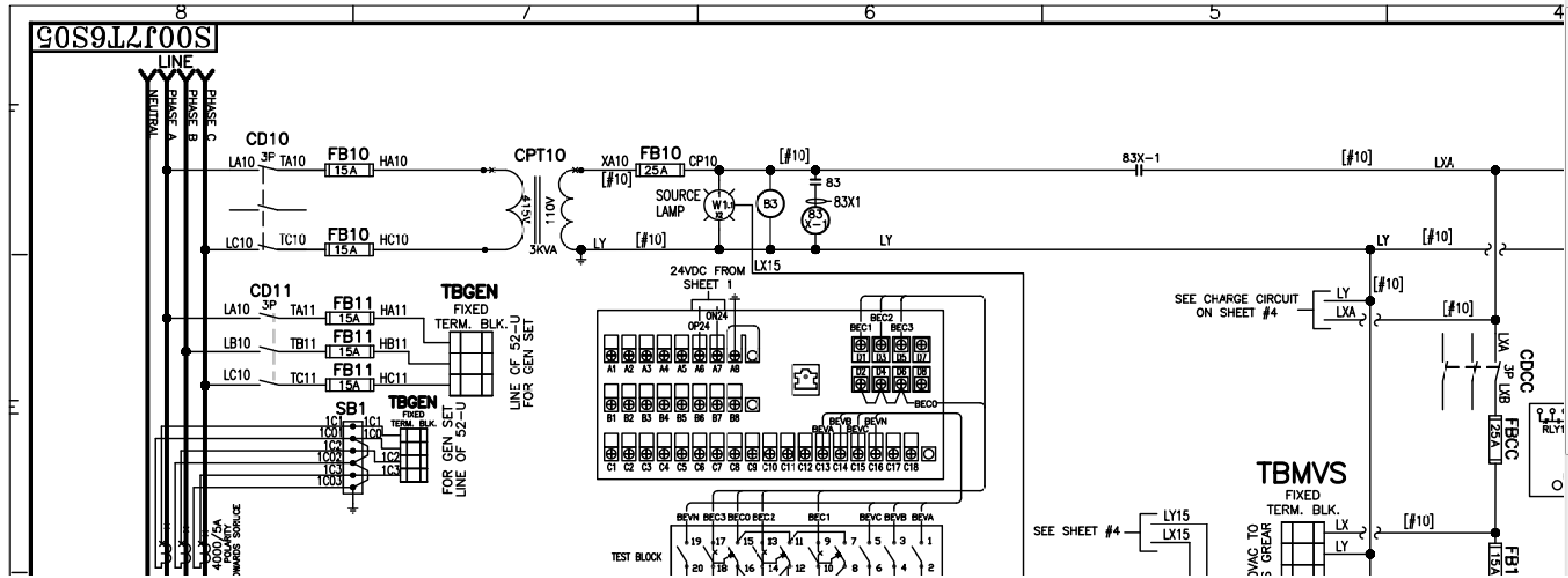

Power System Analysis:

Load Flow / Power Factor

Dave Loucks, PhD, PE, CEM

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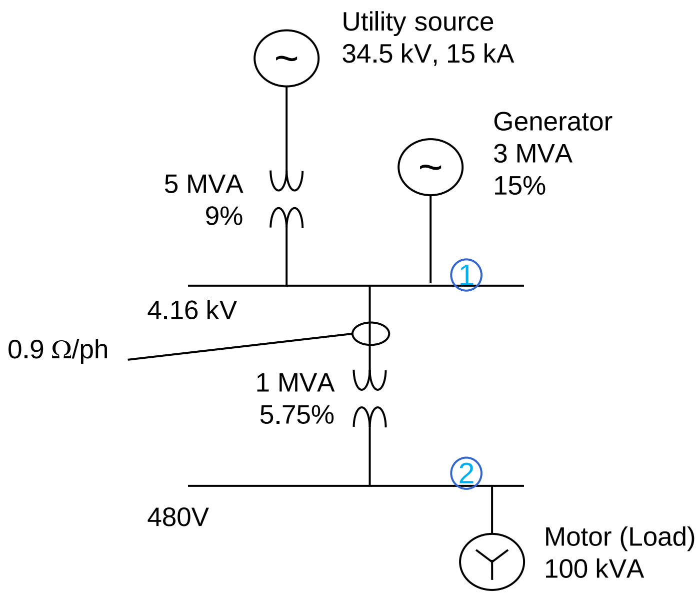
Load Flow

- 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)

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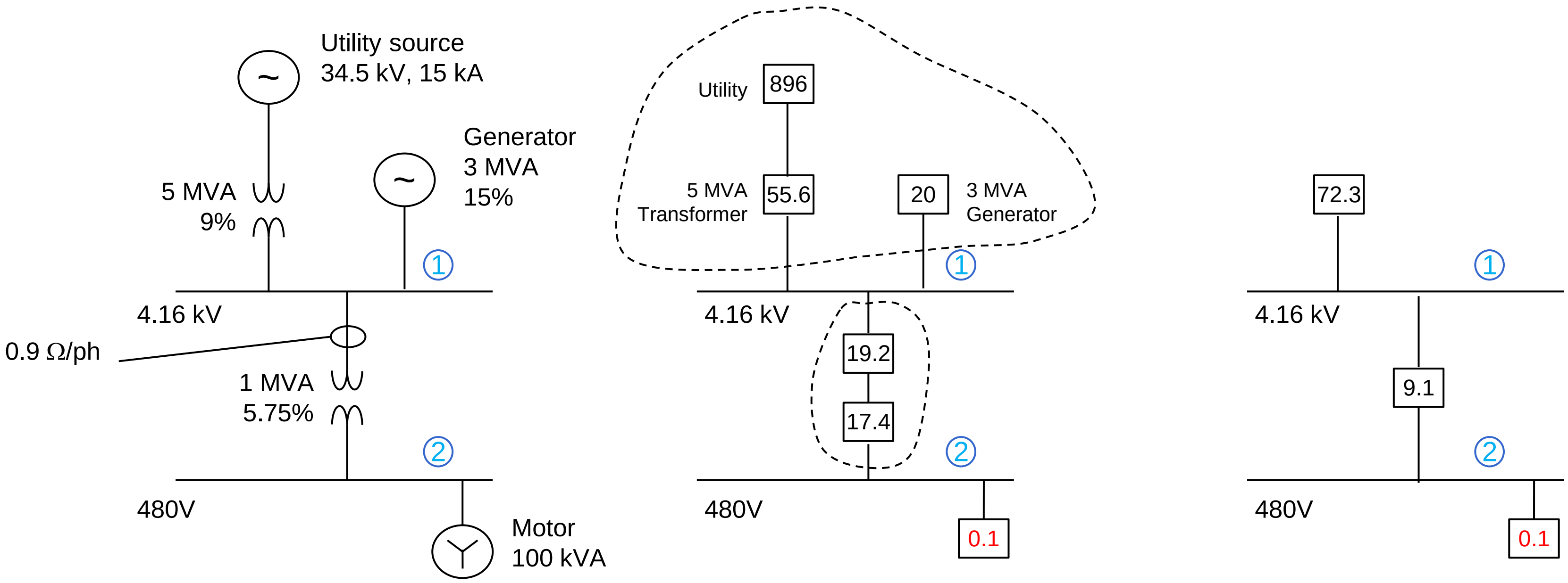
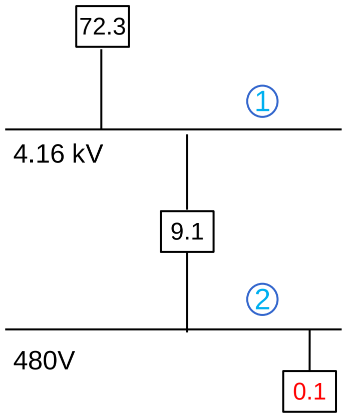
Converted to MVA

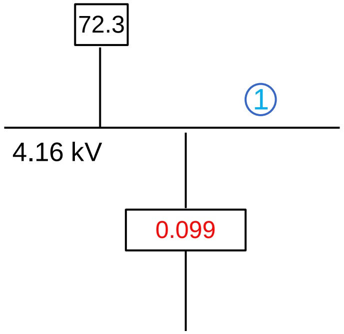
- Same procedure as discussed yesterday
  - Except motors are shown at nominal not SC MVA



Calculate Bus 1 Voltage

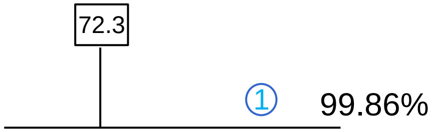
- Voltage on bus 1





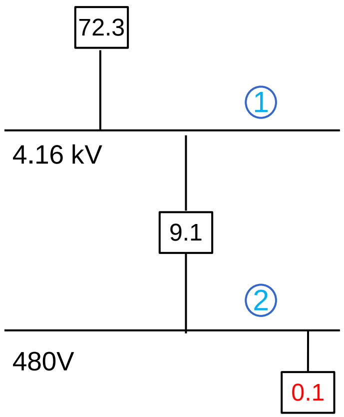
- Voltage drop is Δ% of MVA values

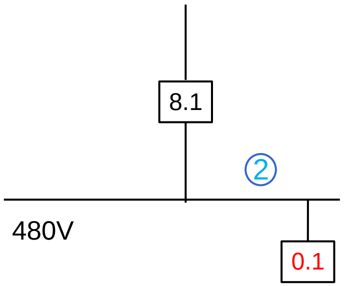
$$\frac{72.3 - 0.099}{72.3} = 99.86\%$$



Calculate Bus 2 Voltage

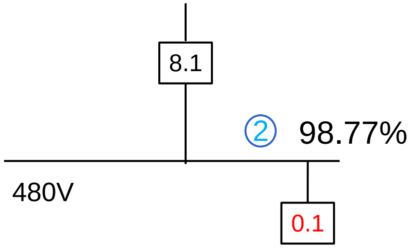
- Voltage on bus 2





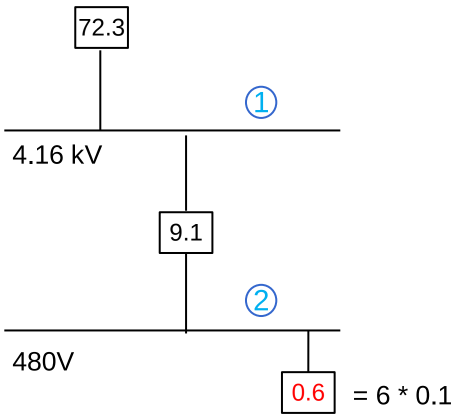
- Voltage drop is Δ% of MVA values

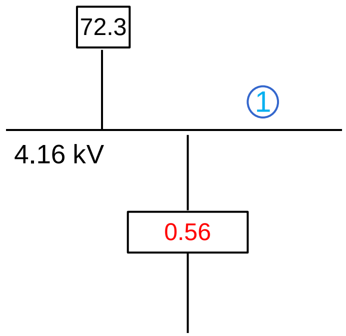
$$\frac{8.1-0.1}{8.1}=98.77\%$$



Calculate Bus 1 Voltage During Inrush

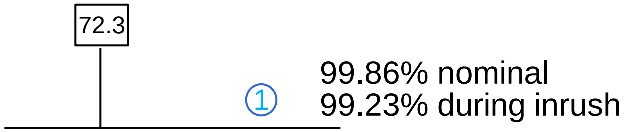
- Voltage on bus 1 (assume 6x locked rotor)





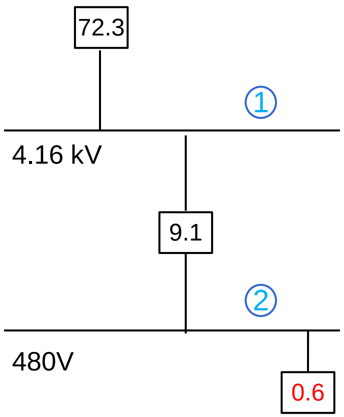
- Voltage drop is Δ% of MVA values

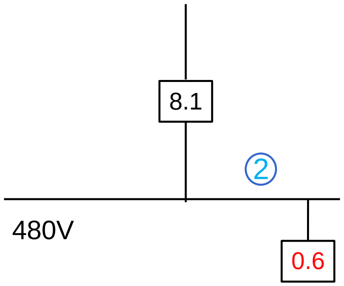
$$\frac{72.3 - 0.56}{72.3} = 99.23\%$$



Calculate Bus 2 Voltage During Inrush

- Voltage on bus 2

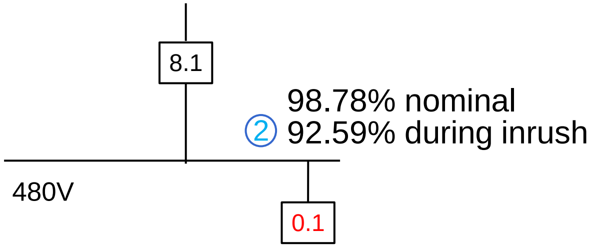




- Voltage drop is Δ% of MVA values

$$\frac{8.1 - 0.6}{8.1} = 92.59\%$$

$$1\text{- } 0.012 = 92.59\%$$



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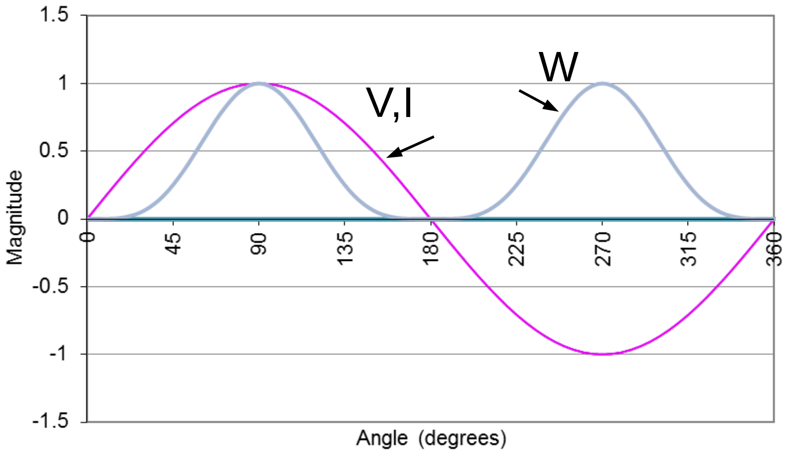
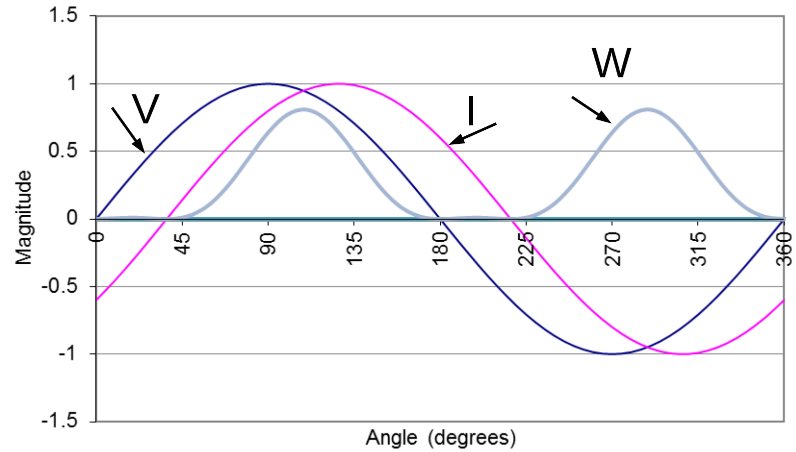
Power Factor



100% (unity) Power Factor

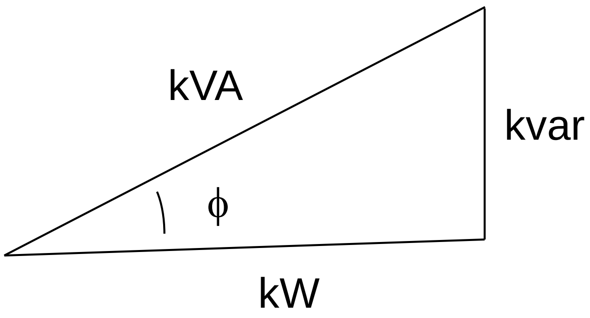


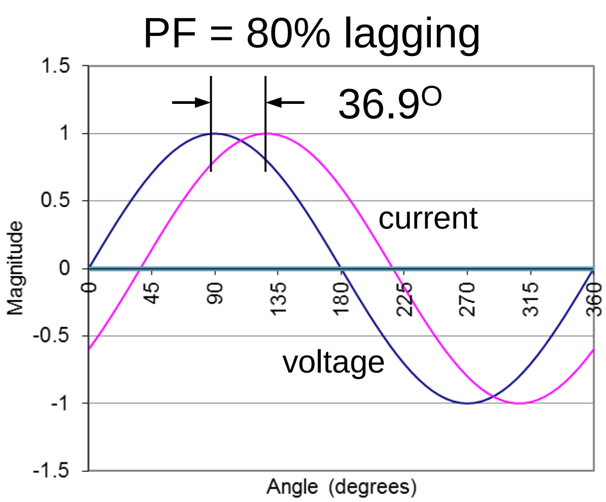
80% Power Factor
Less Watts, Same Current

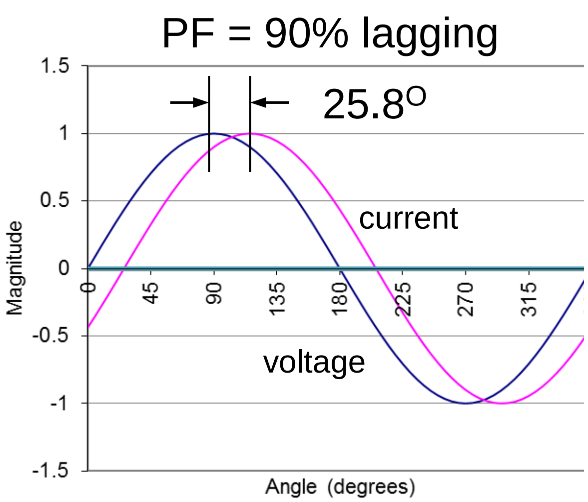
- “Reactive” loads store and return energy each cycle
- Since they don’t “keep” the energy they consume, (ideally) there are no watts

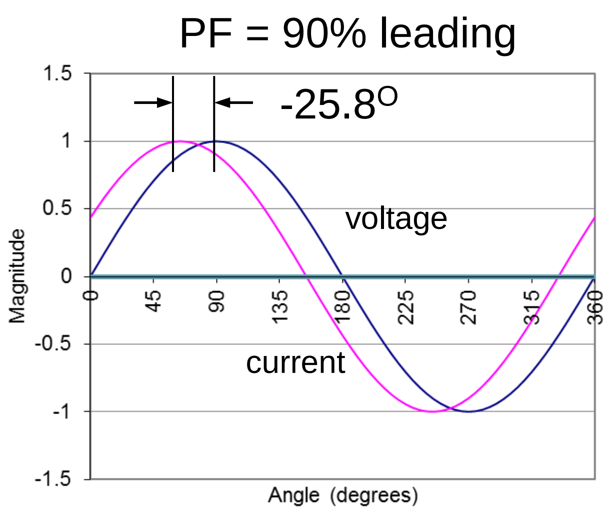
Power Factor

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





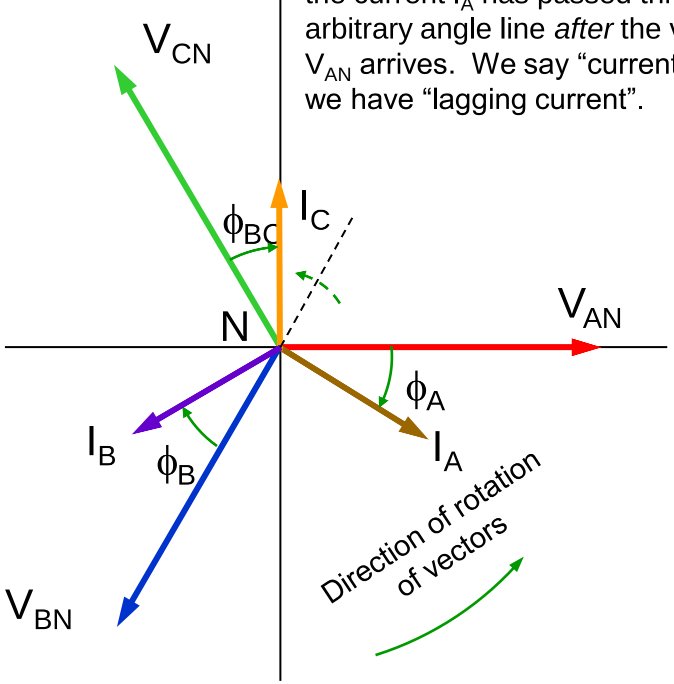




Power Factor Phasor Diagrams

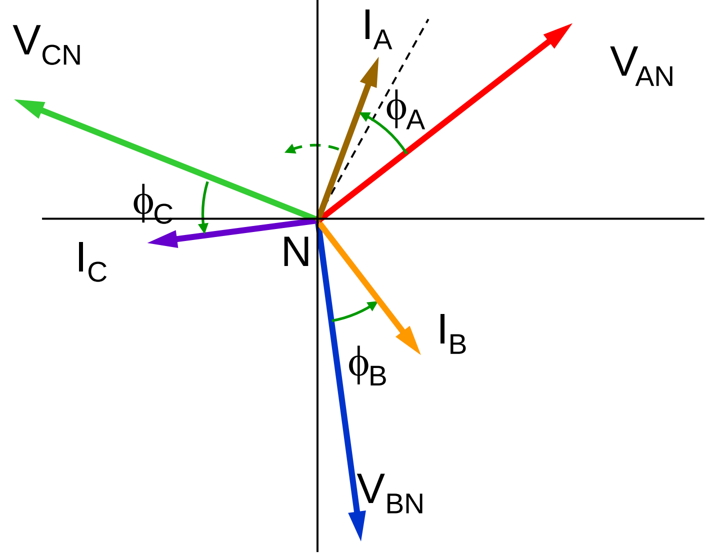
Inductive System

In an inductive system, notice how the current I_A has passed through the arbitrary angle line *after* the voltage V_{AN} arrives. We say "current lags" or we have "lagging current".



Capacitive System

In a capacitive system, notice how the current I_A has passed through the arbitrary angle line *before* the voltage V_{AN} arrives. We say "current leads" or we have "leading current"



PF Rules of Thumb

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

More RoTs: Capacitance vs vars

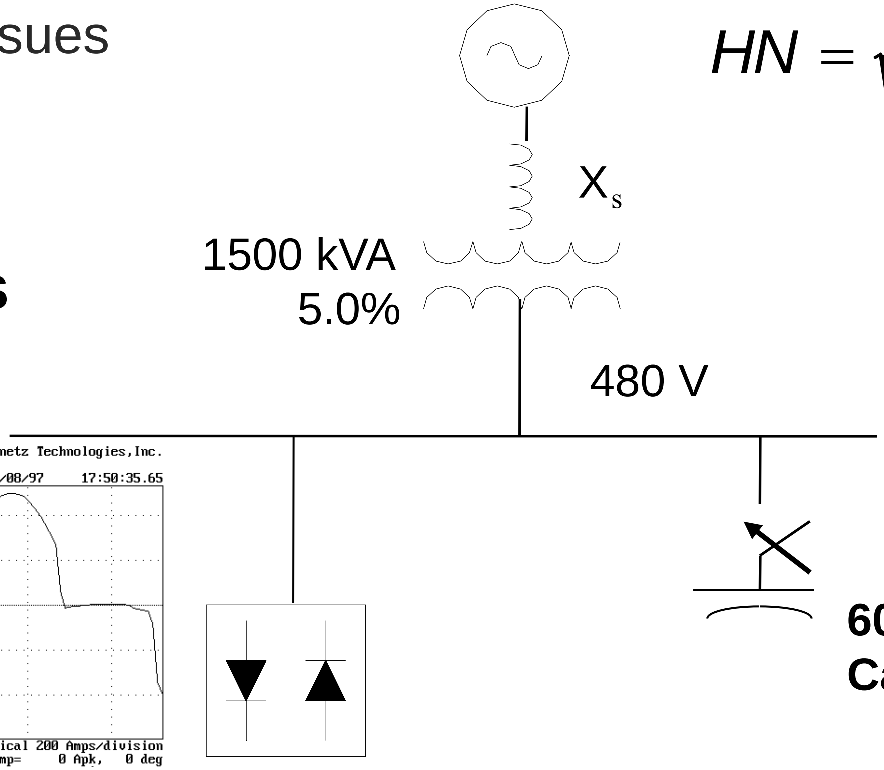
- $kvar = kV * I_{cap}$
- $X_{cap} = \frac{1}{j2\pi f C}$
- $V = I * X_{cap} = I * \frac{1}{j2\pi f C}$
- $C = \frac{I}{2\pi f * kV} = \frac{kvar}{2\pi f * kV^2}$
- $var = 2\pi f C * V^2$
  - Note that the *kvar* varies by the square of the voltage
  - Same capacitance will have many more vars at higher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

But don’t just install a capacitor…

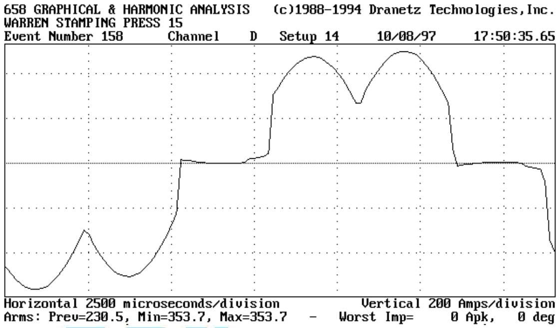
- Applying PF Correction Capacitors
  - Utility penalties for low PF
  - Pressure to reduce operating costs
  - Capacity issues

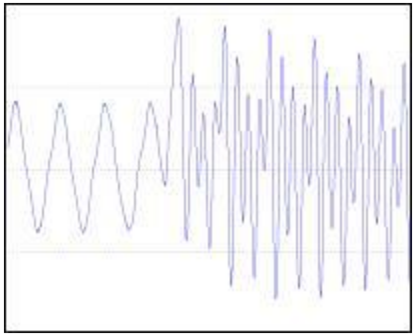
$$HN = \sqrt{\frac{kVA/\%Z}{k\,\mathrm{var}}}$$

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



200 kVA Drive/UPS Source of Harmonics

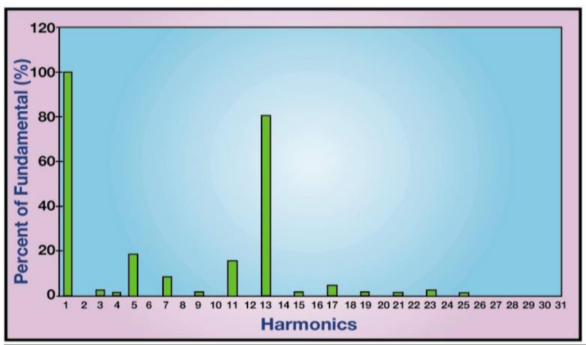


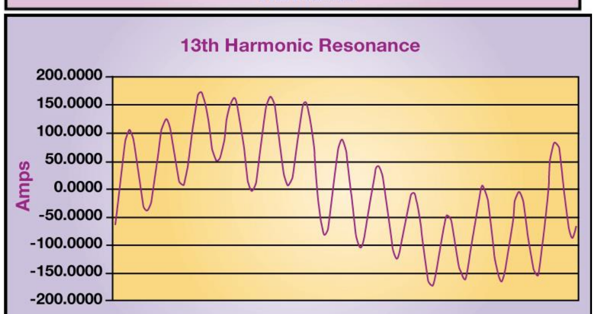


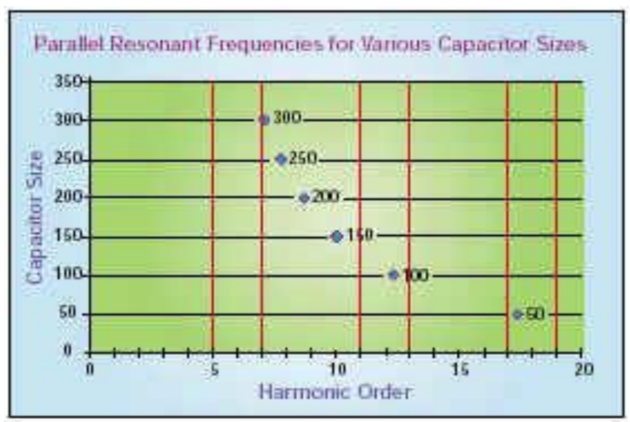
600 kvar Capacitor

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.





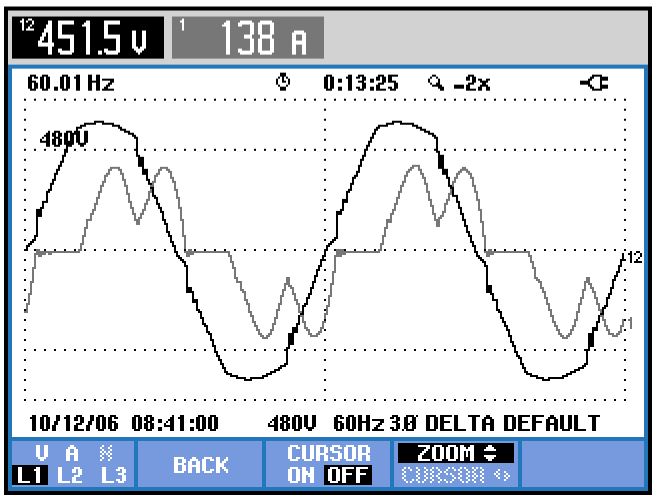


Note!
Every step of a switched capacitor bank must be checked to avoid parallel resonance

Problem gets worse with generators…

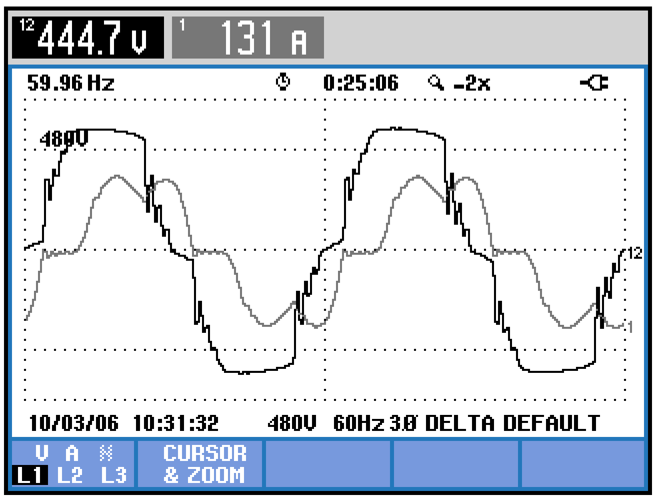
- Generator Concerns
  - Generator impedance is generally 3-4 times (16-18%) the equivalent source transformer (5-6%)
  - Harmonics can change even with the same load

$$HN = \sqrt{\frac{kVA/\%Z}{k\,\text{var}}}$$



Utility Source

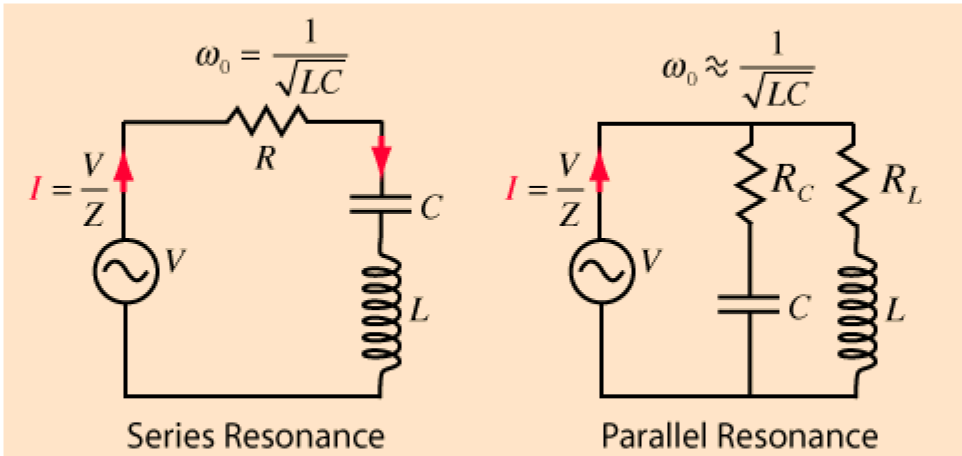
4.4% Vthd



Generator Source

13% Vthd

Wiring to Capacitor Matters



$$\omega_0 = \frac{1}{\sqrt{LC}}\left[\frac{R_L^2 C - L}{R_C^2 C - L}\right]^{\frac{1}{2}}$$

- If R_C greater than 0 (always will be):
  - Capacitive reactance factor decreases with increasing R_C
  - Just like with SPD lead length, minimize capacitor lead length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