University of Idaho
College of Engineering

ECE 528 – Understanding Power Quality

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

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Lecture 16

University of Idaho

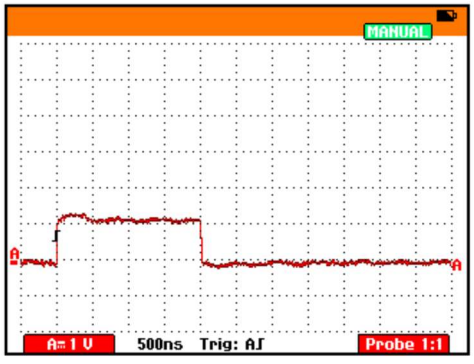
Today…

- Transient overvoltages
  - Reflected and damped transients
  - Finish types of capacitor switching transients
  - Mitigating capacitor switching transients
  - Other switching transients
  - Transient protection summary
- Introduce Long-duration voltage variations

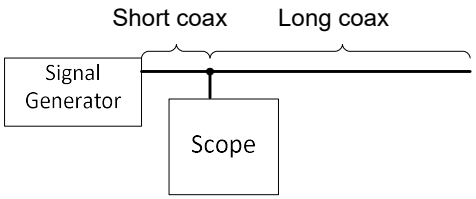
Mitigating inductive load switching transients

- Mitigate Electrical fast transient (EFT) with electrical and physical separation (PSQ p. 192)
- Apply “snubbers” at switches to absorb transient energy
- Apply surge suppressors (MOVs).
- Apply a combination of snubbers and surge supressors (see Littlefuse application note)

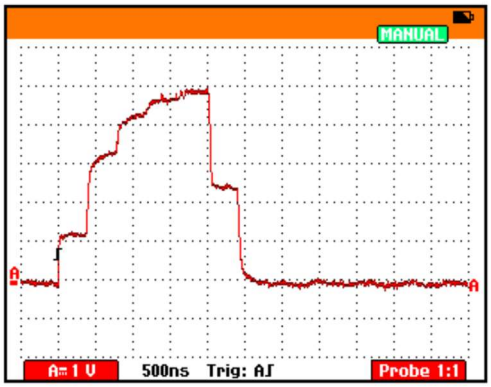
Transient reflections



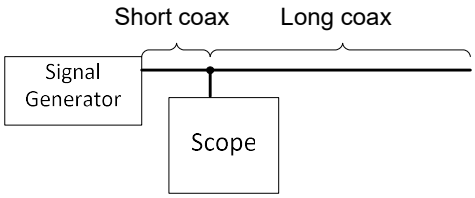
- The source signal
  - 2µs, 1V pulse
- Setup
  - Signal generator to oscilloscope, to ~150’ of 50-ohm coax with 50-ohm terminator



Transient reflections



- Same source signal
- 50-ohm terminator removed
- Notice:
  - Reflections at both far and near ends
  - Gradual damping



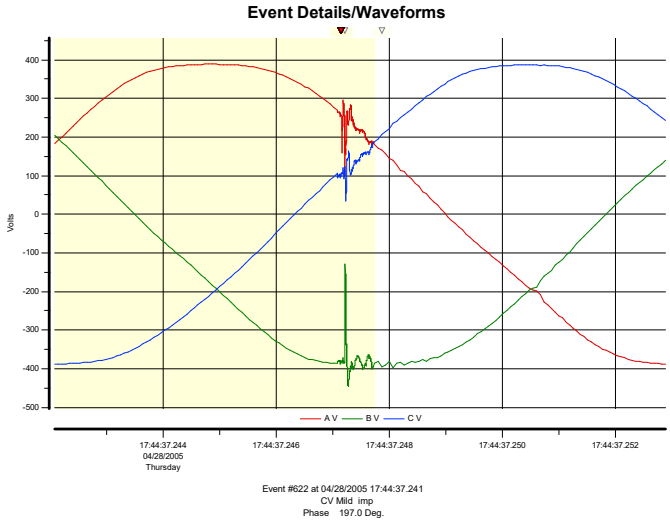
Other switching transients

- Issues:
  - High voltages
    - Sometimes several p.u.
  - Higher frequencies
    - Compared to capacitor switching
  - Multiple sources
    - Any switched load may cause a transient

Reference: (Get a copy – it's a good resource)

IEEE Std. C62.41.1-2002 - IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits

Other switching transients



High dv/dt increases likelihood of capacitive coupling to nearby circuits. May lead to data errors, mis-operation of process control systems.

Switching transient sources
(besides capacitors)

- Normal switching:
  - Load switching – turning equipment on and off
  - Voltage notching – due to commutation in electronic power converters
  - Switching on the power system
    - Transformer energizing – PSQ pg. 194.
- Abnormal switching:
  - Arcing faults
  - Fault clearing – current limiting fuses or fast breakers – current chopping

Equipment Impact

- Nuisance tripping of ASDs
- Power supply failure
- I/O board failures
- Turn-to-turn faults in motors and transformers

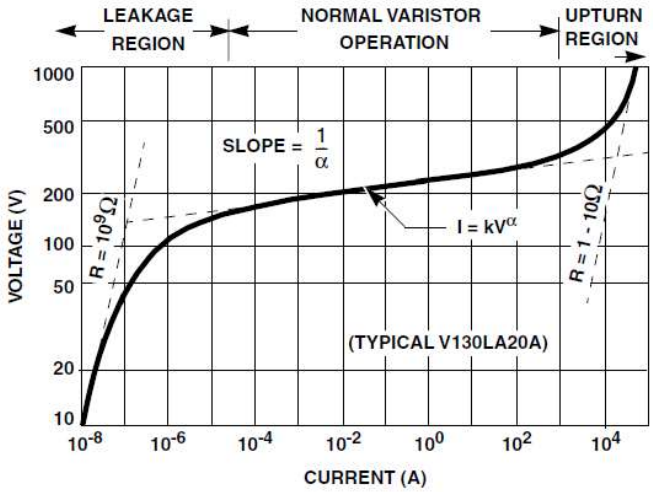
Special considerations for transients

- High frequency
  - Increases capacitive and inductive coupling
  - Conductor lengths become important
    - Reflections/voltage magnification
    - Voltage differences at equipment based on conductor route
- May cause extra zero-crossings
  - Some timing circuits use zero-crossings
- Multiple sources
  - Eliminating all sources is unlikely

Transient overvoltage mitigation

- Standard transient overvoltage protection
  - "Crowbars" – arc gaps or electronic devices
    - May arc through air or other gasses
  - "Clamps" – MOVs
  - Filters
  - Combined devices

Typical MOV operating characteristic



From Littlefuse Application Note AN9767.1, www.littelfuse.com

Note: This is a log-log plot.

Transient overvoltage mitigation

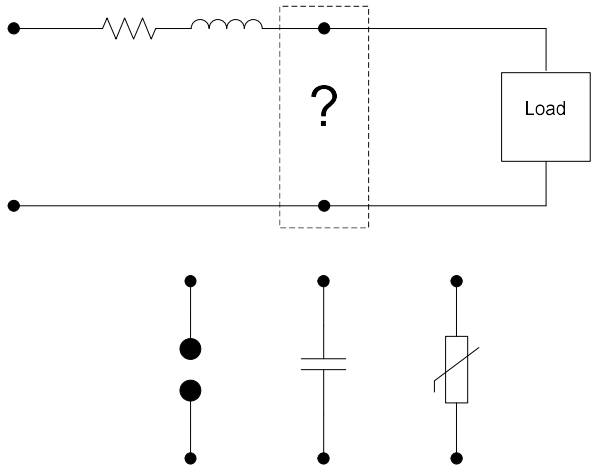
- Some switching transients can be stopped at the source:
  - Shunt-connected devices cannot "tell" which direction the transient is coming from.
  - A "surge capacitor" near a motor contactor can limit the voltage transients associated with motor switching and help suppress high frequency transients from other sources.
  - A "snubber" across the motor contactor contacts can reduce or eliminate arcing when the contactor opens.

Surge Capacitor

Summary of transient overvoltages and mitigation

- Sources
  - Lightning
  - Switching (Capacitors, loads)
  - Faults
- Mitigation
  - Clamping devices (MOVs)
  - Crowbar devices (Arc gaps)
  - Filters (low-pass)

Transient overvoltage mitigation methods



Summary of transient overvoltages and mitigation

- Mitigation continued:
  - Establish common ground reference for power and communication circuits
  - Minimize coupling to communication and control circuits
    - Use twisted, shielded communication conductors
    - Separate communication and power circuits
    - Use optical isolation for communications between devices on different power systems

Long-duration voltage variations - Overview

- Long-duration voltage variations are caused by voltage regulation problems
- Voltage regulation

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

  - A measure of the change in voltage compared to the change in load

NL=no load, FL=full load

"Normal" voltage ranges

- Defined for the U.S. in ANSI C84.1 (Current edition is 2020)
  - "American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60Hertz)"
  - Describes nominal voltages and operating ranges for utility systems and end-user equipment

ANSI C84.1 service and utilization voltage ranges

- Range A Service Voltage:
  - Systems shall be designed and operated so most service voltages are within range A.
- Range A Utilization Voltage:
  - Equipment shall be designed and rated to give fully satisfactory performance in range A.
- Range B Service Voltage:
  - Infrequent, but necessary due to practical design and operating conditions. Corrective measures shall be taken in a reasonable time to return to Range A.
- Range B Utilization Voltage:
  - To the extent practical, equipment shall be designed for acceptable performance in Range B, but not necessarily as good as Range A.

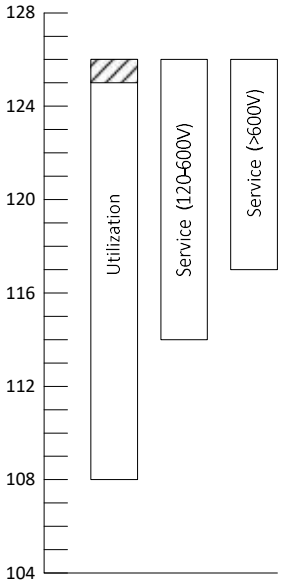
ANSI C84.1 service and utilization voltage ranges

- Service voltage outside Range B:
  - Will occur due to conditions beyond the supplier's control.
- Utilization voltage outside Range B:
  - Equipment may not operate satisfactorily. Protective devices may operate (or be required) to protect equipment.

ANSI C84.1 service and utilization voltage ranges

- **Range A – Normal operating conditions**
  - Shaded area does not apply to systems of 600V or less
  - Note difference between service and utilization voltage range.
  - What the National Electric Code says about voltage drop:
    - Size conductors to limit voltage drop to 5% or less – not a requirement, but a recommendation.
    - However; service voltage may already be at 95% of nominal.

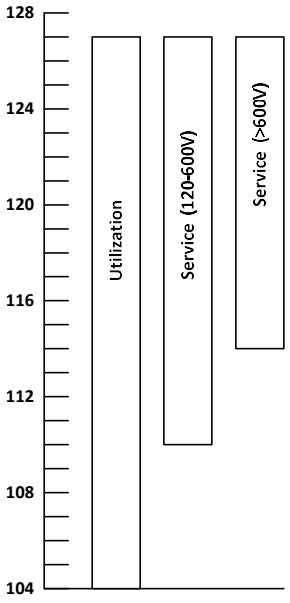
  120V – 5%= 114V 120V – 10% = 108V



(Voltage scale is on a 120V base.)

ANSI C84.1 service and utilization voltage ranges

- **Range B – Unusual conditions**
  - Unusual conditions are not specified
  - Utility must take corrective measures in a "reasonable time"



Voltage rating example: 480V service for a motor:

- What is the range A service voltage range?
  From_____ Volts to _____ Volts
- What is the range A utilization voltage range?
  From _____ Volts to _____ Volts
- A motor designed for a 480V service would have a nominal voltage rating of 460V, not 480V, and should operate satisfactorily at nameplate +/-10%. (per ANSI/NEMA MG 1-2021) (Free from NEMA)*
  Motor "satisfactory" range: From_____ Volts to _____Volts
  Motor range (% of to 480V nominal): From _____ % to _____%

  *Another good motor reference: The "Cowern Papers"
  https://www.baldor.com/mvc/DownloadCenter/Files/9AKK107303

Long-duration voltage variations - where is the issue? System, Service, or Facility Wiring

- System
  - Transmission System
  - Substation
  - Distribution Lines
  - **Capacitors**
  - **Voltage Regulators**
  - Switches
  - Reclosers
  - Fuses
- Service
  - **Distribution Transformer**
  - **Service Conductors**
  - Service Panel/meter
- Facility Wiring
  - Feeders and branch circuits in the facility

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
      - May include excessive voltage imbalance with minor load imbalance
    - Voltage is normal with little or no load at the service point

Utility approach to voltage regulation

- System Problem
  - Change settings on existing regulators or capacitors
  - Install regulators or capacitors
  - Reconductor
- Service point problem
  - Increase service transformer size
  - Increase service conductor size
  - Shorten service length

Next time…

- More on long term voltage variations
  - Voltage regulators
  - Capacitors for voltage regulation