
EC-011 SUPPLEMENTAL READING

Mixed Metal Potentials

When the voltmeter reads protection but the steel is still corroding — and how the composite reading hides what's actually happening at the pipe.

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You're standing at a test station on a compressor station yard. The CP system has been running on this site for years. The survey crew finished a depolarization study yesterday — full 48-hour wait after rectifier interruption, clean numbers across every test point. You're looking at the report now.

THE REPORT

Depolarized potential: -510 mV CSE · Instant-off, rectifier
back on: -670 mV CSE

You do the math in your head. That's a 160 mV polarization shift. Comfortably past the 100 mV criterion. The site passes. You approve the survey report, the compliance folder gets another year of clean records, and the rectifier keeps running where it has been running.

Then six months later, a tie-in excavation opens a piece of station piping near the building, and the steel is pitted. Not catastrophically. But visibly. Where the coating is still attached, you can lift it with a thumbnail. Underneath, there is fresh corrosion on metal that the report says is protected.

The numbers were not wrong. They were measuring what they were designed to measure. The problem is that what they were measuring was not just the steel.

What the Voltmeter Actually Sees

A pipe-to-soil reading is a measurement of the potential difference between whatever metal the positive lead is touching and the reference cell. On a buried single-metal structure — an isolated pipeline, no facility piping, no grounding — that metal is steel, and the reading is what it appears to be.

A compressor station is not always that.

A compressor station contains buried steel structures that are electrically common with a copper grounding grid, with the station's structural steel, with motor frames, with valve actuators, with instrument racks, with everything the safety code requires to be bonded to ground. Most of those connections are made deliberately. A few of them are made accidentally, through shared concrete encasements, shared bolted flanges, or grounding straps installed before the isolation kits.

When all of that is electrically common, the voltmeter does not see the steel. It sees the **mixed potential** of every connected metal in contact with the soil, weighted by how much surface

area each one has and how easily current passes between each metal and the electrolyte around it.

The voltmeter doesn't see steel. It sees an average.

On most compressor stations, the copper grounding network alone — bare buried conductor between ground rods, plus the rods themselves, plus the buried bonding to structural steel — adds up to several times the buried surface area of the station piping. Copper sits more noble than steel in the galvanic series. Its native potential in typical soil is around **-100 to -200 mV CSE**. Steel sits at **-500 to -700 mV CSE** depending on soil chemistry, oxygen, and moisture.

Connect them, and the mixed potential of the system lands somewhere between those two values. The bigger the cathodic (copper) surface area relative to the anodic (steel) surface area, the closer the composite sits to copper's native value. On a compressor station with a serious grounding grid, the composite native reading can sit 100 to 200 mV less negative than what isolated steel would read in the same soil.

That number, the one your voltmeter is showing, is no longer a steel measurement. It is the system's center of gravity.

How to Tell You're In a Mixed-Metal Situation

Before you can interpret the readings correctly, you have to know what kind of system you are reading. The signs are not always obvious from the survey alone, but a short investigation answers it.

Continuity testing. Use your multimeter to check the voltage difference or P/S between the pipe (at a test station) and any nearby grounded structure — a building steel column, a ground rod, or any part of the grounding system. A difference under 50 mV is most likely electrical continuity. On a compressor station, you usually find it. The question is just how many connections are in parallel.

Visual inspection at the station. Walk the yard. Count the bonding straps. Check whether the inlet and outlet flanges have functioning isolation kits — and confirm the isolation kits correctly, not just by looking at the gaskets. Look for shared concrete pads where the pipe and the structural steel are bonded inside the pour. Trace the rectifier negative cable. Look for signs of continuity with the station ground bus instead of an isolated pipe negative.

Survey-data signs. Native potentials that read 100 to 200 mV less negative than the soil conditions would suggest. CP current demand that is larger than the structure size warrants. Polarization decay during a depolarization study that levels off well short of where bare steel in that soil would land. Any of those on their own can be explained other ways; together, they point to mixed metals.

Bell hole evidence. When the steel is exposed during excavation, the most direct test is whether it shows corrosion. A survey that says "protected" and a dig that says "corroding" disagree about something. On a station with copper grounding, the composite reading is the usual suspect.

If the survey and the steel disagree, the survey is the one that needs explaining.

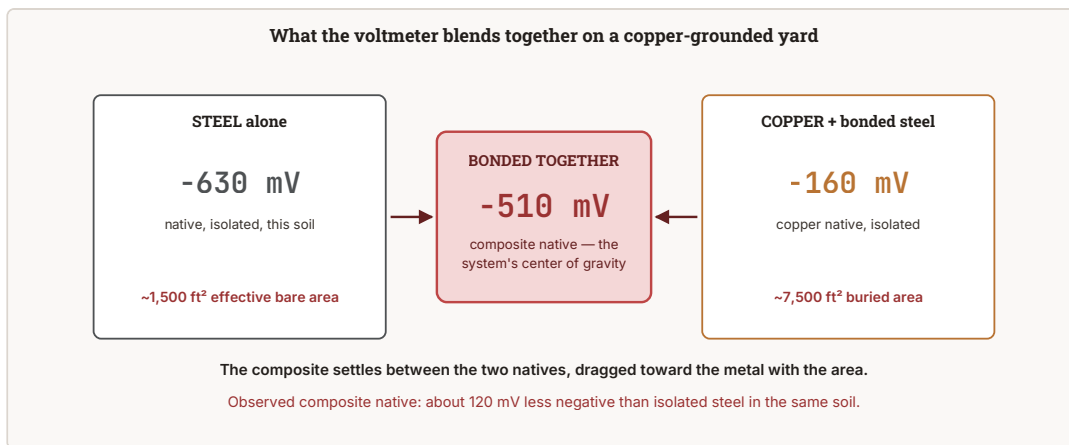
A Worked Example

The math is not complicated, but it is worth running once on representative numbers so the shape of the problem is clear.

Take a compressor station with the following:

- Buried steel station piping: **~1,500 ft²** of exposed surface area (counting coating holidays, bare risers, and incidental bare connections — coating quality matters here, but for the example we are treating the effective bare area conservatively).
- Bare copper grounding grid plus bonded structural steel: **~7,500 ft²** of buried surface area.
- Soil resistivity in the yard: ~5,000 ohm-cm. Moderately conductive. Connected metals communicate well through it.
- Steel native potential alone, in this soil: **-630 mV CSE.**
- Copper native potential alone, in this soil: **-160 mV CSE.**

With those two metals electrically common and in continuous contact with the same soil, the mixed potential of the system settles somewhere between the two natives, dragged hard toward copper because copper has five times the surface area. The observed composite native — what a depolarized survey reads — is roughly **-510 mV CSE.** That is 120 mV less negative than what isolated steel would most likely read in the same soil.



The composite native settles between the two isolated natives, weighted toward the metal with the most buried surface. Figure added for this reprint.

Now turn the CP system on and let it polarize. The crew interrupts the rectifier and measures instant-off at **-670 mV CSE**.

APPARENT POLARIZATION SHIFT

$$-670 - (-510) = 160 \text{ mV}$$

Against the 100 mV polarization criterion, the system passes. Easily. The survey report would call this protected, and an auditor looking at the numbers would have no complaint.

But the actual steel polarization is a different number. The instant-off reading of -670 mV is the composite reading. The steel sits inside that composite, but not at it. Its native — what we are polarizing from — was -630 mV, not -510 mV. The most steel could have polarized is **-670 - (-630) = 40 mV**, and in practice it is less than that, because much of the CP current was absorbed by the copper grounding grid driving it more negative (where it did not need protection in the first place).

40 mV of polarization on steel is not protected steel. The pipe is corroding underneath, slowly, while the paperwork shows compliance.

160 mV of polarization on a composite reading is not 160 mV of polarization on steel.

This is the failure mode. The criterion is being met on a number that is not what the criterion was written to measure.

Three Ways to Get an Honest Answer

There are three workable responses to a mixed-metal system. They are not exclusive — most real stations end up with some combination — but each one addresses the composite-reading problem differently.

1. Electrical Isolation

The cleanest fix. If the pipe is not electrically common (DC) with the grounding grid, the voltmeter reads steel.

Install isolation kits on the inlet and outlet flanges of the station. Verify them with a meter, both when they are new and at every annual survey thereafter — isolation kits fail, and a failed kit is not visible from the outside. Monolithic isolation joints in line pipe segments are an alternative that does not have the maintenance vulnerability of a flanged kit. Dielectric unions handle smaller piping.

This is not always possible. Code-required bonding for personnel safety is non-negotiable. Process equipment that is grounded for instrumentation reasons cannot always be isolated. Older stations may have decades of accumulated unintended bonds buried in concrete, in trenches, in places no one has documentation for. But every flange you can isolate is a flange that takes the grounding grid out of your voltmeter reading.

When DC isolation is achievable, it is the answer. There is no other technique that removes the composite effect rather than working around it.

2. Polarization Coupons

When isolation is not feasible — and on most operating compressor stations, full isolation is not — coupons are the closest thing to asking the steel directly.

A coupon is a piece of steel of known surface area, buried in the soil near the structure, electrically connected to the pipe through a short lead at a test station. Because the coupon is small, isolated, and its area is known, when you read its instant-off potential at the test station, you are reading something much closer to what steel alone would read in that soil. The composite that dominates the structure-side reading does not dominate the coupon reading.

Practical notes:

- Place the coupon in soil that is representative of the structure — same depth, same backfill, same general moisture profile. A coupon set in a different soil environment than the pipe is answering a different question.

- Native (depolarized) coupon readings establish the baseline. CP-on instant-off readings on the coupon establish the polarization. The polarization shift on the coupon is steel polarization, not composite polarization.
- A coupon does not protect the structure. It tells you whether the structure is being protected. Treat it like a thermometer: it reads the temperature, it does not heat the room.

A coupon is the closest thing we have to asking the steel directly.

3. Exaggerated Polarization Targets

When you cannot isolate and you do not have coupons in place yet, the workaround is to set the polarization target higher than the criterion to compensate for the composite skew.

The math works backwards from the worked example. If the composite native is 100 to 200 mV less negative than the true steel native, then to get 100 mV of actual steel polarization, you need 200 to 350 mV of apparent polarization on the composite reading. Different operators land in different places inside that range — 200 mV is conservative on a small grounding grid, 300 to 350 mV is more typical on a station where the copper area dominates.

The honest framing of this approach: it is not a fix. It is a margin. You are saying, "I cannot read steel directly, so I am going to over-polarize the composite by enough that even if the steel is getting a fraction of the apparent shift, it is still getting at least the criterion."

That works, with two cautions.

The first is the current cost. Over-polarizing a system that is mostly copper means most of the additional current is being delivered to the grounding grid. Rectifier output goes up. Power cost goes up. Anode bed life goes down. None of that protects the pipe; it just covers the survey.

The second is the upper bound. Push instant-off readings past **-1.20 V CSE** on buried carbon steel and you start running into cathodic disbondment and hydrogen-related effects. On a station with a mix of pipe grades, including any high-strength material, that margin shrinks. The composite reading can be safely past -1.20 V only if you know the steel underneath isn't. On a system you cannot read directly, that is hard to know.

The exaggerated-target approach is a reasonable interim while isolation is being scoped or coupons are being installed. It is not the long-term answer.

A Few Things That Trip People Up

- **Treating the survey number as the steel number.** This is the central error and the one this article exists to name. A reading on a structure that is electrically common with copper grounding is not a steel reading.
- **Calling a system isolated because the gaskets look right.** Isolation kits fail — the steel-on-steel through-bolts arc through, the gaskets crush, moisture wicks across. The only way to know a kit is working is to check it correctly, every time.
- **Trusting a 100 mV polarization shift on a composite reading.** The criterion was written for the metal it is being measured on. Apply it on a composite and the assurance it provides is proportional to how much of that composite is actually the metal you care about.
- **Sizing the rectifier upward.** If the system is mostly copper and the criterion is being met by polarizing the copper, more current does not produce more steel protection. It produces more bills and shorter anode life. A station where the rectifier output keeps creeping is a station that may need a coupon installed, not more output.
- **Skipping the continuity test on a "known" pipeline.** Stations get modified. Flanges get rebuilt. Grounding gets added. The continuity map you had three years ago may not be the continuity map you have today.
- **Forgetting that a bell hole settles the argument.** When the survey and the steel disagree, the steel is right. The survey is just describing what the voltmeter saw.

Key Takeaways

- A pipe-to-soil reading on a structure that is electrically common with other metals is not a measurement of the structure's metal alone. It is a **mixed potential** — the system's composite, weighted by surface area and the local soil environment.
- On a compressor station with a copper grounding grid, the composite reading typically sits **100 to 200 mV less negative** than what isolated steel would read in the same soil. That offset shows up on both the depolarized reading and the instant-off reading.
- The **100 mV polarization criterion applied to a composite reading does not deliver 100 mV of polarization on the steel.** Most of the apparent shift is happening on whatever metal dominates the composite.
- **Identify mixed-metal systems early.** Continuity tests at the test station, visual inspection of bonding and isolation at the yard, and survey data that doesn't match the soil conditions are the signals.

- **Three responses, in order of preference:** electrical isolation where it is achievable, coupons where it is not, and exaggerated polarization targets (200 to 350 mV on the apparent reading) as an interim while the first two are scoped.
- The exaggerated-target approach has a cost (rectifier output, anode life) and a ceiling (upper-bound CP limits — keep the composite reading less negative than about -1.20 V CSE on buried carbon steel, tighter on high-strength material).
- When a bell hole disagrees with the survey, the bell hole wins. The survey was correctly reporting what the voltmeter saw. The voltmeter just was not looking at steel.

Referenced Standards & Technical Resources

- **AMPP/NACE SP0169** — Control of External Corrosion on Underground or Submerged Metallic Piping Systems. Polarization criteria and notes on dissimilar-metal systems.
- **AMPP TM0497** — Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems. The reference for instant-off and depolarized potential measurement.
- **AMPP/NACE TM0211** — Durability Test for Copper/Copper Sulfate Permanent Reference Electrodes for Direct Burial Applications. Reference electrode performance baseline.
- **ISO 15589-1** — Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems, Part 1: On-land pipelines. Specifies upper-bound CP limits, including -1.20 V on buried carbon steel.
- **Peabody's Control of Pipeline Corrosion**, 2nd Edition — Chapter 4 (Criteria for Cathodic Protection) and Chapter 6 (Stray Current Corrosion). Composite-potential treatment.
- **AMPP/NACE CP 2: Cathodic Protection Technician** course manual — mixed-metal systems and coupon application.
- **AUCSC Intermediate and Advanced Course Manuals** — compressor station CP design, grounding interactions, and coupon practice.
- **49 CFR Part 192 / Part 195** — PHMSA pipeline safety regulations governing external corrosion control and the documentation that demonstrates it.

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