

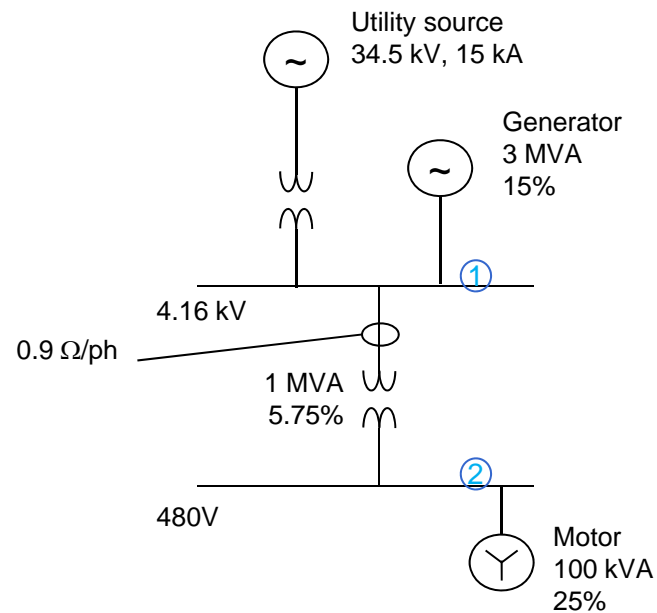
Power System Analysis:

Load Flow, Power Factor Correction

Dave Loucks, PE, CEM

Load Flow

- What is the nominal voltage
 - At bus ① ?
 - At bus ② ?
- ... assuming only load is 100 kVA motor?

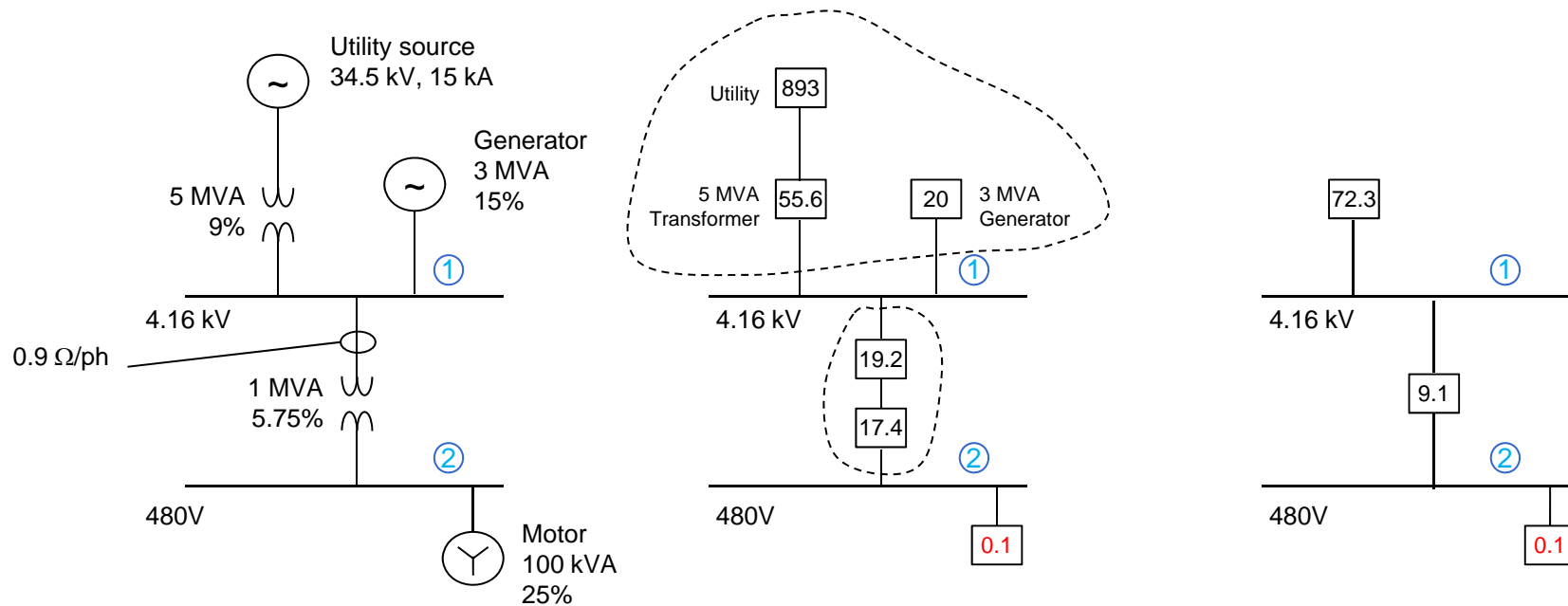


Load Flow

- Convert all components to equivalent MVA
 - $MVA = \sqrt{3} \cdot kV \cdot kA$ (use for incoming)
 - $MVA = kV^2 / Z$ (use for cables)
 - $MVA = MVA / \%Z$ (use for transformers, gens, motors)

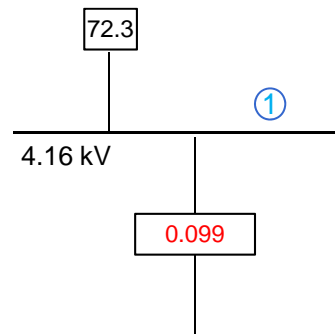
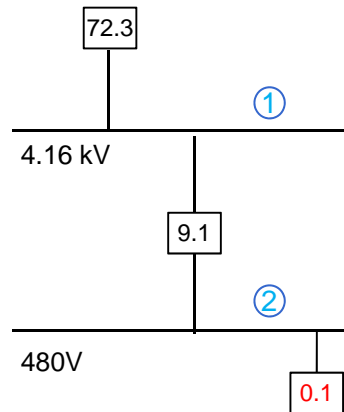
Converted to MVA

- Same procedure as discussed yesterday
 - Except motors are shown at nominal not SC MVA



Calculate Bus 1 Voltage

- Voltage on bus 1



- Voltage drop is ratio of source to load MVA

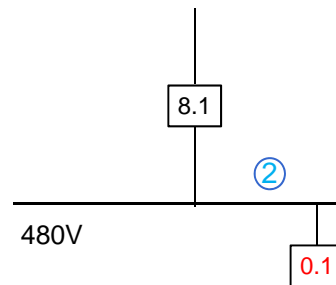
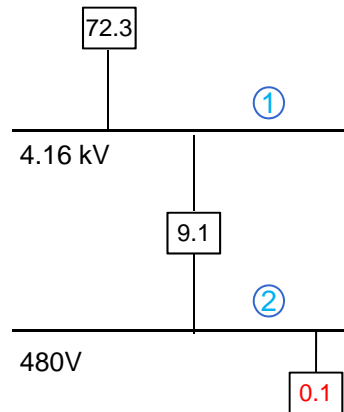
$$\frac{0.099}{0.099 + 72.3} = 0.0013$$

$$1 - 0.0013 = 99.86\%$$



Calculate Bus 2 Voltage

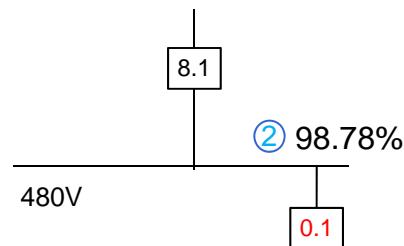
- Voltage on bus 2



- Voltage drop is ratio of source to load MVA

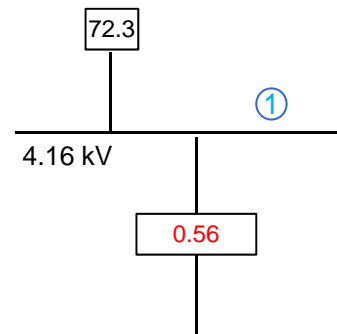
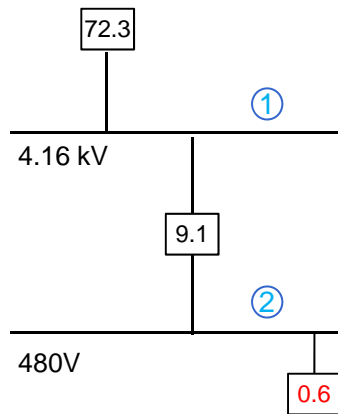
$$\frac{0.1}{0.1 + 8.1} = 0.012$$

$$1 - 0.012 = 98.78\%$$



Calculate Bus 1 Voltage During Inrush

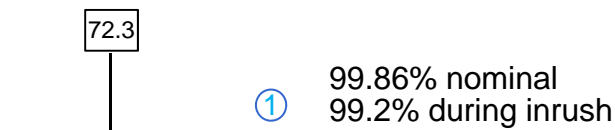
- Voltage on bus 1 (assume 6x locked rotor)



- Voltage drop is ratio of source to load MVA

$$\frac{0.56}{0.56 + 72.3} = 0.0077$$

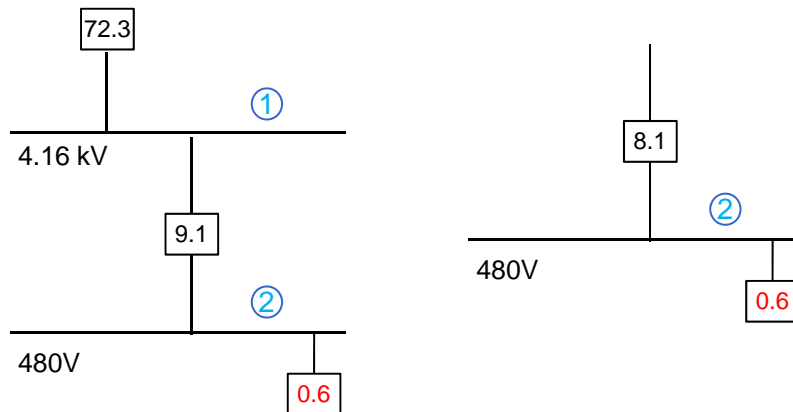
$$1 - 0.0077 = 99.2\%$$



99.86% nominal
99.2% during inrush

Calculate Bus 2 Voltage During Inrush

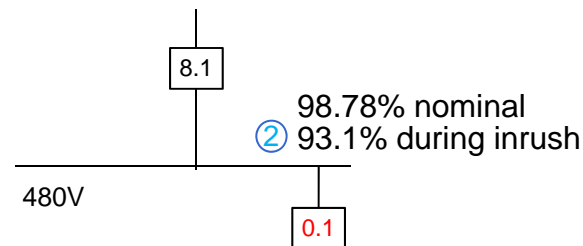
- Voltage on bus 2



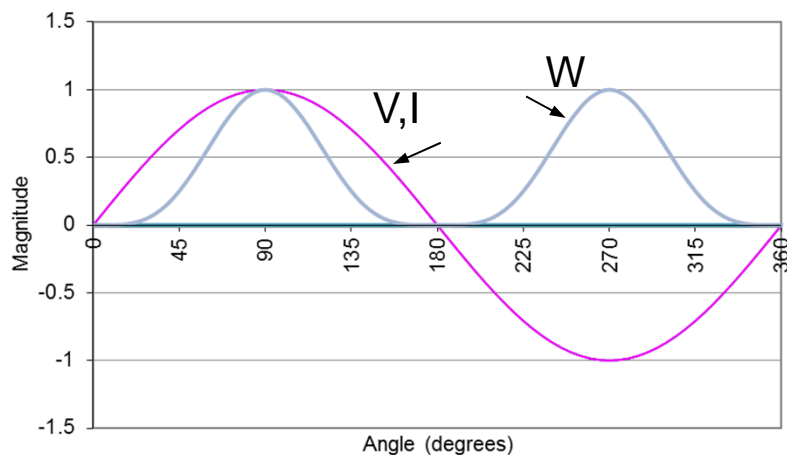
- Voltage drop is ratio of source to load MVA

$$\frac{0.6}{0.6 + 8.1} = 0.069$$

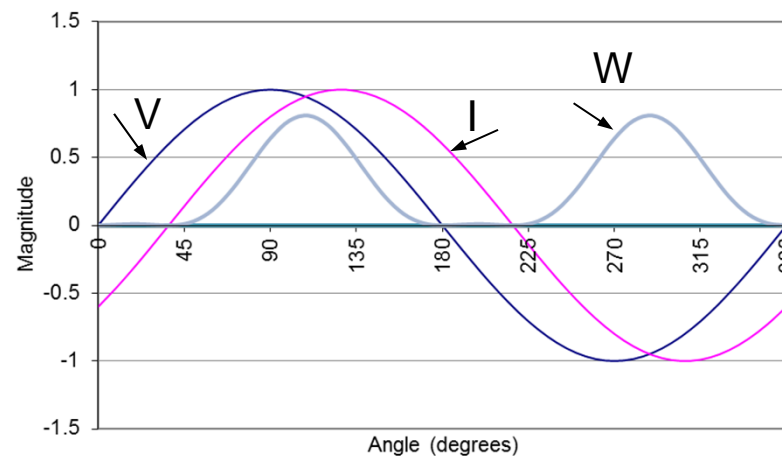
$$1 - 0.012 = 93.1\%$$



Power Factor



100% (unity) Power Factor

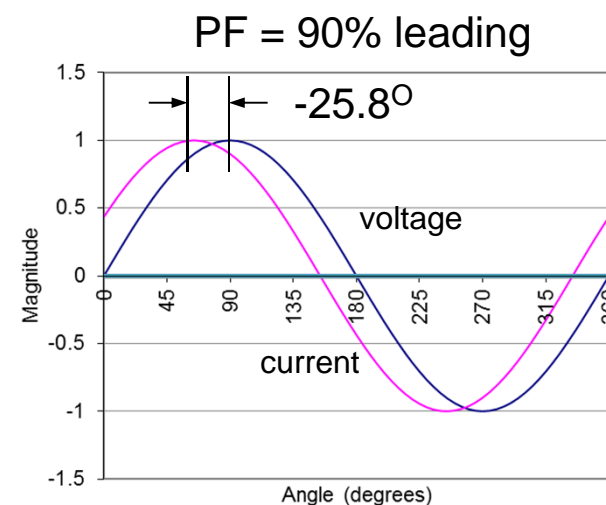
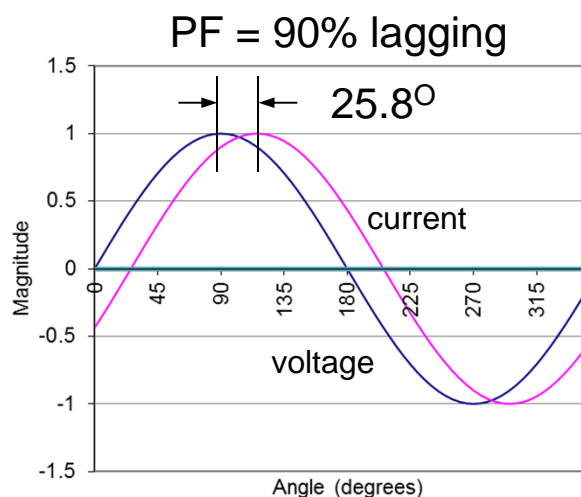
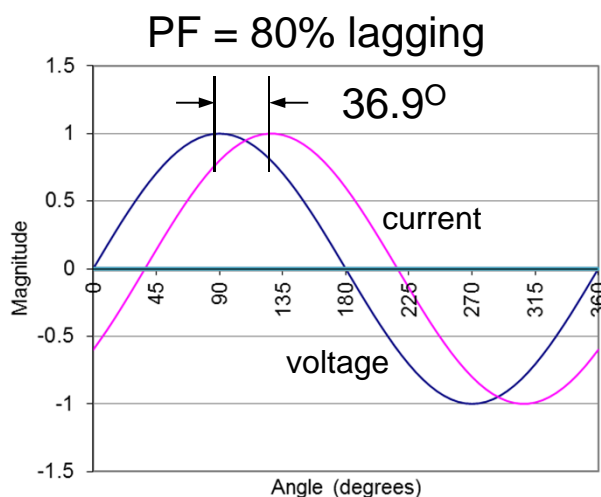
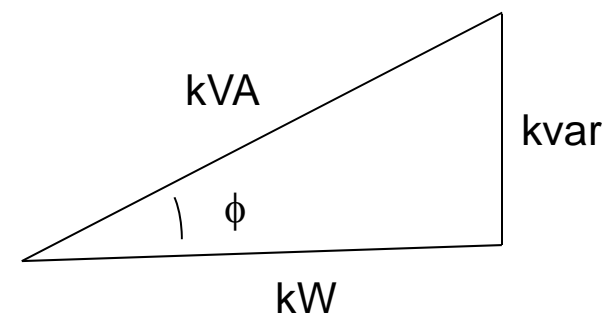


80% Power Factor
Less Watts, Same Current

- “Reactive” loads store and return energy each cycle
- Since they don’t “keep” the energy they consume, (ideally) there are no watts

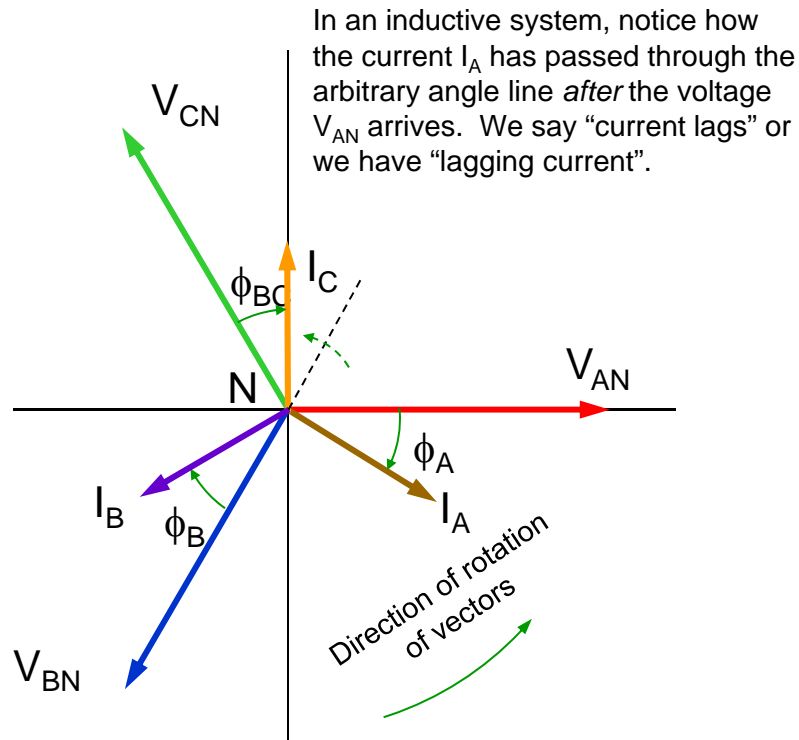
Power Factor

- $kVA = kV * I * \sqrt{3}$
- $\cos \theta = PF = \frac{kW}{kVA}$
- $\sin \theta = \frac{kvar}{kVA}$
- $kW = kVA \cos \theta = kVA * PF$

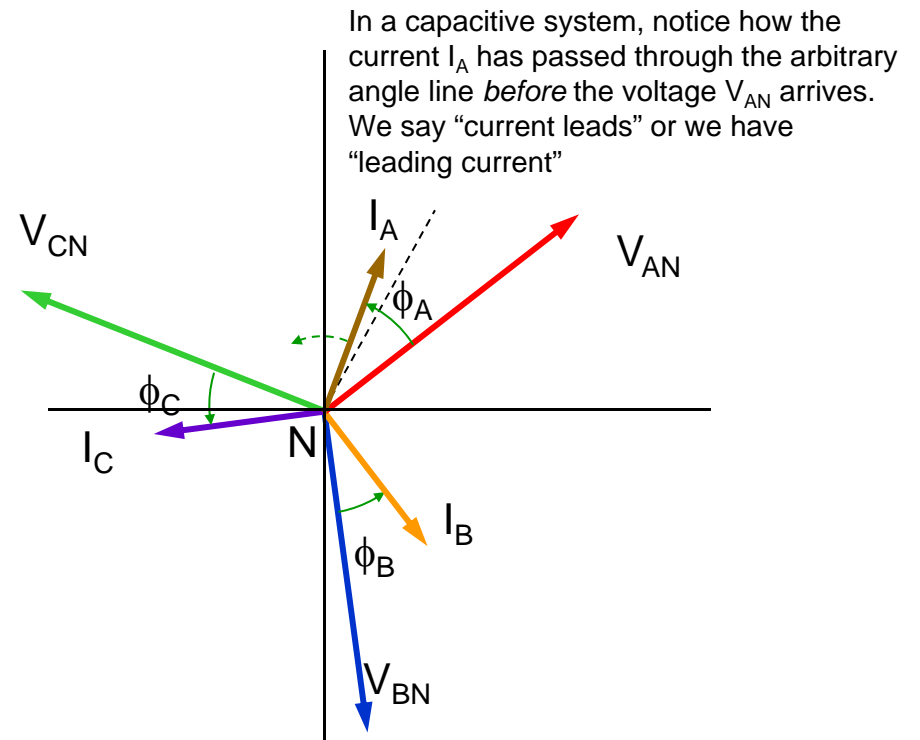


Power Factor Phasor Diagrams

Inductive System



Capacitive System



PF Rules of Thumb

- Use 35.0-11 to size motor capacitors
- $\%CurrentReduction = 100 - 100 \left(\frac{PF_{orig}}{PF_{new}} \right)$
- $ActualVars = NameplateVars * \frac{AppliedVoltage^2}{NameplateVoltage^2}$
- $\%VoltageRise = \frac{MVA_{cap}}{MVA_{SC}}$
 - MVA_{cap} : rating of capacitors added
 - MVA_{SC} : system short circuit capacity

More RoTs: Capacitance vs vars

- $kvar = kV * I_{cap}$
- $X_{cap} = \frac{1}{j2\pi fC}$
- $kV = I * X_{cap} = I * \frac{1}{j2\pi fC}$
- $C = \frac{I}{2\pi f * kV} = \frac{kvar}{2\pi f * kV^2}$
- $kvar = 2\pi fC * kV^2$
 - Note that the *kvar* varies by the square of the voltage
 - Same capacitance will have many more vars at higher voltages

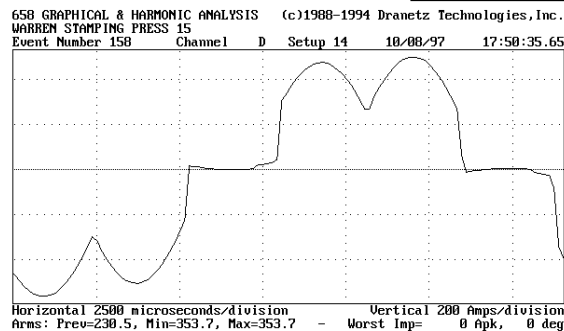
But don't just install a capacitor...

- Applying PF Correction Capacitors
 - Utility penalties for low PF
 - Pressure to reduce operating costs
 - Capacity issues

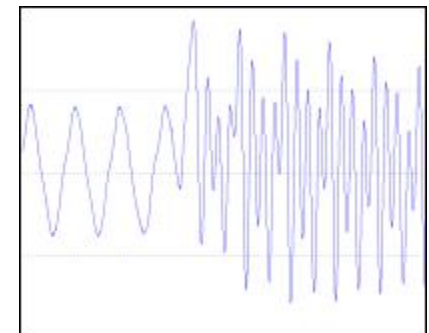
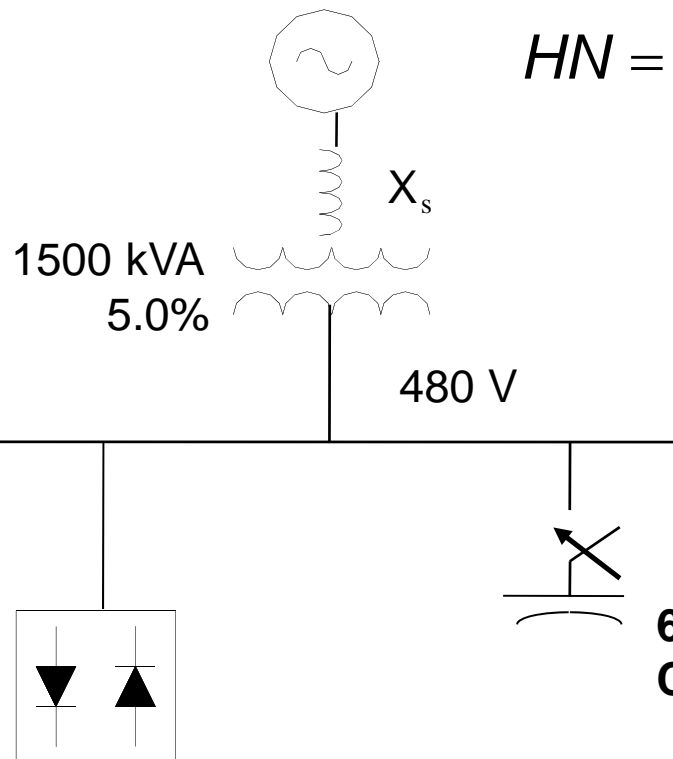
$$HN = \sqrt{\frac{kVA/\%Z}{kvar}}$$

$$HN = \sqrt{\frac{1500/0.05}{600}} = 7.07$$

200 kVA Drive/UPS Source of Harmonics

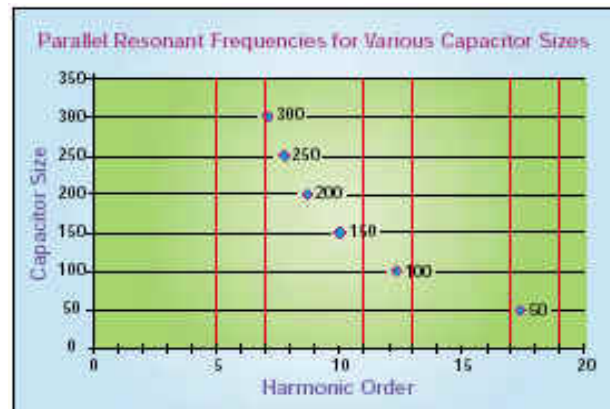
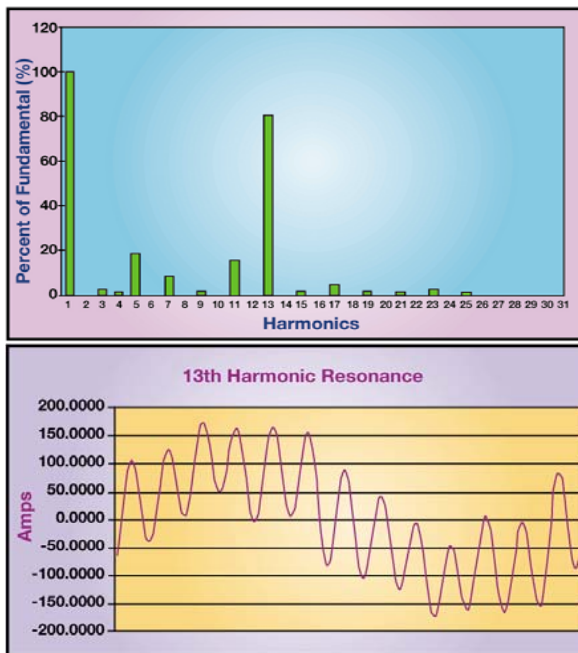


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Harmonic Resonance Solutions

- Apply another method of PF compensation (passive filter, active filter, etc)
- Eliminate harmonic source
- Change size of cap bank to over or under-compensate for required kvar and live with the ramifications.



Note!

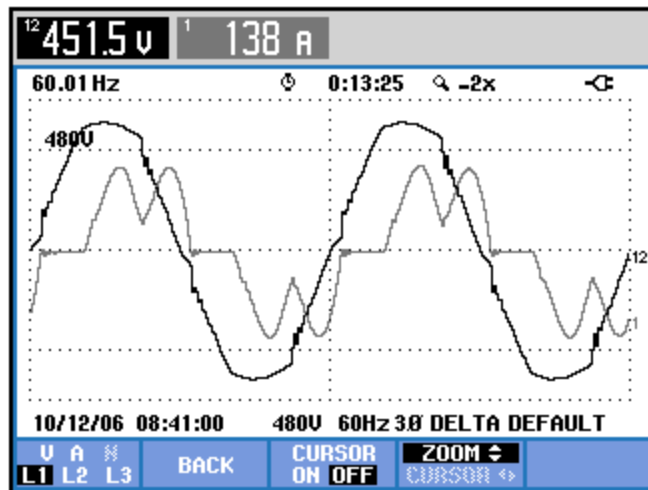
Every step of a switched capacitor bank must be checked to avoid parallel resonance

Problem gets worse with generators...

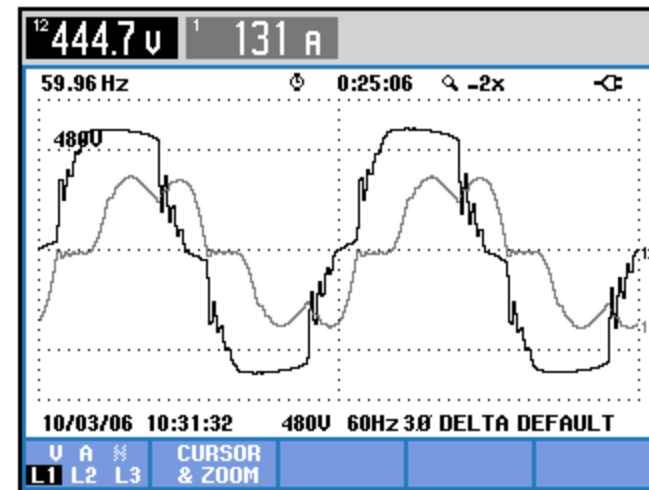
- Generator Concerns

- Generator impedance is generally 3-4 times (16-18%) the equivalent source transformer (5-6%)
- Harmonics can change even with the same load

$$HN = \sqrt{\frac{kVA/\%Z}{kvar}}$$



Utility Source
4.4% Vthd



Generator Source
13% Vthd





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