# ECE 528 – Understanding Power Quality

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

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Lecture 13

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## Today…

- Midterm discussion
- Voltage Transients
  - ITI curve
  - Characterizing voltage transients
  - Collecting data
  - Some sources
  - Some impacts on loads

2 Lecture 13

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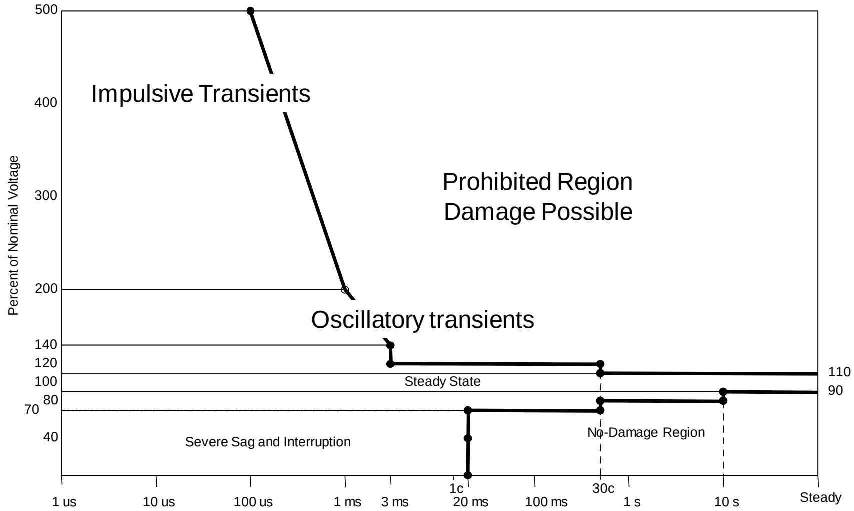
# Transient overvoltages and the ITI Curve



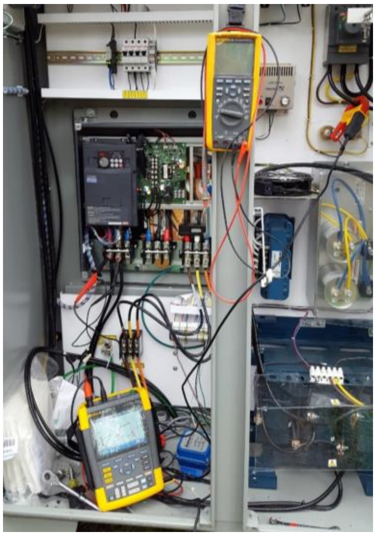





# Analysis of voltage transients

- Transient analysis usually requires waveform data
- Collecting waveforms requires instruments with faster sampling and more data storage
- More capable power quality recorders often record at high frequency, but discard the data until a transient is detected. Then they retain some amount of pre- and post-event data.
- Oscilloscopes may also be useful for capturing transients

## Collecting data:



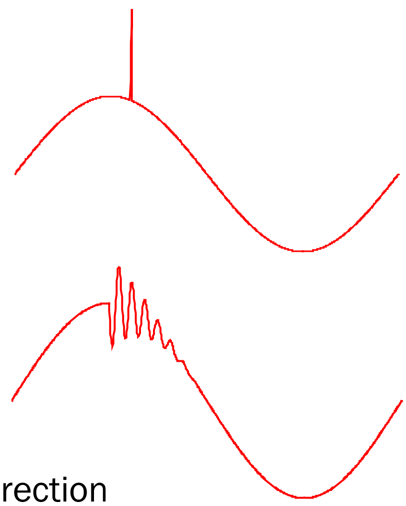






## Three ways waveforms help us identify sources of voltage transients

- Waveform characteristics
  - Impulsive or oscillatory
  - Frequency of oscillation
  - Rise time, decay time, etc.
- Time-stamp
  - Correlation with known events
- Time-of-arrival
  - Used to determine transient direction



## Characterizing transient overvoltages

See Table 2.2 in either text

- Impulsive
  - Nanosecond
    - 5ns rise, lasts <50ns
  - Microsecond
    - 1μs rise, lasts 50ns – 1ms
  - Millisecond
    - 0.1ms rise, lasts >1ms
  - Caused by lightning, removal of an inductive load, loose wiring, and other arcing events





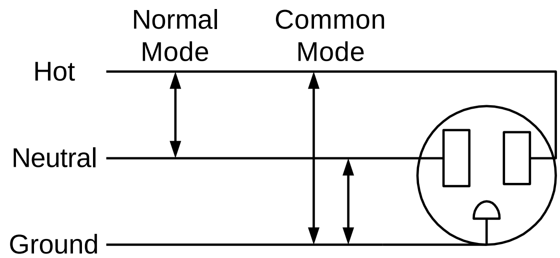
## Characterizing transient overvoltages

See Table 2.2 in either text

- Oscillatory (typical frequency, duration, magnitude)
  - Low frequency: <5kHz, 0.3 – 50ms, 0 – 4 pu
    - Capacitor switching, ferroresonance, transformer energization
  - Medium frequency: 5–500 kHz, 20μs, 0 – 8 pu
    - Back-to-back capacitor switching, cable switching, impulse response
  - High frequency: 0.5 – 5 MHz, 5 μs, 0 – 4 pu
    - Response of system to an impulsive transient

# Characterizing transient overvoltages

- Common Mode (N-G)
  - caused by lightning, utility switching, ground potential differences in a network, and radio and T.V. transmitters
- Normal Mode
  - caused by power electronics, switching power supplies, and arcing loads



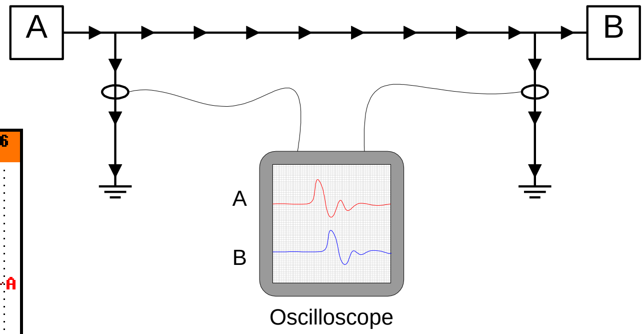


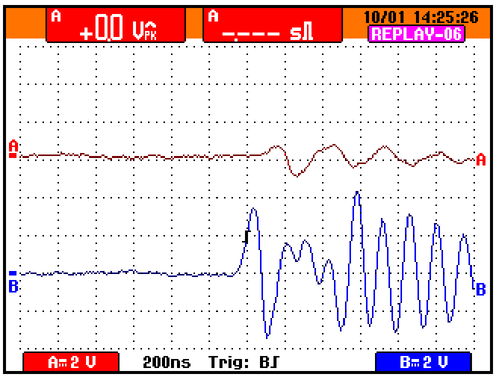



# Time-of-arrival test

- Used to determine a transient's direction of travel.
- Transients travel away from their source, at (nearly) the speed of light.
- We can monitor two locations and determine the direction to a transient source.

# Time of arrival test

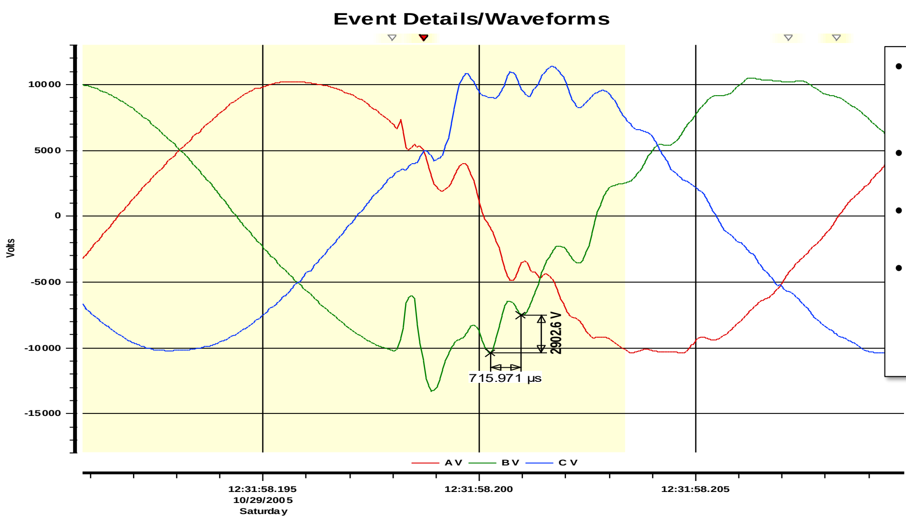






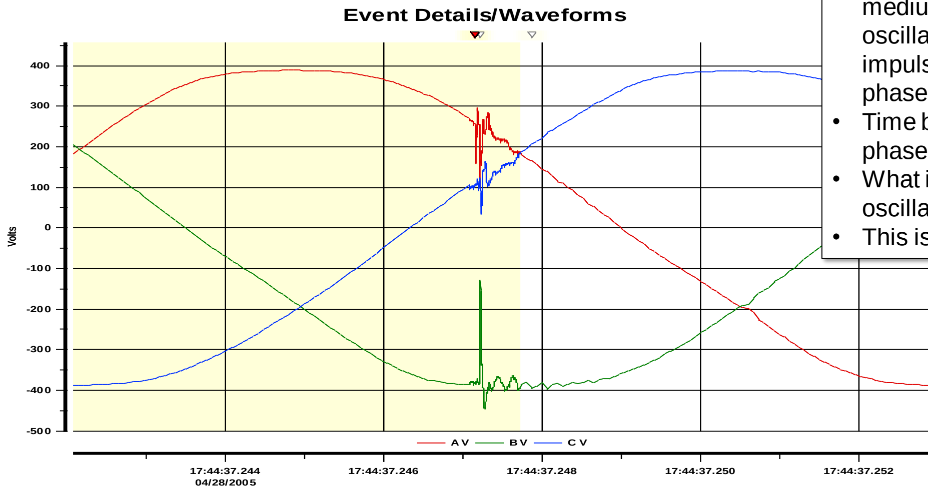

# Some real transient waveforms




- This is a three-phase, low-frequency, oscillatory transient.
- Note time between peaks on B-phase voltage (716µs).
- What is the frequency of the oscillatory transient?
- This is a typical capacitor-switching transient, when the capacitor bank is switched on.

# Some real transient waveforms
## Load switching

University of Idaho




- This is a three-phase medium-frequency, oscillatory transient with an impulsive component on phase B.
- Time between peaks on B-phase voltage is 180µs.
- What is the frequency of the oscillatory transient?
- This is load switching.

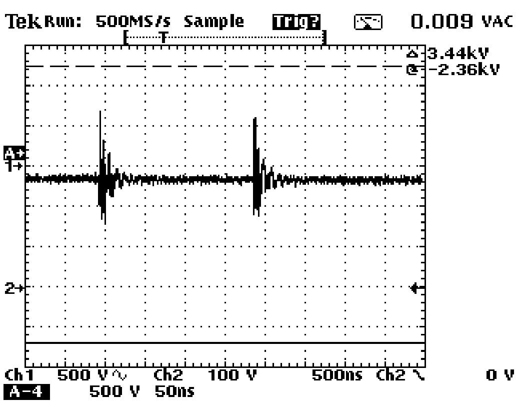




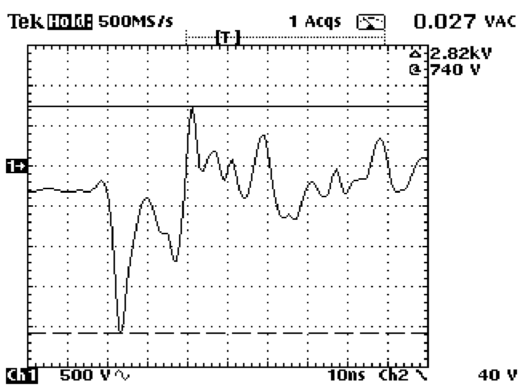
# Some real transient waveforms
## Load switching

University of Idaho

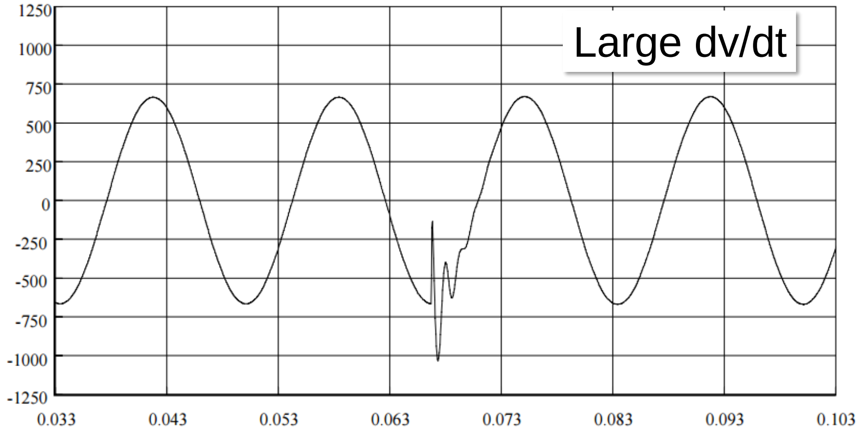
First try with oscilloscope




Adjusted oscilloscope and caught another transient



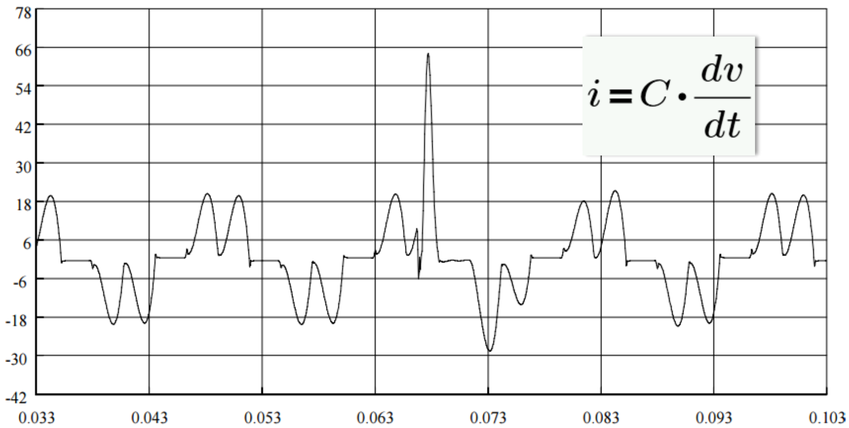
## Impact on loads
## Capacitor switching and ASDs




From: *Effects of Capacitor Switching and Load Switching on Power Quality* – Doug Dorr, EPRI 2009 Power Quality Workshop



## Impact on loads
## Capacitor switching and ASDs

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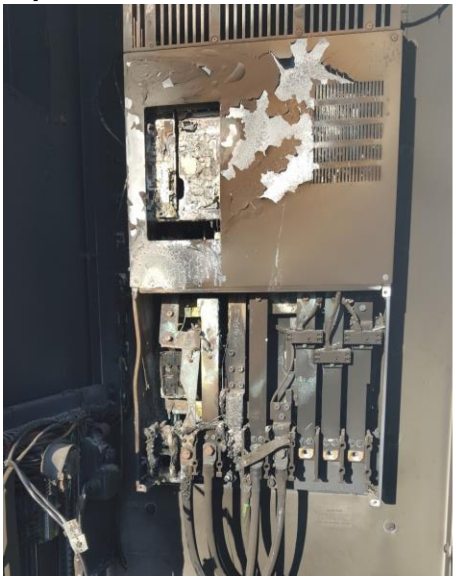
# Impact on loads



- A few "symptoms"
  - Hard disk crash
  - Power supply failure
  - Component failure
  - SCR failure
  - Circuit board failures
  - Process interruptions
  - "letting the smoke out"





# How transients travel through and between electrical systems

- Transients may travel via:
  - Conduction ("Resistive coupling")
  - Inductive coupling
  - Capacitive coupling
  - Far-field coupling

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

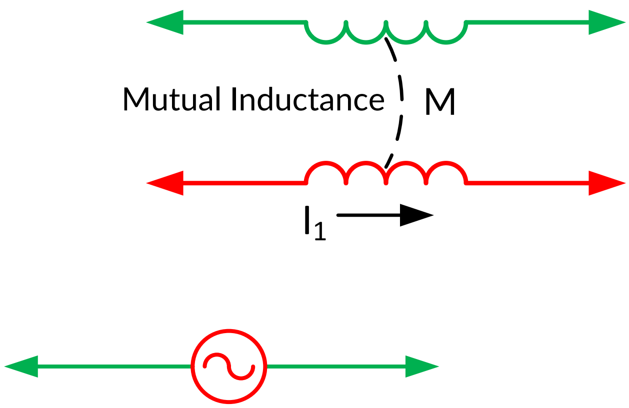
## How transients travel…

- Conduction - Using any <u>and all</u> conductor paths available
  - Power circuits
  - Communication circuits
  - Grounding systems - Water pipes – structural steel



## How transients travel: Inductive coupling

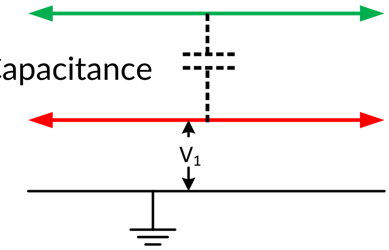
- Produced by the magnetic field between conductors (current in aggressor or source)
- Acts as a series voltage source
- Directly proportional to:
  - Frequency
  - Current
  - Conductor length
- Inversely proportional to:
  - Conductor separation



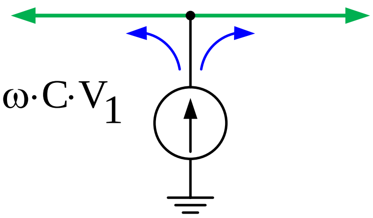

$$V = j \cdot \omega \cdot M \cdot I_1$$

## How transients travel: Capacitive coupling

- Produced by the electric field between conductors (voltage)
- Acts as a current injection point
- Directly proportional to:
  - Frequency
  - Voltage
  - Conductor length
- Inversely proportional to:
  - Conductor separation




$$I = j \cdot \omega \cdot C \cdot V_1$$







## Capacitive and Inductive coupling issues

- Voltages and currents can be capacitively and inductively coupled in any conductor
  - Fencing
  - Piping
  - Building materials
- A transient can couple from circuit 1 to circuit 2, and then from circuit 2 to circuit 3.
- Can you see why we twist conductors in communication circuits?

## Far field coupling

- Circuit components may act like a receiving antenna for radiated electromagnetic energy
  - Far field starts beyond $\lambda/2\pi$ (approximately wavelength/6)
  - With increasing distance, electric and magnetic fields each start to produce their complementary field
  - Capacitive and inductive coupling are no longer separate effects in the far field
  - Absorption of EM radiation in the far field has no impact on the transmitter
  - Examples: Radio and television, Lightning
  - One of the symptoms of arcing connections is radio interference, and we can look for arcing connections with radio receivers





## Next time

- More on Transients
- Principles of protection