ECE 528 – Understanding Power Quality

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

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Lecture 17

Today…

- Long term voltage variations – see PSQ 7.1-7.5 and FPQ 5.4-5.5
- Example – resolving a local (service) voltage regulation problem
- Customer-side mitigation of long-duration voltage variations
- Utility-side mitigation of long-duration voltage variations
  - Voltage regulator operation
  - Capacitors

Investigating voltage regulation problems

- System or Service?
  - System problem
    - Service voltage is not significantly affected by load variations at the service point
    - Voltage is low (or high) with little or no load at the service point
  - Service problem
    - Voltage is significantly affected by load fluctuations at the service point
    - Voltage is normal with little or no load at the service point

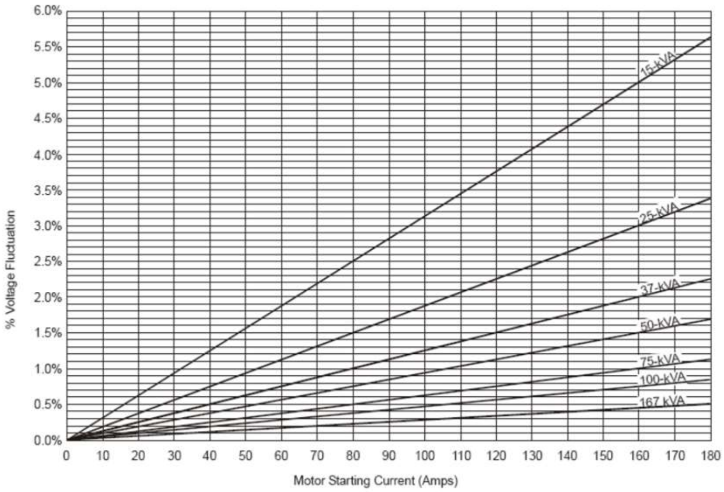
Resolving a local voltage-regulation problem

- Example:
  - Single phase, 120/240V customer reports lights flicker and UPS sometimes "beeps" when some motor loads start. (well pump, AC)
  - Voltage measured at service panel is 122, 122, 244V with almost no load.
  - When well pump starts, current peaks at 160A RMS, and voltage drops to 112.5, 112.5, 225V.
  - Customer is served with a 15kVA transformer and 100' of #2 triplex aluminum cable.
  - Given this data, calculate percent voltage regulation.

$$\text{Percent\_Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \cdot 100$$

Resolving a local voltage-regulation problem

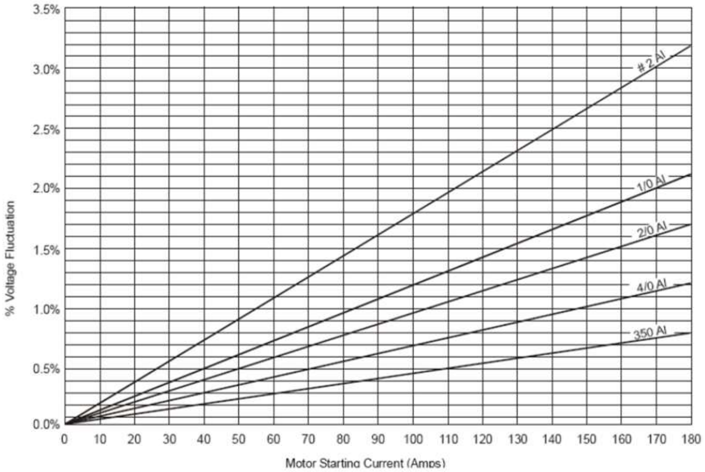
- Voltage drop for transformers, assuming 2% impedance:



Tables or graphs can simplify the process of estimating voltage drop. This is an example used for transformers.

Resolving a local voltage-regulation problem

- Service cable voltage drop, per 100’ of service length:



This graph is used to simplify estimating voltage drop in service cables.

Resolving a local voltage-regulation problem

- From graphs, voltage drop for 160A is ~7.8%, 5% for the transformer and ~2.8% for the conductor. This corresponds to voltage regulation of 8.46%.
- Design goal: <4% (voltage regulation: <4.17%)
- We can change the conductor, the transformer, or both.
- Suggestions?

Customer-side mitigation

- Ferroresonant transformers
  - What do we know about them?
    - Very constant output voltage over a wide range of input voltage
    - Must be oversized
    - Best for relatively constant load – not suitable for motors
    - Inefficient – best for relatively small loads

Customer-side mitigation

- Magnetic Synthesizers (PSQ pg. 71)
  - – Similar to ferroresonant transformer
  - – Specifically designed for three-phase loads
  - – Provides two-way harmonic isolation
    - Load harmonics blocked from reaching source
    - Voltage distortion in source doesn't reach the load
  - – Uses saturated reactors, transformers, and capacitors
  - – Output voltage is relatively constant (+/-4%) over a wide range of input voltage (+/- 40%)

Customer-side mitigation

- Electronic tap-changing transformers or regulators
  - – Use solid-state switches to quickly switch between taps
  - – Can provide voltage in a narrower range than supplied by the utility
    - One example:
      - – Input: +10% to -20% of nominal
      - – Output: +/- 2.5% of nominal

Customer-side mitigation

- UPSs
  - – Normally not intended for long-term mitigation
    - Some models incorporate ferroresonant transformers or electronic tap-changing voltage regulators or transformers
    - Provides voltage regulation over a wider range of input without switching to battery

PSQ Book corrections Ch. 7

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

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

Correct

$$\cancel{\mathrm{kW} = \sqrt{\frac{1}{\mathrm{PF}_{\mathrm{orig}}^{2}} - 1} - \sqrt{\frac{1}{\mathrm{PF}_{\mathrm{new}}^{2}} - 1}}$$

WRONG

Second equation should be:

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

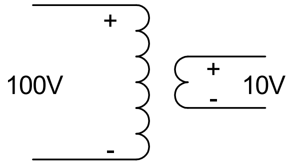
Utility mitigation of long-duration voltage variations
Voltage regulator

- 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

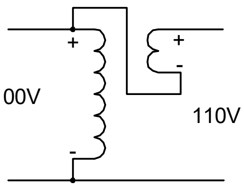
Picture from “How Step-Voltage Regulators Operate” Cooper Power Systems

Understanding regulator operation

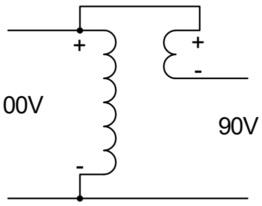
- A 10:1 transformer



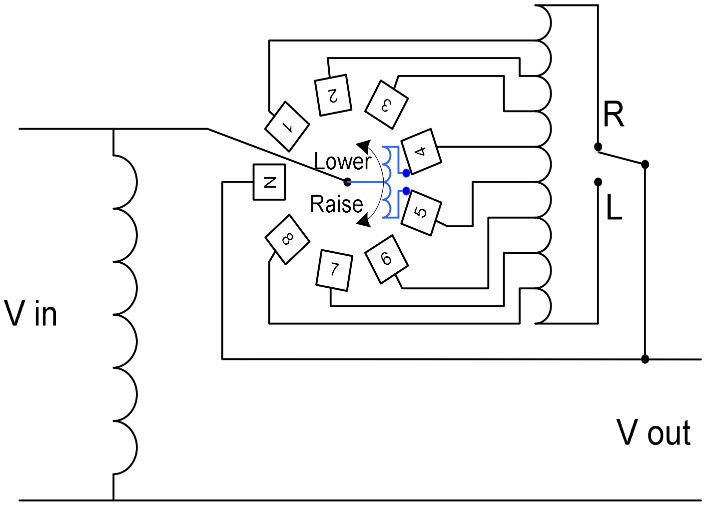
- Connected to Boost



- Connected to buck



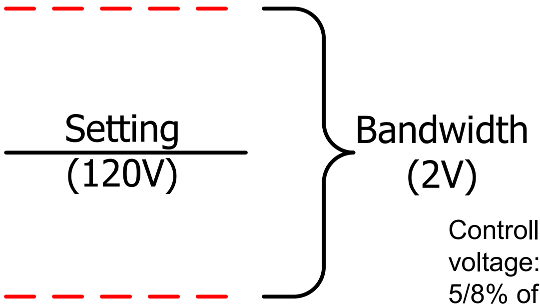
Voltage regulator operation: How the regulator steps



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

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.

Line-drop compensation

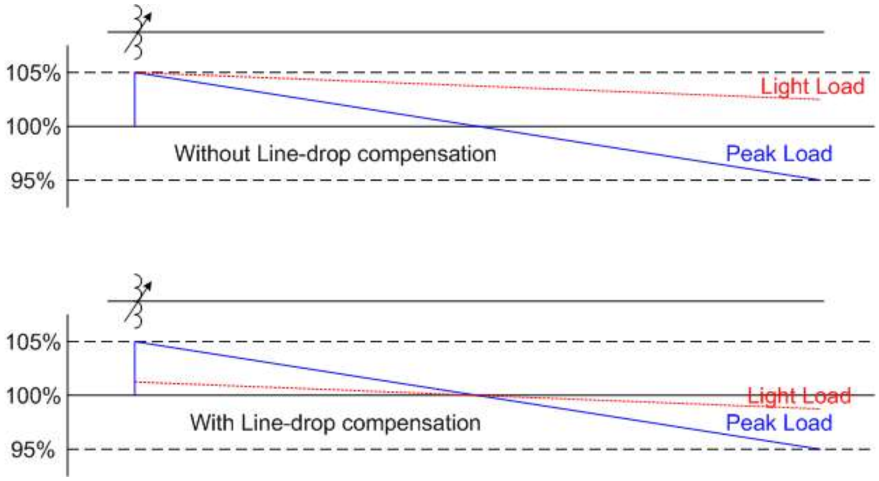
- Provides load-dependent voltage regulation
  - Regulator uses measured V and I to determine voltage drop to a downstream point
  - Regulator control adjusts tap setting to maintain set voltage at the downstream point
- Line is simulated in the regulator controller with two settings:

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.

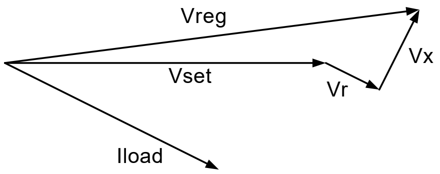
Line-drop compensation and voltage profiles



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:

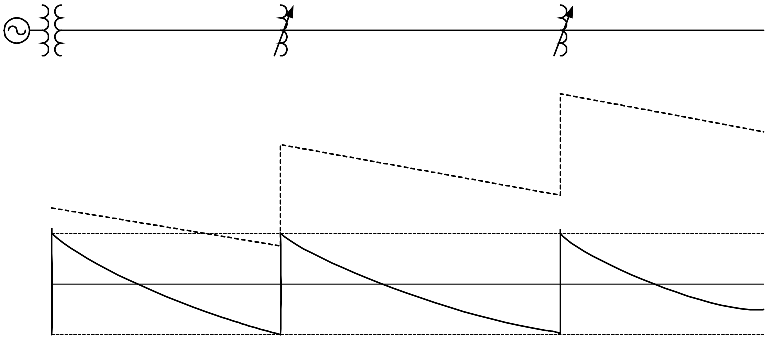
3.9 miles to regulation point, R=0.481 ohms/mi,
X= 0.718 ohms/mi, CT = 200:5, PT = 7200:120.

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

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

Regulators in series

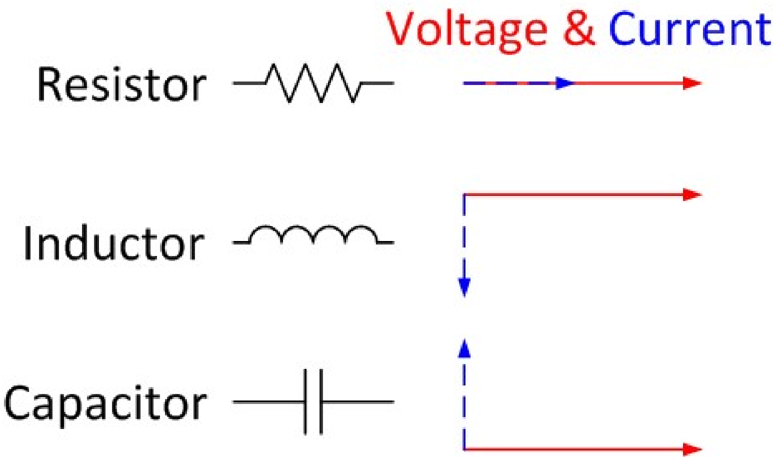
- May occur on long feeders
- Problems arise with load rejection



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
- Series capacitors produce a voltage rise that is proportional to load current
- Shunt capacitors reduce losses by reducing reactive power flow through the system – reactive power is provided near load centers
- Series capacitors help compensate for the line reactance
- 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

Voltage/Current relationships



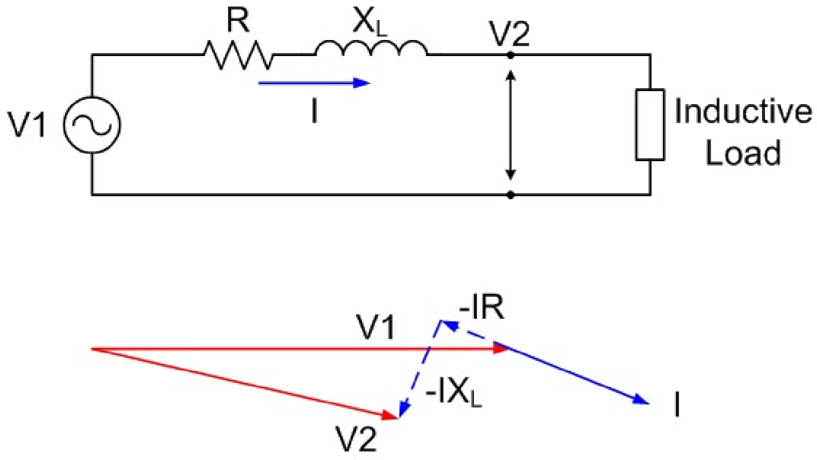
Voltage & Current

Resistor

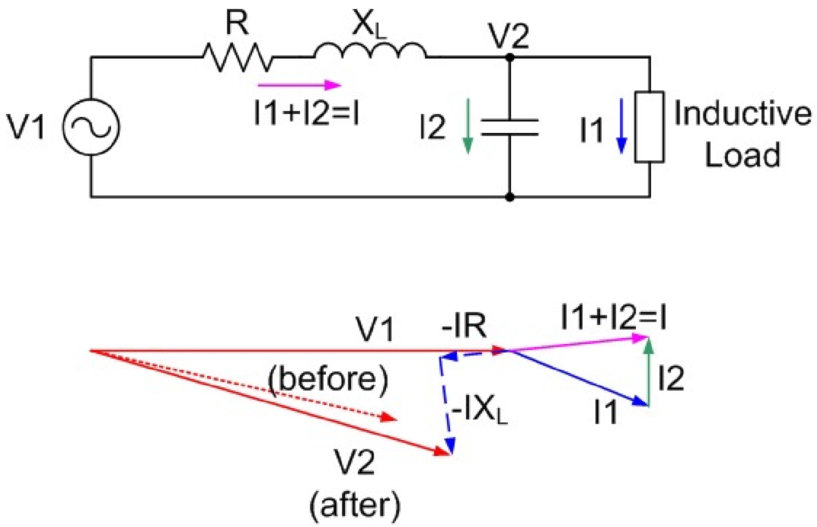
Inductor

Capacitor

Voltage drop without capacitors



Voltage drop with capacitors



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

- Old system
  - 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
  - Regulators operate independently, using voltage and current input
    - 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

Real world regulator and capacitor control

- New system
  - Integrated Volt/Var Control (IVVC)
    - Regulators and capacitors controlled together by computer algorithm
    - Minimizes VAR flow across the system (reduces losses)
    - Optimizes voltage using both capacitors and regulators
    - Incorporates data from voltage and current transducers at regulators, capacitors, and elsewhere

Next time…

- More on capacitor applications