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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 2

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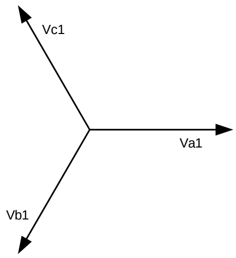
AC calculations

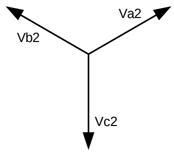
- Symmetrical Components: C. Fortescue, 1918
  - Three unbalanced phasors can be represented by three sets of balanced phasors.
  - This powerful mathematical tool greatly simplifies the analysis of unbalanced faults.

Symmetrical Components

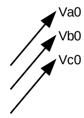
Positive Sequence

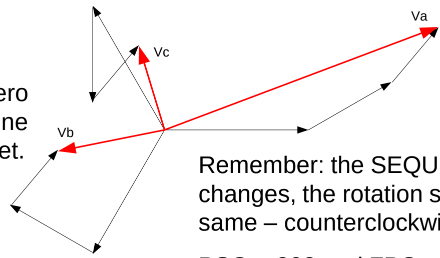


Negative Sequence



Zero Sequence





Positive, negative, and zero sequence phasors combine to form the unbalanced set.

Remember: the SEQUENCE changes, the rotation stays the same – counterclockwise.

See the "PQ Teaching Toy" on the class PQ Links page.

PSQ p 208 and FPQ p 213 may be misleading.

Finding symmetrical components

- The "a" operator: $a := 1\angle 120 \cdot deg$
- Multiplying a phasor by "a" or "a^2" rotates the phasor by 120 or -120 degrees.
- When expressing symmetrical components, it is only necessary to list the A-phase components.

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Finding symmetrical components

I_a , I_b and I_c are an unbalanced set of phasors

- Zero sequence components $$I_{a0} := \frac{1}{3}\left(I_a + I_b + I_c\right)$$
- Positive sequence components $$I_{a1} := \frac{1}{3}\cdot\left(I_a + a\cdot I_b + a^2\cdot I_c\right)$$
- Negative sequence
- components $$I_{a2} := \frac{1}{3}\cdot\left(I_a + a^2 I_b + a\cdot I_c\right)$$

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Matrix form of the equations

- To find the symmetrical components for a set of unbalanced phasors:

$$\begin{pmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{pmatrix} := \frac{1}{3}\cdot\begin{pmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{pmatrix}\cdot\begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix}$$

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Matrix form of the equations

- To find the unbalanced phasors from a set of symmetrical components:

$$\begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} := \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix} \cdot \begin{pmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{pmatrix}$$

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Finding symmetrical components

- The symmetrical components for this unbalance set of phasors:

$$V_a := (277 \angle 0)\cdot V \quad V_b := (287 \angle -120)\cdot V \quad V_c := (267 \angle 120)\cdot V$$

$$|V_{a0}| = 5.774\,V \qquad \arg(V_{a0}) = -90\,deg$$

$$|V_{a1}| = 277\,V \qquad \arg(V_{a1}) = 0\,deg$$

$$|V_{a2}| = 5.774\,V \qquad \arg(V_{a2}) = 90\,deg$$

What do we do with the symmetrical components?

- Fault analysis
  - We may be able to study the symmetrical components of the voltages recorded during a fault to determine what type of fault occurred, and what the corresponding voltages were in other parts of the system. (See FPQ chapter 4)
- Calculation of voltage unbalance
  - Voltage unbalance can cause a large current unbalance in three-phase motors and three-phase diode rectifiers. Motors may overheat, and rectifiers may be overloaded.

Calculating voltage unbalance

- NEMA definition:

$$Unbalance = \frac{Max\ deviation\ \ from\ Mean\ of\ \{Vab, Vbc, Vca\}}{Mean\ of\ \{Vab, Vbc, Vca\}}$$

- IEC definition: ("true unbalance")

  With symmetrical components

$$Negative\ sequence\ unbalance\ \ factor = \frac{V_2}{V_1}$$

See: FPQ p 28, PSQ p 24

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Let's compare methods

- For the voltages given on slide 8:

$$\left|V_{AB}\right| = 488.464\,V$$
$$\left|V_{BC}\right| = 479.882\,V$$
$$\left|V_{CA}\right| = 471.144\,V$$

Don't use line-to-neutral voltages for NEMA unbalance.

$$\text{NEMA\_Unb} = 1.81\cdot\%$$

Negative sequence unbalance factor

$$\frac{\left|V_{a2}\right|}{\left|V_{a1}\right|} = 2.084\cdot\%$$

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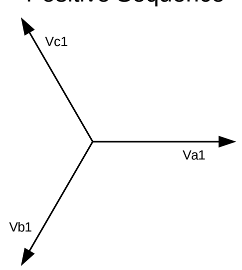
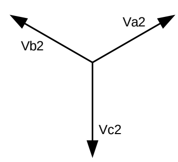
Impact of unbalanced voltage on motors

Positive Sequence



Negative Sequence



All of the phasors rotate counter-clockwise. It is the sequence that changes.

To change the direction of a line-connected three-phase motor, we change the phase sequence by swapping two of the three supply phases.

When the supply voltage is unbalanced, BOTH positive and negative sequence voltage are present at the motor's terminals simultaneously, but the motor can only turn in one direction at a time.

The negative sequence voltage creates an opposing torque; an extra load on the motor. This can overload the motor, causing excessive heating and shorter motor life.

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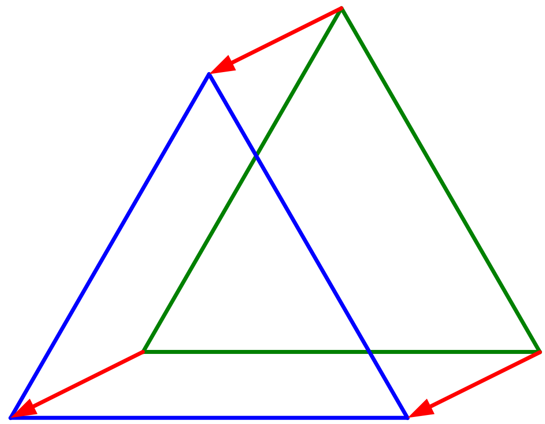
Impact of zero-sequence components on Line-to-line voltages



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Power Factor and Power Factor Correction

- PQ engineers may be called on to assist customers with sizing power factor correction capacitors.
- Power factor correction capacitors, or "caps" as utility engineers call them, provide reactive power, or considered another way, consume negative reactive power.

Power Factor Correction

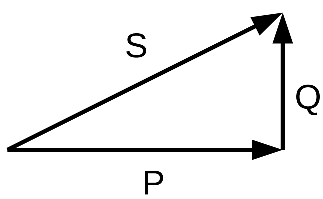
- Large customers are often subject to a "power factor adjustment" in their electric bill for having a low power factor.
- Example: A customer has a balanced 2MW load operating at 480V (3-phase, line-to-line) at a lagging power factor of 80%. The customer wants to correct the power factor to 90% or better.

The reactive power drawn by the load

$$P := 2\text{MW}$$

$$Q := P \tan(\text{acos}(\text{pf}))$$

$$Q = 1.5 \times 10^{3} \cdot \text{kVAR}$$



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Size of Capacitor Bank

- First, calculate the remaining reactive power requirement:

$Q2 := P \cdot \tan(\text{acos}(0.9)) \qquad Q2 = 968.644 \cdot kVAR$

- Correction = initial VAR need – final VAR need

$$Q - Q2 = 531.356\, kVAR$$

- Let us say the customer installs a 600kVAR capacitor.

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Corrected power factor

- With the 600kVAR capacitor:

$Qc := 600kVAR \qquad Q - Qc = 900\, kVAR$

$$PF := \cos\left(\text{atan}\left(\frac{Q - Qc}{P}\right)\right) \qquad PF = 91.192 \cdot \%$$

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Reduction in current from the 480V service

- Load current without capacitors:

$$S := \frac{P}{pf} \qquad S = 2.5 \cdot MVA$$

$$I1 := \frac{S}{\sqrt{3} \cdot 480volt} \qquad I1 = 3.007 \times 10^{3} A$$

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Reduction in current from the 480V source

- Load current with capacitors

$$S2 := \frac{P}{PF} \qquad S2 = 2.193 \cdot MVA$$

$$I2 := \frac{S2}{\sqrt{3} \cdot 480volt} \qquad I2 = 2.638 \times 10^{3} A$$

$$I1 - I2 = 369.058\,A$$

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Next time…

- More AC review
  - Fourier Series
  - Frequency effects

Get texts and work on reading chapters 1 and 2 of both.