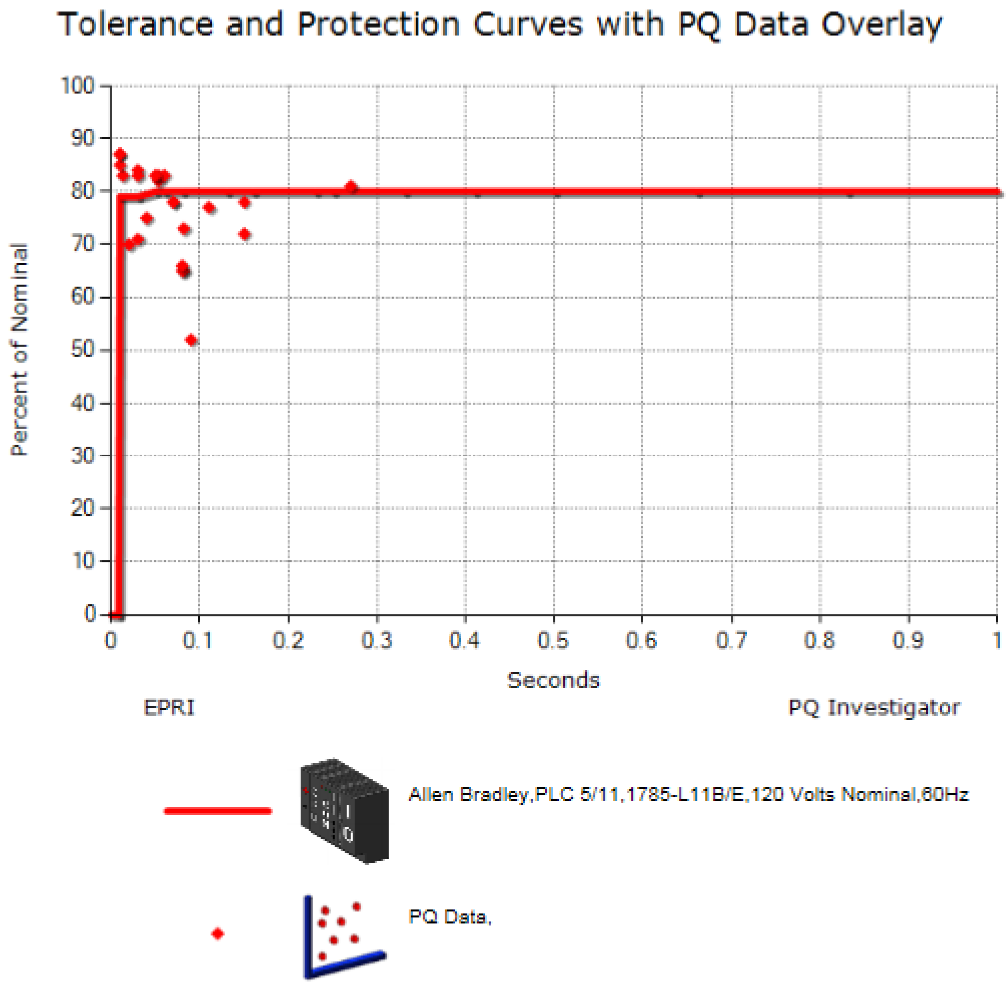
Looking Closely at the Drawings and the UPS

- Apparently the UPS had failed on them at some point in time, and as a work around they bypassed the UPS by using a ‘power strip’ to power the critical loads.



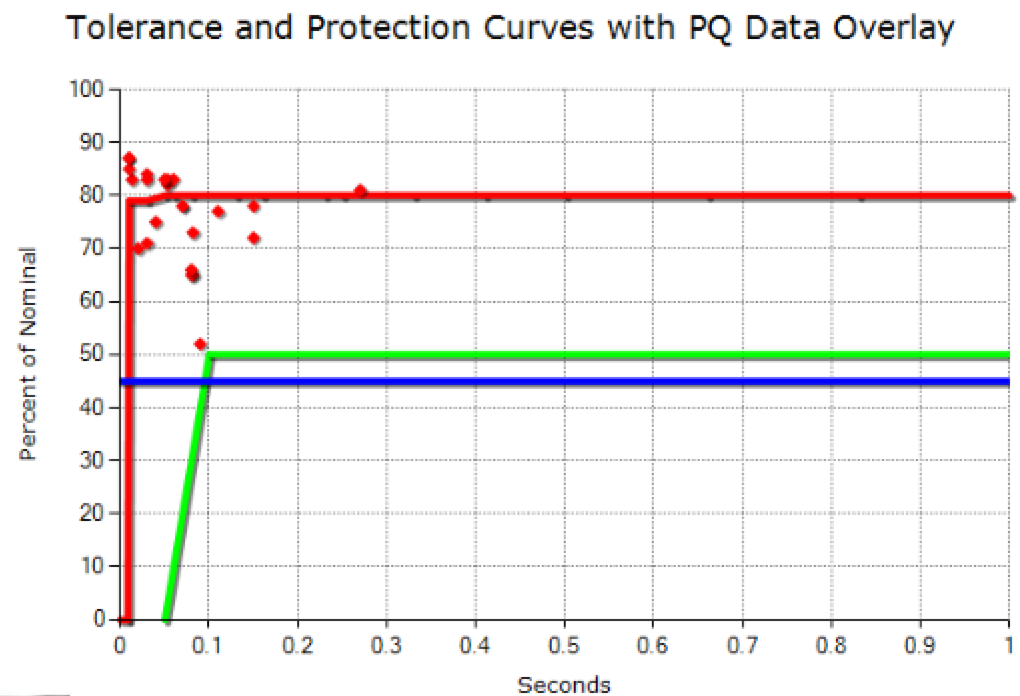
UPS against PQ Environment?

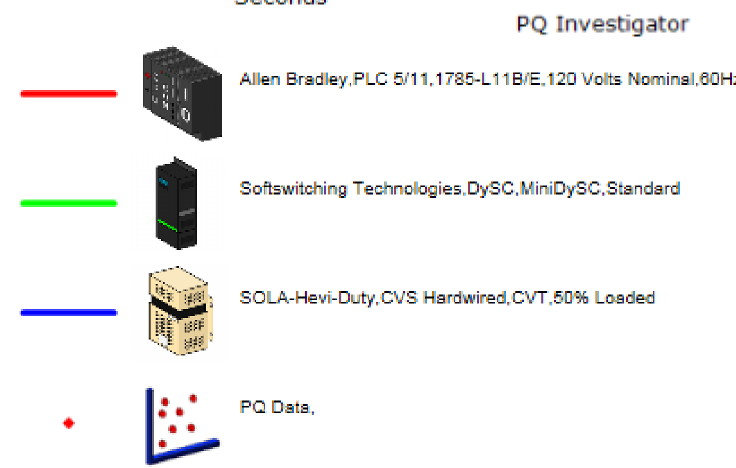
- Once again, here is a facility with a PQ environment that has a majority of its PQ events right in the trip range of an AB PLC5.
- They had tried doing something by installing a UPS to provide back-up power.
- But like most places we see, once the UPS is installed it's forgotten.
- Failed in Service
  – Critical Loads put in power strip instead
- So what did we recommend??

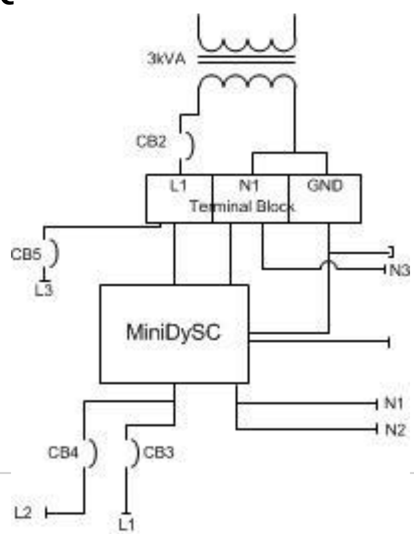


Solution

- This particular location, we recommended that they completely remove the UPS; as it was no longer usable.
- We suggested that they rewire the way the circuits are sourced and install either an AB MiniDySC or a 50% loaded CVT.
- This would provide them the ride-through needed based on the PQ environment.







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Another UPS in the Plant….

- Same plant different location.
- They are again using a UPS for back-up power.
- What do you see??

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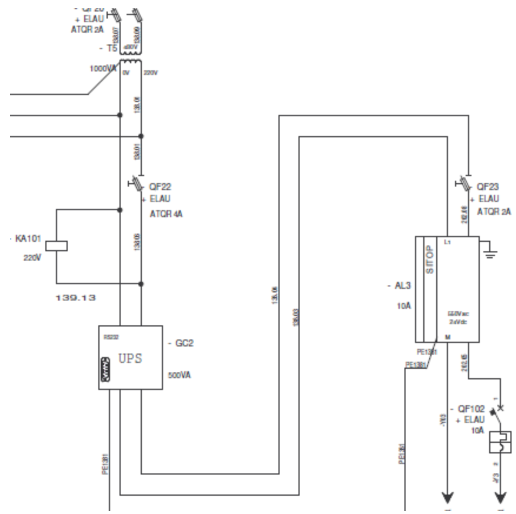
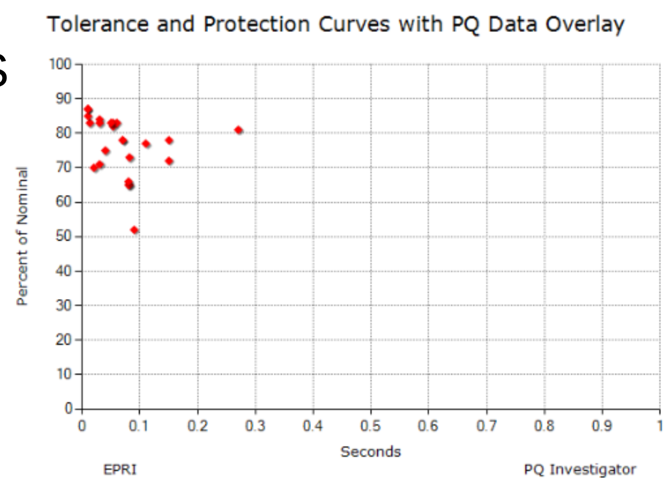
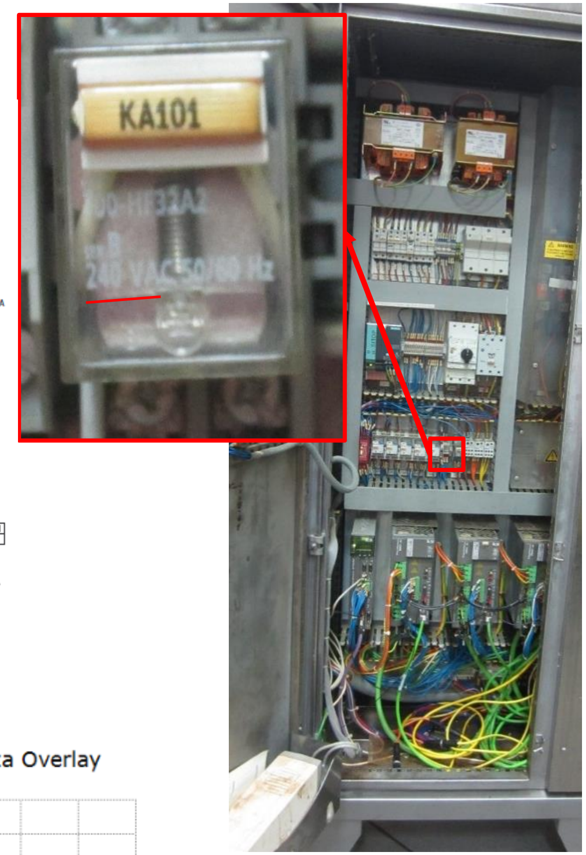
UPS Was Intended to Protect What???

- What is the most sensitive component in the cabinet from a control power standpoint?
- There is a 10A DC Power Supply downstream of the UPS.
- Again, we find an AC ice cube relay being used as a controls permissive.
- It's not on UPS power, but even if it were, the control power is plugged into the Surge Protection Only outlet on a UPS and the UPS is on Battery (unit is faulted).
- What do you do, same PQ environment as the last UPS location??







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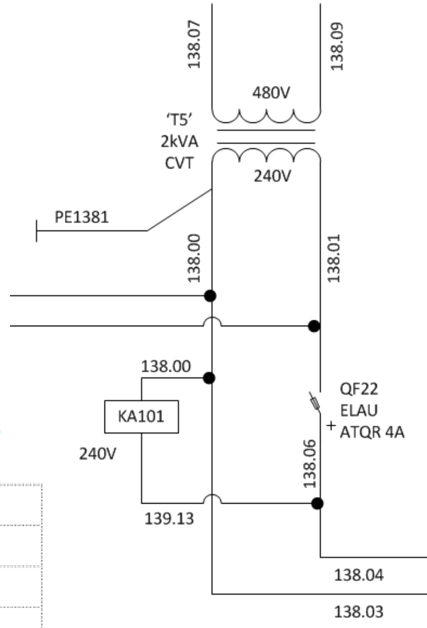
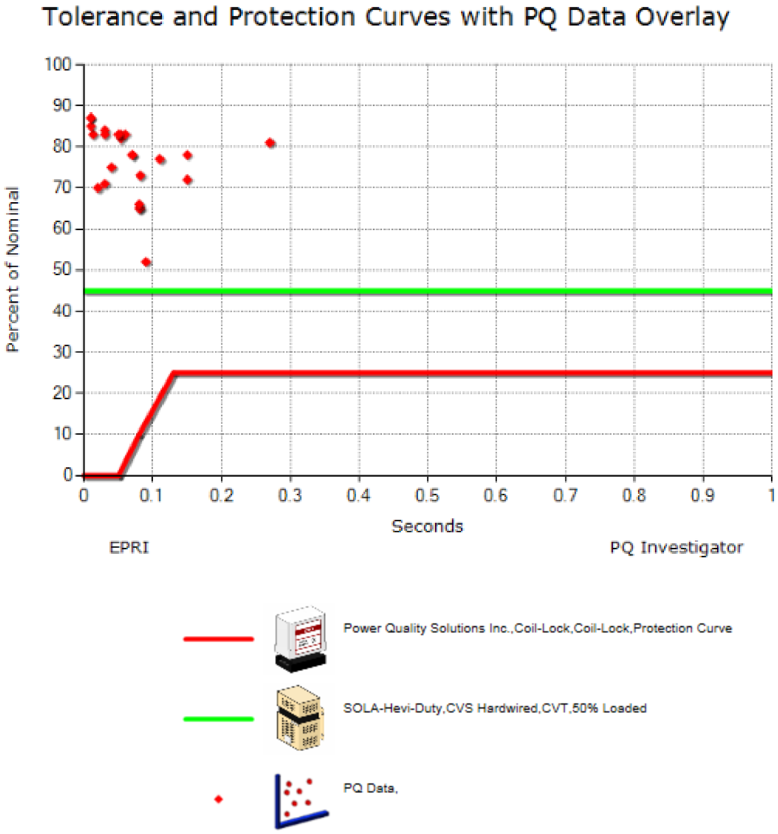
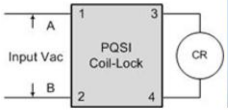
Solution

- The recommendation for this cabinet was again to remove the UPS.
- Then they could either install a 240V coil-lock on the coil terminals of the ice cube relay or replace the upstream 1kVA 480V-220V CPT with a 2kVA CVT (but they would need to verify that the other components could be powered at 240V instead of 220V).







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Protecting Critical and Sensitive Process Equipment at an Automotive Supplier

INTRODUCTION

- An automotive manufacturing part supplier experiencing shutdowns called upon EPRI to help it decrease power disturbance – related delays.
  - This manufacturer supplies fuel injectors to two of the big three U.S. automotive manufacturers.
- Just-in-time (JIT) is a type of inventory management system common in the automotive industry.
- In this particular case, a voltage sag event caused a supply shock to multiple engine assembly plants.
  - In fact, the event was so devastating that the supplier had to fly parts directly to each assembly line to avoid a fine of $1 million per hour that the engine assembly process was delayed.
  - The root cause of this supply shock event was a power disturbance that caused a drive and motor on one assembly machine to fail.
  - Had this manufacturer had a spare drive and motor in stock, the shock could have been minimized. Instead, this supplier experienced a four-day process delay.

SCOPE OF WORK

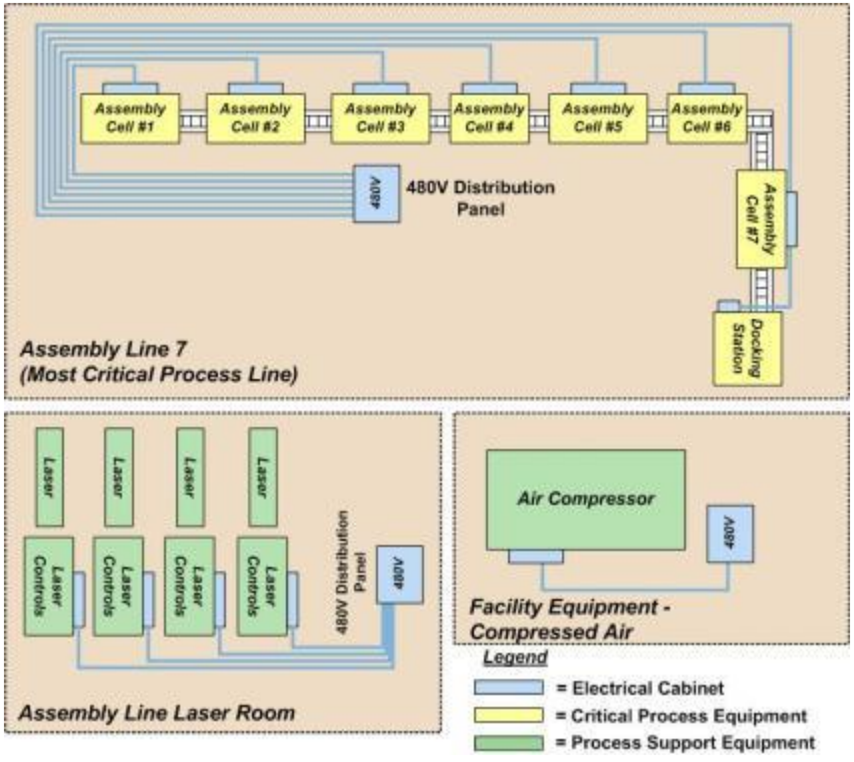
- After a power disturbance caused the devastating supply shock, the fuel injector manufacturer organized a task force to reduce or prevent this from occurring in the future.
  - The task force comprised operations, maintenance (facility and operations), external consultants (EPRI), and the local electric utility.
- The goal of the task force was to identify the root cause of the power disturbance and find a method to isolate or eliminate the probability of reoccurrence.

STRATEGY

- The manufacturer and local utility identified the root cause of the process shutdown to be a 30-cycle interruption.
- Knowing that a power disturbance was the root cause of the shutdown, the team's goal was to reduce the potential of future power disturbance – related shutdowns.
- The local utility was assigned the task of evaluating its infrastructure to identify areas for improvement, while EPRI was asked to evaluate the process equipment's sensitivity to power disturbances.
- EPRI draws upon an extensive knowledge base gained through over 600 industrial power quality projects. Its goal was to identify the elements of the critical process machines sensitive to power disturbances and recommend mitigation solutions to reduce the occurrence of power disturbance – related shutdowns.

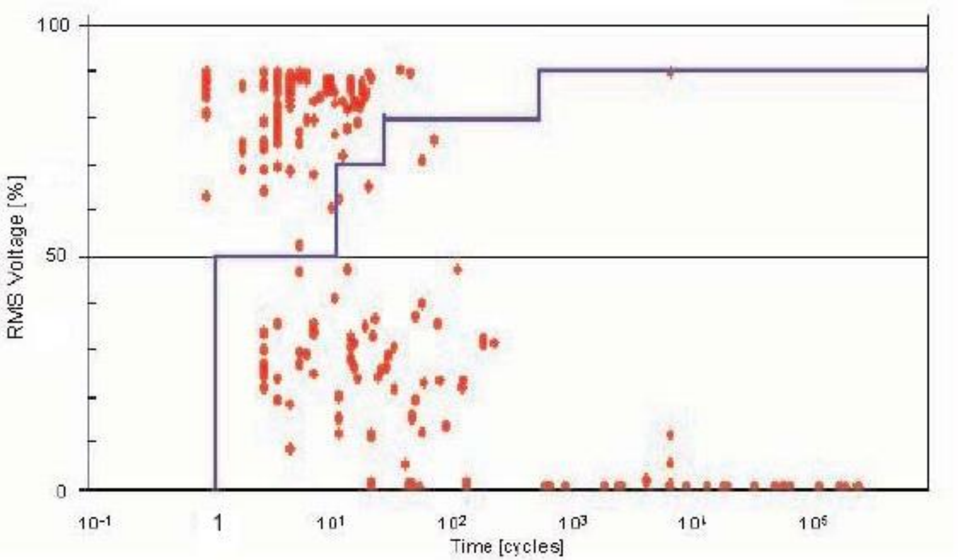
Step 1: Identification of Most-Critical and/or Most-Sensitive Process Equipment

- The manufacturer identified 10 of its most critical or most sensitive process equipment.
  - In order to provide the most accurate analysis and recommendation, all equipment affected by power disturbances had to be included in the project.
  - This is imperative because many process machines are either electrically or mechanically interlocked to one another, and an unidentified weakness of one system could negate any improvements done to others.



Step 2: Evaluation of the Equipment's Electrical Environment

- Power disturbances: a normal component of the industrial electrical environment.
- Equipment shutdowns or misoperations may result from incompatibility between the equipment and its environment.
- The more compatible with its environment, the less likely that equipment shuts down due to disturbances.
- To determine the compatibility level of equipment, **the electrical environment must be characterized** by monitoring and recording power disturbances over time.
- Fortunately, the manufacturer's local utility had recorded voltage sags and interruptions over the past five years where nominal voltage was 90% or less.



Sags and Interruptions

Recorded over

Past 5 Years

Step 2: Evaluation of the Equipment's Electrical Environment

Table 2. One-Year Normalized Histogram of Recorded Voltage Sag Events

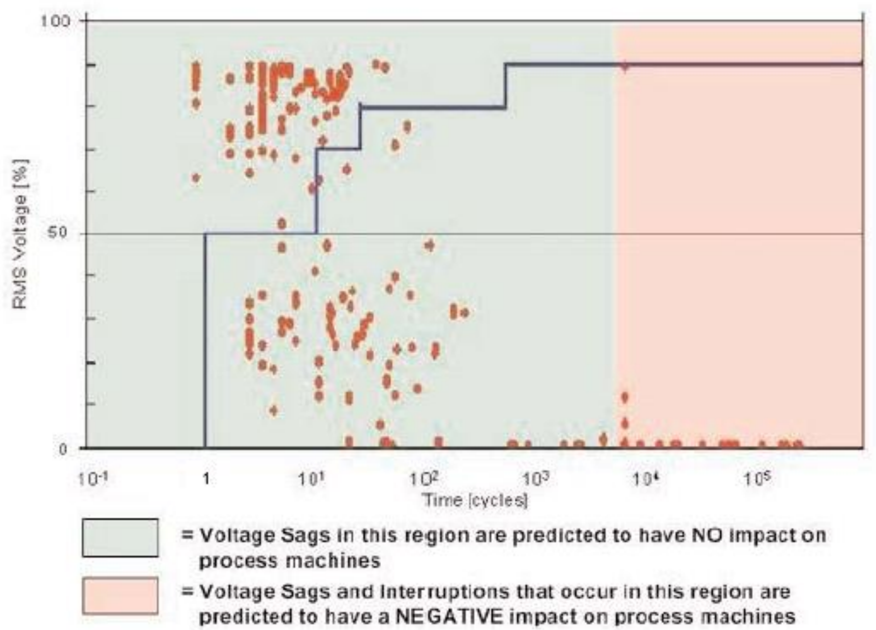
	0–5 cycles	6–9 cycles	10–29 cycles	30–59 cycles	1–5 s	5–30 s	30–60 s	60–120 s	≥120 s
0–10%	0.181	0.000	0.181	0.545	0.728	1.454	0.728	0.364	3.272
10–20%	0.364	0.000	0.909	0.545	0.364	0.000	0.000	0.181	0.000
20–30%	1.090	0.728	0.909	0.545	0.728	0.000	0.000	0.000	0.000
30–40%	0.364	0.545	1.090	0.364	0.909	0.000	0.000	0.000	0.000
40–50%	0.000	0.181	0.364	0.000	0.181	0.000	0.000	0.000	0.000
50–60%	0.000	0.181	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60–70%	1.090	0.181	0.545	0.000	0.000	0.000	0.000	0.000	0.000
70–80%	1.636	0.728	0.728	0.000	0.364	0.000	0.000	0.000	0.000
80–90%	7.271	1.454	3.817	0.364	0.000	0.000	0.000	0.000	0.181

Step 3: Determination of Tolerance Objective

- Before any analysis or recommendation can be made, the manufacturer must determine the tolerance objective.
  - The tolerance objective is the goal of the project.
  - Determines the level of analysis and cost of the recommended solutions.

- Given the potential high cost of process interruptions due to voltage sags at this facility, the manufacturer decided to pursue the goal of protecting one of its sensitive processes (comprising a total of 10 process machines) against all voltage sags and interruptions out to 10–seconds.

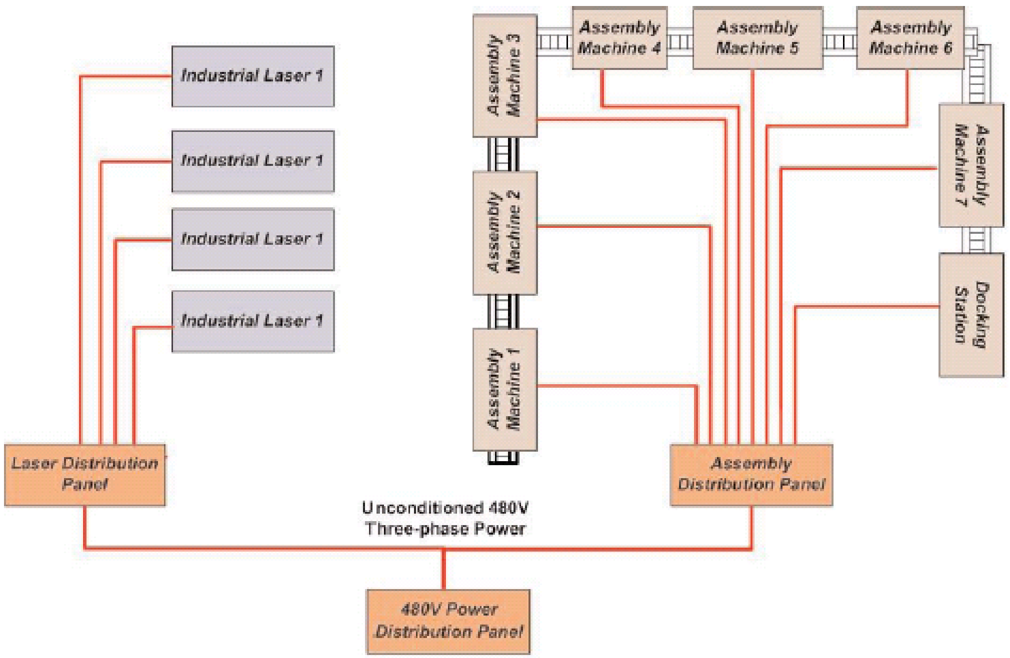
Figure 2. Tolerance Objective of Most Critical Processes



Step 4: On-Site Visit (Data Collection)

- The primary focus:
  - to understand the power distribution configuration, load characteristics, process, process machine power, and control configuration, and operations of all process machines included in the project.
- EPRI's on-site investigation revealed
  - critical assembly machines included in the project were **powered by one 480-V, three-phase power distribution pane**l.
- The industrial welding support lasers that support the assembly machines were also **powered from a single 480-V three-phase distribution panel**

Figure 3. Assembly Line and Process Support Equipment Power Distribution Layout



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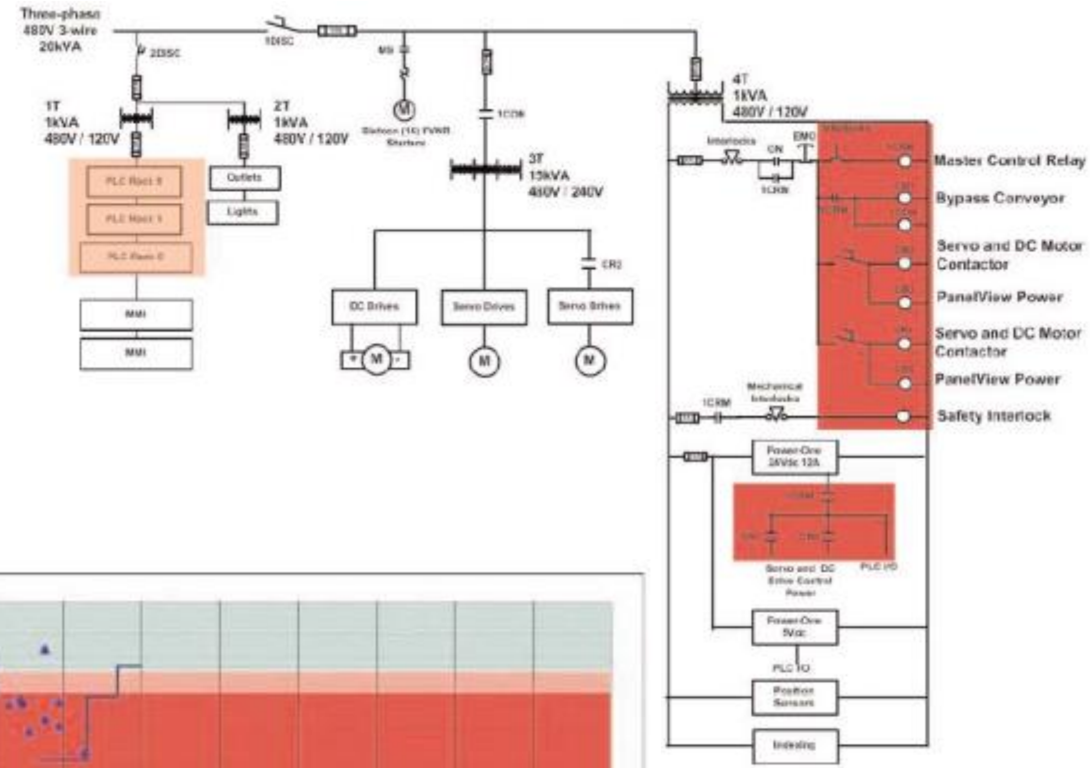
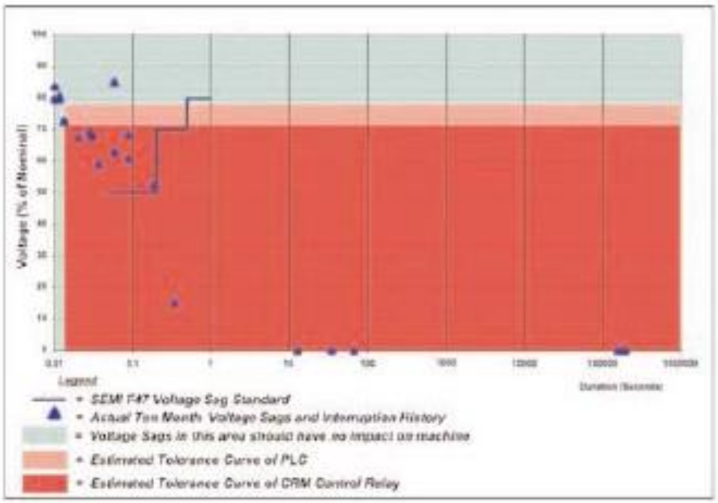
Step 5: Detailed Report (Findings)

- The analysis focused on estimating the actual voltage sag sensitivity of the assembly machines and identifying a solution to meet the objective. In an effort to estimate the actual voltage sag tolerance.

- A single-line diagram was generated from the assembly machine’s electrical schematics.

- A representative assembly machine single-line diagram, including a tolerance curve for the machine’s most sensitive components.





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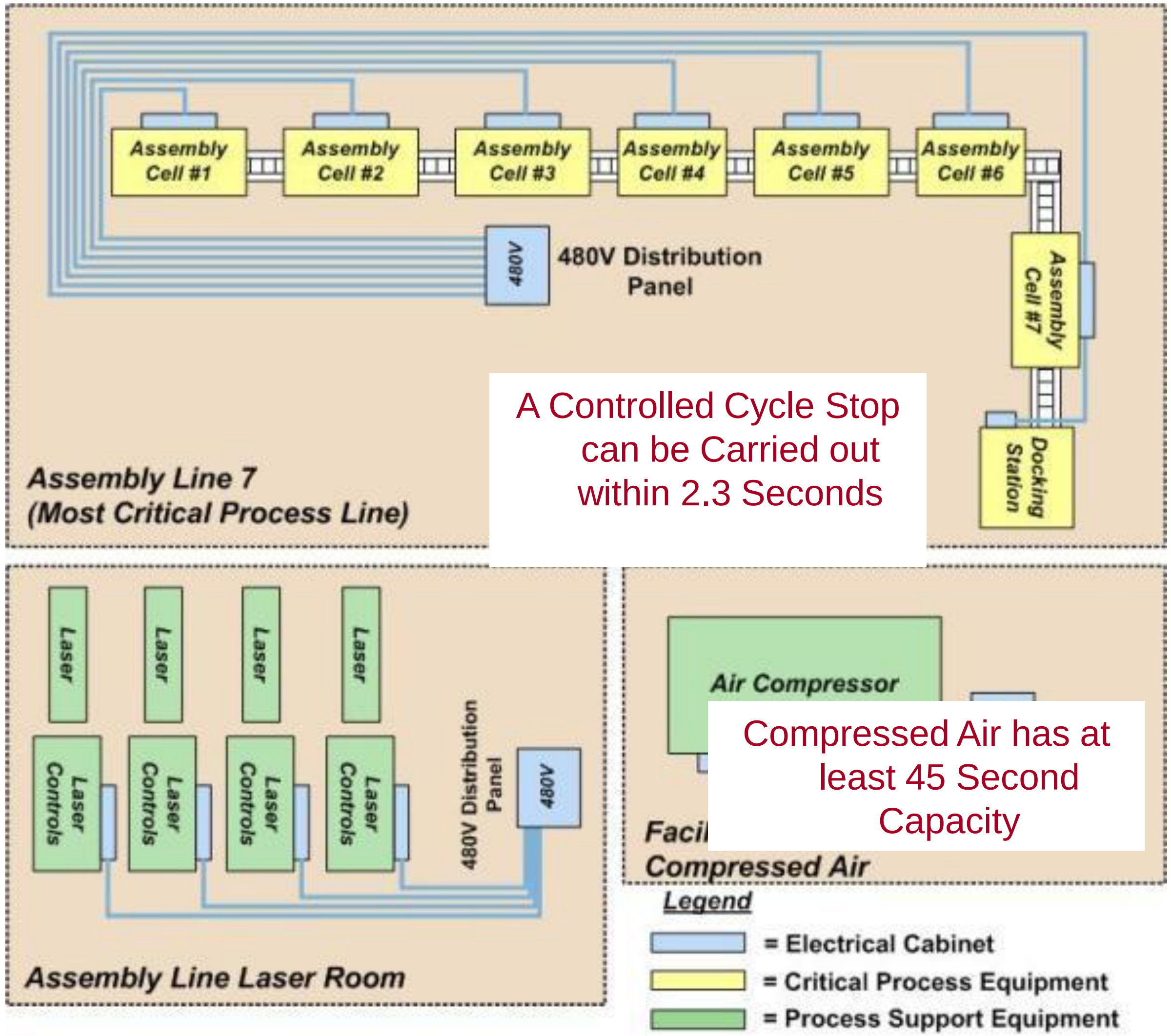
Step 5: Detailed Report (Findings)

- Since the goal was to eliminate delays and failures which could occur if the machines are halted mid-cycle, investigation into the machine operations revealed that a cycle-stop (controlled stop) could be performed within 2.3 seconds.
- Compressed Air has 45 seconds of Capacity.



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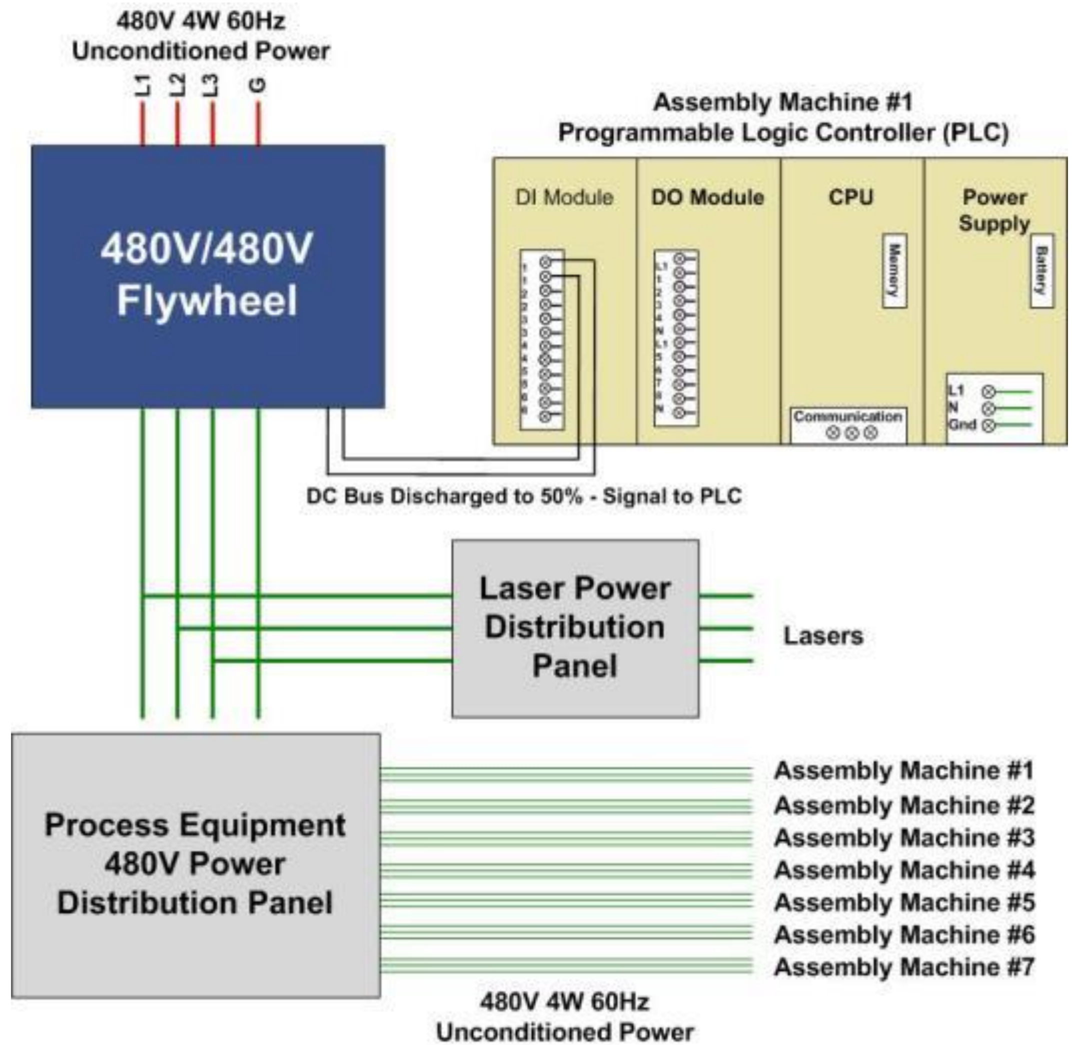
Step 5: Detailed Report (Recommendations)

- The minimum time required to provide conditioned power to all assembly machines to perform a cycle stop on the entire line is approximately 4 seconds. The solution recommended was a $100,000, 300-kVA flywheel to provide up to 13 seconds of conditioned power at full load.
- The recommendation was to install the three-phase, 300-kVA flywheel between the 480-V unconditioned source and the 480-V power distribution panels for the assembly line and lasers,

Step 6: Implementation

- Install the Power Conditioner and Cycle Stop Control Signal

- A 300kVA Flywheel was Installed on Assembly Line 7.



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Step 6: Implementation

- The Power Conditioner Chosen:
  - 300kVA (240kW) UPS
    - 3.1 MJoules,
    - 15 Times the Required Energy

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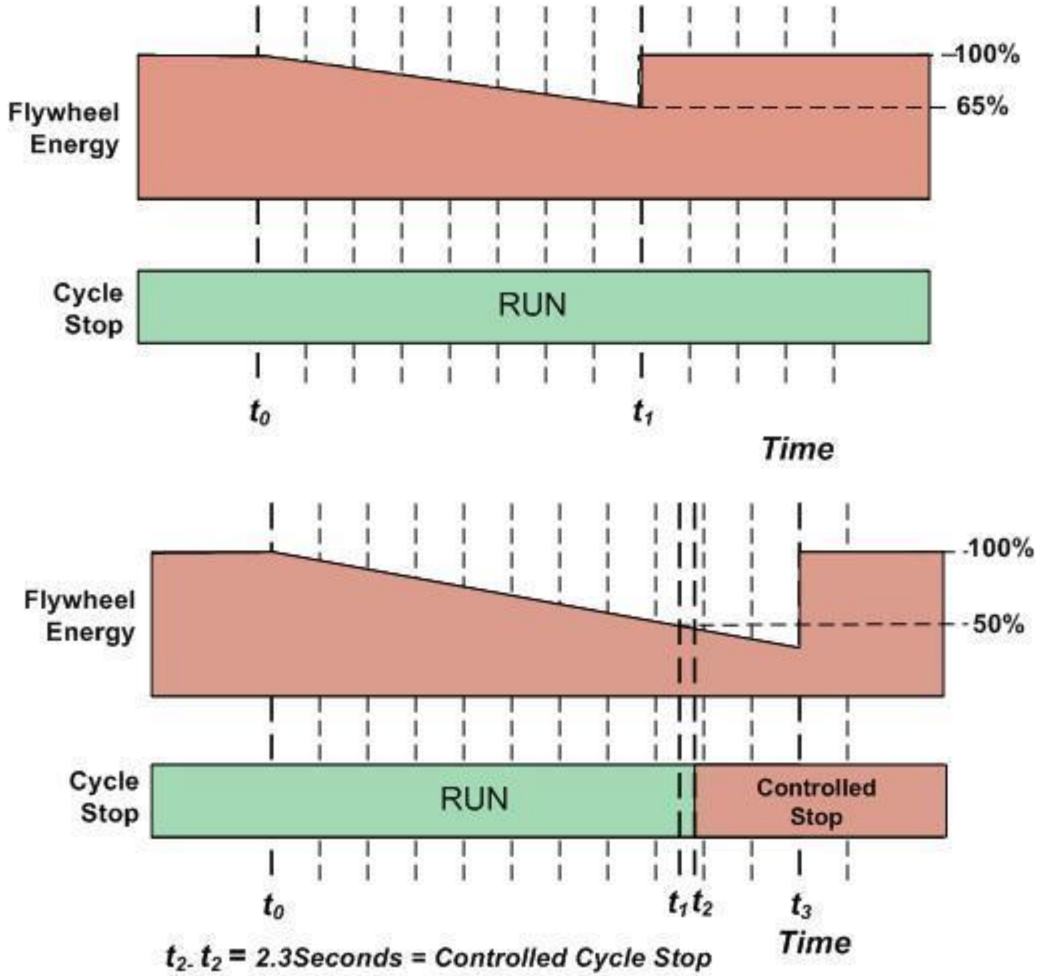
Step 6: Implementation

- Power Conditioner must be Capable of Providing a Signal to the Process to Perform a Cycle Stop if the Interruption Lasts Longer than the Limits of the Conditioner.
- The Flywheel's DC bus Energy Level Signal was Used as a Cycle Stop Trigger



Summary

- Since the installation of the Flywheel on Line 7 in June 2006, the line has not experienced an uncontrolled stop.
- The Manufacturer Justified the Installation of New Flywheels on Three Additional Assembly Lines
- The Cost Justification for the new Flywheels was Based on 18 Voltage Sags or Interruptions Related Shutdowns Occurring per year valued at $30,000 per event
- Yearly losses due to Voltage Sags and Interruptions are Estimated at $540,000.
- The Bottom Line! When looking at recommendations and solutions, think "Out of the Box", be "Creative", and "Analyze" the entire System and not "Just the Power".

Conclusions

- This case study demonstrates that while plants encounter several power quality disturbances, changes as simple as altering parameters on the control can significantly contribute to hardening the plant against PQ events.
- The audit revealed that the plant used several controls that were powered directly from AC and therefore were susceptible to voltage sags.
- It was recommended that the plant install small power conditioners at select locations where control transformers were installed.
- Testing was done to demonstrate that firmware updates and simple parameter reconfiguration of AC drives can allow them to ride through sags as low as 50%.
- The cost benefit of these solutions when compared to more sophisticated solutions such as installing large power conditioners at the service transformer is significant—as much as 50% cheaper.

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Display Manufacturer Case Study

Production Lines

Line A manufactures 19" Displays for monitors with provisions for 21"

Line B manufactures flat panel 19” Displays for monitors with provisions for 17”.

Pegasus Line manufactures 17” Displays for PC monitors.

32” line manufactures TV Displays .

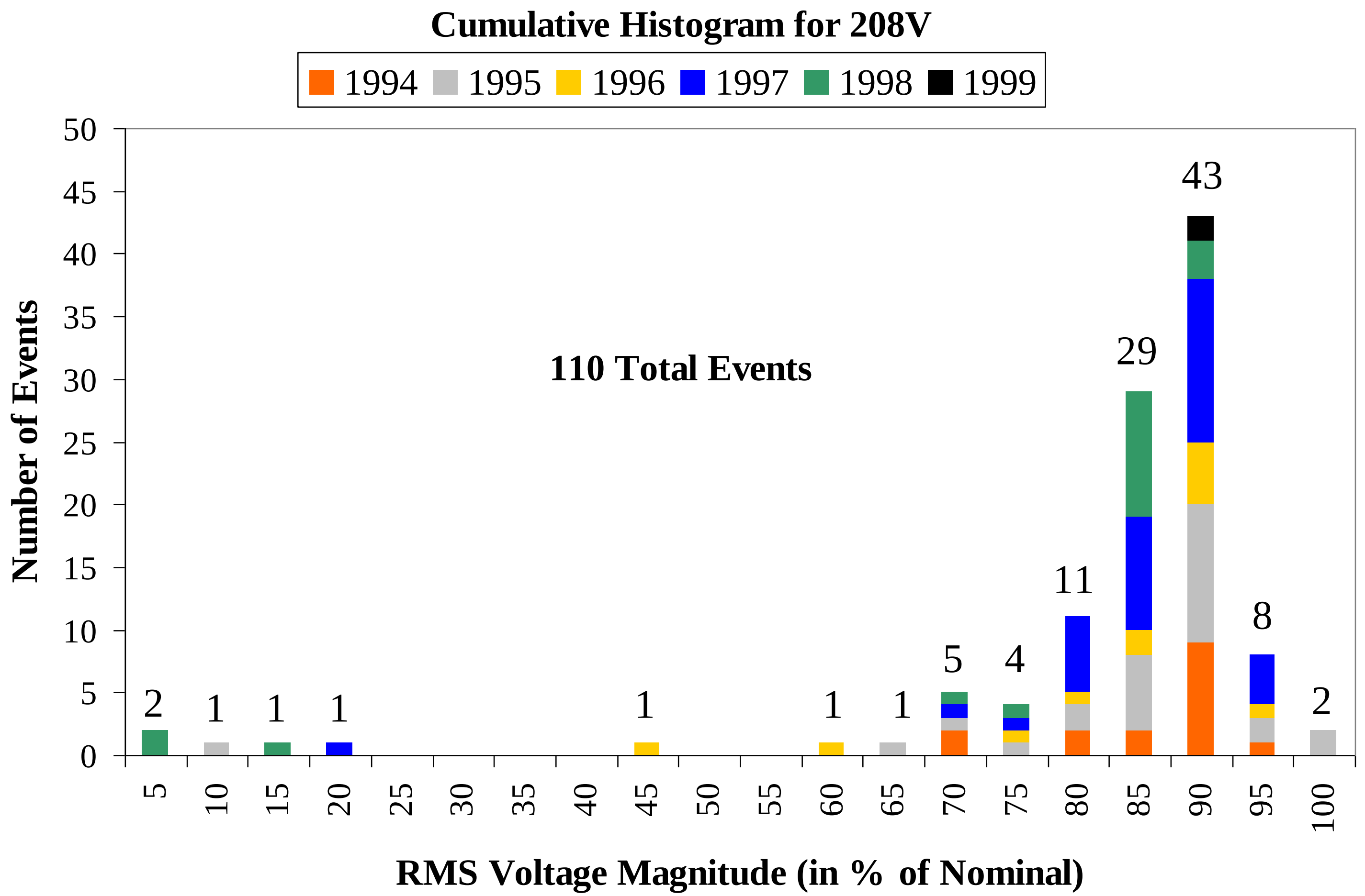
27” Line manufactures TV Displays

20” Line manufactures TV Displays.

Financial Impact of Three Events

Date	Impact	# of Units Rejected (A)	Downtime in Minutes	# of Units missed due to downtime (based on 28 second Mercury Index time) (B)	Total # of Units missed (A) + (B)	Total Cost (based on $180 per unit)
11/19/98	Power fluctuation caused CS light houses to trip	30	20	43	73	**$13,140**
11/23/98	Power Glitch AG, SCR, PII, Lost all screening	73	48	103	176	**$31,680**
01/26/99	Power glitch in screening process	44	10	22	66	**$11,880**
Total		**147**	**78**	**168**	**315**	**$56,700**

Voltage Sag Characteristics Inside the Plant



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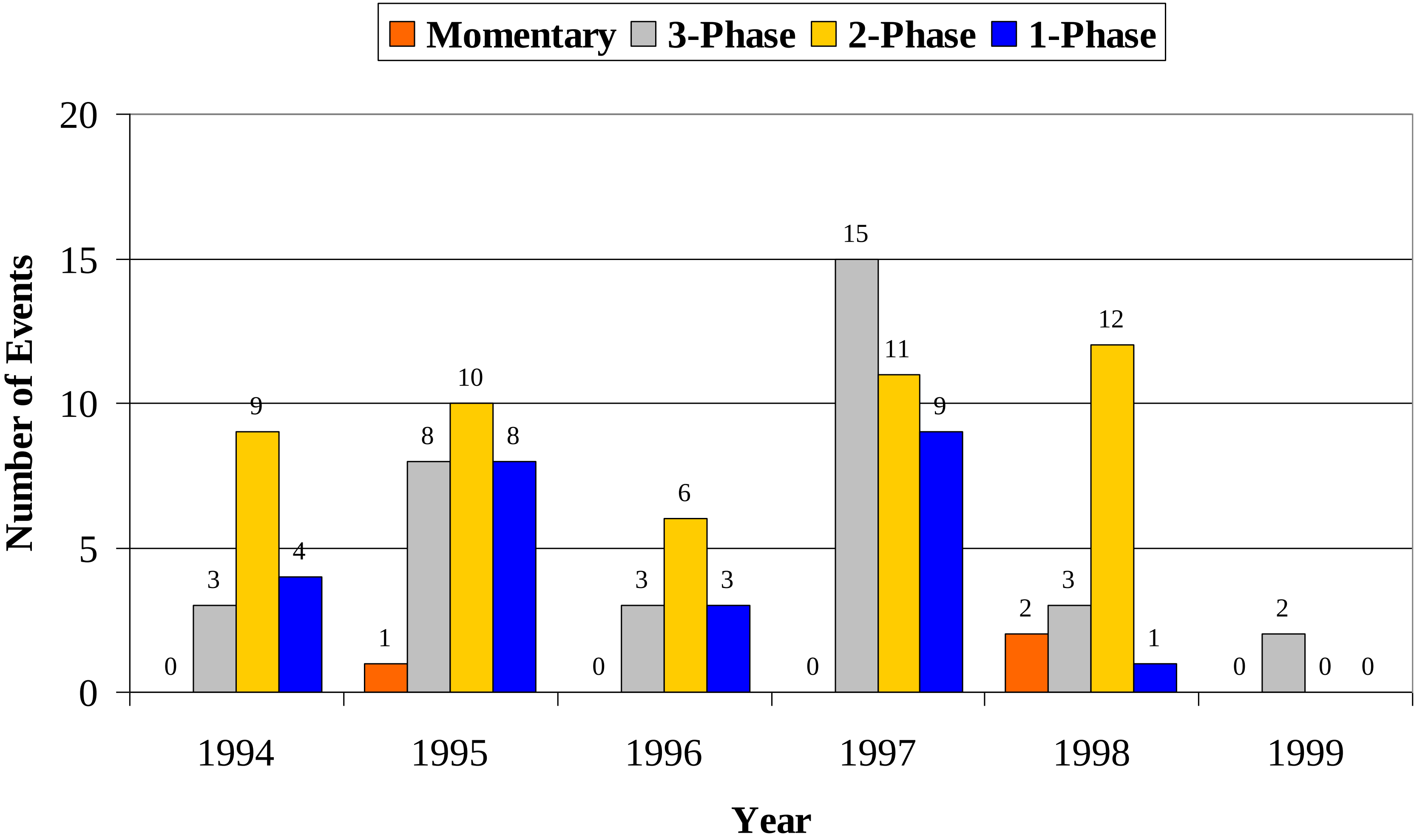
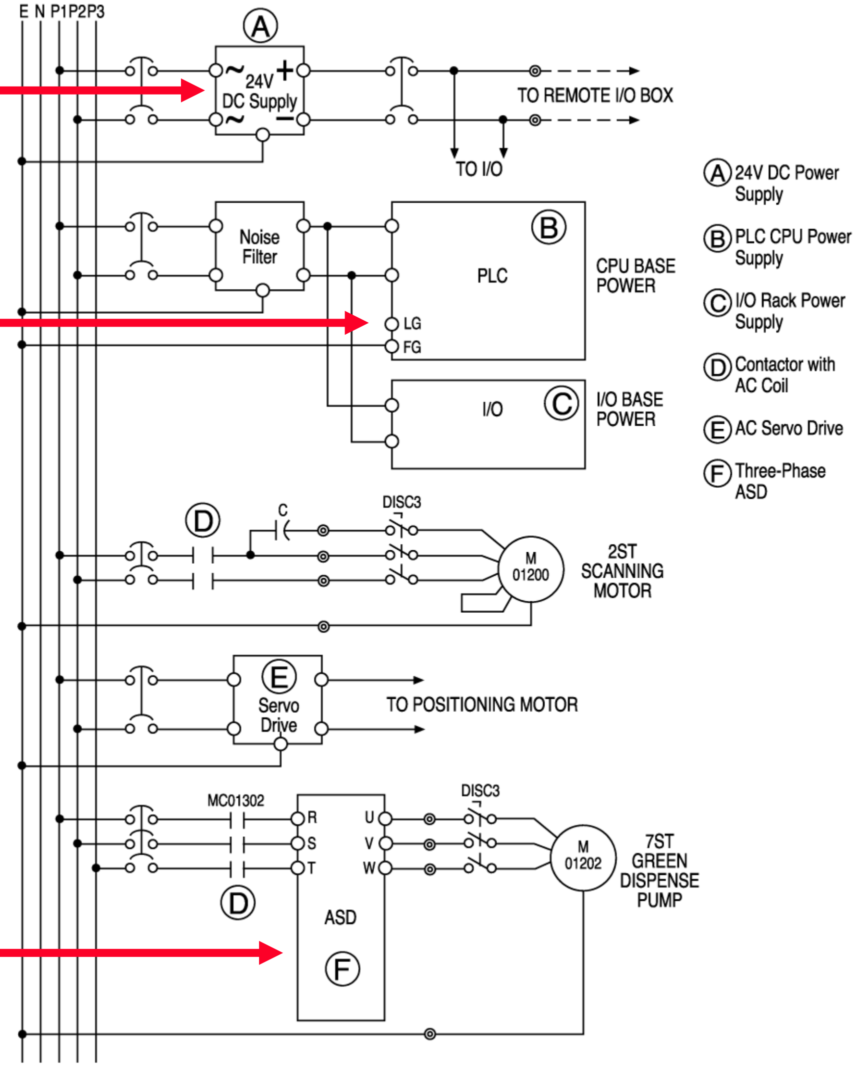
Type of Events

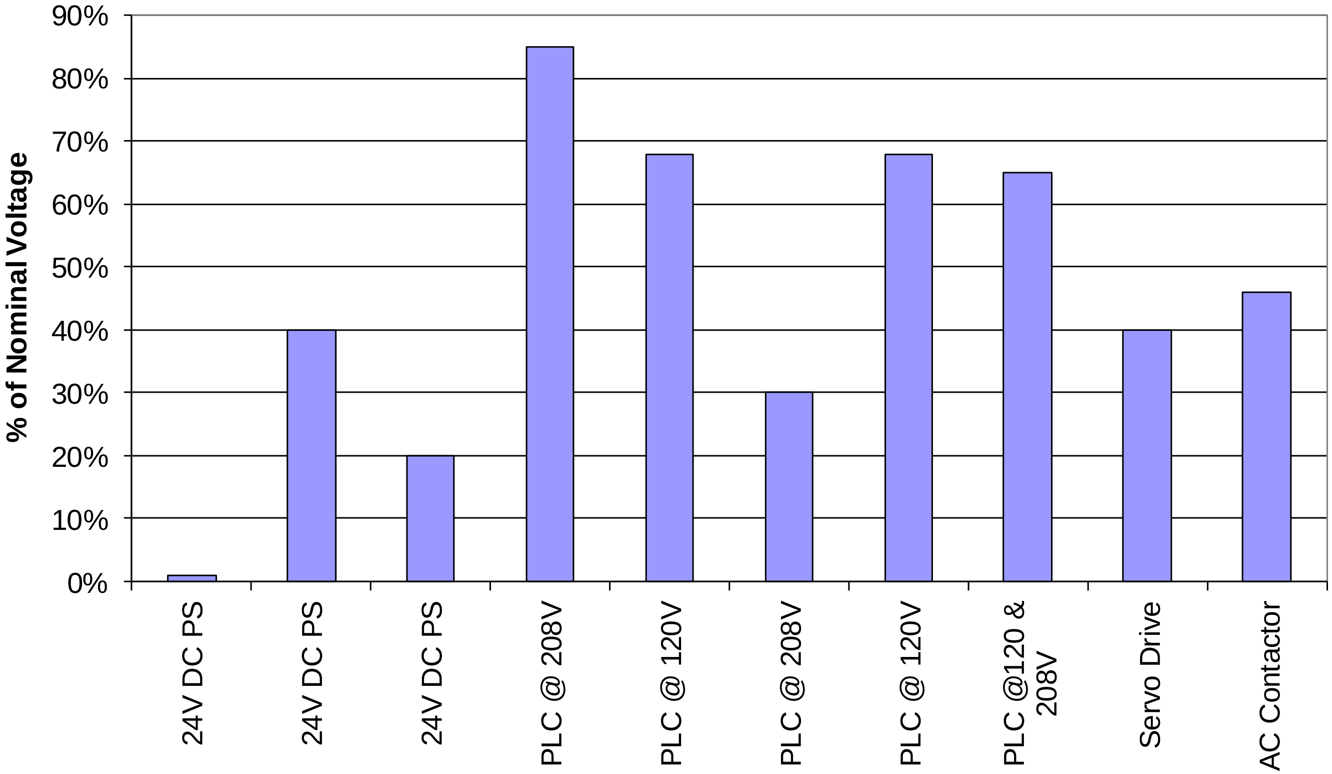


Sensitive Equipment

85% Vnom



How Sensitive?



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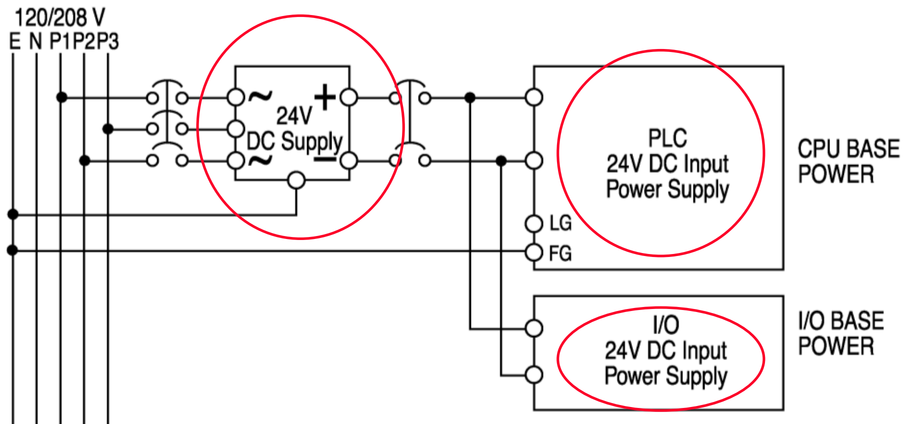
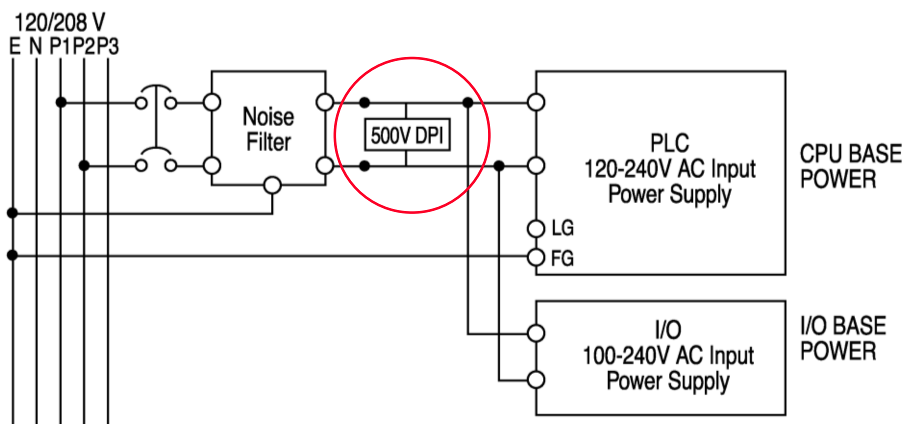
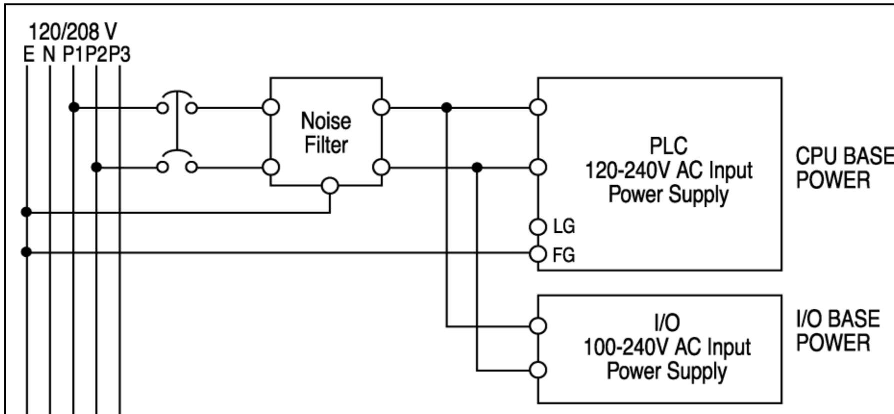
Embedded Solution



Preferred option for CV and C200 Hα Series OMRON PLCs: Option 1



Preferred option for C200H, C200HS, C1000H, OMRON PLCs: Option 3



Existing Arrangement of PLCs

Change PLC Input from AC to DC input.

Use a 3-Phase AC input to 24VDC output Power supply.

If PLC AC power supply is integrated to the Module use a small power conditioning (e.g., Dip Proofing Inverter or CVT).

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AC Versus DC Input for PLCs

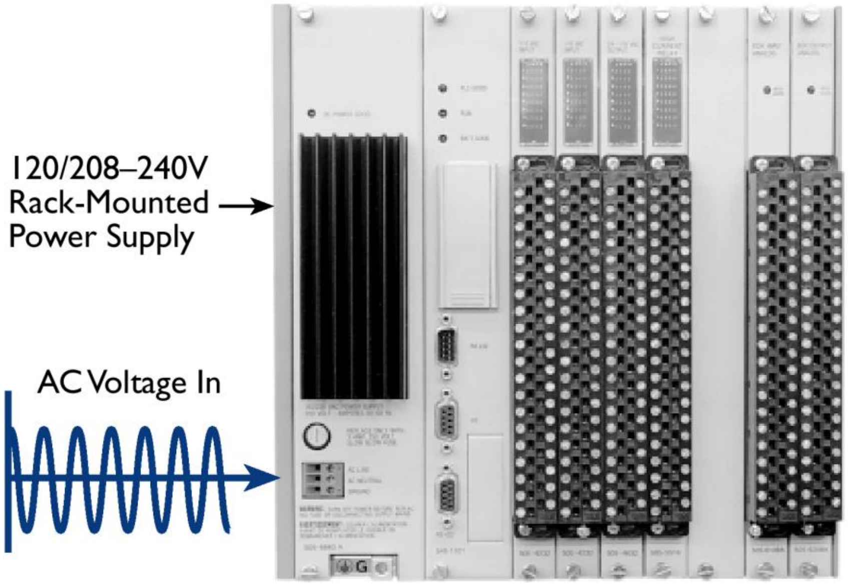


Figure 1. A rack-mounted PLC power supply that requires AC voltage (120/208-240 volts)

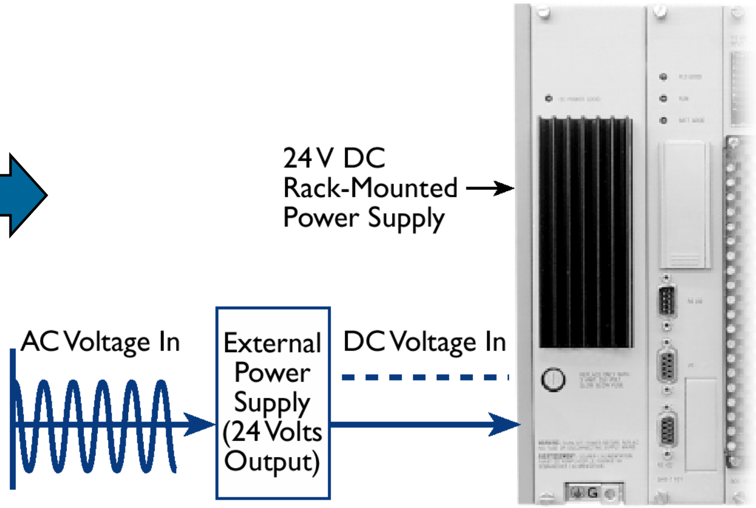
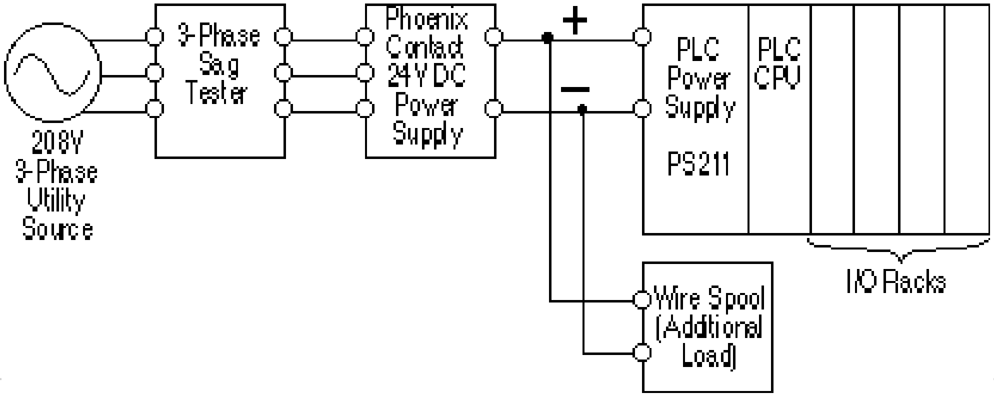


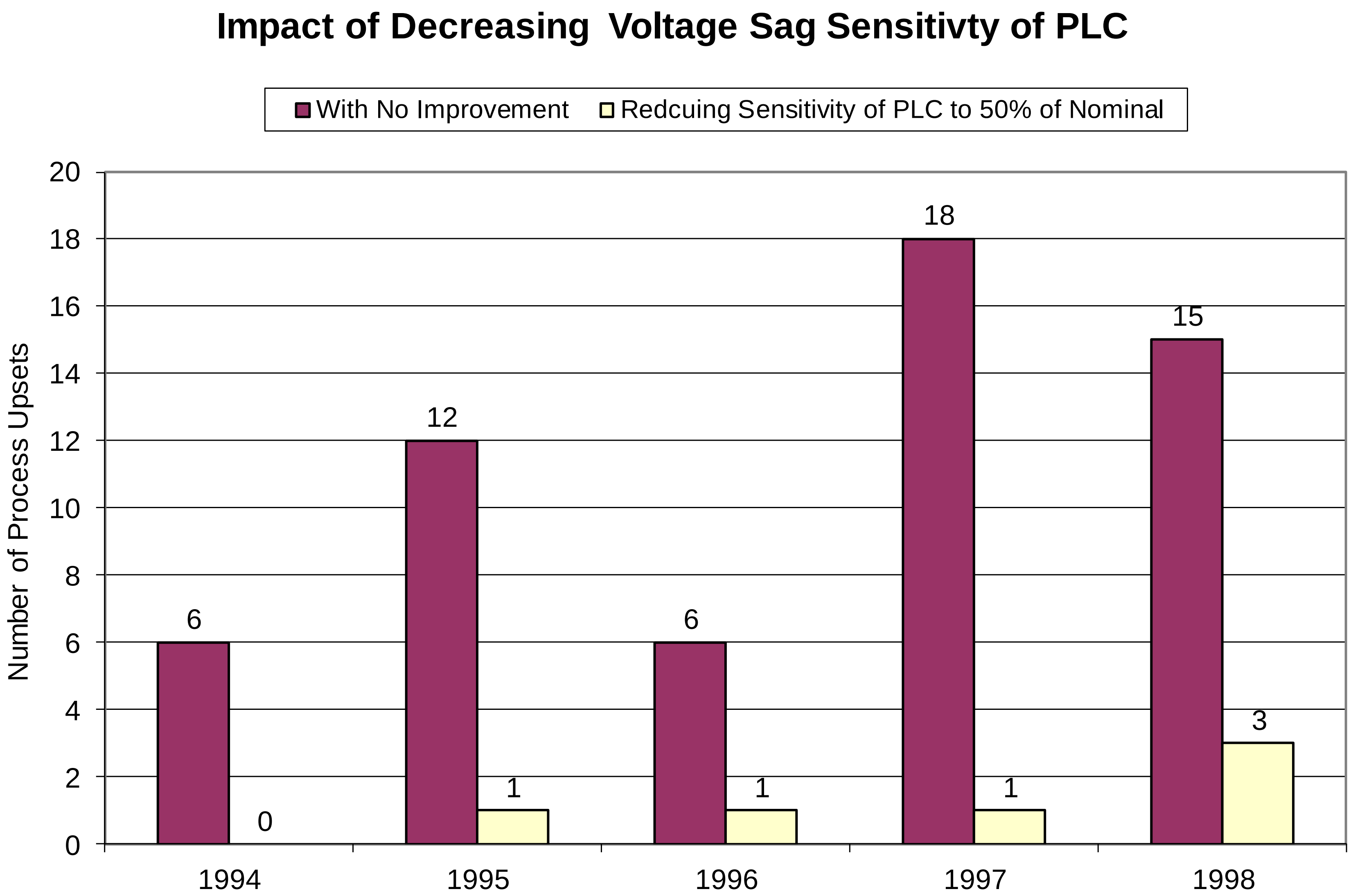
Figure 2. External power supply that provides 24 volts DC to the rack-mounted PLC power supply.

How Effective is a 3-Phase AC Input to 24V DC output Phoenix Contact PS

PLC Power Supply unit	24V DC Source	Loading on 24V DC Source	Voltage Sensitivity Threshold (in %) for 30 Cycle Ride-Through		
			Three Phase Sags	Two-Phase Sags	Single-Phase Sag
CV500-PS211	Phoenix Contact	20%[1]	0%	0%	0%
CV500-PS211	Phoenix Contact	35%	45%	0%	0%
CV500-PS211	Phoenix Contact	60%	50%	0%	0%



How Effective is this Solution?



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Lessons Learned

- In designing new process lines use DC input controllers wherever possible.
- Use a robust DC source for all your DC inputs (such as, 3-Phase AC to 24V DC power supply)
- Know the sag immunity of your DC power supplies in your plant.

Together…Shaping the Future of Electricity