THANKS TO
SOUTHERN IDAHO/
EASTERN OREGON
SUN VALLEY, IDAHO
NACE/SSPC/AMPP

AC Power Involvement with Pipelines: Safety Risks, Corrosion Risks, Measuring, Modeling, and Mitigation, Part 1

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(With Thanks to Mike Ames)

WHAT CREATES THESE ISSUES?

1. Locating/construction of pipelines in electrical power line rights-of-way (ROW), rare in the distant past but expanded in recent decades;
2. Use of **high-dielectric-strength coatings** is newer, with FBE coating on pipelines starting in the mid-1970's. Most were in open-country locations, with only a small percentage in common corridors with AC lines;
3. From 1970's-80's forward, new and dedicated pipeline ROW, separate from other utilities, became much more costly. New pipelines were often installed with FBE coating and placed in common AC power corridors. **These common corridors were thought to be a good use of expensive ROW and easement land.**

PIPE AGES BY DECADE, HAZ LIQUIDS

From US DOT website. Total Haz Liquid PL Miles in 2022 of about 230,000. Total Nat Gas Transmission about 300,000 mi. Total Gas Distribution Mains about 1,356,000 mi.

SHARED CORRIDORS

PIPELINE OPERATOR RESPONSIBILITIES

Operator Duty and Meeting a Particular Standard of Care
Mandated in regulation at federal and state levels in US, and in most other jurisdictions around the world.

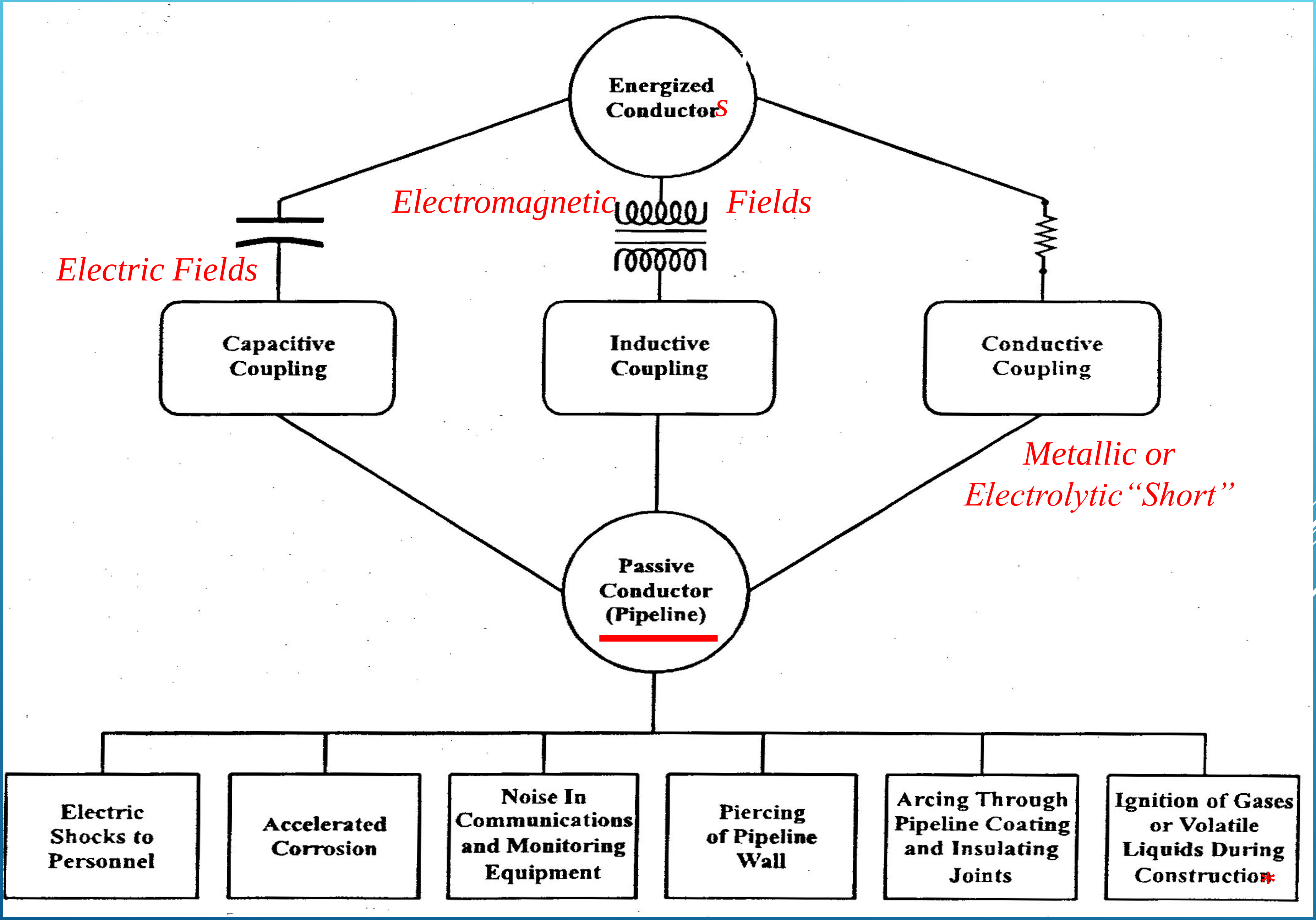
Also meeting definition of a "Prudent Operator" --
Mandated in regulation and what is likely common law.

In the United States, recent "Mega-Rule" additions to CFRs 192 and 195 call for more pipeline survey, detection and correction of interference issues . . . Interference is broad term.

Interference is not just DC and CP-system-related. This includes study of AC structure-to-electrolyte voltages with respect to electrical safety and prospect for AC-induced corrosion.

How many different AC interference concern types are out there? THREE? FIVE?

WHAT TYPES OF INTERACTIONS & RISKS?



NACE SP0177-2007

- Initial publication of this NACE standard, titled "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems," was July 1977 (updated most recently in 2007);

- The safety concern for AC on pipelines was established in 1947, which is now accepted as keeping AC & DC "potentials" below 15 volts for safety;

- In the mid-1980's, **AC-induced corrosion was finally identified** (suspected much earlier) as a direct cause of corrosion in Germany and Australia. Industry has grown this body of knowledge only over the last 30 to 40 years.

NACE SP21424-2018 & 35110-2010

- This newest publication 21424 (December 2017) has laid out AC and DC power interaction criteria, and much more research work (there are also similar European standards);
- AC-induced corrosion is driven both by AC power interaction, AND by how much cathodic protection current is applied (or not)*;
- Also see NACE Publication 35110-2010-SG, for AC Corrosion State-of-the-Art: Corrosion Rate, Mechanism, and Mitigation Requirements (elevated chloride ion, low-oxygen conditions may exaggerate the AC-induced corrosion risks). This document provides calculations for AC current density and risk levels;
- We now calculate/estimate both AC current density and DC current density at a "worst-case holiday" size of about one centimeter (cm) in diameter, or one square cm (less than 0.25 square inch) in circular area;
- *** One technical emphasis, for elevated DC current density providing some protection against AC-induced corrosion, may not be practical in most field situations, I would say. One amp per square meter of DC current density, at worst-case holiday size, is 93 milli-amps per sq ft.**

AC **POWER TRANSFERS** TO PIPELINE, **INDIRECT COUPLING**

Capacitive Coupling

- This process creates charges on the pipeline as one plate of a leaky capacitor, and power line as the other capacitor;
- Normally, current flow from this coupling is low except during construction, where pipeline gets electrically isolated from ground. The pipeline charges to a high voltage with LARGE shock hazards, spark hazard, and sufficient current to cause damage to people and equipment;
- Auxiliary grounding recommended for this situation during construction;
- Once pipe is buried, there is far less capacitive coupling.

Inductive Coupling

- The close-proximity pipeline and parallel power-line orientation induces electromagnetic fields in the pipeline, opposite to those in the power line;
- The model is a power transformer, with the power-line set as primary winding(s), the pipeline as the secondary winding, and the air and earth as the core;
- This process may cause the flow of high AC current levels in/off the pipeline, that needs to be safely returned to the power line network.
- Safety and corrosion risks.

AC **POWER TRANSFERS** TO PIPELINE, DIRECT COUPLING

Resistive Coupling/Faults

- A rare condition of AC short from the power line to earth, or to pipeline directly;
- Coupling causes? Power line contacting a tree, bad insulator allowing contact between tower and phase line, line falling to equipment in the area or to ground;
- Currents coupled to pipeline can be LARGE, and usually of very short duration as switchgear is oriented to disconnect lines that show faulting;
- The major issue is often coating or insulator damage from the high voltages and currents involved.

Power Arcs or Lightning

- AC power arcs can happen during fault currents, where soil ionizes and arcing connects to pipeline. Lightning acts in similar way;
- DC lightning can ionize soil and penetrate to pipeline, even burning holes in the pipe wall. This usually happens with higher soil resistivity, combined with less soil cover over the line.
- Lightning can also cause coating damage, but usually with smaller damage area than a high-power arc or fault.
- **These events are very rare, but terrible in consequences.**

POWER LINE AC FAULT EXAMPLE

LIGHTNING DAMAGE TO PIPE AND COATING

WHAT CAUSES LONG-TERM AC POWER BUILDUP ON PIPELINE? CAPACITANCE & INDUCTION AS STEADY-STATE, "AT A DISTANCE" ISSUES

1. It's good-quality coating on pipe;
2. Lots of power through overhead lines;
3. Pipeline(s) running parallel or near-parallel with overhead AC lines for distance (and changes in orientation/geometry of BOTH);
4. Soil properties plus geometry properties cause "transformer coupling" of primary (AC lines) to secondary (pipeline) as a weak transformer.

AC INTERACTION EXAMPLE

3 Pipelines/Wires Below Grade? Or more?

Soil Properties?

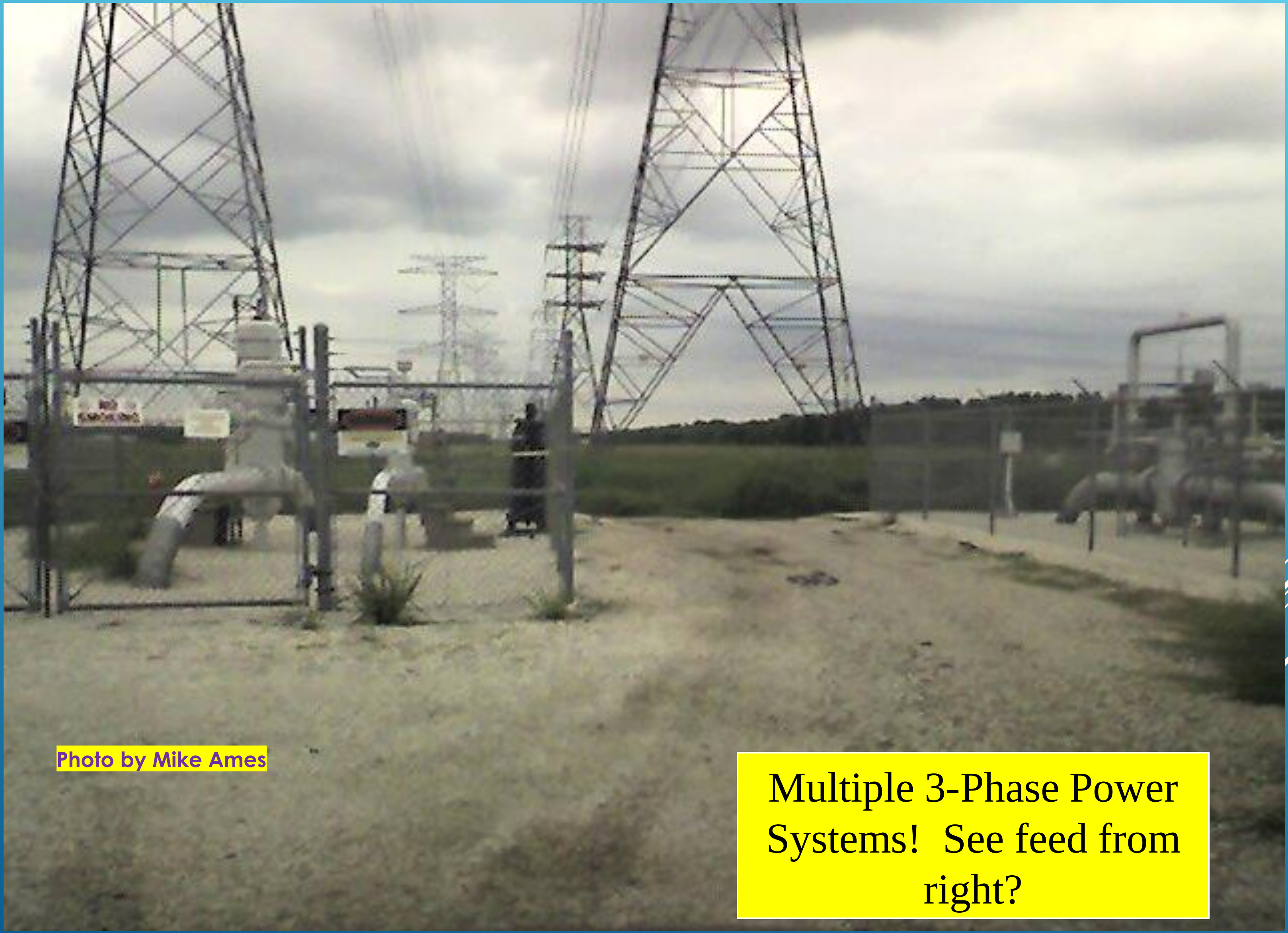
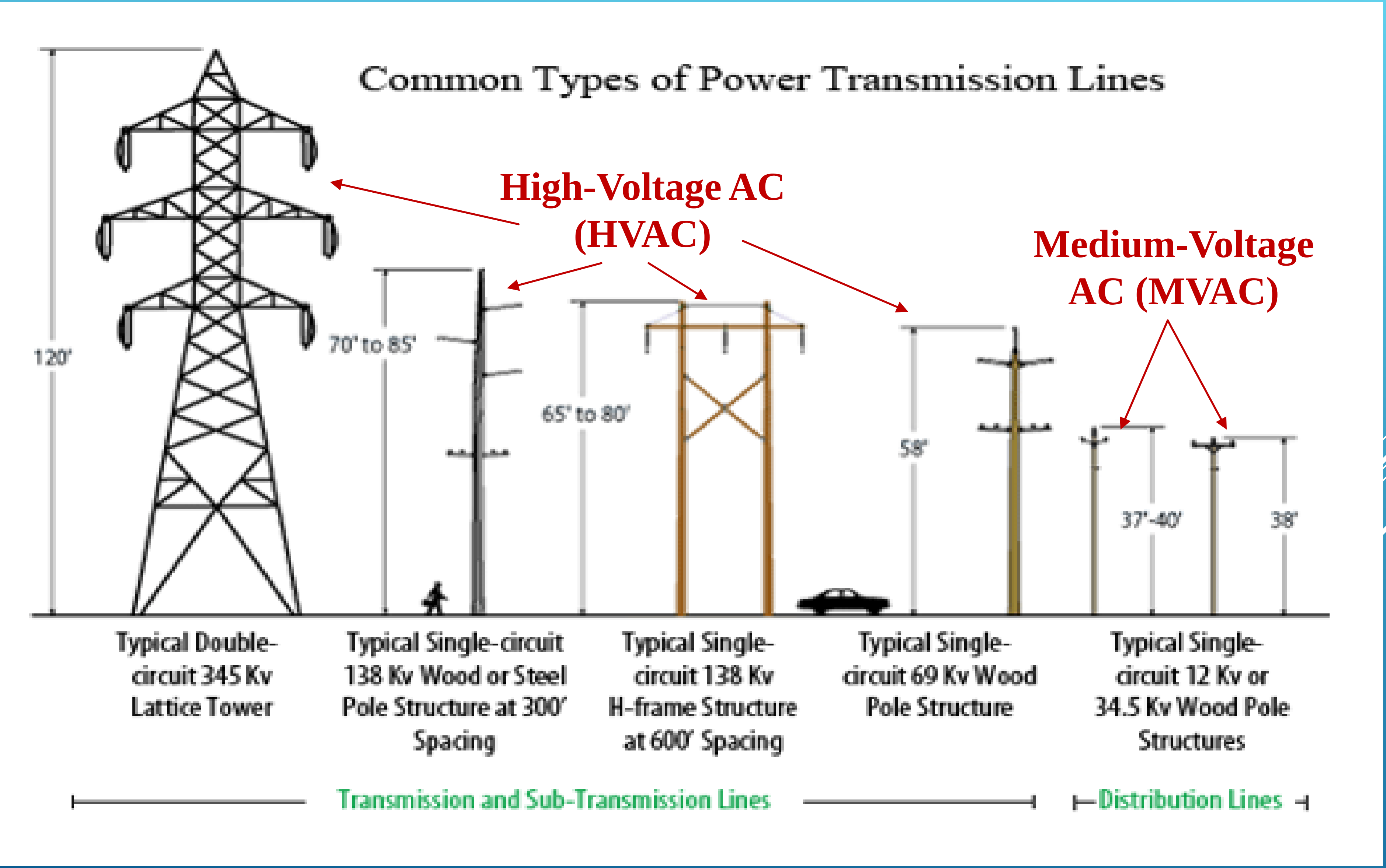


Photo by Mike Ames

Multiple 3-Phase Power Systems! See feed from right?

HIGH-VOLTAGE AC (HVAC) POWER LINE SYSTEM DETAILS



FURTHER AC INTERACTION DISCUSSION

- Does a particular pipeline build power? If so, it has very good coating quality. Poor coating means the pipe is "grounded out" effectively to soils.
- Large electric towers with big power loads cause big power induction on a pipeline. **Pipe/soil/interaction characteristics vary,** meaning **field measurements are vital for accurate modeling.**
- It's typical that pipe approaching at shallow angle, and/or running parallel to an HVAC system will induce high current loads (but not always).
- There are "end effects" to find and control, where current tries to preferentially leave the pipeline **beyond** pipeline deviations away from parallel and close-approach locations.

BARE PIPE VERSUS WELL-COATED PIPE, WITH "POWER BUILD & DISCHARGE"

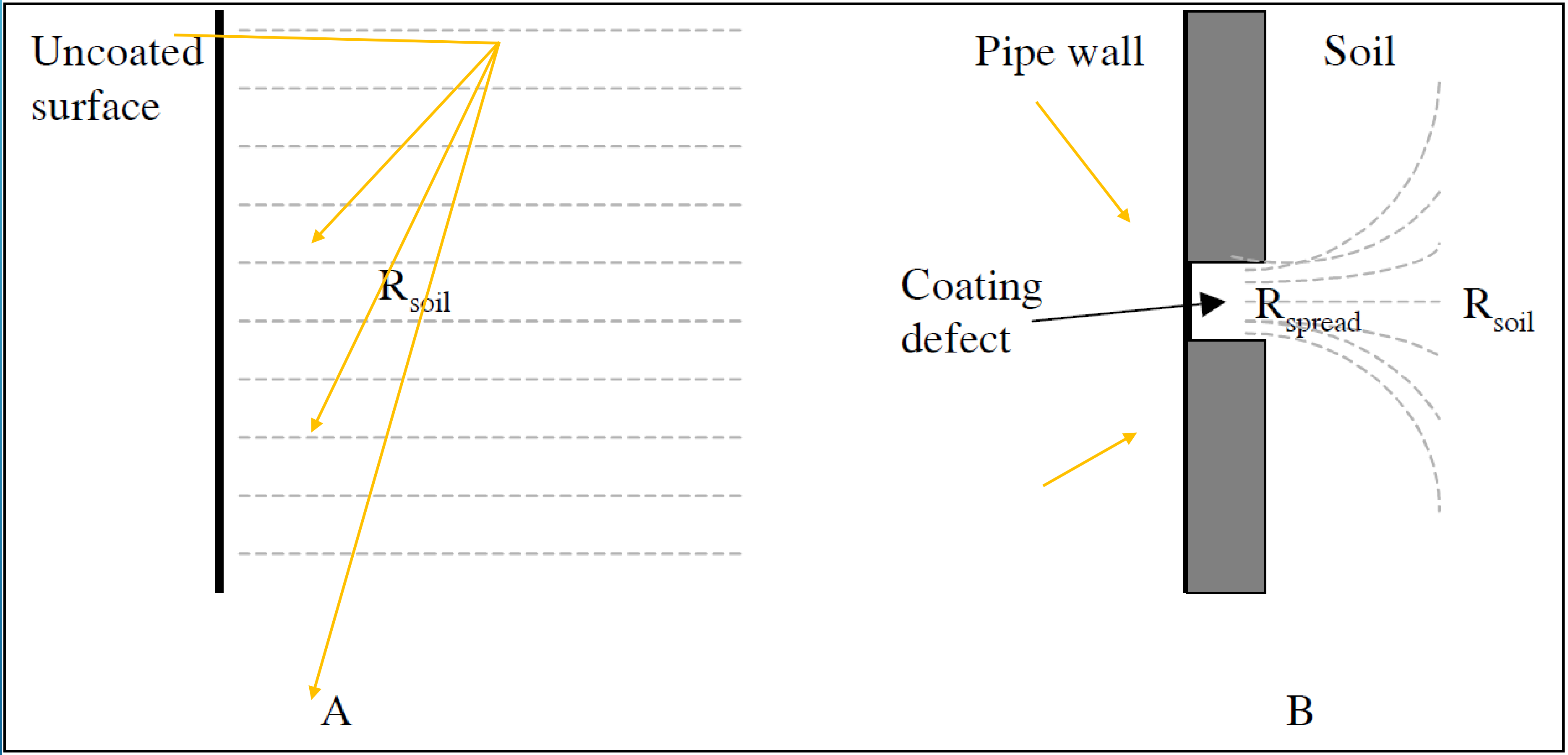
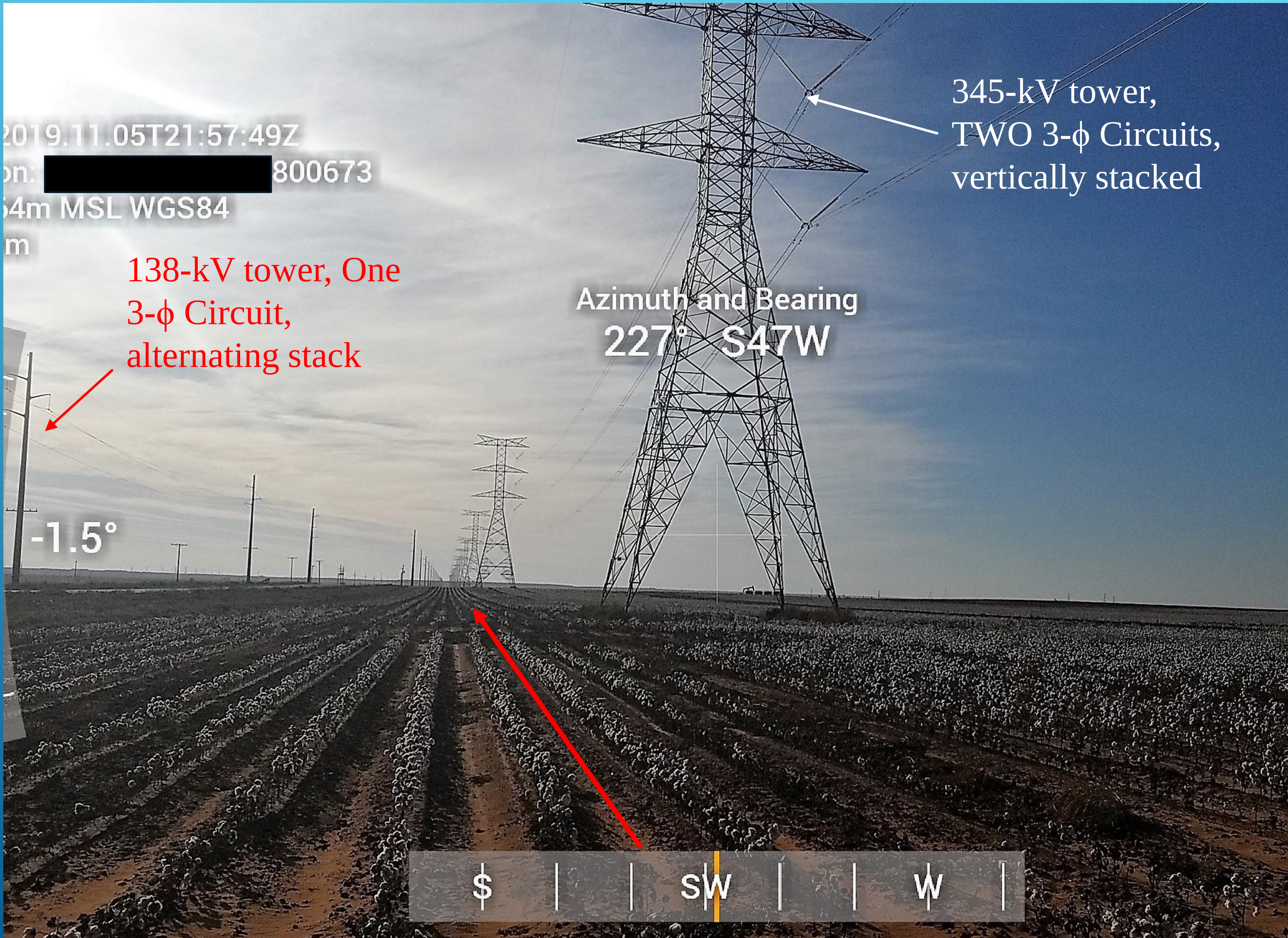


Figure 7: Illustration of geometrical effects on pipe to soil resistance.[24]

From page 14, NACE Paper 35110-2010

COMMON SUBURBAN ROW TODAY

FAIRLY COMMON RURAL ROW TODAY

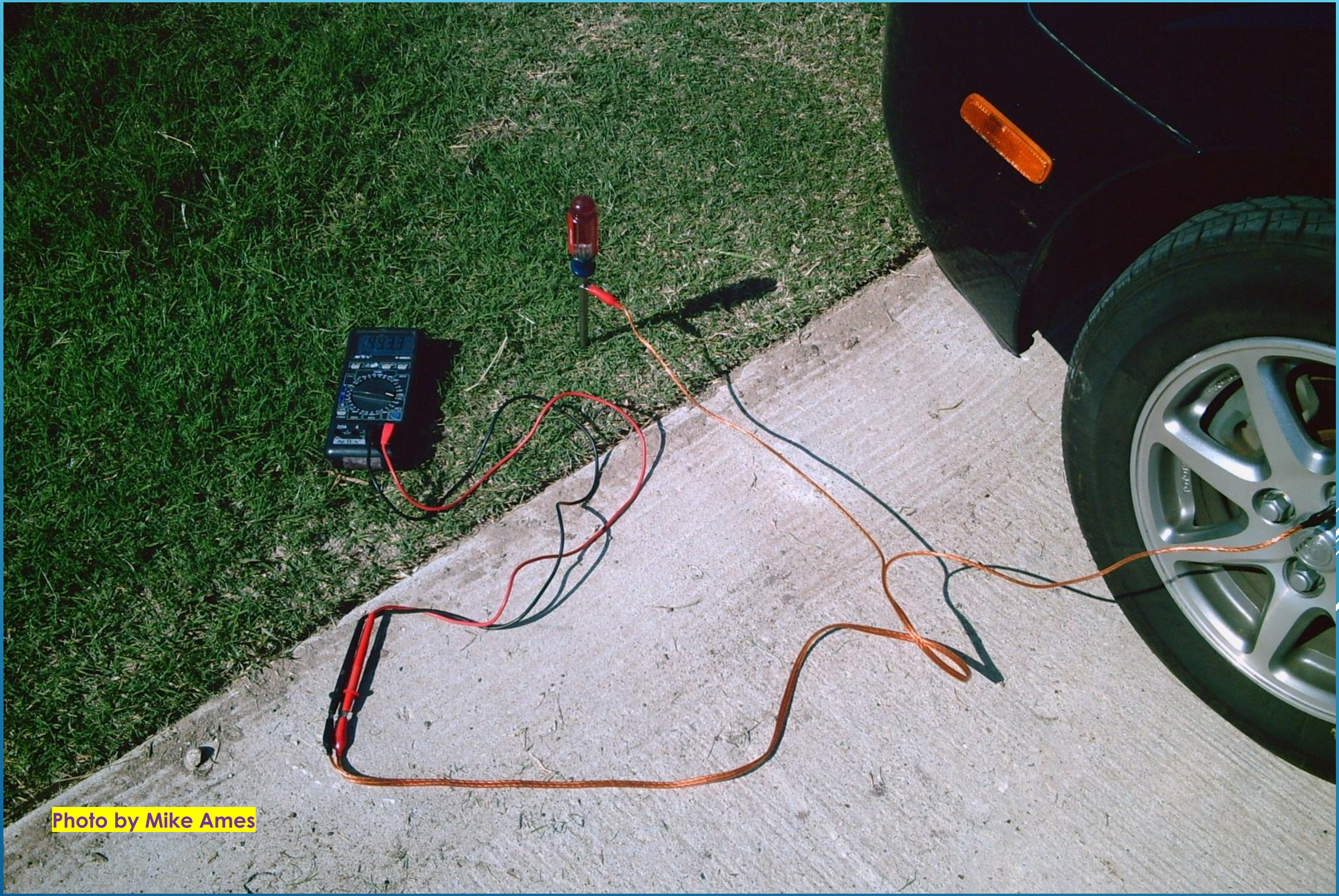


ABOUT CAPACITANCE AND INDUCTANCE

- Putting well-insulated pipelines in High-Voltage AC (HVAC) corridors may cause high AC power loads to pipeline(s) due to capacitive coupling (during construction), and then inductive coupling over the long term. (Can even happen with medium-voltage AC, too.)
- Capacitance is the buildup of charge on each of two separate "usually metal" plates. When charge build gets grounded between the plates, a huge arc (same as lightning) occurs. Don't make a human be the ground!
- Inductively, the pipeline becomes secondary winding of a gigantic transformer, with each AC power conductor as the primary winding. **Three-phase power? Three different fields inducing power onto the pipeline, per circuit!**

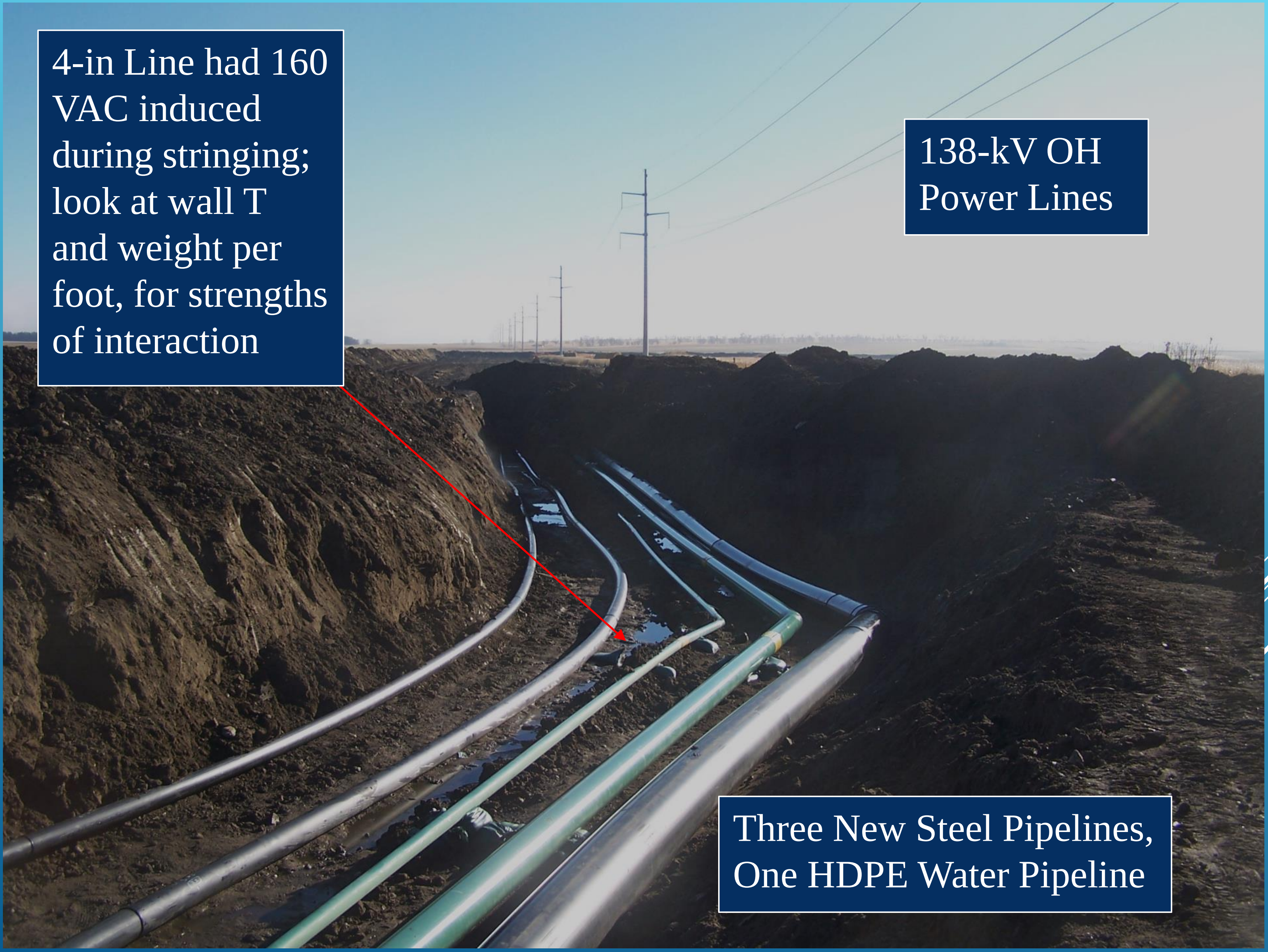
CAPACITIVE COUPLING – WHAT ABOUT A CAR?

SCREWDRIVER FOR GROUND & MEASURE VOLTS AC TO TIRE RIM



WHAT TYPE OF INTERACTION? CAPACITANCE.

BUILDING A SAFETY HAZARD



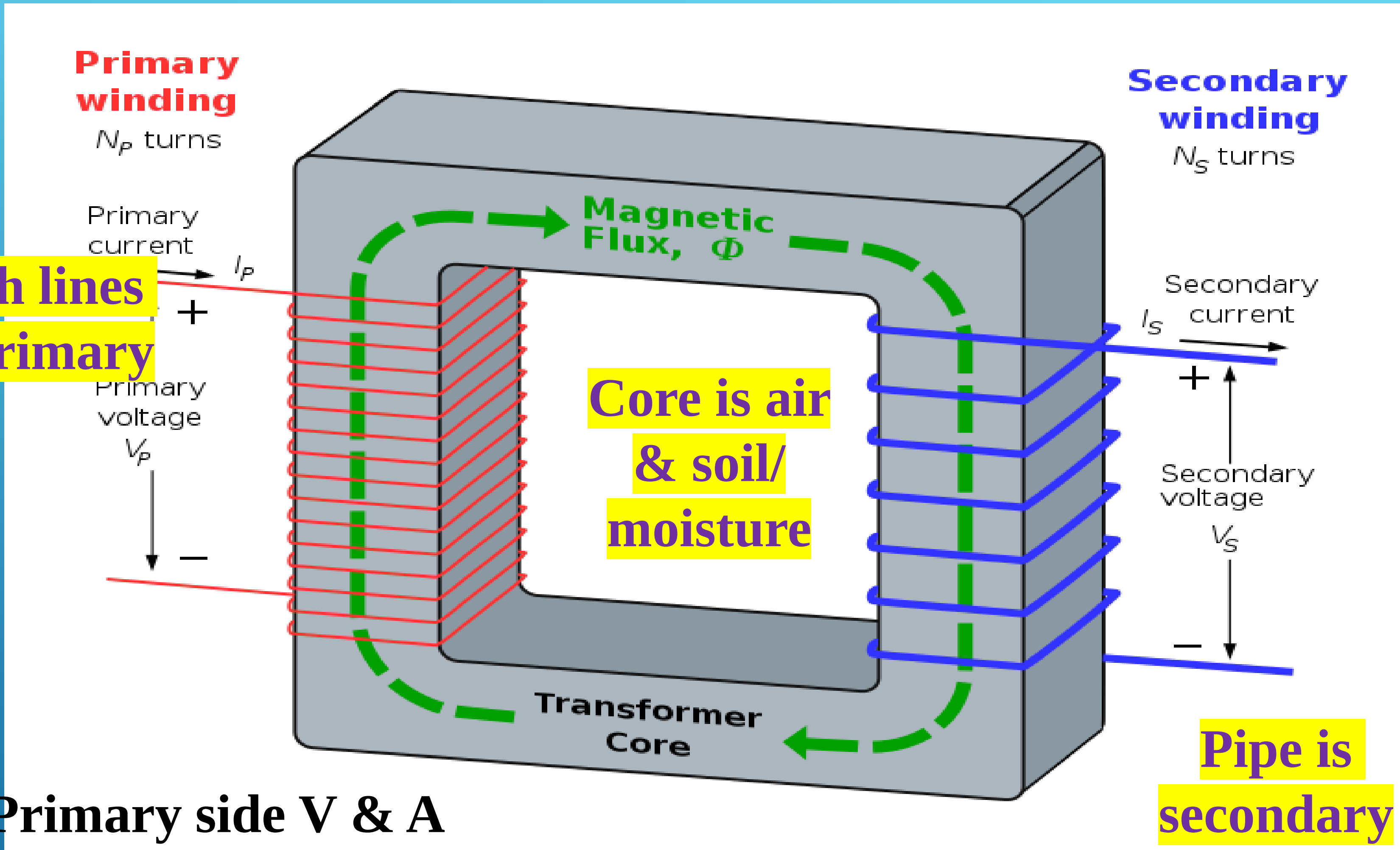
SAFETY HAZARD VOLTAGES FROM CAPACITIVE COUPLING, AC POWER FIELDS TO PIPE

TEMPORARY GROUNDING FOR CONSTRUCTION

AC-INDUCED POWER ON PIPELINE – HOW?

- Faraday's Law of Induction – a wire "cutting" a changing electromagnetic field has electric current flow induced, in direction opposite of the field;
- **Your pipeline is a "secondary" wire;**
- AC high-voltage POWER lines (69-kV and higher always suspect) have 60-Hertz AC electromagnetic fields around them (one field per phase, three phases present in total). Geometry, field strength, coatings all matter, **for strength of primary field**;
- As not all induced current flows off pipeline, POWER builds, **gets stored (higher voltages measured) – and is then DISCHARGING as current flow.**

AC POWER INDUCTION



High lines as primary

Core is air & soil/ moisture

Pipe is secondary

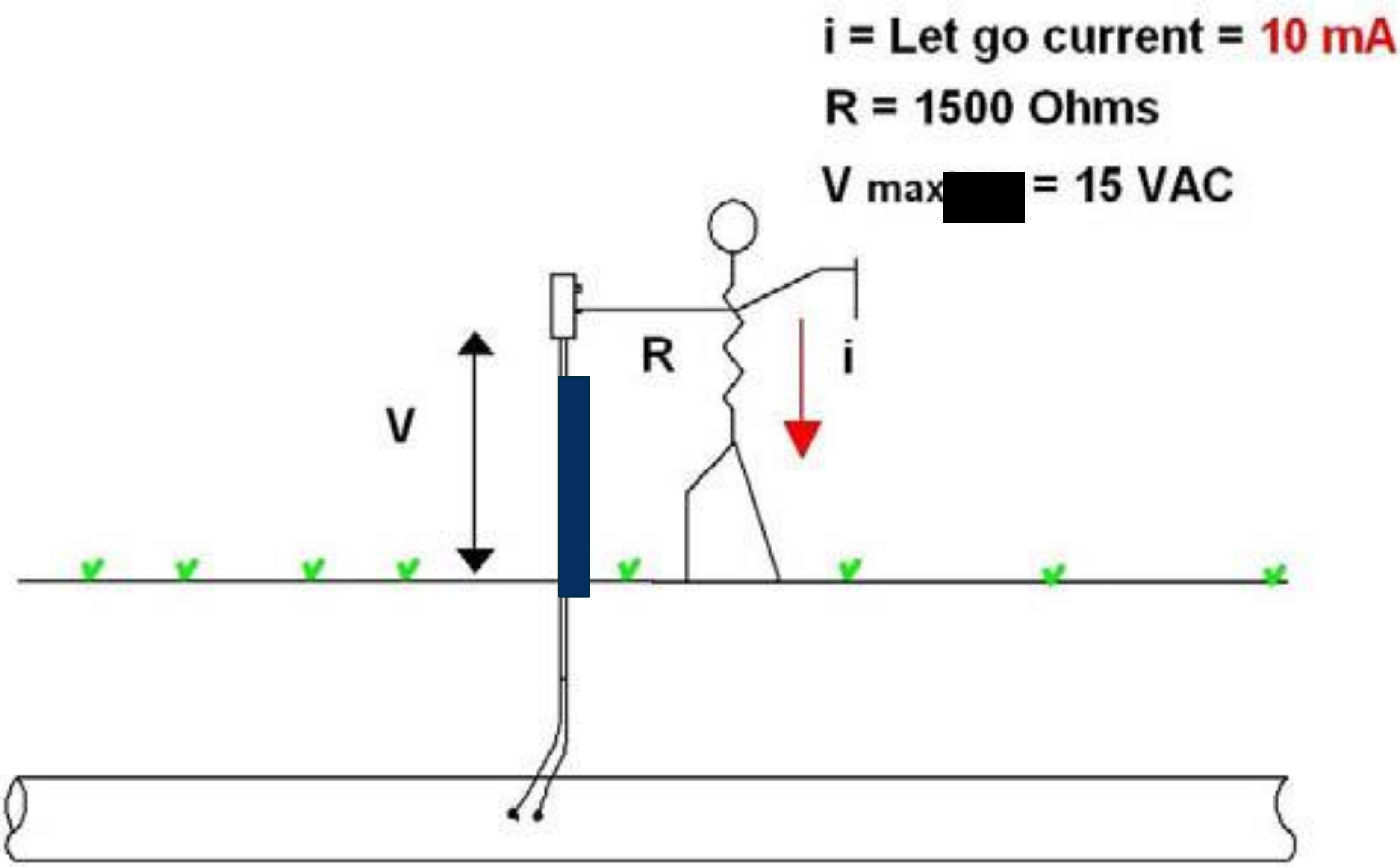
Primary side V & A (power)
V = 138,000 VAC
I = 1,000 AAC (example)
P = 138 megawatts

Secondary side V & A – need to measure;
I measured via LEF/temp ground
Approx 10 V, 2 AAC? 20 W?

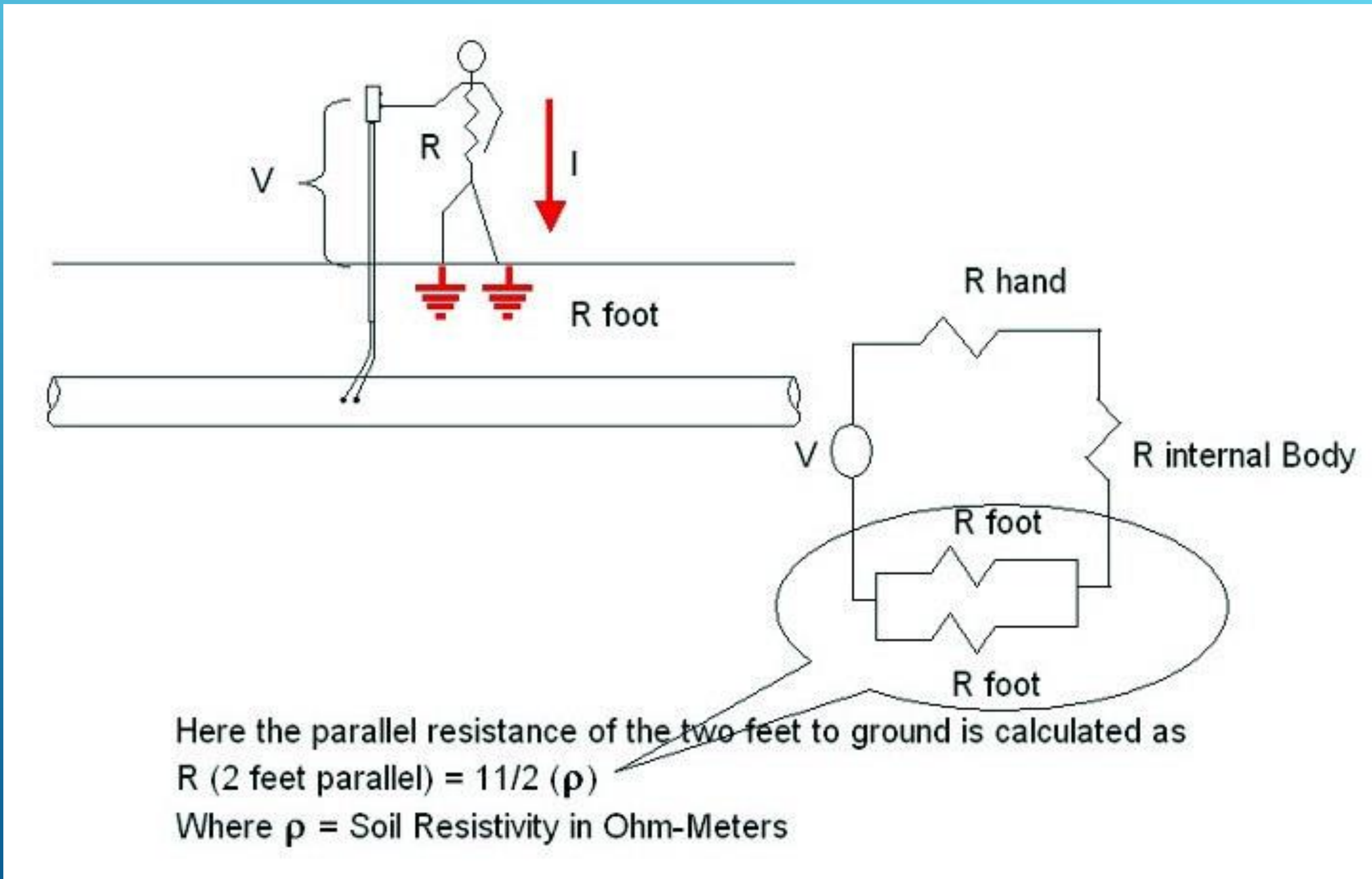
AC SAFETY ISSUES

- Safety threshold of 15 volts (V) AC can be exceeded by a well-insulated pipeline in fairly low-INDUCED-voltage situations, due to capacitive or inductive coupling. Faults, lightning, and arcing are other risks. Capacitive coupling often causes very high AC voltage on pipe strings when on insulating blocks during construction.
- Protective AC safety voltage levels can be achieved with modest additional grounding elements, during construction, to fight capacitive effects;
- Test stations can be hardened against step and touch issues. For dissipation of induced AC power, mitigation grounding is required.

AC SAFETY ISSUES: TOUCH VOLTAGE



STEP VOLTAGES, VIA LEGS/FEET



AC-INDUCED CORROSION FACTORS

- AC-driven corrosion occurs due to good coating and inductive coupling, which loads power to the pipeline over long distances. Capacitive coupling is a tiny influence after pipe is backfilled in the soil;
- Primary corrosion culprit is the **AC Current Density;**
- Where the induced AC power leaves pipe at holidays, as current flow, low soil resistivity drives greater AC-induced corrosion;
- The lower the soil resistivity and the smaller the coating anomaly, **the higher the density of current leaving**, and the higher the probability of corrosion.

THIS AC CORROSION PIT WAS SHAPED BY THE ORIGINAL COATING HOLIDAY (≈ 1.7 SQ CM IN SIZE)

Pit went through 30 percent of wall thickness.
Coating holiday was just outside margins of pit.

WHAT IS MEANT BY AC CURRENT DENSITY?

- The current density is the amount of current (AC or DC) divided by the surface area it is leaving;
- The density is not involved along the pipeline generally, but at each holiday/point of discharge off of pipe into the soil;
- This AC risk evaluation is done for the potential worst-case holiday size. It has to be combined with the DC current density and effectiveness of CP being applied, according to NACE Paper 35110-2010.
- Coupon measurements are the way to get I densities!
- **(Does old coal-tar-enamel-coated pipe have risk?)**

WHAT DETERMINES THE AC CURRENT DENSITY?

- Lower soil resistivities allow higher current flows and densities, away from each coating anomaly;
- The sizes and shapes of coating defects are critically important. Density of current flow from a big coating scrape/loss will be much smaller;
- A small defect in the coating, such as a grain of sand embedded, will cause current to be pushed from a much smaller cross-sectional area. **High AC current density at jump-off point!**
- High soil resistivities may help to reduce corrosion risk to pipeline by lowering the worst-case AC current density. **But they often cause higher AC voltages and increased safety risks.**

CALCULATING AC CURRENT DENSITY FROM NACE PUBLICATION 35110-2010

The equation is: **Iac = 8 * Vac / (rho * pi * diam)**

- Where **Iac** = the current density related to AC power induced on pipeline
- Vac = AC voltage on pipeline for portion being studied
- Rho = soil resistivity in ohm-meters
- Pi = the constant 3.14159 . . .
- Diam = approximate circular diameter of holiday in coating, in meters (m)

**** One centimeter (cm) is equal to 0.01 meter. Theoretical worst-case holiday is 1.1 cm in circular diameter.**

CALCULATING AC CURRENT DENSITY

Results of calculations are interpreted as follows:

1. For Iac less than 30 amps per square meter (A/sq m) as a time-weighted average **and when DC current density exceeds one A/sq m,** the risk of AC-induced corrosion is low **(actually, with Iac/Idc <5, based on research studies)**;
2. For conditions in between 30 and 100 A/sq m, and "adequate" DC current density, **risk level is moderate/of concern** (5 < Iac/Idc < 10);
3. For Iac greater than 100 A/sq m (and without very high DC current densities), **the risk of AC-induced corrosion is significant (Iac/Idc>10).**

- **Driving DC current density to 1.0 A/sq m is TOUGH! That is 93 mA/sq ft in English units. Not practical in most field settings, I say.**

HOW TO IDENTIFY AC-INDUCED CORROSION

- Any suspected AC corrosion area should be exposed, **but not disturbed further** before inspection. Cleaning or blasting will erase critical clues to causation;
- AC-induced corrosion and Microbially Influenced Corrosion (MIC) may look similar. **These may be misread by inspection, especially if location has been cleaned;**
- With MIC, there is often a smooth bottom to pit and elliptical sub-pits. With AC corrosion, the bottom may be more level with small circular dimples scattered across the bottom;
- Measure liquid pH in pit. A high pH (alkaline) indicates A-induced corrosion, while low pH (acidic) indicates DC-related/possible MIC;
- MIC may show some channel corrosion under surrounding coating, due to corrosive acids formed by bugs. For AC corrosion, the pit is locally confined, with coating usually disbonded only on the outer edges of the main pit.

FURTHER AC CURRENT DENSITY DISCUSSION

- Does a particular pipeline build power? If so, it has very good coating quality, or a duri-crust layer formed on surface over time;
- Large electric towers with big power loads cause big power induction on a pipeline. **Pipe/soil/interaction characteristics vary,** meaning field measurements and accurate modeling are vital;
- Pipe usually approaches at shallow angle, and/or runs parallel to an HVAC system to induce high power loads, but not always;
- There are "end effect" power buildups s as well, where current tries to preferentially leave the pipeline beyond the lengths of apparent interaction.

AC-INDUCED CORROSION, AND CORROSION PRODUCT/CURRENT EXIT

Photo by Mike Ames;

Anomaly indicated by CIS/ACVG & DCVG results;

Large ball of corrosion product was adhered to pipe over pitting attack area.

A "CLASSIC" AC CORROSION PIT FOUND (RT)

MIC Pitting Example, Above

No other corrosion attack outside initial holiday-sized surface. Large-diameter coating defect was apparently in place.

ANOTHER ANOMALY, UPON EXCAVATION

REMOVED CORROSION PRODUCT BALL

PIPE SURFACE UNDER CORROSION PRODUCT

Photos by Mike Ames

OBSERVATIONS, BOTH AC PIT EXAMPLES

- The characteristic AC corrosion circular dimpling is seen in bottom of each pit;
- Layers of corrosion attack are evident in the pit outer walls, and indicated by rings in the corrosion product balls (taken from above holiday in each photo set;
- Layers and rings of corrosion product are due to periods of higher current loads, and changing periodic soil resistivities due to rains/increased soil moisture;
- Loss of 0.132” on a 0.403” wall indicates 32.8% corrosion pitting. The time elapsed for this case was unknown. **Pipe installed when? AC power installed when? Load changes with time? Profile the history.**

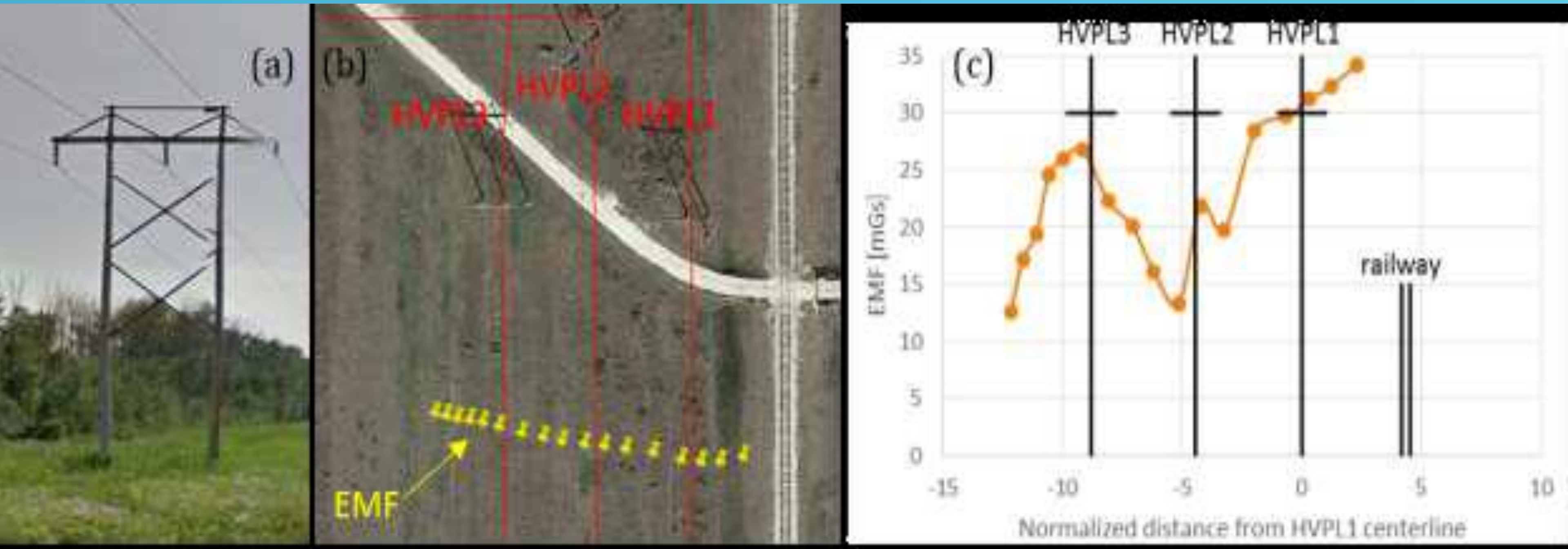
GOOD INSPECTIONS BEFORE ANOMALY CLEANING!

- DO NOT ALLOW wire-brush, abrasive-blast or other clean-up of anomaly before detailed inspections! Important clues can be erased. GET GOOD PHOTOS! Obtain samples of corrosion product, liquids for study work/lab use.
- Characteristic shapes and edges are too subtle to establish only visually, to say if the corrosion was from MIC, or from AC-induced mechanism. Do separate MIC testing?
- Can you measure pH of liquids? Of metal surfaces? Take photos of pH paper reactions, assigned to each spot on pipe, anomaly, etc.

FIELD STUDY: HVAC SYSTEM DESCRIPTIONS

- Take photos of AC power line towers, especially at changes in tower type, wire orientations, etc.;
- Phase wires each have a field. Need this documentation to show particular field changes, which may include wire heights above ground, wires being transposed down the tower run, and similar;
- What about multiple sets of power lines in same ROW? Photos can describe those details. Using range-finder to sight in particular separation distances is also useful. How low toward ground do wires reach between towers? Measure, photograph.

FIELD TEST FOR ELECTROMAGNETIC FIELD STRENGTH (EMF) – TRI-FIELD METER IN HAND, OR ON GROUND



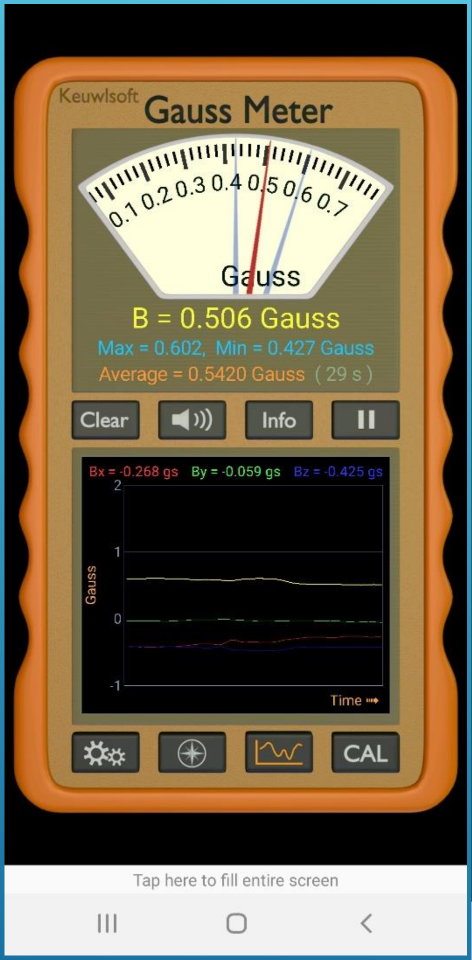
Use a Tri-field EMF meter, placed on level ground. Take 3-axis gauss readings across Power line each direction on perpendicular route, at 5-foot intervals.

THE 3-DIMENSIONAL EMF ANTENNA

- There are numerous styles of "gauss-meters", and the best is one using a 3-axis antenna. Very common now in market
- The single-antenna units can be used (not common any more), but must be oriented in all 3 positions in the same spot, one after another, to gather the EMF field density in milligauss, per orientation.

CELL PHONE APPS FOR EMF

- There are free apps for cell phones to measure EMF;
- They are not calibrated but can indicate relative strength of the field;
- Uses the cell phone's antenna to collect the EMF;
- The orientation may be one axis or all three axes. [New apps are three-axis.] Turn phone across all three axes if need be, and record info for each one.

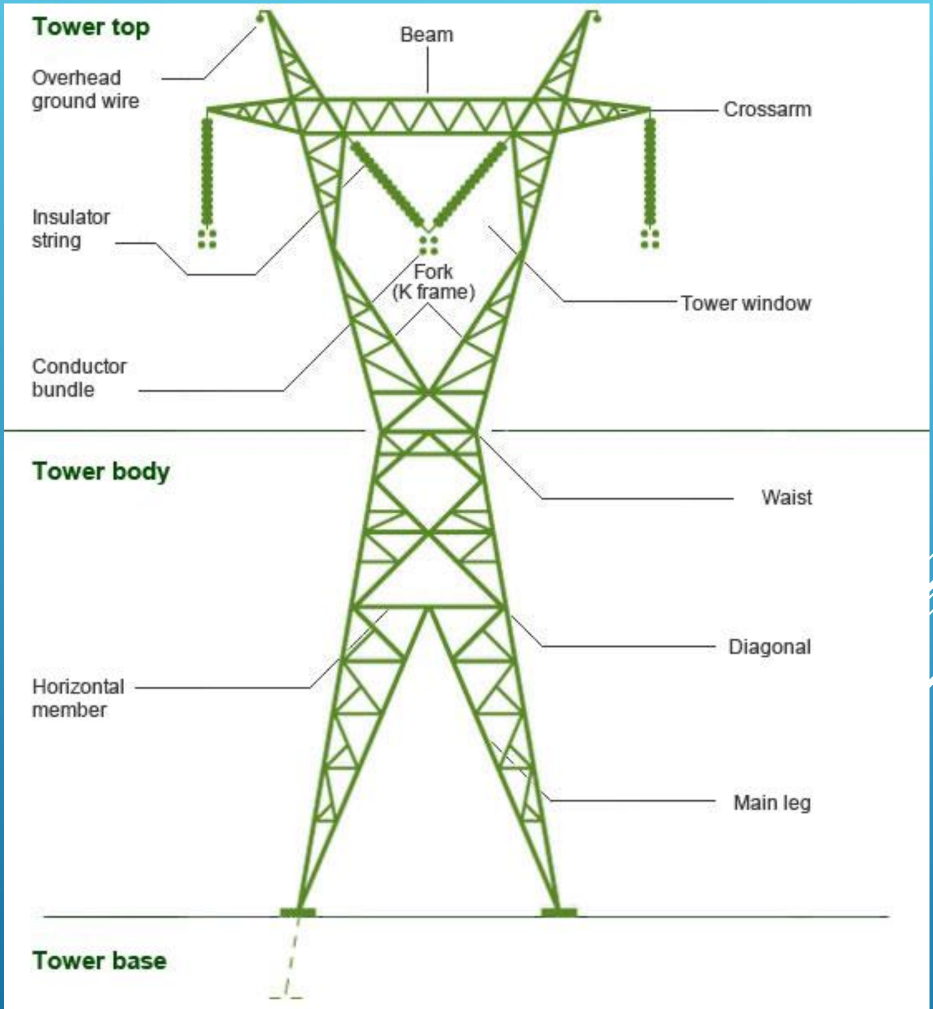


FIELD EXAMPLE – EMF READINGS AND LONGITUDINAL ELECTRICAL FIELD (LEF). OKAY, WHERE TO SET UP?

LEF TEST EQUIPMENT & GEOMETRIES

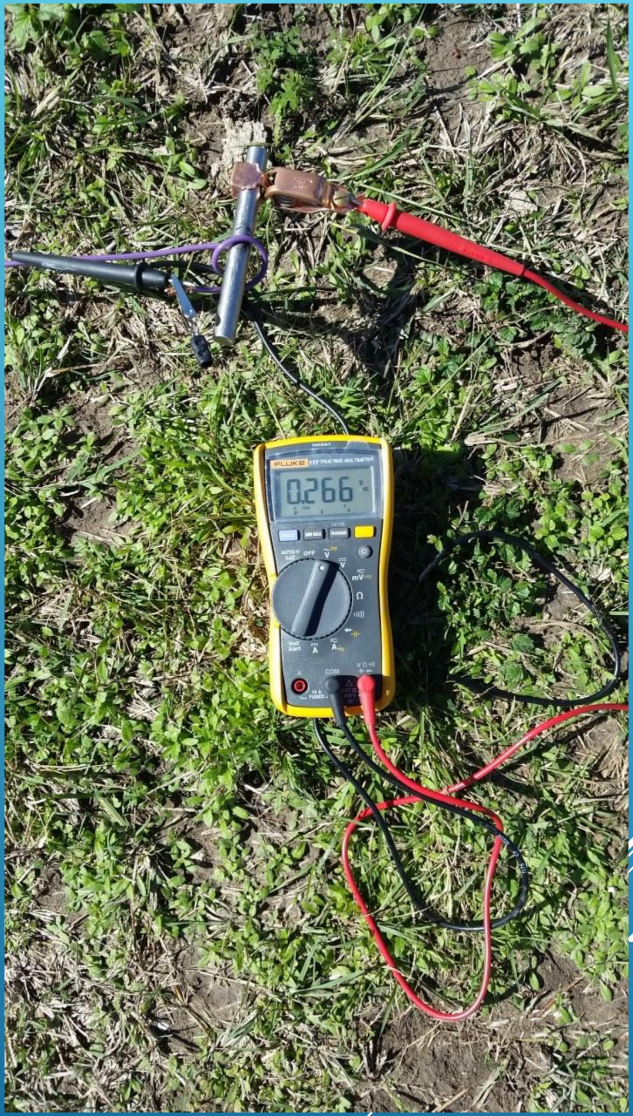
- **Needed**
  1. **Insulated Wire 100-300’**
  2. **High-Impedance AC Voltmeter**
  3. **Steel Pins, Jumpers**

- **Voltmeter to be true RMS type**
- **Wire to be known gage and insulated >= 600V**



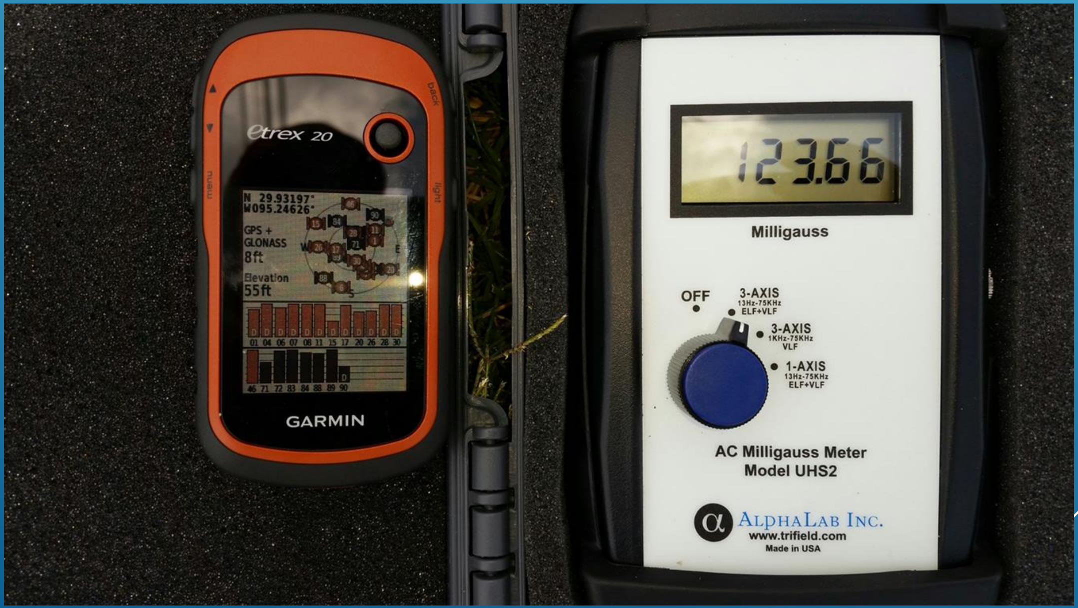
LONGITUDINAL ELECTRIC FIELD (LEF) STRENGTH

- A wire of 100 ft up to 330 ft (100 meters) in length, laid on the ground and grounded at one end with a steel pin set.
- AC voltages are measured in the wire as induced by the overhead power lines (discussed in Session 3).

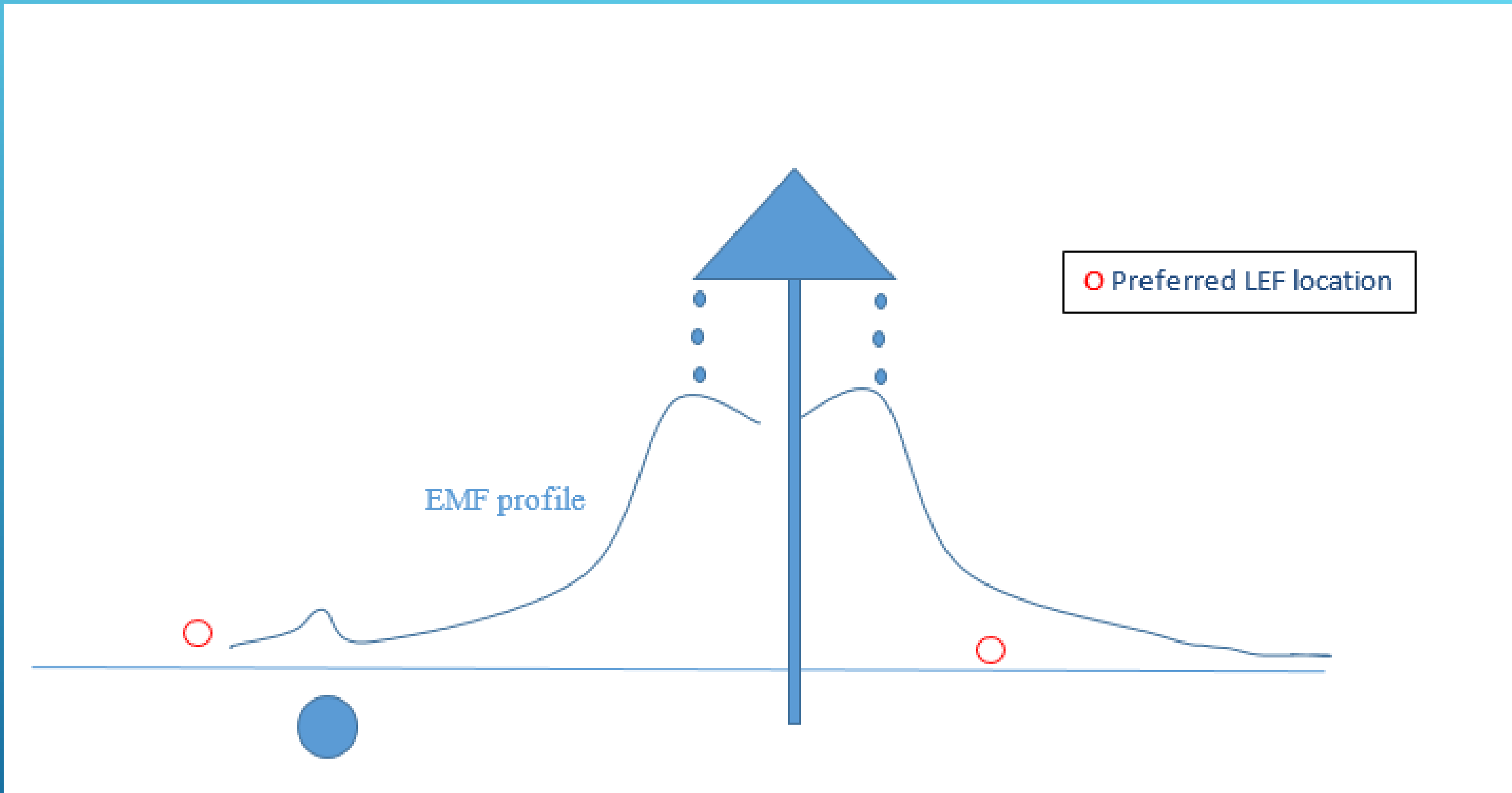


CHOOSING EACH LEF SITE

- Take EMF as 3-axis gauss readings. For highest EMF field strengths found, choose those for LEF sites;
- If geometry changes are causing the increased strength, set up LEF's only on straight runs of existing pipe, existing power lines, or new pipeline route.
- Tight GPS information is crucial at each measurement point!



USING EMF RESULTS TO LOCATE LEF TESTS

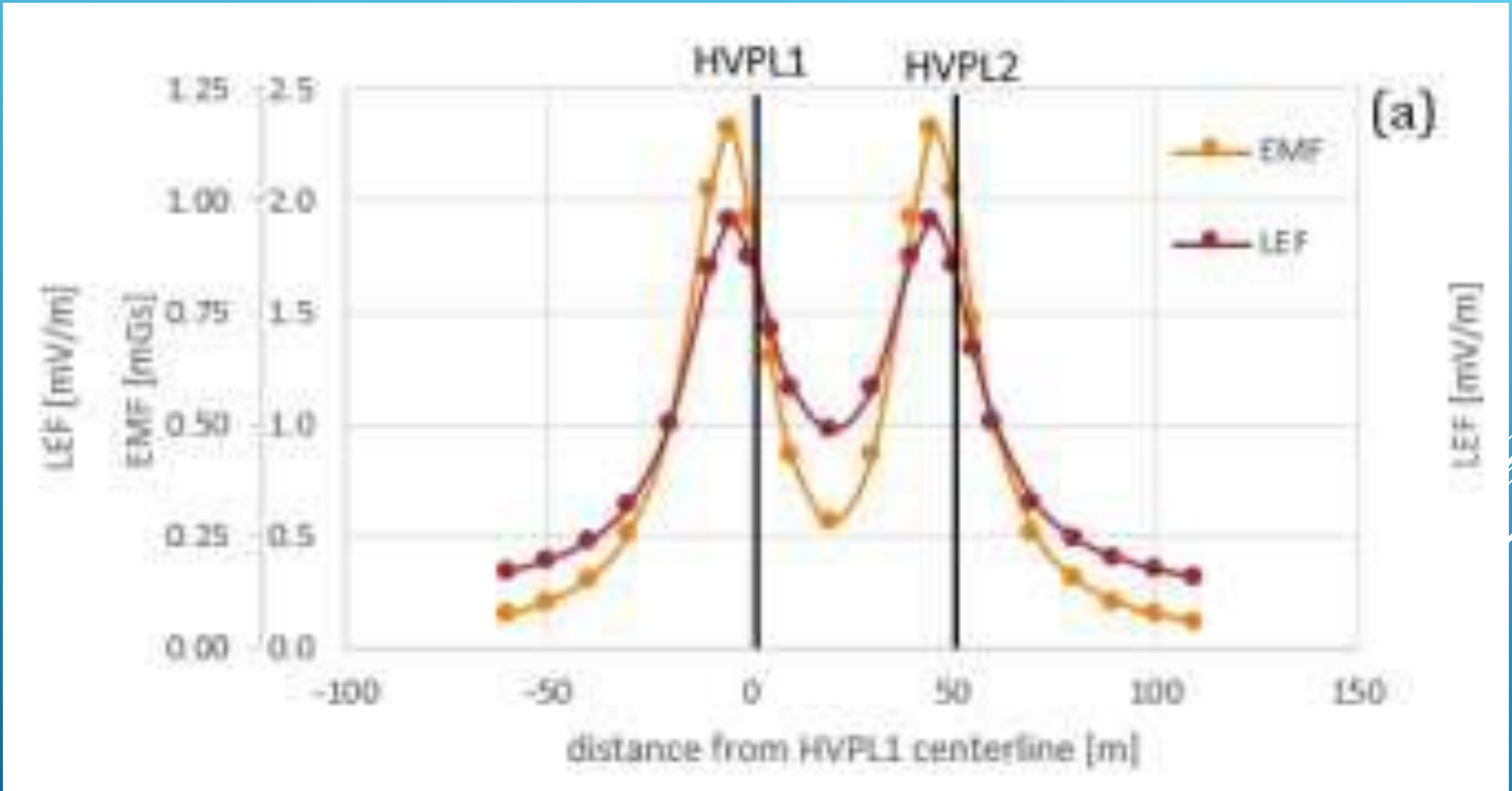


See the EMF rise at pipe? Secondary field at pipeline due to AC induction building power.

AC POWER WITH PIPELINES AT LEFT; DO LEF TESTING ON RED LINES, UNDER EACH CONDUCTOR – THE MORE, THE BETTER.

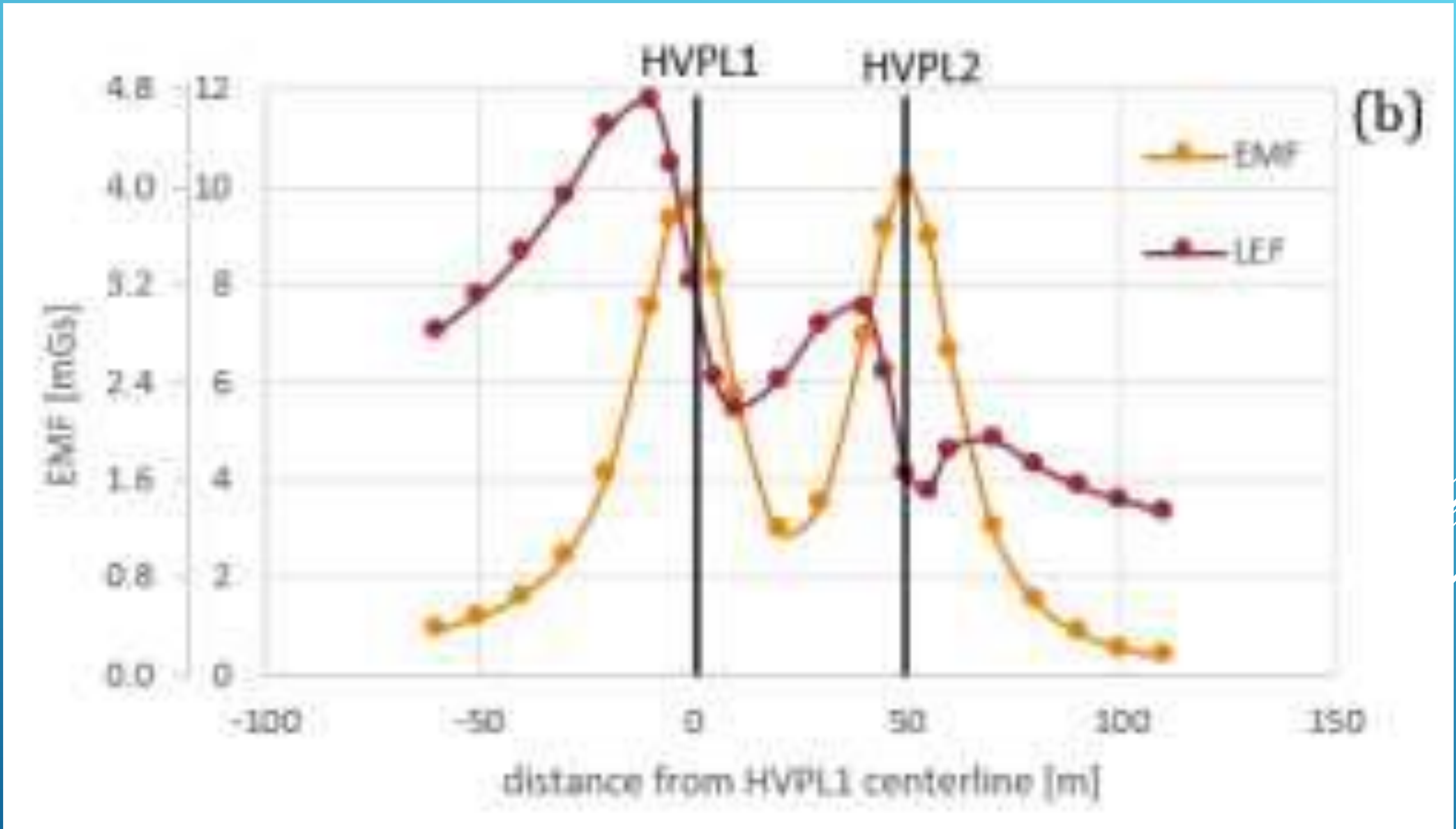
YOU’RE ESTIMATING STRENGTH OF FIELD FROM EACH CONDUCTOR.

FIELD RESULT EXAMPLE FOR EMF & LEF, WITH VERTICAL O/H WIRE ORIENTATIONS



Thanks to Mike Ames for these results.

FIELD RESULT EXAMPLE FOR EMF & LEF, WITH HORIZONTAL O/H WIRE ORIENTATIONS



Thanks to Mike Ames for these results. If you can data-log over time, LEF is even better.

COUPON TEST STATIONS FOR AC STUDIES

Three different coupons installed with one stationary reference cell. Uses? AC I density, DC I density, per surface area exposed.

Note the two different 100-sq-cm coupons on cell body. Would you choose 10-sq-cm, or 100, or something else? Depends on pipe age, for one.

What about old coal-tar enamel coating on old pipeline? I would use 10-sq-com coupon for AC current density calculations. Then compare to TS readings.

COUPONS/REF CELLS FOR VARIOUS PURPOSES

Pictured with a 10 cm2 Coupon

One coupon on different style reference cell, with far more surface area in soil contact. This design is meant for dry/desert soil conditions.

COUPONS FOR AC & DC MEASUREMENTS

THIS TS HAS STATIONARY REFERENCE CELL & COUPONS

- TS hardware comes with stationary reference cell and two or more coupons – built into reference cell;
- Both the reference cell and internal coupons have to come into "equilibrium" with soils after installation; could be 45 to 90 days before reliable data can be taken;
- Compare readings from stationary reference cell and each coupon to a portable reference cell, two or three times over a period of weeks, to see when equilibrium is reached;
- Coupons can work in a variety of ways – one coupon might be only "native earth" contact; one might be wired to pipeline through interrupter switch.

COUPONS FOR VARIOUS PURPOSES

- Coupons for CP measurements are often sized at 10 square centimeters (sq cm), to model a larger holiday;
- AC current density measurement coupons usually sized at one sq cm (that worst-case holiday size for AC corrosion damage);
- Some people choose 100-sq-cm coupon for CP measurement and modeling – I consider this too large, especially if multiple large coupons are used on single pipeline (unless pipe has bad coating quality);
- Some have “native” coupon metal surface, with no CP applied. BIG help with CP survey work;
- Today, we want coupons that allow measurement and then calculation of DC current density (good CP applied to a known holiday), and of AC current density.

AC CORROSION THEORY - SUMMARY

- Science now shows that AC current density higher than 30 A/sq m, in combination with poor CP applied, causes highest risk for AC-induced corrosion;

- For DC current density above one A/sq m (this number is hard to achieve in field), the AC current density might be tolerated at far larger numbers, before AC-induced corrosion risk occurs. Measurement information is only safe way to manage the risks;

- If DC current is applied at levels too high (DC current density above three A/sq m being discussed **[280 mA/sq ft!]**), the alkaline chemistry at holiday may increase the risk of AC-induced corrosion. Don’t over-drive your CP systems, and don’t suffer or cause stray current interference on top of your own CP.

FIELD DATA, THEN MODELING

- The model in graphs presented show the field-measured AC Voltages, then calculated Current Density ranges in their as-found status, and then in their post-mitigated status;
- These models were produced using the available information from the facility owner, the power line company, and field inspections of the areas concerned.
- Modeling available from:
  - Safe Engineering Services (SES) Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis (CDEGS);
  - Elsyca Inductive and Resistive Interference Simulator (IRIS);
  - Technical Toolboxes/Pipeline Research Council International (PRCI) AC Mitigation Toolbox (ACTB).

AC MITIGATION – MODELING DEFINES WHAT IS REQUIRED AND WHERE

- Linear wire provides a benefit in the mitigation of AC corrosion;
- The linear grounding offers lower-resistance current flow path for AC power buildup, making each coating holiday higher-resistance by comparison.

Decoupling is needed, to drain AC power and not affect CP current application to structure.

WHAT IS NEEDED FOR PROPER AC MITIGATION MODELING?

Needed information:
Good info may reduce overall cost of grounding system. Accurate information will reduce the number of overly conservative assumptions used. Some information listed may not apply for each job.

Pipeline:
Plan & profile, total length of pipeline
What is at each end of pipeline?
Does it connect to any other pipelines along the route?
Distances from electric lines to pipeline, 100-ft frequency
What electrical lines cross the pipeline?
Location of above ground equipment such as valves or above ground piping
Buried depth of the pipe, pipe diameter and wall thickness
Pipe coating and resistance value
Existing CP system and grounding system design info
Grounding of pumping station, any other grounding for pipeline

Transmission Power Lines that parallel the pipeline(s)
Plan & profile, transmission structure drawings
Voltage of each circuit, phase arrangement of each circuit,
Maximum design current for each circuit
Fault current (magnitude and phase angle) at beginning and end of interaction areas, each power circuit
Number of shield wires, wire sizes, size and spacing of conductors
Number conductors in bundle for each circuit
Structures (number and depth of ground rods)
Ground readings of structures, pictures of structures
Aerial video of transmission line (geo referenced would be great)

Electric Generation site (when involved)
Grounding system (switch yard and around generators).
Fault current (single phase fault) magnitude and phase angle
Current contribution from sources (step up transformers and from all lines)
Structure information for all transmission lines with shield wires connecting to substation grid.

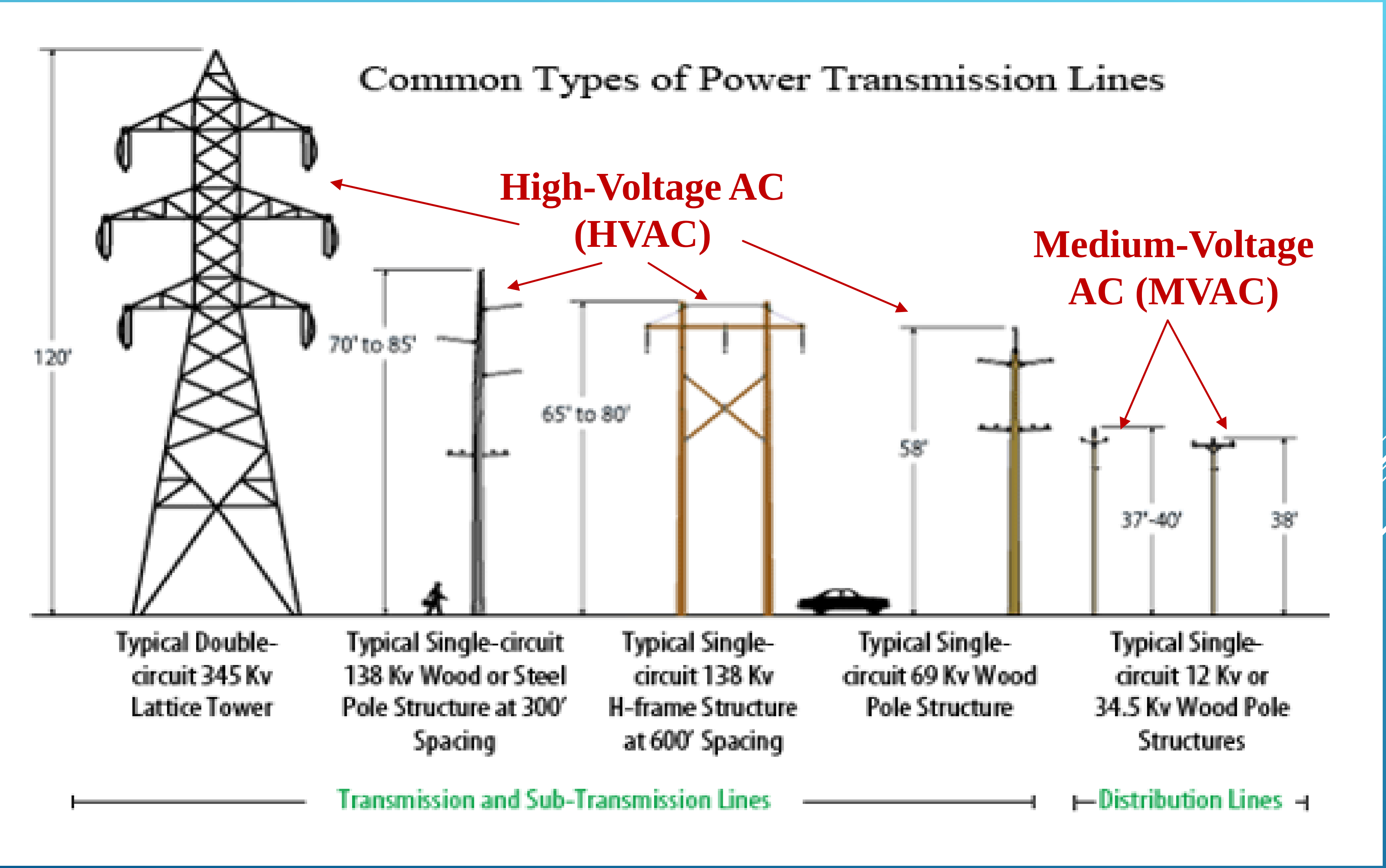
Proper AC mitigation modeling is based on loads and capabilities of the AC power system(s) and the orientation of the pipeline with the power lines, as well as the topography and other information.

Field survey work is needed to determine separation distances, orientation angles, AC voltage measurements, and soil resistivity profiles.

Check with your AC Mitigation Modeling Company for a document to be used for this data request to power company.

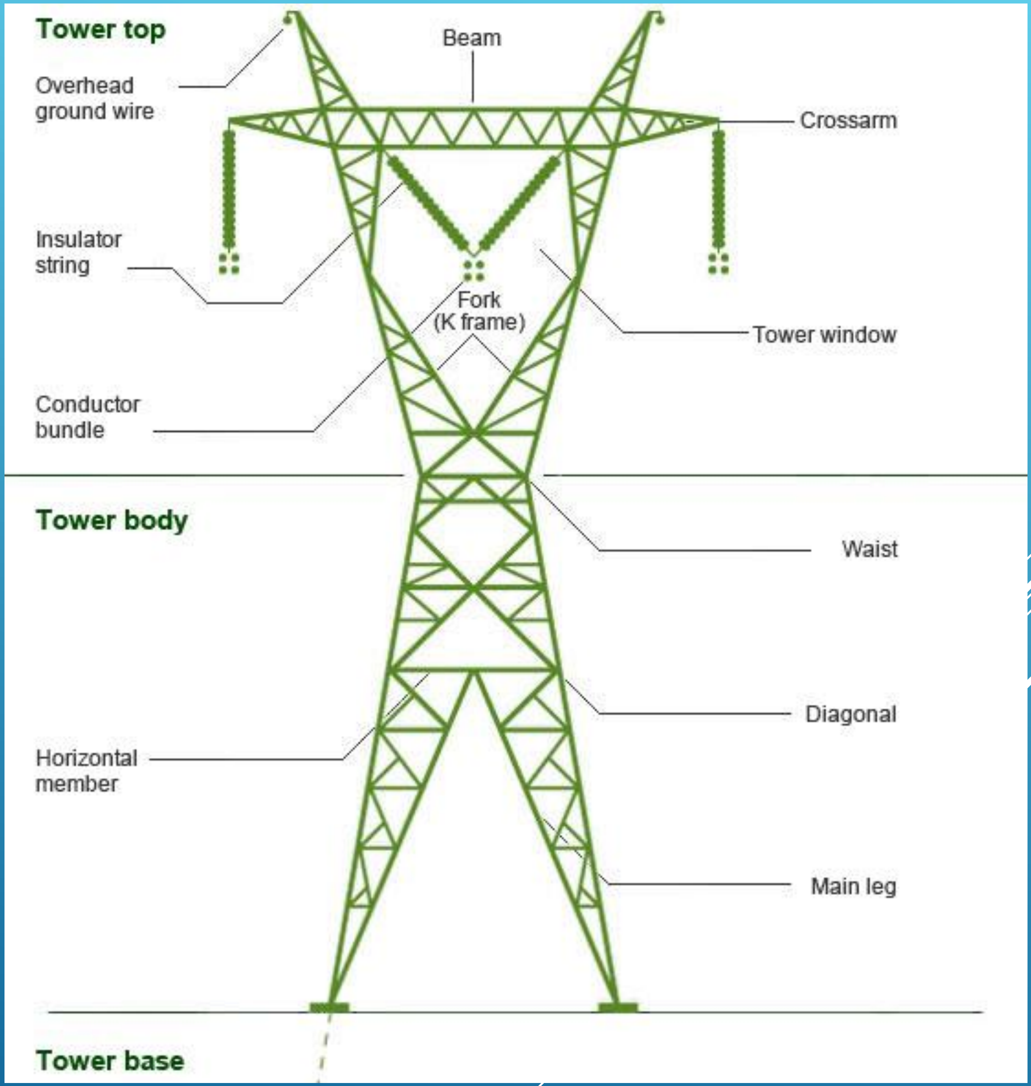
Then, don't hold your breath.

HIGH-VOLTAGE AC (HVAC) TOWER AND WIRE CONFIGURATIONS



HVAC TOWER DESCRIPTIONS, WIRE POSITIONS, NUMBER OF CIRCUITS

- **Photographs with GPS Location Data Vital**
- **Count wires, look for changes in positions with distance**
- **Pick up changes in direction on aerials and from ground; tower designs will be different at these points, too.**



Steel Lattice Tower Type

QUESTIONS OR COMMENTS?

For technical support – Free survey software:

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