ECE 528 – Understanding Power Quality

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

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Lecture 27

Today…

- Utility mitigation of long-duration voltage variations
  - Voltage regulators
  - Capacitors

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Midterm questions/FPQ book clarifications

- 1e – See lecture 22. Looking for why we'd use one form of THDv versus the other form discussed.
- 4 – Drive manufacturers often use 0.75kVA/hp as drive rating.
- 5 – FPQ equations 7.25, 7.26, 7.27, and duty limits for Peak Voltage and RMS voltage should use capacitor rated voltage – yours may be 600V
- 5 – FPQ equation 7.34 should use capacitor voltage from eq. 7.33
- 5 – Remember to compute fundamental kVAR from filter and compare to requirements:

$$kVAR_{.fund} = \sqrt{3} \cdot I_{.fund} \cdot SysV \quad \text{or} \quad kVAR_{fund} = I_{fund}^{2} \cdot X_{fund}$$

I_{fund} from eq. 7.32, X_{fund} from eq. 7.31

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PSQ Book corrections Ch. 7

- Page 342, section 7.5.6: Calculating capacitance to correct displacement power factor

$$kvar = kW\left(\tan\left(\theta_{orig}\right) - \tan\left(\theta_{new}\right)\right)$$

Correct

~~$$kW = \sqrt{\frac{1}{PF_{orig}^{2}} - 1} - \sqrt{\frac{1}{PF_{new}^{2}} - 1}$$~~

WRONG

Second equation should be:

$$kvar = kW \cdot \left(\sqrt{\frac{1}{PF_{orig}^{2}} - 1} - \sqrt{\frac{1}{PF_{new}^{2}} - 1}\right)$$

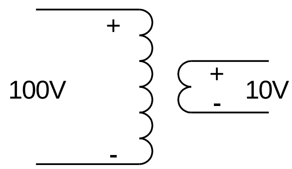
Utility mitigation of long-duration voltage variations - Voltage regulator

- Automatically boosts or bucks the voltage
- Typical range is +/-10% in 32 steps
- 20%/32 = 5/8% per step
- Usually single-phase devices, controlled independently

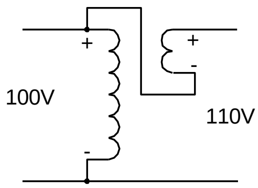
Picture from "How Step-Voltage Regulators Operate" Cooper Power Systems

Understanding regulator operation

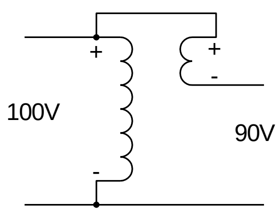
- A 10:1 transformer



- Connected to Boost



- Connected to buck



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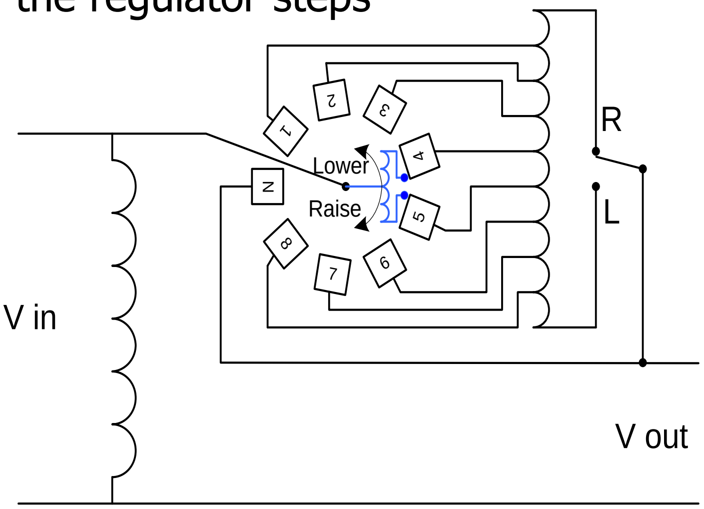
Voltage regulator operation
How the regulator steps



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Voltage regulator control

- Control settings include
  - Voltage level – the target voltage
  - Bandwidth – the difference between the upper and lower acceptable voltage, around the voltage setting
  - Time delay – how long the voltage must be “out of band” before the regulator control initiates a tap change

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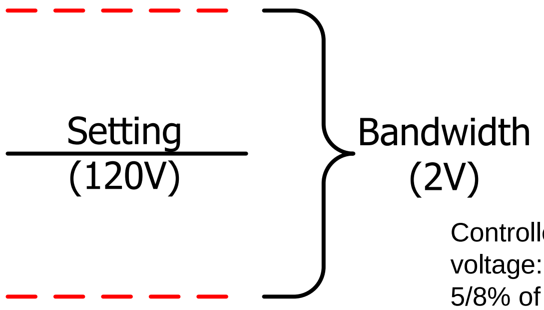
Voltage regulator control example



Controller uses 120V control voltage:
5/8% of 120V = ?
Bandwidth / 2=?

Bandwidth and time delay settings help prevent "hunting" – frequent stepping up and down.

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Line-drop compensation

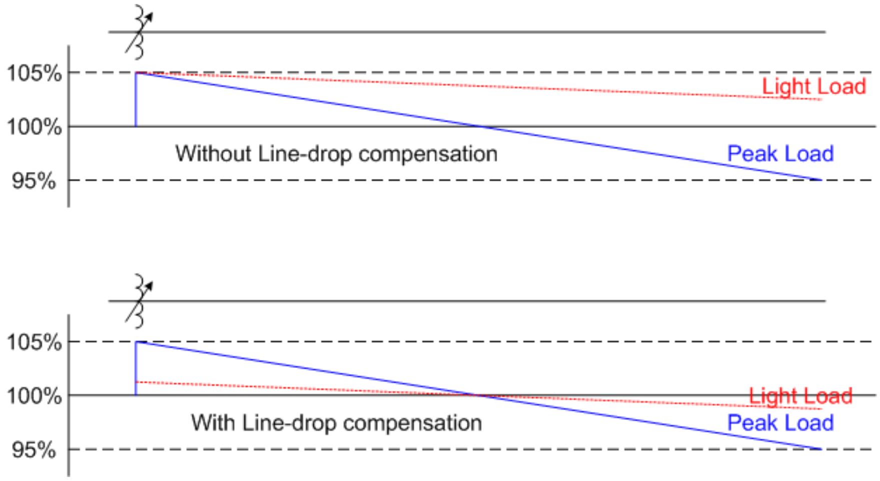
- Provides load-dependent voltage regulation
  - Regulator uses measured V and I to determine voltage drop to a downstream point
  - Regulator control adjusts tap setting to maintain set voltage at the downstream point
- Line is simulated in the regulator controller with two settings:

  R – proportional to the resistance of the line

  X – proportional to the inductive reactance of the line

  The units for R and X settings are volts.

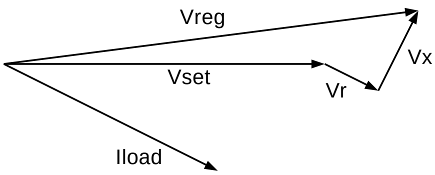
Line-drop compensation and voltage profiles



R and X settings for line-drop compensation

$$R_{setting\_volts} = R_{line\_ohms} \cdot \left(\frac{CT_{rating}}{PT_{ratio}} \right)$$

$$X_{setting\_volts} = X_{line\_ohms} \cdot \left(\frac{CT_{rating}}{PT_{ratio}} \right)$$



Example:

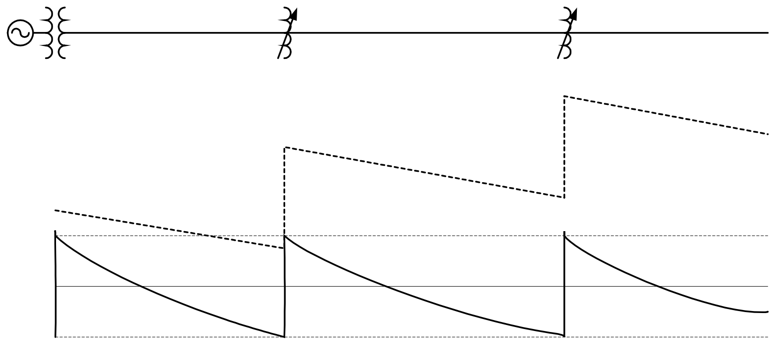
3.9 miles to regulation point, R=0.481 ohms/mi, X= 0.718 ohms/mi, CT = 200:5, PT = 7200:120.

$$R := 200 \cdot \frac{120}{7200} \cdot 0.481 \cdot 3.9 \cdot V \qquad R = 6.253\,V$$

$$X := 200 \cdot \frac{120}{7200} \cdot 0.781 \cdot 3.9 \cdot V \qquad X = 10.153\,V$$

Regulators in series

- May occur on long feeders
- Problems arise with load rejection



Capacitors

- May be installed in shunt or series
  - Shunt most common on distribution
  - Shunt and series used in transmission
- Shunt capacitors produce a voltage rise that is nearly independent of load – Remember from HW 3?
- Shunt capacitors reduce losses by reducing reactive power flow through the system – reactive power is provided near load centers
- The series RLC circuit formed by the line and the capacitor allows current to flow
- Current flow results in out-of-phase voltage drops across the line inductance and shunt capacitance

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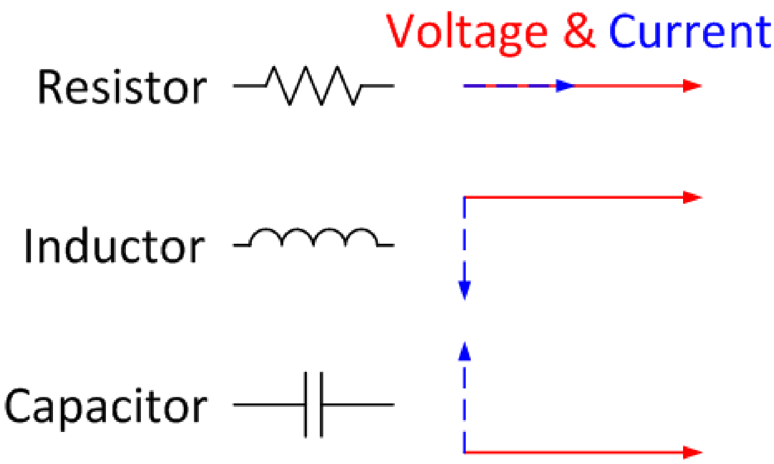
Voltage/Current relationships



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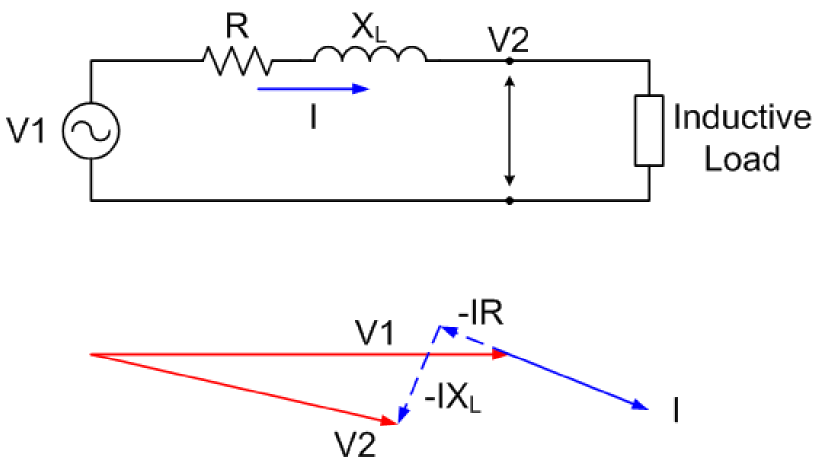
Voltage drop without capacitors



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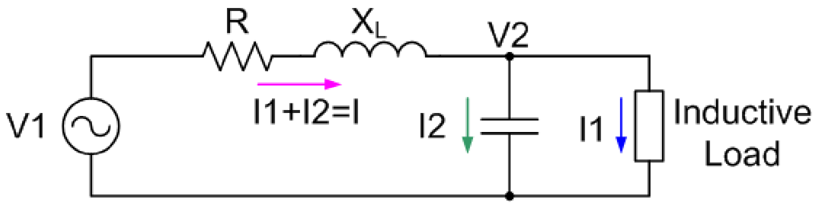
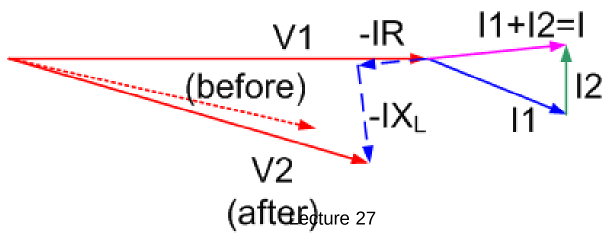
Voltage drop with capacitors





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Utility capacitor control

- Capacitors may be controlled based on:
  - Power factor
  - Voltage
  - Time
  - All three
- Voltage “override” is common
  - Capacitors are controlled to provide reactive power, with minimum and maximum voltage settings

Real world regulator and capacitor control

- Capacitors
  - Radio controlled from the substation
  - Substation measures reactive power need by feeder and substation total
  - Switches on capacitors when need exceeds size of next capacitor in the list
  - Capacitors use voltage override to help prevent under- or over-voltages

Real world regulator and capacitor control

  - Capacitor control system ensures power factor near unity on feeders
- Regulators
  - Only R setting is used
  - X has little effect at high power factors
  - R may be adjusted in the field to increase or reduce voltage based on voltage recordings

Next time…

- End user mitigation
- Midterm exam due
- Read chapter 7