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College of Engineering

ECE 528 – Understanding Power Quality

http://www.ece.uidaho.edu/ee/power/ECE528/

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Lecture 31

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Today…

- Power factor correction capacitors in end-user facilities
  - Required capacitance
  - New displacement power factor
  - Voltage rise
  - Loss reduction
  - Reduced power factor charges
- Power quality and reliability benchmarking
  - Dealing with real world data
  - Power Quality contracts – sag score

Displacement Power Factor correction for end users; An example

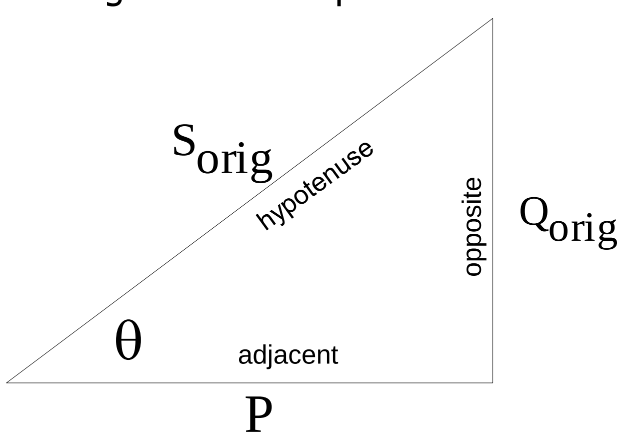
- Transformer: 3-phase, $480V_{L-L}$, 2500kVA, Z=5.5%
- Load: 4 x 500kW motors, DPF=84% lagging
- Minimum capacitor size is 25kVAR on each phase

Questions:

1. Determine the minimum size of a 3-phase capacitor bank to correct the DPF to at least 92%
2. What is the approximate percent voltage rise due to the capacitor bank
3. What is the approximate percent loss reduction due to the capacitor bank

Some Mathcad definitions: $\mathrm{kVAR} := \mathrm{kW}$ $\qquad \mathrm{kVA} := \mathrm{kW}$

Using the power triangle, calculate Q_{orig}, the original reactive power



$$DPF_{orig} := 0.84$$

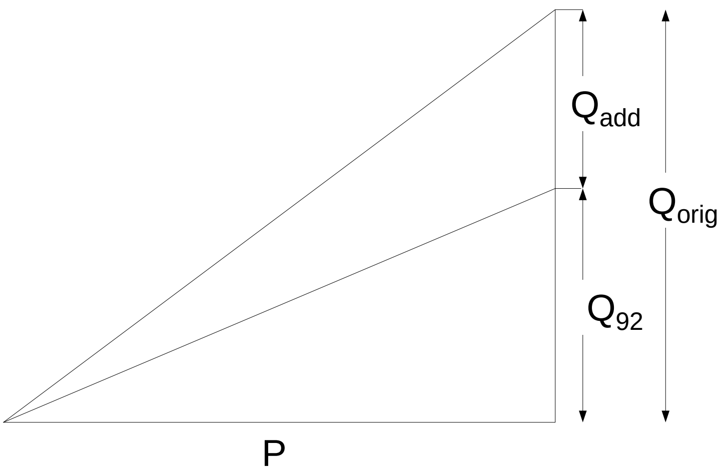
$$P := 4 \cdot 500\mathrm{kW} = 2 \times 10^3\ \mathrm{kW}$$

$$Q_{orig} := P \cdot \tan\left(\mathrm{acos}\left(DPF_{orig}\right)\right)$$

$$Q_{orig} = 1.292 \times 10^3\ \mathrm{kVAR}$$

$$\sin = \frac{\text{opposite}}{\text{hypotenuse}} \qquad \cos = \frac{\text{adjacent}}{\text{hypotenuse}} \qquad \tan = \frac{\text{opposite}}{\text{adjacent}}$$

Using the power triangle, calculate Q92; the Q at a DPF of 92%, the additional reactive power needed, and the size of the capacitor



$$DPF_{92} := 0.92 \qquad P = 2 \times 10^{3}\ kW$$

$$Q_{orig} = 1.292 \times 10^{3}\ kVAR$$

$$Q_{92} := P \cdot \tan\left(\mathrm{acos}\left(DPF_{92}\right)\right)$$

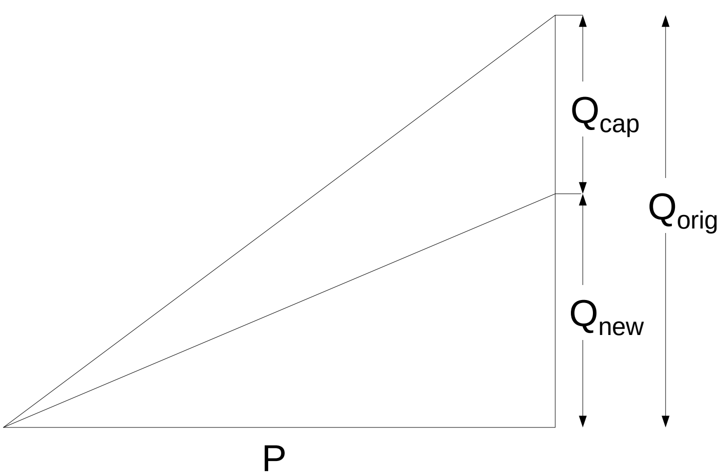
$$Q_{92} = 851.996\ kVAR$$

$$Q_{add} := Q_{orig} - Q_{92}$$

$$Q_{add} = 439.876\ kVAR$$

$$Q_{cap} := 450\ kVAR$$

Calculate the new DPF for the chosen capacitor bank size



$$Q_{orig} = 1.292 \times 10^{3}\ kVAR$$

$$Q_{cap} = 450\ kVAR$$

$$Q_{new} := Q_{orig} - Q_{cap}$$

$$Q_{new} = 841.872\ kVAR$$

$$DPF_{new} := \cos\left(\mathrm{atan}\left(\frac{Q_{new}}{P}\right)\right)$$

$$DPF_{new} = 92.167\% \qquad \text{(lagging)}$$

Calculate voltage rise and loss reduction

- Voltage rise: $Tr := 2500kVA \quad T_Z := 5.5\% \quad Q_{cap} = 450kVAR$

$$V_{rise} := \frac{Q_{cap} \cdot T_Z}{Tr} = 0.99\%$$

- Loss reduction: $DPF_{orig} = 84\% \quad DPF_{new} = 92.167\%$

$$Loss\_reduction := 1 - \left(\frac{DPF_{orig}}{DPF_{new}}\right)^2 = 16.938\%$$

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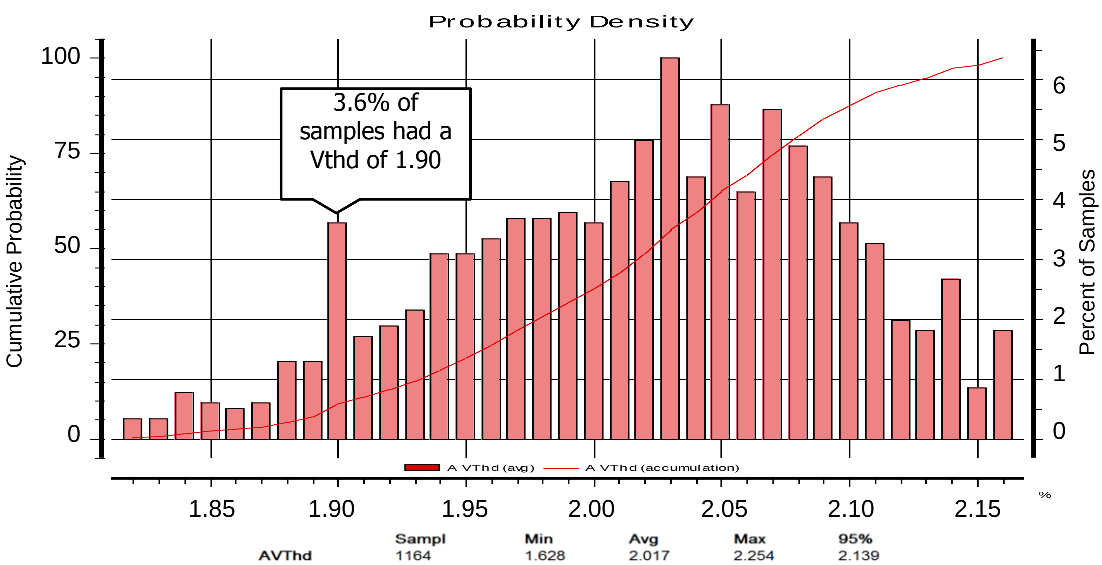
Some Mathcad suggestions

- Work using variables
  - Better accuracy; internal precision is about 17 decimal places
  - Faster revisions; change one value and all subsequent calculations change accordingly
- Annotate your work
  - Know why you did what you did later on
- Highlight your answers

Harmonic indices (PSQ section 8.4)

- STHD95 – System Total Harmonic Distortion CP95
  - Example use:
    - Comparing V_{THD} between different substations, is the substation's V_{THD} above or below the STHD95 value?
  - Calculation:
    - For each substation, the CP95 value of the V_{THD} recorded at the substation is calculated and weighted based on substation loading
    - The STHD95 is the "net CP95" value of all of the individual weighted CP95 values for individual substations

Harmonic indices: V_{THD} CP95



Harmonic indices

- SATHD – System Average Total Harmonic Distortion
  - An "average of averages"
  - Example use:
    - Similar to STHD95 – find the mean THD of a group of feeders or substations
  - Calculation:
    - Sum the kVA-weighted, average THDs and divide by the total system kVA

Use of harmonic indices

- STHD95 and SATHD describe the overall voltage THD on a system, but not the voltage THD experienced by individual customers
- Benchmarks may be chosen for these indices to help prioritize system improvements
- The data used to calculate STHD95 and SATHD can help identify areas of high and low distortion within a system

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Benchmarking: Real-world data issues

- Voltage THD may not be the same on all three phases
  - General approach is to average the voltage THD.
    - Simpler reporting (one number)
    - May mask high values on one phase

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Including Power Quality and reliability in distribution planning – the concept

- Additional utility system costs will be offset by reduced customer costs
  - More frequent tree-trimming
  - Shorter spans
  - Longer cross-arms
  - Increased animal guards
  - Reclosers/sectionalizers/fuses
  - Designing for higher wind-loading

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Including Power Quality and reliability in distribution planning - difficulties

- Accurate customer costs are difficult to obtain
  - Labor to respond to events
  - Production quantity and quality
  - Equipment damage
  - Disposal of waste
  - Failure to meet delivery obligations, and more…
- Certain PQ or reliability improvements may only benefit one customer or a small group of customers
- Normal statistical variation can mask the true impact of system changes in the short term

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Including Power Quality and reliability in distribution planning - contracts

- In the case of power quality contracts, costs are assigned to specific events
- Utility can analyze the cost of power quality events accurately and select improvements accordingly
- Offsetting utility costs, in the form of contract penalties, provide incentives to maintain or improve power quality and reliability

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Power quality contract example: Sag score

- What counts:
  - 75% or less on one or more phases
  - 15-minute aggregation
  - No minimum duration
  - All three phases are included, regardless of voltage
  - Voltages over 1pu set to 1pu
- What does not count:
  - Sags on unloaded feeders
  - Customer-caused sags

(See PSQ, section 8.5)

$$SagScore = 1 - \frac{V_A + V_B + V_C}{3}$$

Try one:

Va=0.818 pu

Vb=0.574 pu

Vc=0.823 pu

Sag score?:

But how much does it cost?...

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Power quality contract example:

Calculating Payments

- SGPA (Service Guarantee Payment Amount) = $50,000
- Target sag score = 3.000
- Prior to sag, the score was 2.900 (no payment due)
- Payment starts for sag scores above target.
- For this example: Payment = (new sag score - target) x $50,000

________ = (2.9000+________ - 3.000) x $50,000

- After the target is reached: Payment = (individual sag score) x $50,000

Next time…

- Start Distributed Generation (Distributed Resources) and Power Quality
  - Read Chapter 9
  - Homework 6 available