



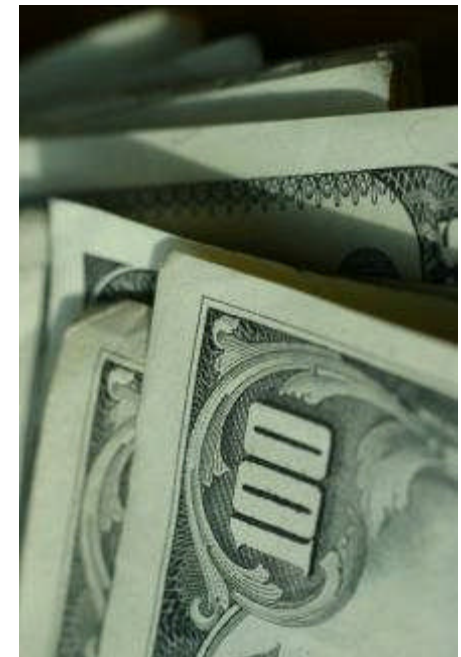
Utility Systems Technologies, Inc.

Quality Power. Better Business.

Power Quality Basics

Who cares?

- \$100+ billion in losses per year
 - Just in the U.S.
- Financial impact
 - Scrap, equipment damage, etc.
- Operational impact
 - Downtime, critical shipments, etc.



Power Quality = Financial Problem

Trends

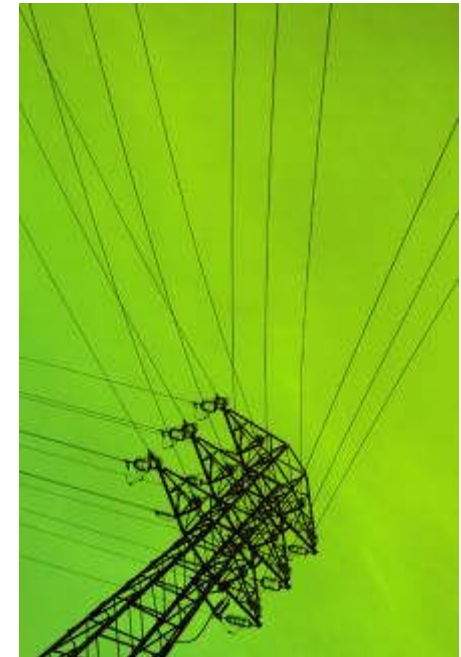
- Electric grid degradation ↑
- Sensitive loads ↑
- Energy costs ↑
- Environmental regulations ↑
- Financial sensitivity ↑



A Perfect Storm

What does “Quality” mean?

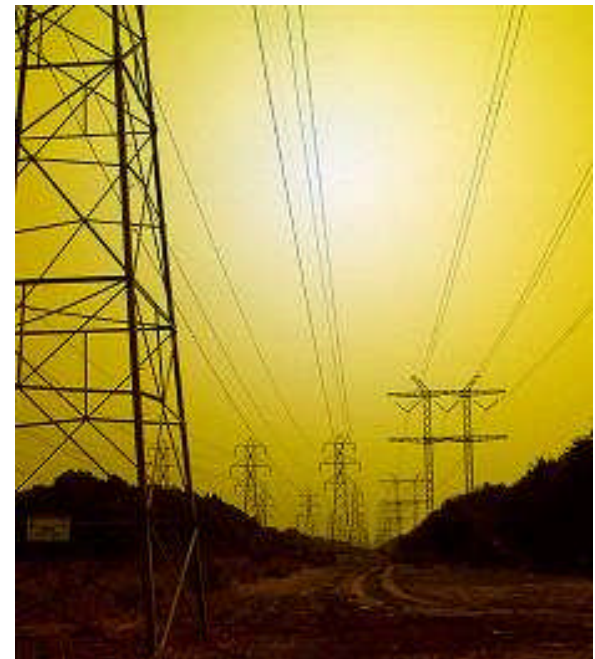
- Absence of malfunctions or failures
- Depends on point of view
 - Utility has one view
 - Customer may have another view



Quality = Proper Equipment Operation & Longevity

**Power =
Current, Time & Voltage**

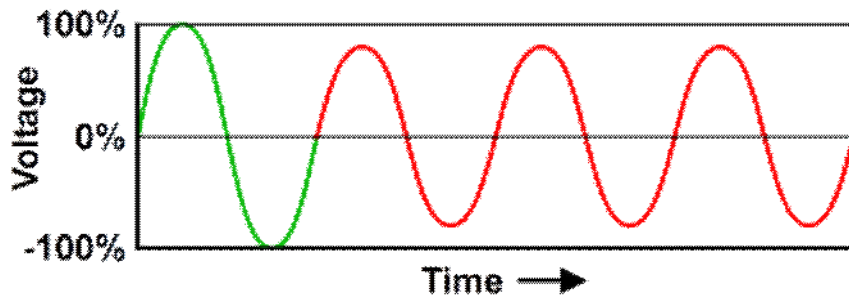
- Amps are governed by the load
- Time cannot be changed
- **Only voltage is controllable**



Power Quality = Voltage Quality

Undervoltage

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Voltage 90% of nominal or less

Source: Utility or facility

Duration: > 1 minute

Incidence: Medium - high

Symptoms: Malfunction or
premature equipment failure

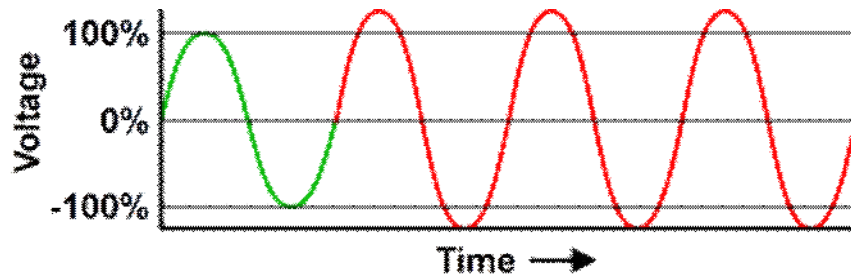
Protection: Voltage regulation

Undervoltage can result from low distribution voltage, high voltage drop, heavy loads, etc. Symptoms include premature failure and overheating of motors. May also increase sensitivity to voltage sags.

Causes Equipment Shut Down or Malfunction

Overvoltage

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Voltage >110% above nominal

Source: Utility

Duration: > 1 minute

Incidence : Medium - high

Symptom: Malfunction or
premature equipment failure

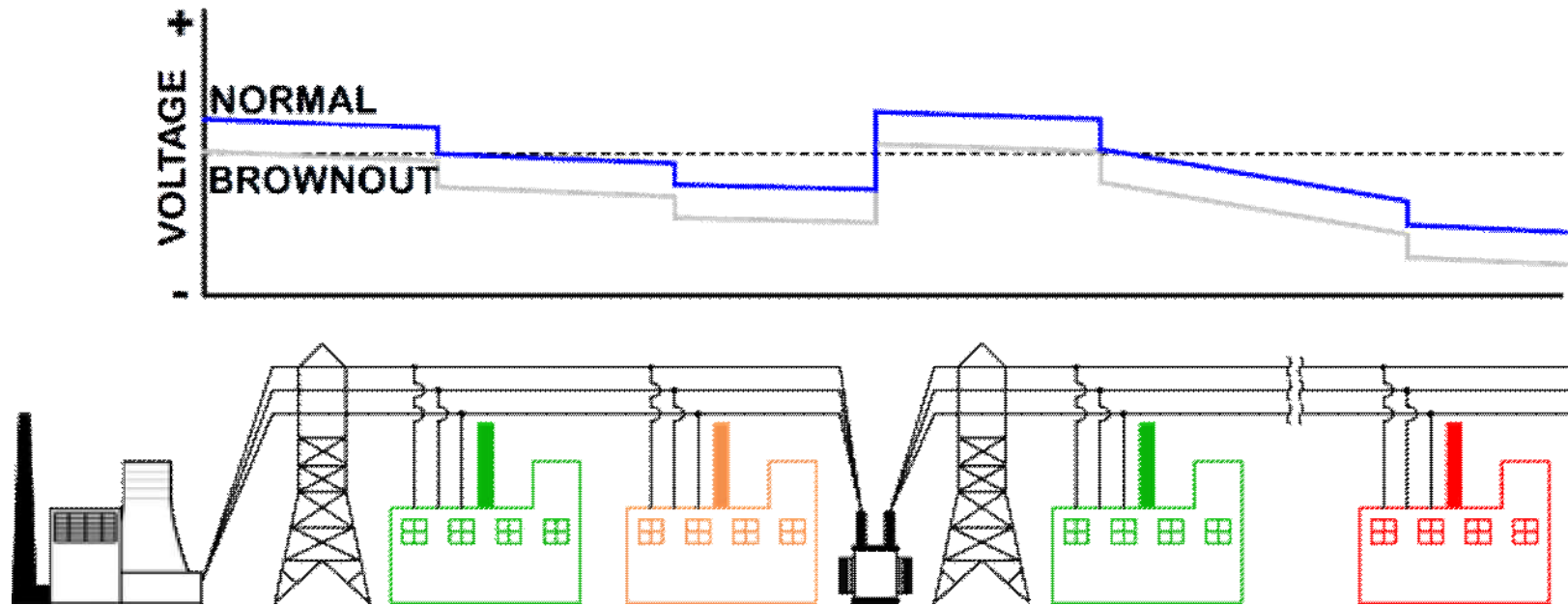
Protection: Voltage regulation

Overvoltage usually results from high distribution voltage. Often a problem nights, evening and weekends. Premature failure of electronics and printed circuit boards is a common symptom.

Causes Premature Circuit Board Failure

Distribution Voltage Regulation

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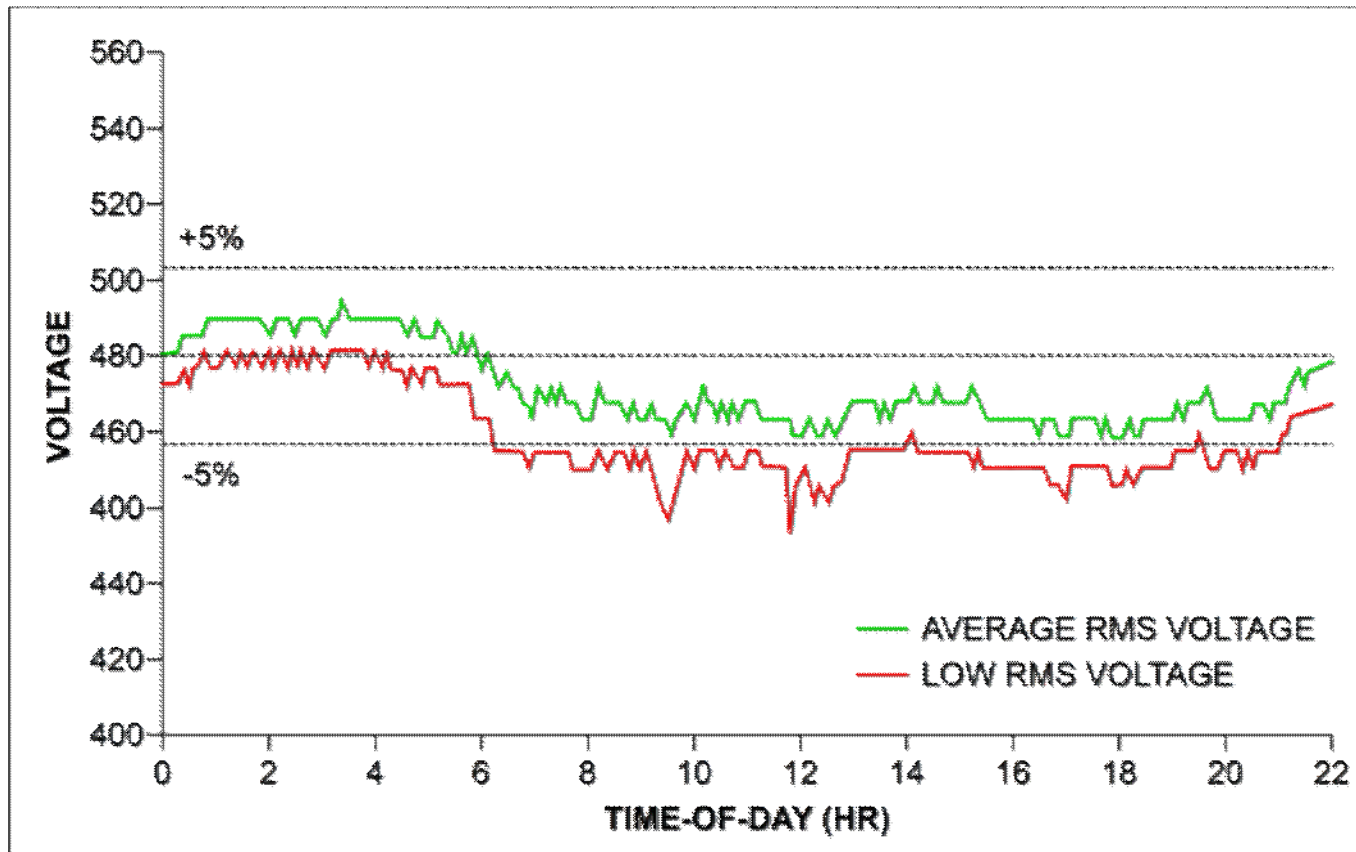


Brownout – intentional reduction in grid voltage

Major Cause of Under/Overvoltage

Daily Voltage Fluctuations

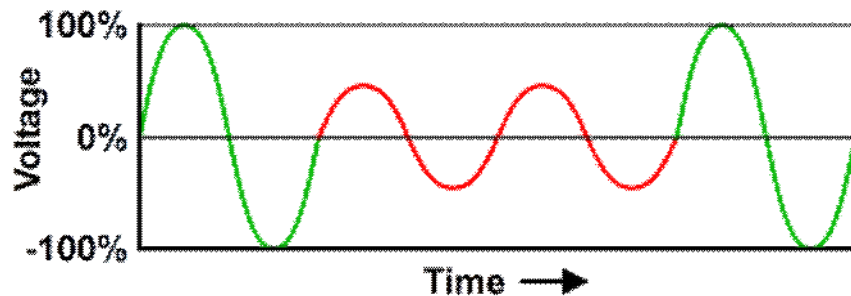
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Utility Has Limited Control of Deviations

Voltage Sag

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Very short, deep voltage drop

Source: Utility or large load start

Duration: 0.5 cycles – 60 seconds

Incidence : Avg. 40 – 60
events/year in U.S.

Symptom: Shut down or
malfunction

Protection: Sag protection

Voltage sags are particularly problematic for industry where the malfunction of a device may result in huge financial losses. Weather and utility equipment problems are major cause of sags.

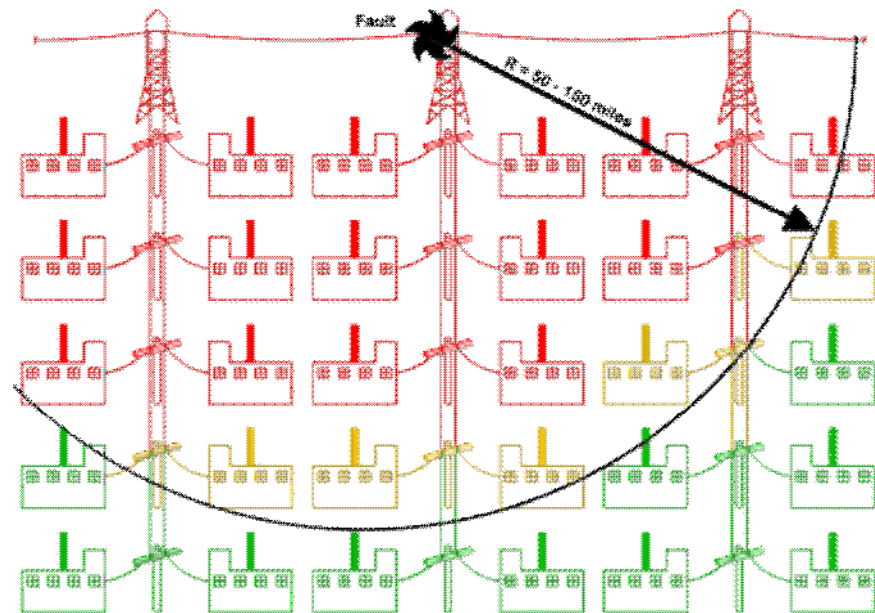
Cause Frequent Shut Down of Sensitive Loads

Voltage Sags

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Affect large areas

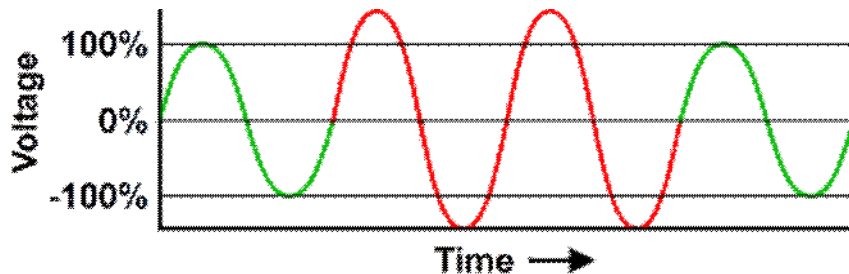
- Events usually start on the transmission or distribution system
 - Weather events
 - Cap bank switching
- Affect huge areas
- 75% of sags affect 1 phase



Often Seem Like Very Brief Interruptions

Swell

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Very short, high voltage rise

Source: Utility or facility

Duration: 0.5 cycles – 60 seconds

Incidence : Very low

Symptom: Malfunction

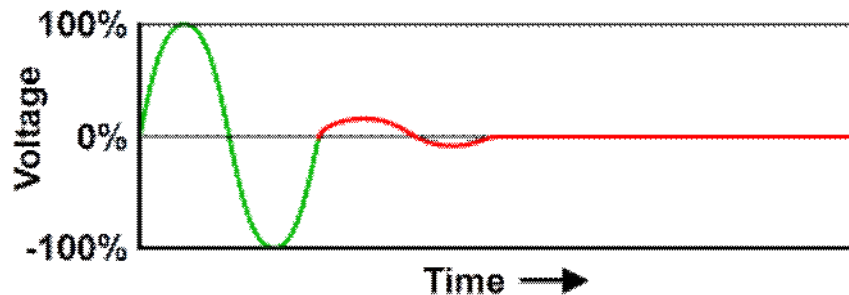
Protection: Voltage isolation

Swells are not a common problem. Most often caused by energizing a capacitor bank or the sudden shut down of very large loads.

Most Often Causes Control Problems

Interruption

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Voltage <10% of nominal

Source: Utility

Duration: 0.5 cycle - >1 hour

Incidence : ~2 per year in U.S.

Symptom: Equipment shutdown

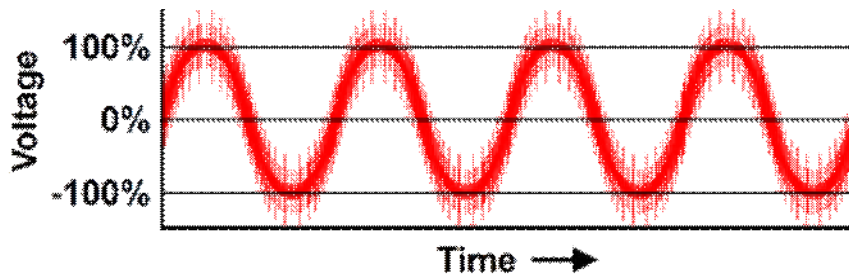
Protection: Energy storage or self-generation

End users in North America experience real interruptions only a few times per year. Voltage sags occur much more frequently and may be mistaken for interruptions.

Causes Little Equipment Damage

Noise

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Distortion of voltage waveform

Source: Power Electronics

Duration: Steady state

Incidence : Low

Symptom: Malfunction

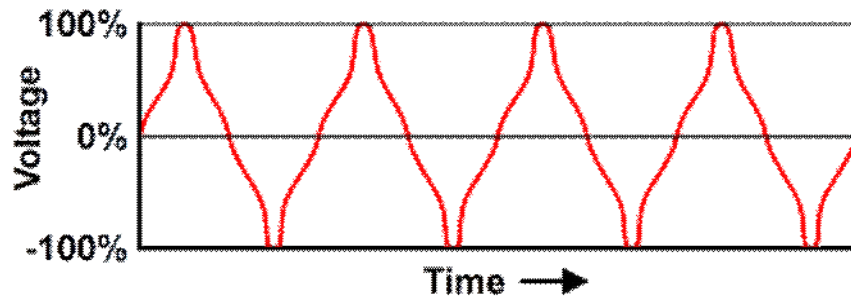
Protection: Filters or transformers

Noise seldom reaches the level of being a major power quality problem. Removing or correcting the source of the noise or applying an appropriate filter are the most common remedies.

Causes Malfunctions or Overheating

Harmonics

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Deformed voltage waveform

Source: Power Electronics

Duration: Steady state

Incidence : Low - medium

Symptom: Overheating or malfunction

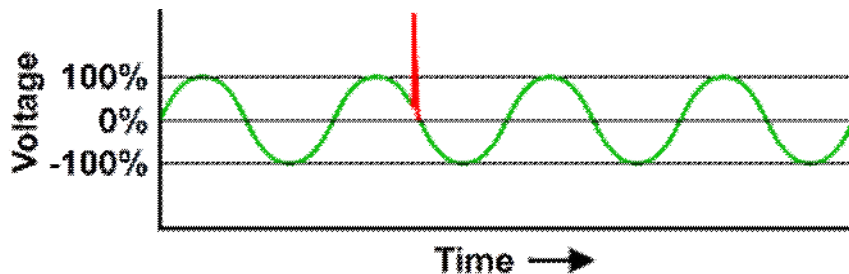
Protection: Filters

Harmonics seldom reach the level of being a major power quality problem. High levels of harmonics can be treated by modifying or isolating the source or applying active or passive harmonic filters.

Causes Significant Overheating

Transient

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Very high voltage pulse

Source: Typically lightning

Duration: <50 ns – 5 ms

Incidence : Low

Symptom: Equipment damage

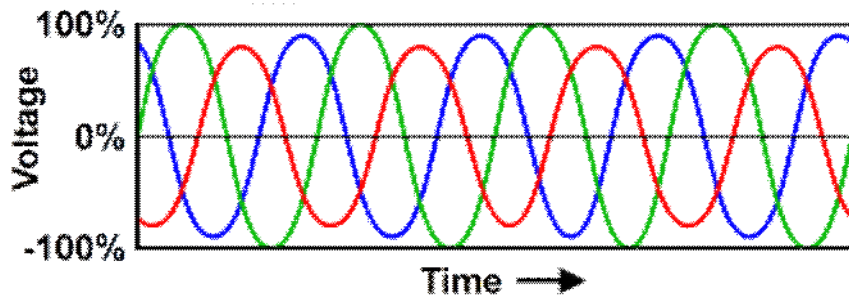
Protection: Surge suppression

Damage from transients occurs infrequently but it can be very devastating when it does occur. Surge suppression is very inexpensive “insurance” for business and industry.

Potentially Widespread Equipment Damage

Unbalance

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Varying voltage levels

Source: Utility or facility

Duration: Steady state

Incidence : Medium

Symptom: Malfunction and
overheating

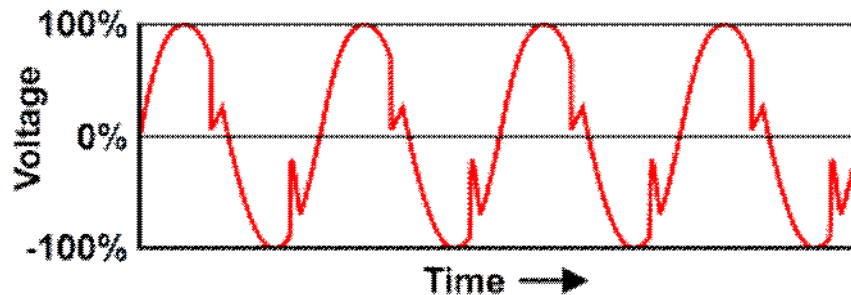
Protection: Voltage balancing

Voltage unbalance affects only three phase systems. Most often it is caused by unequal loads on distribution lines or within a facility. High voltage unbalance can severely degrade motor efficiency and life.

Causes Efficiency Loss and Overheating

Notching

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Deformed voltage waveform

Source: Electronic devices

Duration: Steady state

Incidence : Very low

Symptom: Malfunction

Protection: None

Notching can be caused by certain electronic devices. While it is rarely a problem, the solution usually involves isolation of sensitive equipment from the offending device.

Causes Operation Problems

Other PQ Terms

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Common, but undefined, terms:

- “Outage” or “Blackout” \approx interruption
- “Brownout” \approx intentionally low grid voltage
- Surge \approx high energy transient

Avoid these terms



~~Glitch~~
~~Clean power~~
~~Spike~~
~~Dirty power~~

Proper Terminology Is Important

Voltage Problem Summary

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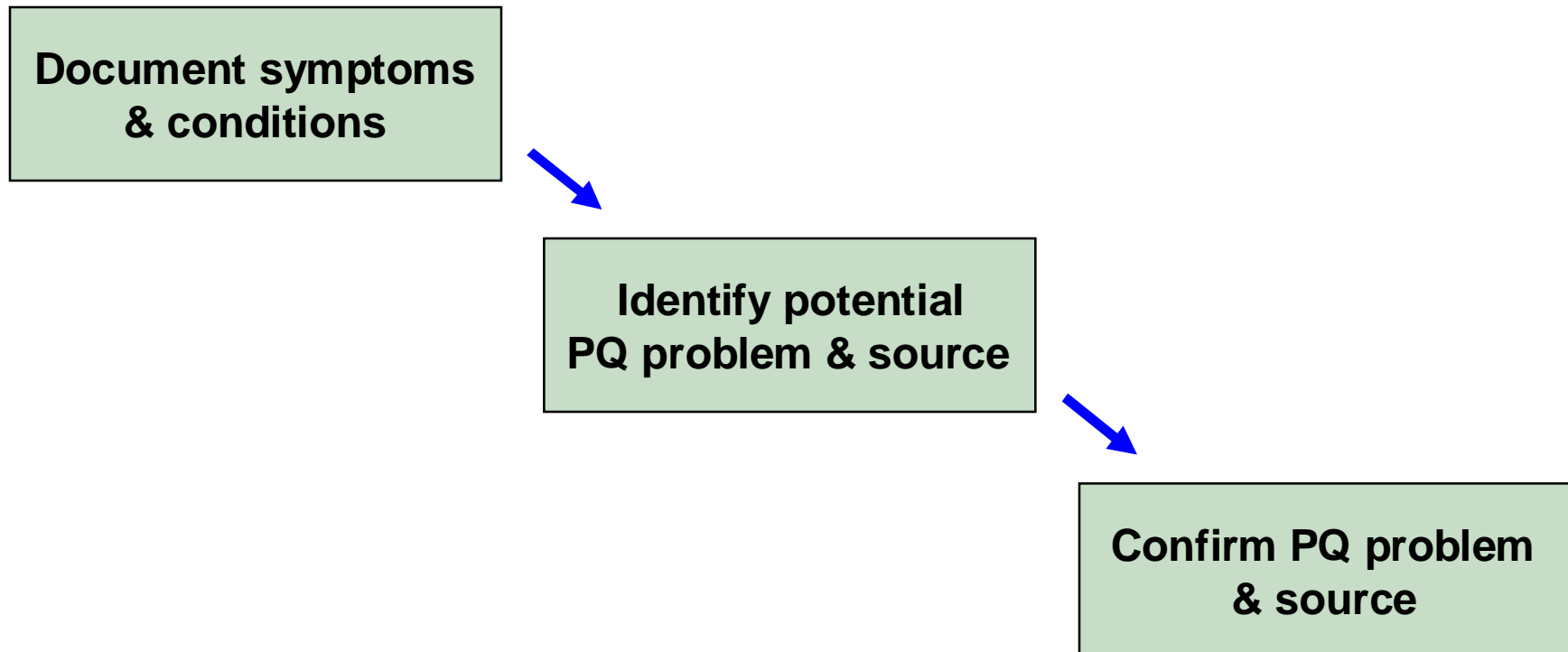


Problem	Typical Duration	Typical Voltage Change from Nominal	Typical Incidence Frequency/Cost
Transient*	<50 ns – 5 ms	Thousands of %	Low/\$\$\$\$
Sag*	0.5 cycles – 60 s	10 – 90%	High/\$-\$\$\$
Swell	0.5 cycles – 60 s	110 – 180%	Low/\$
Interruption*	0.5 cycles – >1 hour	<10%	Very Low/\$\$-\$\$\$
Undervoltage*	>1 minute	90 – 99%	Medium/\$\$-\$\$\$
Overvoltage*	>1 minute	101 – 110%	Medium/\$\$-\$\$\$
Harmonics	Constant	0 – 20%	Low/\$-\$\$
Noise	Constant	0 – 1%	Low/\$-\$\$
Notching	Constant		Very Low/\$
Unbalance	Fluctuating	0 – 15% Phase-Phase	Medium/\$-\$\$

Most Problematic *

Identifying PQ Problems

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Problem Identification Is Key

Document Symptoms

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Record suspected PQ events

- Malfunction or damage
- Time & date
- Any power info available
- Weather conditions
- Operating situation
- Loads starting/stopping
- Recent changes
- Other anomalies



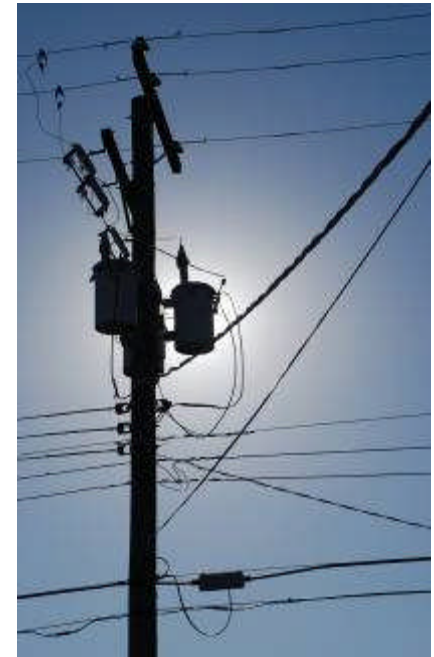
First Step in Solving PQ Problems

Identify Problems

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A process of elimination

- Measure RMS voltages over time
 - At service entrance
 - At machine level
 - Check unbalance
- Then, check for sag or transients
- Then, check for noise or harmonics
- Etc.



Electrical Forensic Investigation

Power Quality Monitoring

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Invaluable Protection

- Easily identify problem & trends
- Permits proactive protection
- Support for insurance claims
- Protect major investments
- Relatively inexpensive (\$2 – 5K)
- At least one unit at service entrance



An Important Maintenance Tool

Confirm Source

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Compare records & measurements

- Records should confirm measurements
- Identify source of problem
 - External, internal or both
- Identify PQ problem type
 - May be multiple problems



Solution Depends on Source & Problem

Under/Overvoltage Solutions

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Typical products

Device	kVA Size	Advantages	Disadvantages
Servo-mechanical voltage regulator	5 – 2,000	Low price	Slow response High Maintenance
Electronic tap switching voltage regulator	5 – 2,000	Very fast response Solid state	Higher price
Ferroresonant transformer	0.5 - 25	Very fast response Solid state	Very poor efficiency Single phase only

Three phase regulators are often used to correct **voltage unbalance**

Voltage Regulators

Voltage Sag Solutions

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Typical products

Device	kVA Size	Advantages	Disadvantages
UPS	5 – 2,000	Line isolation Many choices	Poor efficiency High cost
Flywheel	20 – 150	No batteries	Small sizes Mechanical device
Active voltage conditioner	10 – 2,000	Lowest cost Very high efficiency	Sag protection only

Swells often require a custom solution

Very Different Technology Choices

Interruption Solutions

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Typical products

Device	kVA Size	Advantages	Disadvantages
UPS – double conversion	5 – 2,000	Voltage regulation Line isolation	Poor efficiency High O&M cost
UPS – line interactive	20 – 50	Voltage regulation Lower cost	Mostly smaller sizes
UPS - standby	0.3 – 5	Lowest cost Very high efficiency	No regulation

Lots of Products – Lots of Confusion

Typical products

- Filters, transformers and other devices
- Passive devices designed for a specific problem
- Active devices respond to changing problems
- Typically designed for the specific application

Solutions May Require Customization

Typical products

- TVSS – Transient Voltage Surge Suppressor
- Large variation in protection levels & price
- Usually applied at service entrance
- May be included in other devices

Inexpensive Protection from Catastrophe

Comparing Typical Solutions

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Power Conditioner Type	Effectiveness for Power Quality Problems			Typical Efficiency (%)
	Undervoltage Overvoltage	Voltage Sags	Interruptions	
Mechanical Voltage Regulator	Fair - Good	None	None	97 - 99
Electronic Voltage Regulator	Superior	Poor - Fair	None	95 - 99
Ferroresonant Transformer	Good - Superior	Poor - Fair	None	60 - 90
Active Voltage Conditioning	None - Poor	Superior	None - Poor	94 - 99
Double Conversion UPS <u>w/o</u> Batteries	Fair - Good	None - Poor	None	85 - 94
Double Conversion UPS <u>with</u> Batteries	Fair - Good	Good - Superior	Good - Superior	85 - 94
Line Interactive UPS	Fair	Good	Good	94 - 97
Standby UPS	None - Poor	Poor - Fair	Good	97 - 98
Flywheel UPS	None - Poor	Superior	Poor - Fair	96 - 98

No Device Solves Every Problem

What is a power conditioner?

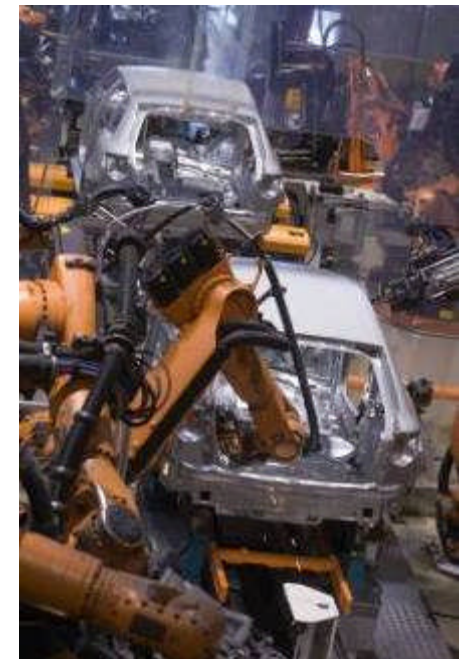
- No standard definition
- Traditionally – a voltage regulating device with other capability
- Could be almost anything
- Check the specs



A Very Confusing Term

What is the best solution?

- Define \$ cost of PQ problems
- Define cost of solution
- Calculate solution effectiveness
- Calculate payback



Simple Cost-Benefit Analysis

Cost of PQ Problems

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Define \$ cost per PQ event

- Scrap, disposal & cleanup
- Lost productivity & overtime
- Lost energy or extra energy
- Maintenance & service costs
- Extra QA or mandatory reporting



Easy to Under-Estimate PQ Costs

Owning cost of PQ solutions

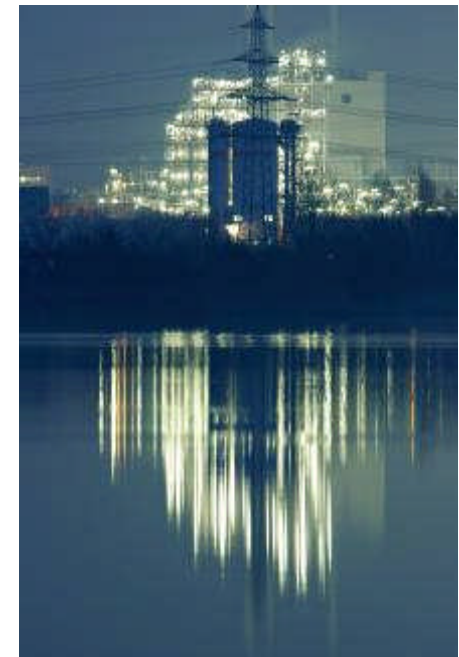
- First cost + installation
- Operation & maintenance
 - Energy cost
 - Service & maintenance labor
 - Regular replacement parts
 - Batteries, capacitors, etc.



O&M Can Be a Major Cost

How many events are avoided?

- Compare performance to problems
 - Will solution correct all events
- Availability & reliability
 - Is solution “on-line” 24/7/365
 - Estimate service or recharge time
 - Adjust effectiveness for unavailability



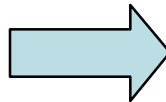
Consider Time “Off-line” Solution Requires

Solution Payback

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Calculate value of solutions

$$\frac{\text{Problem Cost} - \text{Solution Cost}}{\$ \text{ Savings}}$$



$$\frac{\text{Solution First Cost}}{\$ \text{ Savings}}$$

Investment Payback

Payback May Be In Months or # of Events

Sag Protection Example

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A food/beverage plant -

- 5 deep voltage sag events/year
 - Shut down only bottling line
 - Rest of plant rides through sags
 - But, bottling line shutdown stops plant
 - Costs \$20,000 per sag event
 - Bottling line needs 500 kVA



A Typical Problem

Sag Protection Example

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Compare UPS and sag mitigator each 500 kVA, 480V, 3 phase

	UPS	Sag Mitigator
First cost, typical installation	\$210K	\$130K
Annual service contract	\$7K	N/A
Annualized wear parts (batteries)*	\$18K	N/A
Annual energy losses**	\$50K	\$4K
Total annual operation & maintenance cost	\$75K	\$4K
10 year total owning cost (First + 10x annual O&M)	\$960K	\$170K

*24 to 30 month replacement cycle **UPS: 90% efficiency, \$0.10/kw-hr, HVAC load

Huge Difference in Owning Cost

Sag Protection Example

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Assume both solutions correct same # of sag events

Both solutions save = $5 \times \$20,000 = \underline{\$100,000/\text{year}}$

UPS costs \$96K/year - Sag mitigator costs \$17K/year

UPS saves \$4K/year – Sag mitigator saves \$83K/year

Payback: UPS ~ 50 years – Sag mitigator ~ 18 months

Sag Mitigator Needs No Batteries

Key Evaluation Parameters

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- Performance
 - More may not mean better
 - Buy only what is needed
- Operating costs
 - Efficiency (e.g. energy cost)
 - Maintenance (e.g. batteries)
 - Service contracts
 - Required redundancy



Know What You Are Buying

Choosing a “Green” Solution

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- Efficiency
 - Choose the highest possible
 - Can up to 99%
- Environmental issues
 - Avoid batteries when possible
- Some solutions can save energy
 - With high efficiency, and
 - Optimized voltage levels



Eco-Friendly Power Quality