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# ***Electric Power Quality***

**Ward Jewell**

**Professor, Electrical Engineering  
Director, Center for Energy Studies  
Wichita State University**

**Consulting Electrical Engineer**



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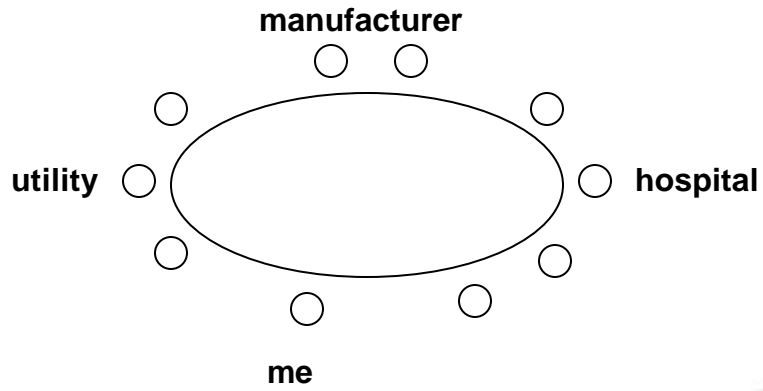
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## ***Hospital CT scanner failures***

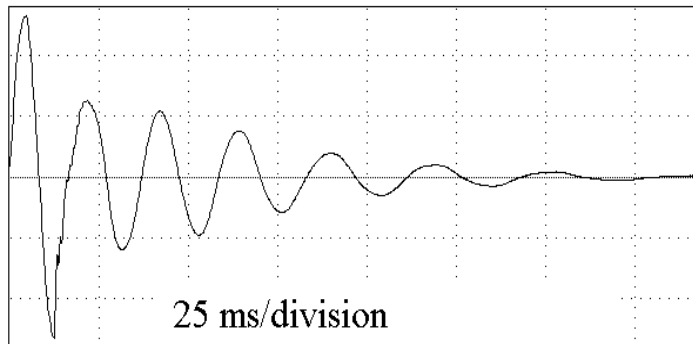
During a normal half-hour series of scans, a CT scanner records images on a microcomputer that also controls the scanner. As often as twice each day, this hospital's scanner would shut down before a series was complete. The recorded images were lost, and the patient was subjected to a repeat of the entire series. Utility personnel found one cause of the shutdowns to be momentary power outages caused by trees brushing against utility distribution lines. They corrected this by trimming trees. Another cause was then found to be voltage sags that occurred when the hospital's chiller started. An improper setting on the scanner's power control was corrected, and this problem disappeared.



# ***MEDIATE !!!***

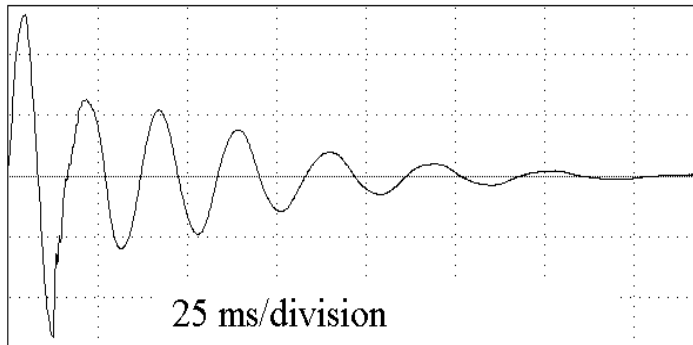


Volts (50 V/division)



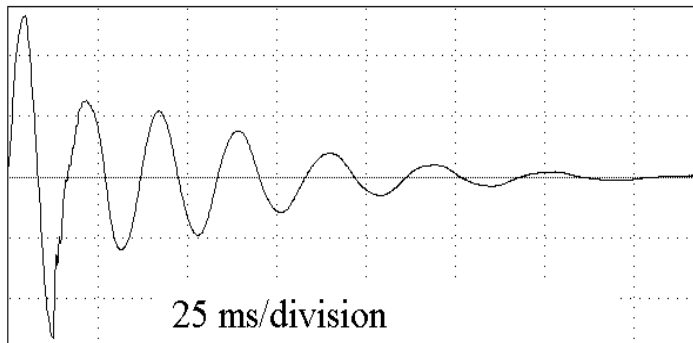
***Momentary outage when tree limbs contact distribution line***

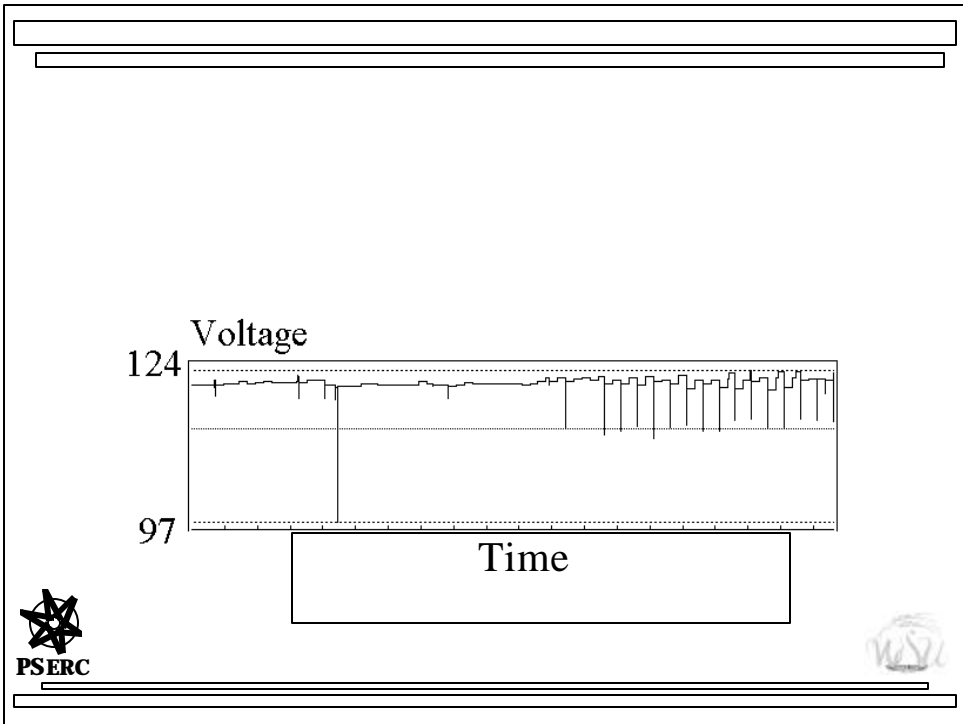
Volts (50 V/division)



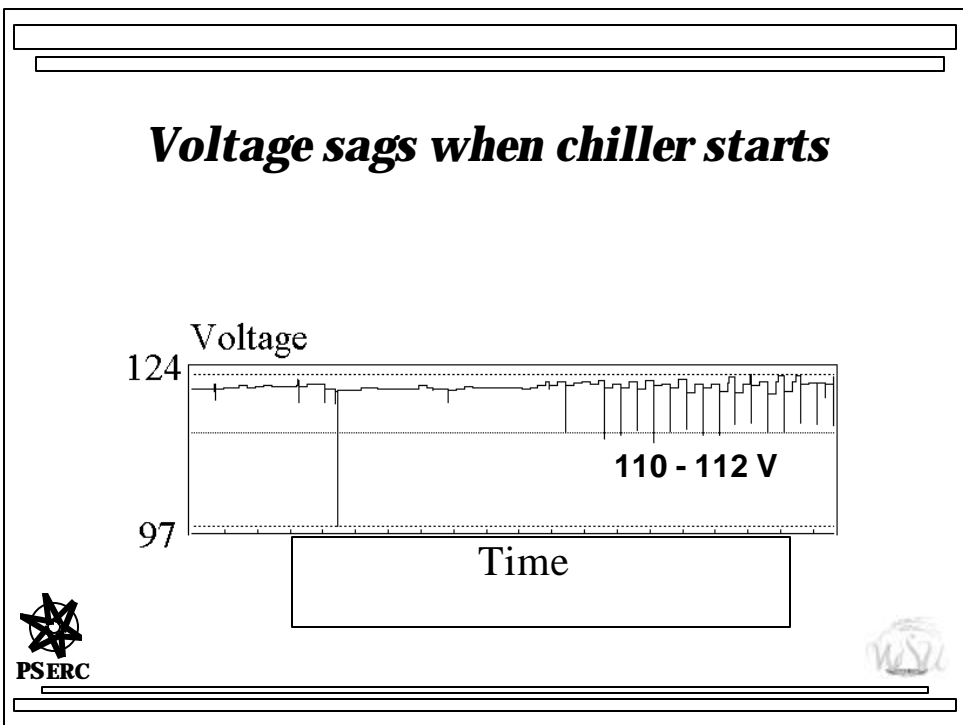
***Recloser operates***

Volts (50 V/division)





***Voltage sags when chiller starts***



***“... voltage setting should be  
+10% of supply voltage ...”***

**- CT scanner installation manual**

**Nominal voltage 120 V: 108 - 132 V**



***“... voltage setting should be  
+10% of supply voltage ...”***

**- CT scanner installation manual**

**Nominal voltage 120 V: 108 - 132 V**

**Measured voltage at installation 126 V:  
113 - 139 V**

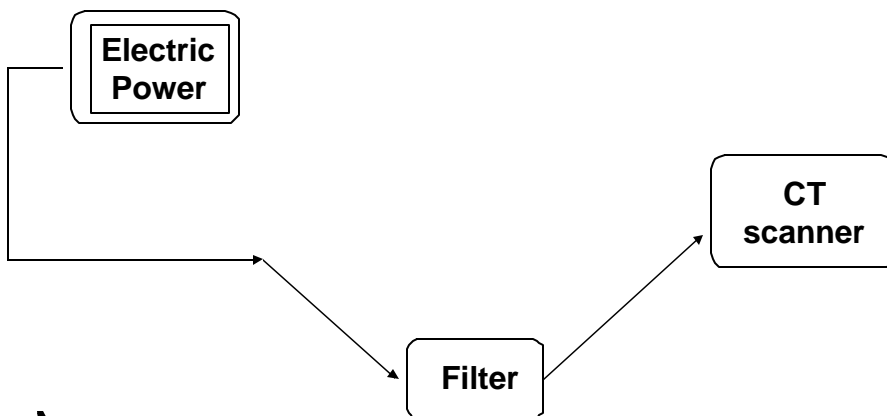


## ***Solution:***

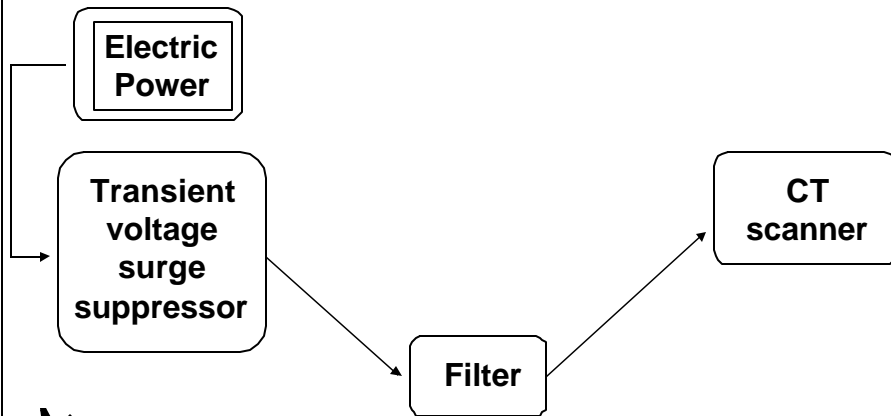
- Trim trees
- Remove instantaneous recloser trip
- Reset CT scanner low voltage dropout to 108 V.



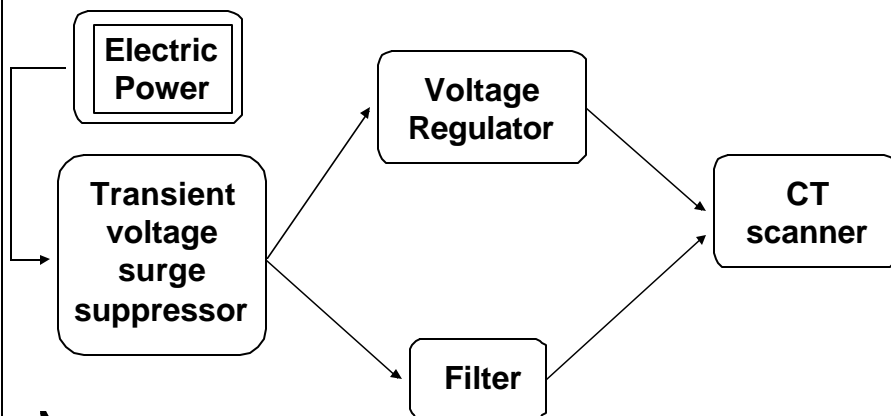
## ***Power Line Conditioners***



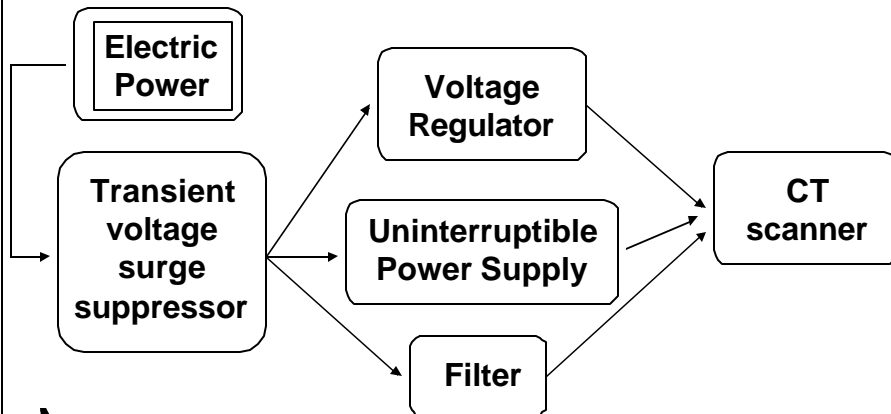
## ***Power Line Conditioners***



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## ***Power Line Conditioners***



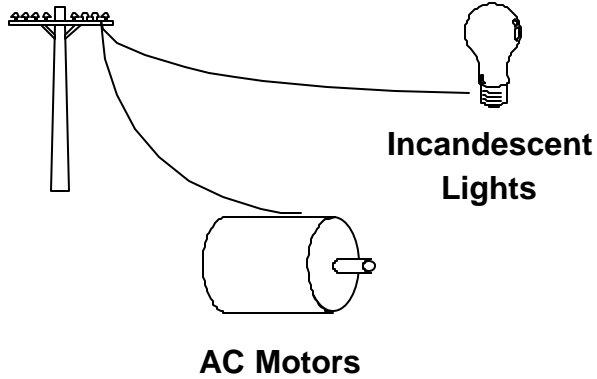
## ***Another option: Static transfer switch***

- Transfers load to another source
- Electronic switch
- Fast; user notices no change

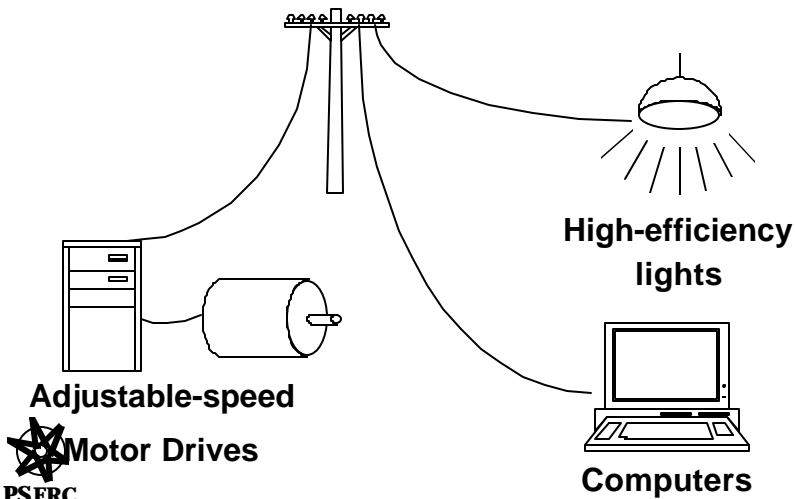




***Our power systems were designed  
for:***

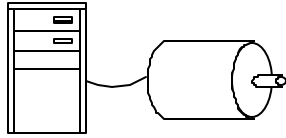


***Now the power system serves***

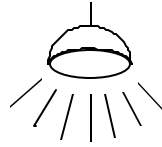


## ***Disturbing loads***

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**Adjustable-speed  
Motor Drives**



**High-efficiency  
lights**



PSERC

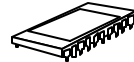


## ***Sensitive Loads***

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**Computers**



**Microprocessor-controlled  
equipment**

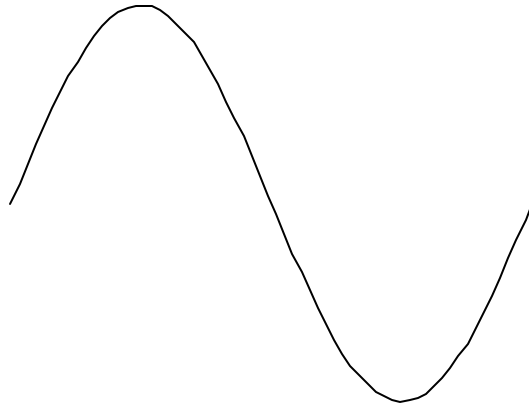


PSERC



# ***POWER QUALITY***

**IS**



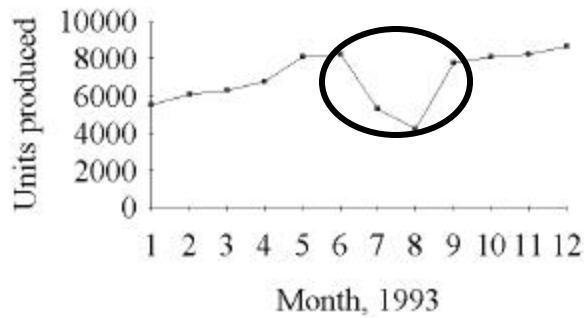
# ***A POWER QUALITY PROBLEM***

**IS**

**when something doesn't work because of  
the electric power supplied to it.**



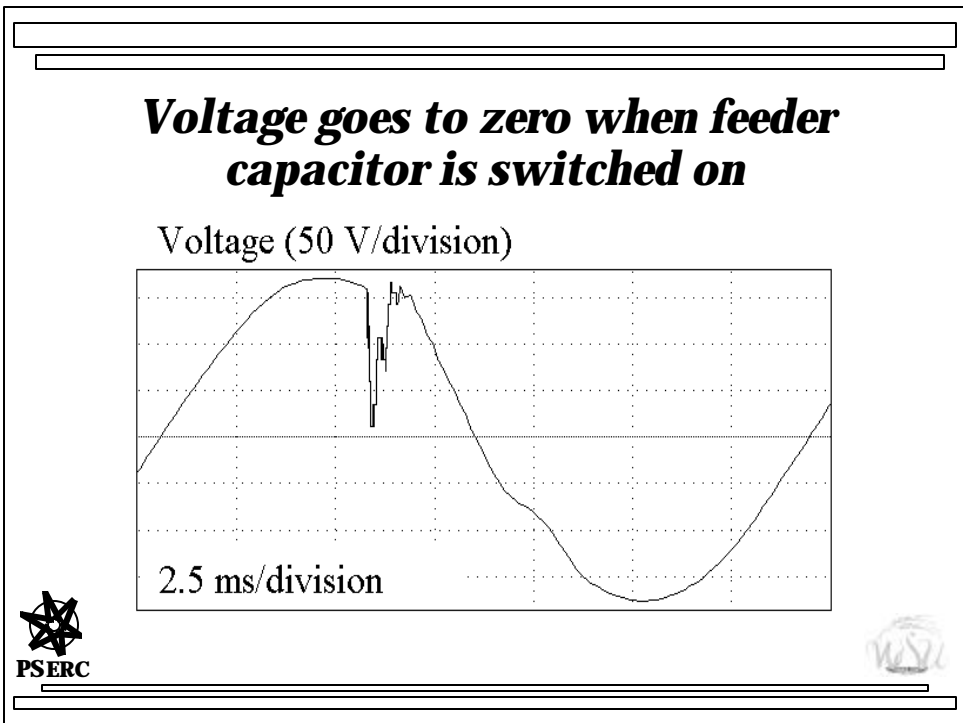
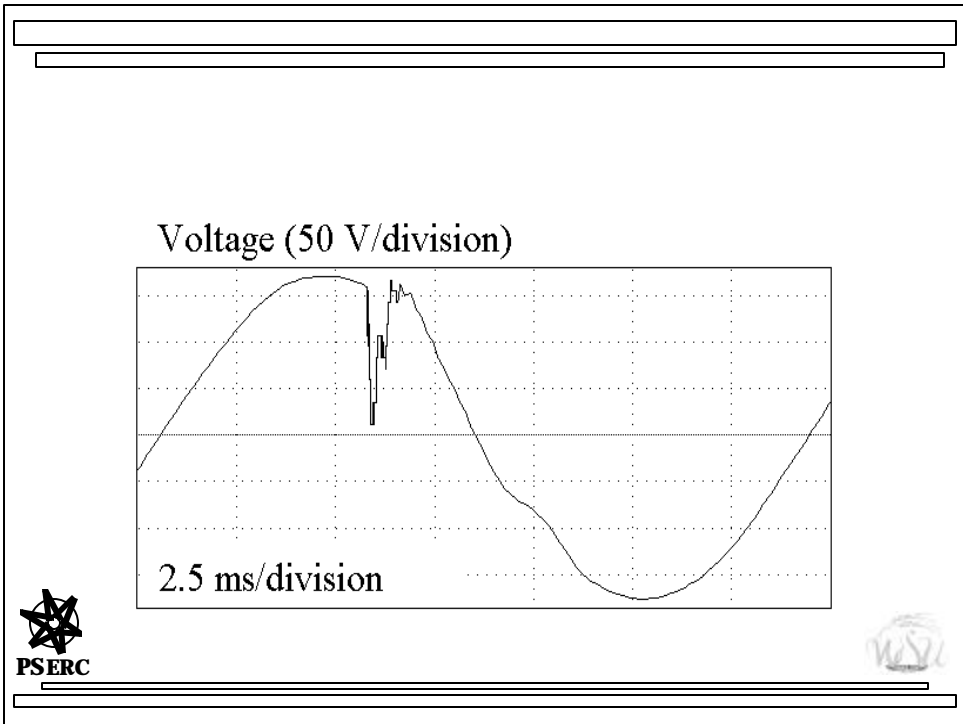
## ***Power quality problems***



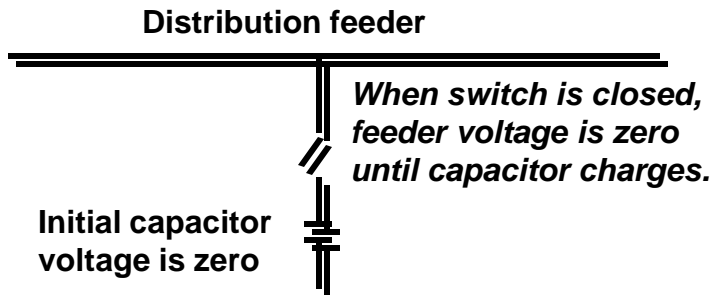
## ***Radio transmitter damage***

A commercial FM radio station experienced repeated failure of its transmitter. Utility engineers determined that each failure coincided with switching of capacitors at the distribution substation. Capacitor switching transients were recorded at the radio station service entrance. An electrical snubber was designed to reduce the frequency and damp oscillations in the transmitter. The snubber was installed, and no further rectifier failures occurred.

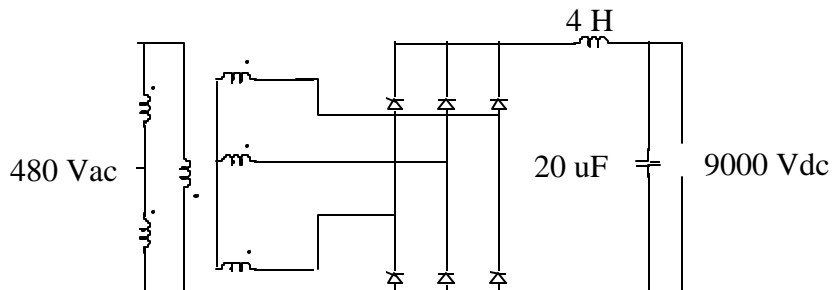




## Capacitor switching

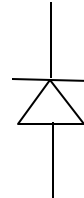


## Transmitter dc power supply



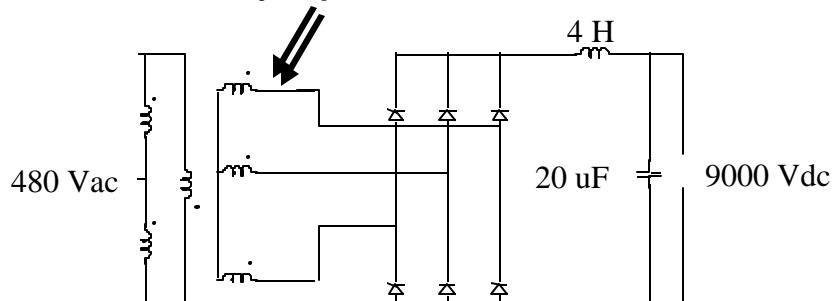
## Diode ratings

- Reverse voltage
- Forward voltage drop
- Forward current
- Turn off time:  $\sim 0.3$  ms

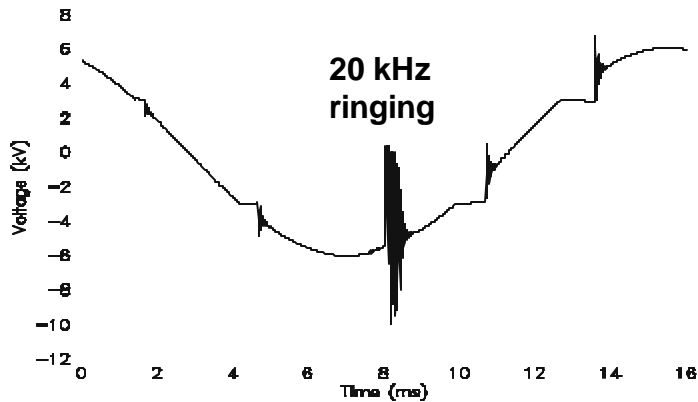


## Transmitter dc power supply

*Reactance,  
stray capacitance*

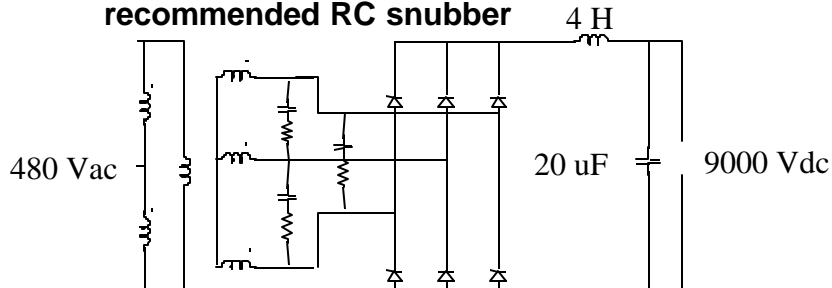


## ***Transformer high voltage when capacitor switched***



## ***Solution: call someone who knows what to do!!!***

Transmitter design engineer recommended RC snubber



***No more failures!***





## *Metal fabrication plant equipment failures*

An industrial plant where sheet metal is fabricated experienced various machinery failures. An initial survey revealed adjustable speed dc motor drives, a common disturbing load, in use in the plant. Power quality measurements confirmed that one of the drives was causing severe "notching," a transient voltage disturbance. This was corrected using series reactors. A grounding error on a transformer was also found and corrected.

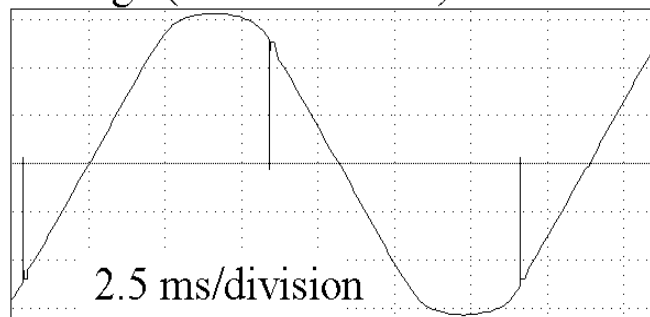


PSERC



## *Voltage notching*

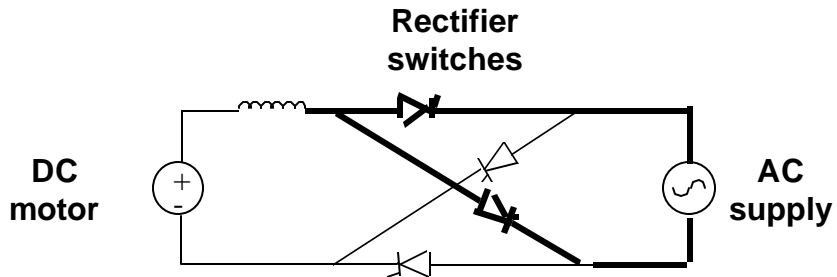
Voltage (280 V/division)



PSERC



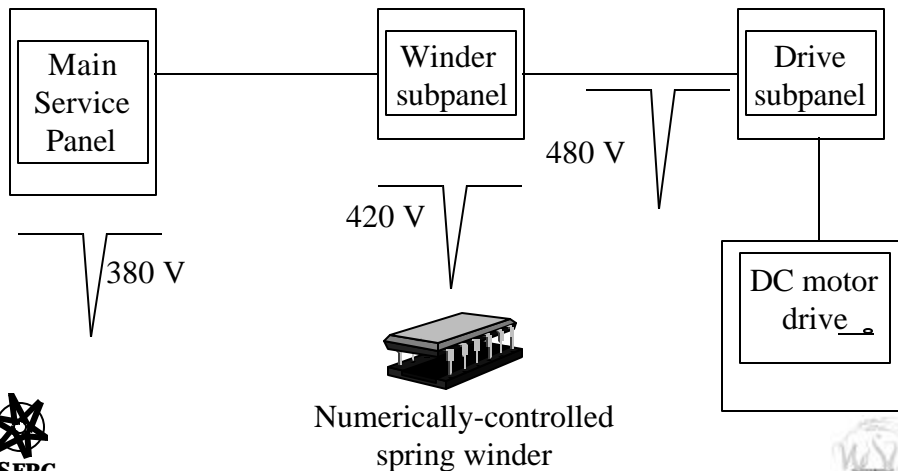
## ***DC motor adjustable speed drive***



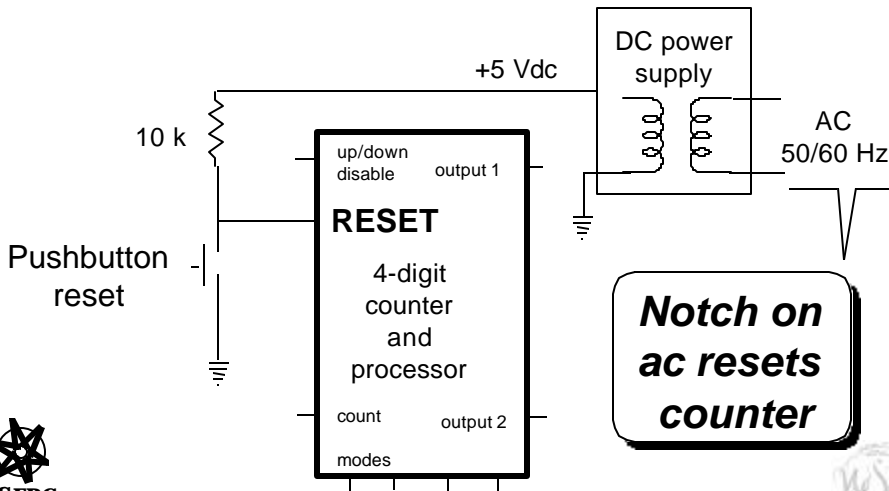
***Two switches closed causes momentary short circuit and "notch"***



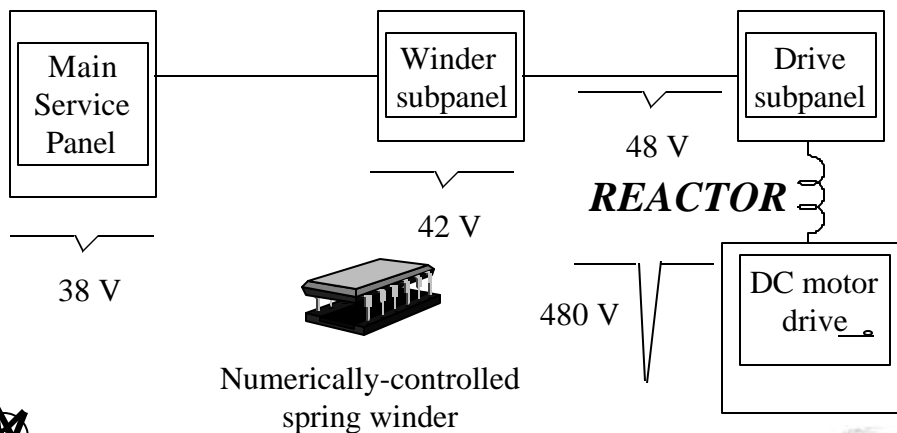
## ***Voltage notching***



## Spring winder counting circuit

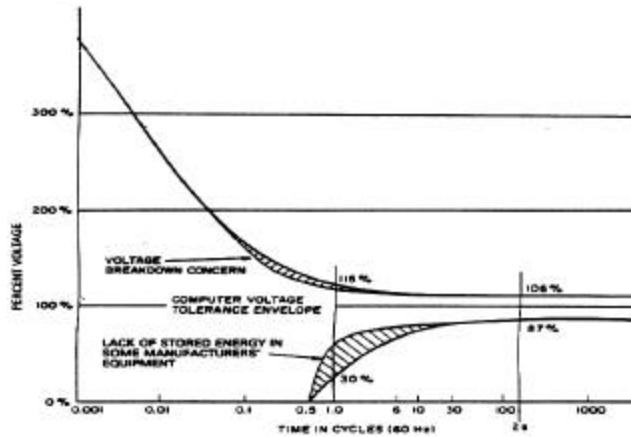


## Series Reactors



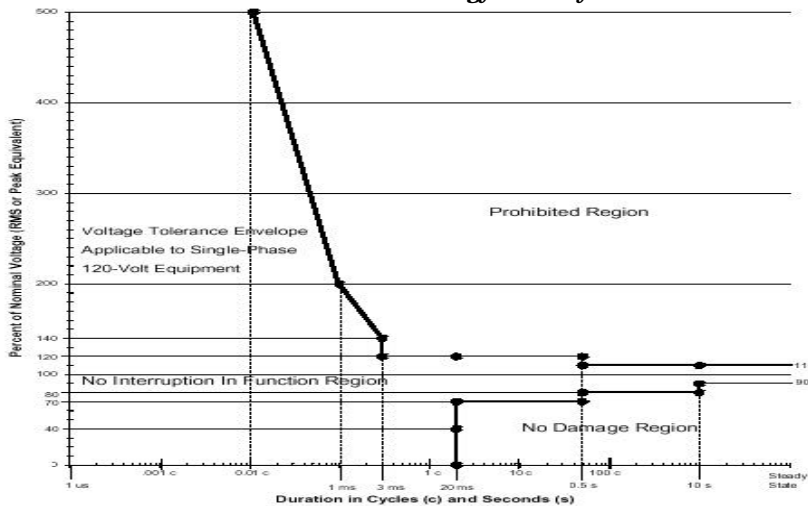
# The CBEMA curve

Computer Business Equipment Manufacturers' Association



# The ITIC Curve

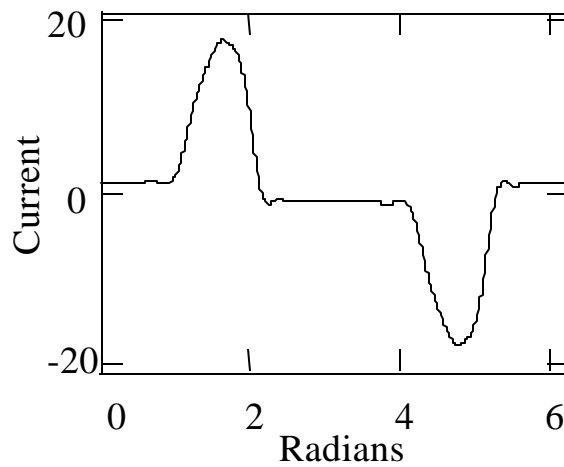
Information Technology Industry Council



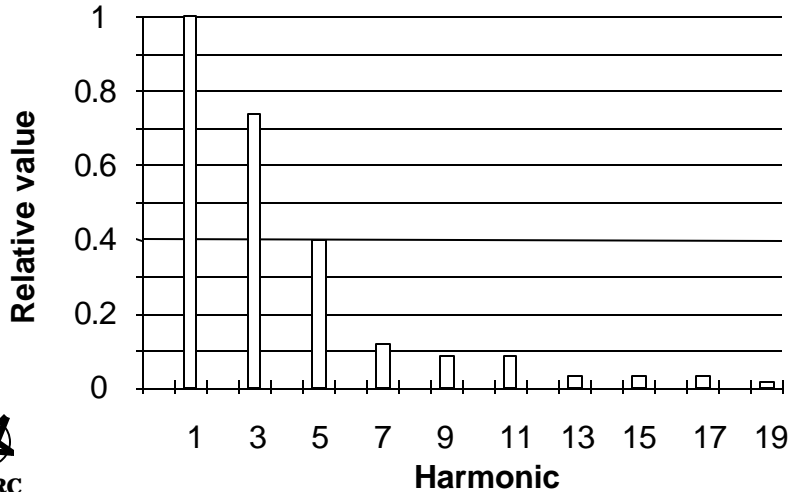
# Harmonics



## *Distorted current waveform to PCs*



## Fourier series - spectrum - of pc current waveform



## Total Harmonic Distortion (THD)

	Harmonic number	$\frac{I_h}{I_1}$	$\left(\frac{I_h}{I_1}\right)^2$	
<b>fundamental</b>	1	1	1	$\sum_{h=2}^{19} \left(\frac{I_h}{I_1}\right)^2 = 0.732$
	3	0.737	0.543	
	5	0.399	0.159	$\sqrt{\sum_{h=2}^{19} \left(\frac{I_h}{I_1}\right)^2} = 0.855$ <b>THD = 85.5%</b>
	7	0.115	0.013	
	9	0.083	$6.889 \cdot 10^{-3}$	
	11	0.082	$6.724 \cdot 10^{-3}$	
	13	0.029	$8.41 \cdot 10^{-4}$	
	15	0.029	$8.41 \cdot 10^{-4}$	
	17	0.029	$8.41 \cdot 10^{-4}$	
	19	0.012	$1.44 \cdot 10^{-4}$	

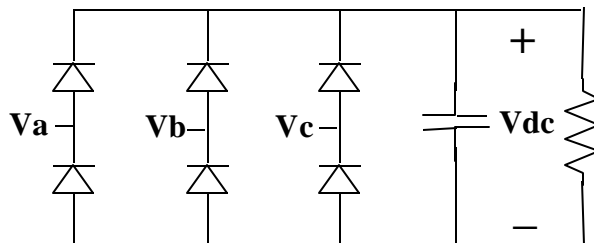


## ***What causes harmonics?***

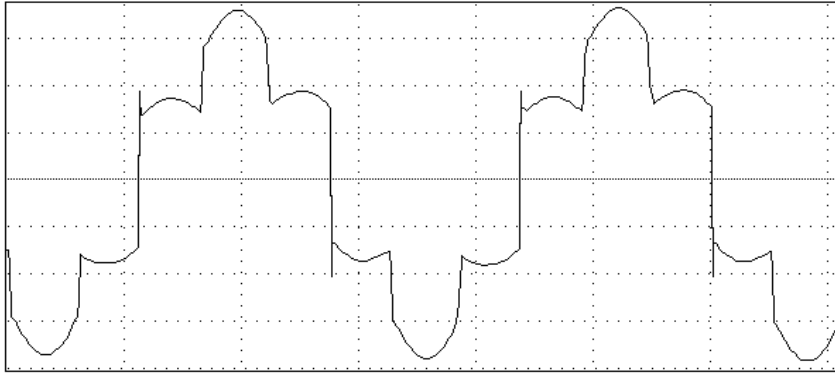
- Saturated transformers
- Arcs
  - Arc furnaces, fluorescent lights
- Rectifiers
  - Microprocessors, motor drives, ***any*** electronic load



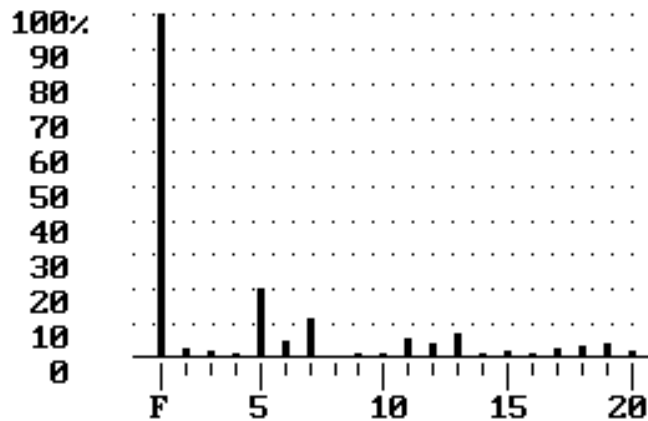
## ***Three-phase full wave rectifier***



## *AC current to 6-pulse battery charger*



## *AC current to 6-pulse battery charger*





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## ***Harmonics cause***

- **Transformers to overheat**
- **Transformer secondary voltage distortion**
- **Increased power system losses**
- **Telephone and wired communication systems noise**
- **Neutral overloads**



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## ***Other harmonic issues***

- **Watt-hour meters**
  - **May read high or low**
- **Protective relays**
  - **May not sense RMS values**
  - **Nuisance trip or fail to trip**
- **Digital clocks**
  - **May run fast**



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## ***Solutions***

- Use full sized or oversized neutral conductors
- Oversize or harmonic rate transformers
- Detune system (move capacitors, install reactors)
- Filter (install passive or active harmonic filters)



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## ***Power Quality Disturbances***

- **Voltage transients**
  - One time; impulse or oscillatory; shorter than half cycle
- **Voltage variations**
  - One time; sag, swell or interruption; longer than half cycle
- **Voltage imbalance**
  - Steady state
- **Waveform distortion (voltage or current)**
  - Steady state; dc offset, harmonics, interharmonics, notching, noise
- **Voltage fluctuations**
  - Intermittent
- **Frequency variations**
  - Shorter than ten seconds



## *Power Quality References*

***IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment***, IEEE Emerald Book (IEEE Std. 1100-1992), IEEE, 345 E. 47th St., New York, NY, 10017-2394, 1992.

***Guideline on Electrical Power for ADP Installations***, Federal Information Processing Standards Publication 94 (FIPS PUB 94), NTIS, US Dept. of Commerce, Springfield, Virginia, 22161.

*The IAEI Soares Book on Grounding*, 4th Edition, International Association of Electrical Inspectors, 930 Busse Highway, Park Ridge, Illinois, 60068, 1991.

Jerry C. Whitaker, *AC Power Systems Handbook*, CRC Press, 2000 Corporate Blvd., Boca Raton, Florida, 33431, 1991.

*Power Quality Assurance Magazine*, Intertec International, 2472 Eastman Ave., Bldgs. 33 and 34, Ventura, California, 93003-5792.

Roger R. Block, *The "Grounds" for Lightning and EMP Protection*, Second Edition, Polyphaser Corporation, 1993.

*Agricultural Wiring Handbook*, National Food and Energy Council, 409 Vandiver West, Suite 202, Columbia, Missouri, 65202, 1990.

*Power Line Interference, A Practical Handbook*, National Rural Electric Cooperative Association, 1800 Massachusetts Ave, NW, Washington, DC 98501, 1992.

*Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents* (ANSI/IEEE C57.110-1986), IEEE, 345 E. 47th St., New York, NY, 10017-2394, 1988.

*IEEE Recommended Practice for Harmonic Control in Electric Power Systems* (IEEE 519), IEEE, 345 E. 47th St., New York, NY, 10017-2394, 1992.

*National Electrical Code 1993* (ANSI/NFPA 70), NFPA, Batterymarch Park, Quincy, Massachusetts, 02269, 1992.

*National Electrical Safety Code 1990* (ANSI C2-1990), IEEE, 345 E. 47th St., New York, NY, 10017-2394, 1989.

*The Dranetz Field Handbook for Power Quality Analysis*, Dranetz Technologies Inc., 1000 New Durham Road, Edison, New Jersey, 08818, 1991.

Alexander McEachern, *Handbook of Power Signatures*, Basic Measuring Instruments, 335 Lakeside Drive, Foster City, California, 94404, 1989.

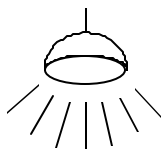


# *Site Surveys*



## *Power quality is suspected when:*

Lights  
flicker

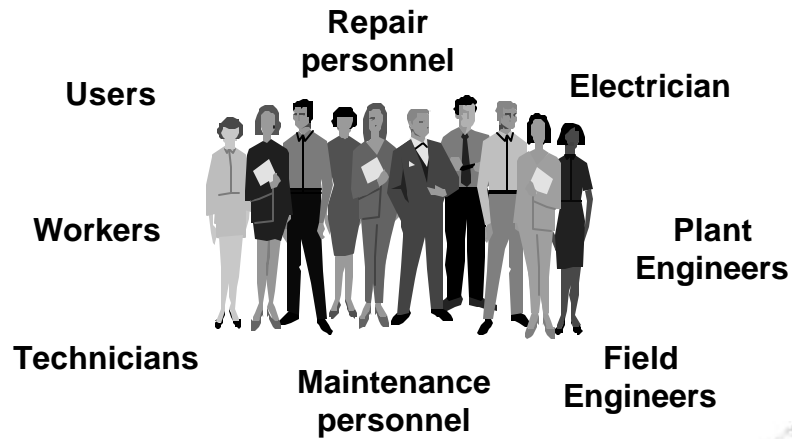


or

Someone else  
can't figure out  
what's wrong



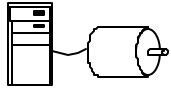
## ***Talk to everyone***



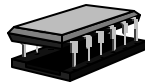
## ***Acknowledge frustration!!!!***



## ***Determine exactly what is wrong***



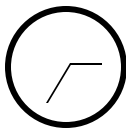
**What's not working?**



**What's it doing?**



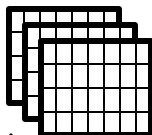
## ***When does it happen?***



**Time of day?**

**How often?**

**When did it start?**



**Time of week, month, year?**



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## ***What changed before the problem started?***

- Changes to electric power system?
- New equipment?
- Equipment relocated?



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## ***Have user keep a log***

Date	Time	Equipment	Problem	Observations, notes

**Compare with utility  
operation and service logs**



## ***Walk through the facility***



- List disturbing loads
- List susceptible loads
- Talk with people as you go



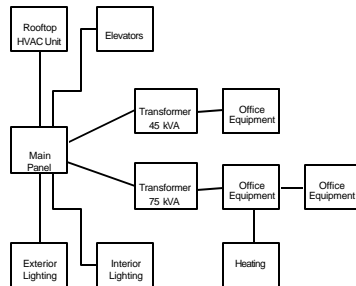
## ***Inspect feeder***

- Trim trees
- Check recorders for activity
- Transformers
- Capacitors
- Fuses
- Connections





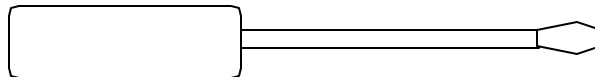
## Get wiring diagrams



Identify connections among disturbing and affected loads



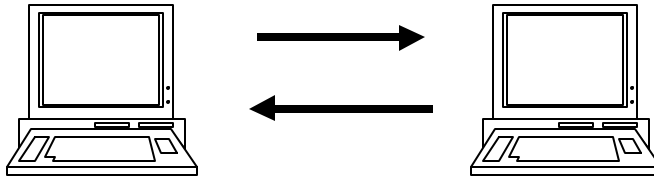
## Inspect and repair facility wiring and grounding



- National Electrical Code
  - Correct safety problems first
- Powering and Grounding Sensitive Electronic Equipment (IEEE 1100, the *Emerald Book*)
  - Use Figure 6-1 forms



***Replace equipment with duplicate  
if possible***



**If replacement works,  
the problem isn't power quality.**



***Ask for help from  
equipment design engineer***



**Describe problem  
first by phone  
then fax or e-mail**



***Most problems  
will be solved  
by now.***



***Still no solution?***

- Measure power quality
  - Digital multimeter (true rms reading)
  - Wiring and grounding survey equipment
  - Oscilloscope
  - Power quality monitor
  - Field strength meter
  - Spectrum analyzer

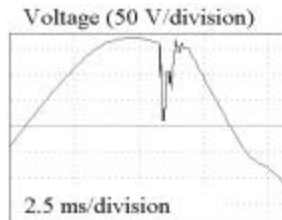


## ***Power quality analysis technique***

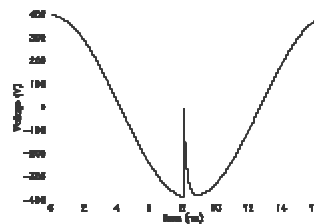
- Begin at affected equipment
- Move away from affected equipment to locate source
- Measure at service entrance to determine if source is inside facility
- Measure on transformer primary (distribution feeder) to determine if utility or another customer is source
- Connect monitor to phone line for long-term remote operation if no disturbance is detected



## ***Simulate if necessary***



*Actual*



*Simulated*

- Duplicate disturbance and effects to verify cause
- Safely test various solutions before implementing



## ***Specify solution***

**Do not allow a vendor to specify equipment  
(you may get something you don't need)**

*Instead:*

**Specify the equipment needed,  
then request quotes from several vendors**



## ***Summary***

- Mediate - people will be frustrated
- Talk to the people using the equipment
- Fix NEC problems - power quality will improve
- Call equipment designers for help
- Specify the needed solution

