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

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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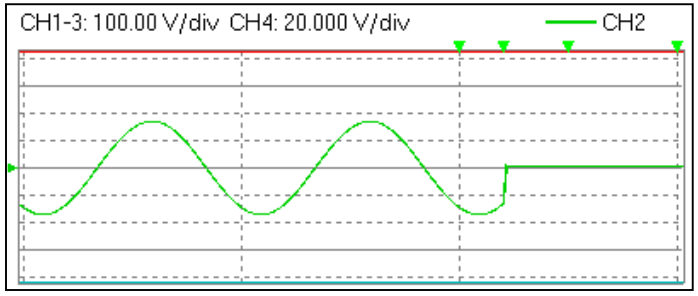
Sustained Interruption (Outage)

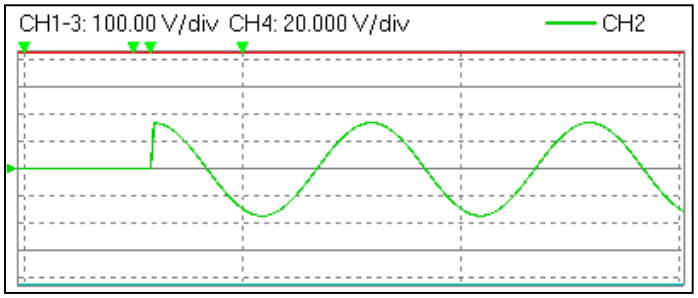
Typical Duration: > 1 Minute

Typical Magnitude: 0.0 pu

pu = per unit (1 pu = nominal)



HIOKI 3196 Event Data 06/10 15:19:22.802

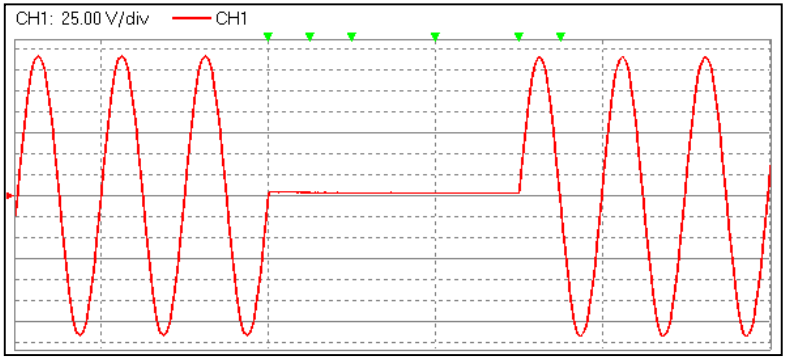


HIOKI 3196 Event Data 06/10 15:21:25.919

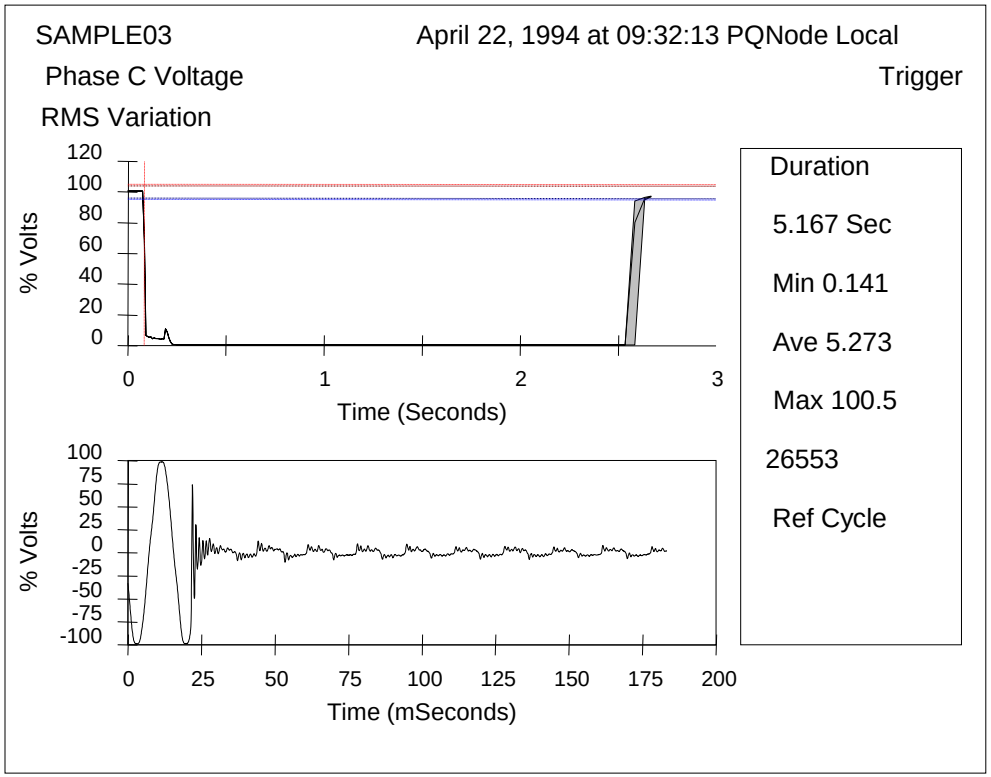
Momentary Interruption

Typical Duration: 0.5 cycles – 3 s (180 cyc.)

Typical Magnitude: < 0.1 pu



HIOKI 3196 Event Data, 3 cycle Interruption



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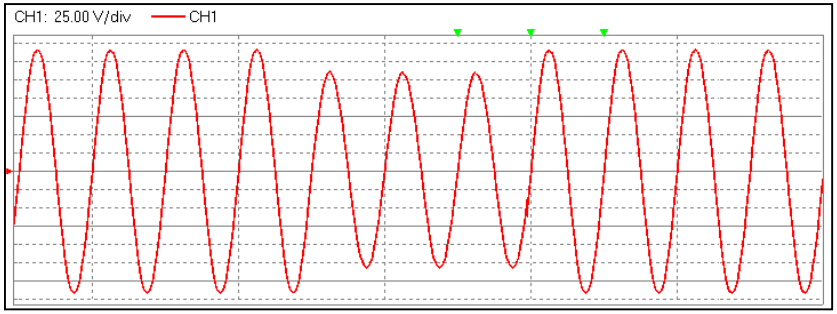
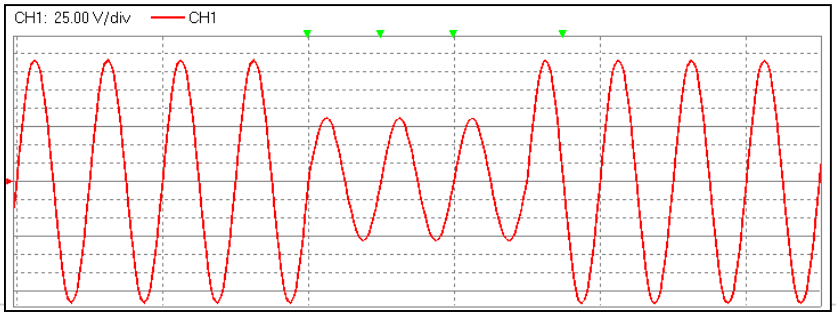
Voltage Sag Common Depths and Durations

	Typical Duration	Typical Magnitude
Instantaneous	0.5 – 30 cycles	0.1 - 0.9 pu
Momentary	30 cycles - 3 s	0.1 - 0.9 pu
Temporary	3 s - 1 min	0.1 - 0.9 pu



HIOKI 3196 Event Data
3 cycle, 0.8 pu

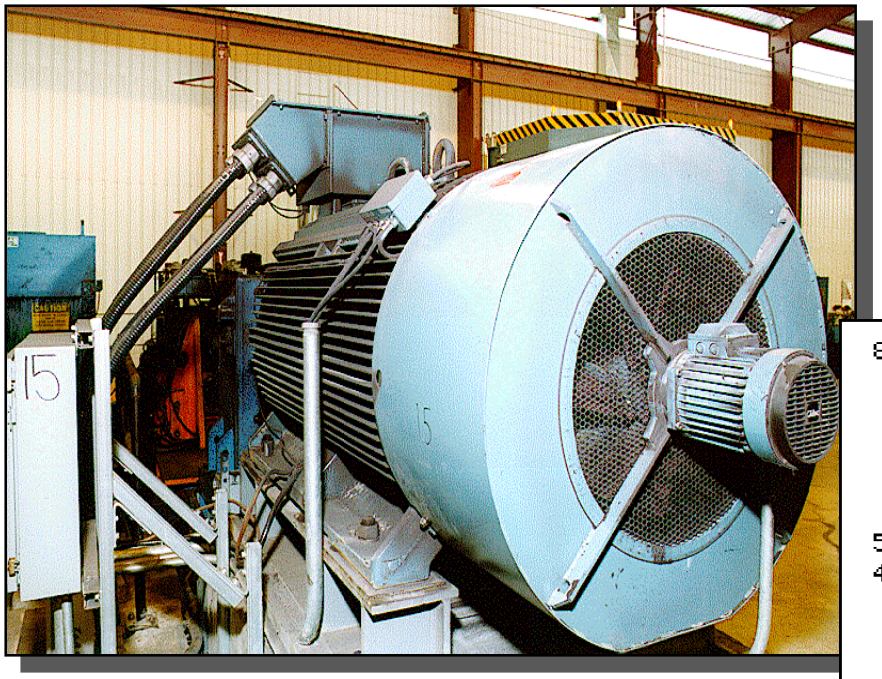


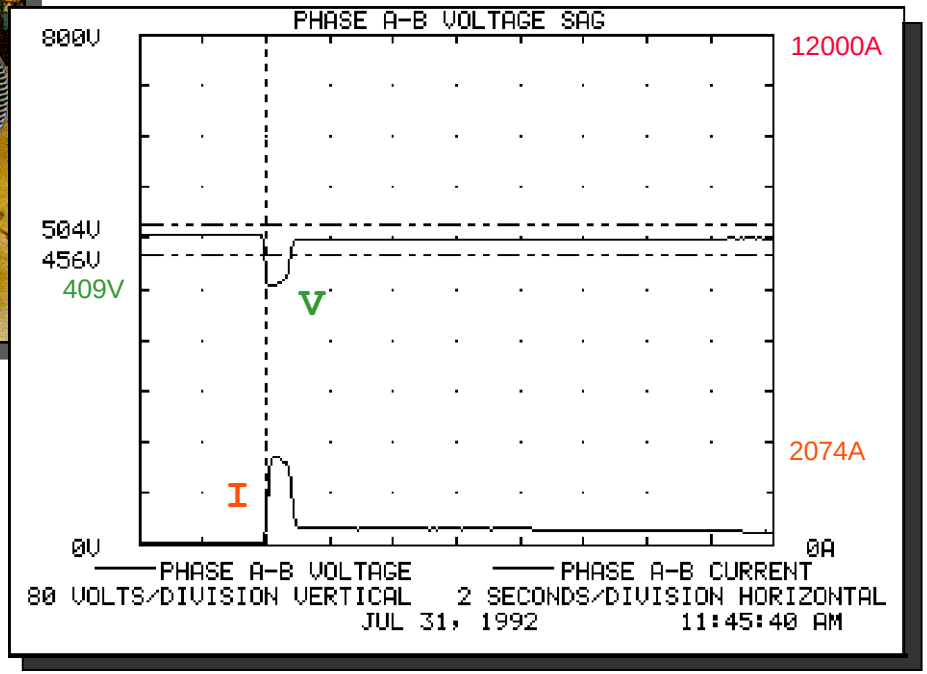
HIOKI 3196 Event Data
3 cycle, 0.5 pu

Why Voltage Sags Occur...

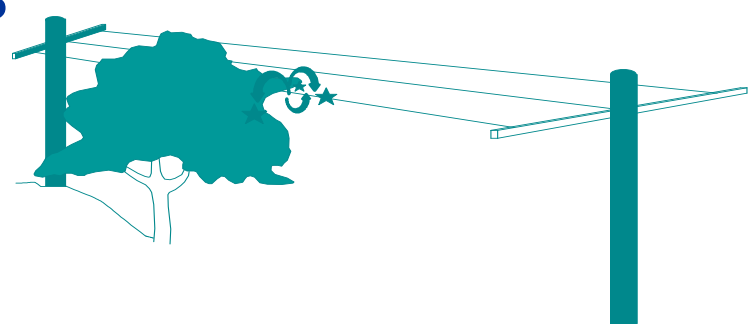
- Line-to-Ground/Line-to-Line Faults Occur on the Utility System due to:
  - Weather
  - Trees
  - Public Interference
- Internally induced plant events (starting of large high inrush load)
- Although the utility can reduce the number of events (tree trimming, root cause analysis), it is impossible to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

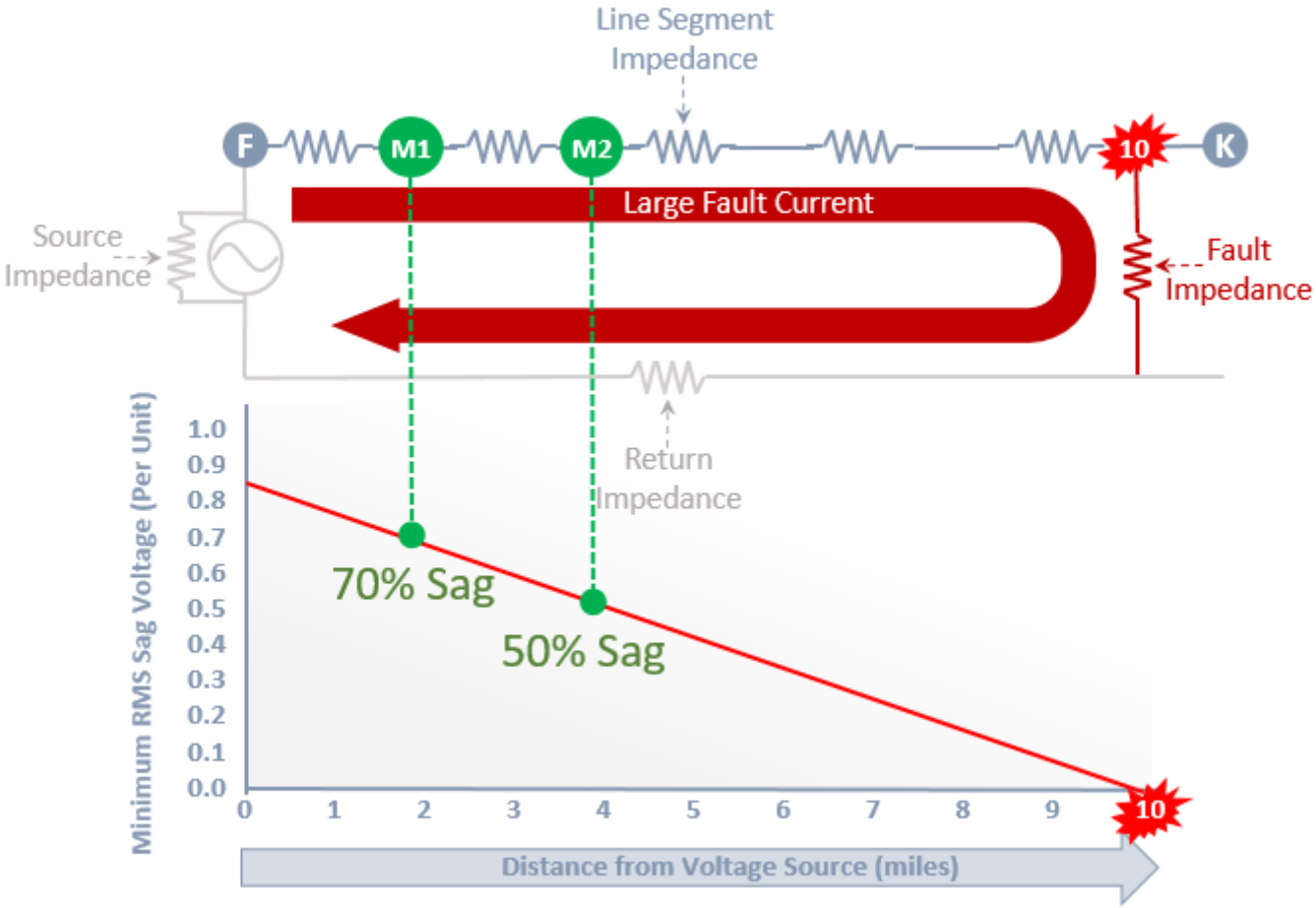
Voltage Sag Caused by Starting a Large Motor

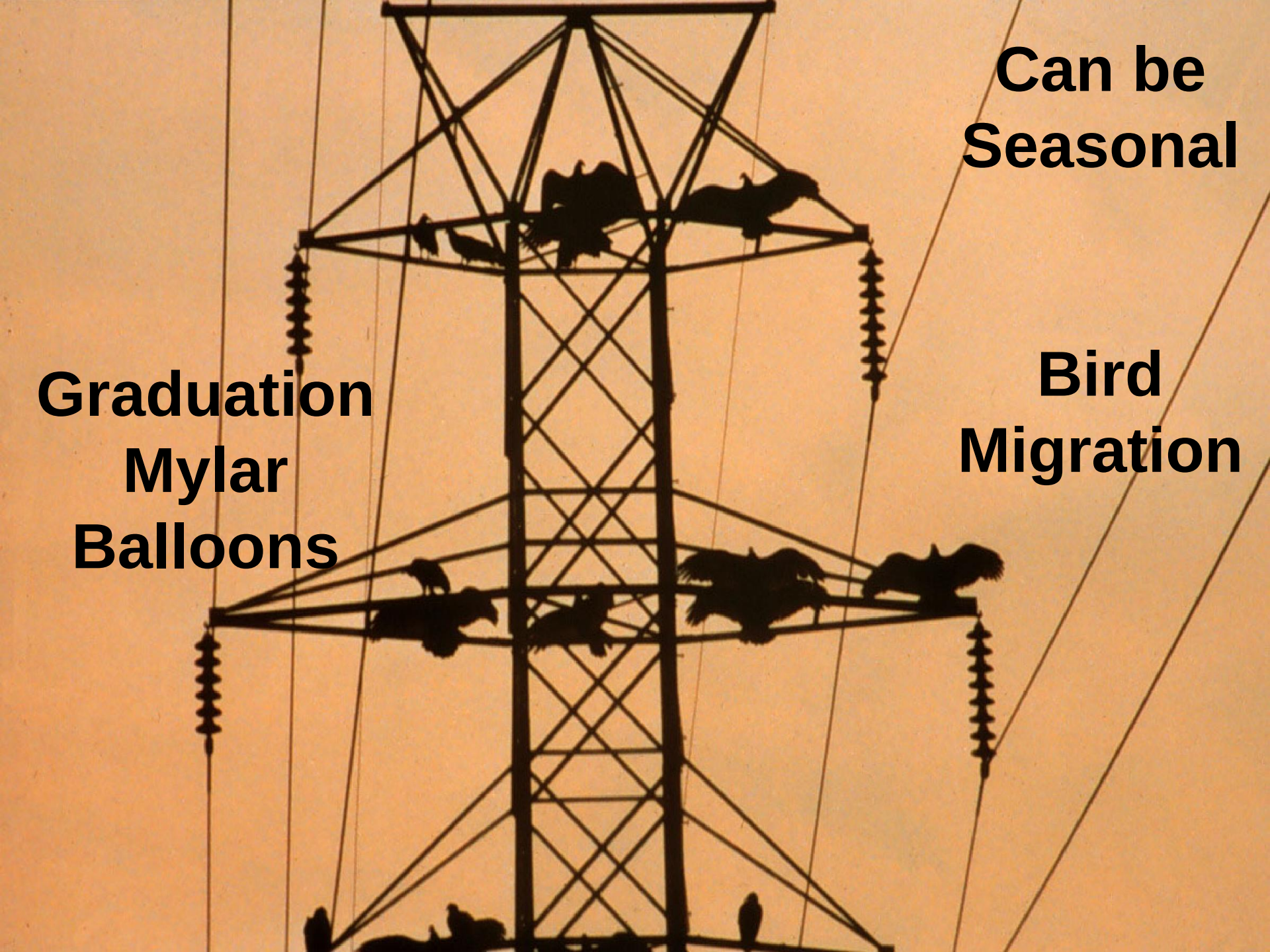


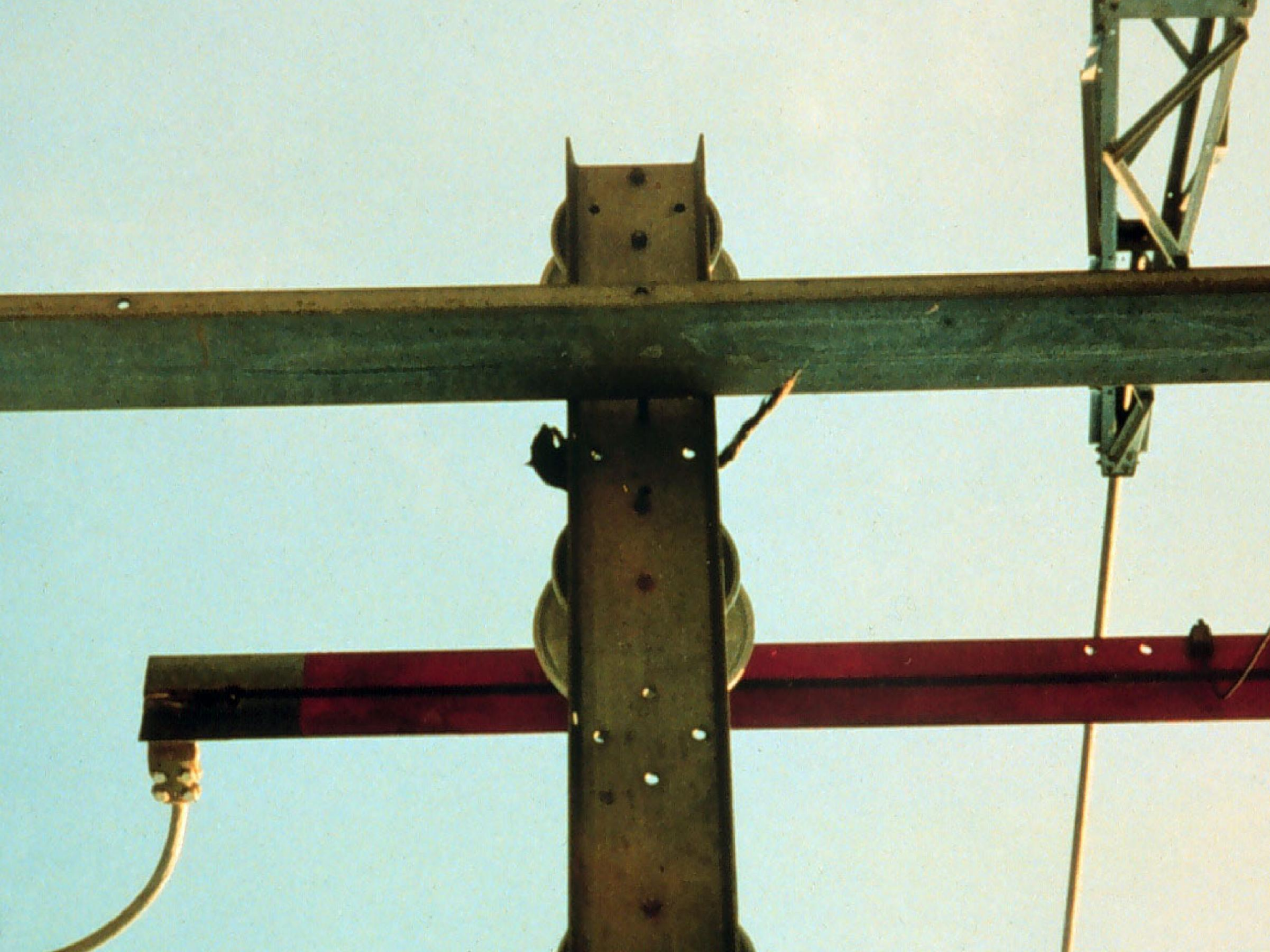


Voltage Sags Caused by Faults



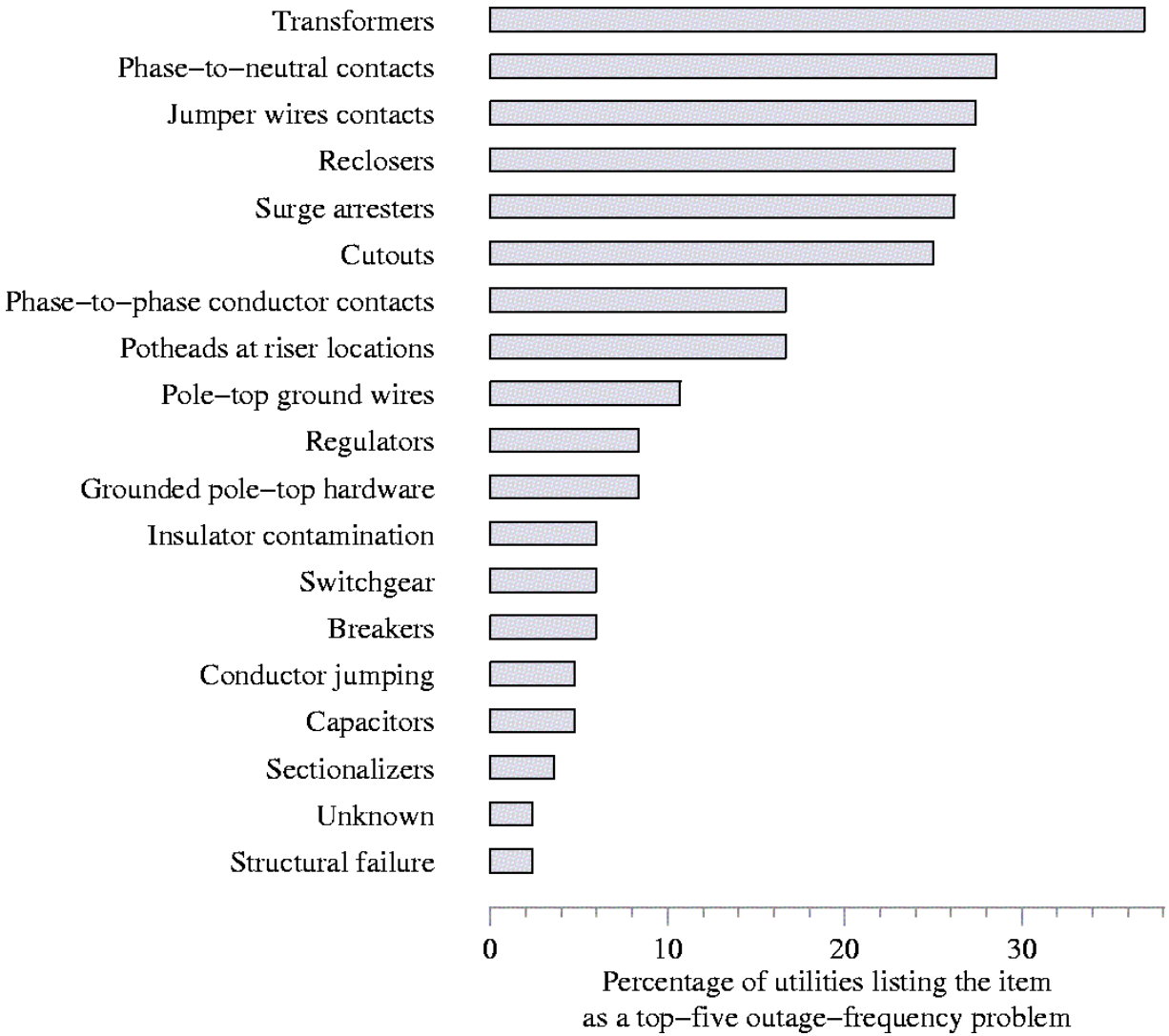



Can be Seasonal
Graduation Mylar Balloons
Bird Migration



Locations Where Animal Faults Occur

Data source: EPRI TE-114915



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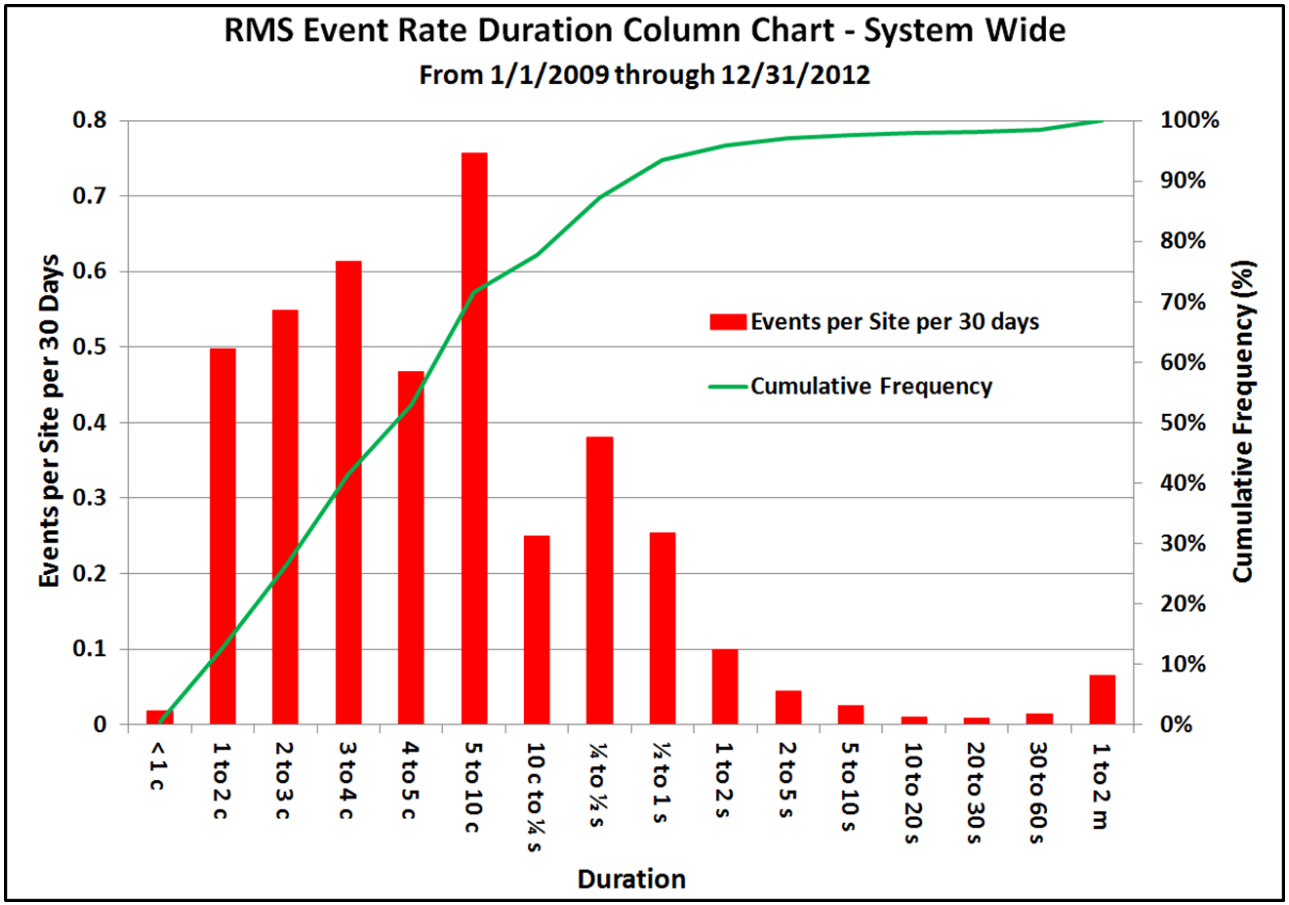
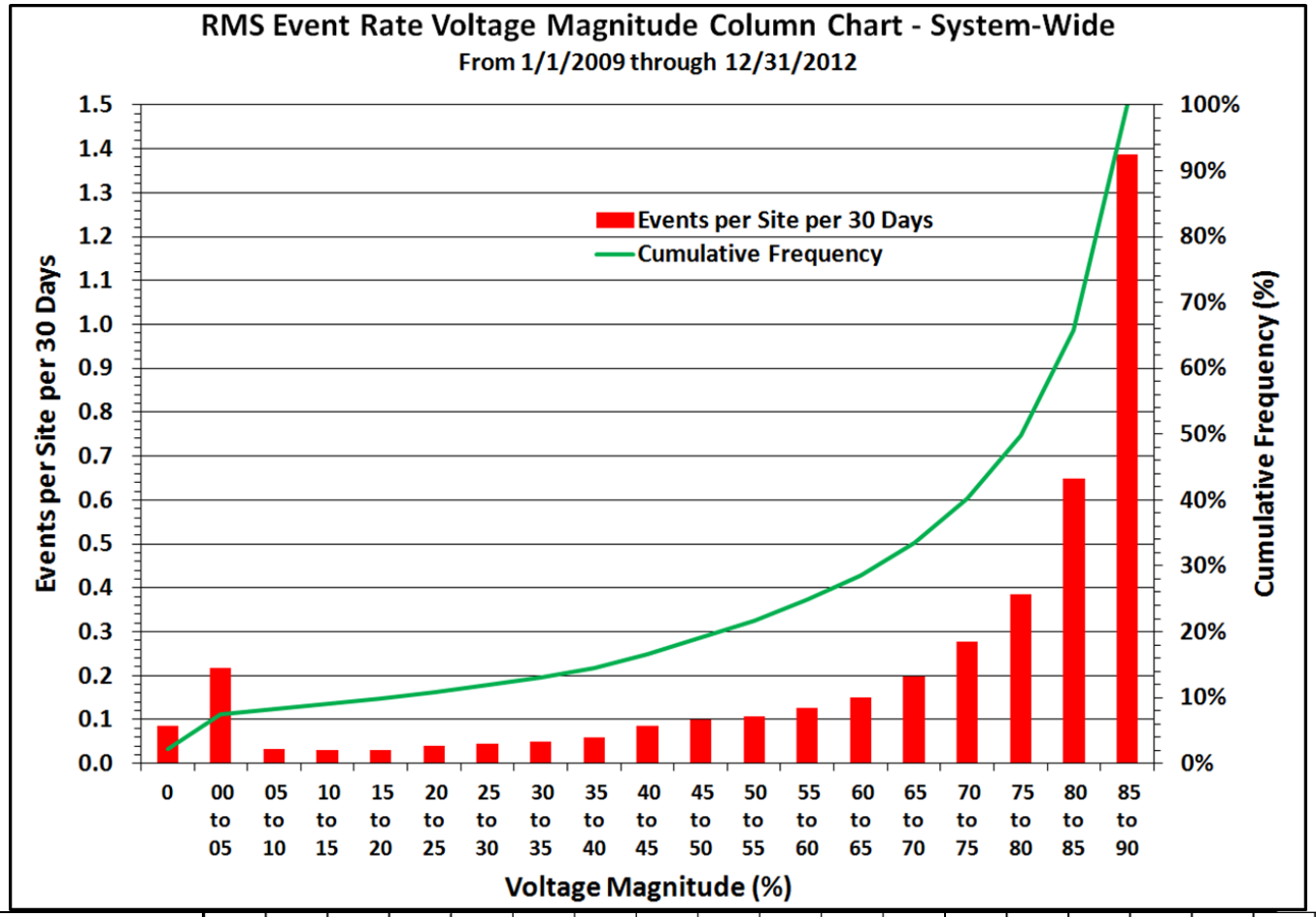
RMS Variation Event Rate Duration—System-wide All Sites, One-minute Temporal Aggregation, Events per Site per 30 Days



Duration	< 1 c	1 to 2 c	2 to 3 c	3 to 4 c	4 to 5 c	5 to 10 c	10 c to ¼ s	¼ to ½ s	½ to 1 s	1 to 2 s	2 to 5 s	5 to 10 s	10 to 20 s	20 to 30 s	30 to 60 s	1 to 2 m
Events per Site per 30 days	0.018	0.497	0.549	0.613	0.467	0.757	0.250	0.381	0.254	0.100	0.045	0.025	0.009	0.008	0.014	0.064
Cumulative Frequency	0.005	0.127	0.263	0.414	0.529	0.716	0.778	0.872	0.935	0.959	0.970	0.976	0.979	0.981	0.984	1

RMS Variation Event Rate Magnitude—System-wide All Sites, One-minute Temporal Aggregation Events per Site per 30 Days



Magnitude	0	00 to 05	05 to 10	10 to 15	15 to 20	20 to 25	25 to 30	30 to 35	35 to 40	40 to 45	45 to 50	50 to 55	55 to 60	60 to 65	65 to 70	70 to 75	75 to 80	80 to 85	85 to 90
Events per Site per 30 Days	0.09	0.22	0.03	0.03	0.03	0.04	0.05	0.05	0.06	0.08	0.10	0.11	0.13	0.15	0.20	0.28	0.38	0.65	1.39
Cumulative Frequency	2%	7%	8%	9%	10%	11%	12%	13%	15%	17%	19%	22%	25%	29%	33%	40%	50%	66%	100%

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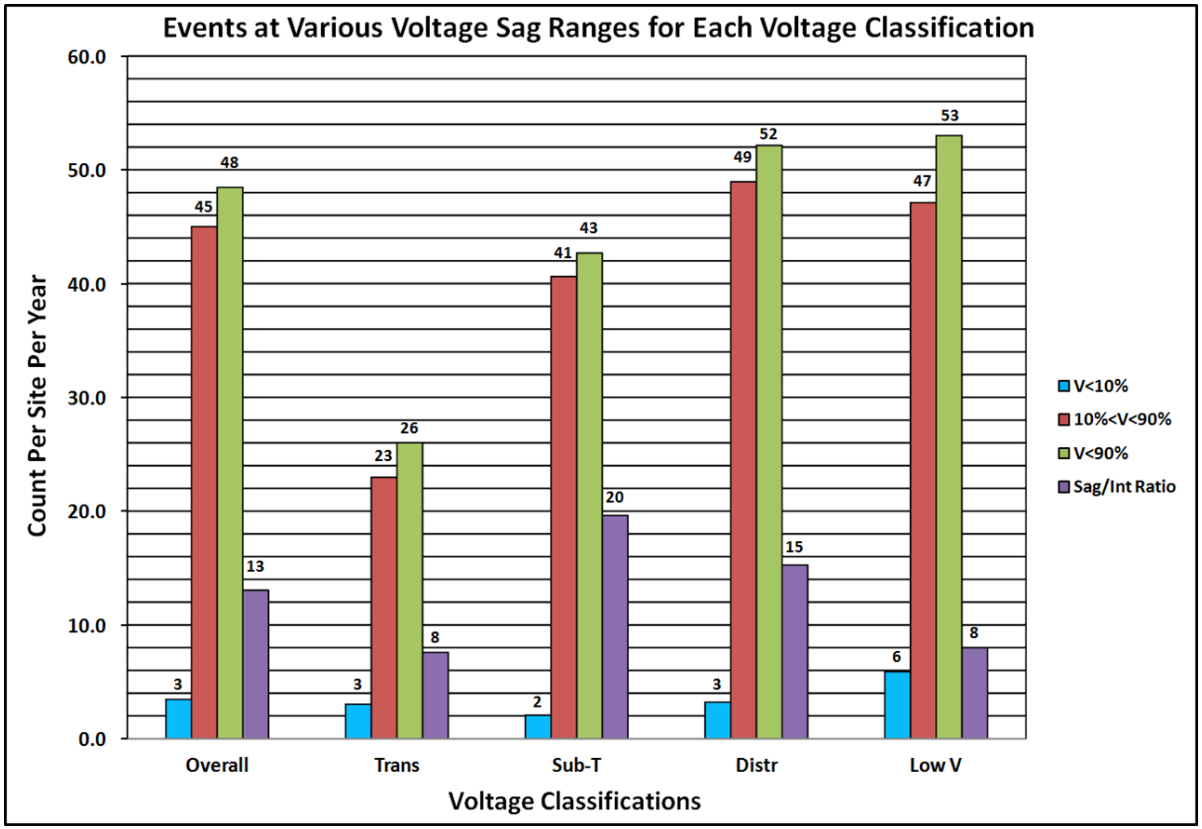
Sag and Interruption Rates per 365 Days
Sag to Interruption Ratio

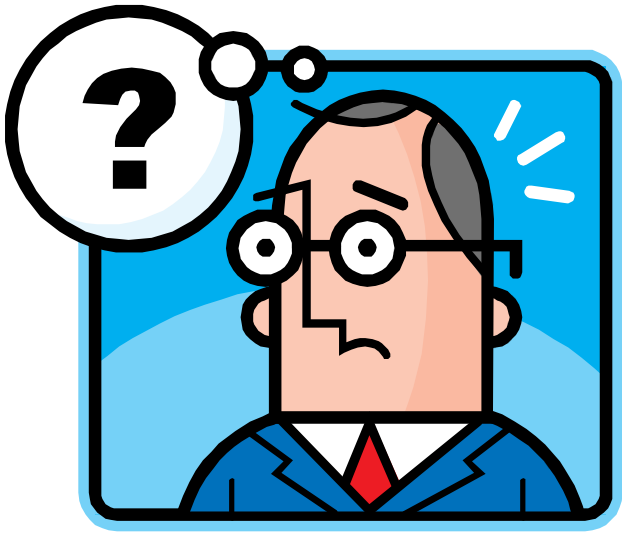


365 Days	All Voltages	Voltage Classifications			
Ranges	Overall	Trans	Sub-T	Distr	Low V
V<10%	3.4	3.0	2.1	3.2	5.9
10%<V<90%	45.0	23.0	40.6	48.9	47.1
V<90%	48.5	26.0	42.7	52.2	53.0
Sag/Int Ratio	13	8	20	15	8

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

$$SARFI_x = \frac{\overline{\sum N_i}}{N_T}$$



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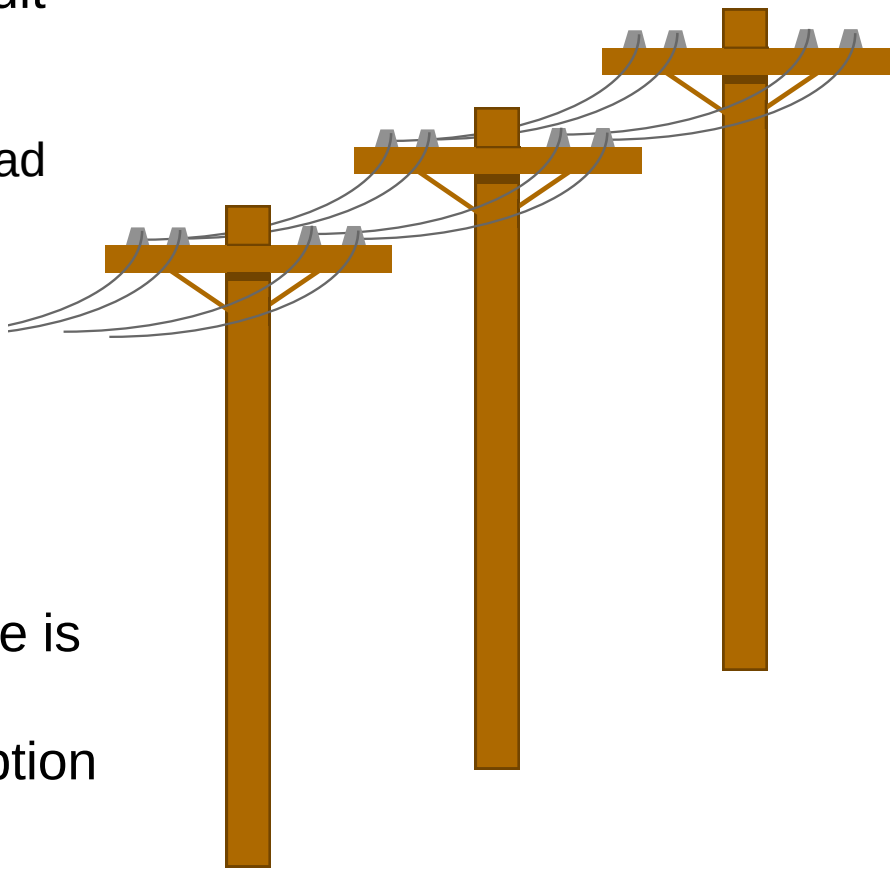
TPQ-DPQ III SARFI Results

TPQ-DPQ III	SARFI-CBEMA	SARFI-ITIC	SARFI-SEMI	SARFI-90	SARFI-70	SARFI-50	SARFI-10
Trans	10.7	8.4	6.6	22.8	6.4	4.3	2.5
Sub-T	14.6	9.9	7.0	35.3	9.1	5.0	1.5
Dist	23.3	17.4	11.6	52.2	16.2	8.6	3.2
Low V	29.8	24.8	18.2	53.0	23.3	14.4	5.9

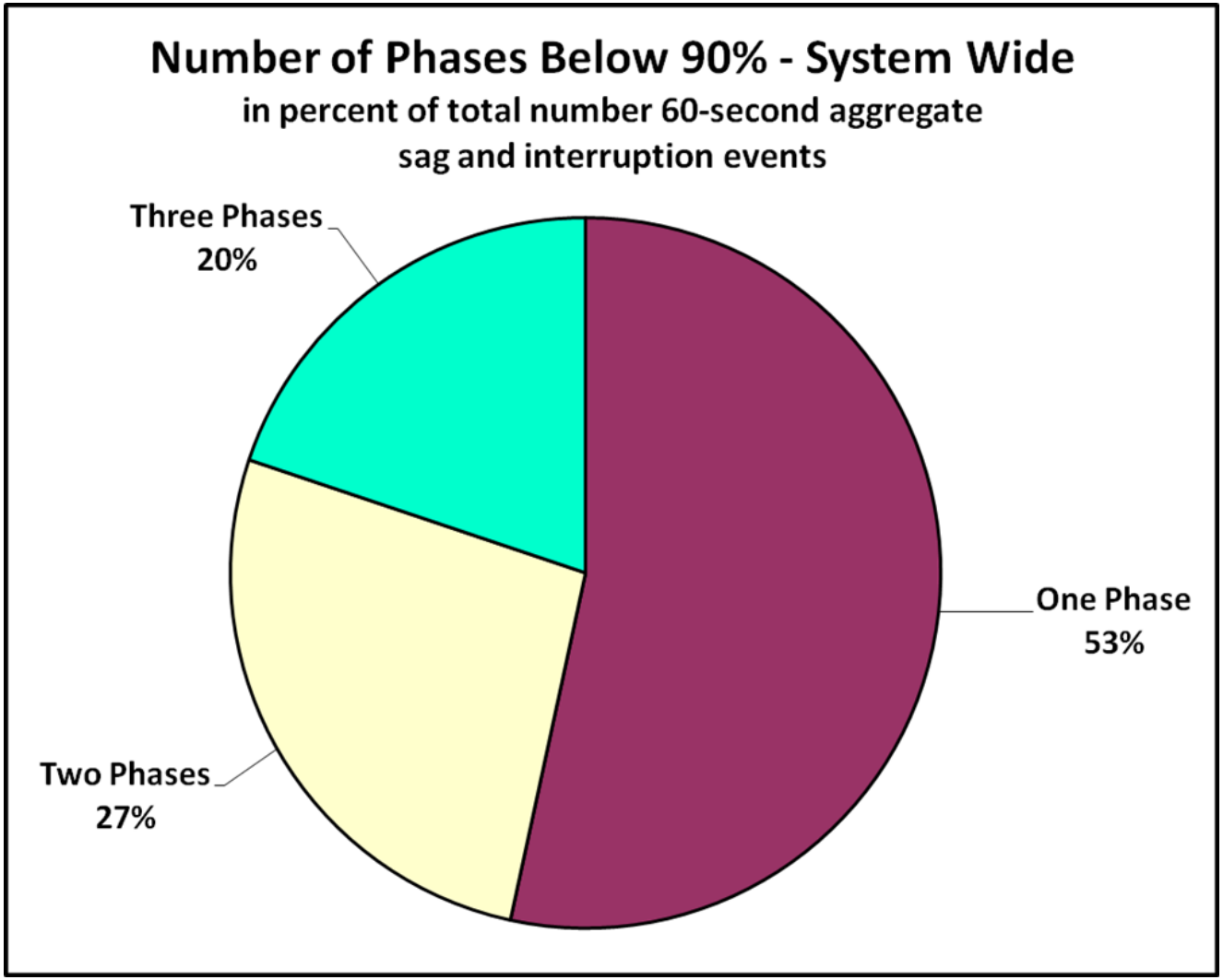
How Common are Sags and Interruptions?

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"?



Ref: EPRI TPQ-DPQ III Study, June 2014

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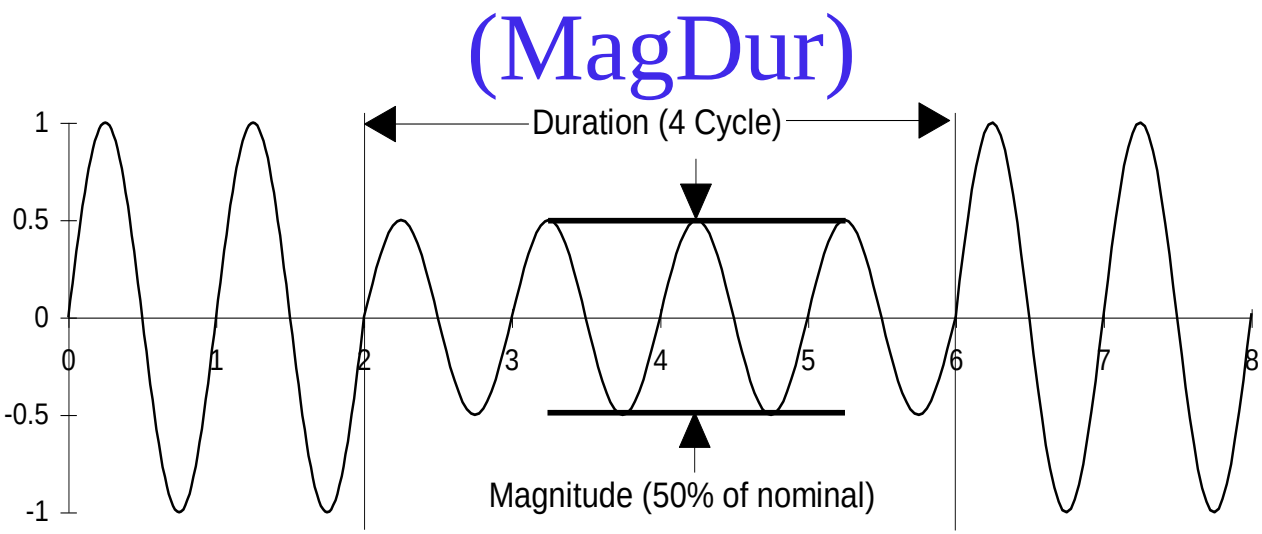
Effects of Voltage Sags



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

For every 1 momentary interruption a customer will see 8 to 20 voltage sags (EPRI TPQ-DPQ III Study)

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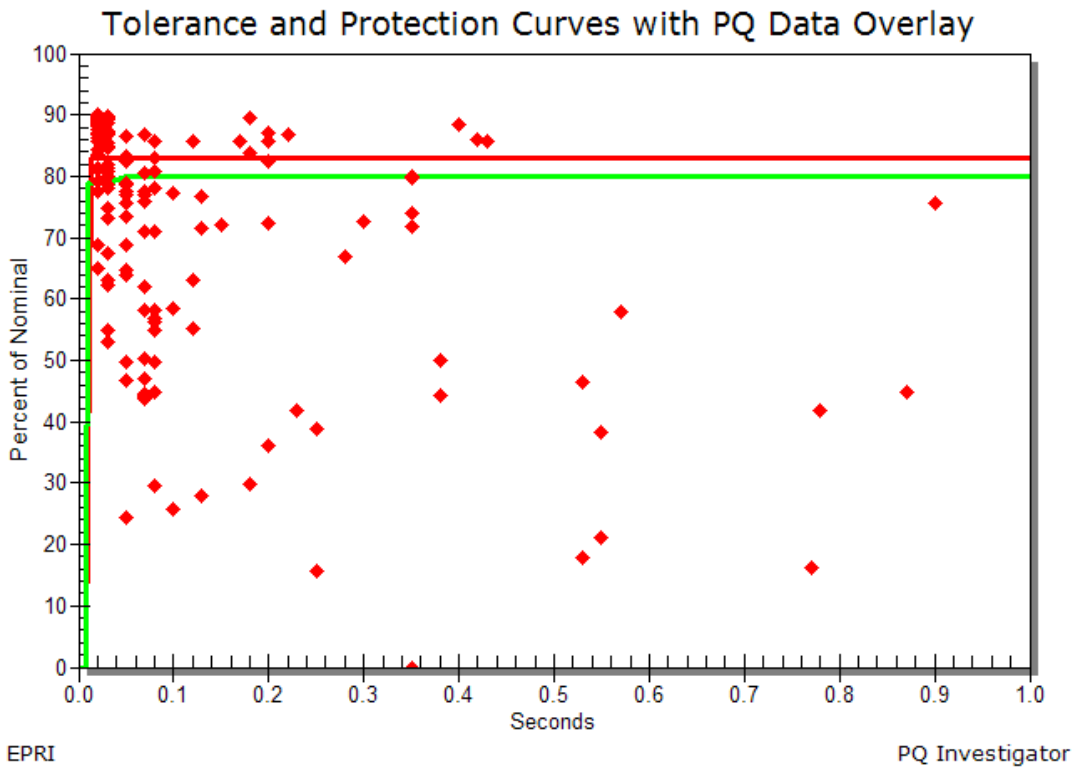
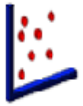
Who's "Fault" is it?



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

Allen Bradley,PLC 5/11,1785-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)

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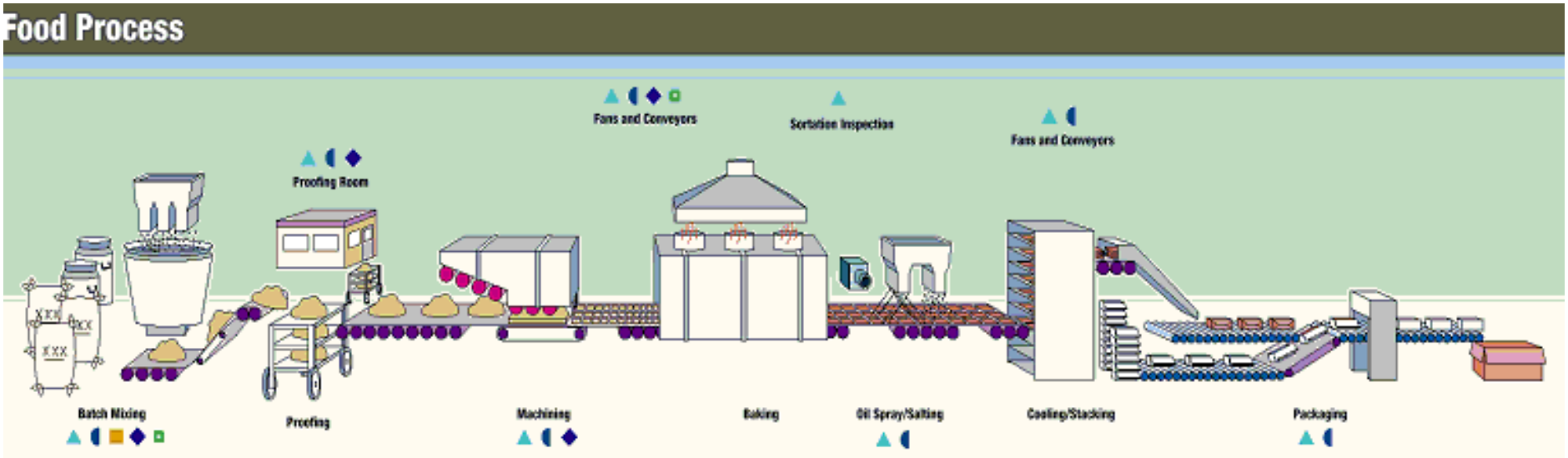
Why is PQ Important - Impacts



- 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

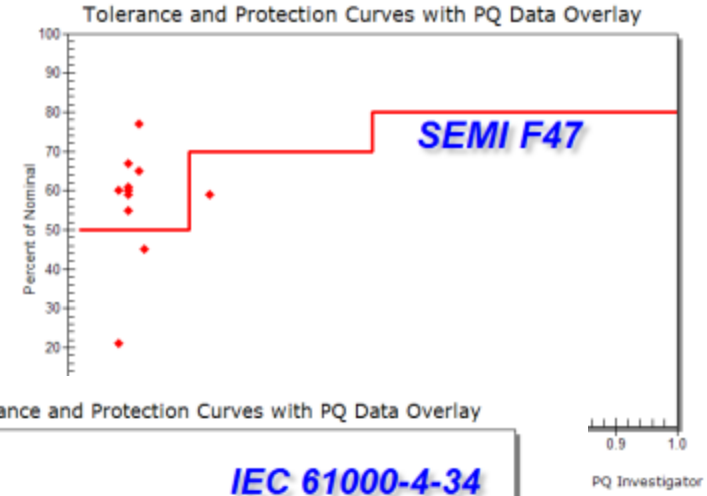
No.	Process	Reported Cost	Service Voltage	Load
1	Semiconductor	$1,500,000	69 kV	25 MW
2	Semiconductor	$1,400,000	161 kV	30 MW
3	Semiconductor	$ 700,000	12.5 kV	10 MW
4	Metal Casting	$ 200,000	13.8 kV	16 MW
5	Chemical Plant	$ 160,000	12.5 kV	5 MW
6	Pulp and Paper Mill	$ 110,000	161kV	100 MW
7	Aerospace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

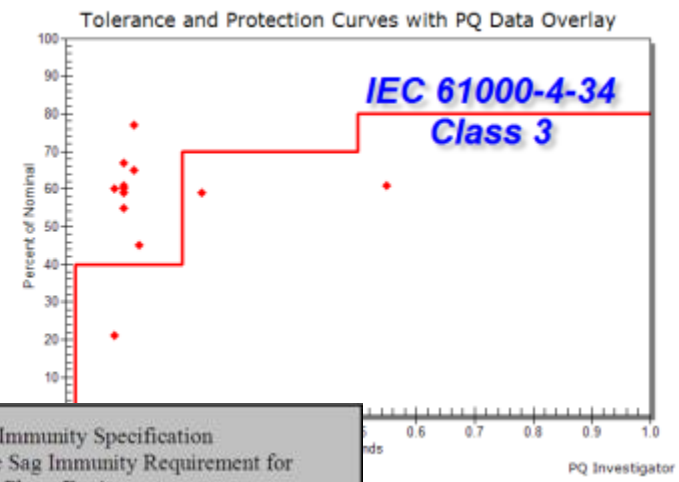
Important Realization

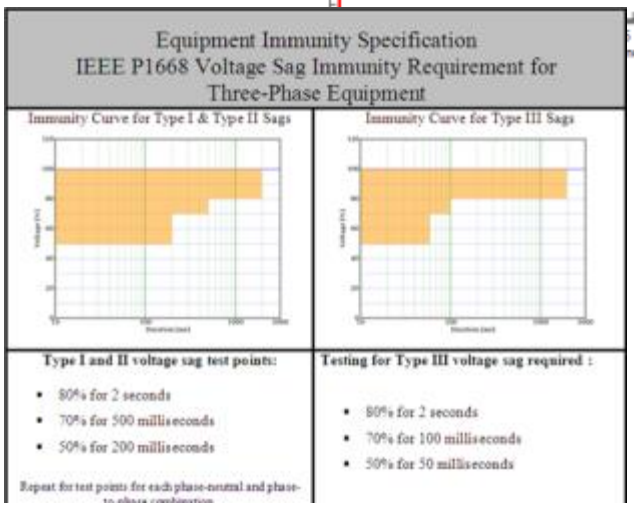
- Utilities Share Responsibility
  - Tree Trimming, Lighting Arrestors, Grounding, Maintenance, Provide PQ information to industrials, etc
  - Circuit patrols, Reviewing customer complaints and device operations, line device settings.
- Industrials Share Responsibility
  - Understanding Equipment Vulnerability, 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







Equipment Immunity Specification
IEEE P1668 Voltage Sag Immunity Requirement for Three-Phase Equipment

Immunity Curve for Type I & Type II Sags	Immunity Curve for Type III Sags
Type I and II voltage sag test points: • 80% for 2 seconds • 70% for 500 milliseconds • 50% for 200 milliseconds Repeat for test points for each phase-neutral and phase-to-phase combination	**Testing for Type III voltage sag required :** • 80% for 2 seconds • 70% for 100 milliseconds • 50% for 50 milliseconds

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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

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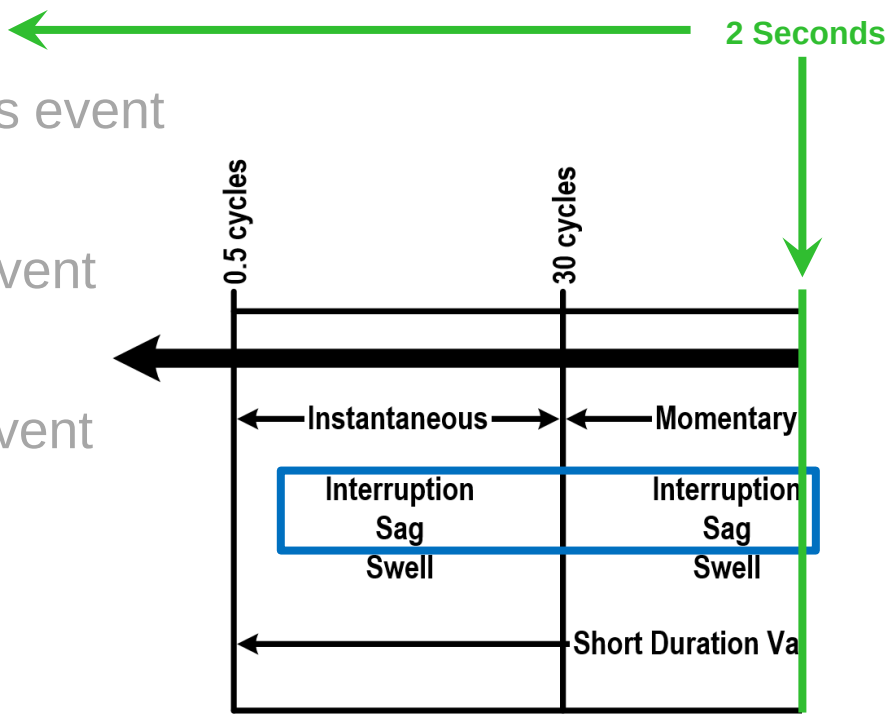
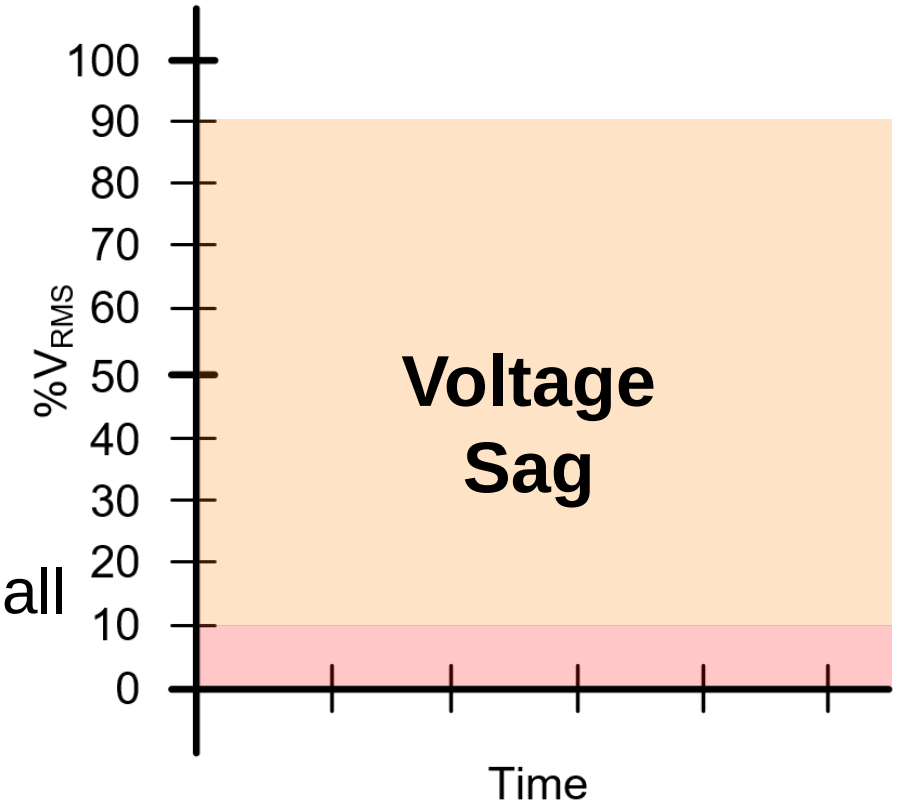


IEEE Std. 1668 – Why is it necessary?

- 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



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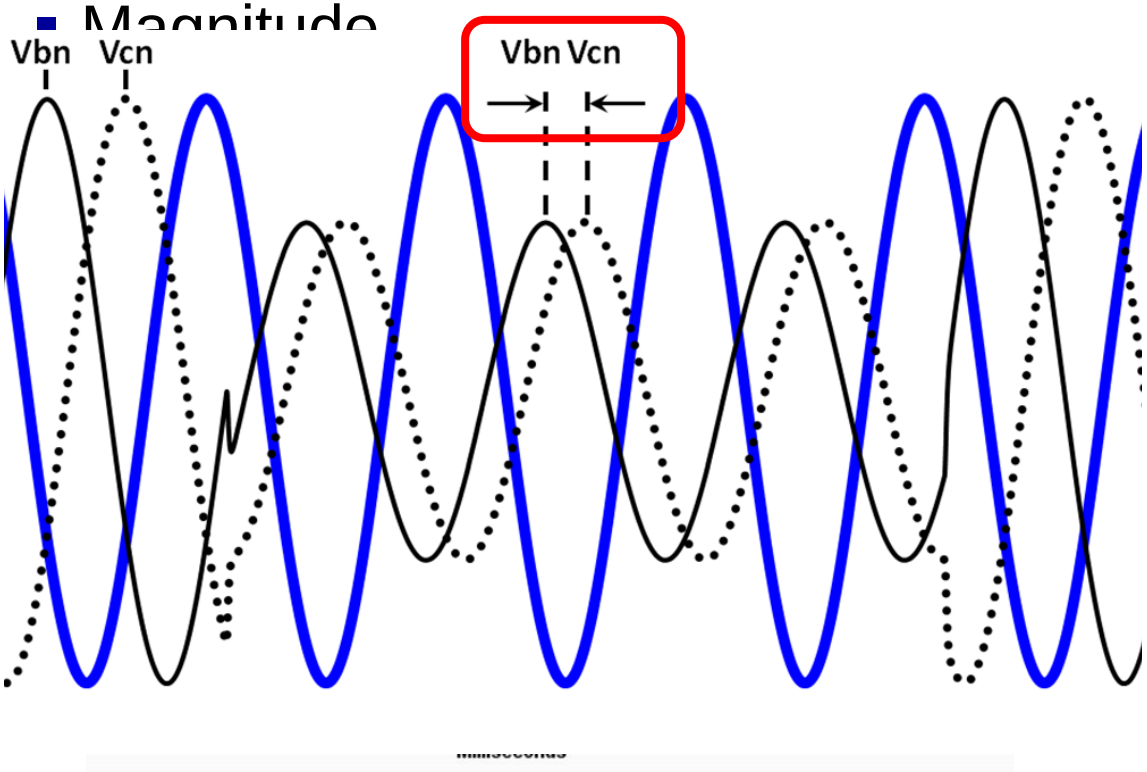
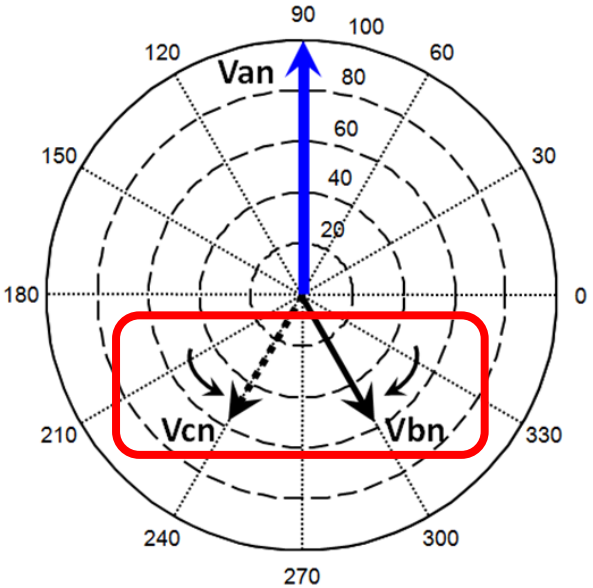
IEEE Std. 1668 – Why is it necessary?

- Magnitude





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IEEE Std. 1668 – Why is it necessary?

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

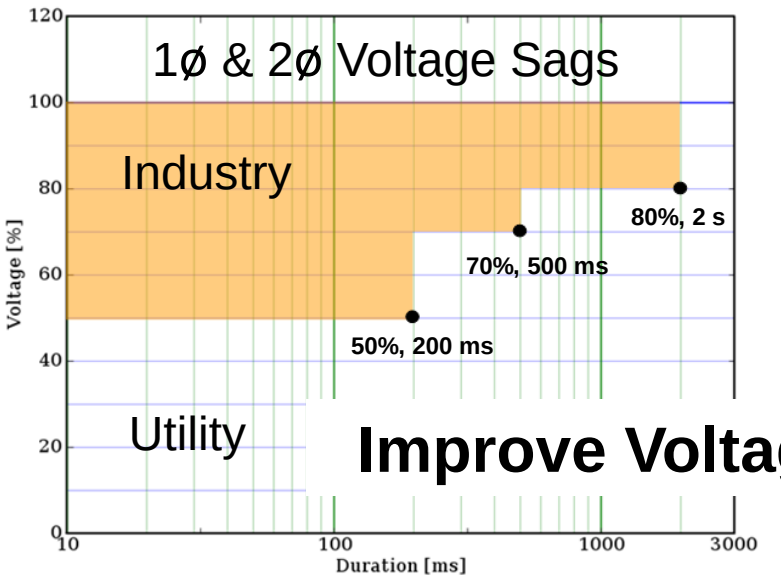

Figure 22—Recommended Type I & Type II test levels

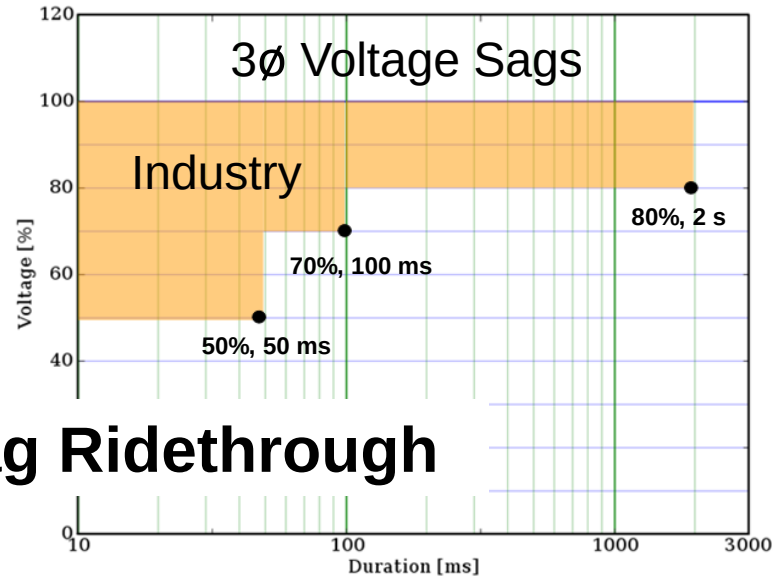

Figure 23—Recommended Type III test levels

Improve Voltage Sag Ridethrough

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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.

Contents

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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

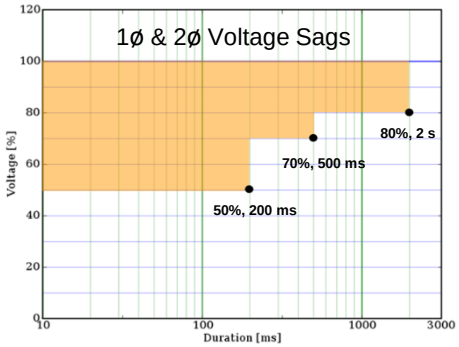

Figure 22—Recommended Type I & Type II test levels

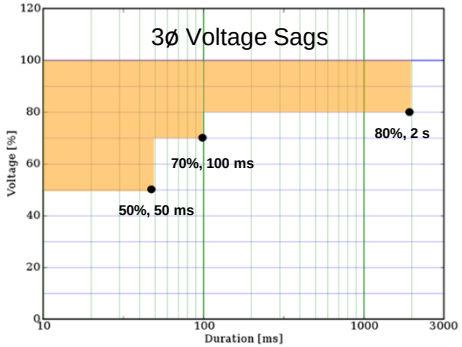

Figure 23—Recommended Type III test levels

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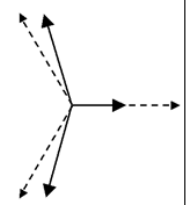
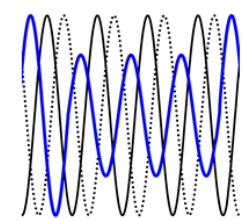
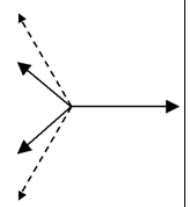
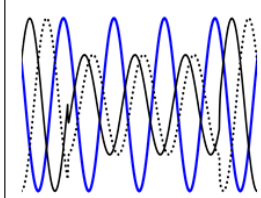
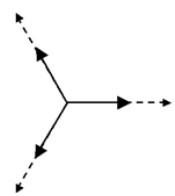
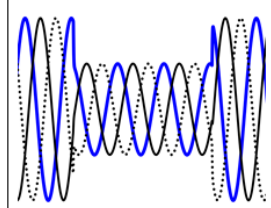
What does IEEE Std. 1668 Accomplish?

- 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]

Voltage-sag type	Description[a]	Vector diagram	Waveform
Type I	This is a voltage sag in which a drop in voltage takes place mainly in one of the phase-to-ground voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{E}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{E}\sqrt{3}$		
Type II	This is a voltage sag in which a drop-in voltage magnitude takes place mainly in one of the phase-to-phase voltages. $\overline{U}_a = \overline{E}$ $\overline{U}_b = -\frac{1}{2}\overline{E} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{E} + \frac{1}{2}j\overline{V}\sqrt{3}$		
Type III	This is a voltage sag in which there is a drop-in voltage magnitude that is equal for the three voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{V}\sqrt{3}$		

[a]Where: V – characteristic voltage of the sag event, E – pre-sag voltage, and Ua, Ub, Uc – phase-to-neutral voltages.
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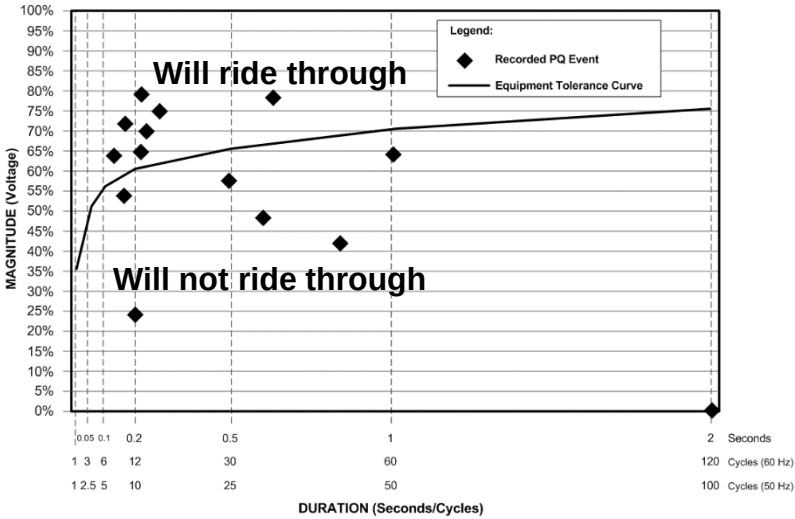
What does IEEE Std. 1668 Accomplish?

- 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



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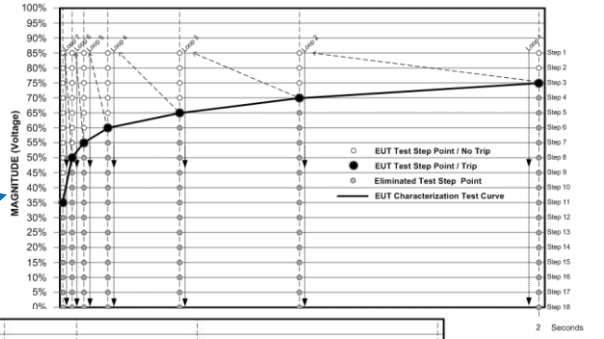
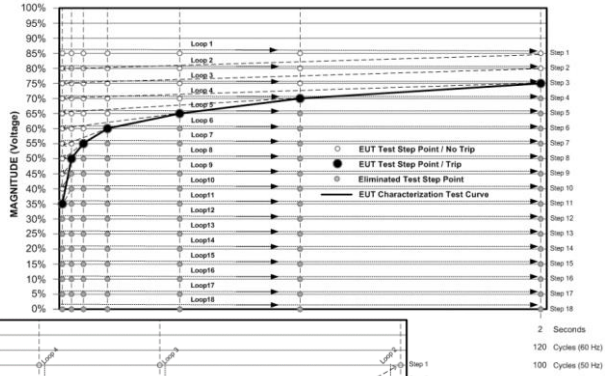
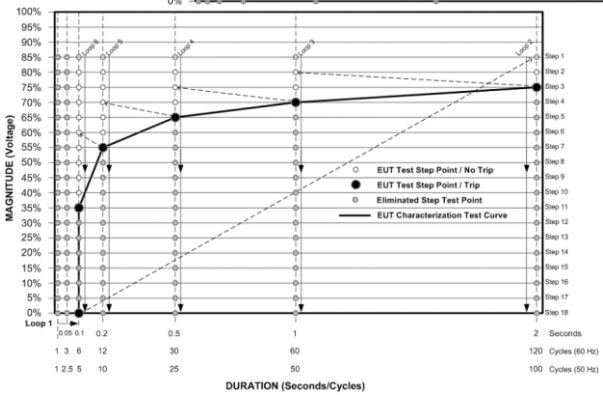
What does IEEE Std. 1668 Accomplish?

- 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







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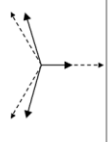
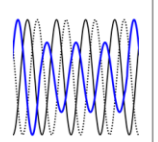
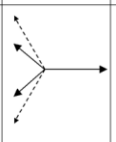
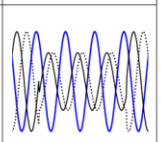
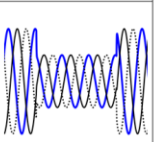
Use IEEE Std. 1668 in Procurement!

- 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

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

Voltage-sag type	Description[a]	Vector diagram	Waveform
Type I	This is a voltage sag in which a drop in voltage takes place mainly in one of the phase-to-ground voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{E}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{E}\sqrt{3}$		
Type II	This is a voltage sag in which a drop-in voltage magnitude takes place mainly in one of the phase-to-phase voltages. $\overline{U}_a = \overline{E}$ $\overline{U}_b = -\frac{1}{2}\overline{E} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{E} + \frac{1}{2}j\overline{V}\sqrt{3}$		
Type III	This is a voltage sag in which there is a drop-in voltage magnitude that is equal for the three voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{V}\sqrt{3}$		

[a]Where: $\overline{V}$ – characteristic voltage of the sag event, $\overline{E}$ – pre-sag voltage, and $\overline{U}a$, $\overline{U}b$, $\overline{U}c$ – phase-to-neutral voltages.
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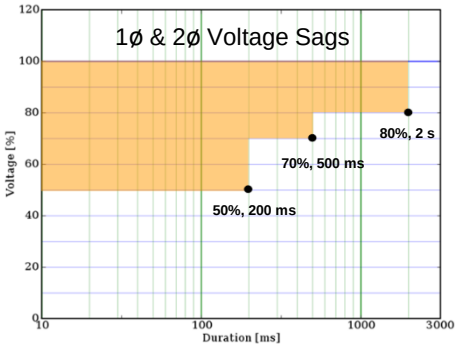


Figure 22—Recommended Type I & Type II test levels

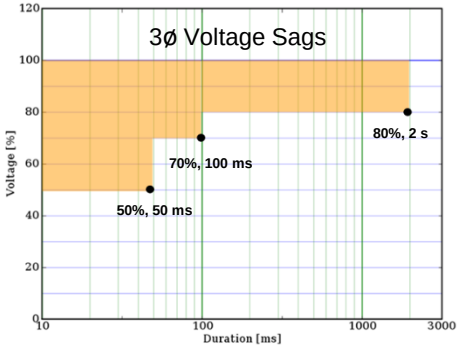
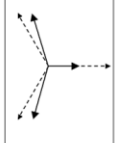
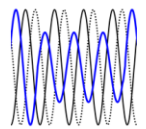
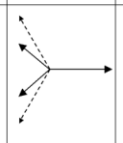
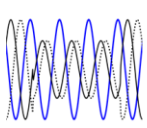
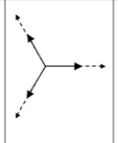
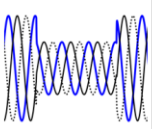


Figure 23—Recommended Type III test levels

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

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

Voltage-sag type	Description[a]	Vector diagram	Waveform
Type I	This is a voltage sag in which a drop in voltage takes place mainly in one of the phase-to-ground voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{E}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{E}\sqrt{3}$		
Type II	This is a voltage sag in which a drop-in voltage magnitude takes place mainly in one of the phase-to-phase voltages. $\overline{U}_a = \overline{E}$ $\overline{U}_b = -\frac{1}{2}\overline{E} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{E} + \frac{1}{2}j\overline{V}\sqrt{3}$		
Type III	This is a voltage sag in which there is a drop-in voltage magnitude that is equal for the three voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{V}\sqrt{3}$		

[a]Where: $\overline{V}$ – characteristic voltage of the sag event, $\overline{E}$ – pre-sag voltage, and $\overline{U}a$, $\overline{U}b$, $\overline{U}c$ – phase-to-neutral voltages.

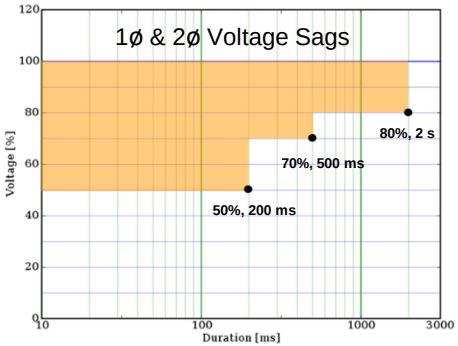


Figure 22—Recommended Type I & Type II test levels

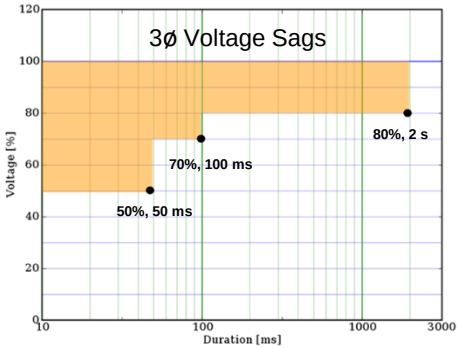


Figure 23—Recommended Type III test levels

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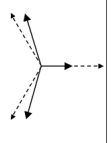
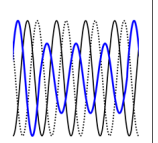
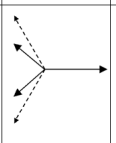
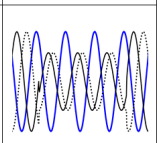
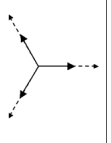
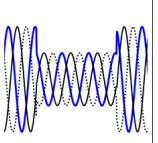
How may IEEE Std. 1668 be used in Procurement?

- 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)

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

Voltage-sag type	Description[a]	Vector diagram	Waveform
Type I	This is a voltage sag in which a drop in voltage takes place mainly in one of the phase-to-ground voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{E}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{E}\sqrt{3}$		
Type II	This is a voltage sag in which a drop-in voltage magnitude takes place mainly in one of the phase-to-phase voltages. $\overline{U}_a = \overline{E}$ $\overline{U}_b = -\frac{1}{2}\overline{E} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{E} + \frac{1}{2}j\overline{V}\sqrt{3}$		
Type III	This is a voltage sag in which there is a drop-in voltage magnitude that is equal for the three voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{V}\sqrt{3}$		

[a]Where: $\overline{V}$ – characteristic voltage of the sag event, $\overline{E}$ – pre-sag voltage, and $\overline{U}a$, $\overline{U}b$, $\overline{U}c$ – phase-to-neutral voltages.
© CIGRE 2010

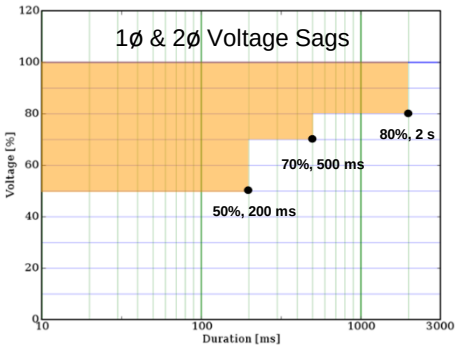


Figure 22—Recommended Type I & Type II test levels

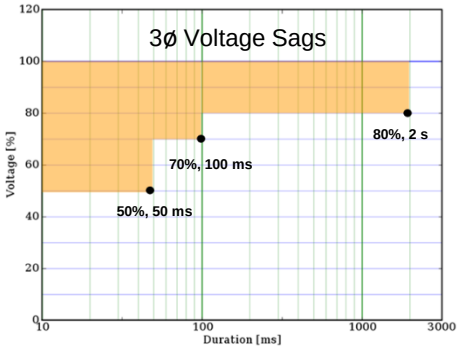


Figure 23—Recommended Type III test levels

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 volt-age sag immunity requirements defined by IEEE 1668 shown in Figure 1. The acceptable pass/fail criteria for single-phase equipment shall be "Full Operation".

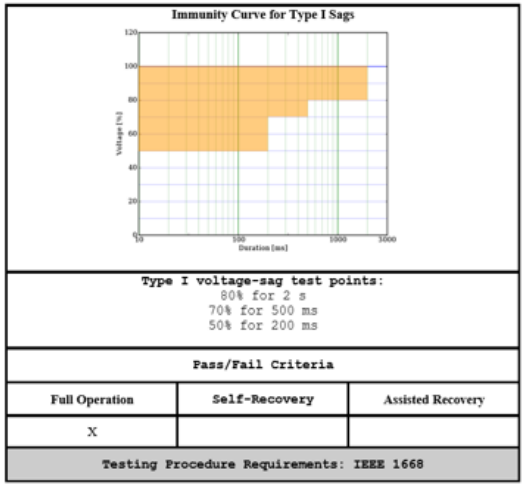


Figure 1
Voltage Sag Immunity Requirements for Single-Phase Equipment

* 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.

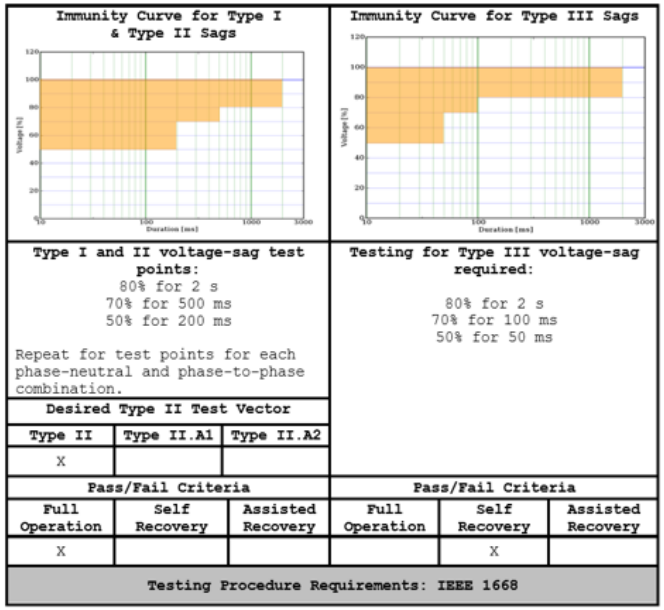


Figure 2
Voltage Sag Immunity Requirements for Three-Phase Equipment

* 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

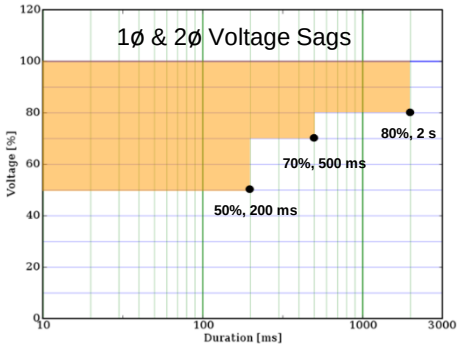


Figure 22—Recommended Type I & Type II test levels

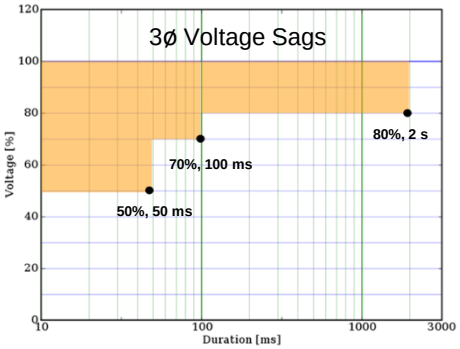


Figure 23—Recommended Type III test levels

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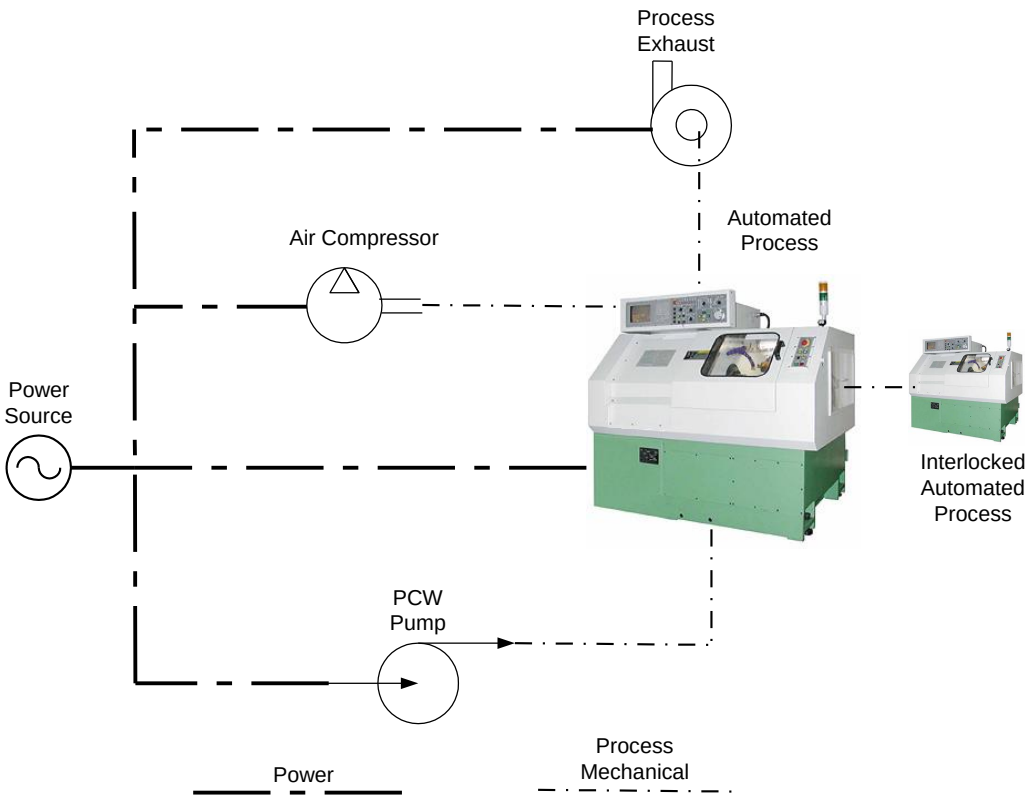
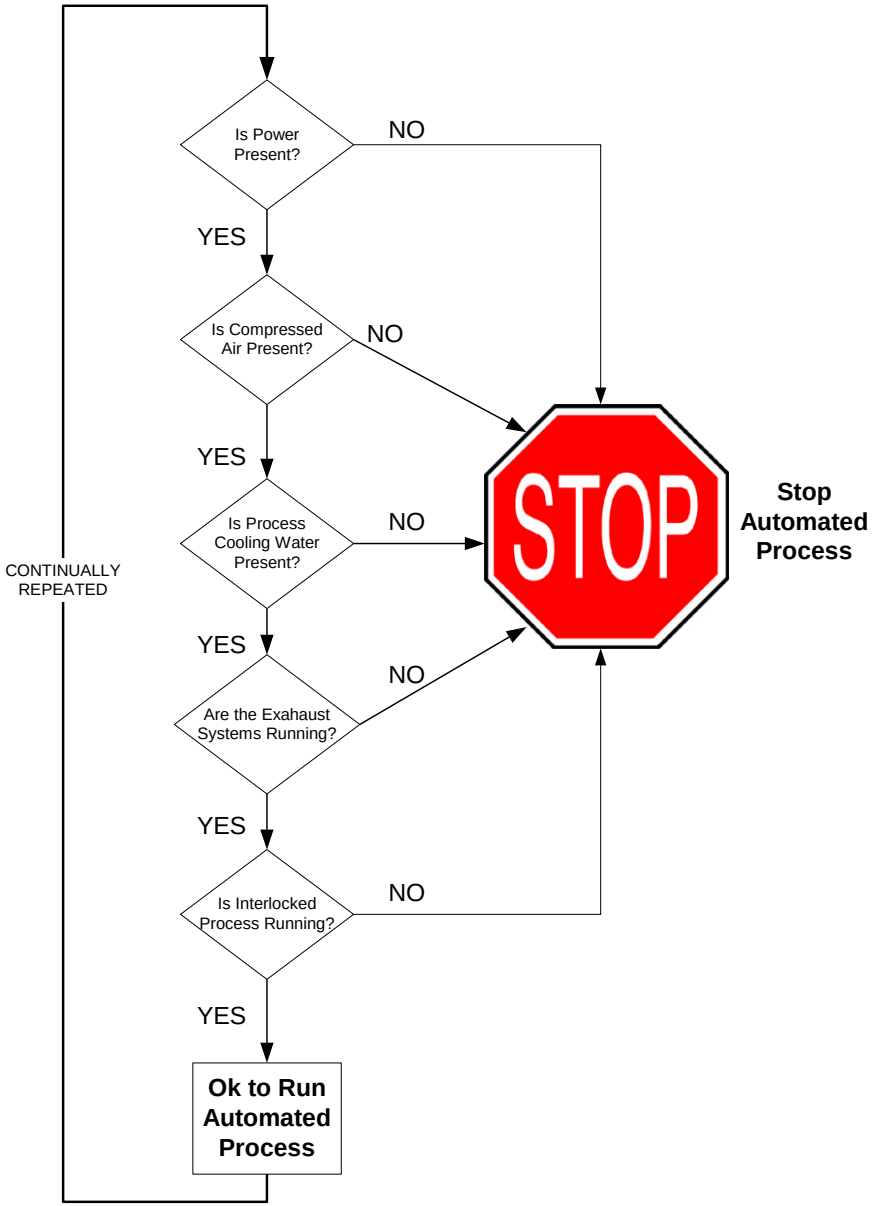
2.0 Effects of Voltage Sags on Industrial Equipment, and Susceptibilities

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

Interrelated Processes





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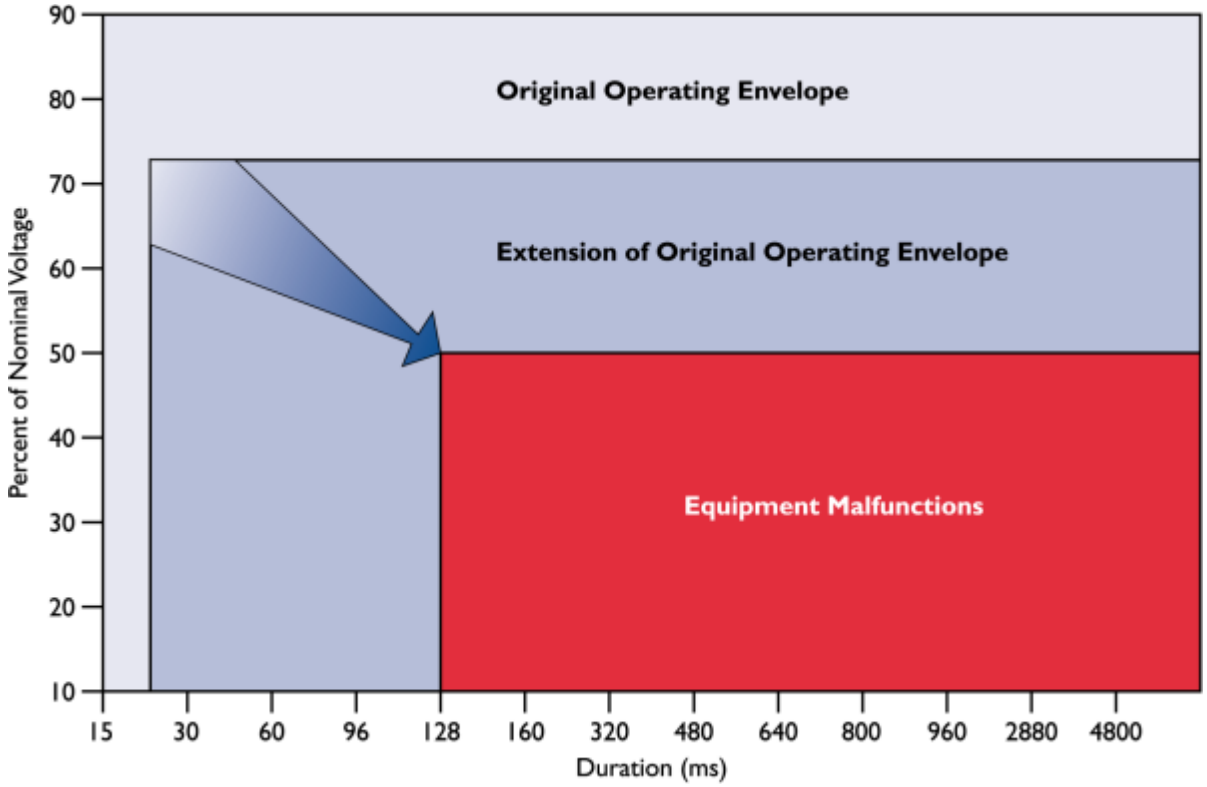
Goal – Extending the Operating Envelope

"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.



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Voltage Sag Test Equipment Pioneers: EPRI Porto-Sag

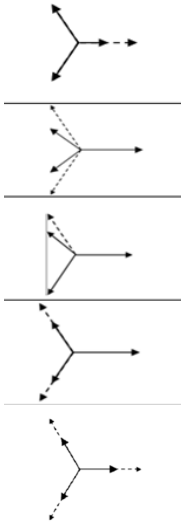
As featured in Plant Engineering Magazine, August 8, 2002

Versions of the Porto-Sag EPRI Built

Patented Tri-Mode

Model PS200-3P-T-TM

Sag Types Per IEEE 1668



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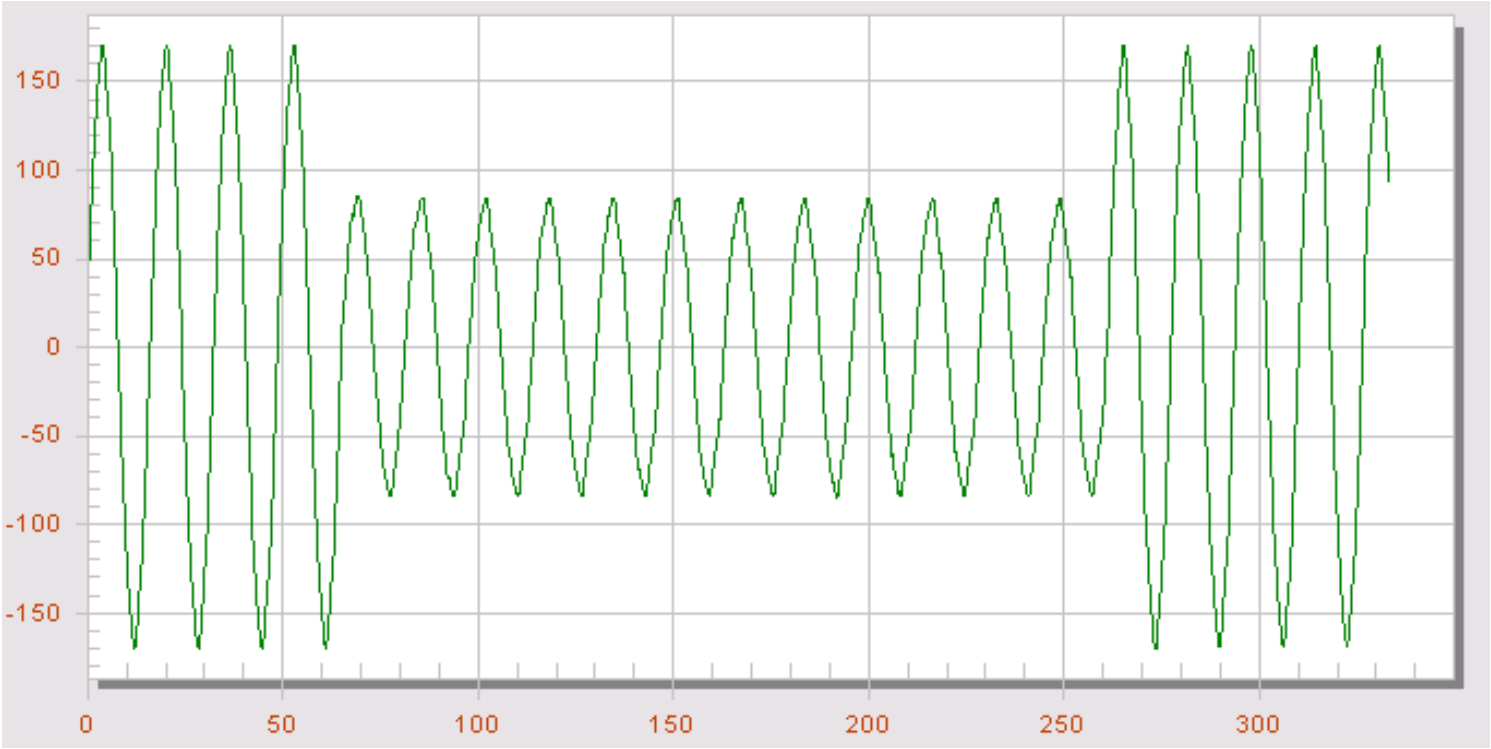
Sample Output Waveform



Source: EPRI Porto-Sag Generator

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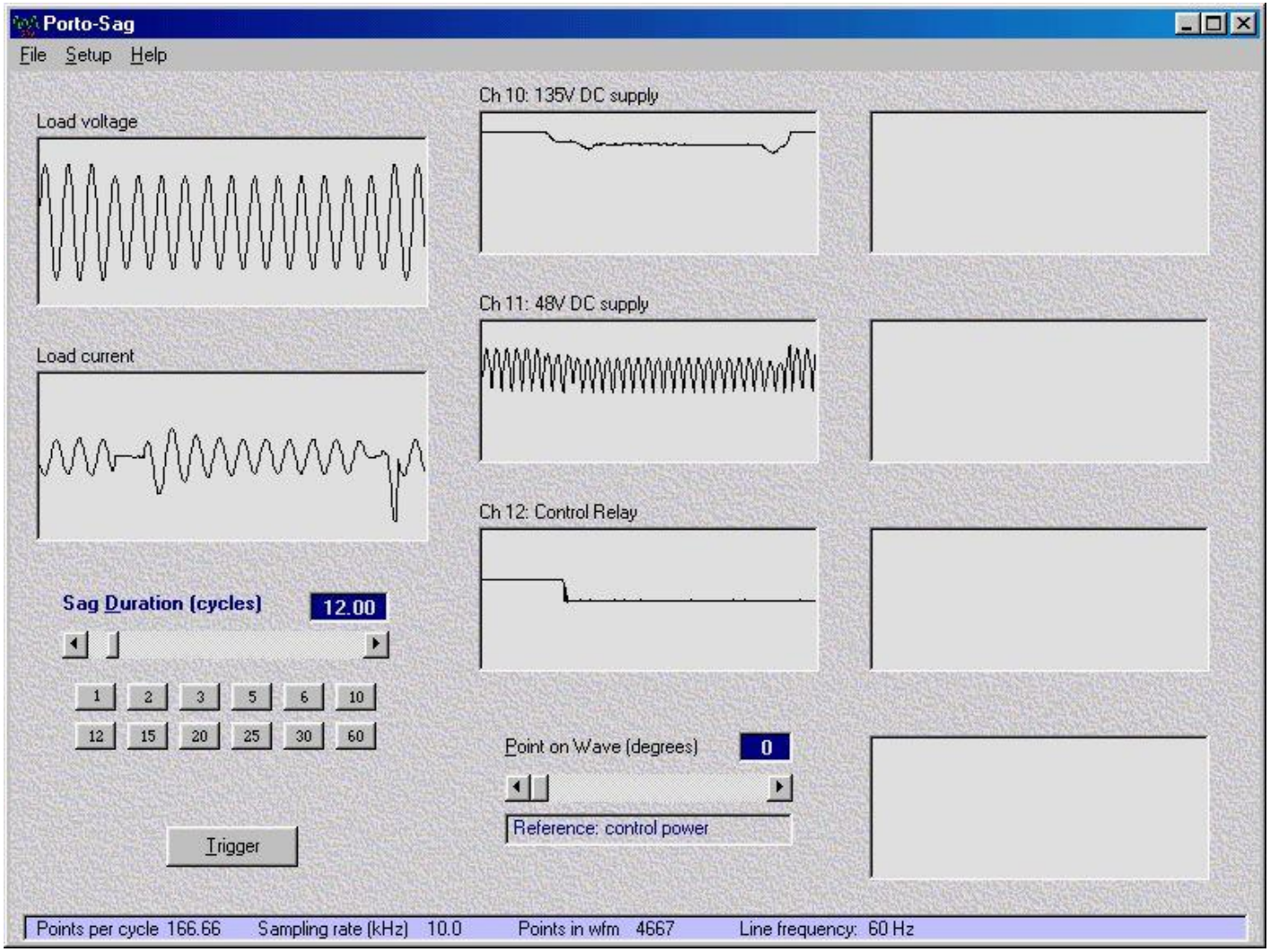
Porto-Sag Software Interface



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Single-Phase Sag Generators (Portable)

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

1 Phase Voltage Sag Generator

Omniverter offers a new diagnostic tool to industry, business and electric utilities who wish to perform voltage sag testing to IEC6100-4-11, IEEE1668 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.

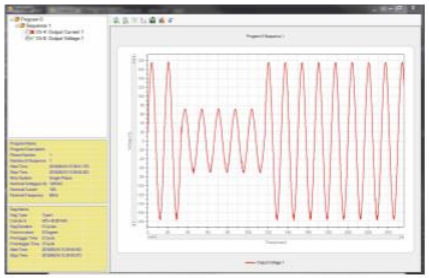
omniverter

tame your power—keep your profits

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

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 ¼ cycle to 30 seconds full load, (60 sec. half load) in ¼ 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.



Voltage Sag Generator software is a powerful diagnostic tool for capturing analyzing and exporting waveforms

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	$20A_{rms}$ continuous
Max load inrush current	$50A_{peak}$ for ½ cycle
Input configuration	1-phase Y + N+G or Split phase + G
Output configuration	1-phase Y + N+G or Split phase + G
Monitoring points	Phase A-N, or Li-L2

Data Acquisition

Sampling rate	10 kHz
Resolution	16 bits
Max input voltage	3 channels ±10 V_{peak} AC or DC 3 channels ±350 V_{peak} AC or DC (approx 240 V_{rms})

Sag Control

Sag duration	¼ cycle to 30 sec. in ¼-cycle steps at full load (60 secs. at half load)
Sag magnitude	3% to 100% in 3% steps
Point-on-wave	360° in 1° increments
Trigger output	TTL compatible

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L3R 0G9 Canada
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US Tel: 440-290-4499
Fax: 416-849-2298
www.omniverter.com
info@omniverter.com

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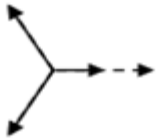
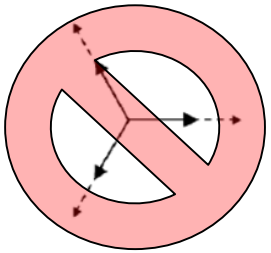
Sag Generators – PSL Industrial Power Corrupter

- 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.



Type I

Type IIA.1



Type III

Interruptions Only

Sag Generator – Omniverter 3-Phase

Voltage Sag Generator

3-Phase 60A-600A up to 277/480V

3-Phase Voltage Sag Generator

Omniverter offers a new diagnostic tool to industry, business and electric utilities who wish to perform voltage sag testing to IEC6100-3-11, 61000-3-34, IEEE1668 and to SEMI F47

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 such as HVAC, semiconductor tools, machine tools, lighting or even entire process lines.
Its built-in data acquisition system automatically captures voltages, currents and other user connected signals during induced sag events.
Capable of performing all tests listed in Standard

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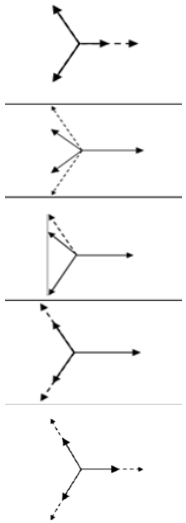
Voltage Sag Vector Cross Reference

Vector Type	Voltage Sag Description	Other Common Designators	IEC 61000-4-34 Reference Figure
A	Single-Phase	Type I	Figure 3A
B	Phase to Phase Alternative 1	Type II A1	Figure 3B
C	Phase-to-Phase	Type II	Figure 3C
D	Phase to Phase Alternative 2	Type II A2	Figure 3D
E	Unbalanced Three-Phase	N/A	N/A
F	Balanced Three-Phase	Type III	N/A

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



Type I

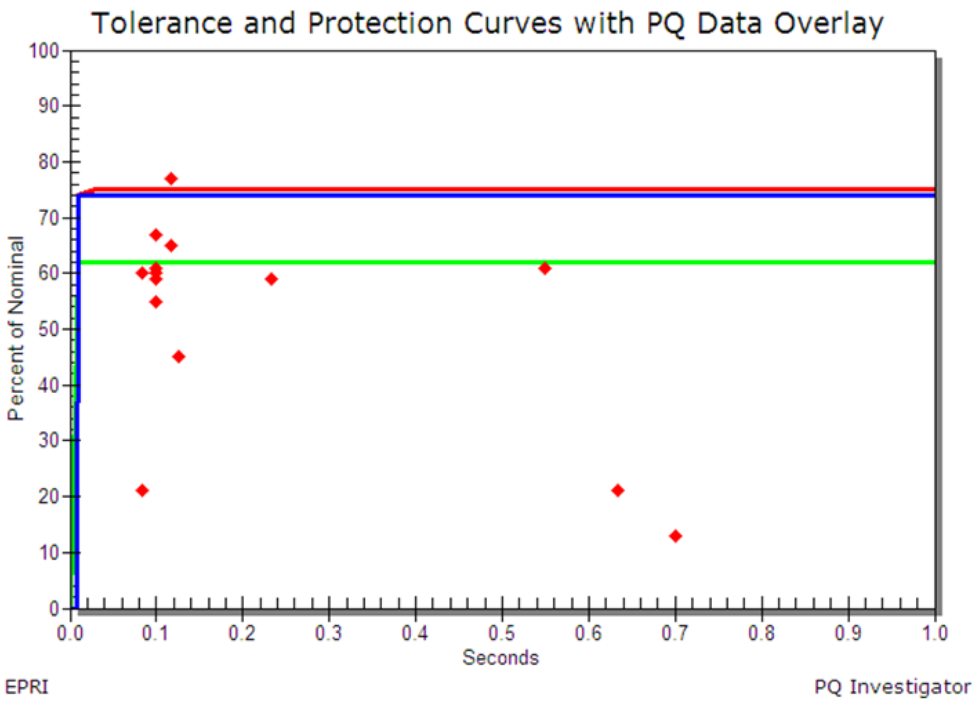
Type II

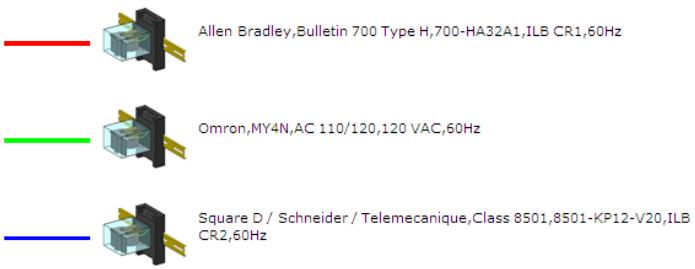
Type IIA.1

Type IIA.2

Type III

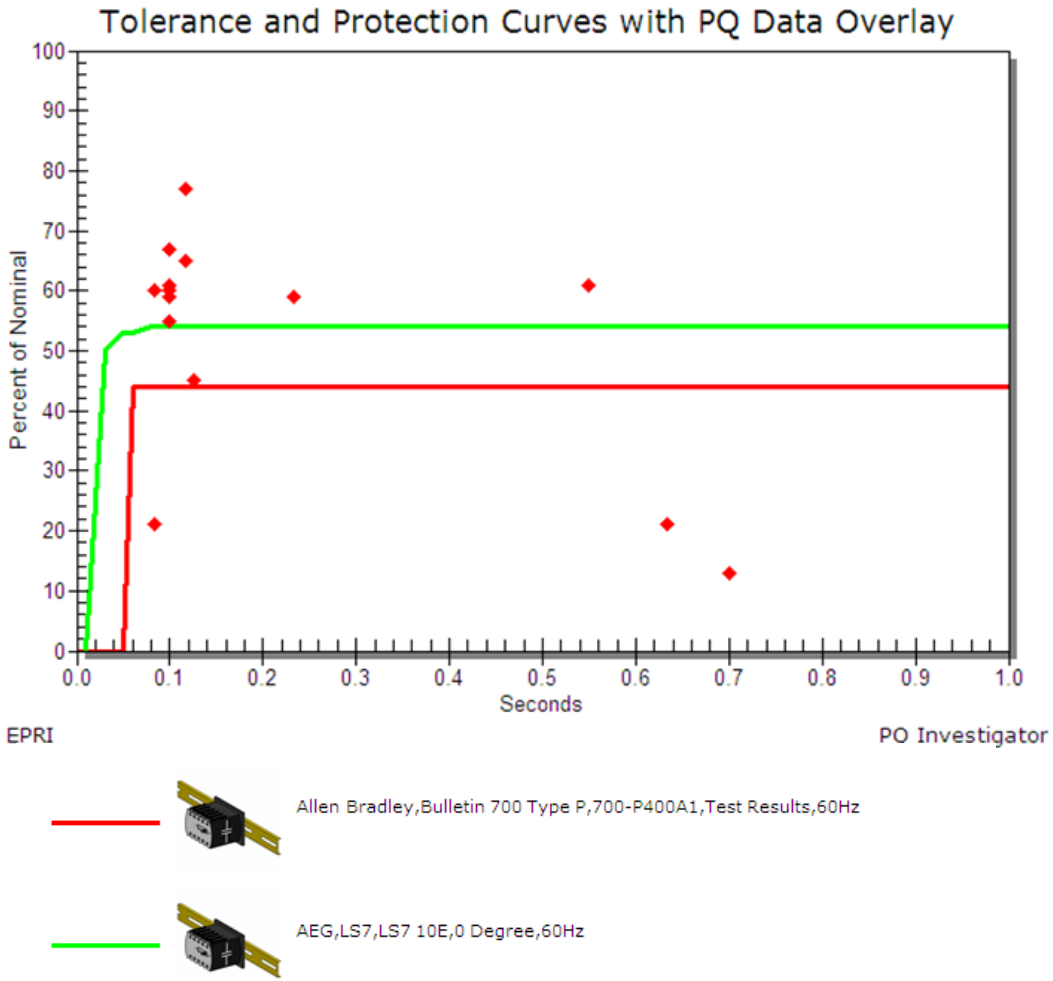
Voltage Tolerance Curve: Ice Cube Relay





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 ?

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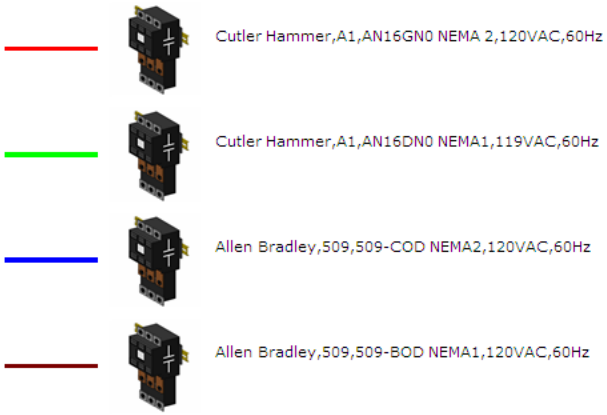
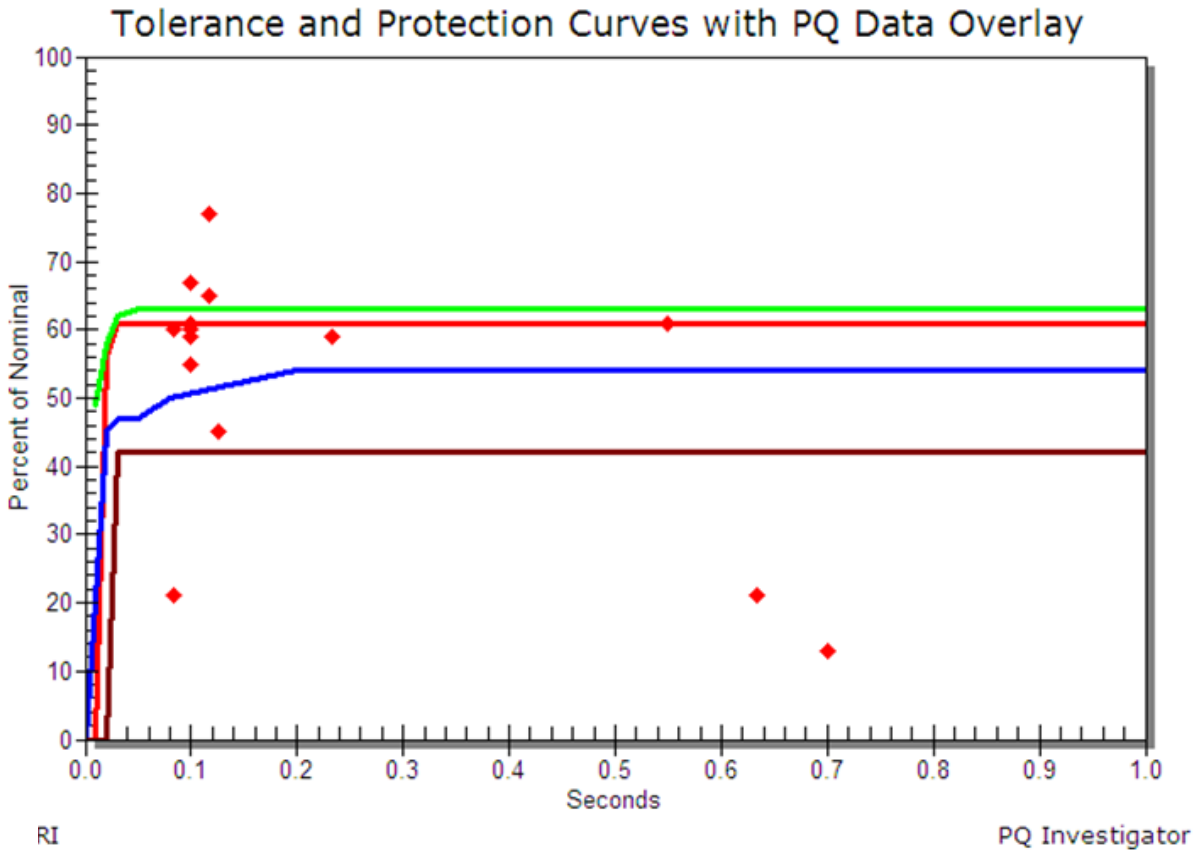
Voltage Tolerance Curve of Motor Starters

Which motor starters are the most susceptible to voltage sags?





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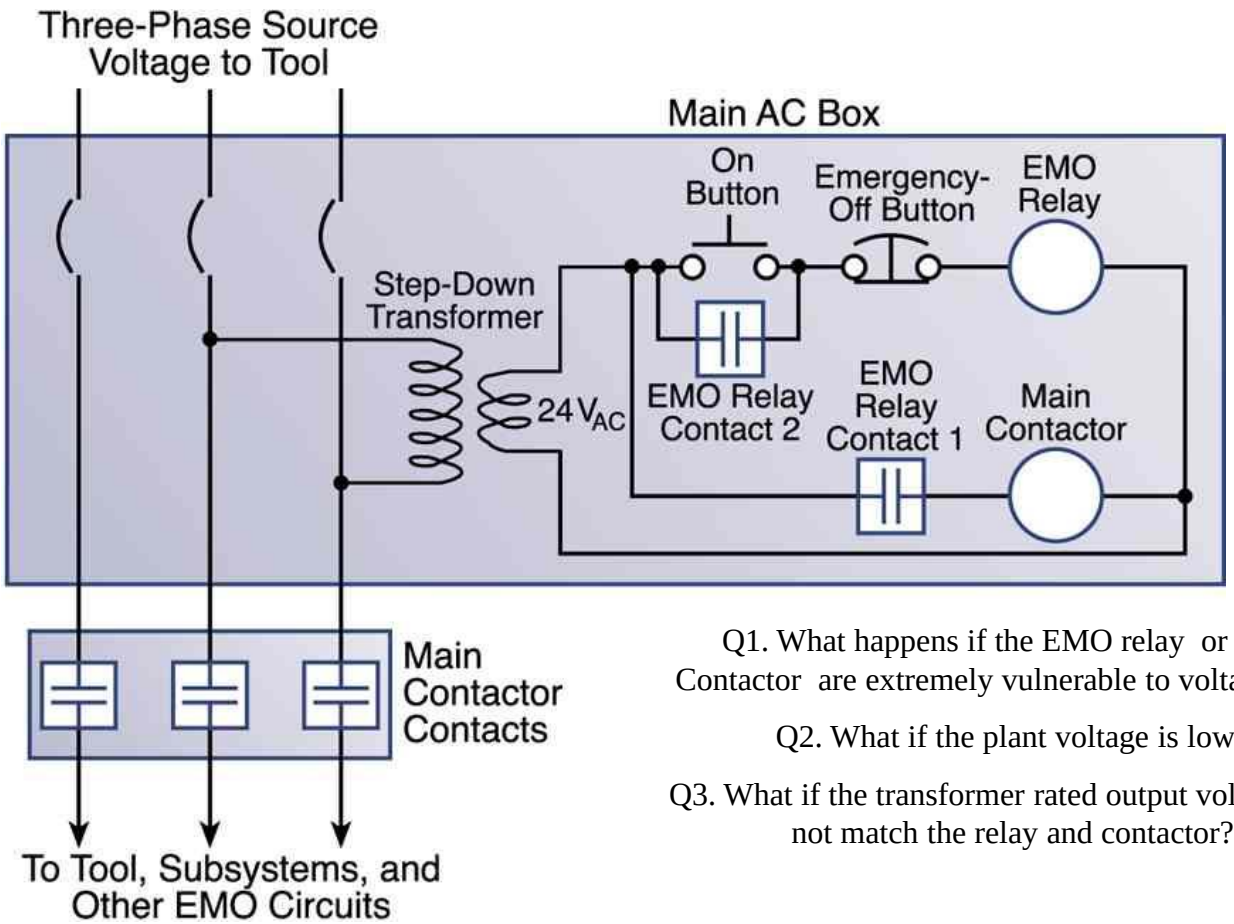
Emergency Off (EMO) Circuit



Q1. What happens if the EMO relay or Main Contactor are extremely vulnerable to voltage sags?

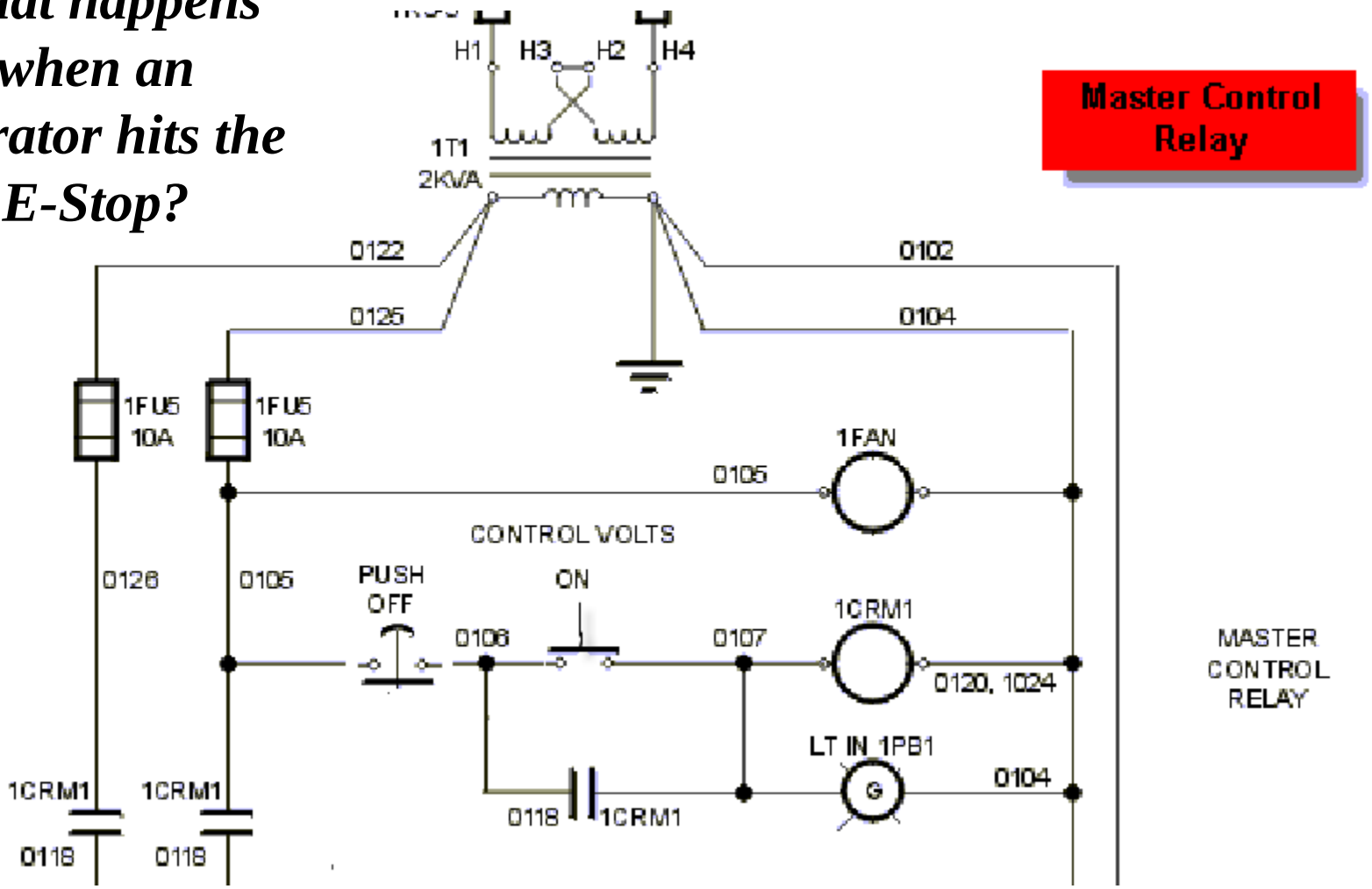
Q2. What if the plant voltage is low?

Q3. What if the transformer rated output voltage does not match the relay and contactor?

Master Control Relay Example

What happens if 1CRM1 is a sensitive relay?

What happens when an operator hits the E-Stop?



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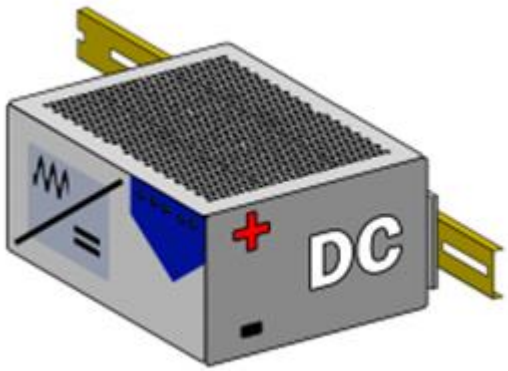
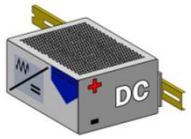
DC Power Supplies

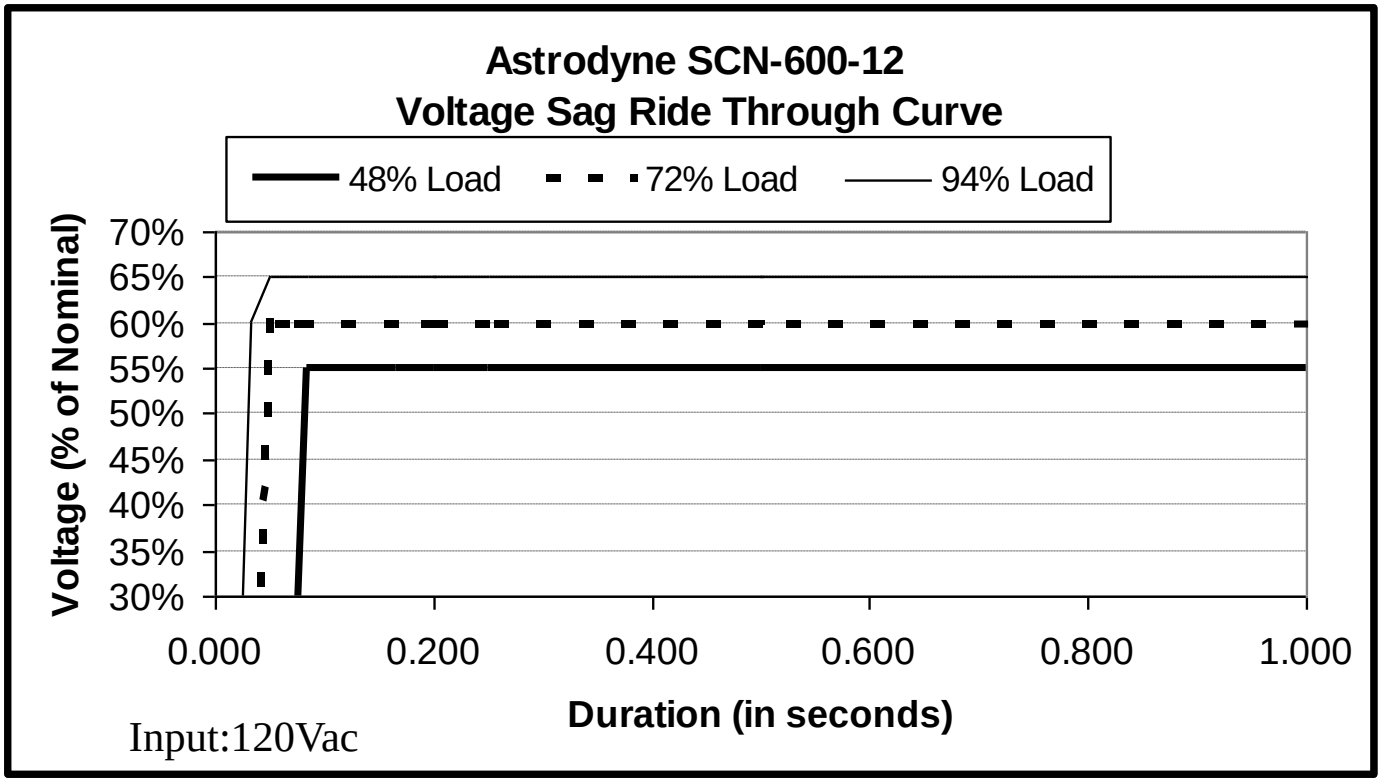
- DC Power supplies range from single-phase linear to switch-mode designs and are used to power user interface PCs, tool controllers, and instrument I/O applications.
- The voltage sag ride-through of most power supplies designed for PC, tool controllers, and instrument I/O applications is directly related 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.





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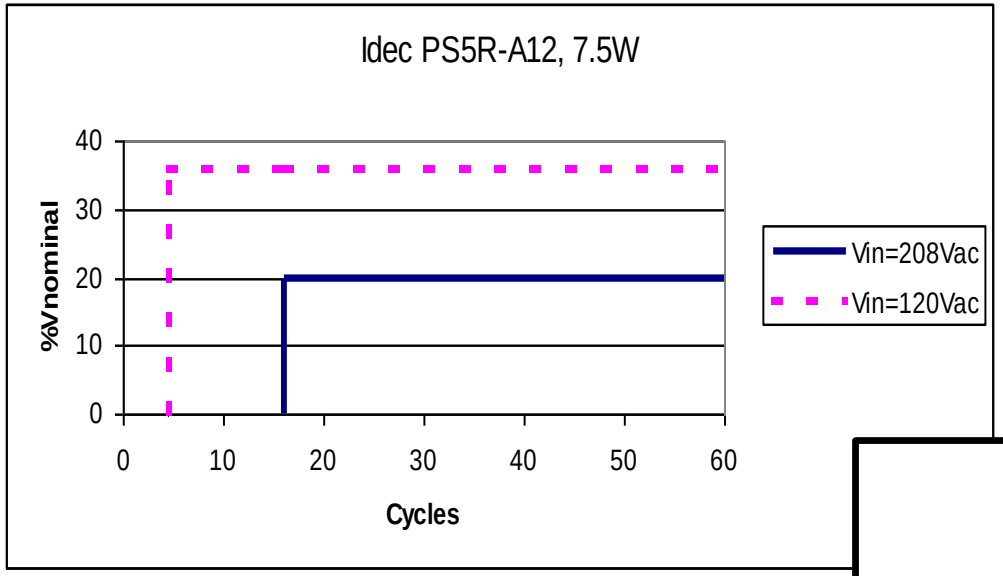
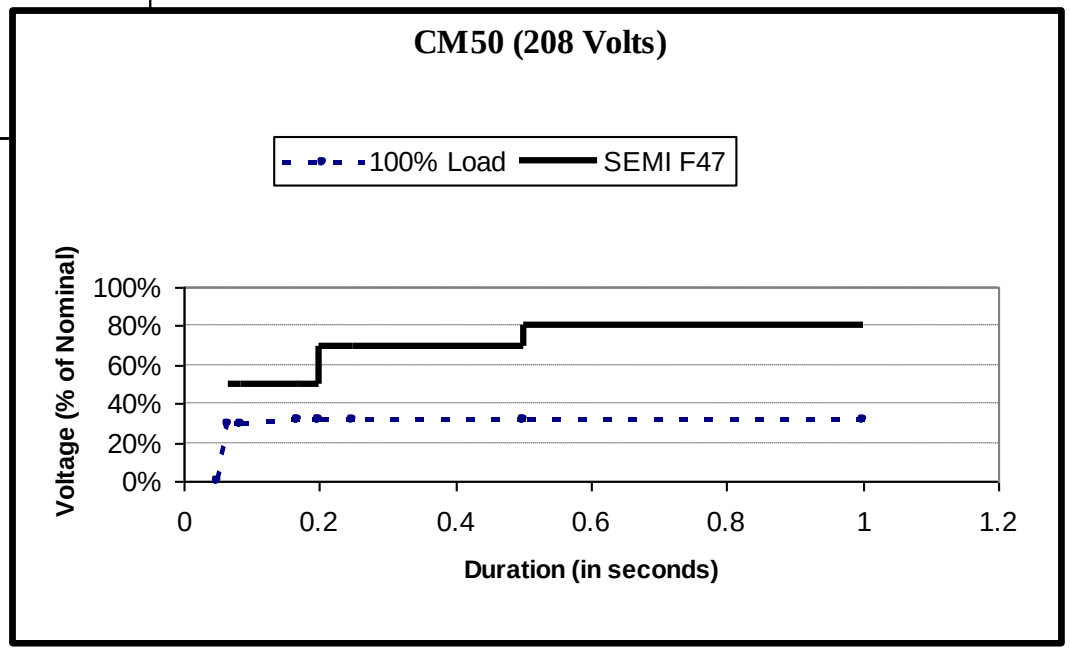
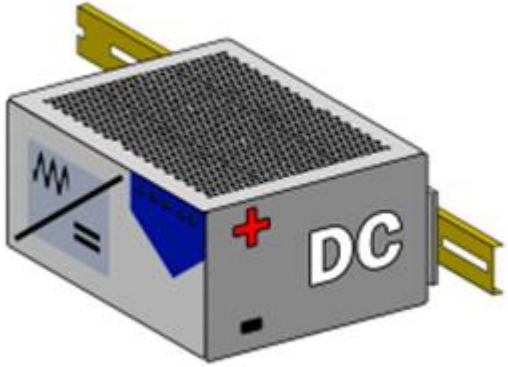
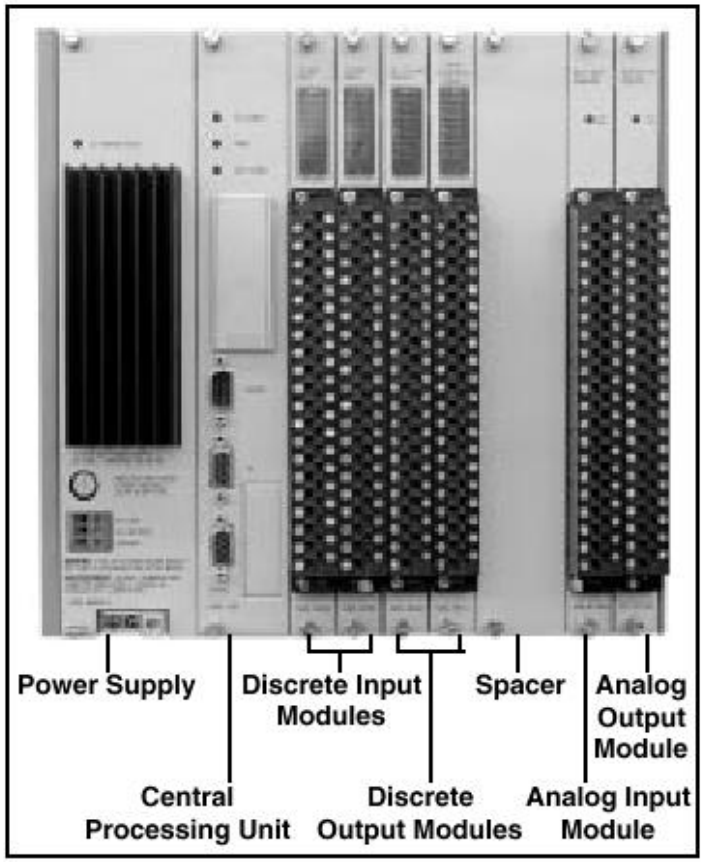
DC Power Supply Susceptibility Example 2: Universal Input Types







PLC Based Control Systems



PLC

--Select Manufacturer--
--Reset--
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

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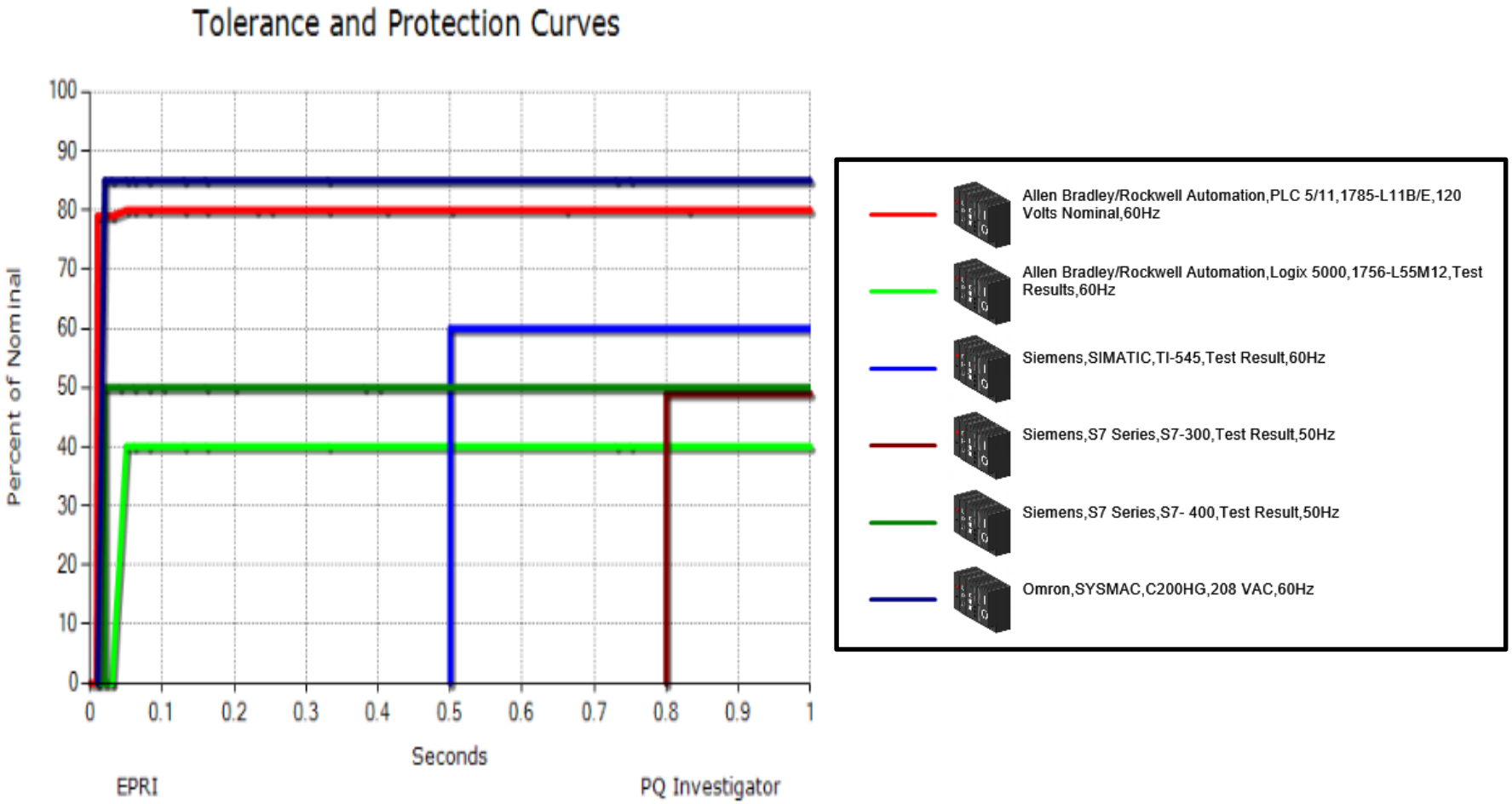
Example Voltage Sag Ride-Through of AC Powered PLCs



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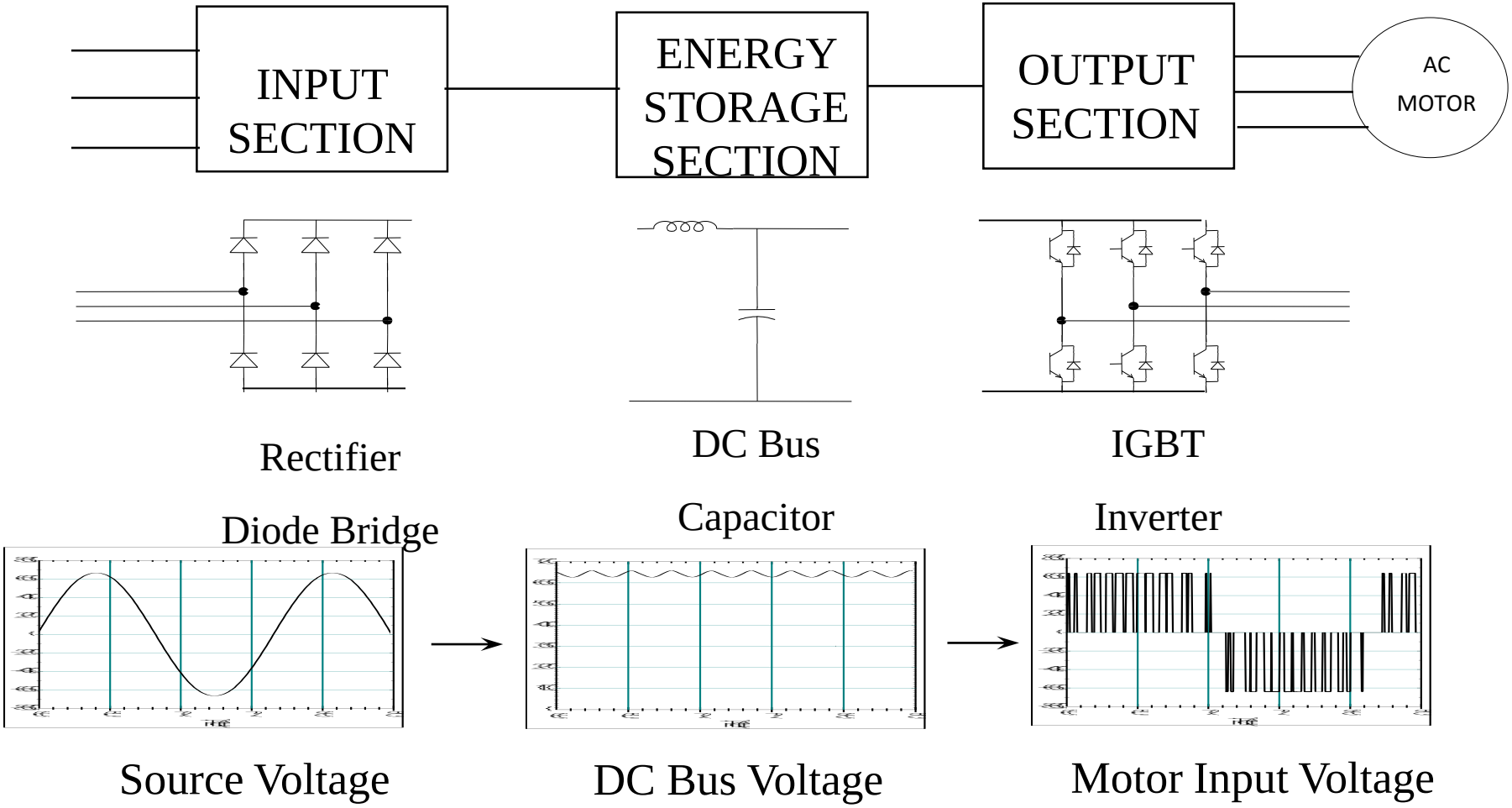
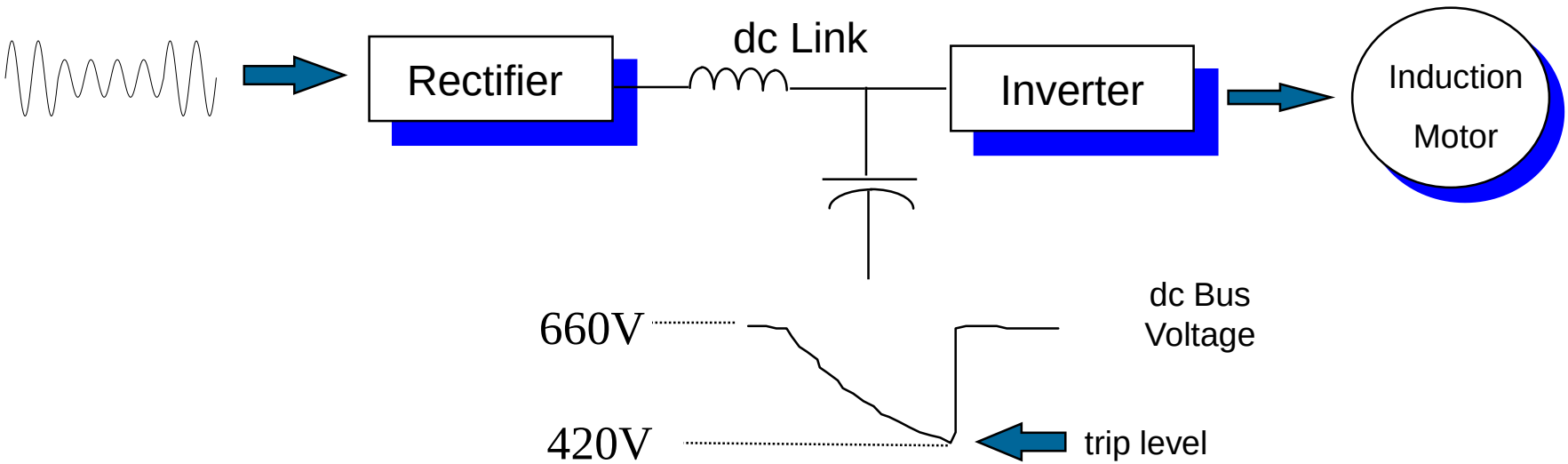
Adjustable Speed Drives

AC PWM Drive

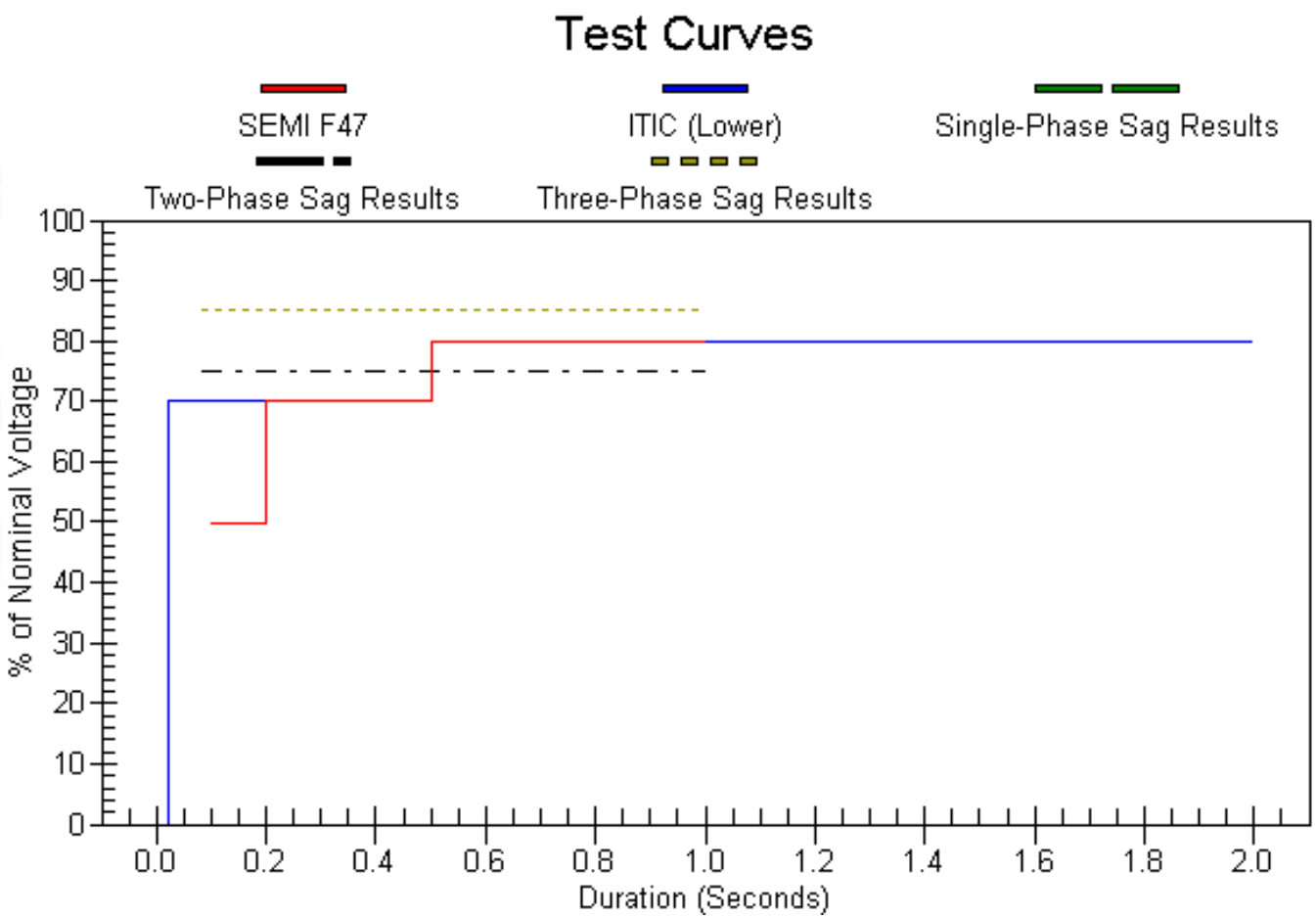


Voltage Sag Impact on ASD



Drive Trips on Undervoltage

Example Drive Response



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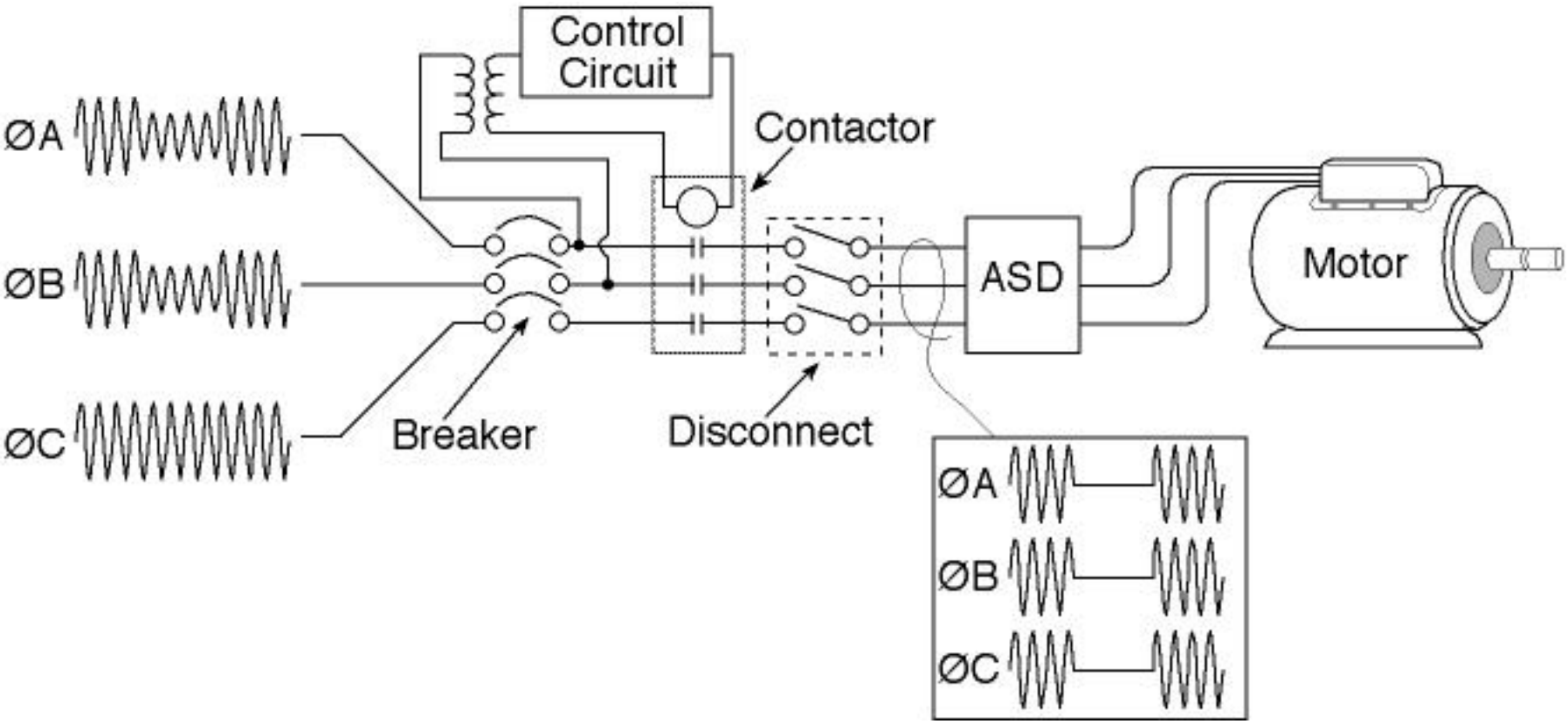
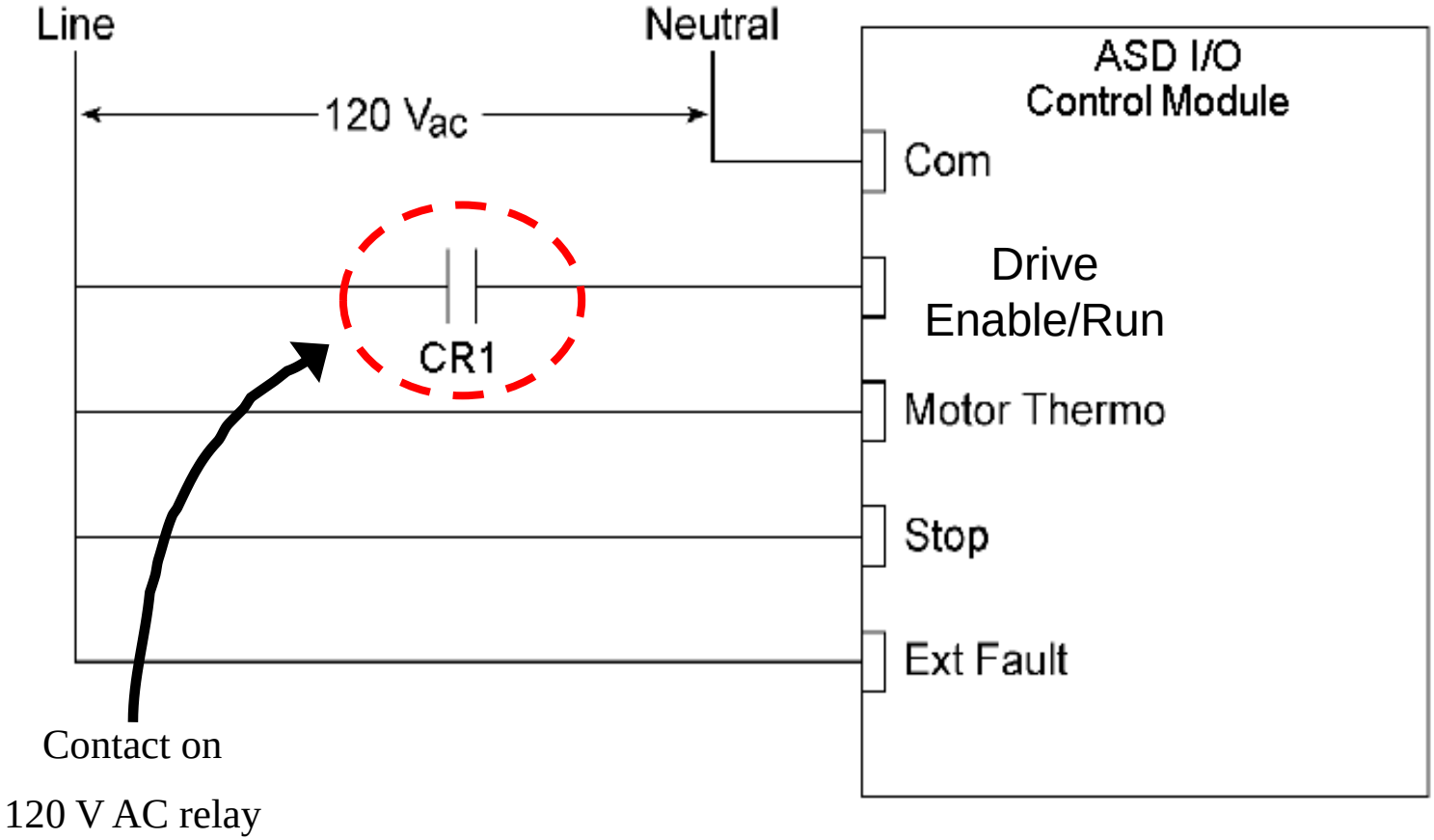
Line-Side and Motor-side Contactors

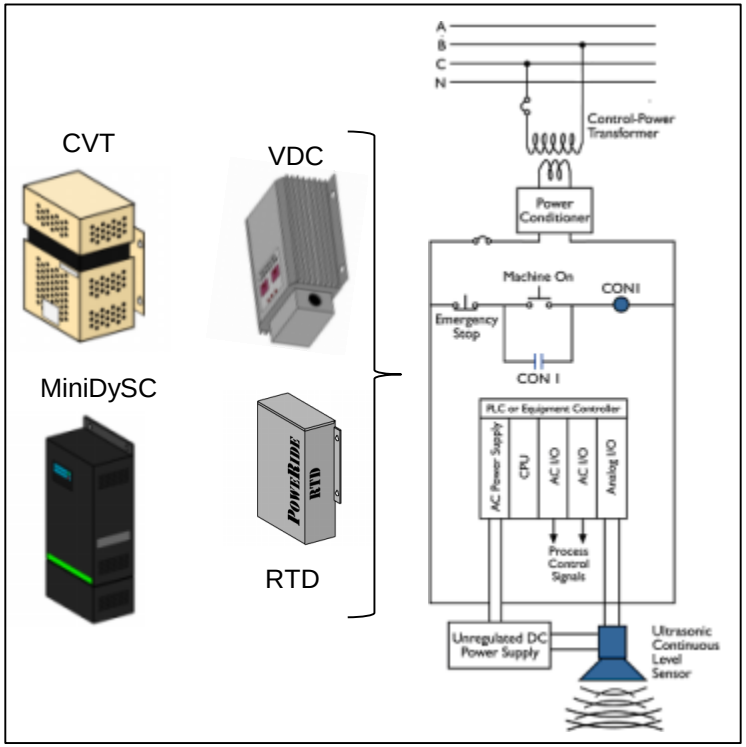


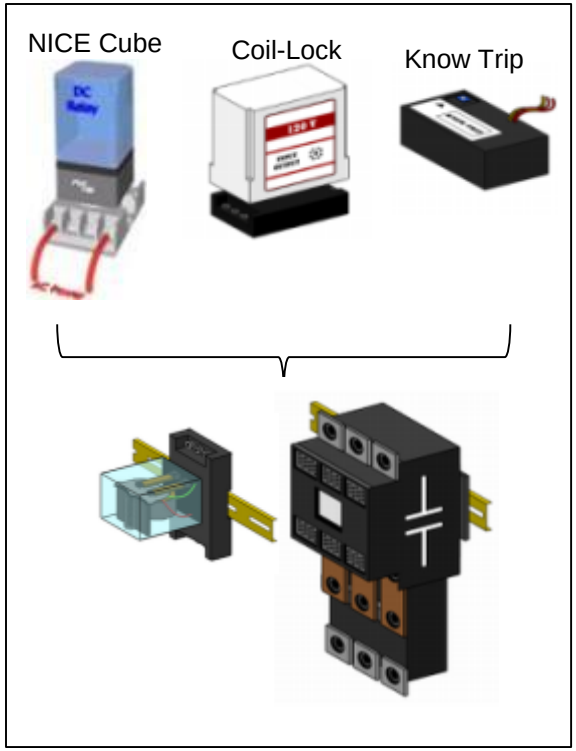
ASD Enable/Run Signal

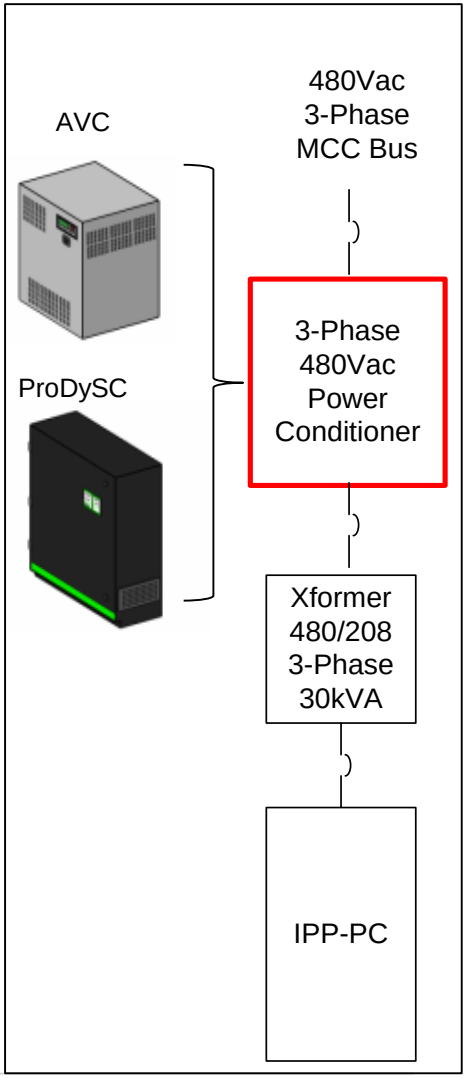


Mitigation Solutions

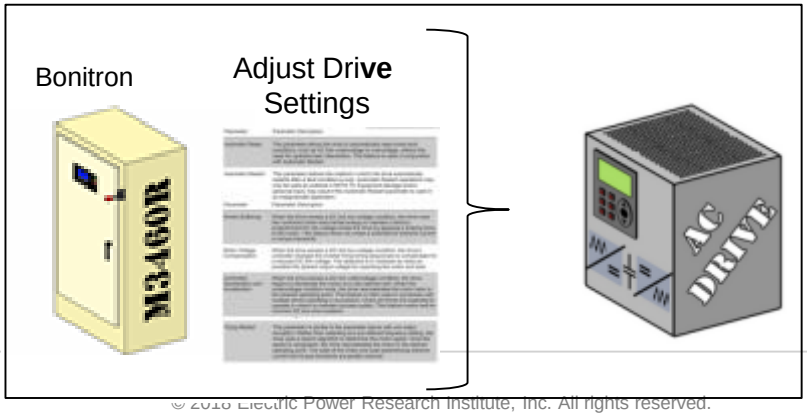
PQ Solution – Add Mitigation







Where Possible Avoid Battery Based Solutions!



Uninterruptible Power Supply (UPS)

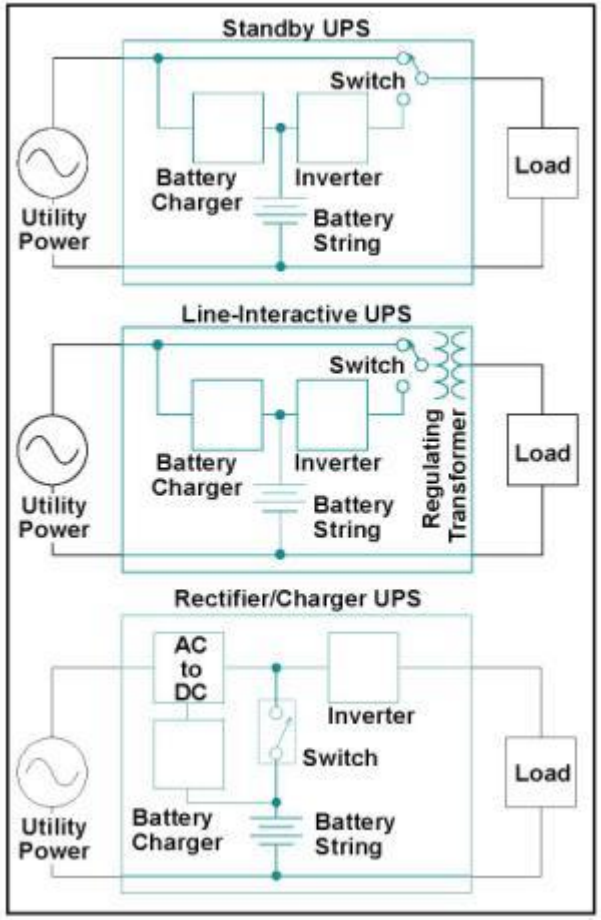
For Control Loads

Small 500Va to 3kVA

UPS Systems are sometimes Used

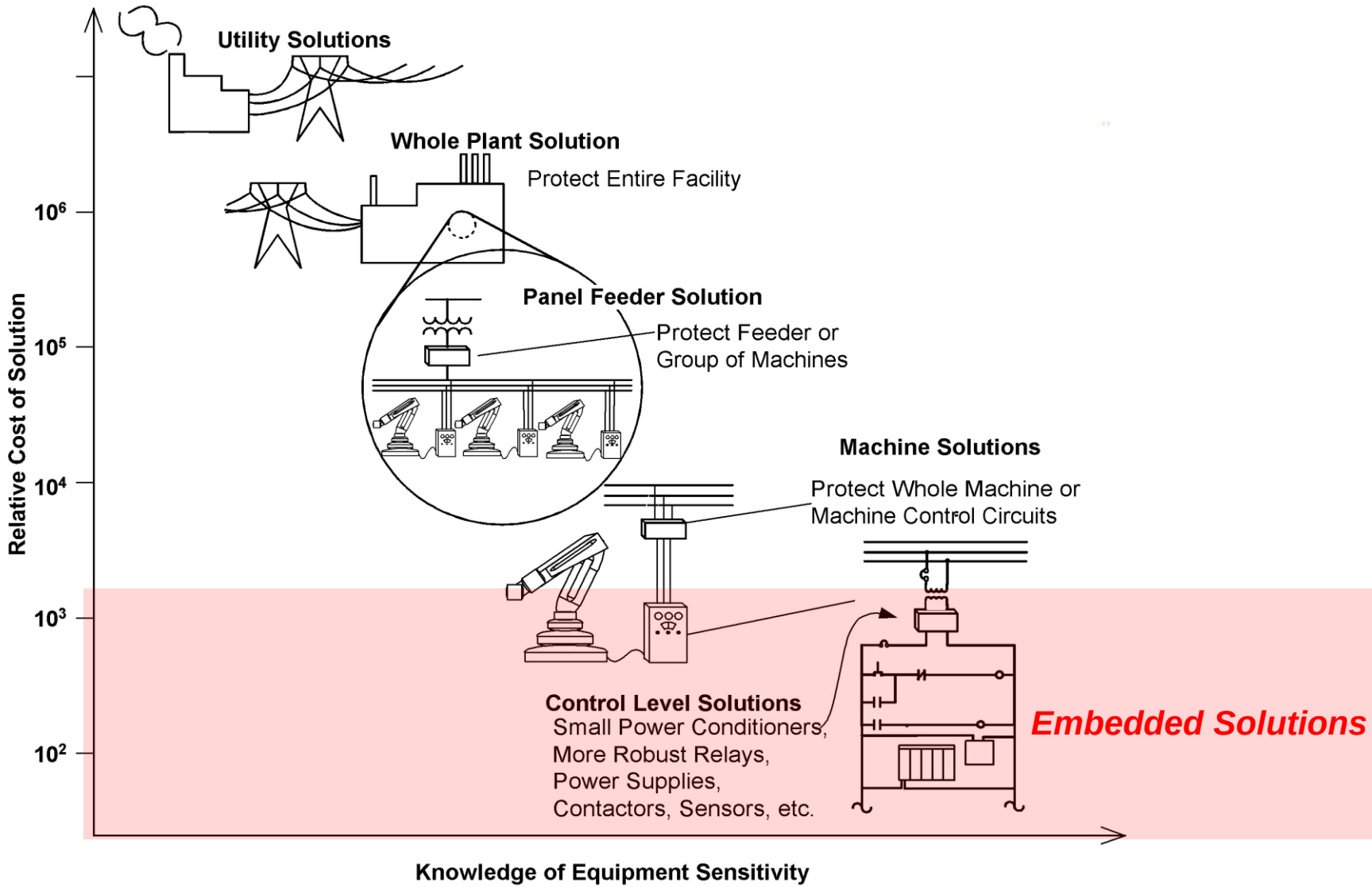
Battery Based UPS Are Often "Overkill"

"Abandoned in Place" UPS Systems



Double Conversion

Mitigation Levels



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

Mitigation Approaches	Solution:	Electrical Efficiency:	Comprehensive Whole Plant Solution:	Petroleum Fuel Requirement:	Battery Requirement:	Energy Storage Requirement:	Annual Maintenance Cost:	Battery Replacement Period (years):	Fan Assembly Replacement Period (years):	DC Bus Cap Replacement Period (years):	Bearing Replacement Period:	Bridge-power Duration (s):	Current Limit, % of Nominal:	Dynamic Voltage Regulation:	Long-term Interruption Support:
Sag RT	OmniVerter AVC_2	99%	No	No	No	No	Low	None	7	12	None	No	200%	Yes	No
Sag RT + 15s Interruption	OmniVerter $AVC_{RTS\text{ - Battery (30s)}}$	99%	No	No	Yes	Yes	Medium	5	5	12	None	30	200%	Yes	No
	CAT UPS 900Z	98%	No	No	No	Yes	High	None	None	10	4	16	200%	Yes	No
Bridge Power + Gen Sets	OmniVerter $AVC_{RTS\text{ - Battery (30s)}}$ + Generator	99%	No	Yes	Yes	Yes	Medium	5	7	12	None	30 s + Gen	200%	Yes	Yes
	CAT UPS + Generator	98%	No	Yes	No	Yes	High	None	None	10	4	16 s + Gen	200%	Yes	Yes
Bridge Power + Alternate Feed	OmniVerter $AVC_{RTS\text{ - Battery}}$ + MV Feed	99%	No	No	Yes	Yes	Low	5	7	12	None	30 s + MV Feeder	200%	Yes	Yes
	CAT UPS + MV Feed	98%	No	No	No	Yes	Med	None	None	10	4	16 s + MV Feeder	200%	Yes	Yes
Full Load Battery plus Alternate Feed	8 MW UPS Battery System + MV Standby Feed	98%	Yes	No	Yes	Yes	Low	Included in warranty (Typically 10 years)			None	15 s + MV Feeder	**110%**	Yes	Yes

Pro | Neutral | Con

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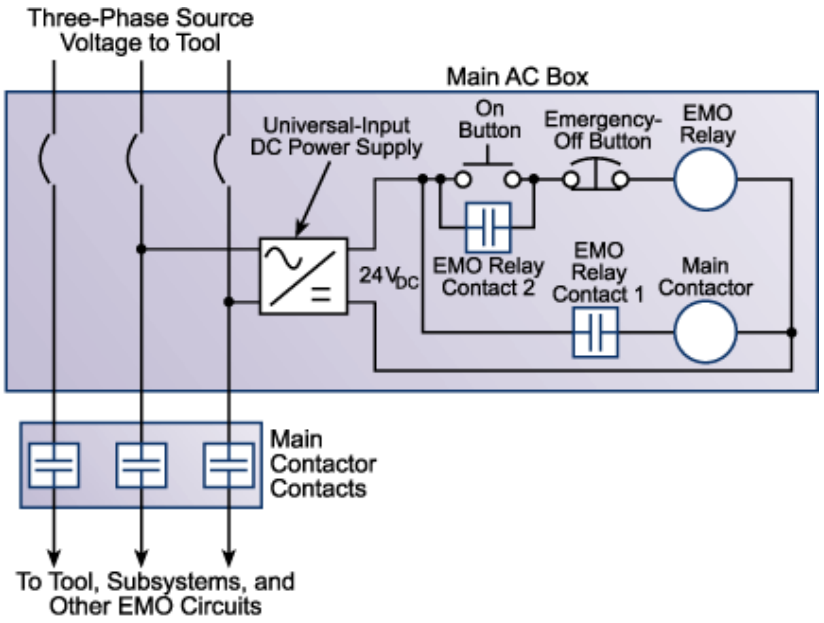
Method 1: Design with DC Power

- 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



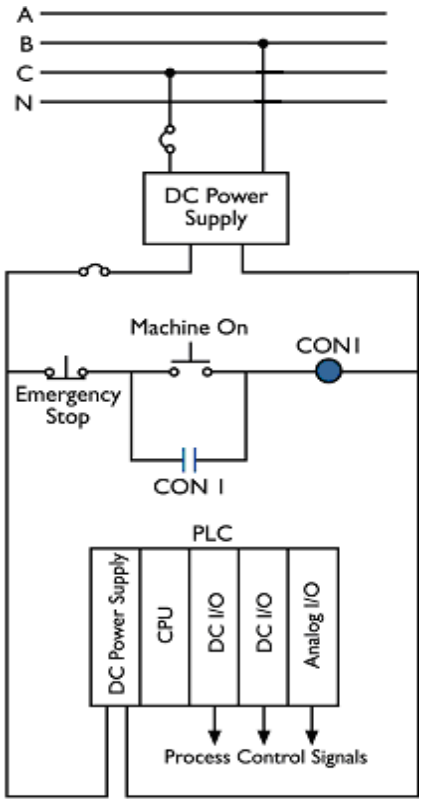
DC Powered Emergency Off Circuit

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

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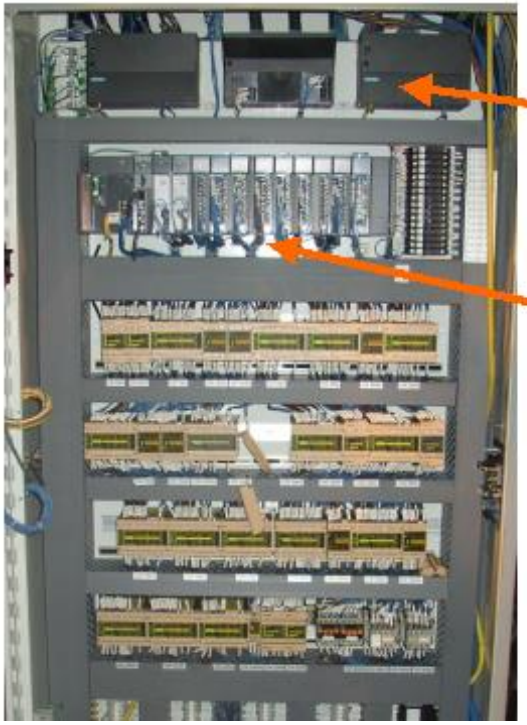
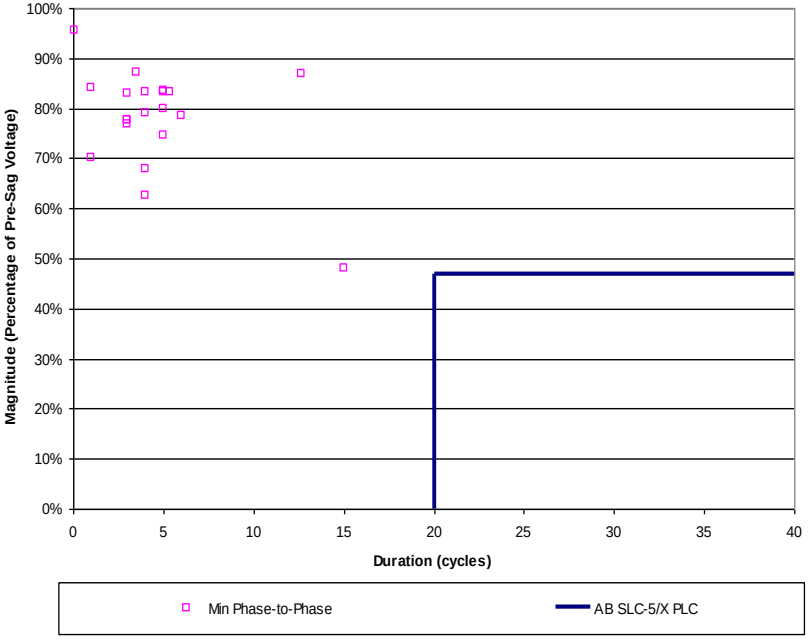
DC Powered PLC System in Weld Shop



(3) Three phase input Siemens SITOP DC Power Supplies

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



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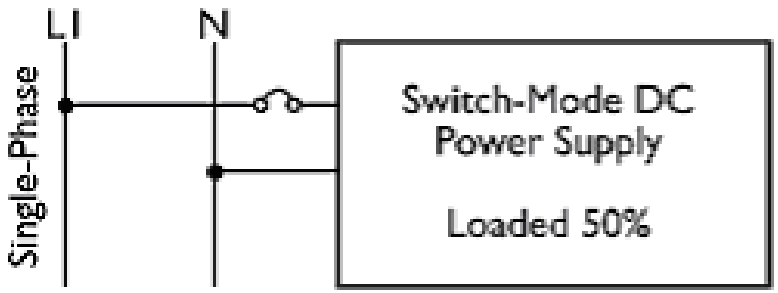
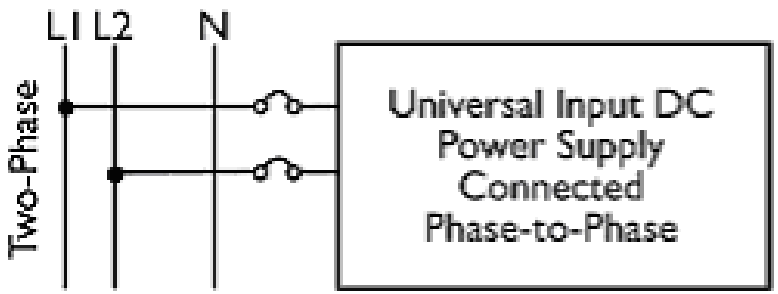
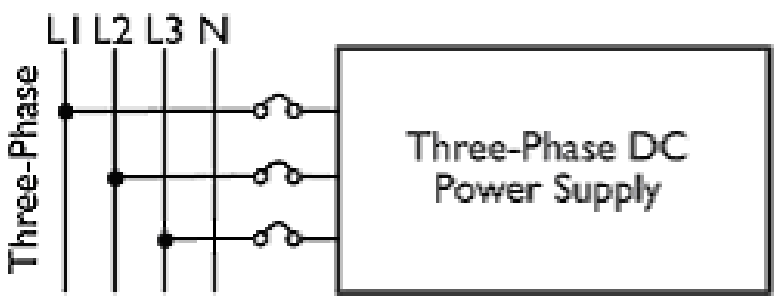
Summary of Robust Power Supply Strategies



Most relevant to single-phase circuits. In order to ensure robustness, design for 50% loading.

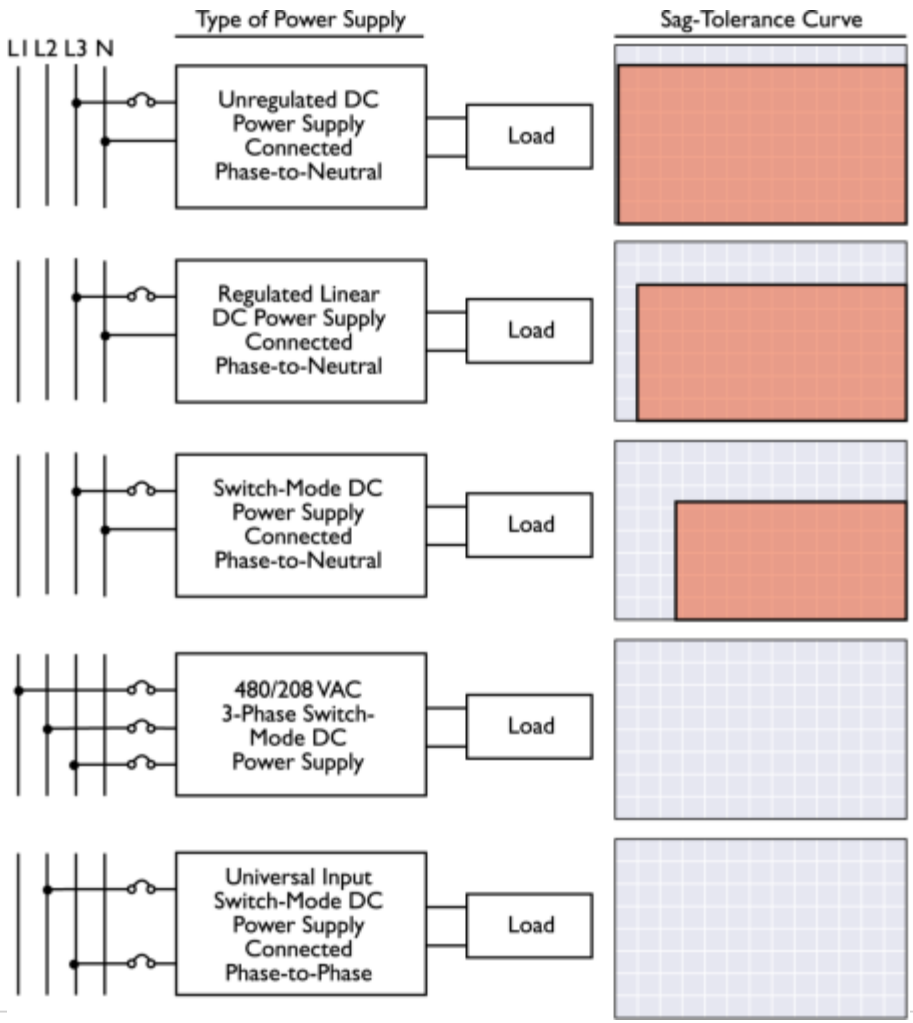


Most relevant to 208-VAC, three-phase systems. Input voltage ranges from 85 VAC to 264 VAC connected phase-to-phase. Will maintain output down to 41% nominal input voltage even at 100% load.



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

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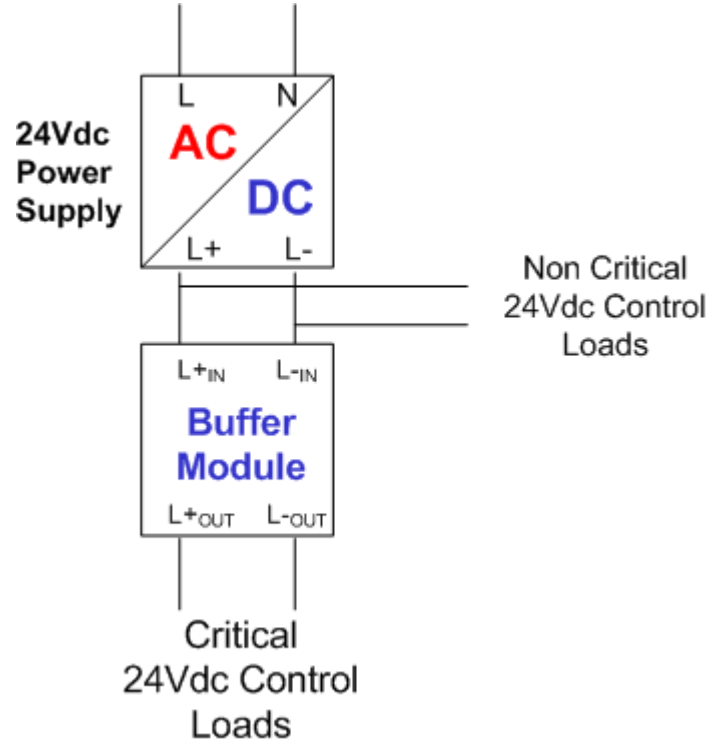
24Vdc Energy Storage Options

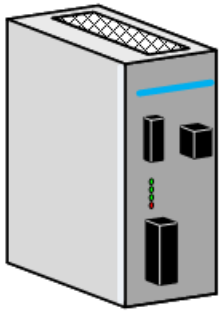
- The PQI now has two 24Vdc Energy Storage Options that can harden 24Vdc Based Controls.



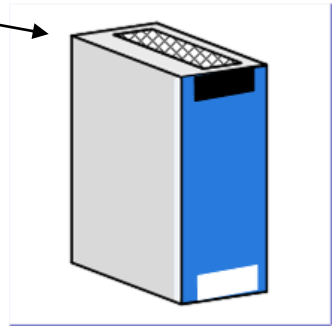
[Mitigators of Type "24Vdc Energy Storage Module"]

--Select Mitigator--
24Vdc Buffer Module
24Vdc Ultracap Buffer Module

View



ABB



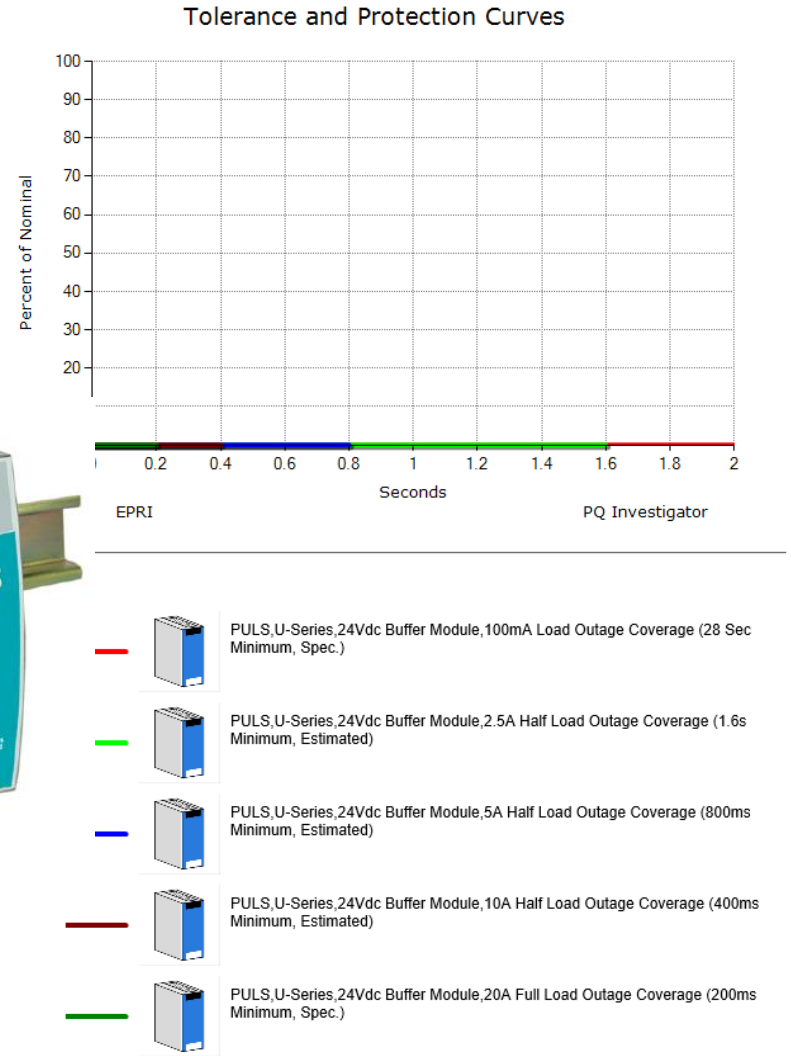
PULS

--Select Protection Curve--
U-Series,24Vdc Buffer Module,20A Full Load Outage Coverage (200ms Minimum, Spec.)
U-Series,24Vdc Buffer Module,100mA Load Outage Coverage (28 Sec Minimum, Spec.)
U-Series,24Vdc Buffer Module,10A Half Load Outage Coverage (400ms Minimum, Estimated)
U-Series,24Vdc Buffer Module,5A Half Load Outage Coverage (800ms Minimum, Estimated)
U-Series,24Vdc Buffer Module,2.5A Half Load Outage Coverage (1.6s Minimum, Estimated)

--Select Protection Curve--
CP-B,24Vdc Ultracap Buffer Module,3A Model Full Load Outage Coverage (13 sec)
CP-B,24Vdc Ultracap Buffer Module,10A Model Full Load Outage Coverage (38 sec)
CP-B,24Vdc Ultracap Buffer Module,20A Model Full Load Outage Coverage (15 sec)

PULS DC BUFFER Module

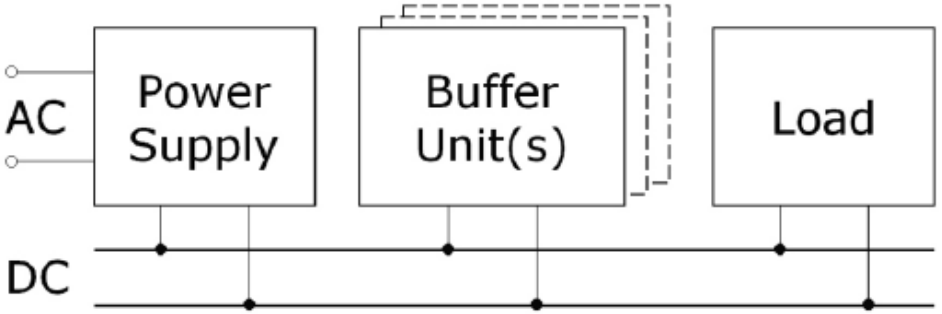
Select	Model	Manufacturer	Part Number	Description	Cost USD
☐	24Vdc Buffer Module	PULS	UF20.241	DC Buffer, ~100Ws - 24Vdc,20A, 200ms Outage Coverage at Full Load	310



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

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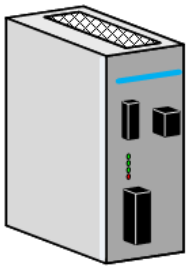
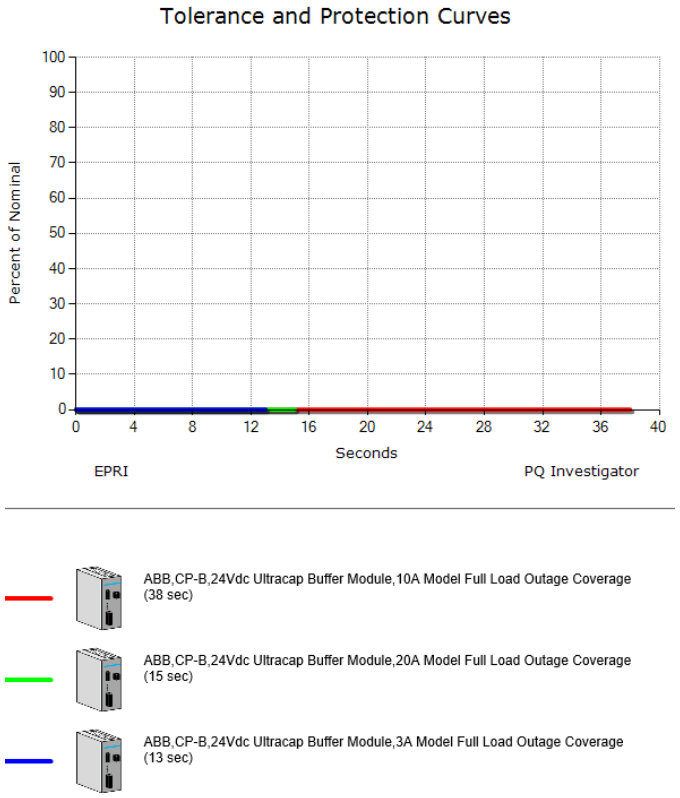
ABB Ucap DC Power Supply Buffer Module



- 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.

Ref: ABB Buffer module CP-B 24/20.0 data sheet



DEMO:
Sequence “0”

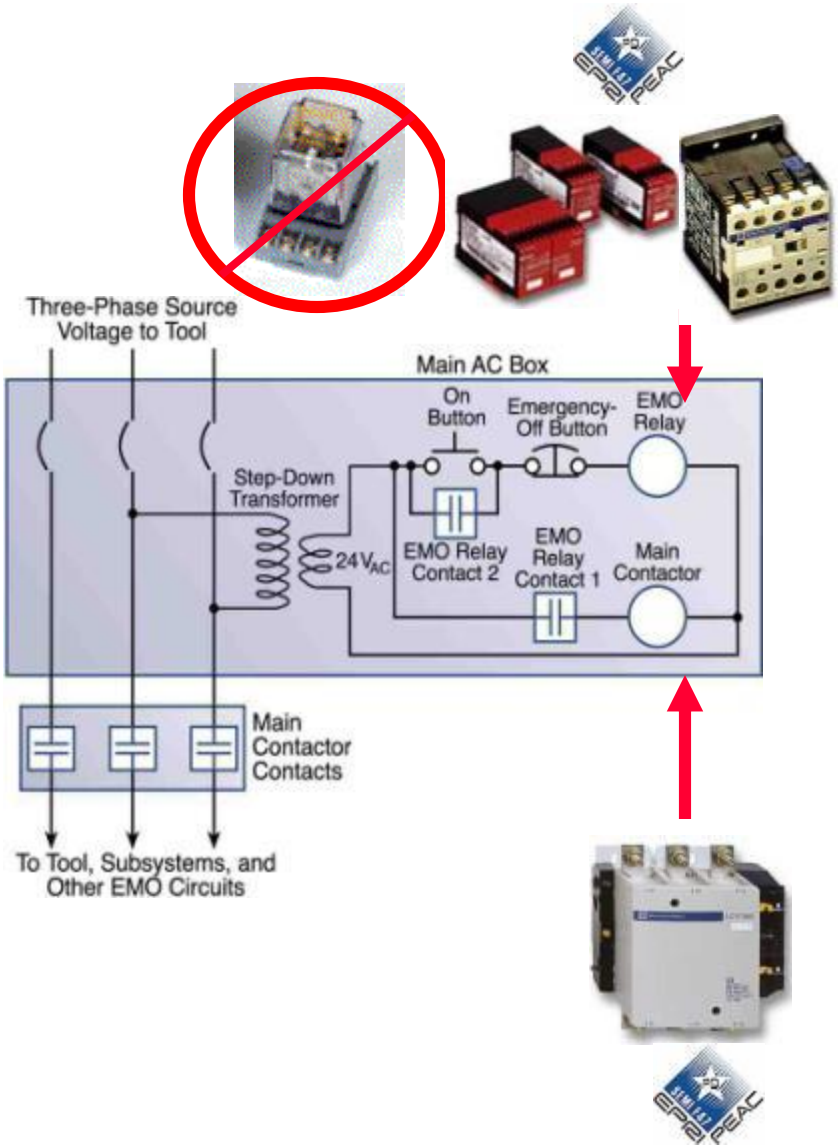
PLC DC P/S “ON”

Connect Buffer Module to 24VDC

Select	Model	Manufacturer	Part Number	Description	Cost USD
☐	24Vdc Ultracap Buffer Module	ABB	CP-B 24/3.0 1SVR 427 060 R0300	DC Ucap Buffer - 1000 Ws, 24Vdc, 3A, 13s Outage Coverage at Full Load	870
☐	24Vdc Ultracap Buffer Module	ABB	CP-B 24/10.0 1SVR 427 060 R1000	DC Ucap Buffer - 10000 Ws, 24Vdc, 10A, 38s Outage Coverage at Full Load	2500
☐	24Vdc Ultracap Buffer Module	ABB	CP-B 24/20.0 1SVR 427 060 R2000	DC Ucap Buffer - 8000 Ws, 24Vdc, 20A, 15s Outage Coverage at Full Load	2600

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.



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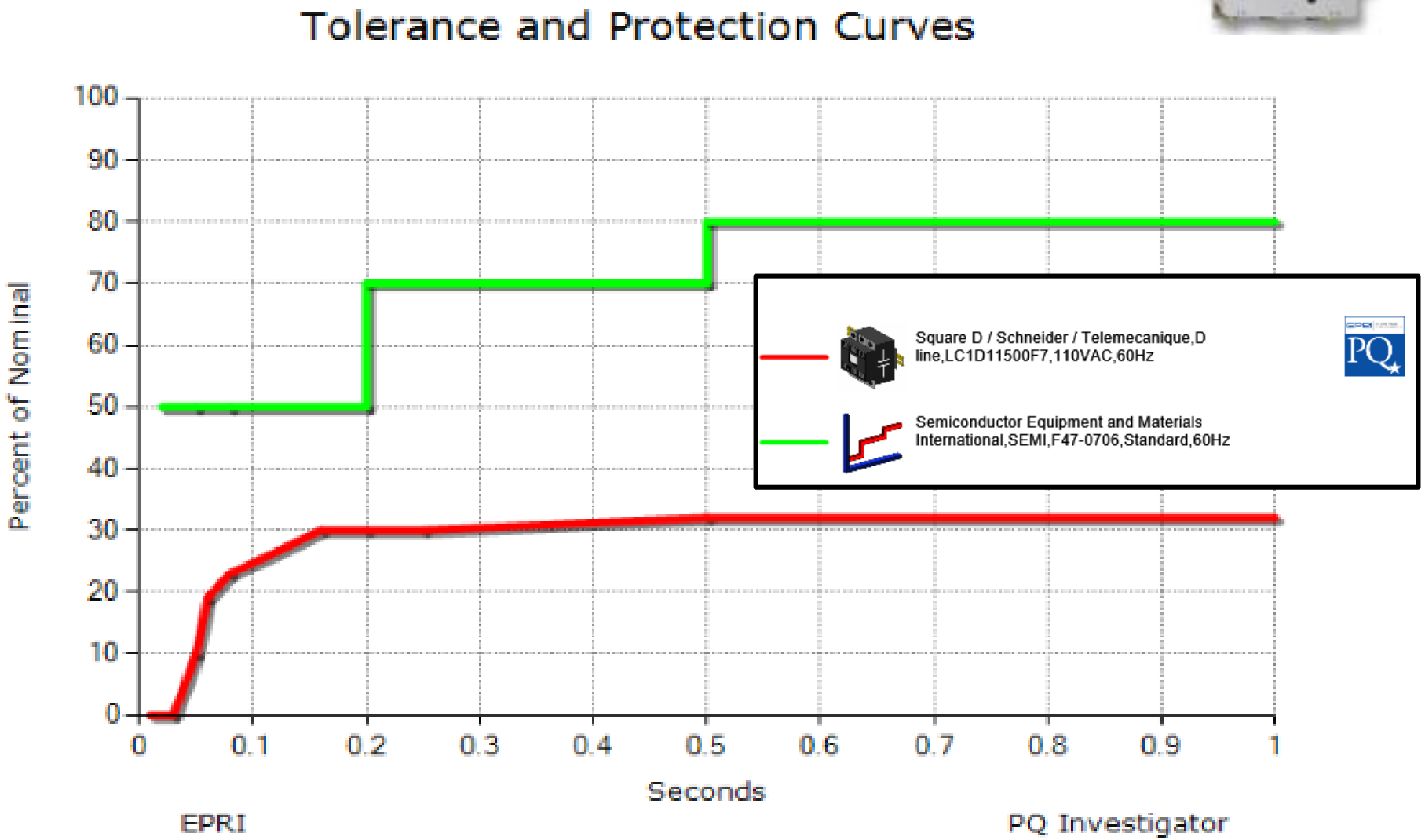
Example Robust Contactor



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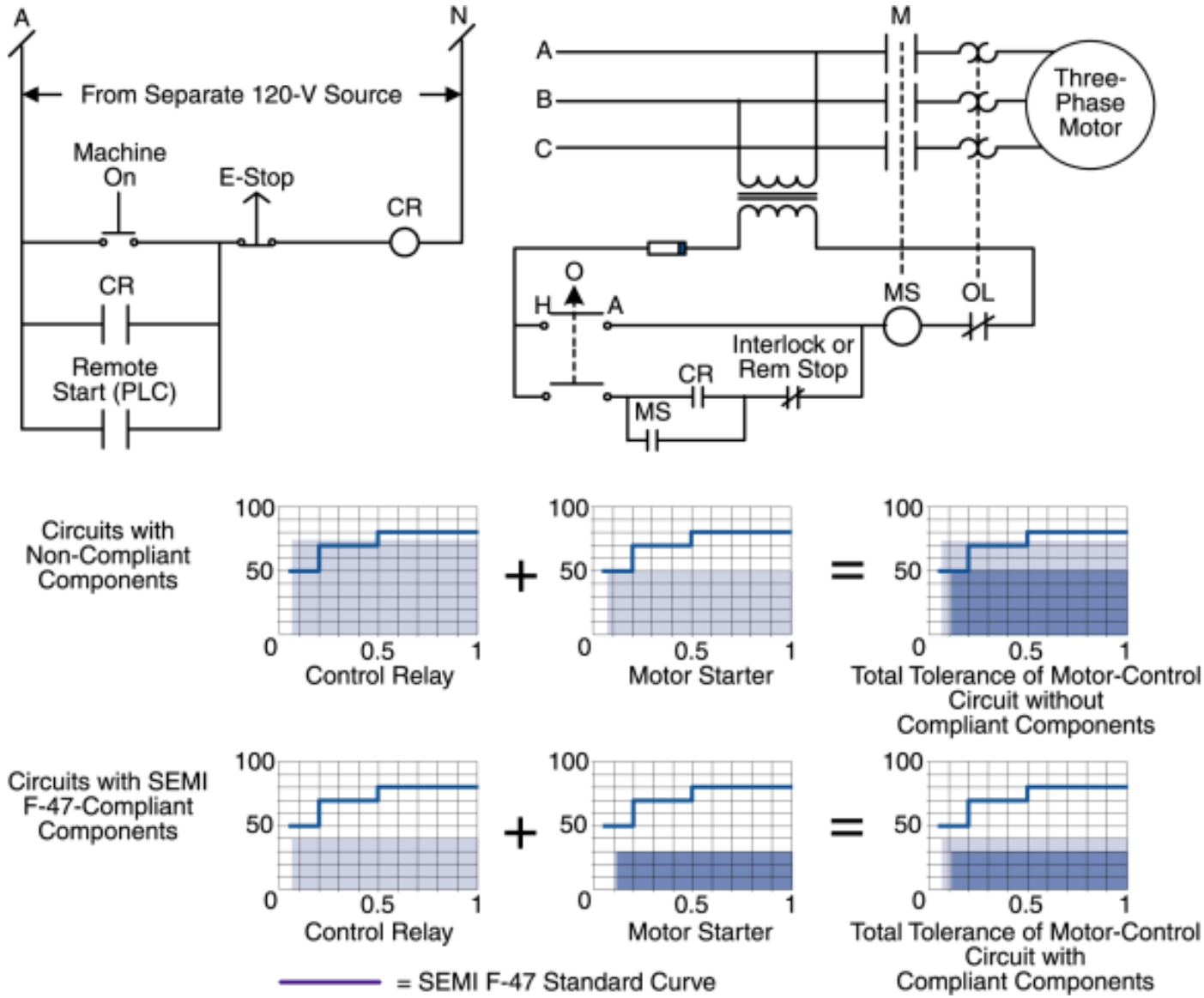
Example Voltage Sag Response of Motor Controls Based on Robustness of Components



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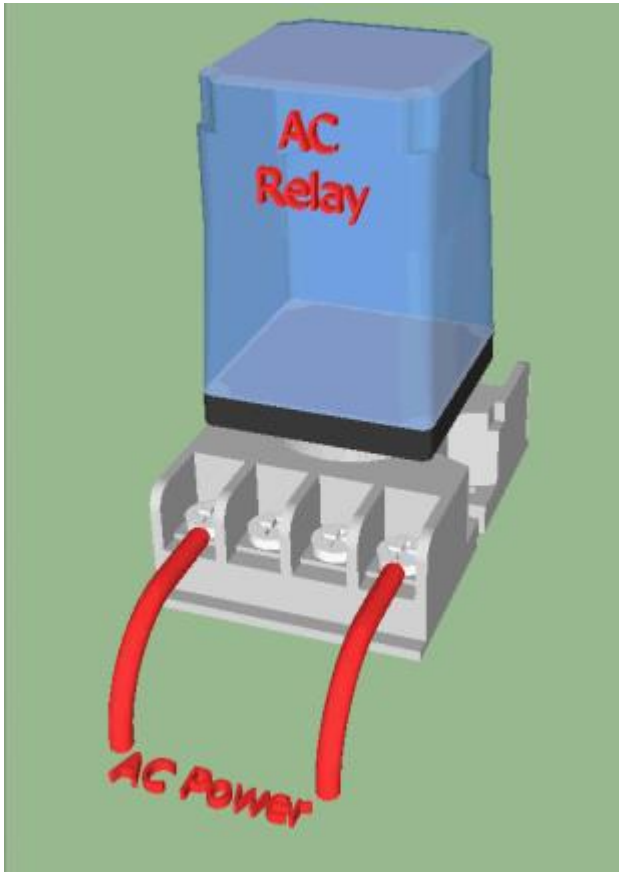
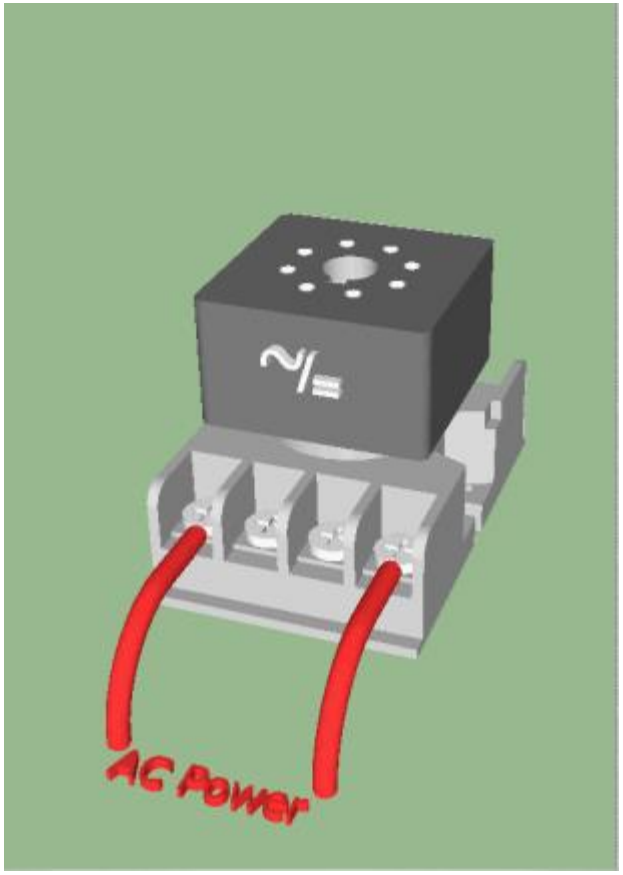
New Solution for an Old Problem: "Nice Cube" Concept

Original "AC Ice Cube"

Drop out ~70% Vnom

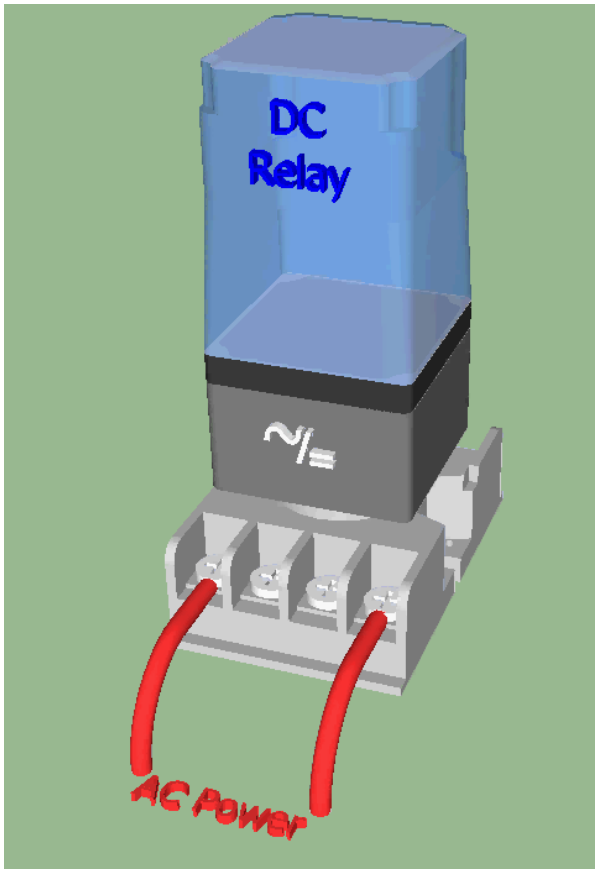


Remove "AC Ice Cube" Insert "Nice Cube" Puck Into Base

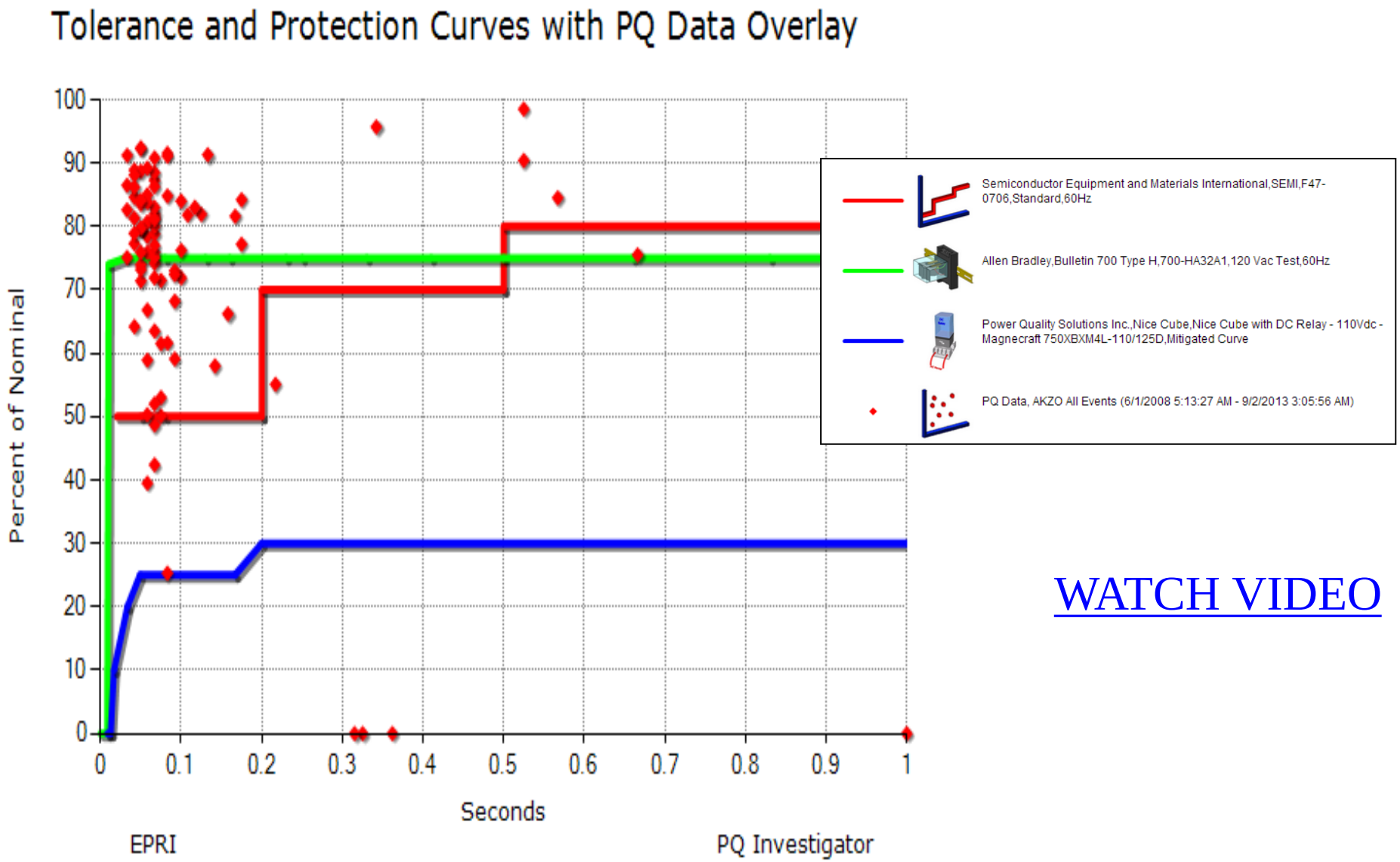


Insert "DC Ice Cube"

Drop Out ~ 25-30% Vnom



Nice Cube Relay



WATCH VIDEO

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Nice Cube Relay

General Specifications	(UL 508)			750XBX
Contact Characteristics			Units	Standard
Number and type of Contacts				DPDT
Contact materials				Silver Alloy
Thermal (Carrying) Current			A	16
Maximum Switching Voltage			V	300
Switching Current @ Voltage		~	Resistive	16A @ 277V 50/60Hz
		~	Resistive	16A @ 120V 50/60Hz
		⎓	Resistive	16A @ 28V
			HP	1/3 @ 120VAC
			HP	1/2 @ 240 VAC
			Pilot Duty	B300
Current rating with magnetic blowout - Code 69		⎓	A	3 @ 150VDC
Minimum Switching Requirement			mA	100 @ 5VDC (.5W)
Coil Characteristics				
Voltage Range		~	V	6....240
		⎓	V	6....125
Operating Range	% of Nominal	~		85% to 110%
		⎓		80% to 110%
Average consumption		~	VA	3
		⎓	W	1.4
Drop-out voltage threshold		~		15%
		⎓		10%
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	~	Vrms	1500
	Between poles	~	Vrms	1500
	Between contacts	~	Vrms	1500

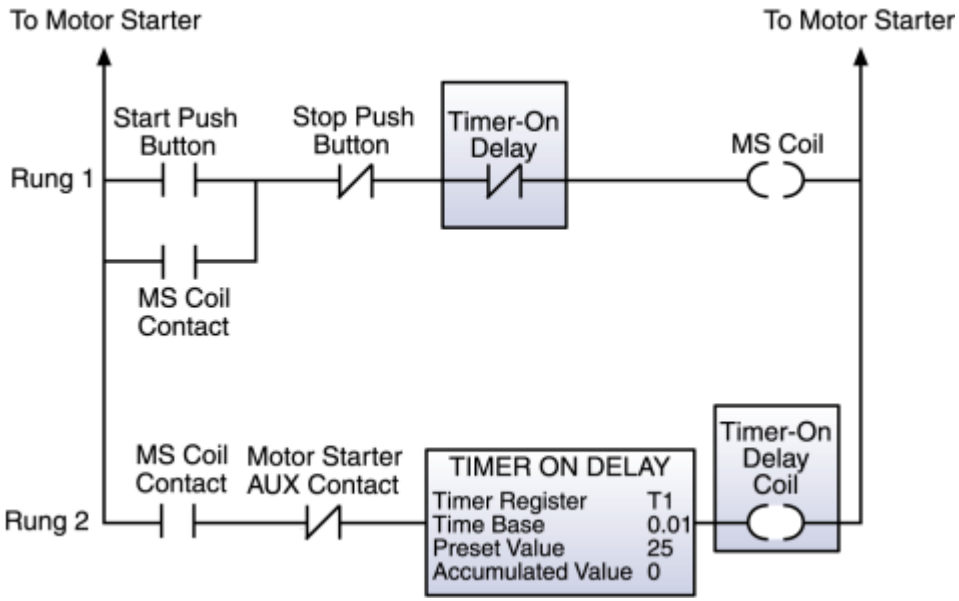
PQSI VNC 120Vac and 24Vac Models

PQSI NiceCube Models	Comments
NiceCube VNC 120Vac Input	UL/CSA Compliant File ##255764
NiceCube VNC 24Vac Input	UL/CSA Compliant File ##255764

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

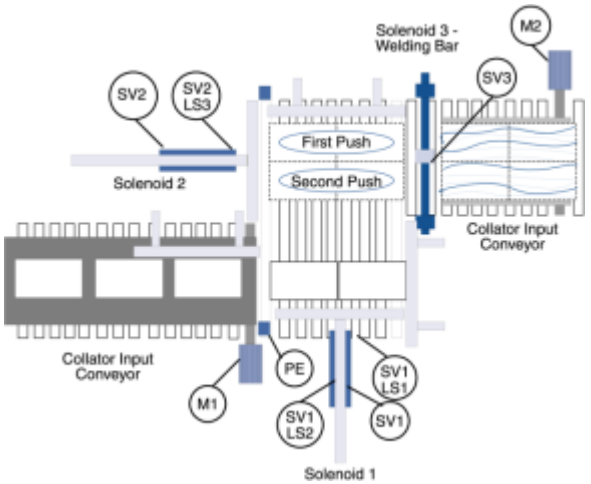
Method 3: Apply Custom Programming Techniques – Delay Filters

- **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 unlatch 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 memor**y 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

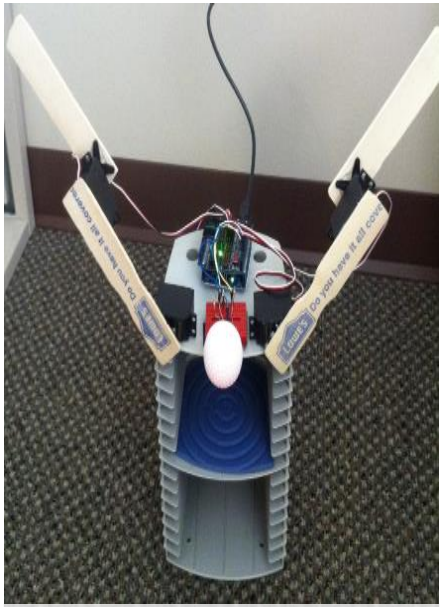
8. IF SOL3 TIMER IS DONE, TURN M2 ON FOR 5 SECONDS AND RESET ALL COUNTERS AND TIMERS (PE_COUNT AND PUSH_COUNT)

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.

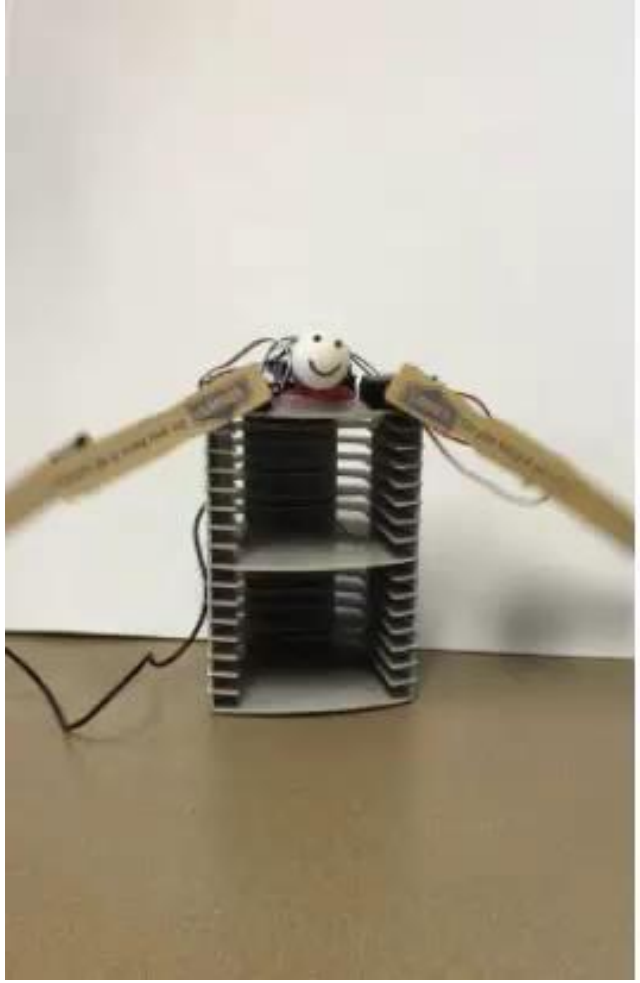
```
/*
    Address = 0 / EEPROM Address for state variables

    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);
  }
```

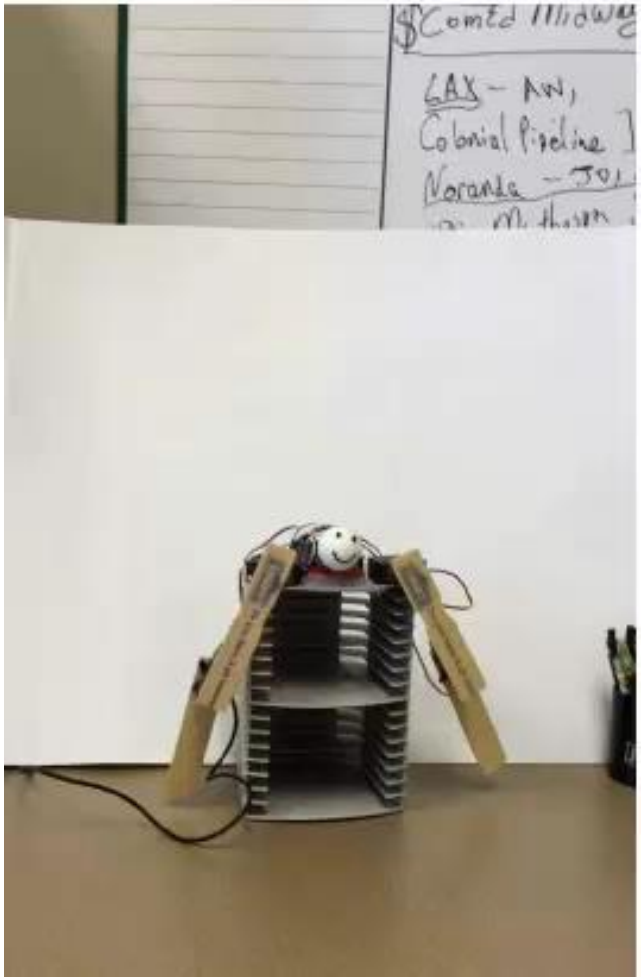


YMCA BOT Demo State Machine Programming Using Volatile vs. Non-Volatile Memory

"YMCA" States Written to Volatile Memory



"YMCA" States Written to Non-Volatile Memory



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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

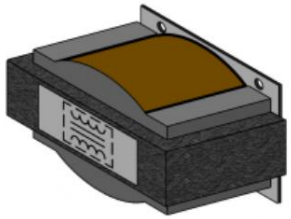
Video 1: Visualizing PQ Drive Parameters for Improved Voltage Sag Ride-Through

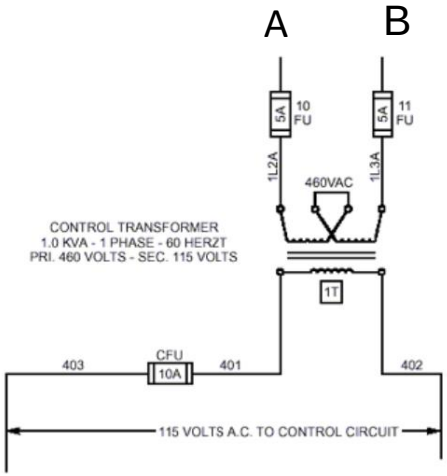
Method 5 – Select Appropriate Trip Curves for Circuit Breakers

- 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

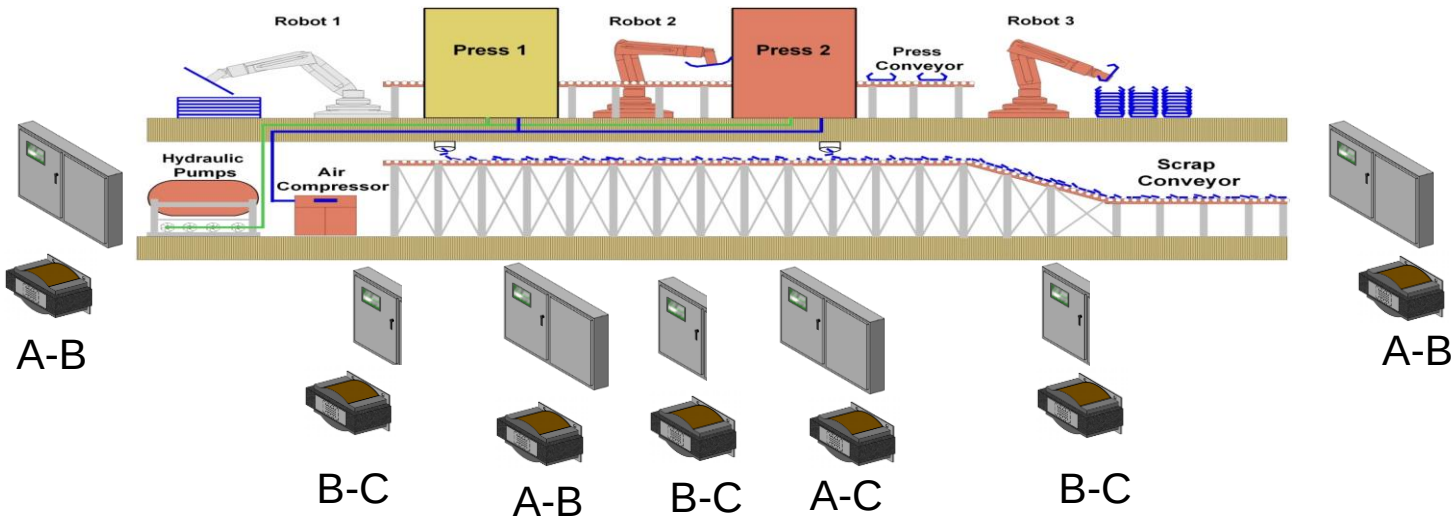
- If CPT output voltage is not at rated output:
  - Adjust CPT taps up (if available on transformer)
    - 1) Lower Input Tap (i.e. from 460/480 to 440/460)
    - 2) Raise Output Tap (i.e. from 110/115 to 115/120)
  - Lowers susceptibility of control components to voltage sags by raising the nominal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





Method 7: Coordinate Control Power Transformer Wiring Adjustments

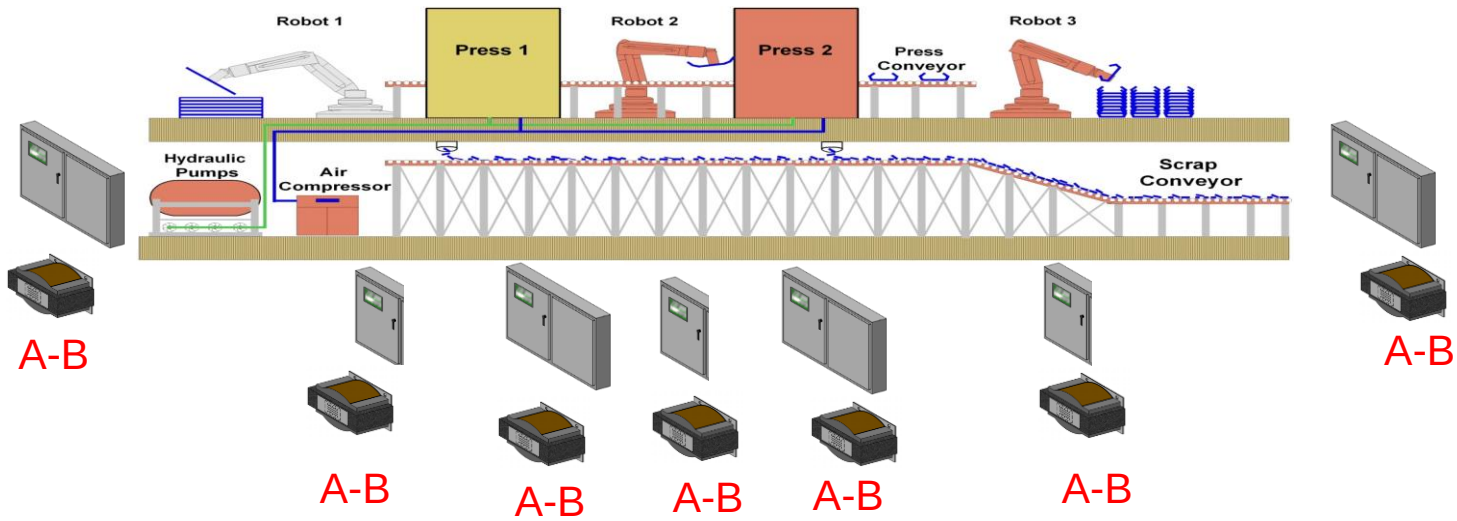
- Within a process line with multiple control cabinets, the Control Power Transformers (CPTs) may be derived from various phase-to-phase combinations and be at various output voltages.
- A voltage sag on most any phase combination will cause the line to trip somewhere.



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.

LINE 1



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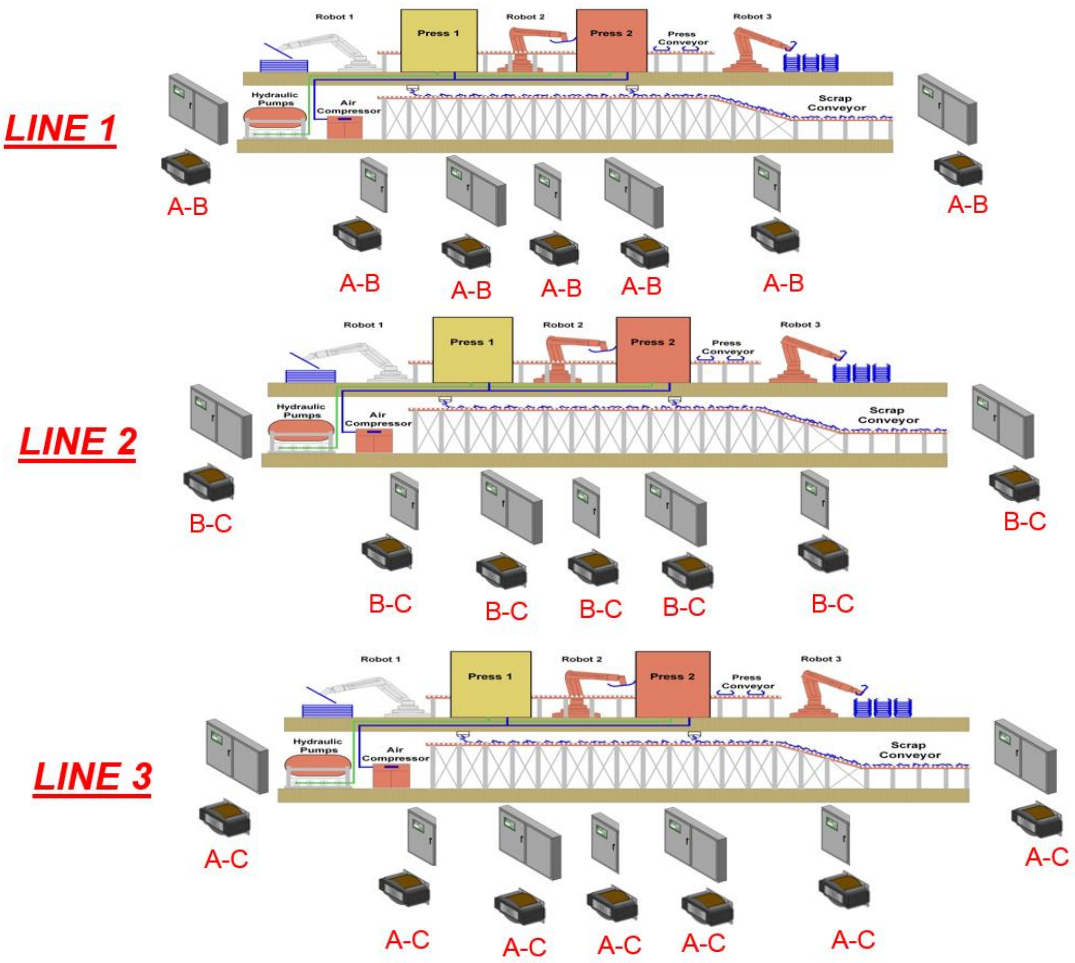
Method 7: Coordinate Control Power Transformer Wiring Adjustments (3)

- 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!



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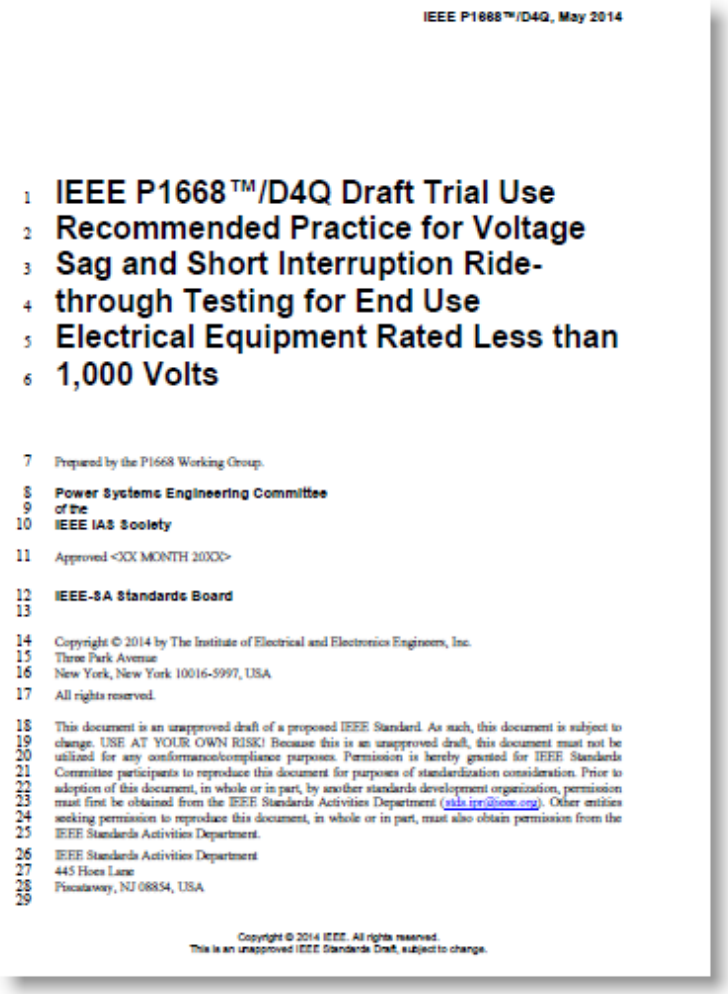
Method 8 – Specify a Voltage Sag Recommended Practice for OEMs!

- 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™/D4Q, May 2014

IEEE P1668™/D4Q Draft Trial Use Recommended Practice for Voltage Sag and Short Interruption Ride-through Testing for End Use Electrical Equipment Rated Less than 1,000 Volts

Prepared by the P1668 Working Group.

Power Systems Engineering Committee of the IEEE IAS Society

Approved <XX MONTH 20XX>

IEEE-SA Standards Board

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IEEE P1668 – User Specs Desired Machine Response

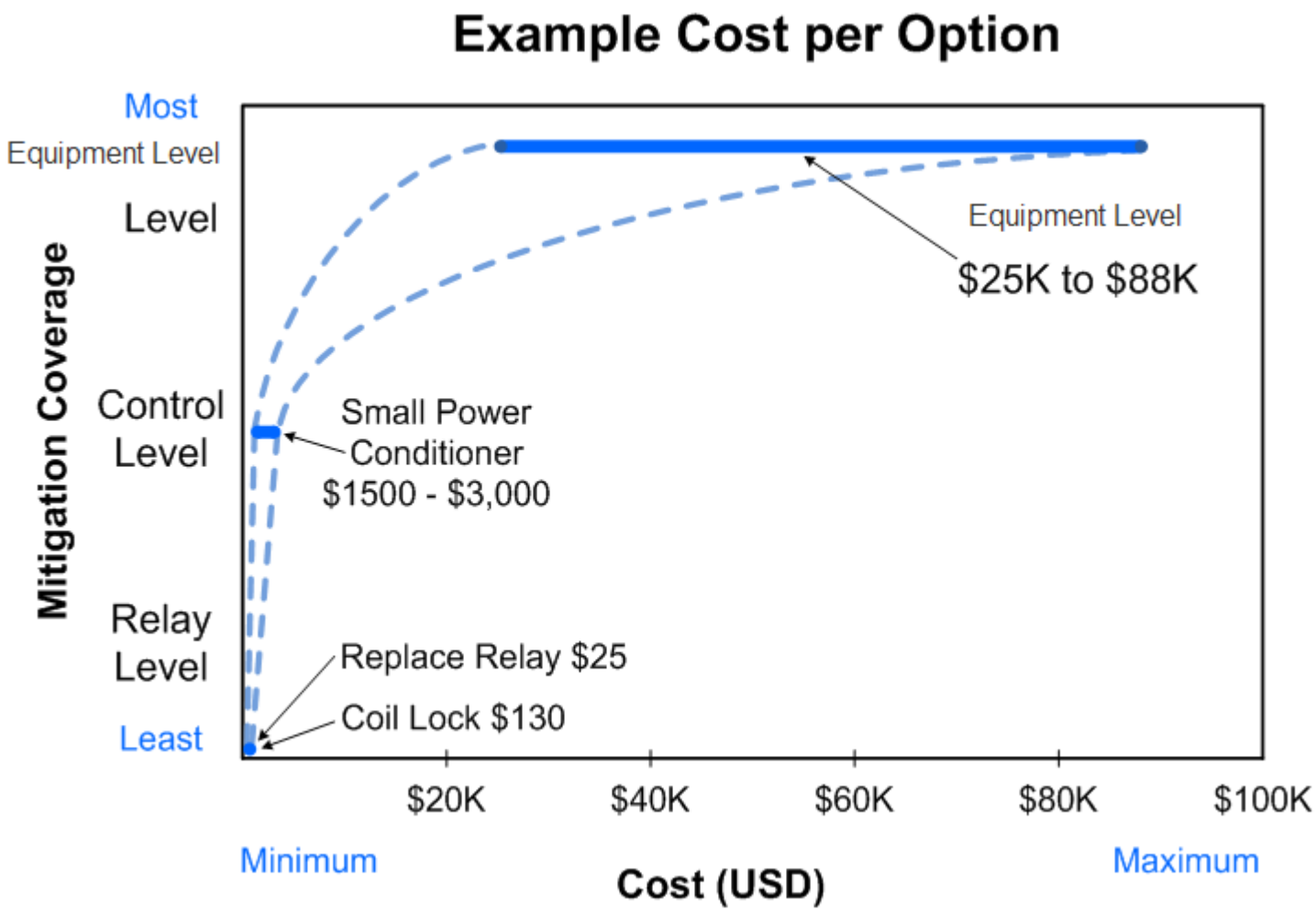
- **Full (normal) operation** – equipment performs as expected or intended and all of its relevant parameters are within technical specification or within allowed tolerance limits. Equipment performance should be expressed and measured against the set of relevant/critical “equipment outputs” (e.g. speed,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

FYI

4.0 Embedded Solutions through targeted power conditioning

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

Example Cost vs. Coverage



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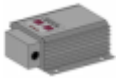
Typical PQ Mitigation Devices

Comparison of Power Conditioning Devices					
Application	**Device**	**Coverage (Vnom) / Duration**			**Notes**
		1 ϕ	ϕ - ϕ	3 ϕ	
3ϕ	ProDySC	0% / 2 sec.	30% / 2 sec.	50% / 2 sec.	at full load 
3ϕ	AVC (two rated models)	45% / 30 sec.	45% / 30 sec.	50% / 30 sec.	at full load 
		25% / 30 sec.	25% / 30 sec.	50% / 30 sec.	
1ϕ Contrl Ckt	PowerRide RTD	0% / 2+ sec.	0% A-B, B-C; 70-80% C-A / 2+ sec.	70-80% / 2+ sec.	3-phase Input, 1-phase Output 
1ϕ Contrl Ckt	MiniDySC	0% / 0.05 sec. 50% / 2 sec.	n/a	n/a	
1ϕ Contrl Ckt	CVT	40-50% / 2+ sec.	n/a	n/a	
1ϕ Contrl Ckt	VDC (6T Model)	37% / 2+ sec.	n/a	n/a	
1ϕ Contrl Ckt	Coil Hold-in (CoilLock and KnowTrip)	25% / 2+ sec.	n/a	n/a	for relays, contactors, motor starters  
1-phase	Supercapacitor UPS	0% /15 sec.			

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“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.

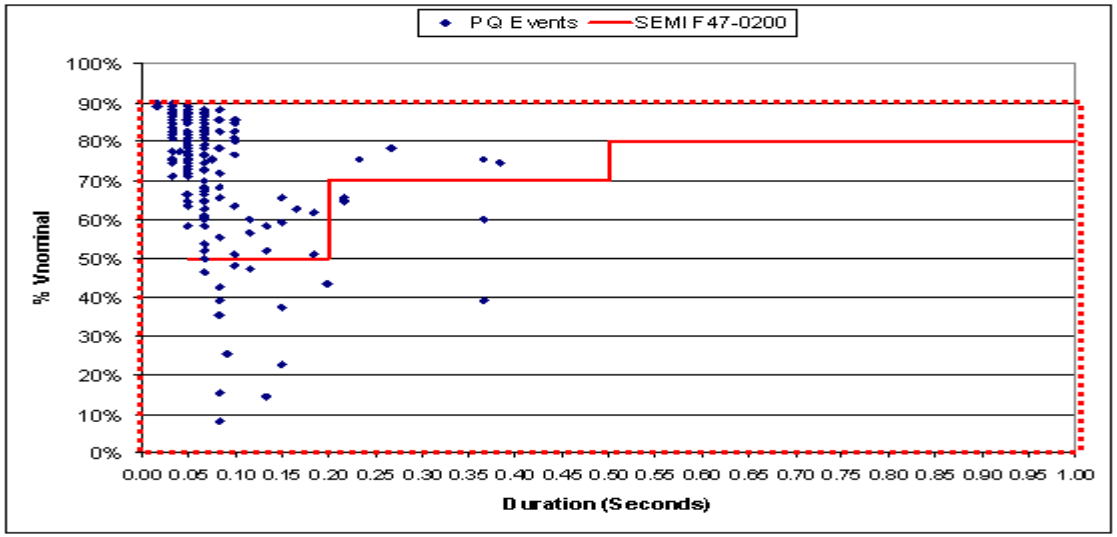
Industrial UPS Example: SDU DIN Rail DC UPS Series

- **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



15 to 45 Seconds @ Full Load

Marathon Power Supercapacitor UPS Product Matrix

Marathon Power, SuperCap UPS, Supercapacitor UPS

Applied To: Control Circuit

Mitigated Circuit: 1T (CPT) 1.50 kVA - 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:

Select	Model	Manufacturer	Part Number	Description	Cost USD
☐	Supercapacitor UPS	Marathon Power	ARTE-1000-01 + ACPR-0458-36	1000RT UPS Electronics + Cap Pack, 1kVA, 120V, 700W, 8.3A, 50/60Hz	2650
☐	Supercapacitor UPS	Marathon Power	ARTE-3000-01 + ACPR-1058-96	3000RT UPS Electronics + Cap Pack, 3kVA, 120V, 2100W, 25A, 50/60Hz	5000
☐	Supercapacitor UPS	Marathon Power	ARTE-1000-02 + ACPR-0458-36	1000RT UPS Electronics + Cap Pack , 1kVA, 220V, 700W, 4.5A, 50/60Hz	2650
☐	Supercapacitor UPS	Marathon Power	ARTE-3000-02+ ACPR-1058-96	3000RT Electronics + Cap Pack UPS, 3kVA, 220V, 2100W, 13.6A, 50/60Hz	5000

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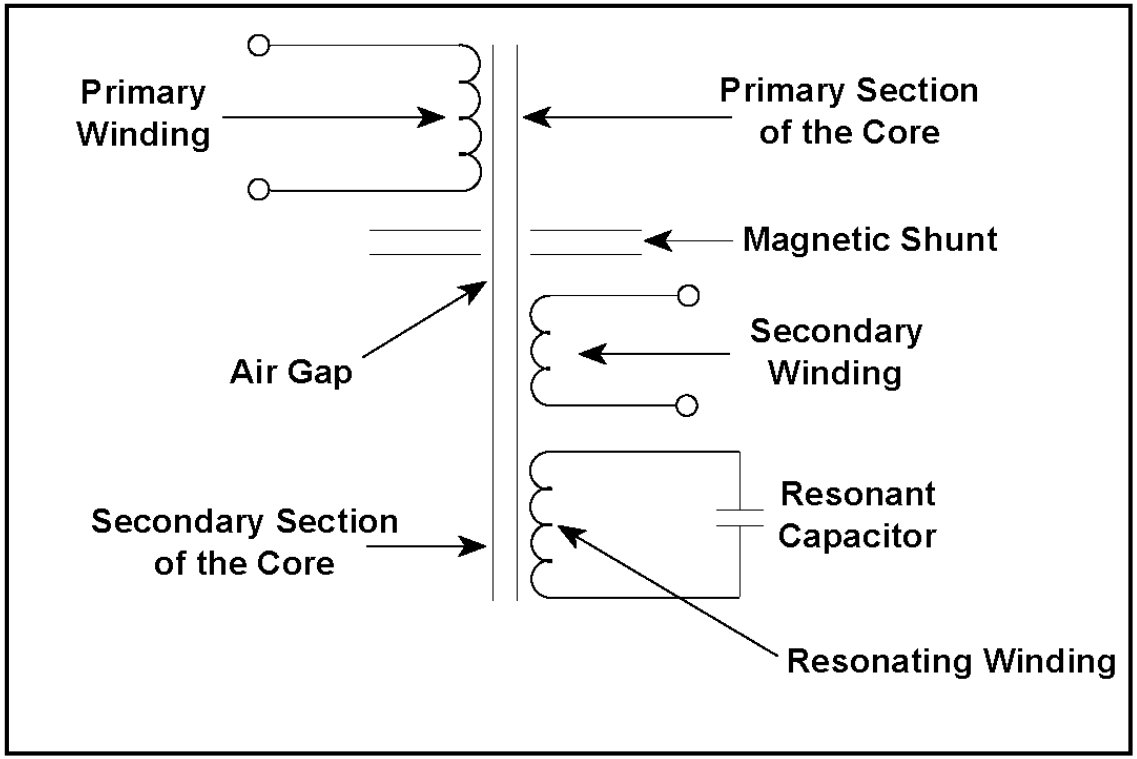
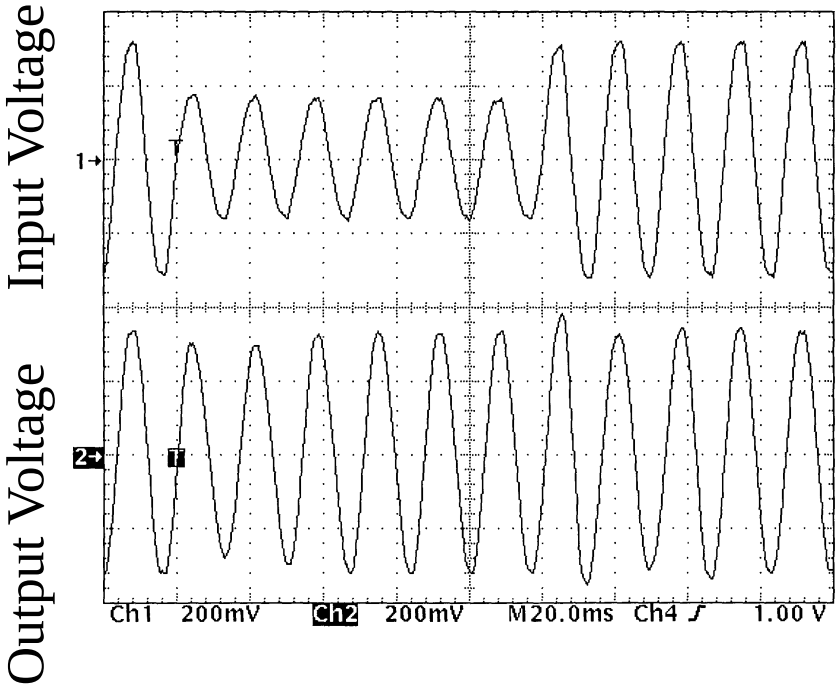
Constant Voltage Transformer (CVT)



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.



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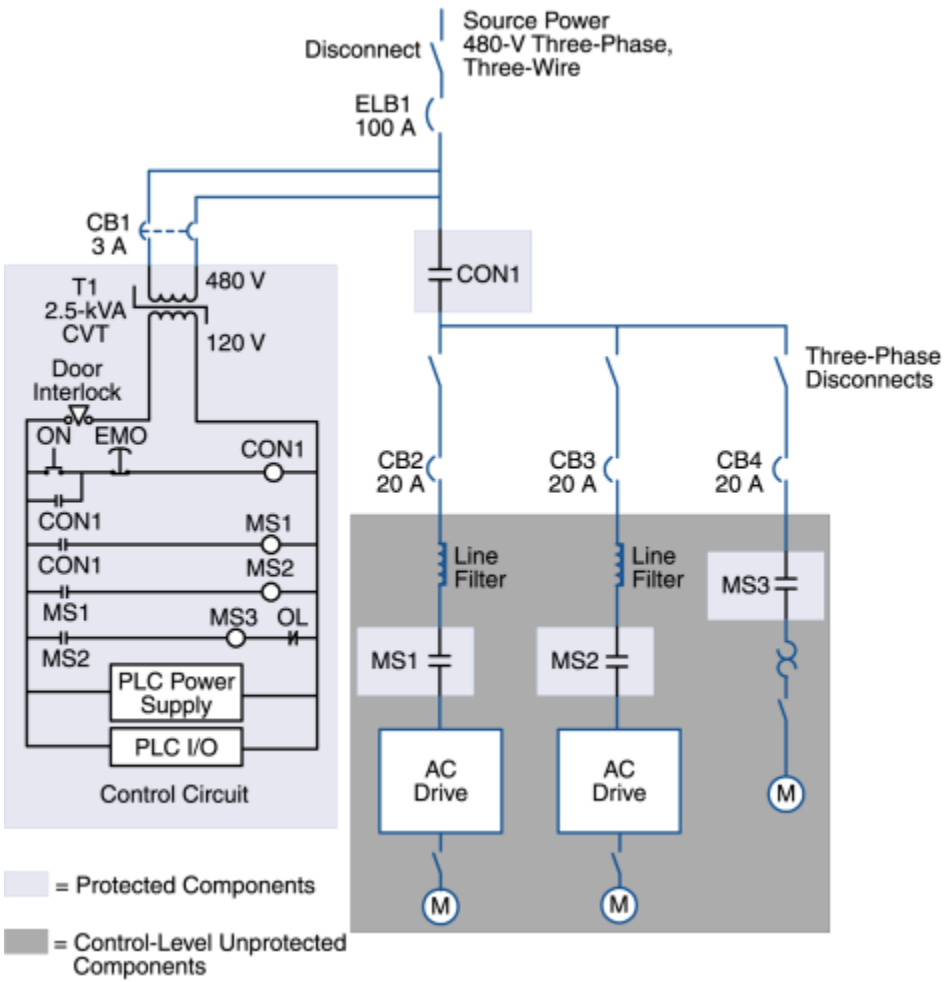
Example Control Level Solution Application

- 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 though 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

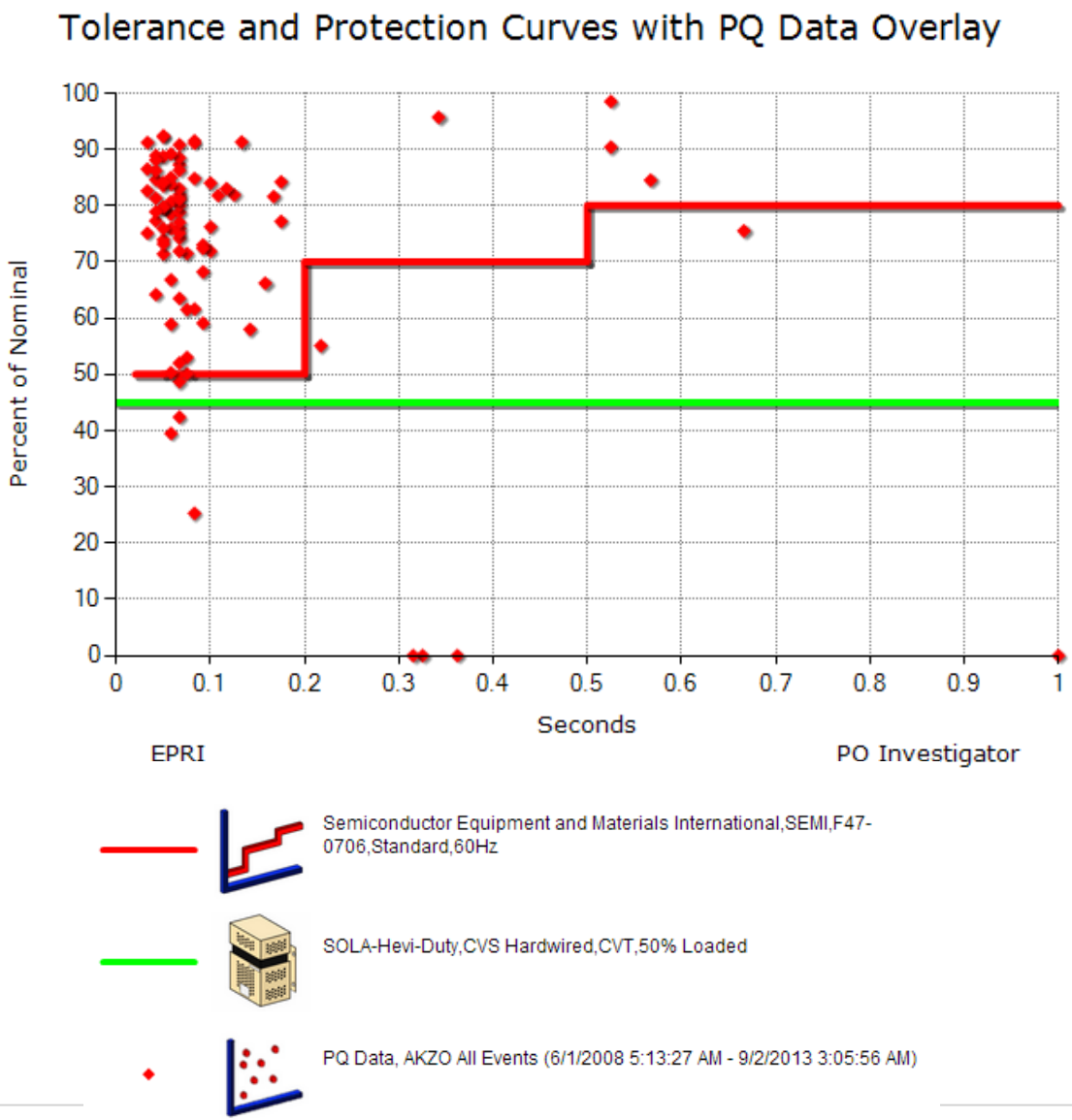
- In order to get the best voltage sag ride-through, size a CVT to 2.5 X Nominal Load VA.
  - *This does not always mean just doubling the CPT size. If you are specifying a CVT > 3KVA look at the application closely. These units get very large and require significant mounting brackets.*
- Also make sure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

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

CVT Coverage vs. Sample Historical Data



Watch Video

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

CVT Sizing Worksheet (Recommended Minimum Size: 500 VA)

CVT Circuit or Load	*Measured Steady-State RMS Current*	*Measured Peak Inrush Current*

Sum of Steady-State RMS Currents <3.3

Circuit Voltage x 120

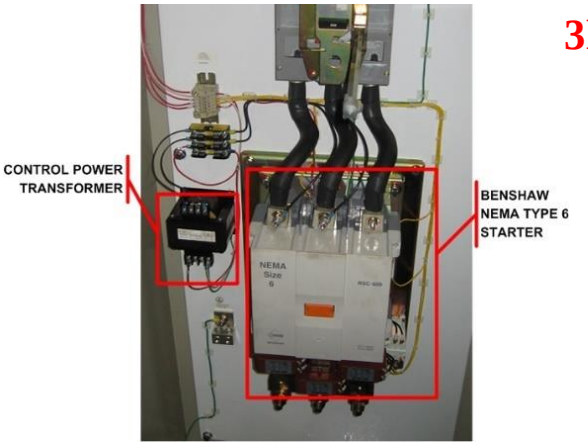
Steady-State Load VA = <400 x 2.5 = <1000

Highest Peak Inrush Current 40.5

Circuit Voltage x 120

Inrush Load VA = 4860 x 0.5 = 2,430

Use the larger of these two values.



3kVA Closest Size

$3,300 List

NEMA Size	Operating Volt Amperes Burden [VA]	
	60 Hz Coils	
	Inrush	Sealed
00	70	8
0	192	29
1 & 1P	192	29
2 (2...3 poles)	240	29
2 (4...5 poles)	315	38
3 (2...3 poles)	660	45
3 (4...5 poles)	840	58
4 (2...3 poles)	1225	69
4 (4...5 poles)	1490	96
5 (Series L)	1490	96
6*	4860	254

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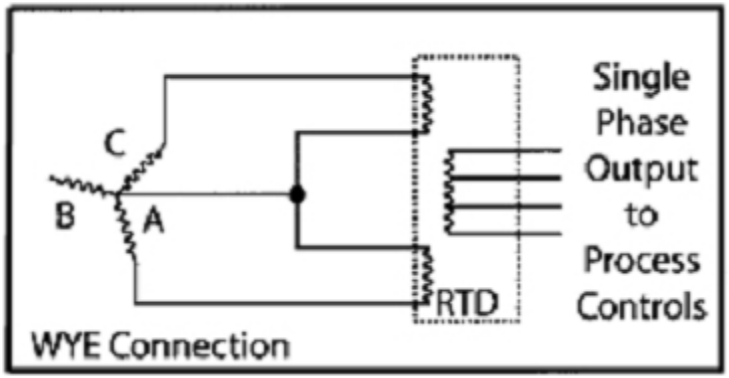
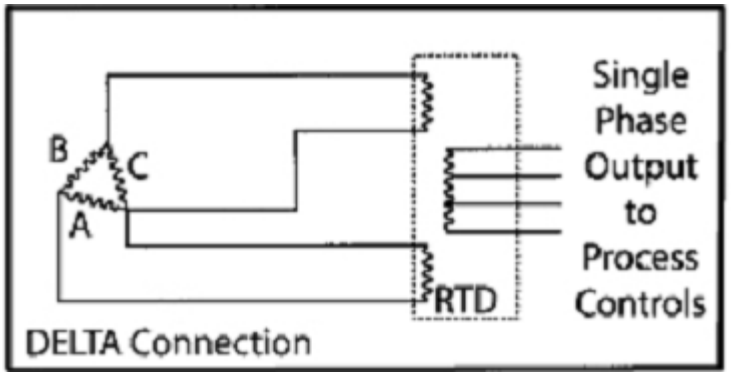
UPPI PowerRide RTD: CVT on STEROIDS

No need to oversize by factor of 2.5

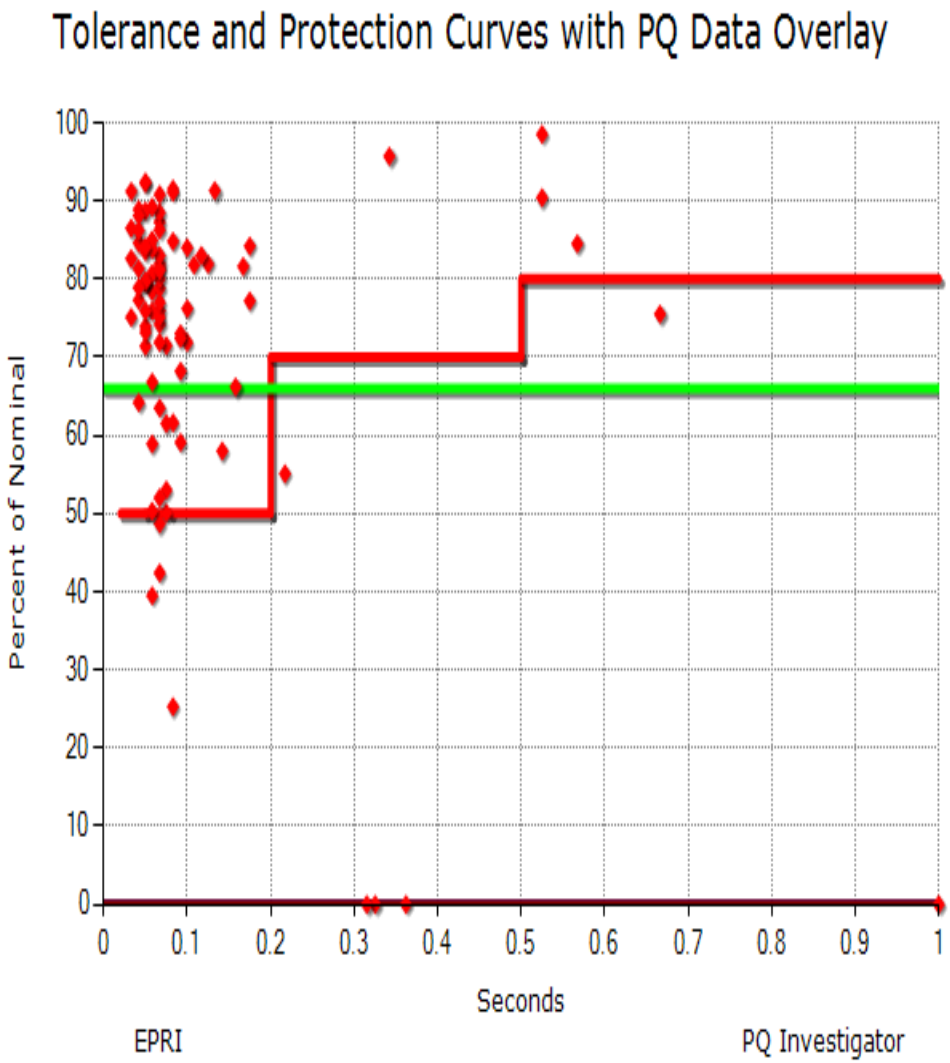
Apply same Inrush caution as with Standard CVT.





Power Anomaly	Result
Loss of Phase A	Output remains constant
Loss of Phase B	Output remains constant
Loss of Phase C	Output remains constant
Loss of Phase A and B - 33% sag on remaining phase	Output remains constant
Loss of Phase B and C - 33% sag on remaining phase	Output remains constant
Loss of Phase A and C	Output goes to 0
Loss of A and 33% Sag on C	Output remains constant
Loss of C and 33% Sag on A	Output remains constant
37% Sag on A and C	Output remains constant

Power Ride RTD Coverage vs. Sample Historical Data



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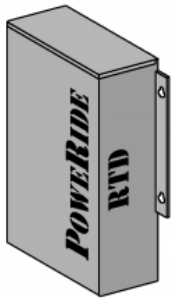
UPPI PoweRide RTD: Example Suggested List Price

Contact UPPI for accurate Pricing



No need to oversize by factor of 2.5

Apply same Inrush caution as with Standard CVT.

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

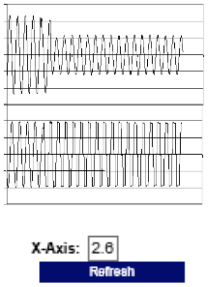
Dip Proofing Inverter

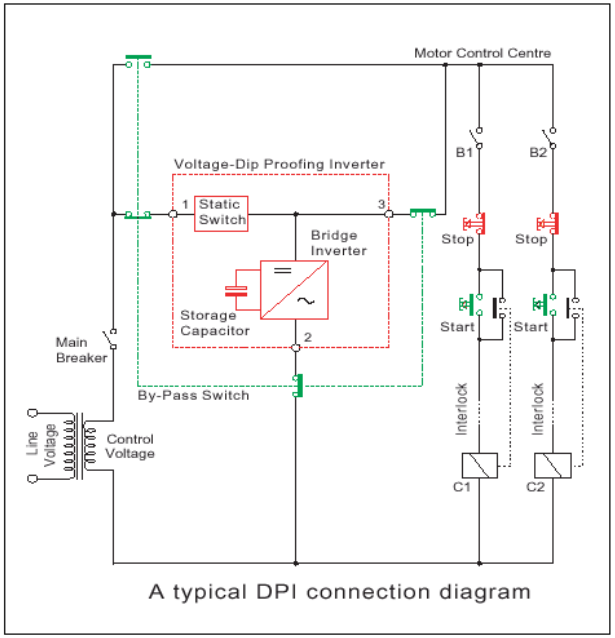
- Electrolytic Capacitor Based UPS
- Square-Wave Output
- Sizing:
  1. Determine Control Voltage Requirement
  2. Determine Overall KVA/Current Requirements of Load
  3. Measure Real Power Load Requirements (Watts)
  4. Select Matching from of Product Matrix and note “Joules” of energy available
  5. Calculate to determine ride-through time in seconds…

     Ride-Through Time = Joules Available/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.

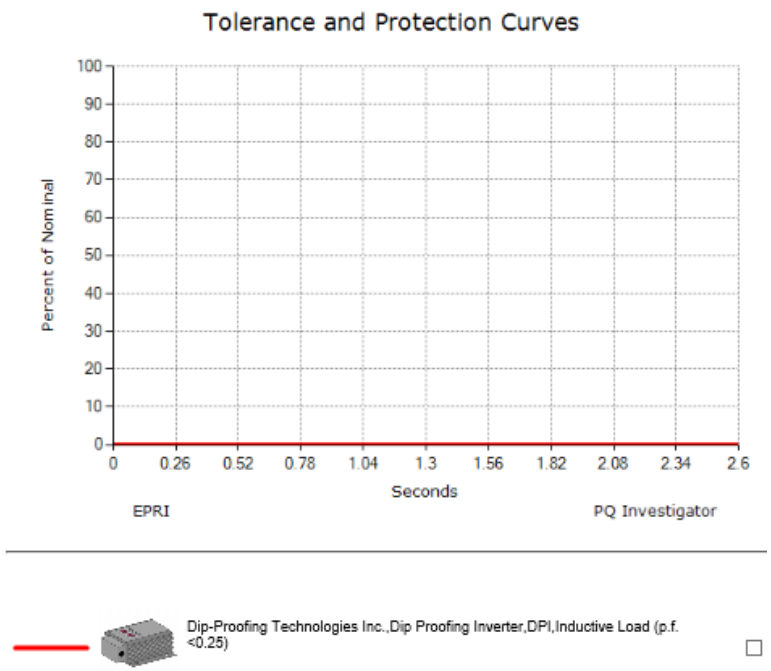
*Note: You can adjust

- Ride-Through Time Down by changing dip switch settings.
- Transfer Level from 50 to 80%, 90% special order





A typical DPI connection diagram



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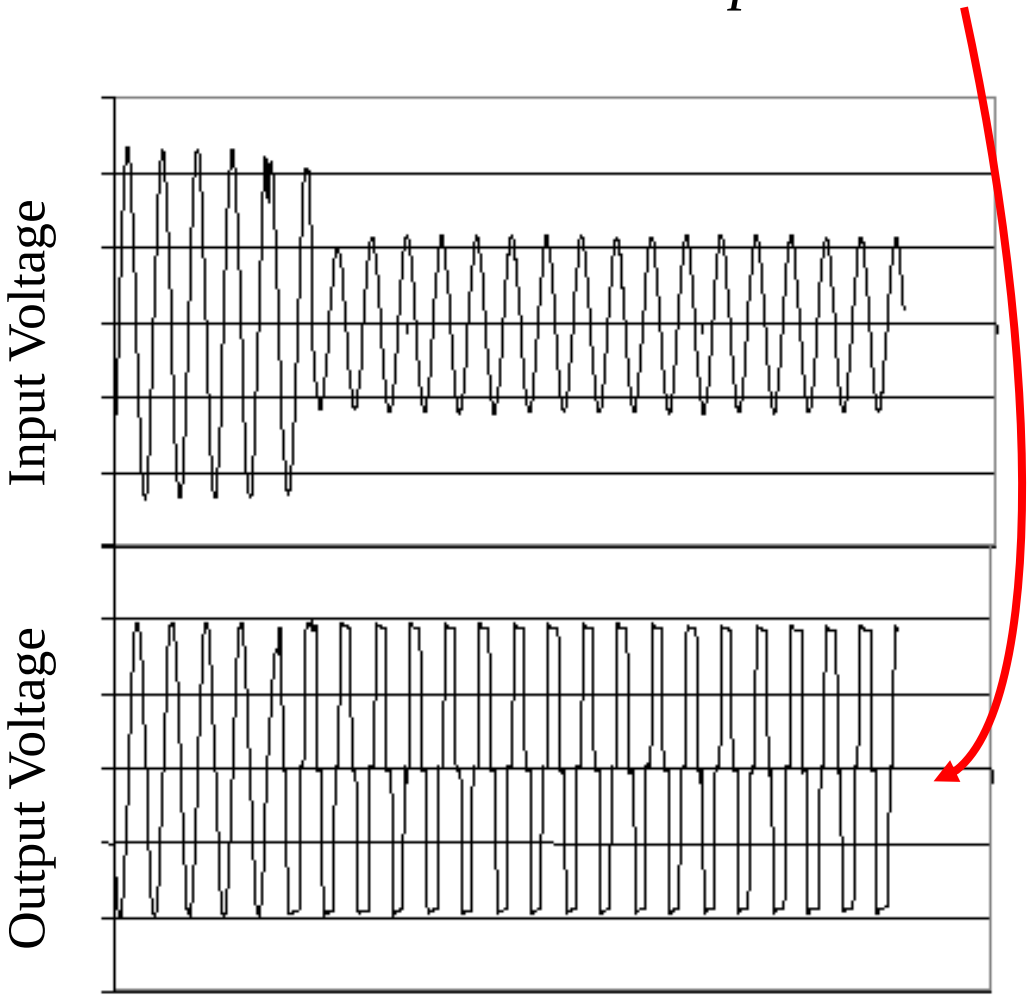
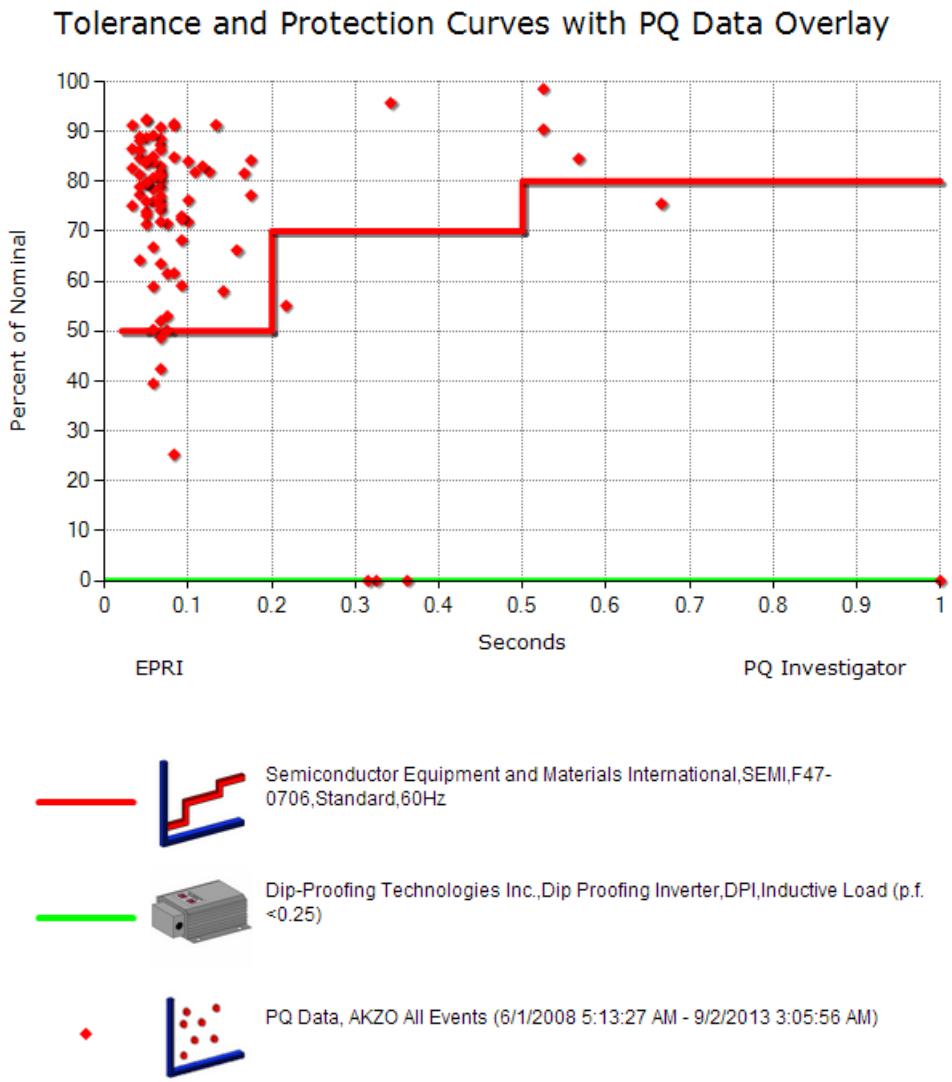
DPI Output

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



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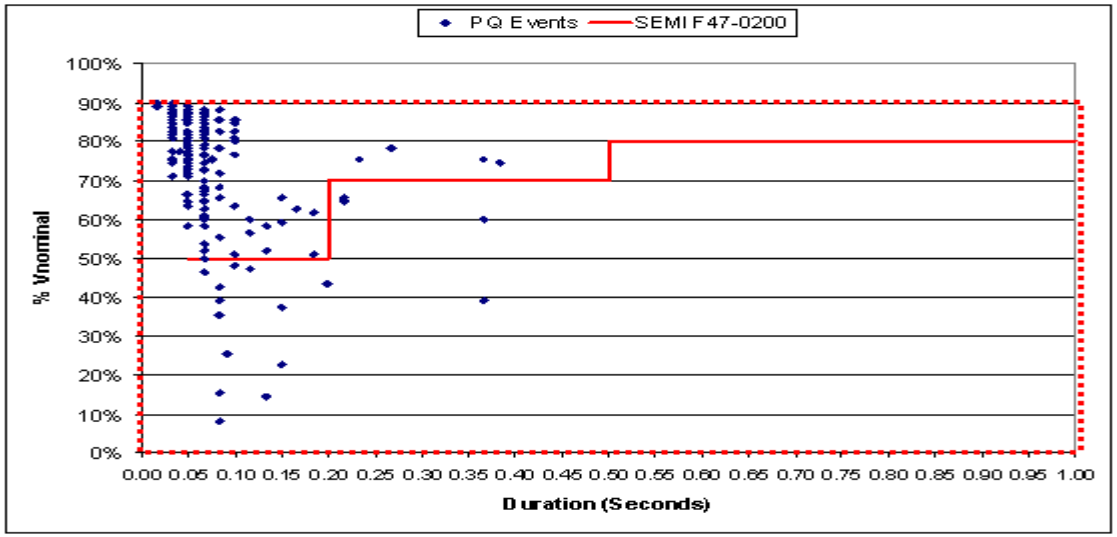
DPI Product Matrix

MitigatorModel	Manufacturer	Mfr Part Number	MitigatorDescription	Mitigator Cost ()
DPI	Dip Proofing Technologies	DPI53S6.6mF120V2A	DPI, 0.25kVA, 120V, 2A, 31J, 50/60Hz	1500
DPI	Dip Proofing Technologies	DPI53S13.2mF120V4A	DPI, 0.5kVA, 120V, 4A, 68J, 50/60Hz	1900
DPI	Dip Proofing Technologies	DPI53S19.8mF120V6A	DPI, 0.75kVA, 120V, 6A, 103J, 50/60Hz	2400
DPI	Dip Proofing Technologies	DPI53S39.6mF120V8A	DPI, 1kVA, 120V, 8A, 217J, 50/60Hz	2800
DPI	Dip Proofing Technologies	DPI54L33mF120V25A	DPI, 3kVA, 120V, 25A, 181J, 50/60Hz	3200
DPI	Dip Proofing Technologies	DPI54L66mF120V25A	DPI, 3kVA, 120V, 25A, 371J, 50/60Hz	3800
DPI	Dip Proofing Technologies	DPI54L99mF120V25A	DPI, 3kVA, 120V, 25A, 556J, 50/60Hz	4200
DPI	Dip Proofing Technologies	DPI53S2.04mF230V2A	DPI, 0.46kVA, 208 or 230V, 2A, 910J@230V, 50/60Hz	1500
DPI	Dip Proofing Technologies	DPI53S4.08mF230V4A	DPI, 0.92kVA, 208 or 230V, 4A, 1820J@230V, 50/60Hz	1900
DPI	Dip Proofing Technologies	DPI53S6.120mF230V6A	DPI, 1.38kVA, 208 or 230V, 6A, 273J@230V, 50/60Hz	2400
DPI	Dip Proofing Technologies	DPI53S12.24mF230V8A	DPI, 1.84kVA, 208 or 230V, 8A, 584J@230V, 50/60Hz	2800
DPI	Dip Proofing Technologies	DPI54L15mF230V25A	DPI, 5.75kVA, 208 or 230V, 25A, 373J@230V, 50/60Hz	3200
DPI	Dip Proofing Technologies	DPI54L30mF230V25A	DPI, 5.75kVA, 208 or 230V, 25A, 746J@230V, 50/60Hz	3800
DPI	Dip Proofing Technologies	DPI54L45mF230V25A	DPI, 5.75kVA, 208 or 230V, 25A, 1.2kJ@230V, 50/60Hz	4200
DPI	Dip Proofing Technologies	DPI54L90mF230V25A	DPI, 5.75kVA, 208 or 230V, 25A, 2.2kJ@230V, 50/60Hz	5900

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

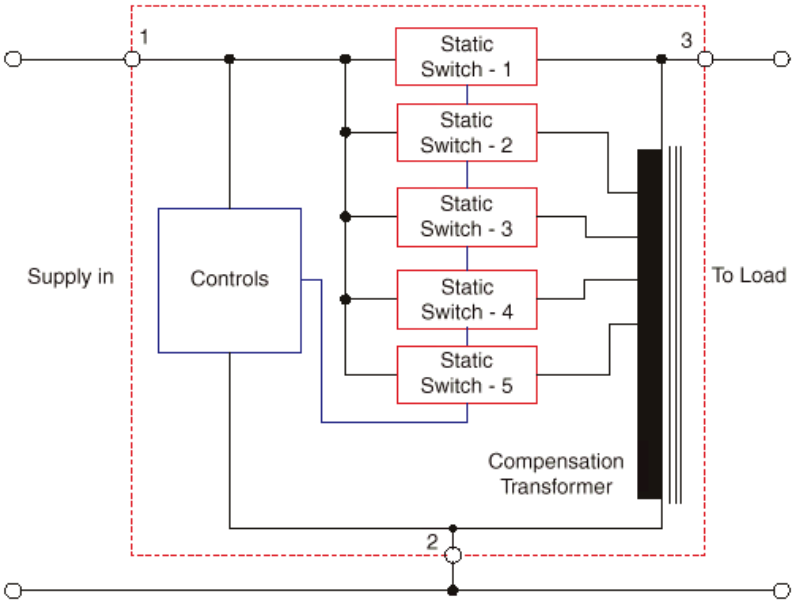


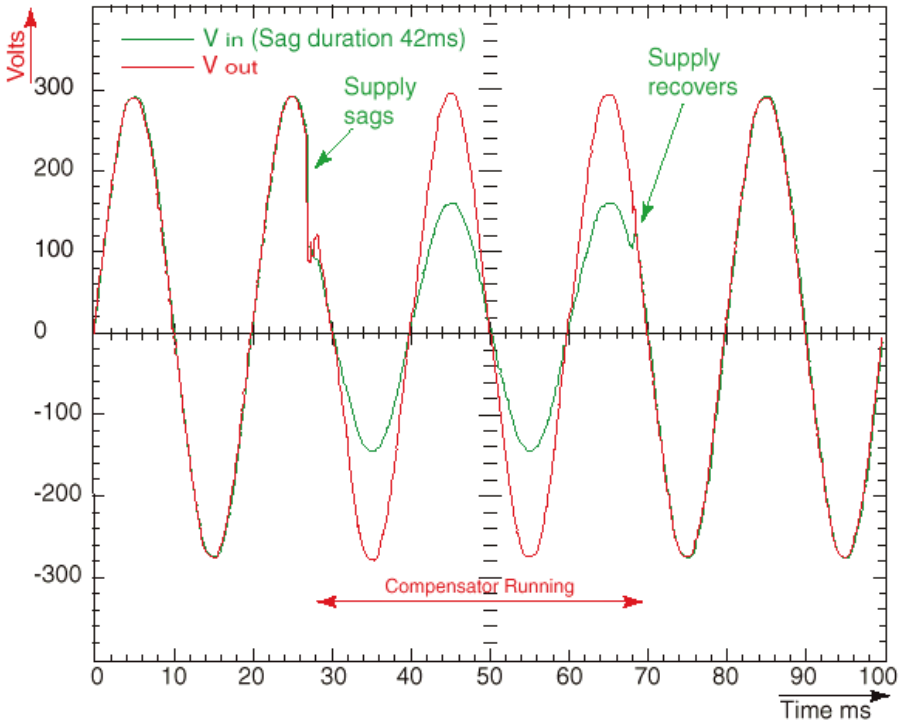
Fig 1
Compensator Block Diagram

VDC Output

AC Output is a Sine Wave instead of a Square Wave

Product by Dip Proofing Technologies

www.dipproof.com
www.measurlogic.com



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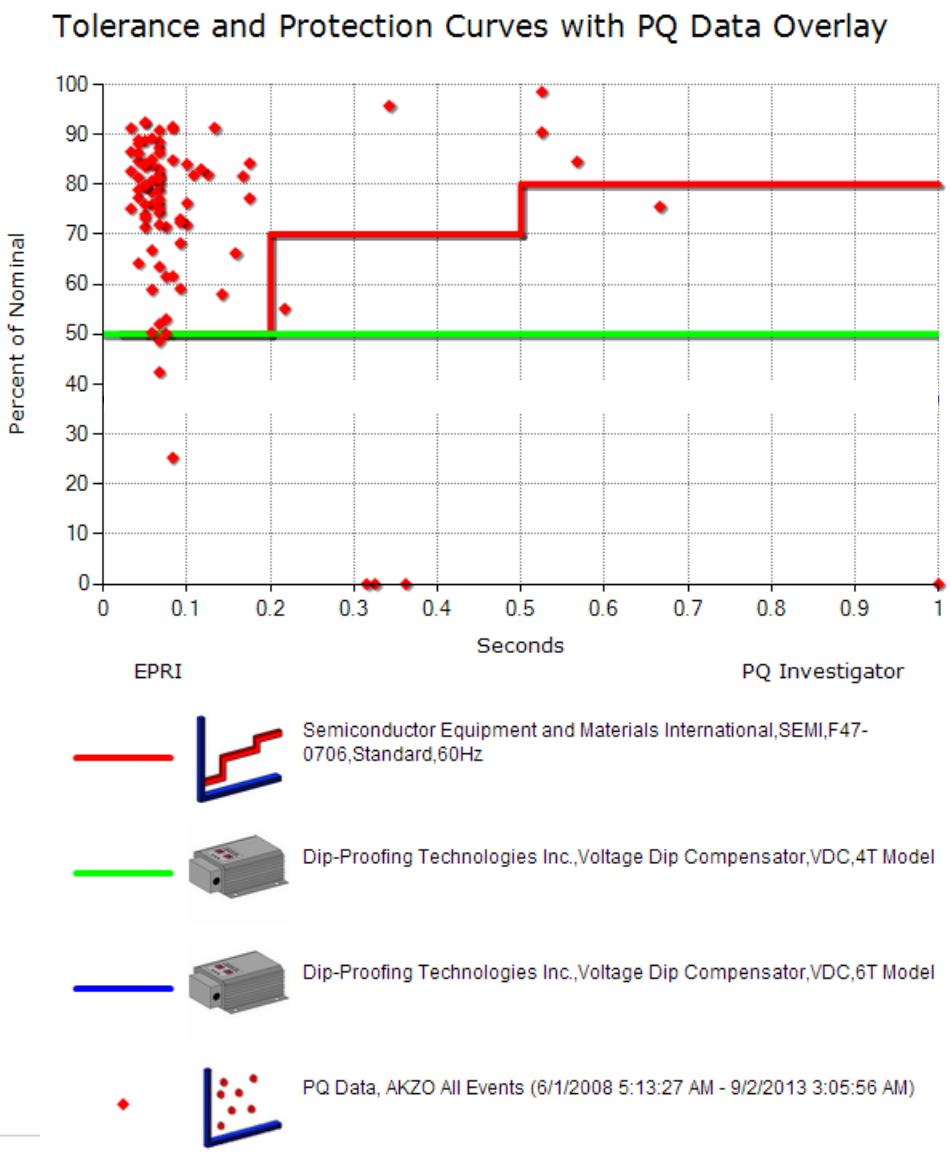
VDC Coverage (4T Model) vs. Sample Historical Data



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VDC Sizing

Technical Specifications

MODEL	VDC S4T1K120	VDC S6T1K120	VDC L4T3K120	VDC L6T3K120	VDC S4T1K208	VDC S6T1K208	VDC L4T5K208	VDC L6T5K208
	120V				208V*			
AC INPUT SUPPLY								
Single phase supply voltage:	120V				208V			
Maximum input voltage:	+10%							
Minimum input voltage:	-50%	-64%	-50%	-64%	-50%	-64%	-50%	-64%
Full load current:	8.5A		24A		4.8A		24A	
Maximum surge current for 3 cycles duration:	550A							
AC OUTPUT								
Nominal output voltage:	120V				208V			
Voltage fluctuations over full operating range:	± 10%							
Nominal load current:	8.5A		24A		4.8A		24A	
Power factor range:	cos Φ from 1 to 0							
Wave shape:	Sinusoidal							
Nominal load (VA):	1000		3000		1000		5000	
Maximum up-time (sec):								
Timer Control:	0.05 to 3.15s in 0.05s steps							
I^2T Control:	Provides extended ride-through time (see user manual for details)							
Overload current Limit (A RMS):	12A		35A		12A		28A	
Short curcuit current Limit (A RMS):	30A		75A		35A		75A	

General Sizing Rule up to existing CPT size.

120Vac Sizes – 1kVA, 3kVA

208Vac Sizes – 1kVA, 5kVA

VDC Product Matrix in PQI

Mfr Part Number	MitigatorDescription	Mitigator Cost ()
VDC S4T1K 120	VDC, 1kVA, 120V, Output, 8.5A, 50/60Hz,	1900
VDC L4T3K 120	VDC, 3kVA, 120V, Output, 24A, 50/60Hz	3000
VDC S4T1K 208	VDC, 1kVA, 208V, Output,4.8A, 50/60 Hz	1900
VDC L4T5K 208	VDC, 5kVA, 208V, Output, 24A, 50/60Hz	3800

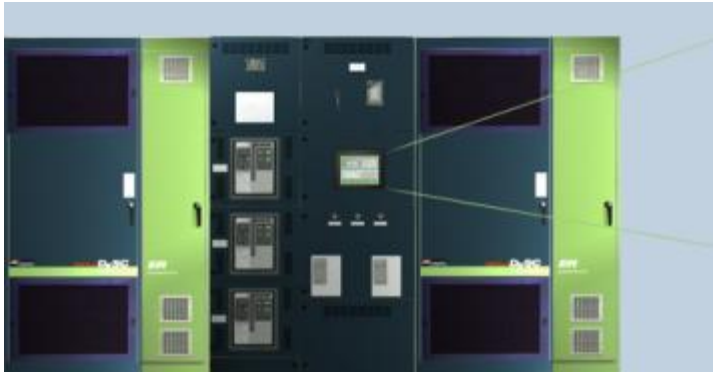
Dynamic Sag Corrector

- 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

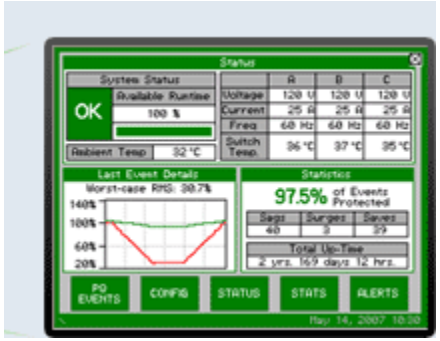
400-3200Amps



ProDySC

Three-Phase Protection

25-200Amps

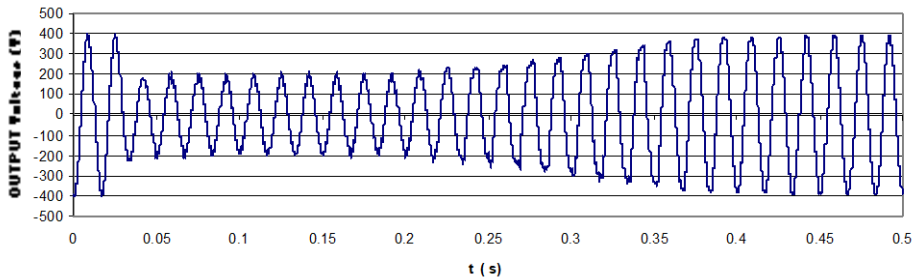


MiniDySC

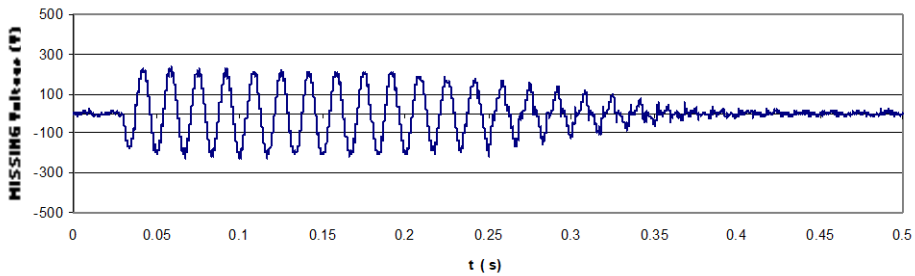
Single-Phase Protection

1-50 Amps

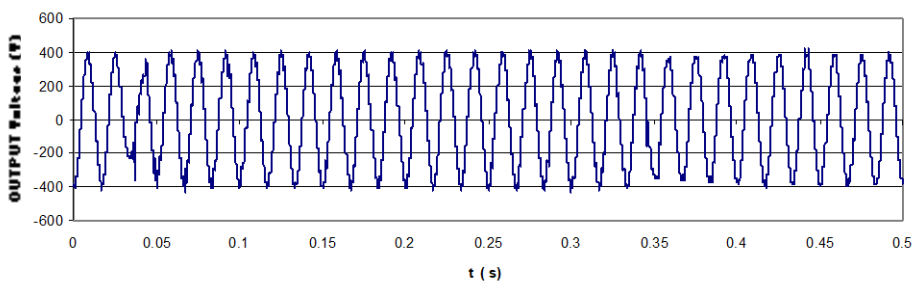
Example DySC Output



Input Voltage (Van)



Missing Volts



DySC Output Voltage

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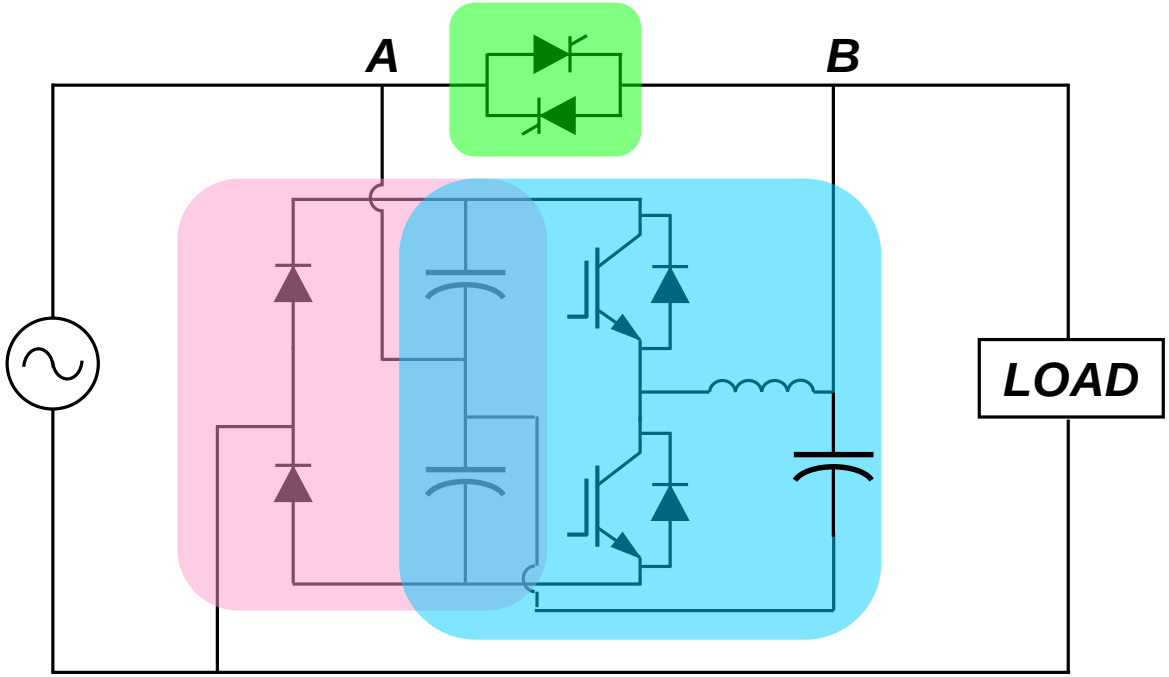
Single Phase DySC Topology



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.

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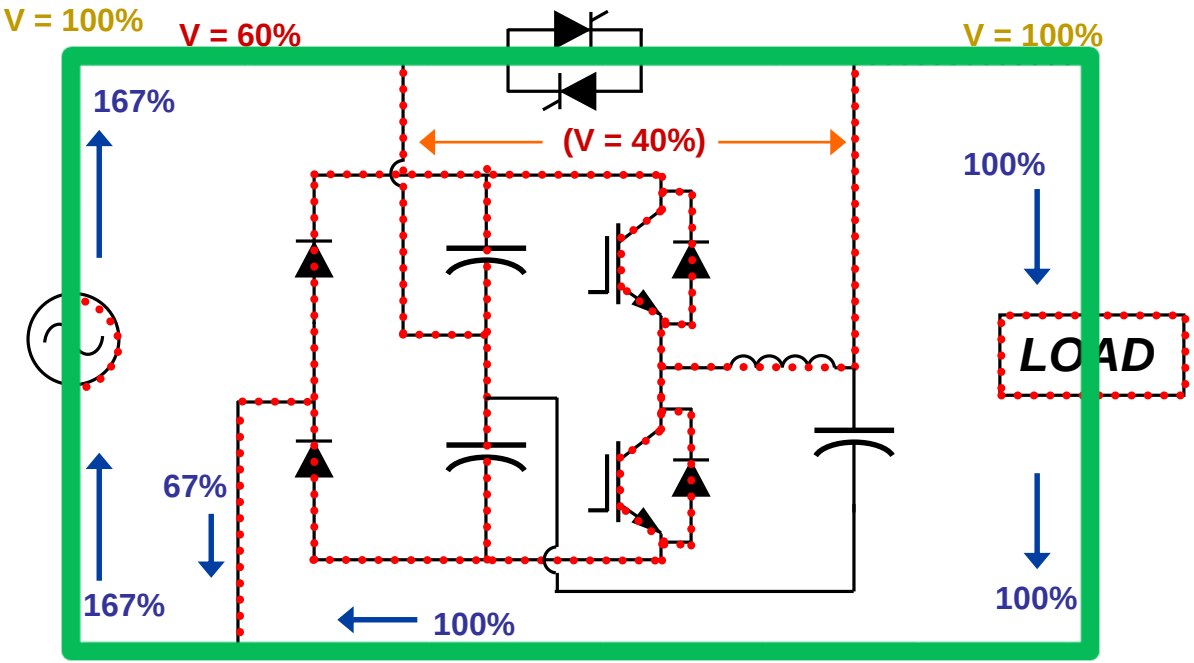
DySC Operation

- **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

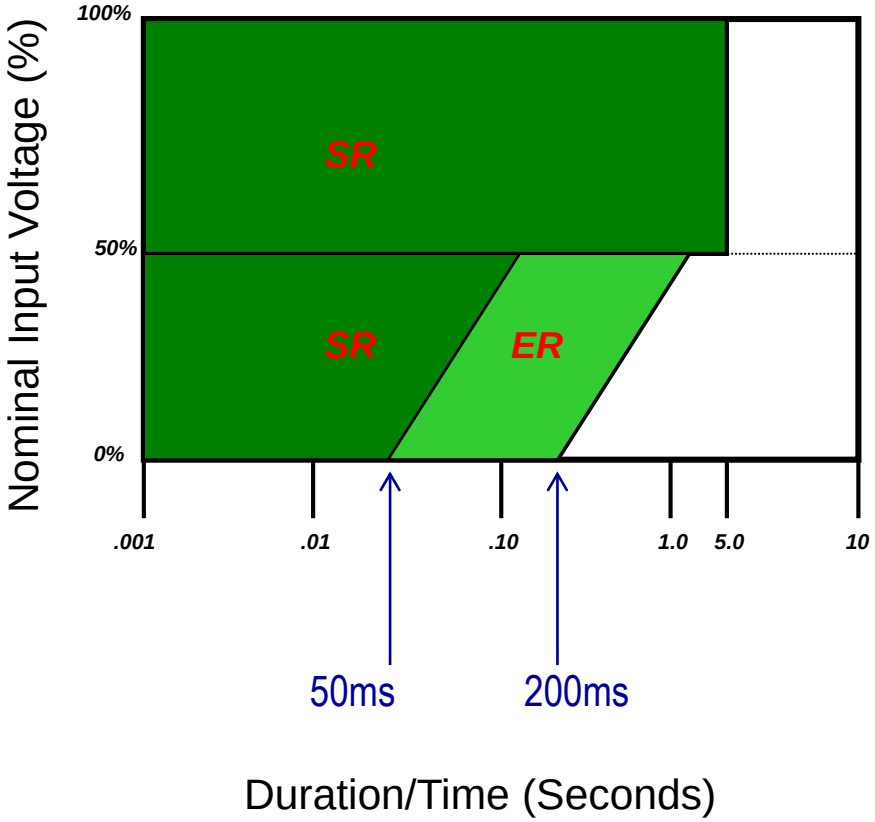
- DC voltage is sufficient to correct voltage sags if input line voltage remains ≥ 50%.
- Stored Energy in capacitors is not needed unless input drops below 50%.
- Correction for up to 5 seconds or 2 seconds cumulative every minute (design limits).



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

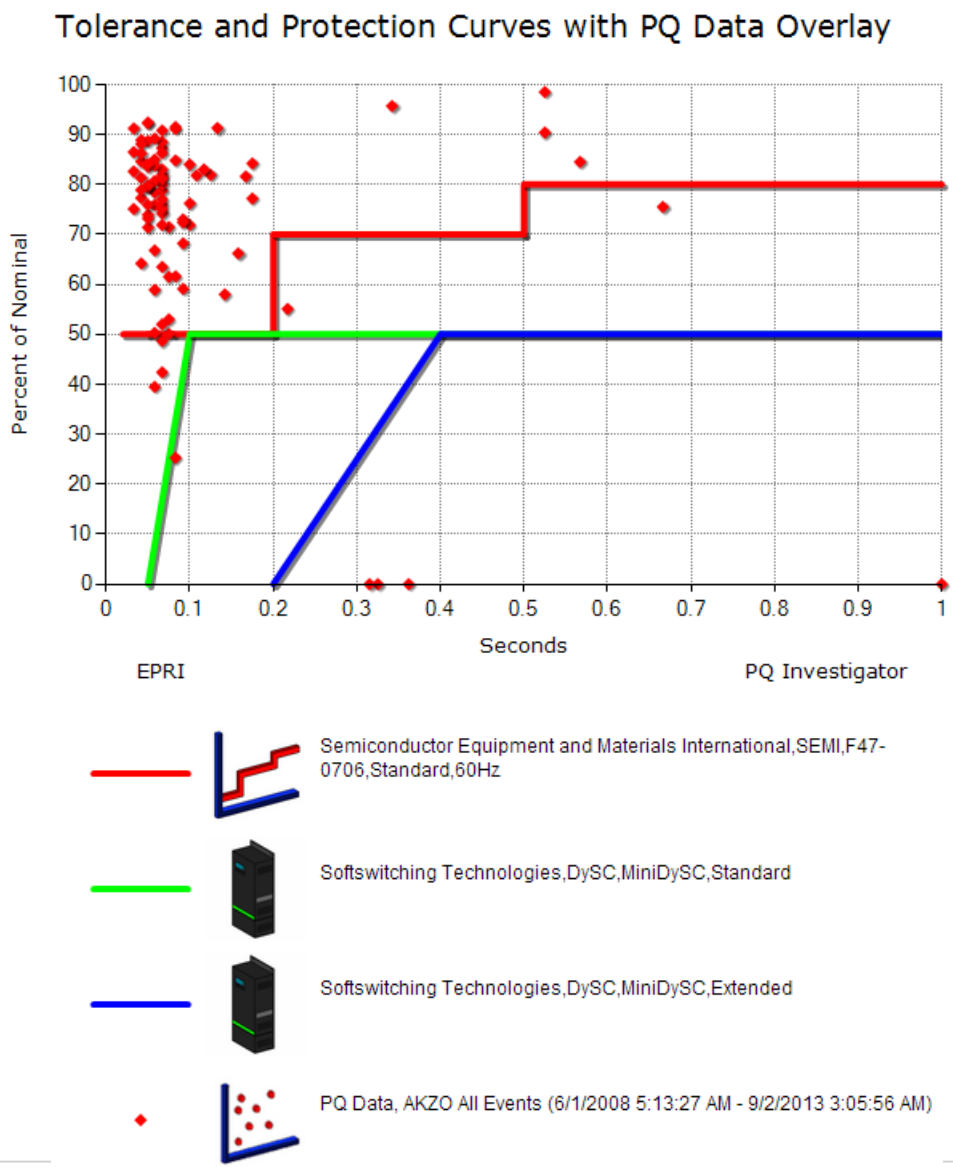
- Power in = Power out = Load power (determined by load)
  = (voltage) x (current)
- Load voltage remains 100%, load current remains 100%
- Input voltage dip to 60% causes input current 167% of load
- Load energy comes from the AC source, not capacitors

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



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Static Series Compensator with Stored Energy Supply >

Coverage out to 5 seconds

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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.

Mfr Part Number	MitigatorDescription	Mitigator Cost ()
1608N-002A120V2E	MiniDySC - 1Ph , 0.24kVA, 2 A, 120 VAC, L-N, Extended, 50/60Hz	1650
1608N-002A120V2S	MiniDySC - 1Ph , 0.24kVA 2 A, 120 VAC, L-N, Standard, 50/60Hz	1200
1608N-006A120V2E	MiniDySC - 1Ph ,0.72kVA, 6 A, 120 VAC, L-N, Extended, 50/60Hz	2300
1608N-006A120V2S	MiniDySC - 1Ph , 0.72kVA, 6 A, 120 VAC, L-N, Standard, 50/60Hz	1800
1608N-012A120V2S	MiniDySC - 1Ph , 1.44kVA, 12 A, 120 VAC, L-N, Standard, 50/60Hz	2500
1608N-012A120V2S-R	MiniDySC - 1Ph , 1.44kVA, 12 A, 120 VAC, L-N, Standard, Rack Mount, 50/60Hz	2700
1608N-025A120V2E	MiniDySC - 1Ph , 3kVA, 25 A, 120 VAC, L-N, Extended, 50/60Hz	3600
1608N-025A120V2S	MiniDySC - 1Ph , 3kVA, 25 A, 120 VAC, L-N, Standard, 50/60Hz	2700
1608N-050A120V2E	MiniDySC - 1Ph , 6kVA, 50 A, 120 VAC, L-N, Extended, 50/60Hz	6800
1608N-050A120V2S	MiniDySC - 1Ph , 6kVA, 50 A, 120 VAC, L-N, Standard, 50/60Hz	4400
1608N-002A208V1E	MiniDySC - 1Ph , 0.42kVA, 2 A, 208 VAC, L-L, Extended, 50/60Hz	2200
1608N-002A208V1S	MiniDySC - 1Ph , 0.42kVA, 2 A, 208 VAC, L-L, Standard, 50/60Hz	1600
1608N-003A208V1E	MiniDySC - 1Ph , 0.62kVA, 3 A, 208 VAC, L-L, Extended, 50/60Hz	2400
1608N-003A208V1S	MiniDySC - 1Ph , 0.62kVA, 3 A, 208 VAC, L-L, Standard, 50/60Hz	1800
1608N-012A208V1S	MiniDySC - 1Ph , 2.5kVA, 12 A, 208 VAC, L-L, Standard, 50/60Hz	3300
1608N-025A208V1E	MiniDySC - 1Ph , 5.2kVA, 25 A, 208 VAC, L-L, Extended, 50/60Hz	4800
1608N-025A208V1S	MiniDySC - 1Ph ,5.2kVA, 25 A, 208 VAC, L-L, Standard, 50/60Hz	3700
1608N-050A208V1E	MiniDySC - 1Ph ,10.4kVA, 50 A, 208 VAC, L-L, Extended, 50/60Hz	9100
1608N-050A208V1S	MiniDySC - 1Ph ,10.4kVA, 50 A, 208 VAC, L-L, Standard, 50/60Hz	5900
1608N-012A220V2S	MiniDySC - 1Ph ,2.64kVA, 12 A, 220 VAC, L-N, Standard, 50/60Hz	3300
1608N-025A220V2E	MiniDySC - 1Ph ,5.5kVA, 25 A, 220 VAC, L-N, Extended, 50/60Hz	4700
1608N-025A220V2S	MiniDySC - 1Ph ,5.5kVA, 25 A, 220 VAC, L-N, Standard, 50/60Hz	3600
1608N-050A220V2E	MiniDySC - 1Ph ,11kVA, 50 A, 220 VAC, L-N, Extended, 50/60Hz	9100
1608N-050A220V2S	MiniDySC - 1Ph ,11kVA, 50 A, 220 VAC, L-N, Standard, 50/60Hz	5900
1608N-003A230V2E	MiniDySC - 1Ph ,0.69kVA, 3 A, 230 VAC, L-N, Extended, 50/60Hz	2400
1608N-003A230V2S	MiniDySC - 1Ph ,0.69kVA, 3 A, 230 VAC, L-N, Standard, 50/60Hz	1800
1608N-012A230V2S	MiniDySC - 1Ph ,2.76kVA, 12 A, 230 VAC, L-N, Standard, 50/60Hz	3300
1608N-025A230V2E	MiniDySC - 1Ph ,5.75kVA, 25 A, 230 VAC, L-N, Extended, 50/60Hz	4800
1608N-025A230V2S	MiniDySC - 1Ph ,5.75kVA, 25 A, 230 VAC, L-N, Standard, 50/60Hz	3600
1608N-050A230V2E	MiniDySC - 1Ph ,11.5kVA, 50 A, 230 VAC, L-N, Extended, 50/60Hz	9100
1608N-050A230V2S	MiniDySC - 1Ph ,11.5kVA, 50 A, 230 VAC, L-N, Standard, 50/60Hz	5900
1608N-002A240V1E	MiniDySC - 1Ph ,0.48kVA, 2 A, 240 VAC, L-L, Extended, 50/60Hz	2200
1608N-002A240V1S	MiniDySC - 1Ph ,0.48kVA, 2 A, 240 VAC, L-L, Standard, 50/60Hz	1600
1608N-002A240V2E	MiniDySC - 1Ph , 0.48kVA, 2 A, 240 VAC, L-N, Extended, 50/60Hz	2200
1608N-002A240V2S	MiniDySC - 1Ph , 0.48kVA, 2 A, 240 VAC, L-N, Standard, 50/60Hz	1600
1608N-003A240V1E	MiniDySC - 1Ph , 0.72kVA, 3 A, 240 VAC, L-L, Extended, 50/60Hz	2400
1608N-003A240V1S	MiniDySC - 1Ph , 0.72kVA, 3 A, 240 VAC, L-L, Standard, 50/60Hz	1800
1608N-003A240V2E	MiniDySC - 1Ph , 0.72kVA, 3 A, 240 VAC, L-N, Extended, 50/60Hz	2400
1608N-003A240V2S	MiniDySC - 1Ph , 0.72kVA, 3 A, 240 VAC, L-N, Standard, 50/60Hz	1800
1608N-012A240V1S	MiniDySC - 1Ph , 2.88kVA, 12 A, 240 VAC, L-L, Standard, 50/60Hz	3300
1608N-012A240V2S	MiniDySC - 1Ph , 2.88kVA, 12 A, 240 VAC, L-N, Standard, 50/60Hz	3300
1608N-025A240V1E	MiniDySC - 1Ph , 6kVA, 25 A, 240 VAC, L-L, Extended, 50/60Hz	4800
1608N-025A240V1S	MiniDySC - 1Ph , 6kVA, 25 A, 240 VAC, L-L, Standard, 50/60Hz	3600
1608N-025A240V2E	MiniDySC - 1Ph , 6kVA, 25 A, 240 VAC, L-N, Extended, 50/60Hz	4800
1608N-025A240V2S	MiniDySC - 1Ph , 6kVA, 25 A, 240 VAC, L-N, Standard, 50/60Hz	3700
1608N-050A240V1E	MiniDySC - 1Ph , 12kVA, 50 A, 240 VAC, L-L, Extended, 50/60Hz	9100
1608N-050A240V1S	MiniDySC - 1Ph , 12kVA, 50 A, 240 VAC, L-L, Standard, 50/60Hz	5900
1608N-050A240V2E	MiniDySC - 1Ph , 12kVA, 50 A, 240 VAC, L-N, Extended, 50/60Hz	9100
1608N-050A240V2S	MiniDySC - 1Ph , 12kVA, 50 A, 240 VAC, L-N, Standard, 50/60Hz	5900

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**

CoilLock

Low Voltage Ride Through Module

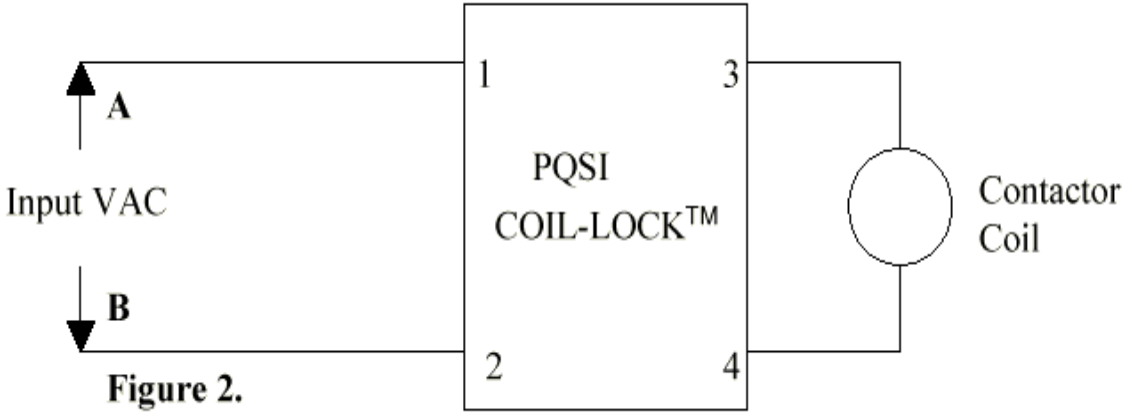
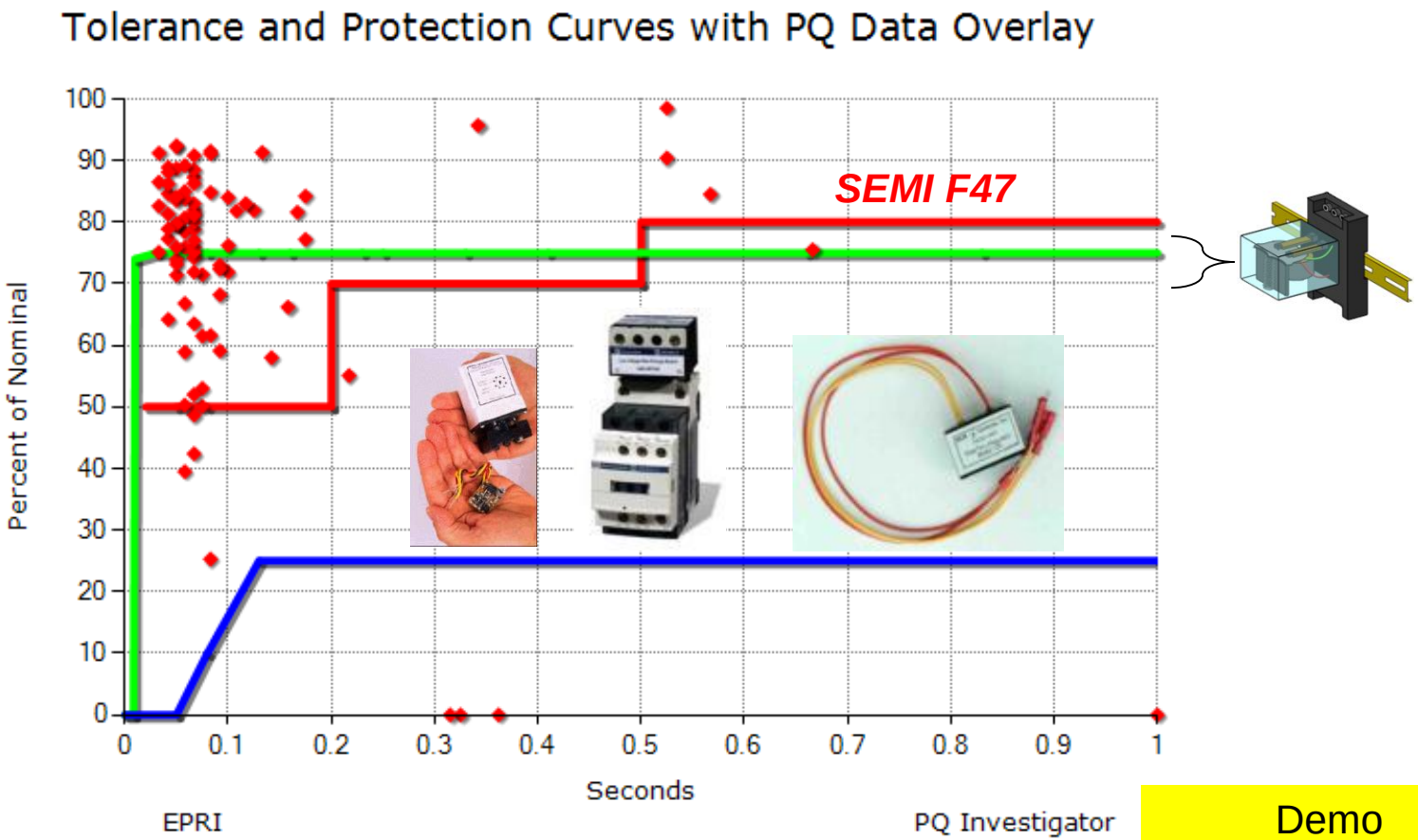


Figure 2.

Coil Hold-In Device Ride-Through Curve



Demo

PLC DC Powered
Sequence Set to "1"

8 cycle sag, 40%

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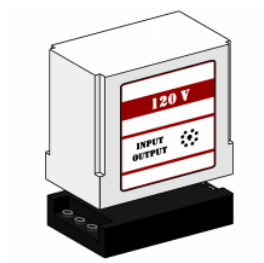
Coil Hold-In Device Costs

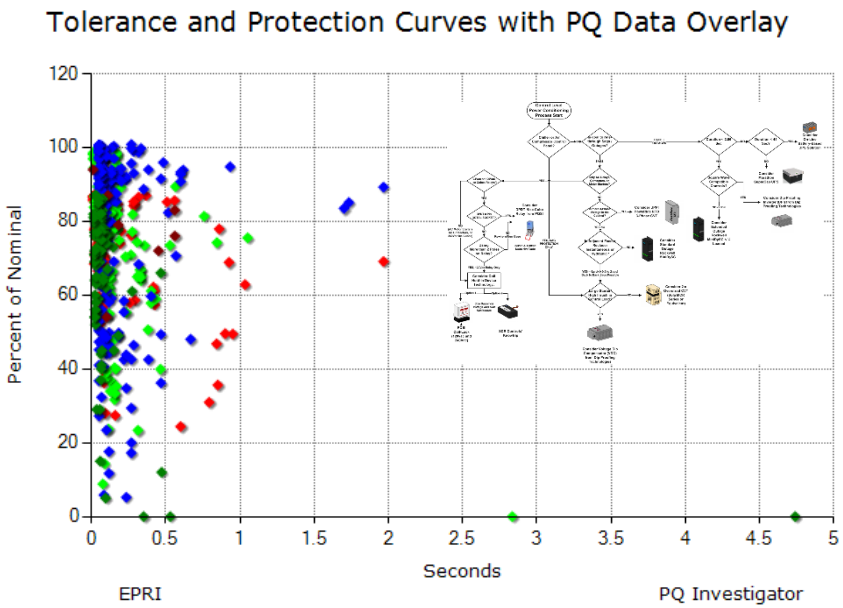


PQSI Coil Lock			
Model Number	Coil Resistance Measured with DC Ohmmeter	Comments	Price
1000-120V	801 to 4.5k Ohms [1]	UL Compliant File E255764	120
1001-120V	201 to 800 Ohms [1]	UL Compliant File E255764	120
1002-120V	8 to 200 Ohms [1]	UL Compliant File E255764	120
1002-120V-CE	8 to 200 Ohms [1]	UL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

Know Trip		
DESCRIPTION	PART NUMBER	LIST PRICE
MODEL 120 8.0 - 35 OHMS	MODEL 120	$268
MODEL 120-8.5 36 - 200 OHMS	MODEL 120-8.5	$268
MODEL 120A 201 - 800 OHMS	MODEL 120A	$268
MODEL 120B 801 OHMS and UP	MODEL 120B	$268
MODEL 120HP .5 - 7.9 OHMS	MODEL 120HP	$696
MODEL 240 151 OHMS and UP	MODEL 240	$417
MODEL 240A 5 - 35 OHMS	MODEL 240A	$1,006
MODEL 240B 36 - 150 OHMS	MODEL 240B	$1,006
MODEL 480 151 OHMS and UP	MODEL 480	$423
MODEL 480 and RC4 40 - 150 OHMS	MODEL 480 & RC4	$615

Control Level Mitigation Decision Tree

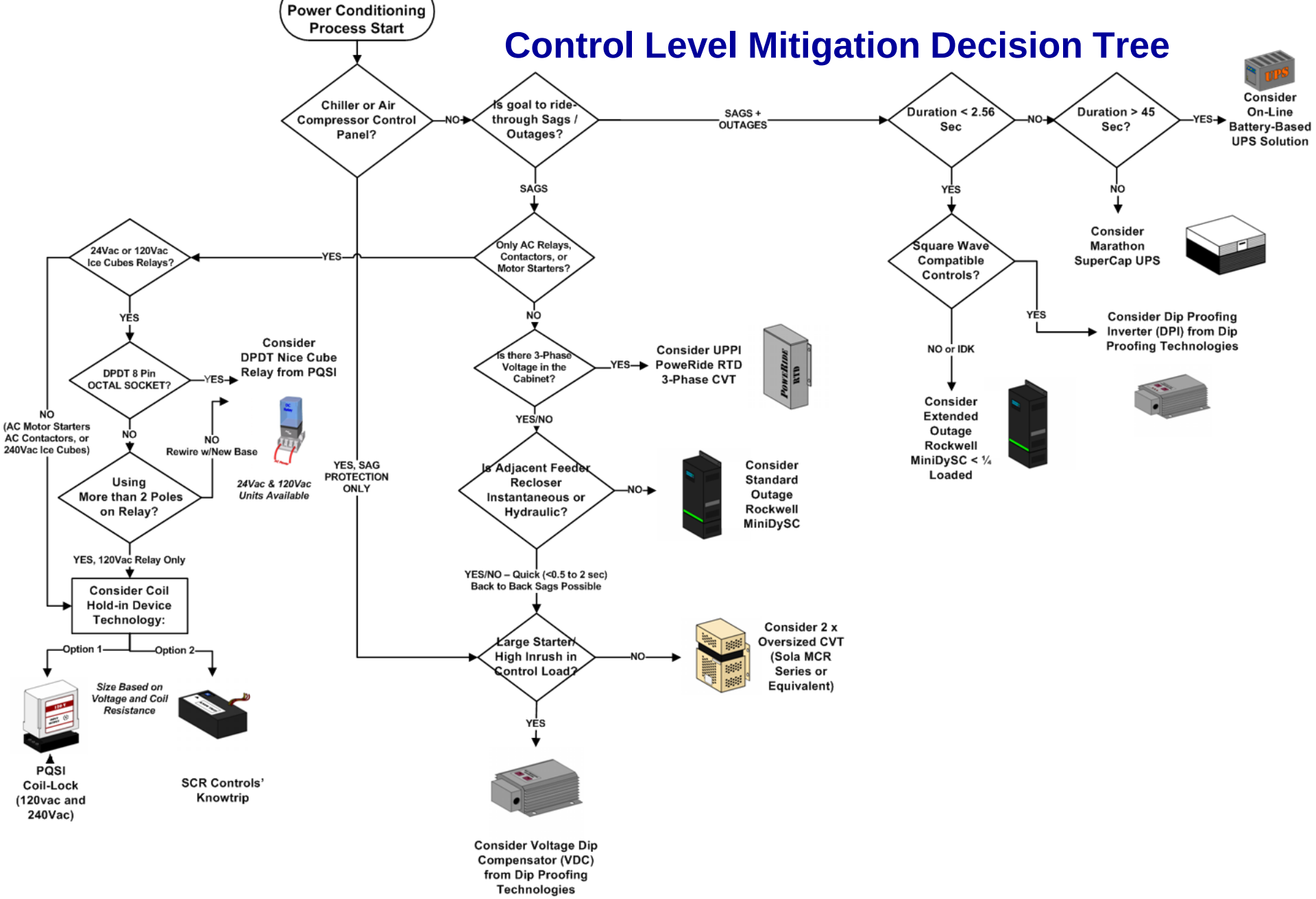
- Some of you have asked “how do I know what type of mitigation technique to use?”
- EPRI’s team has learned how to do this because we are constantly conducing PQ Audits and making these decisions.
- A simplified approach for selecting a general strategy is presented in this example to help you determine what approach makes sense against the goals o 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



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