From Symptoms to Solutions:
Managing Power Quality Issues

April 25, 2017

Meet Your Presenters:

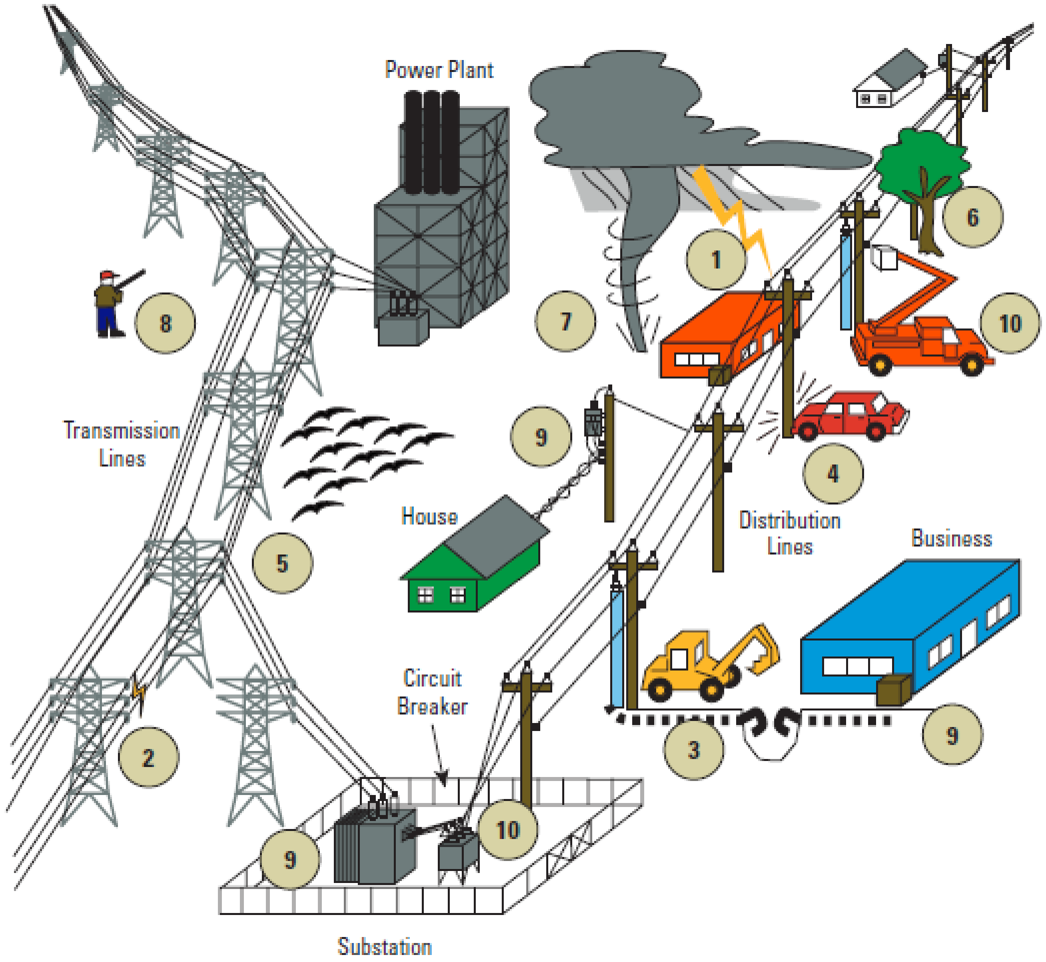
Mike Carter

Topics

- Power Quality Symptoms
- What Is Normal?
- Power Quality Approach
  - Find and fix
  - Ride-through Solutions
  - Protection/Compensation Schemes
- Other Power Quality Solutions

Power Quality Symptoms

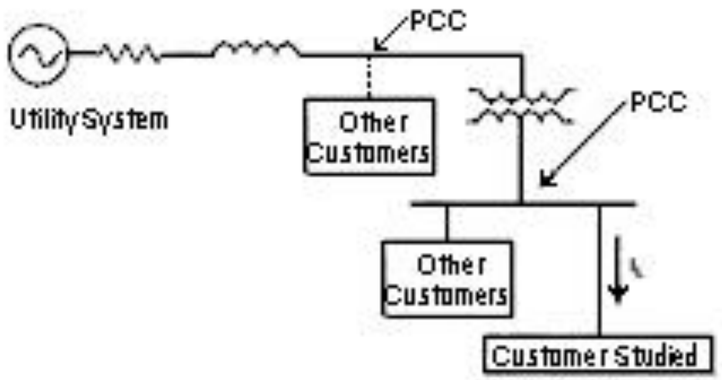
What Can Go Wrong?



Power Quality Symptoms

Power Quality Problem Defined

- Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment
  - Generally, quality of the voltage
  - Surveys show that 65% to 85% of power quality problems are the result of something happening within the facility
    - On the customer side of the point of common coupling (PCC)
  - PCC—the point between the end user or customer where another customer can be served
  - Perfect power quality is not attainable



Power Quality Symptoms

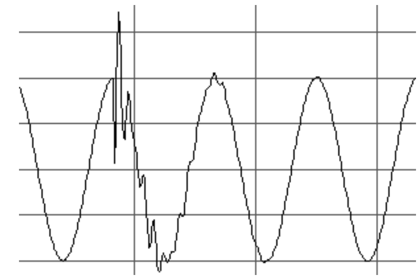
Electromagnetic Phenomena (IEEE 1159)

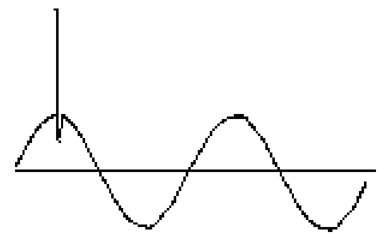
- Transients
  - Impulsive
  - Oscillatory
- Short-duration variations (0.5 cycles – 1 minute)
- Long-duration variations (> 1 minute)
- Voltage imbalance/unbalance
- Inductance and capacitance effects
  - Power Factor
- Waveform distortion
  - Harmonics
  - Noise
- Voltage fluctuation/flicker (<25 Hz)

Power Quality Symptoms

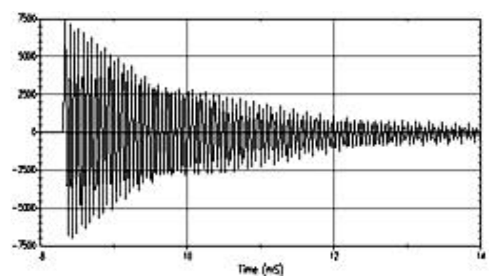
Electromagnetic Phenomena

- Transients—short-term (generally < 0.5 cycle) frequency change in the steady-state condition.
- Low frequency transients
- High frequency transients (~100 kHz)





Images source: PQ Network



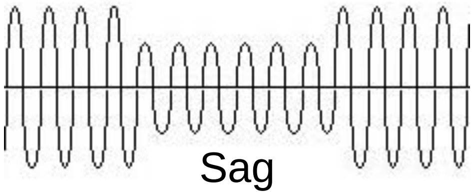
Power Quality Symptoms

Electromagnetic Phenomena

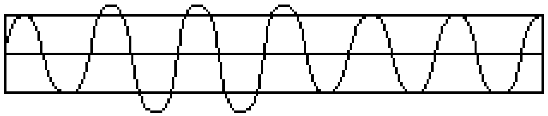
- Short-duration variations (0.5 cycles – 1 minute)
- Long-duration variations (> 1 minute)

Category	Typical Duration
Instantaneous	0.5-30 cycles
Momentary	30 cycles – 3 seconds
Temporary	3 seconds – 1 minute

Category	Voltage Magnitude
Interruption	<0.1 pu*
Sag (dip)	0.1 – 0.9 pu
Swell	1.1 – 1.8 pu



Sag



Swell

Category	Voltage Magnitude
Interruption, sustained	0.0 pu*
Overvoltages	1.1 – 1.2 pu
Undervoltages	0.8 – 0.9 pu

*pu = per unit

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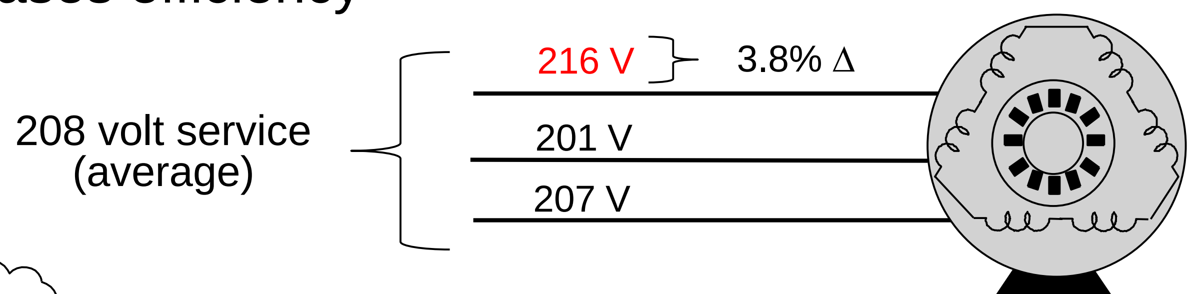
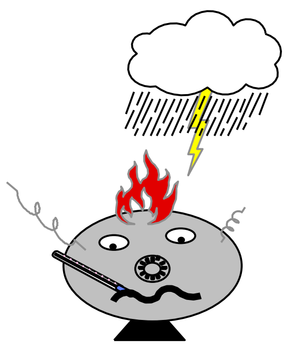
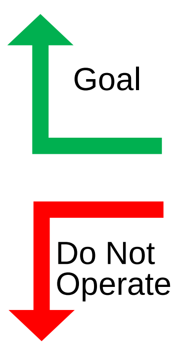
Power Quality Symptoms

Electromagnetic Phenomena

- Voltage imbalance/unbalance (phase-to-phase)
  - Causes overheating that deteriorates motor winding insulation
  - Decreases efficiency







Unbalance	Derating
1%	None
2%	95%
3%	88%
4%	82%
5%	75%

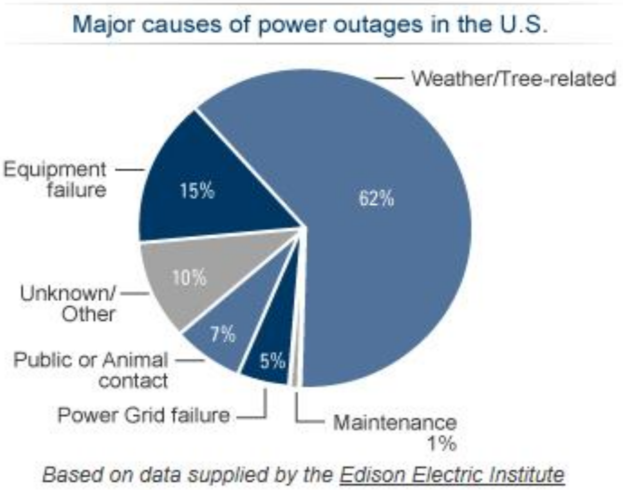
Poll Question

- What percentage of power quality problems originate from inside the utility customer's facility?
  a) 5% to 10%
  b) 40% to 50%
  c) 65% to 85%

What Is Normal?

Voltage Sags

- Sags are mostly instantaneous (<30 cycles)
  - Duration of 166ms (10 cycles) or less
  - Depth of 20% to 30%
    - Usually caused by weather, trees, and public interference
    - Average of 28 distribution sags per year <1 minute (70% are single-phase)
- Interruptions
  - In the EPRI study, 37% < 0.5 seconds and 66% < 1.5 seconds
    - Average of 1 to 2 per year at distribution level



What Is Normal?

Typical Recloser Operation During a Feeder Fault

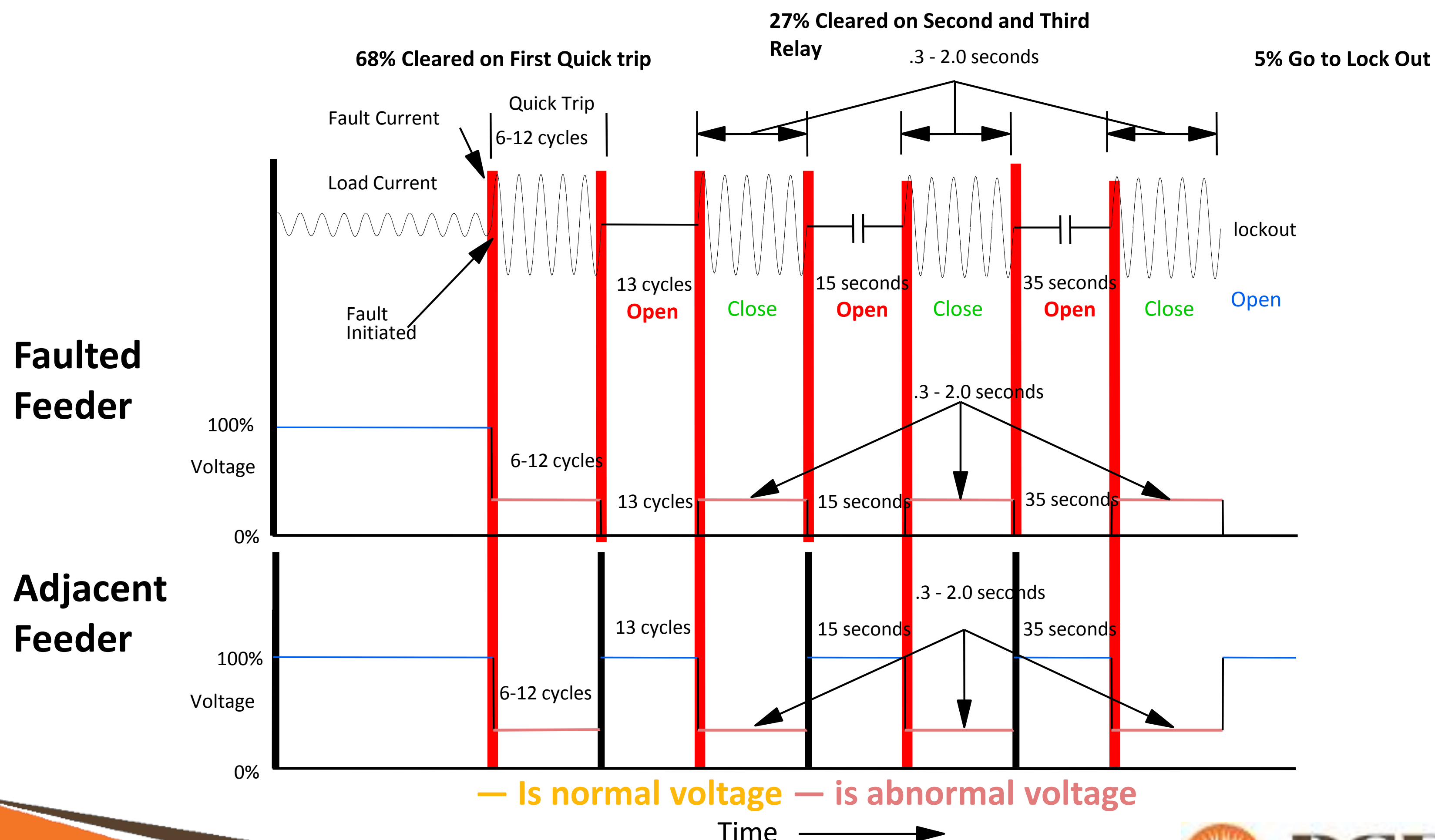


*Image courtesy of Progress Energy

What Is Normal?

Voltage Regulation Standards

- The national standard in the U.S. is ANSI C84.1
  - Range A is for **normal conditions**
    - +/- 5% on a 120-volt base at the service entrance
    - -2.5% to +5% for services above 600 volts
  - Range B is for **short durations** or unusual conditions

ANSI C84.1 Requirements for Voltage Regulation				
Base	Range A		Range B	
	+5%	-5%	+5.8%	-8.3%
120V	126	114	127	110
480V	504	456	508	440

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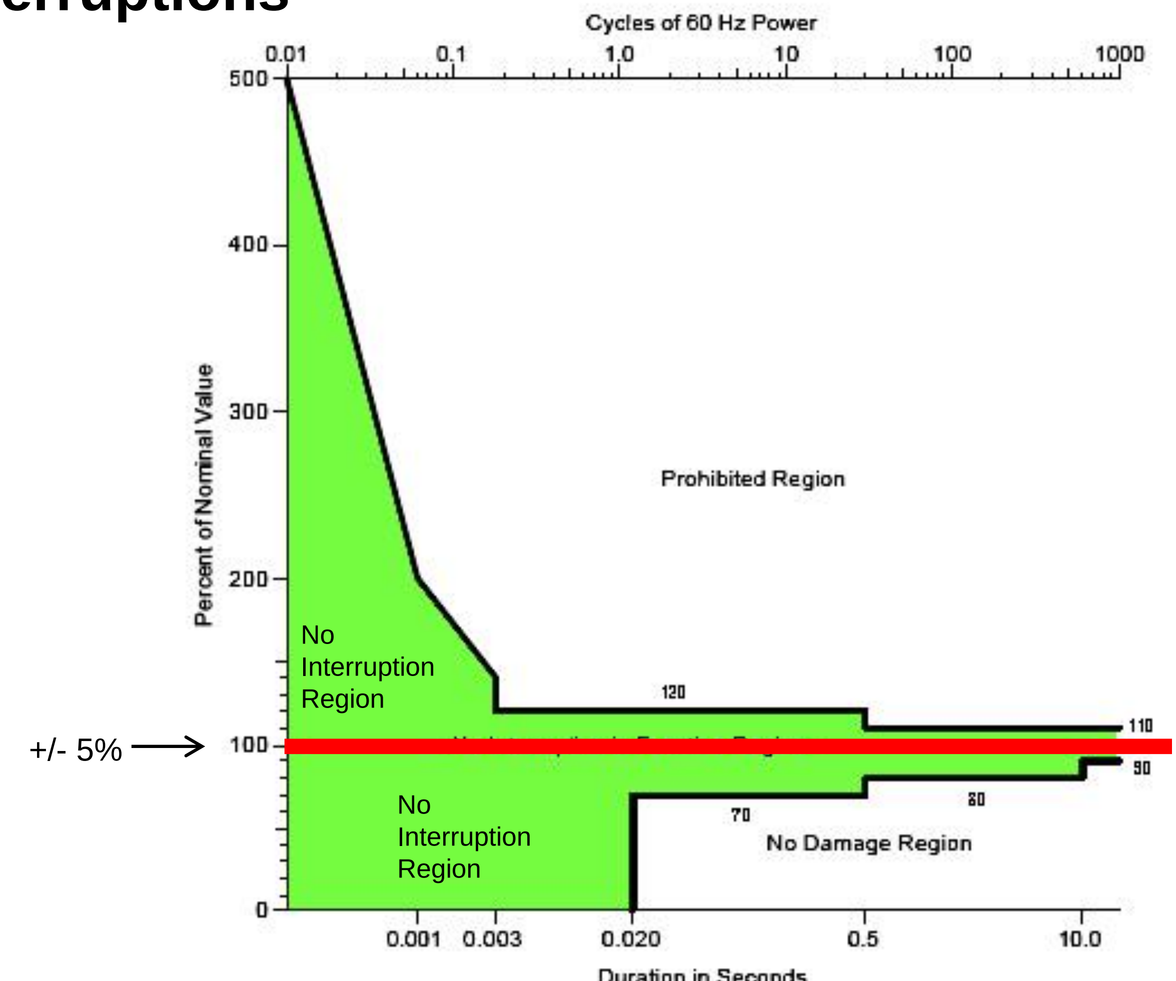
What Is Normal?

Acceptable Sags/Interruptions

- Voltage variation tolerance curves
- The ITIC* curve



Source: ITIC

*ITIC– Information Technology Industry Council

Systematic Approach

1. Find and fix it first!

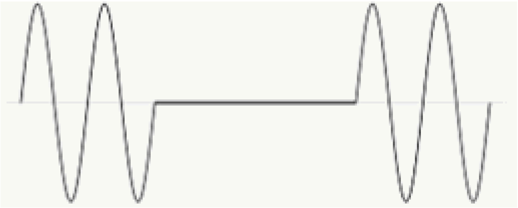
2. Make it survive or ride-through.

3. Compensate when it does occur.

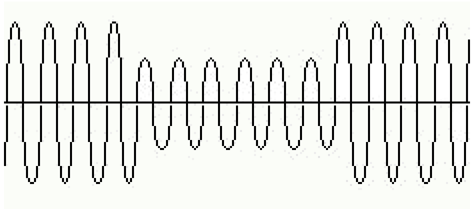
Poll Questions

- Which occurs more frequently?
  a) Interruptions
  b) Sags

- Which lasts longer each occurrence?
  a) Interruptions
  b) Sags



Interruption

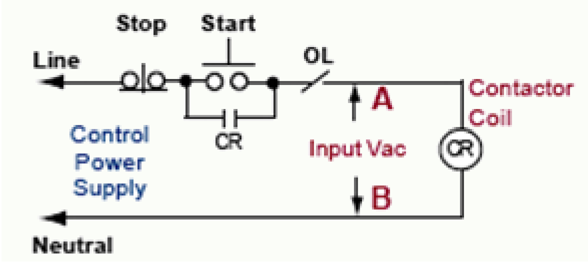


Sag

Find and Fix the Problem

Why Equipment Trips from Sags*

- Not enough voltage to sustain operation
- An undervoltage circuit trips
- An unbalance relay trips
- A quick-acting relay shuts the system down
- A reset circuit may incorrectly trip at the end of the voltage sag



*Alex McEachern, Power Standards Lab

Find and Fix the Problem

Identify Power Quality Problems

- Add a power quality relay
  - PQube three-phase and single-phase monitoring up to 690V, 50/60Hz.
    - Voltage dips, swells, and interruptions – waveforms and RMS graphs
    - Frequency events, impulse detection, time-triggered snapshots
    - Daily, weekly, monthly trends. Cumulative probability, histograms, and more.
    - Built-in Li-Ion UPS.

Source: Power Standards Lab

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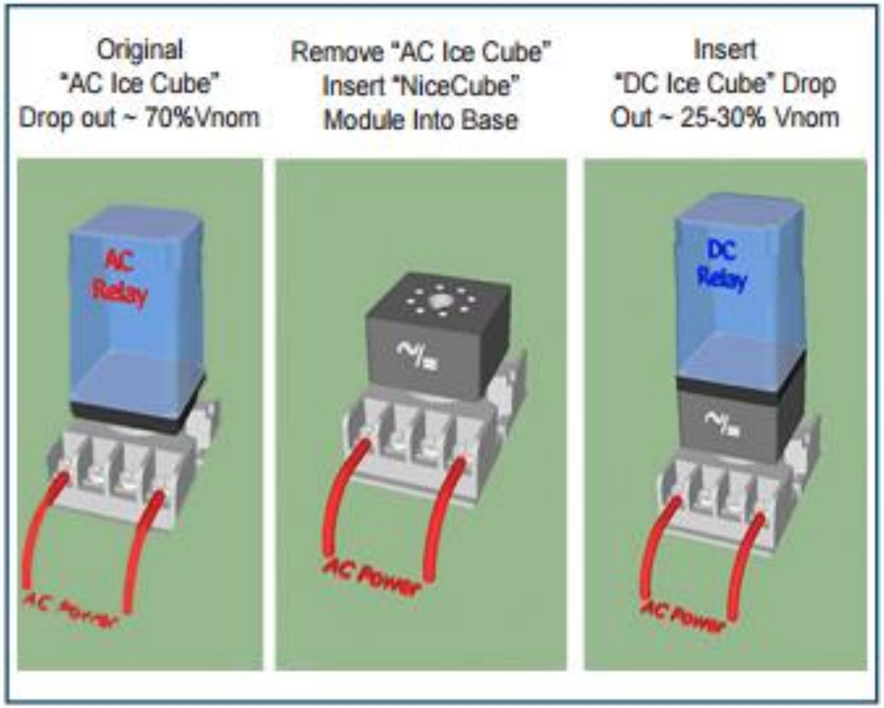
Ride-Through Solutions

Ice Cube Relays

- Use DC instead of AC
  - Control circuits, controllers, input/output devices (I/O), and sensors

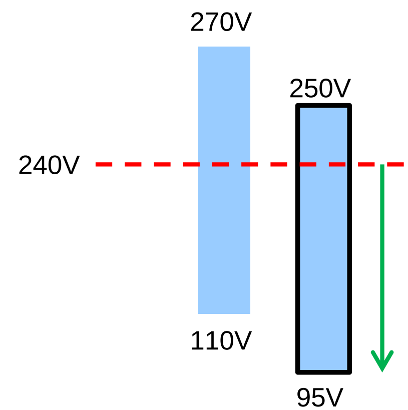


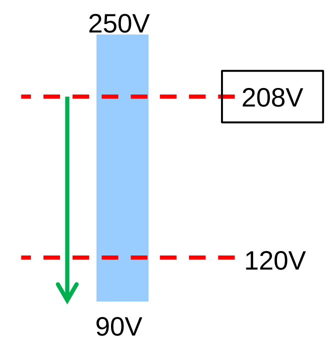
Source: Power Quality Solutions, Inc.

Ride-Through Solutions

Increase Voltage Headroom

- For brownout conditions, <50% sag
  - Choose a different power supply setting range
    - Where your nominal operating voltage is nearer the top of the range
    - For a 240 voltage, choose 95 V to 250 V versus 110 V to 270 V (bad for swells)
  - Connect your single-phase power supply phase-to-phase
    - 208 V versus 120 V for a 90 V to 250 V device because 90 V is 45% of 208 V but 70% of 120 V
  - Reduce the load on your power supply
  - Use a bigger power supply
    - Would be more lightly loaded

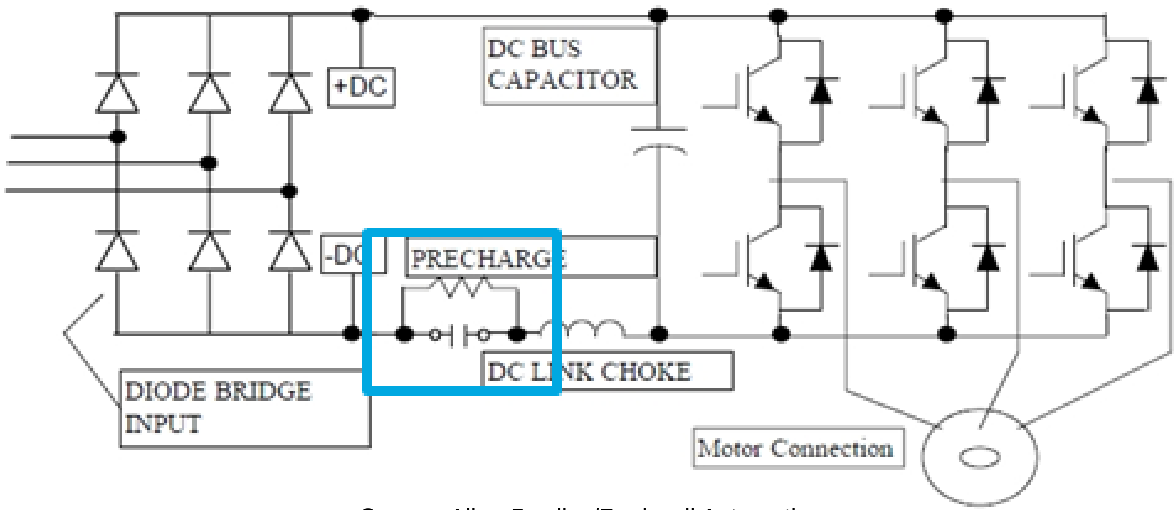




Ride-Through Solutions

Motor Drives

- Change the unbalance, undervoltage, or reset trip settings to achieve ride-through
  - IEEE P1668 contains draft ride-through recommendations
  - Lower the pre-charge point (V_2)
  - Consider oversizing the drive
    - To increase the capacitor bank
  - Add an additional capacitor bank to the DC bus

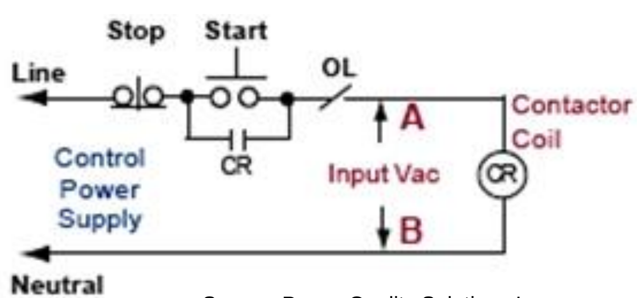


Source: Allen-Bradley/Rockwell Automation

Ride-Through Solutions

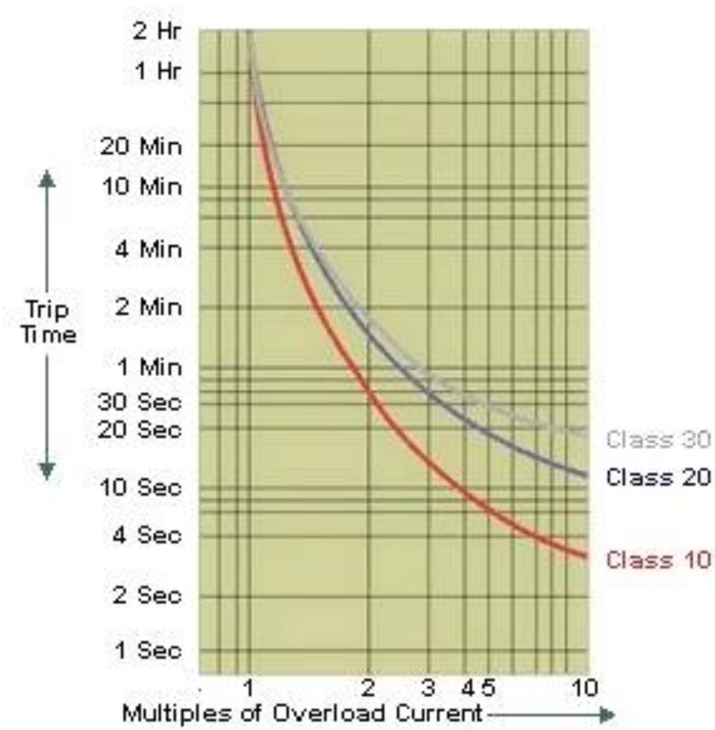
Breakers and Relays

- Select appropriate circuit breakers (trip curves)
- Slow the Emergency Off (EMO) relay down
  - Increase mechanical mass (such as a contactor)
  - Use a relay hold-in accessory



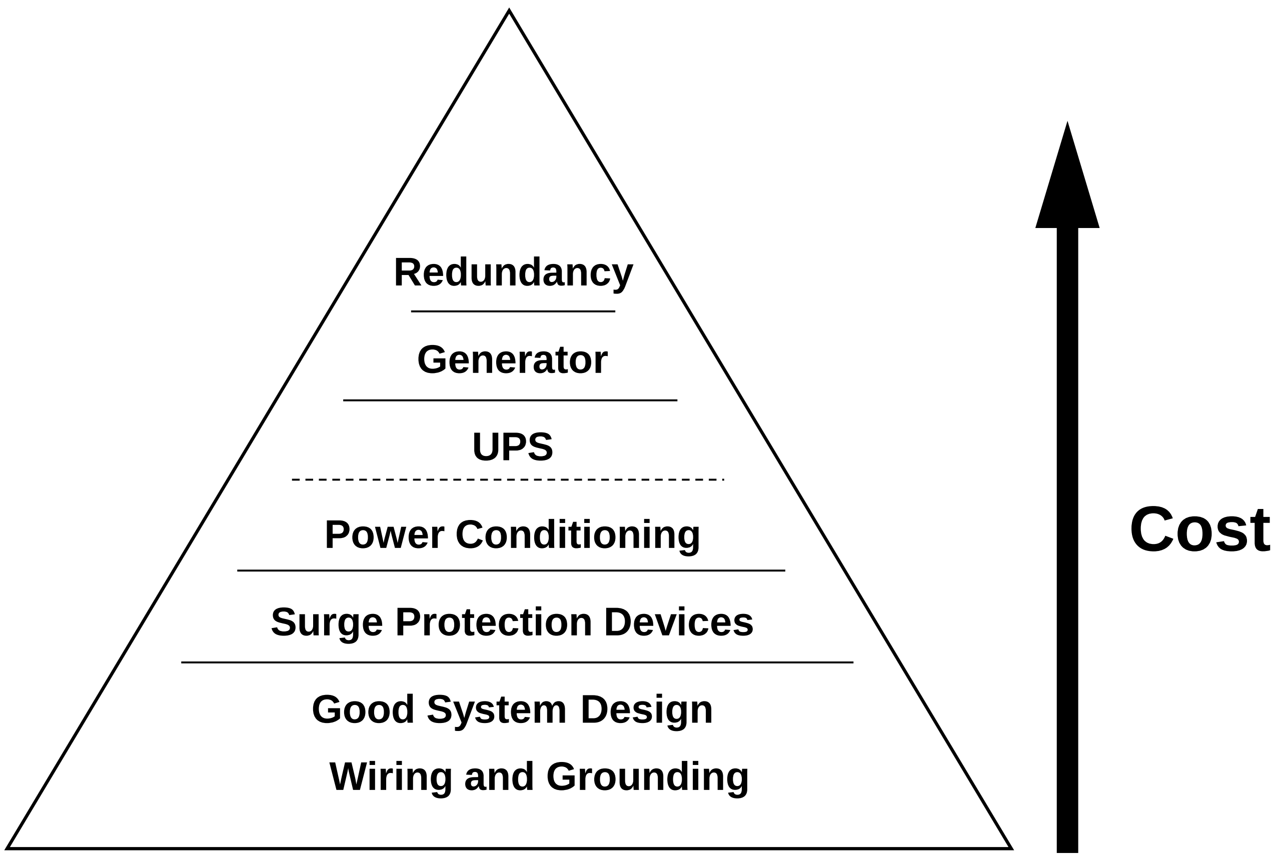
Source: Power Quality Solutions Inc.

- Compensate for the upstream voltage sag itself (last resort)



Source: Siemens AG

Protection Schemes

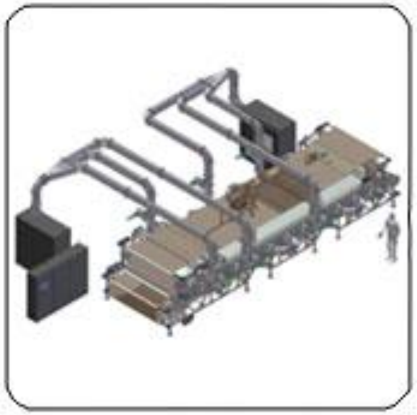


Source: Liebert Corporation

Compensation Schemes

- Facility

- Equipment



- Component

Cost

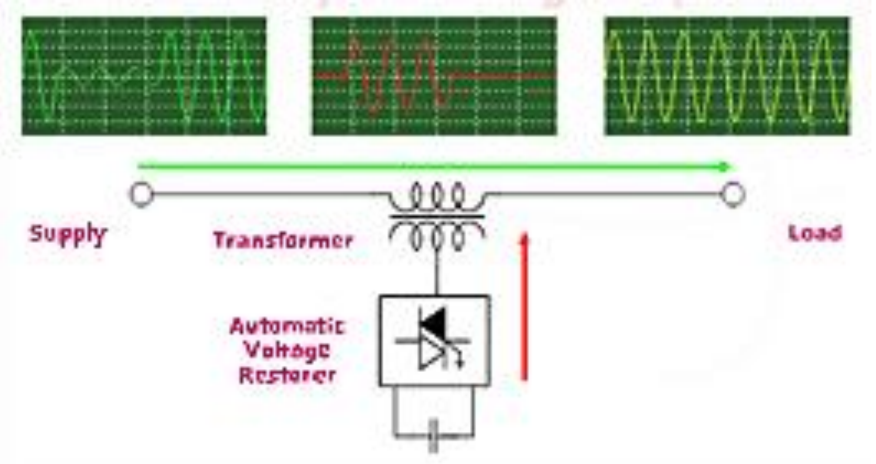
Poll Question

- What is the **first** step in achieving increased ride-through capability?
  a) Compensate for deviations.
  b) Fix the source problem.
  c) Make equipment survive.

Facility Level Protection

Solid-State Voltage Compensation

- Static transfer switch (STS)
  - Utility level protection
  - When a dual distribution feeder service is available
- Low-voltage static series compensator (LV-SSC)
  - Dynamic Sag Corrector (MegaDySC)
    - From 263 kVA to 1330 kVA
    - For ride-through
      - Down to 50% of nominal voltage
      - Up to 12 cycles with no energy storage

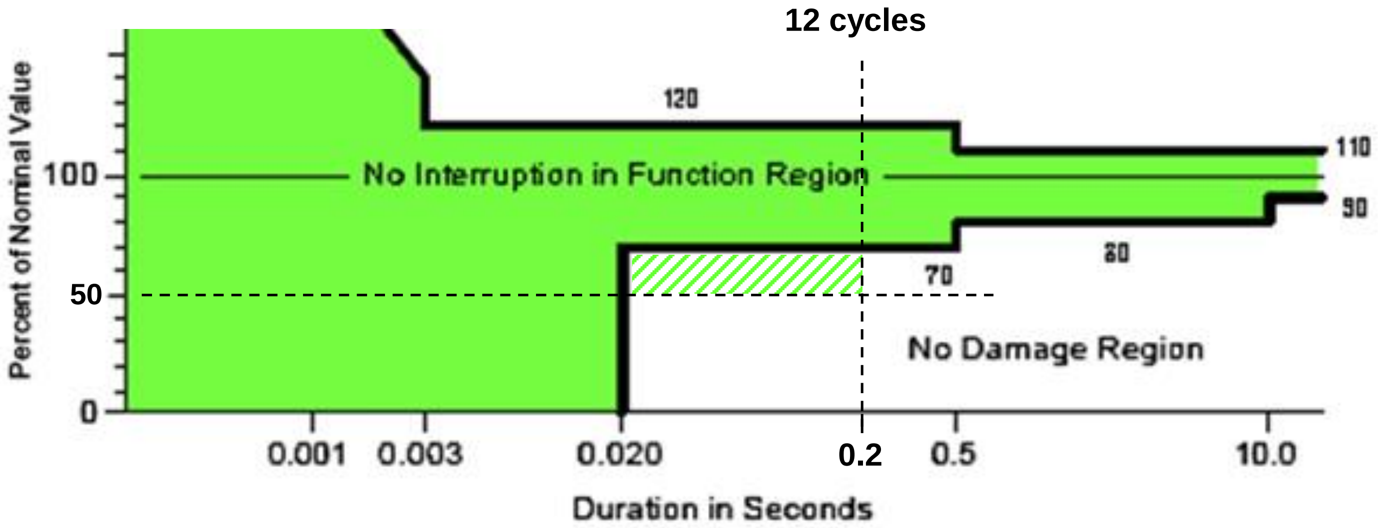


Source: Leonardo ENERGY

Facility Level Protection

Solid-State Voltage Compensation

- Dynamic Sag Corrector (MegaDySC)—from 263-1330 kVA
  - For ride-through to 50% of nominal voltage for up to 12 cycles with no battery storage.



Facility Level Protection

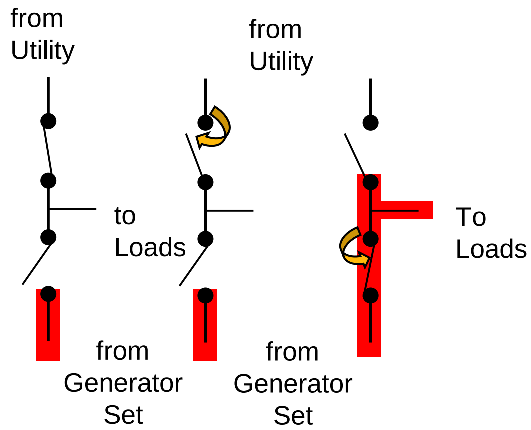
Backup Generators

- Capital costs

Capital Costs, $/kW			
Diesel	**Natural Gas**	**Micro-turbine**	**Fuel Cell**
$150-$250	$200-$300	$1,000	$3,000-$4,000

- Installation costs
  - Roughly 50% of the purchase cost, and can approach $10,000 for a 100 kW unit
  - Does not change drastically with size, so there is no penalty for oversizing
- Maintenance costs
  - $500 to $1,000 per year
  - Includes an oil change and tune up every 1,500 hours
  - Diesels considered most mechanically reliable

Facility Level Protection



Automatic Transfer Switches

- Open-transition *break before-make* switching
  - Lowest cost
  - Most reliable
  - Requires one-half to three seconds decay interval

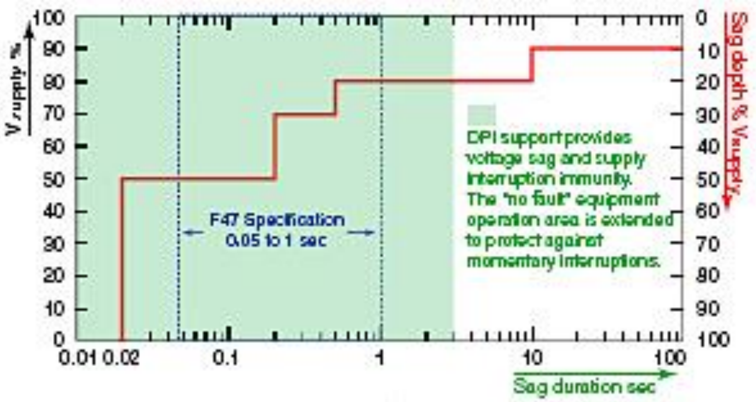
Generator Compatibility with UPS

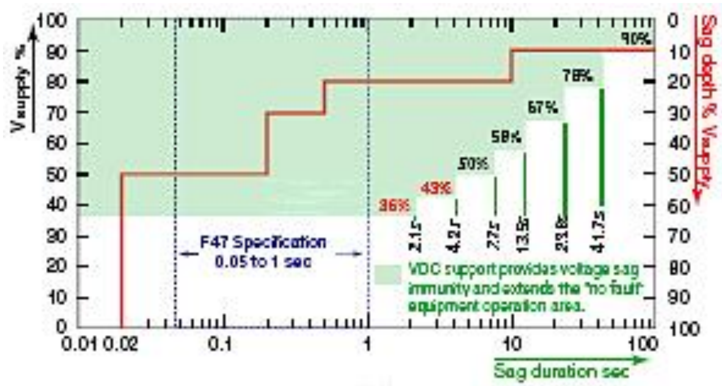
- UPS feeds non-linear harmonics to generators
  - Power pulsations upon load changes
  - Overheating
  - *Bypass not available* alarms from the UPS

Equipment Level Protection

Solid-State Voltage Compensation

- Voltage Dip-Proofing Inverter (DPI)
  - Square-wave output to the load
  - An off-line device
    - Transfer time less than 700 μs
    - Up to 3 kVA and 25A for 120V
    - Up to 4.5 kVA and 20A for 208/230V
  - Good for interruptions and sags
- Voltage Dip Compensators (VDC)
  - Good for sags down to 36% for two seconds





Source: Measurlogic, Inc.

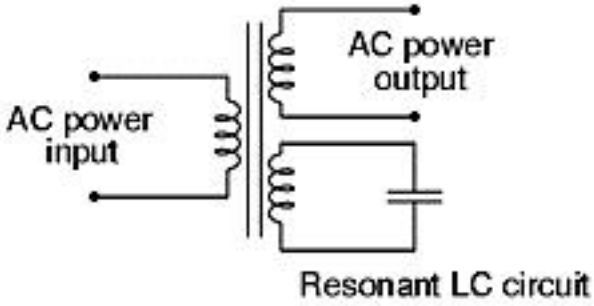
Equipment Level Protection

Dynamic Sag Corrector (ProDySC)

- From 9 to 167 kVA

Constant Voltage/Ferroresonant Transformers

- Maintains two separate magnetic paths with limited coupling between them
- Provides 90% output at input voltage range of ±40%



- Inefficient at low loads
- Current limited
  - Not good for high inrush current applications such as motors
- Size at least 2.5 times the nominal VA load requirement

Poll Question

- What **two** metrics determine what type of compensation equipment to use?
  a) Duration
  b) Frequency
  c) Harmonic distortion
  d) Magnitude

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Equipment Level Protection

Uninterruptible Power Supply (UPS)

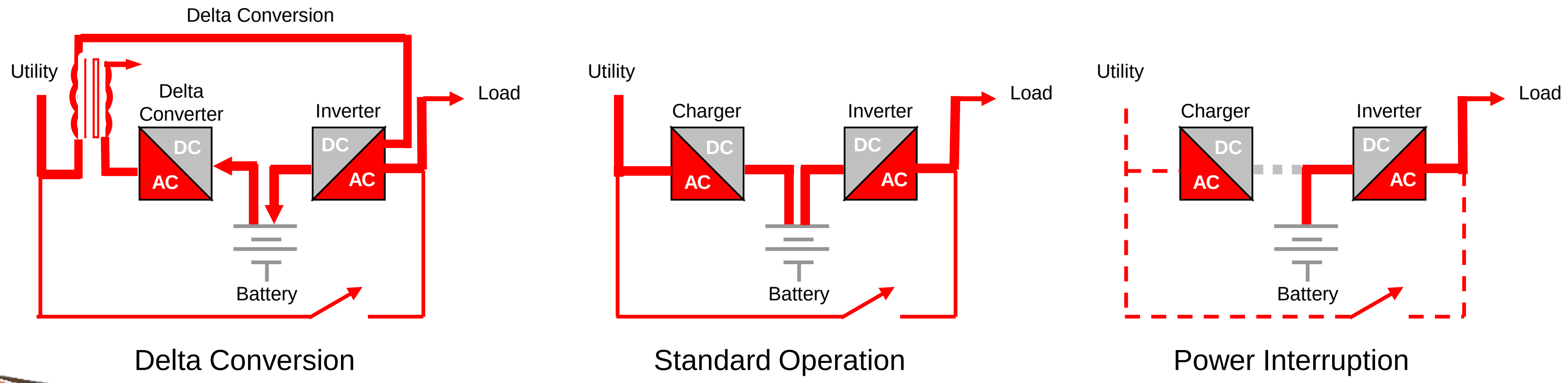
- Three types
  - Online or *true* UPS (double conversion)
  - Offline UPS (standby battery and inverter)
  - Hybrid or line-interactive or direct ferroresonant transformer UPS
- Energy Storage (≈50% of system cost)
  - Lead Acid Batteries
  - Flywheels
  - Ultra-capacitors
- UPS cost
  - $300-2,000 per KVA
    - 5 KVA for doctor's office is $1,500 to $2,000
    - 10-20 kW for retail chain is $15,000 to $20,000
    - 1 MW for data center is $400,000 plus $200,000 installation
  - Flywheel is 50% more

Source: LBNL

Equipment Level Protection

Uninterruptible Power Supply (UPS)

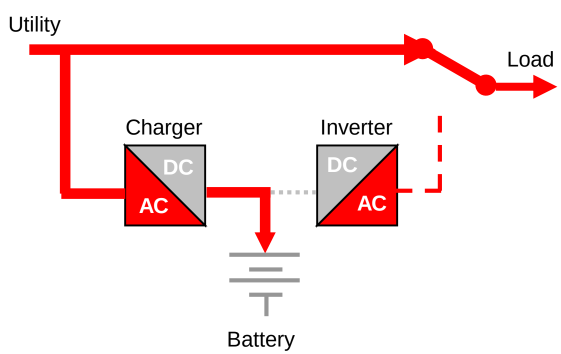
- Online UPS (double conversion or true online)
  - *Continuously* powers the load
  - No switchover time
  - Best power conditioning
  - Best waveform
  - Delta converter more efficient than double conversion



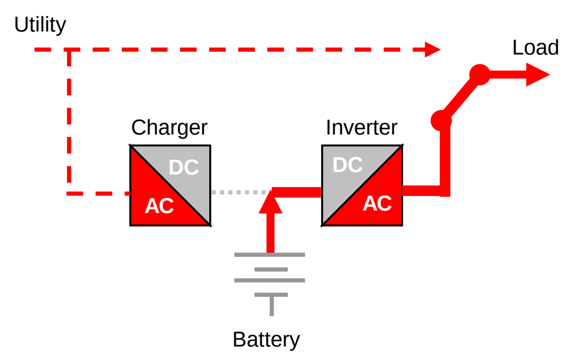
Equipment Level Protection

Uninterruptible Power Supply (UPS)

- Offline UPS (standby)
  - Only supplies power *when power is interrupted*
  - Switchover time can be a problem
  - Square nature of sine wave can cause problems
  - Only conditions power during interruption



Standard Operation

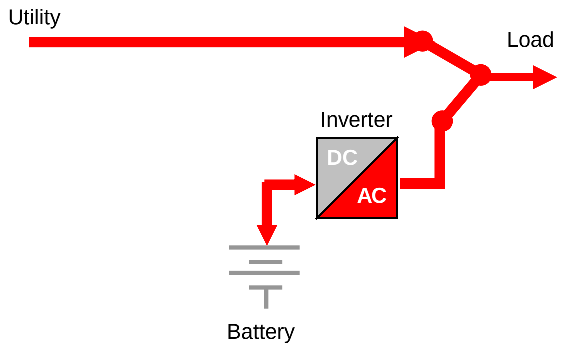


Power Interruption

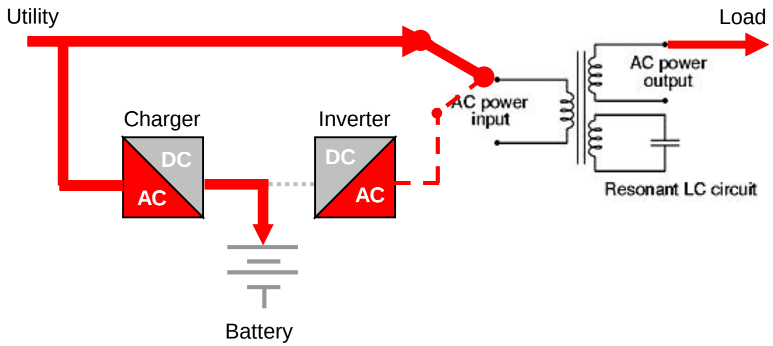
Equipment Level Protection

Uninterruptible Power Supply (UPS)

- Hybrid or line-interactive UPS
  - Supplies additional power during sags
  - Provides some power conditioning
- Hybrid direct ferroresonant transformer
  - UPS supports voltage regulation of ferroresonant transformer
  - Maintains output briefly when a total outage occurs
  - Can be unstable with PF-corrected power supply loads



Line-interactive Standard Operation

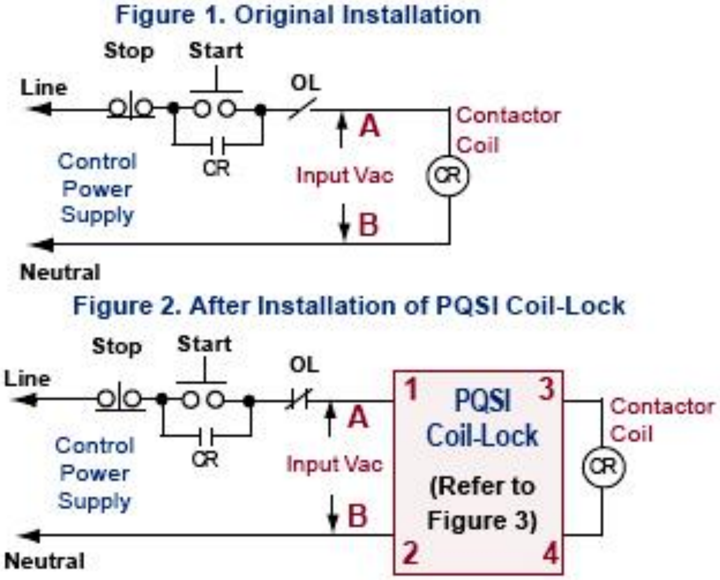


Ferroresonant Transformer

Equipment Level Protection

Coil Hold-In Devices

- Coil-Lock
  - Provides ride-through for a 75% voltage drop for up to three seconds
  - $100 to $140 per unit



Images source: Power Quality Solutions Inc.

Component Level Protection

Dynamic Sag Corrector (MiniDySC)

- From 1.2 kVA to 12 kVA

UPPI PoweRide

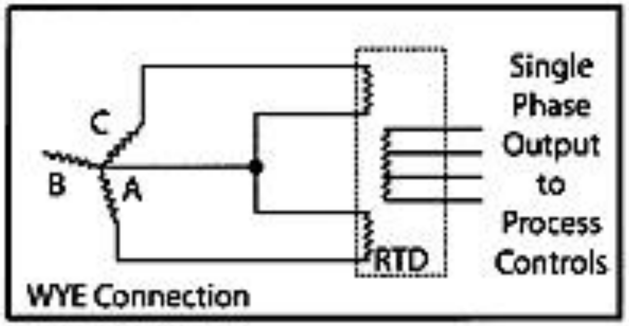
- Uses two phases of a three-phase supply as input and a single-phase output; up to 10 kVA
- Works when one of the two input phases is lost

AND

the remaining phase drops by 33%

OR

when both of the input phases experience a 33% drop in voltage



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Other Power Quality Solutions

Harmonics

Solutions	Advantages	Disadvantages
Active Filters	Can handle load diversity	Highest cost
Broadband Blocking Filters	Makes 6-pulse into 18-pulse equivalent at reasonable cost	One filter per drive
12/18-Pulse Converter	Excellent harmonic control for larger drives (>100 HP)	High cost
Harmonic Mitigating/Phase Shifting Transformers	Substantial (50-80%) reduction in harmonics when used in tandem	Harmonic cancellation highly dependent on load balance
Tuned Filters	A single filter can compensate for multiple drives	Care is needed to ensure that the filter will not become overloaded
K-Rated/Drive Isolation Transformers	Offers series reactance (like line reactors) and provides electrical isolation for some transient protection	No advantage over reactors for reducing harmonics unless used in pairs for phase shifting
DC Choke	Slightly better than AC line reactors for 5th and 7th harmonics and less voltage drop	Not always an option for drives
Line reactors	Inexpensive	May require additional compensation

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Other Power Quality Solutions

Harmonic Resonance

- Large amounts of capacitance in parallel with inductance
  - For example PF correction and welders
- Initiated by two events
  - Harmonic producing loads are operating on the power system
  - Capacitor(s) and the source impedance have the same reactance (impedance) at one of the load characteristic frequencies
- Two possible solutions
  - Apply another method of KVAR compensation
    - Harmonic filter, active filter, condenser, and so on

    OR
  - Change the size of the capacitor bank
    - Over-compensate or under-compensate for the required KVAR and live with the ramifications

Source: Eaton Performance Power Solutions

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Poll Question

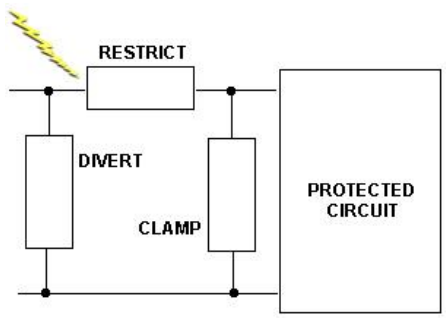
- Would you like someone from PSE&G to contact you?
  a) Yes
  b) No

- How valuable has this Webinar been to you?
  a) Not valuable at all.
  b) Slightly valuable.
  c) Moderately valuable.
  d) Very valuable.
  e) Extremely valuable.

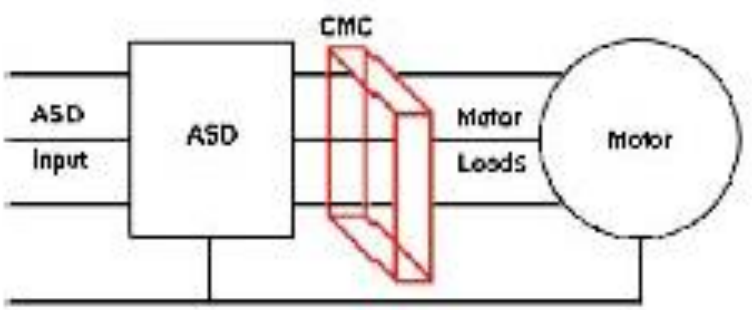
Other Power Quality Solutions

Transients

- Transient Voltage Surge Protection Device (SPD)



- EMI Solutions
  - Use of Shielded/Armor Cable
  - Use a common-mode choke (CMC)

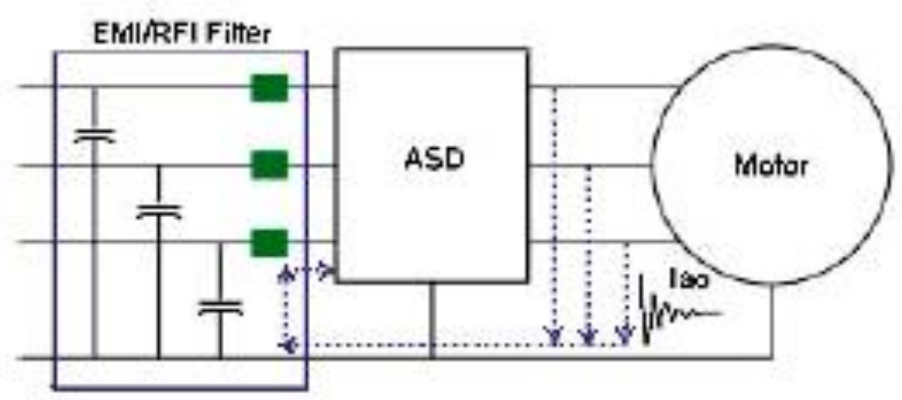


Source: The Engineering Handbook

Other Power Quality Solutions

Transients

- EMI Solutions (continued)
  - Separate control/signal cables from high-voltage wires
  - Ground the power conductors to the cabinet ground bus and motor ground and place them in a conduit
  - Capture/return emissions to the source with EMI Filters

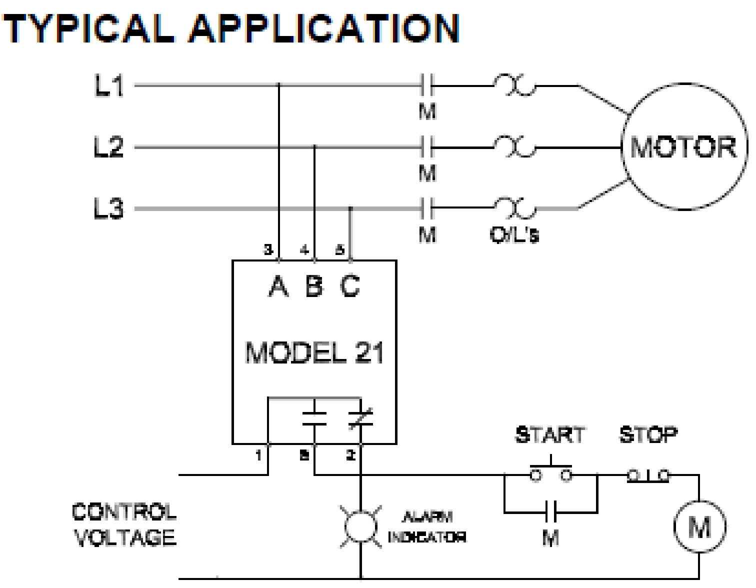


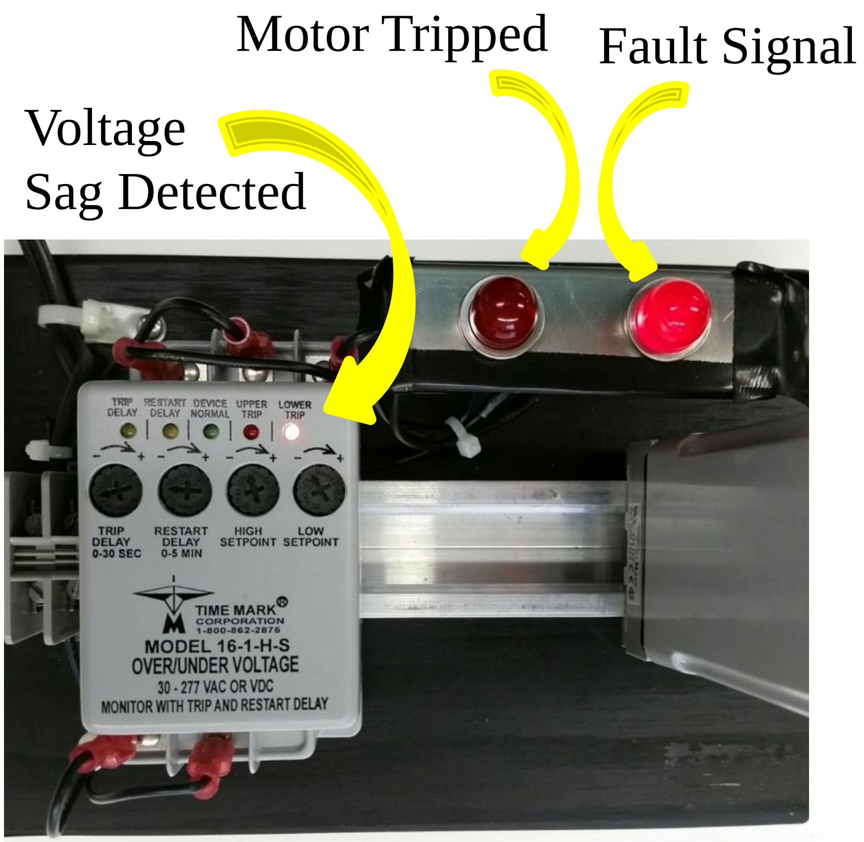
Source: The Engineering Handbook

Other Power Quality Solutions

Voltage Imbalance/Unbalance

- Regularly monitor voltages at the motor terminals
  - Verify that voltage unbalance < 3% (ANSI C84.1-2006)
- Install phase monitors/protectors





Source: Time Mark Corporation

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  - Email:
    - LargeCustomerSupport@pseg.com
  - Phone:
    - 1-855-249-7734
  - Websites:
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