Lightning & Over-Voltage Protection for Pipelines

Mike Tachick, Dairyland Electrical Industries

AUCSC

Appalachian Underground Corrosion Short Course

CP Needs Isolation

- Coatings, insulation systems isolate the structure
- Direct grounding affects CP
- If grounded, requires more current, affects CP voltage
- Therefore, CP systems should be isolated from other structures and ground

Consequence of Isolation

- Isolated structures can be shifted in voltage easily
- Helps with CP, but allows unsafe conditions during lightning/faults
- Therefore, CP systems need BOTH DC isolation and safety grounding

Over-voltage Protection Concepts

- Minimize voltage difference between points of concern:
  - At worker contact points
  - Across insulated joints
  - From exposed pipelines to ground
  - Between grounding systems
  - Across a grounding system
  - Pipe to other nearby structures: casing, tower, substation

Over-Voltage Sources

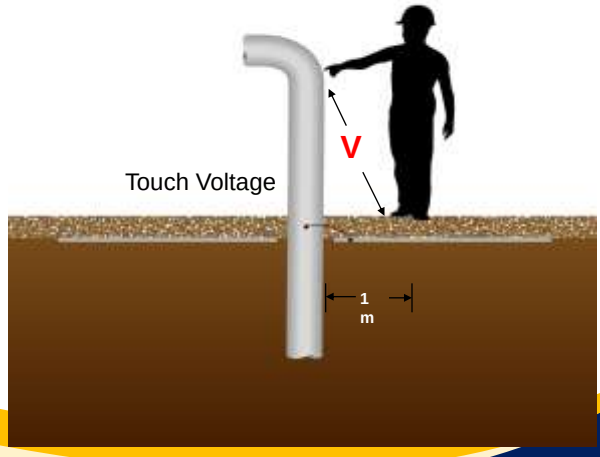
Temporary:

- Lightning
- AC power system faults

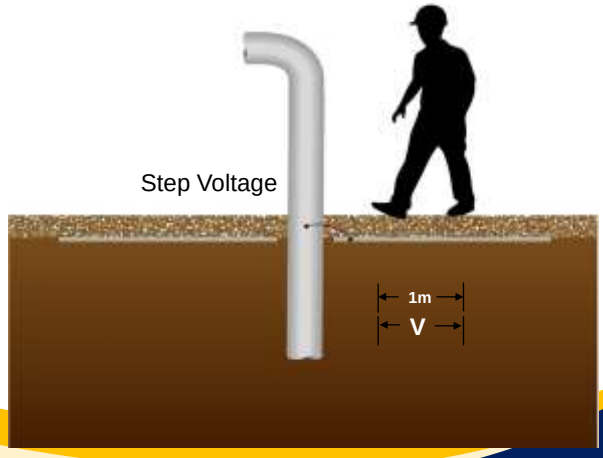
Steady-state:

- Induced AC voltage

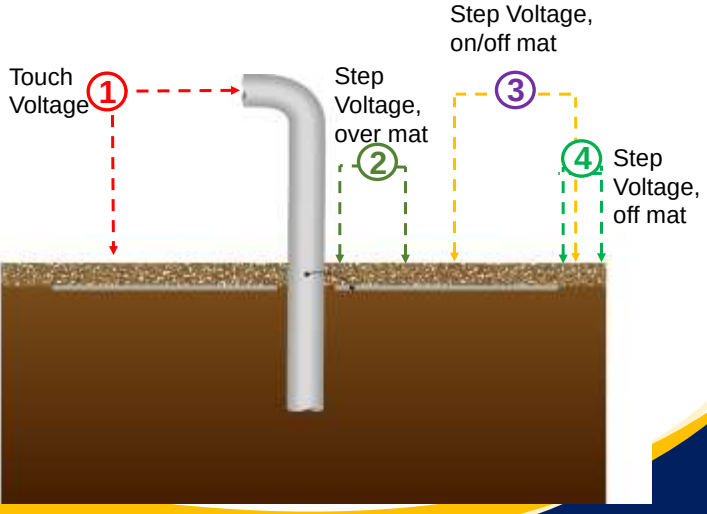
Touch Voltage



Step Voltage

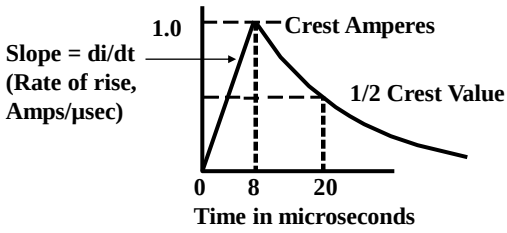


Various Touch/Step Cases



NACE: GCM "shall be engineered…"/ CSA: must evaluate all four cases

Key Parameters of Lightning Waveform



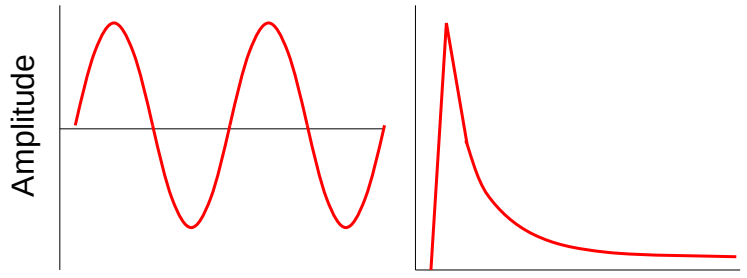
Lightning has very high di/dt (rate of change of current)

Lightning standards

- Typical waveforms for testing replicate lightning characteristics
  - 8 x 20 microsecond waveform
  - 4 x 10 microsecond waveform
- Current levels for testing are usually 50kA, 75kA or 100kA peak
- Actual: 1kA to 200kA (wide range)

AC Faults

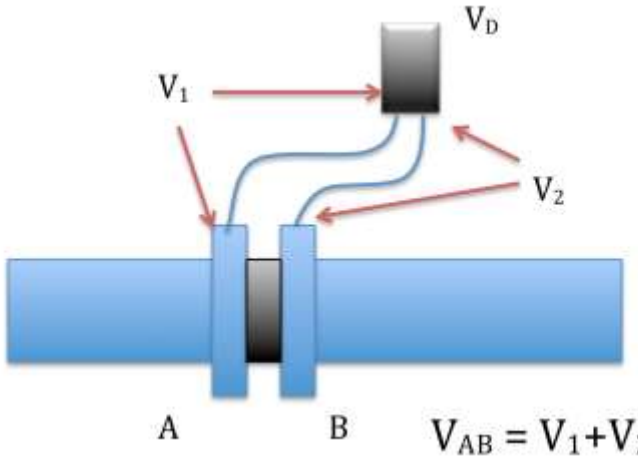
- Events last several cycles typically (60Hz = 60 cycles per second)
- Current levels are hundreds or thousands of amps AC on pipeline, and can be higher.
- Usually relates to electrical insulation breakdown or reduction of some type
- Breaker or fuse clears the fault



Lightning Over-Voltage

- Protective products (decouplers, arresters) have voltage drop across them
- Conductors that attach products have even higher voltage drop during lightning surge
- Use very short conductors or bus bars for product attachment

Lightning Over-Voltage



Lightning Over-Voltage

- Voltage determined by the inductance of the current path and the rate-of-rise of current

$$V = L \bullet di/dt$$

- Inductance relates to conductor length or multiple conduction paths
- Rate-of-change of current is a high value for lightning

Lightning Over-Voltage

- Given typical wire, 0.2µH/foot
- Given waveform with 10,000A/µs

Result is:

$$V = L\ di/dt = 0.2\mu H/ft \bullet 10{,}000A/\mu s$$
$$= 2{,}000V/ft$$

This is the voltage per foot of conductor length

- Therefore, keep conductors short!

Conductor length example

Protect insulation systems

Prevent arcing at insulators

Step and Touch Voltage

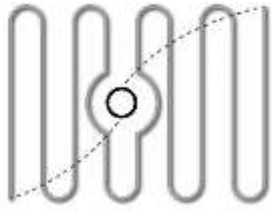
- Grounding mats (or gradient control mats) can provide step/touch protection
- Use grid-type grounding mat designs for lowest step and touch voltage
- Install within 4 ft of ungrounded pipeline segments
- Connect mats to pipe with short conductors (important for lightning)

Gradient Control Mats

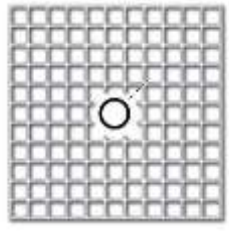
Grounding Mat Design

- Best performance comes from a gridded mat
- Worst performance from single conductor system (spiral, zig-zag) due to conductor length inductance
- Difference can be up to 1000:1 in voltage performance
- Connect any mat to pipe with short bonds, otherwise touch voltage is raised for lightning conditions

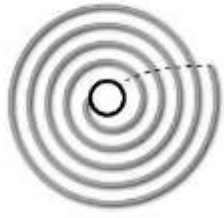
Grounding Mat Design



Zig-zag Mat

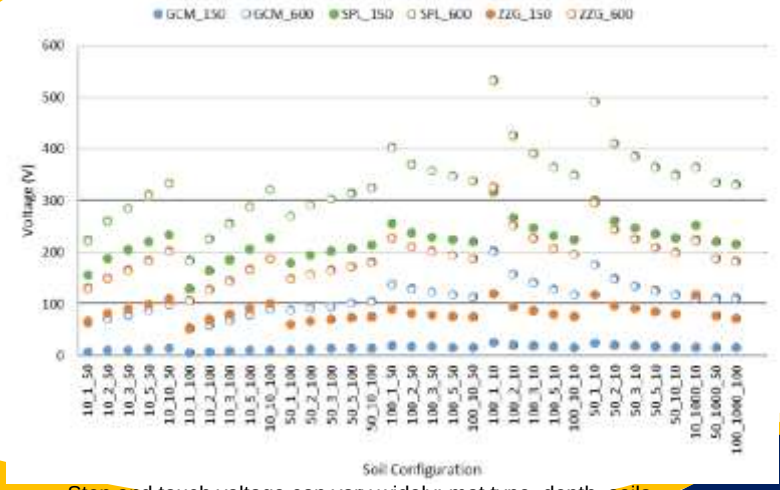


Grid Mat



Spiral Mat

Grounding Mat Performance



Step and touch voltage can vary widely: mat type, depth, soils

AC Induction

- Effect from current flow on power line nearby
- Magnetic field from current interacts with pipe
- Raises voltage on coated pipelines
- Worse effects on well coated lines

AC Mitigation

- Establishes low resistance pipe to ground bond
- Collapses induced AC voltage, allows AC current to flow
- No effect upon CP if decoupled
- Must be rated for steady-state and fault conditions

Mitigation guidance

- NACE SP0177-2007, limits voltage to 15V
- 15V based on human health issues, and is a steady-state limitation
- Does not guarantee protection for AC faults and lightning, doesn't address AC corrosion

Induction Variables

Variable	Change	Induction result
Soil resistivity	Increase	Increase
Coating resistance	Increase	Increase
Load current	Increase	Increase
Dist from tower	Increase	Decrease
Change in distance	Any change	Increase

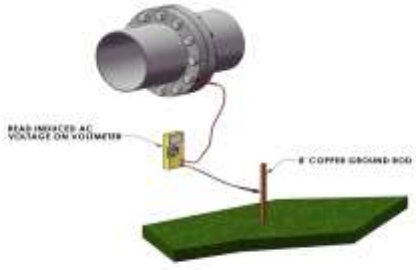
AC Mitigation Practices

- Use mats at all facilities and test stations near HVAC corridors and for those pipelines that come from corridors (basically good practice everywhere)
- Mats are for step and touch voltage but usually don't provide much AC mitigation (other specific AC mitigation grounding system needed)

AC Mitigation Practices

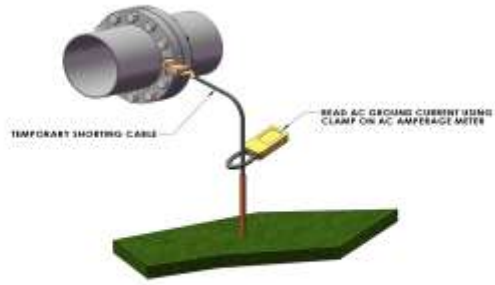
- Final mitigation design creates low resistance ground without affecting CP
- Can test by bonding pipeline temporarily to well grounded object (fence, culvert, station ground)
- Measure resulting AC voltage on pipe, and AC current drain

Field Measurements



Open Circuit Voltage

Field Measurements



Short Circuit Current

Final Installation

Same AC result, but decoupled

Final AC Design

- Grounding system is one acceptable for safety (not transmission towers)
- Usually is separate system (copper mitigation wire, zinc ribbon, anodes as grounds, deep well)
- Decouplers used to provide CP isolation from ground, with AC continuity
- Other objects addressed: insulated joints, casings, proximity to substations and towers

AC Mitigation Results

- Voltage is limited on pipe
- Current path is established for lightning, AC fault current, steady-state AC current
- Safety problem has been addressed
- Decoupling prevents CP from being bonded to grounding system
- Didn’t create new hazards: not bonding to inappropriate grounded objects

Other Points with Voltage Difference

- Isolation joints
- Isolated measurement lines
- Isolated sections of pipe
- Station ground, fence
- Adjacent grounding systems
- Vault contact points
- Casings
- Wells

Cautions

- While testing, be aware of open circuit induced voltage (before mitigation)
- After mitigation, beware of open-circuiting any connections for test: voltage will rise to unmitigated levels
- Coordinate your activity with others
- Unmitigated steady-state voltage will rise greatly during a fault or lightning event

Resources

- NACE SP 0177 (wire charts, safety considerations)
- Search nace.org for papers
- dairyland.com for tech articles/data
- Ask Dairyland for guidance on any of these topics