ECE 528 – Understanding Power Quality

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

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Lecture 1

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Getting Started

- Introductions
- Course Logistics
- Class website: www.ece.uidaho.edu/ee/power/ECE528/
- Texts and software
- General Information, Syllabus, Grading
- Lecture Notes / Quizzes / Homework / Exams
- Shorthand references:
  - PSQ – Power Systems Quality text (example: PSQp23)
  - FPQ – Fundamentals of Electric Power Quality text
  - L##Snn – Lecture number ##, Slide nn (this is L1S2)

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How to get the most out of this class

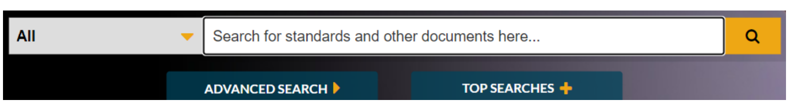
- Pause playback and consider the questions on the slides
- Start on homework and exams early
  - Your brain will work on them without “you”
  - Work on the problems as they’re discussed
- Collaborate for understanding – including with your instructor
- Homework and exams
  - Email drafts of homework and exam problems 48 hours or more before due date
  - You’ll get feedback you can implement
  - <u>Submit final drafts in Canvas</u>

IEEE Papers and Standards via UI library

(try this before watching the next lecture)

1. Library homepage: www.lib.uidaho.edu
2. Databases A-Z

3. Pick ***IEEE Xplore***
4. Log in with your Uidaho credentials if you haven’t
5. Search:

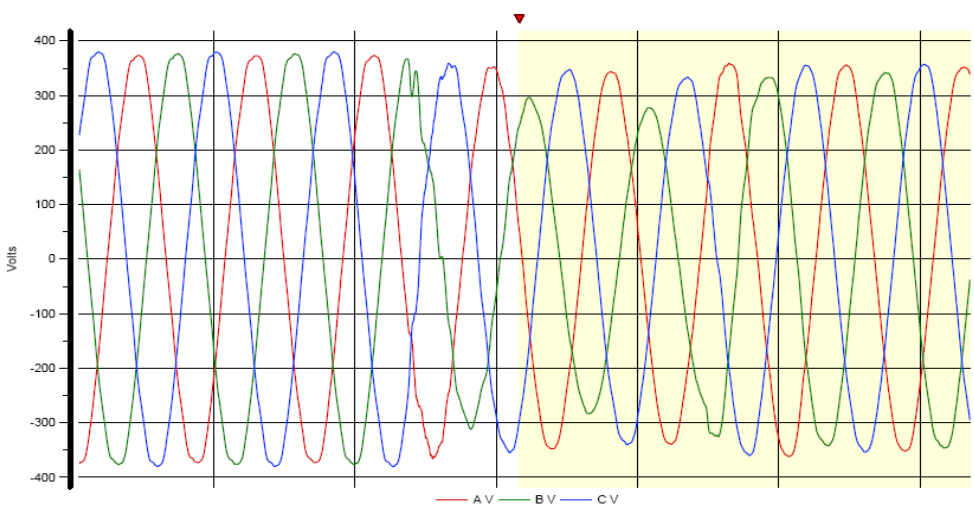


6. Practice this: Find and download a PDF copy of the paper:
   “Are Voltage Sags Destroying Equipment?” by A. Bendre, D. Divan W. Kranz, and W. Brumsickle

What is “Power Quality” (PQ)?

- Power Quality = Voltage Quality (from PSQ)
  - The closer frequency, amplitude, distortion, and balance are to perfect, the better the Power Quality is
- Voltage quality issues may be temporary or continuous
  - Faults, switching, lightning
  - Harmonic distortion
  - Use of power conductors for data transmission
  - System design problems
- Power Quality can be like Electromagnetic Compatibility
  - Emissions – what a device puts into its environment
  - Immunity – what a device can tolerate in its environment

A temporary voltage quality issue



What is "Power Quality" (PQ)?

- From IEEE 1100-2005:

  "The concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment"

- From IEC61000-1-1

  "…the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment."

PQ Problems:

- From PSQ, a PQ problem is:

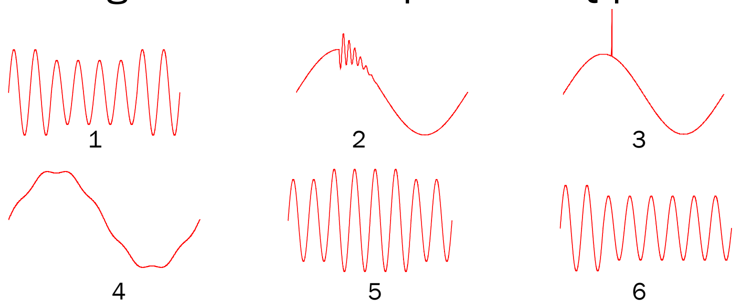
  "Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment."

- The "Power Quality Equation":

Electrical Disturbance + **Path** + **Vulnerable Equipment** = **Power Quality Problem**

What is a PQ problem?

Do these voltage waveforms represent PQ problems?



<u>Only</u> if they cause equipment to misoperate or fail.

Is it a PQ problem?

- A network server reboots randomly.
- Utility distribution capacitors blow fuses repeatedly.
- Variable speed drives at a sewage treatment plant trip off occasionally while the rest of the plant keeps running.
- A retail store reports that individual cash registers sometimes stop working properly.
- Variable speed drives in the HVAC system for a hospital occasionally fail catastrophically during the regular generator test.
- A customer receives a small shock when they touch a cable-TV signal splitter in their home.

Why is power quality important?

- Power quality problems impact us more often:
  - New equipment:
    - more efficient, more features but may be more sensitive and may be "always on"
  - Emphasis on efficiency:
    - increased use of power electronics
    - 24/7 production streams operating at nearly 100% capacity - no time to catch up after interruptions
    - Increased use of automation

Why is power quality important?

- Systems are interconnected and interdependent
  - This class relies on power and communication systems in Northern and Southern Idaho to be operating properly.
  - Smart home devices.
  - Business networks
    - Delta Airlines: power problem in their main computer network in Atlanta impacted thousands of flights worldwide for several days
    - My electronic work documents are stored on servers approximately 200km from my office.

What is Power Quality Engineering?

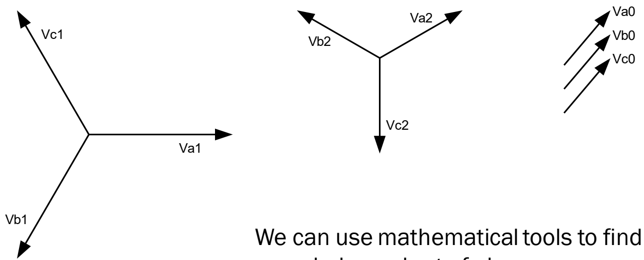
- PQ Engineers investigate equipment malfunctions and failures to determine:
  - Is the malfunction or failure a "PQ problem", i.e., was it caused by an electrical disturbance?
  - What mitigation is appropriate? (disturbance, path, vulnerability, some combination?)
- We may find that the problem isn't strictly a "Power Quality problem" after all!

Review - AC calculations

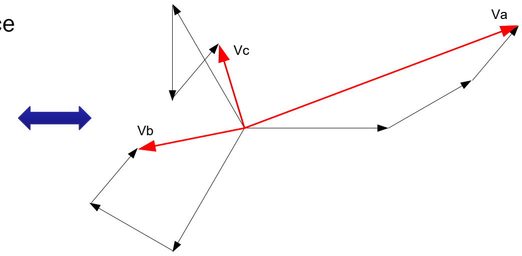
- Symmetrical Components: C. Fortescue, 1918
  - Three unbalanced phasors can be represented by three sets of balanced phasors.
  - This powerful mathematical tool greatly simplifies the analysis of unbalanced faults.

Symmetrical Components

Positive Sequence Negative Sequence Zero Sequence



Very unbalance voltage phasors (red)



We can use mathematical tools to find the symmetrical components for an unbalanced set of phasors.

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

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.

Finding symmetrical components

I_a , I_b and I_c are an unbalanced set of phasors

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

Finding symmetrical components:

Matrix form of the equations

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

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

Finding the unbalanced phasors:

Matrix form of the equations

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

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

Finding symmetrical components

- The symmetrical components for an unbalanced set of phasors:

$V_a := 277\angle 0\ \boldsymbol{deg}$ $\quad V_b := 287\angle -120\ \boldsymbol{deg}$ $\quad V_c := 267\angle 120\ \boldsymbol{deg}$

$a := 1\angle 120\ \boldsymbol{deg}$ $\quad \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} := \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$

$V_{a0} = 5.774\angle -90°$ $\quad V_{a1} = 277\angle 0°$ $\quad V_{a2} = 5.774\angle 90°$

Note – line-to-neutral voltages are used here.
What if you're given line-to-line voltages?
Can you still find positive and negative sequence values?

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

Let's compare methods

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- For the voltages given on slide 20:

$$|V_{AB}| = 488.464V$$
$$|V_{BC}| = 479.882V$$
$$|V_{CA}| = 471.144V$$

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

$$NEMA\_Unb = 1.81 \cdot \%$$

Negative sequence unbalance factor

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

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Impact of unbalanced voltage on motors

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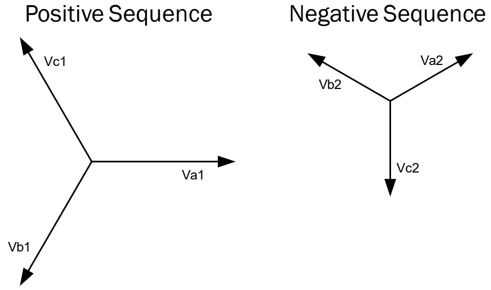

All of the phasors rotate counter-clockwise. It is the sequence that changes.

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.

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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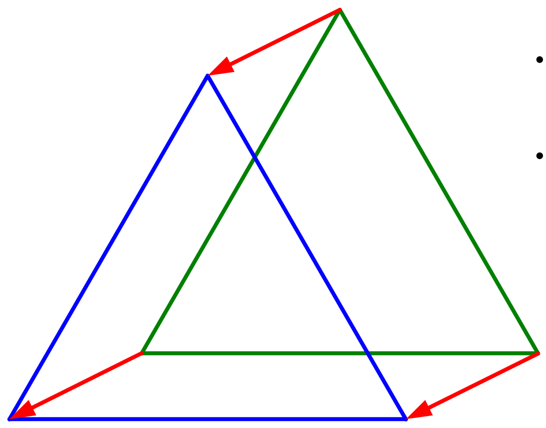

- The green triangle represents a set of balanced line-to-line voltages.
- Adding zero-sequence voltage (red arrows) does not make the line-to-line voltages unbalanced.
- Some three-phase systems are “corner grounded” but can provide balanced voltage to three-phase motors.

Questions?

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- Before next session:
  - Visit class website – locate handouts and homework
  - Visit Canvas – locate handouts and homework
  - Visit UI library online, log in and visit IEEE Xplore database – download and read the paper: “Are Voltage Sags Destroying Equipment?” by Ashish Bendre et.al.
- Coming up: More AC review
  - Power Factor
  - Fourier Series