

BEYOND

SMART CITIES



ELECTRICAL POWER SYSTEMS - CEM

REFRESHER TRAINING

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FOR ENERGY MANAGEMENT AND EFFICIENCY PROFESSIONALS



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ESTIMATING SAVINGS FROM

POWER FACTOR IMPROVEMENT - 2

FOR ENERGY PROFESSIONALS

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ENERGY SPECIALIST CURRICULUM



WHAT SHOULD YOU LEARN



Electrical Basics (DC/AC, Single and 3-Phase Power)

Resistive and Inductive Loads, Power Factor

Voltage Imbalance, Grounding and Harmonics

Estimating Savings from Power Factor Improvement

Important 3-phase Motor Equations and Estimating Power Consumption



POWER QUALITY

Power Quality is related to how well a bus voltage—usually our facility load bus voltage—maintains a pure sinusoidal waveform at rated voltage and frequency.

PQ issues involve all momentary phenomena including spikes, notches and outages; as well as harmonics and power factor.

Modern electronic equipment both causes and is affected by the problem.

Power Quality is becoming one of the most important issues in energy management today.



HARMONICS



- ✓ Harmonics are a multiple of the fundamental frequency. If the fundamental frequency is 50 hertz, the 2nd harmonic is 100 Hz, the 3rd is 150 Hz, the 4th is 200 Hz, etc.
- ✓ Harmonics are usually generated by solid-state-based equipment such as switching power supplies in PCs, DC drives, variable frequency drives (VFDs), electronic ballasts, arc welders and ovens.

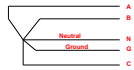


IMPORTANCE OF GROUNDING

- ✓ Up to 80 percent of PQ problems in facilities today may be caused by wiring and grounding systems that met the NEC at the time, but do not meet the needs of today's sensitive electronic equipment.
- ✓ The first step taken to deal with PQ problems should be to inspect the wiring and grounding, and clean and tighten all connections. Loose connections come from vibration, oxidation, corrosion, and age.
- ✓ In a typical delta-wye main load center for a facility, the supply system ground, the neutral connection of the wye, and the equipment ground must all be bonded together in that enclosure.
- ✓ Each piece of equipment should be fed separately, and with a ground that directly returns to the single ground point at the load center (Frame steel grounds are not acceptable for good PQ systems). This eliminates ground loops. Note that ground leads must be run in the same cable or raceway as the power leads



TYPICAL FACILITY ELECTRICAL DISTRIBUTION SYSTEM



3 Φ
Y System

$$V_{L-L} = 380 \text{ V}$$

$$V_{L-N} = 380/\sqrt{3} = 220 \text{ V}$$

$I_N = 0$ in a balanced 3 Φ system

Most facilities are upgrading internal distribution to 380 V



VOLTAGE IMBALANCE



❑ Problems can occur because of voltage imbalance between the three phases. This can be a serious problem in motors, and is discussed in the motor section, M1.

❑ Percent voltage imbalance is found as the ratio of the largest phase voltage difference from average, divided by the average voltage.

❑ For example, if we have 220, 215 and 210 volts, the voltage imbalance is $5/215 = .023$, or 2.3 percent.



UPGRADE NEUTRALS



❑ Many neutrals were not designed to carry any significant amount of current, and are simply too small.

❑ Unbalanced loads, harmonics, and especially triplen harmonics cause neutral current to increase—can be up to 1.73 to 3.0 times the phase current.

❑ Add neutrals—run a separate neutral for each single phase load.

❑ Oversize the neutral, or run parallel neutrals to several large loads.

NOTE: Over sizing Neutrals amounts to “treating the symptoms” it does not reduce the intensity of the harmonics.



WHAT PROBLEMS OCCUR BECAUSE OF HARMONICS?



- Circuit breakers tripping
- Neutrals overheating (smoke, fire)
- Panel or transformer overheating
- RFI - Radio Frequency Interference
- Errors/damage in Electronic Equipment
- Digital clocks running fast
- Failures in power factor correction capacitors



MOTOR PROBLEMS ALSO OCCUR

- ✓ Increased motor losses and overheating
- ✓ Power Factor decrease (from wave distortion as compared to wave displacement)
- ✓ Reduced torque and torque pulsation Negative sequence harmonics - like the 5th and 11th - try to force the motor to rotate in the reverse direction and cause torque pulsation. The 5th harmonic seriously reduces motor torque.
- ✓ Vibration & overheating Reduces motor life, damages bearings and insulation - extreme cases can result in motor "cogging" wh



IEEE 519 PQ STANDARDS

- ✓ Old standard is IEEE 519-1998.
- ✓ Newest standard is IEEE 519-2014
- ✓ The IEEE 519-2014 standard defines the voltage and current harmonics distortion criteria's for the design of electrical systems.
- ✓ THD (E) is Voltage Total Harmonic Distortion.
- ✓ For low voltage systems (less than 69 kV), the limits are:

General Systems	5%
Special Applications	3%

(E.g. hospitals)



MITIGATION OF HARMONIC PROBLEMS

- ✓ Derate equipment (symptom treatment)
 - 50% Transformers
 - 70% Load centers
 - Circuit breakers
 - Neutrals
- ✓ Install preventive equipment
 - Inductors
 - Harmonic filters
 - Isolation transformers
 - Locate near drive if possible
 - Connect back to "strongest" point of power system – the load center



POWER FACTOR (COS PHI) CONSIDERATIONS

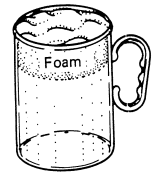
- ✓ What is the power factor?
- ✓ How is the power factor computed?
- ✓ What does a low power factor mean to electric costs (i.e.-tariff costs, I²R losses, affect on PF)?
- ✓ How can power factor be improved?
- ✓ How will power factor correction affect the system (Harmonics, capacity restoration, resonance, etc)?



WARNING ON POWER FACTOR CORRECTION

- ✓ Before installing power factor (Cos phi) correction equipment-especially capacitors-in your facility, make sure you perform a power quality test to determine if there is little/no harmonics present which could adversely affect the electrical system.
- ✓ Harmonic resonance effects can greatly increase the current through the power factor correction capacitors.
- ✓ Make sure to measure "true power factor" which accounts for harmonics.





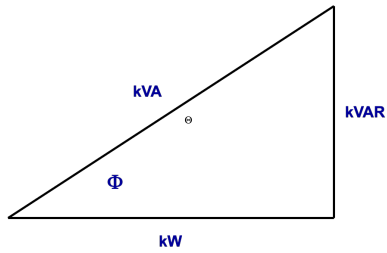
Mug capacity—
total power
(kVA)

Foam—reactive power (kVAR)
Beer—real power (kW)

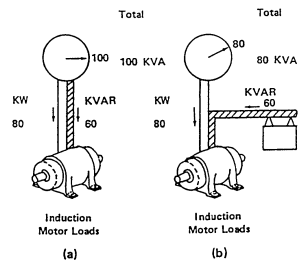
$$\text{Power factor} = \frac{\text{beer (kW)}}{\text{Mug capacity (kVA)}}$$



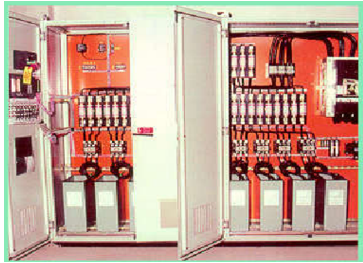
POWER TRIANGLE



SCHEMATIC ARRANGEMENT SHOWING HOW CAPACITORS REDUCE TOTAL KVA BY SUPPLYING MAGNETIZING REQUIREMENTS LOCALLY.



POWER FACTOR (COS PHI) CORRECTION EQUIPMENT PANELS



SAMPLE POWER FACTOR EXAMPLE

A facility is operating with a demand of 2000 kW.
The 2500 kVa transformer is fully loaded. How
many kVARs are required to bring the power factor
(Cos phi) back to unity?

$$kW^2 + kVAR^2 = kVa^2$$

$$kVAR^2 = kVa^2 - kW^2$$

$$kVAR = \sqrt{2500^2 - 2000^2} = 1500$$

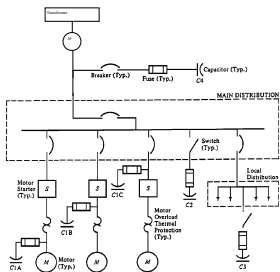


SAMPLE POWER FACTOR PROBLEM

During my last energy audit I saw a 100 kW electric motor that
had the following full load information on the nameplate: 380
volts; 182 amps; three phase; 95% efficient What is the power
factor of this motor?



WHERE TO PUT POWER FACTOR CORRECTION CAPACITORS



SAMPLE CEM TEST QUESTION

- ☒ A facility is operating at a power factor (Cos phi) of 70% with a real power load of 2000 kW. How much corrective capacitance in kVAR is needed to improve the facility power factor to 90%?
- ☒ $kVAR = \text{Table Factor} \times \text{Real power load in kW}$

CEM REVIEW QUESTIONS

1. If power factor (Cos phi) correction capacitors are located at the utility meter, but on the customer's side of the meter, the power factor out in the customer's facility will not be improved.
A. True B. False
2. A facility has a 100 kW electric resistance oven for drying parts. What is the power factor (Cos phi) of the oven? A. 0 % B. 50% C. 90% D. 100%



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