The InterNational Electrical Testing Association Journal

WINTER 2026

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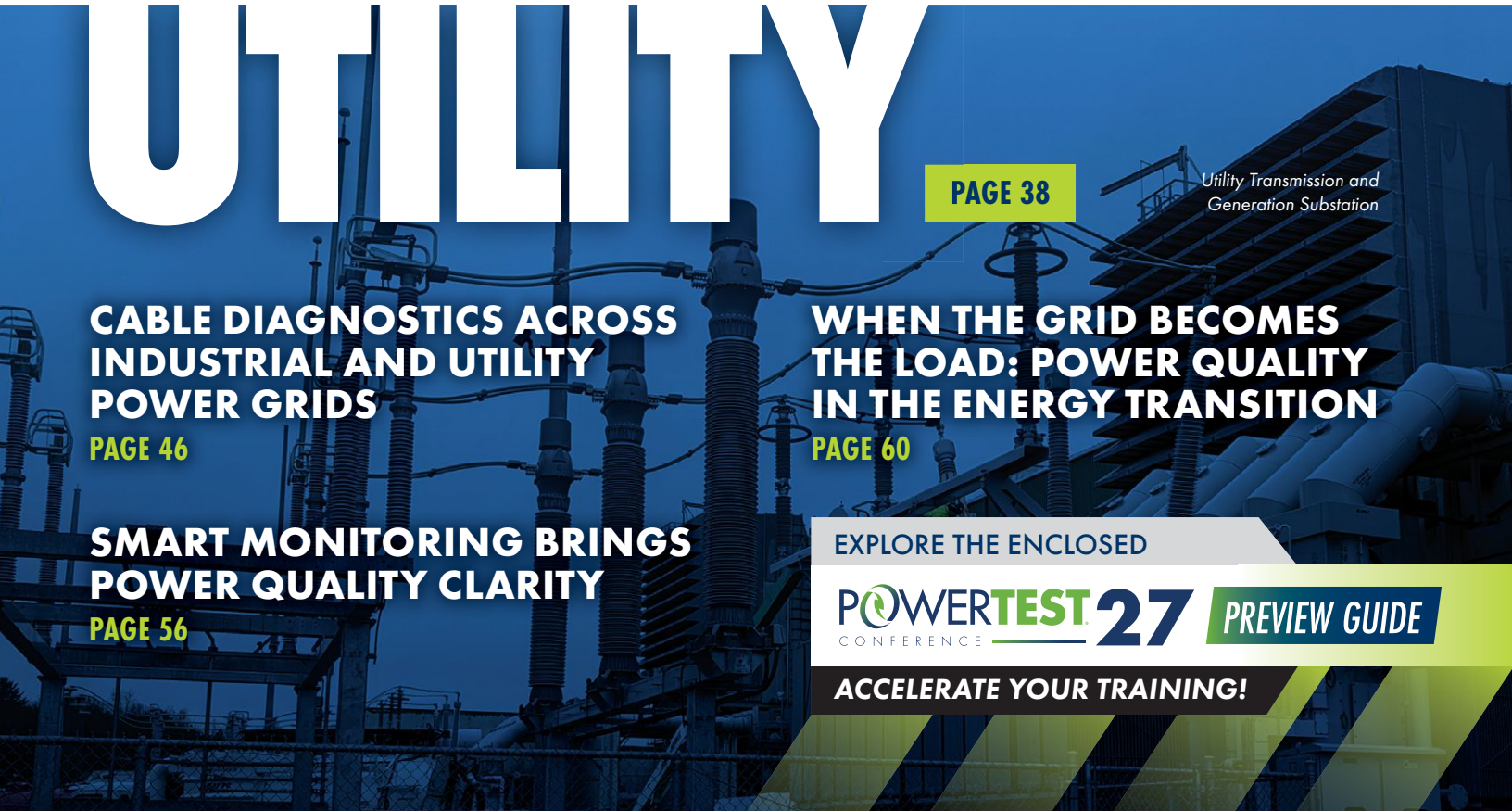
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POWER QUALITY RISKS

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INDUSTRIAL VS UTILITY



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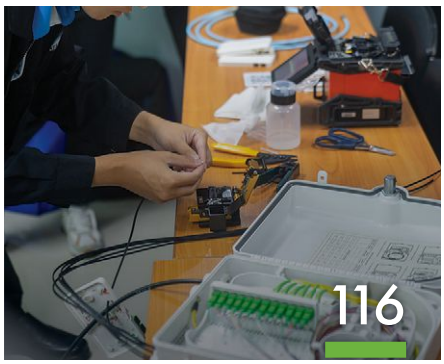
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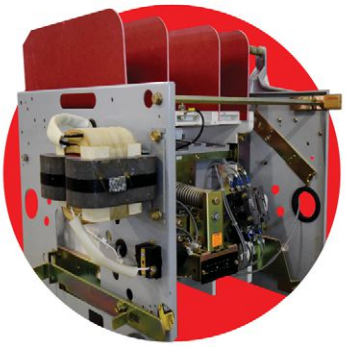




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ANSWERING THE CALL FOR RELIABILITY



As 2026 draws to a close, I'm struck by how much our industry has asked of us this year, and by how well the NETA community has answered. Demand for reliable, safety-tested electrical power has never been higher, and the professionals who commission and maintain that infrastructure have never been more essential.

That pressure shows up everywhere. AI-driven data center growth continues to strain the supply chain, with transformer and switchgear lead times stretching to a year or more and, for some custom equipment, multiple years. Each delayed delivery puts more weight on the equipment already in service, and on the technicians who keep it safe and dependable. Quality testing, maintenance, and a trained workforce matter more than ever.

Vincenzo Pagliuca of The Hartford Steam Boiler Inspection and Insurance Company opens this issue with power quality risks in industrial facilities versus utility systems. He shows how monitoring, mitigation, and standards such as ANSI/NETA support risk management for insurers, owners, and operators. Melvin Liwag of Orlando Utilities Commission (OUC) follows with a case study demonstrating how real-time transformer monitoring helped OUC trace partial outages at a large manufacturer to their root cause, and how utility-customer collaboration pays off.

Nilson Baroni Jr., Daniel Bento, and Marcelo Plantier of BAUR look at cable diagnostics across industrial and utility grids. They explain why testing purpose matters, from acceptance under ANSI/NETA ATS to maintenance under MTS. Howard Penrose of MotorDoc offers a forward look at power quality in the energy transition, in which batteries, solar, and inverter-based resources make the grid both a source and a load.

NETA recently presented EPIC, the Electrical Power Innovations Conference, in Fort Worth, Texas, from October 11–13. EPIC looks ahead at grid modernization, renewable integration, digitalization, AI, and cybersecurity, the same issues our authors raise here. The second edition of the conference was very successful and engaging, not only with the technical, forward-looking content but also with a focus on workforce development covered in breakout sessions. My thanks to every speaker, sponsor, and attendee.

As the year closes, I encourage you to read these articles, share them with your teams, and consider writing for *NETA World* yourself. Your field experience is what makes this community strong.

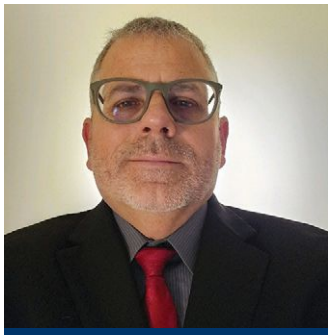
Thank you for your continued support, and best wishes for a safe and prosperous new year.



Dan Hook, President
InterNational Electrical Testing Association

KEN MORTON

ALWAYS CHASING THE WHY



KEN MORTON

This issue of *NETA World's* "Insight & Inspiration" series features Ken Morton, Quality Manager at Vector Power. With 33 years in the electrical industry, Morton's career has taken him from commercial and light industrial electrical work to the U.S. Army Prime Power School and ultimately into electrical testing, training, quality, and technical leadership. Today, he manages Vector Power's quality program, develops and facilitates training, provides safety training and technical support, serves as the company's NETA Technical Advisor, and participates in a variety of industry committees and educational programs. He is a NETA Level 4 Certified Senior Technician.

NW: **How long have you been in the field, and what was your path to your current position?**

Morton: I've been in the electrical industry for 33 years. I started as a commercial and light industrial electrician and worked my way up to project superintendent. When the 2008 recession hit, my family took a huge financial blow. The Las Vegas construction economy was devastated, and we lost everything. I reenlisted in the Army as a reservist, driving heavy equipment transports, with plans to move to Wyoming and start driving in the gas fields.

Someone had a better plan, though. An officer encouraged me to apply to the U.S. Army Prime Power School. I went into the year-long program determined to learn everything I could and graduated as Distinguished Honor Graduate for both the overall course and my specialty phase as an instrumentation technician. I spent 12 years as a reservist performing electrical maintenance and repairs on emergency systems, distributed generation, and critical infrastructure for the Army before retiring with 28 years of total service.

My NETA journey also began after Prime Power School. Shermco Industries hired me as a protection and controls technician right out of school. Going from that intense training environment to applying the knowledge through hands-on work for 12- to 16-hour days really solidified my understanding of how

things work. It also showed me how little I actually understood and that there is always another layer to learn, even with things that seem simple.

Working out of Shermco's Tulsa office exposed me to all types and vintages of equipment as well as excellent in-house training. I eventually became production manager and moved into a hybrid role involving operations, environment, health, safety, and training. I later worked for EPS, helping to develop its training facility in Nashville and to standardize operating procedures across business units.

When Vector Power started up, I jumped at the opportunity to work with Pat Beisert and Tom Sandri again, and it has been a very exciting ride.

NW: **What attracted you to electrical testing?**

Morton: Even after spending 20 years as an electrician, I had no idea testing existed as a separate trade and didn't really know what I was getting into. Everyone at the schoolhouse told me to apply to a testing company, so I did. I have always wanted to understand the *why* behind how things work, so testing has really allowed me to lean into that curiosity.

NW: **Who influenced or mentored you along the way?**

Morton: There have been so many. Mark Cade and James Grant contributed significantly to my technical and leadership development during my years as an electrician. There were also many Army leaders and technical experts who influenced me, especially LTC Mike Schilling, SFC Kenneth Smalls, and MSG William Davenport, along with everyone in Delta Company.

Within the testing world, there have again been so many: Chris Haire, Jim Harrison, Pat Beisert, Monica Griggs, Ernie Victory, and many others. I've been fortunate to learn from a lot of great people throughout my career.

NW: **What about this work keeps you committed to the profession?**

Morton: I'm fascinated by how electricity and power systems work. I also love the people and teaching. It may sound corny, but I love my country, and I see this profession as a way to continue contributing to its health and security now that I can't be a soldier anymore.

NW: **Describe one of your best workdays. What happened?**

Morton: I got a call from a local hospital at 10:00 PM on Christmas night. They were desperate for help, and three other companies had turned them down.

A fuse had blown in an incoming medium-voltage switch that fed the neonatal intensive care unit and burn ward, and the replacement fuse had also blown. The hospital was operating on generator backup, but the generator had recently been submerged in water, so they didn't trust it to last. I got to the site, identified the problem as a failed surge arrester, had parts hot-shotted up from Dallas, and had the hospital back on utility power by 10:00 AM.

Days like that make it very clear why this work matters.

NW: **Tell us about a day that didn't go as planned. How did you respond, and what did you learn?**

Morton: We were about 14 hours into a long day of brownfield work in a substation, cutting circuits over from old electromechanical relays to modern digital relays. We discovered a problem with the drawings. If we wired the system as shown, a blocking scheme wouldn't work properly.

The site engineer had already left and told us we had to complete the scope that day. We were certified as protection and controls leads for the client and had some latitude to make this type of correction as long as it was redlined

and reviewed afterward, so we corrected the drawing and implemented the change.

But finding the error distracted us from our normal routine of verifying that a control cable was isolated and de-energized before cutting it.

About 30 seconds after cutting into a control cable, the station phone rang. That's not something you want at 9:00 PM when you're the only ones there. The operator told us a circuit breaker had opened in the yard.

We confirmed it and quickly realized what we had done. Fortunately, no load was dropped, and we were able to close the circuit breaker back in and finish the rest of the task without issue.

Reviewing the incident afterward reinforced some major lessons: Stop and reassess whenever something distracts you from a critical task, and use place-keeping practices to mitigate the effects of distraction. The client understood how we had gotten into the situation because of the incorrect drawings and appreciated that we recovered and stayed on schedule. But I maintain that continuing when you are unsure is always risky.

***NW:* Which energy or industry trend do you think will most affect your work in the future?**

Morton: For my part of the industry, the massive influx of young, inexperienced workers is going to be a huge challenge. As an industry, we are way behind the curve in replacing retiring experts while also building a larger workforce to accommodate the explosion in infrastructure. We need to find ways to accelerate the safety and technical expertise of this new workforce without sacrificing quality—all while recognizing that nothing fully replaces experience and seasoning.

That makes training and knowledge transfer incredibly important. We have to prepare people more quickly, but we also have to prepare them well.

***NW:* What advice would you give a young person interested in becoming an electrical testing technician?**

Morton: I talk to young people about this every chance I get. I always encourage them to learn as much as they can, as soon as they can.

Instead of going to the bar every night after work, spend some of those nights reading and learning about your trade. Ask yourself, "What did I see or do today that I didn't fully understand?" Then look it up and chase the rabbit.

This field offers incredible opportunities for people willing to go above and beyond their peers when it comes to knowledge. You may have to put in years of very long days away from home, but if you become the person everyone turns to for answers, you will eventually be given opportunities to move out of the field and into roles that help support and shape the future of companies and the industry.

This industry has completely changed the trajectory of my family's future, as it has for many others we know, unlike any other trade I have seen. It—and the people I work with—has been an incredible blessing. NW





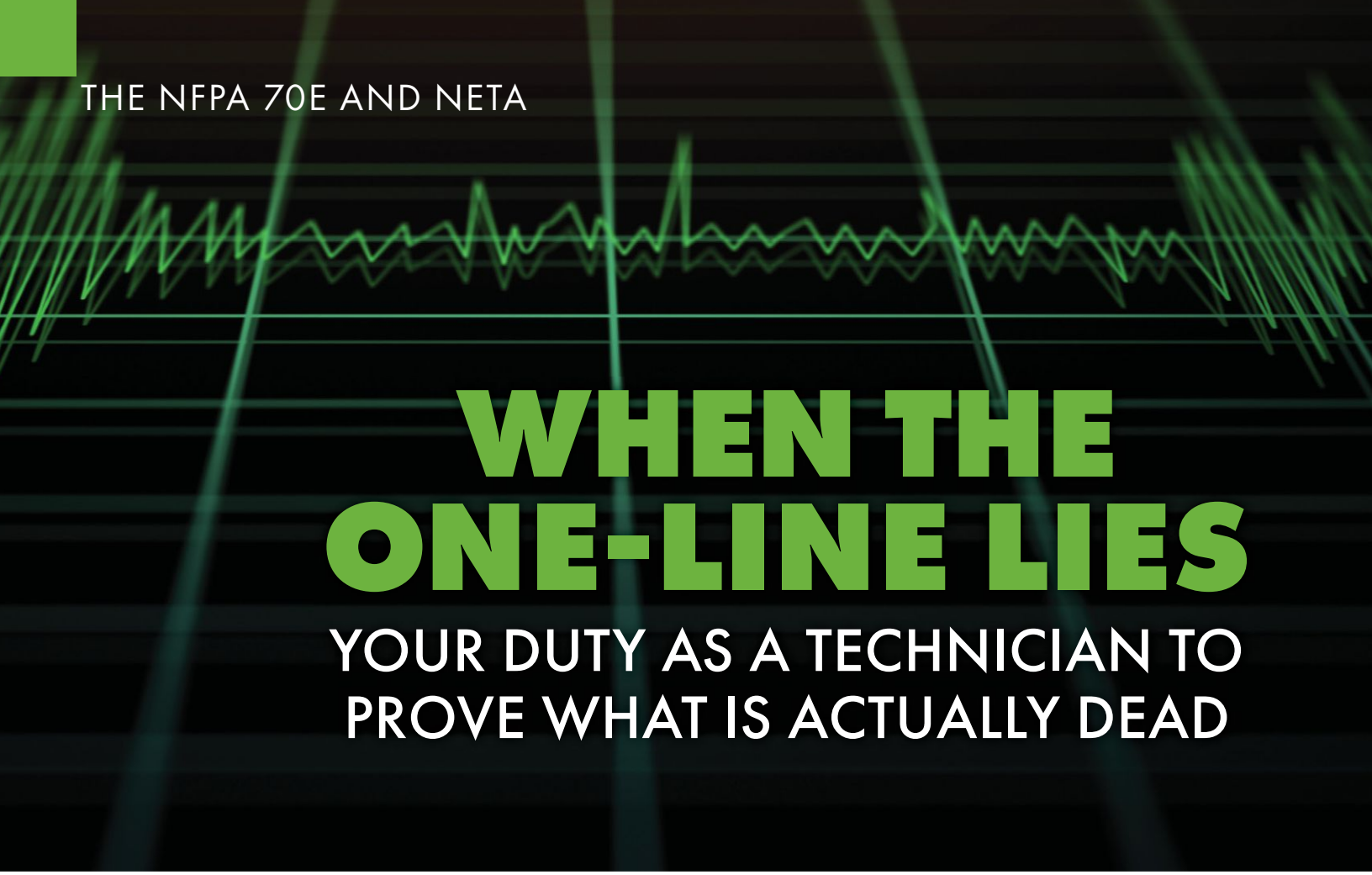
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WHEN THE ONE-LINE LIES

YOUR DUTY AS A TECHNICIAN TO PROVE WHAT IS ACTUALLY DEAD

BY RON WIDUP, *Vector Power*

A recent article in *BBC Science Focus* had the following statement from Dr. Kirsty King: "Lie detectors don't work. Body language is unreliable. But there are ways to tell if someone is lying. You just have to listen carefully to what they're saying. Spotting a liar is a vital skill. We all want to be better at it because lies can affect us in any number of ways, some of them harmful."

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You know what one-line diagrams are. They tell you how a system was designed, and it gives you the road map to the electrical infrastructure. It helps you plan switching and maintenance tasks. But it doesn't tell you everything that can energize the equipment you'll be working on today.

When it comes to electrical safety, don't let a one-line be a liar—identify and spot those hidden gotchas before they get 'cha.

PICTURE THIS

You are part of a crew that arrives to test a low-voltage switchgear lineup during a planned maintenance outage. The customer has opened the upstream breaker. The main disconnect is locked and tagged. The mimic bus shows the section de-energized, and the one-line shows no second source of power. Everyone agrees that the equipment is dead.

Then a technician puts a meter on a control terminal and finds 120 volts present. (Side note: Great job, Super Tech! You just did test-before-touch in accordance with NFPA 70E Article 120.6(7).)

That changes everything—but it may also have prevented an injury. So where did that voltage, that wasn't identified on the one-line, come from? Was it a separate control power transformer, a battery system, a temporary feed, or simply a modification that never made it on the drawing? The important thing is this: the system didn't match the picture of what should have been there. The one-line lied to you.

You've all probably seen a similar situation before. (I have!) Every experienced test technician has seen some version of it. A circuit breaker says open, but it's closed. A tie breaker was closed that should have been open. A control circuit came from another lineup. A customer-installed jumper appeared in the switchgear without documentation. A supposedly discharged capacitor still held energy. It goes on and on…

That's why understanding and following NFPA 70E is so important. We should all be very familiar with Article 120.6, *Process for Establishing and Verifying an Electrically Safe Work Condition*. It gives us a specific procedure for establishing and verifying an electrically safe work condition. And these steps (there are nine of them) within the 70E matter because no single indication proves that equipment is safe.

A drawing, an open breaker, a tag and a lock, and an operator's verbal statement all provide useful information, but none of them can take the place of you verifying the absence of voltage at that critical point of exposure—the place you are about to touch. (So test it, Electro-Boy!)

YOUR STARTING POINT: THE ONE-LINE DIAGRAM

OK, we're giving the one-line a lot of grief by calling it a liar, but truth be told, a one-line diagram is one of the most useful documents on a job, and its importance to overall safety and maintenance planning is critical. It shows the intended sources, buses, transformers, protective devices, and normal connections.

It helps us plan isolation points and understand how equipment should operate.

Did you catch that? It tells us that the equipment *should* operate. That's a big ask, but also remember this: a one-line often describes the system *as designed or as last documented*. It may not show a temporary generator, portable cables, an added UPS, an external control-power source, or a field modification made during an emergency. Depending on the customer or the facility, you might get lucky, and the drawings may remain accurate for years… but real-world field conditions often reveal that's just simply not the case.

That doesn't make the drawing useless; it means the drawing is one piece of evidence in the quest to isolate and verify sources of energy. The technician must compare it with equipment nameplates, conductor routing, device positions, local and remote indications, operating records, and actual electrical measurements.

Think about it like this: your safest mindset is to treat the drawing as a theory of the system. Your job is to test that theory before your body enters the circuit. They might not lie to you as much as politicians do, but sometimes the drawings might tell you the truth, just not always the whole truth. (Vote for me!)

OPEN DOES NOT MEAN DE-ENERGIZED!

An open breaker tells you something about the position of a device. It does not prove that you opened the right device, that every pole is separated and isolated from the source, or that another source cannot reach the work area. It also does not prove that stored or induced energy is gone.


DANGER
DANGER
DANGER

When on a maintenance outage, here's a few examples of energy sources that deserve your attention during planning and execution of tasks:

- **Separate control power.** Trip, close, relay, metering, space-heater, and auxiliary circuits may remain energized after the primary source is isolated.
- **Generators and transfer switch equipment.** Automatic starting controls, closed transition switches, and alternate sources of supply can change the assumed state of a bus.
- **UPS and battery systems.** AC input isolation does not remove DC energy or output supplied by an inverter!
- **Photovoltaic and battery energy storage.** Multiple conversion stages of energy and various sources can energize equipment from directions that older one-lines did not anticipate.
- **Capacitors and VFD DC buses.** Stored electrical charge on capacitors can remain after energy isolation.
- **Voltage and control power transformers.** A secondary source can create an unexpected backfeed path through a transformer.
- **Induction.** Nearby energized conductors can produce measurable and hazardous voltage on isolated conductors, especially over long parallel runs or in high-voltage substations.
- **Temporary wiring and undocumented changes**
  Watch this one—it will get you. Outage work, construction, heating up the coffee pot, or emergency repairs often introduce energy sources that do not appear on the drawings.

YOUR TEST SETS CHANGE THE SYSTEM

Test technicians face a condition that many electrical safety discussions barely address: we bring energy to the job.



A circuit may begin in an electrically safe work condition. But once the test leads are connected and the test set is energized, that condition changes. Insulation-resistance testing, high-potential testing, primary- and secondary-injection testing, turns-ratio testing, breaker timing, and functional testing can introduce voltage, current, stored charge, or mechanical movement. (Remember, energy is both electrical and mechanical!)

The test source may also reach farther than expected. A lifted lead may still connect to another device. A CT circuit can develop hazardous voltage if opened under the wrong conditions. A test voltage can appear at the far end of a cable. A breaker can operate remotely while another worker has their hands inside the mechanism. A motor or generator can jog or rotate.

This leads to a rule that belongs in every maintenance test plan and job hazard analysis (JHA)—account for not only the facility's energy, but the possible energy sources introduced by the test crew. If you take time to

perform a short safety briefing, it can prevent a long post-accident investigation.

OK, so now you have the ANSI/NETA specs out, you are about to test the device. Ask yourself these seven questions:

1. What normally supplies this equipment?
2. What could supply it under an abnormal or temporary condition?
3. What energy will our test equipment introduce?
4. Where can that energy travel, including through control wiring, transformers, grounds, and connected equipment?
5. Who controls each source and who can change its state?
6. What must be isolated, discharged, restrained, blocked, or grounded?
7. How will we verify the condition at every point where a person may be exposed?

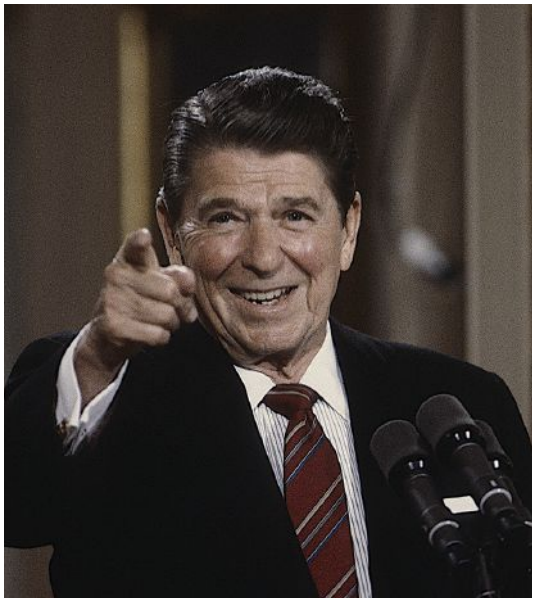
TRUST THE PROCESS AND VERIFY THE SYSTEM

Verification is how you, as an experienced test technician in the field, close the gap between your field-testing execution plan and the actual electrical system.

Plant personnel may have followed the switching order exactly. The electrician may have applied every lock correctly. The engineer may have issued the best drawing available. But if there is a failed contact, a hidden source of power, a wiring error, or an undocumented change, you can still have unexpected energy at the work location. The meter does not assign blame; it reports the condition.

Your experience teaches us what normally happens, but electrical safety processes ask us to consider what else can happen. You know: "Trust, but verify."

It takes me back to an article I wrote for *NETA World* in Summer 2023 about the possible effects of AI on future electrical standards—and the infamous quote by U.S. President Ronald Reagan, which came about



from Suzanne Massie, an American scholar of Russian history.

She advised Reagan on the Soviet Union during the final years of the Cold War, and as they prepared for talks with Mikhail Gorbachev, she taught him the Russian proverb, "Doveryai no Proveryai," which translates to **"Trust, but Verify."**

The next time the breaker is open, the lock is on, and you look at the drawing that says the bus is dead, look around and ask yourself one more question before you reach in: What could still put energy here?

Then test the answer. Don't let it lie to you.

And remember this: test before touch!

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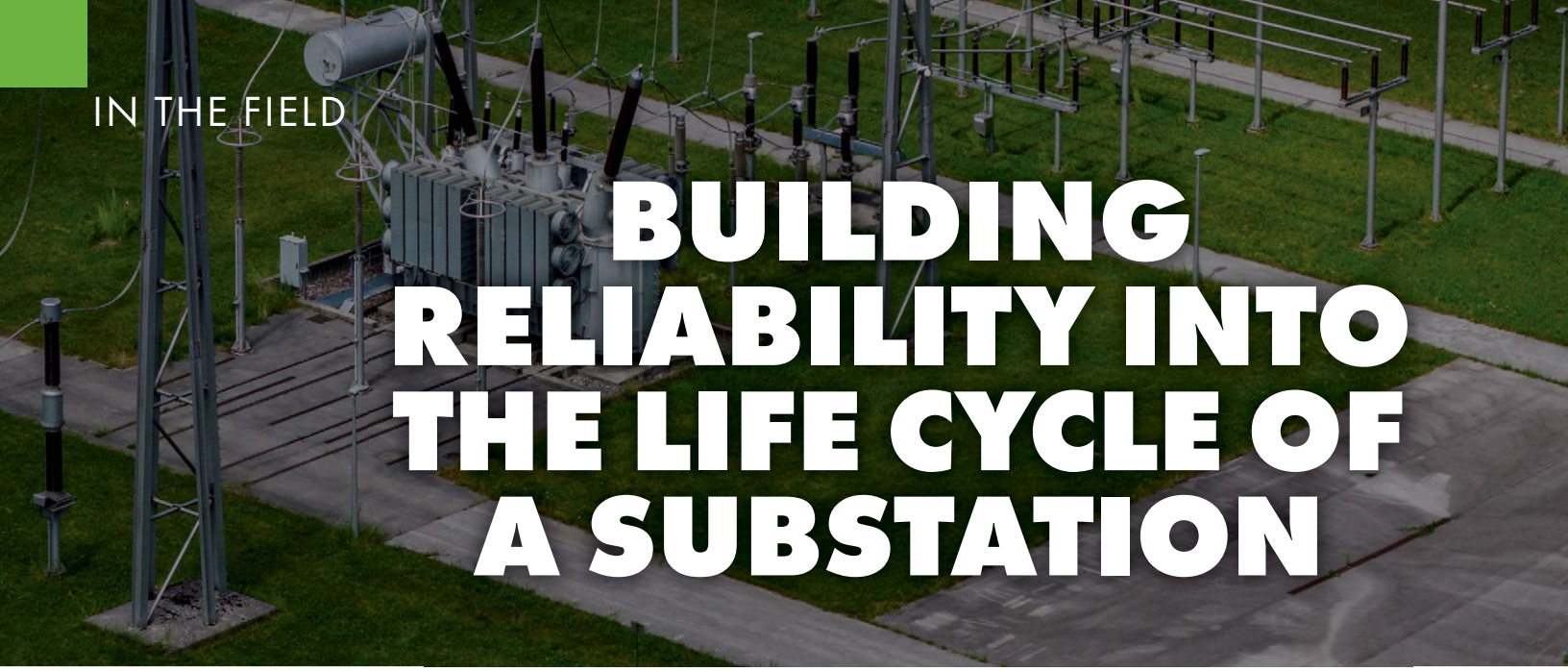
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BUILDING RELIABILITY INTO THE LIFE CYCLE OF A SUBSTATION

BY MOSE RAMIEH, *CBS Field Services*

Utility and industrial substations are made reliable through testing and validation at each stage of their life cycle. Each stage has its own opportunity to avoid nuisance issues or catastrophic failures. Acceptance testing determines whether the substation starts out as designed. Routine inspections monitor whether it stays that way. Maintenance testing determines how well we understand its condition as it ages.

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The misses rarely look dramatic when they begin: an alarm wired to the wrong indicator, an annunciation no one chases, a pass/fail test result accepted as the whole answer. Diane Vaughan's study of the Challenger disaster, which coined the phrase the normalization of deviance, showed how tolerated deviations like these compound until something goes badly wrong. Once an incident begins, the outcome is largely a matter of luck.

This article follows a substation's life in that order, with field stories from each stage and the newer testing technologies that are changing what maintenance test results can uncover. The aim is a virtuous cycle in which each stage's findings strengthen the next, improving substation safety and reliability.

ACCEPTANCE TESTING

Acceptance testing sets the tone for everything that follows. It is the best time to find a problem, and it produces the baseline data that every later inspection and maintenance test will be compared against. A substation that starts with proper documentation, a verified functional design, and a correct installation has a reference point for its entire life.

Component testing confirms that transformers, circuit breakers, and other apparatus were undamaged in shipping and installation. What matters more is whether the controls and functions work as a system, and that is the one place acceptance testing should never be compromised. Functional testing takes time: every circuit, input, and output must be exercised and confirmed. This builds confidence in the system being turned over. The strongest program I have seen functionally tested the equipment three times: at the factory, after assembly into the e-houses, and finally onsite, verifying every external input and output. Each pass found something the last one

missed, or something that wasn't yet a variable at that stage. Consider the following examples from the field:

A technician once operated a transformer's mechanical alarms and walked to the panel to confirm the indicators were lit. They did, and a wiring error went unnoticed. A second pass, operating each alarm independently, exposed it: the low oil alarm stayed dark while the winding temperature alarm lit (Figure 1).

On more than one substation that I have started up, acceptance testing found breakers installed backwards: once by the contractor for convenience, once from a mirrored drawing by the designer. Either way, the CTs feeding the differential circuit were wired to the wrong bushings (1, 3, 5 versus 2, 4, 6).

While I was reviewing functional testing on one project, a breaker was opened and showed red and green indicating lights simultaneously. The technician in charge did not investigate at the time, and it took an independent verification program to find and correct the wiring fault. One habit helps: yellow-line the drawings (Figure 2) with an actual highlighter as each circuit is verified.

Verify shorting blocks and test switches in both the open and closed positions. I have

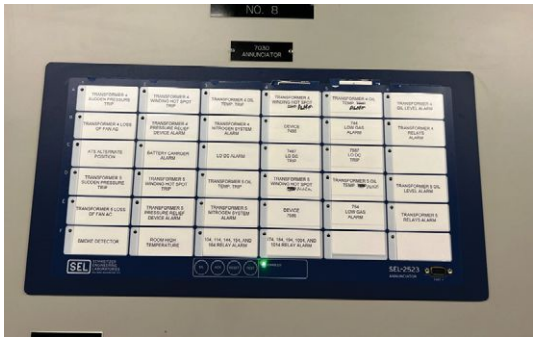
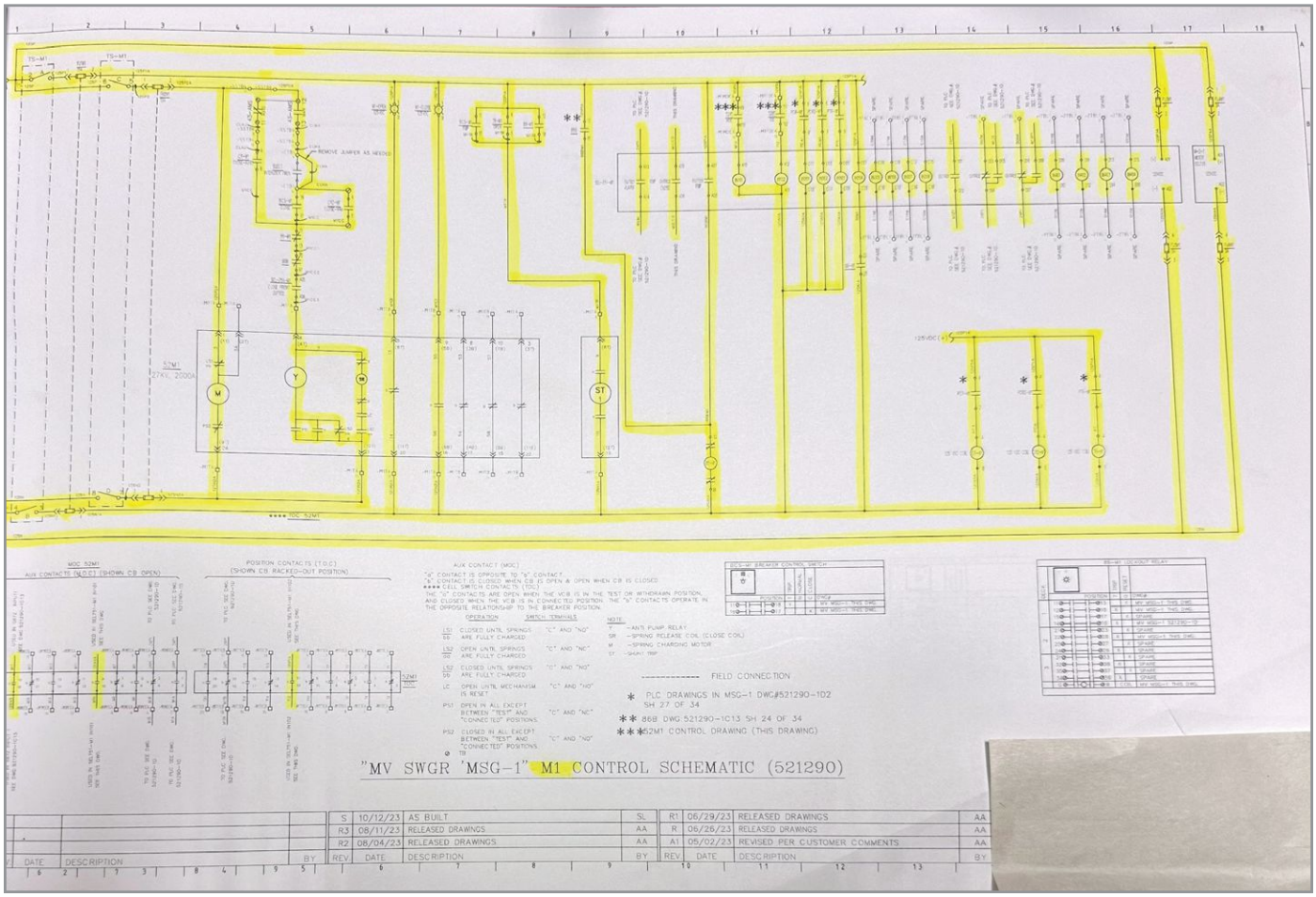
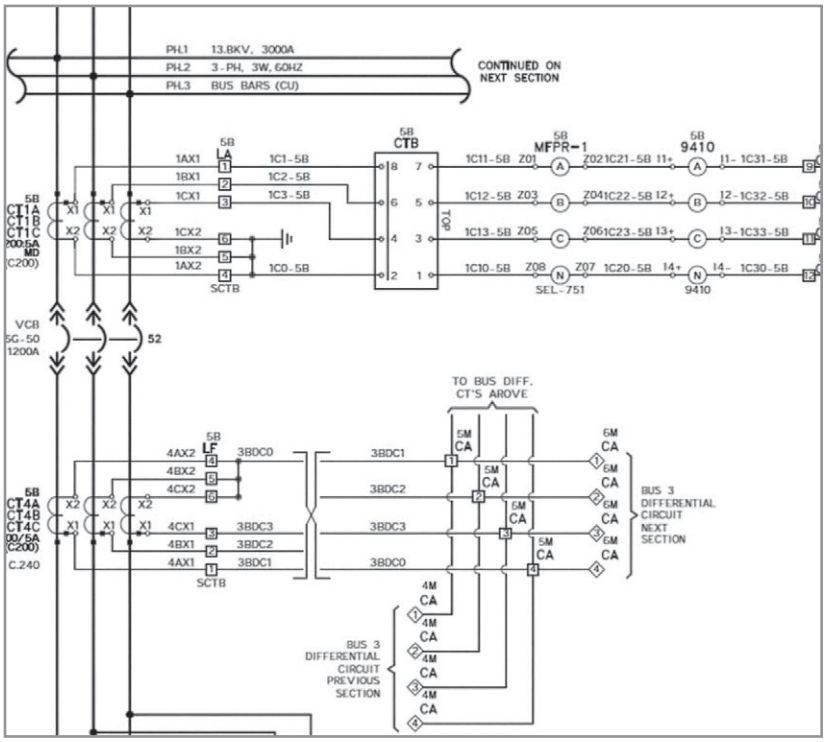


Figure 1: *Transformer Annunciation Panel*

Figure 2: *Breaker Controls Drawing*





Figures 3 and 4: *CT Diagram and PK Block Shorting Bar Installed Backwards*



found many miswired so they failed to short the CTs, which can lead to dangerous failures. Verify single-point grounding on simple and differential circuits alike, since multiple grounds can cause misoperation during faults.

In addition, pay particular attention to PK-style CT shorting blocks. I have found many with the shorting bar on the wrong side of the circuit and, more subtly, installed backwards (Figures 3 and 4). The point of the bar should face into the block, not out.

Finally, for bus differential systems, primary current injection is the most practical way to

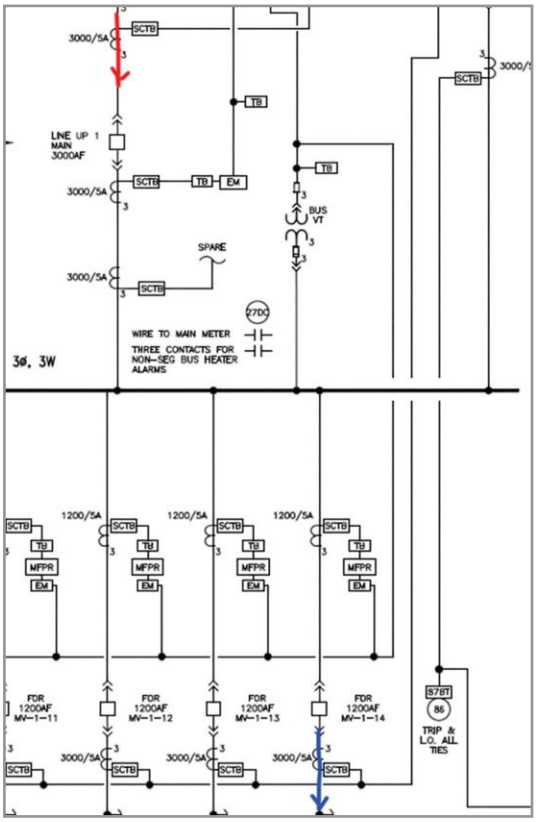


Figure 5: *Differential CT Diagram*

confirm CT polarity and wiring (Figure 5). Inject primary current through each phase of the main breaker and out each phase of each feeder breaker. This verifies the entire system in a way individual component testing cannot.

ROUTINE INSPECTIONS

If acceptance testing sets the tone, routine inspections catch small problems before they become failures. Something as simple as a decaying filter, a corroded battery post, or a space heater that has quietly stopped working can start causing damage that no one sees until it is serious.

Alarms and indicators need attention long after acceptance testing ends. One client's transformer annunciators would randomly and mysteriously alarm. Left unresolved, this kind of normalized issue erodes confidence in the monitoring system and invites operators to silence or ignore a real problem. Control lights also carry more information than most technicians give them credit for. Beyond breaker status, they indicate trip coil health



Figure 6: *Control Lights Not Working*

and the presence of control voltage (Figure 6). Relay targets and self-test warnings deserve the same attention on every visit.

Infrared inspection is one of the highest-value routine tasks a crew performs. In one case, a secondary bus connection on a utility transformer was found running dramatically hot. Had it failed, the entire system would have lost at least a phase, and customers would have lost power. Because periodic surveys have blind spots between visits, critical systems are worth upgrading to continuous online thermographic monitoring, which provides 24/7 visibility rather than a snapshot at each interval (Figures 7 and 8).

Poor cable insulation, often on top of a transformer and inaccessible without an outage, has triggered sudden-pressure devices during heavy rain, tripping the transformer offline and forcing an extended outage while the cause was identified (Figure 9). In another case, differential electromechanical relays misoperated because underground CT wiring from a remote breaker had degraded until the circuit was effectively open.

Mechanical inspections round out the routine inspection program. A rusting switch operating rod or fence post is not only an environmental issue; it can point to ground current that needs to be addressed. In one case, a rusted rod was found only when it broke during an attempt to open the switch for maintenance. Uncommon causes matter too: a ground switch misoperated after wasps built a nest in its mechanism (Figures 10 and 11).

MAINTENANCE TESTING

Early in my career, maintenance testing was simpler. A vacuum breaker meant a bottle integrity test, pass or fail. A power transformer meant a winding power factor test, and 0.5% was good enough to walk away. Ratioing a load tap changer transformer meant hand-cranking a single-phase TTR one tap at a time.

What has changed is how much information we collect. We don't get many chances to rely on feelings or opinions in this line of work. As the saying goes, "In God we trust; all others shall bring data." Data is most useful in context. When a technician gets hung up on a bad result, I encourage them to keep testing. If you stop at the first high-voltage bushing to chase a bad reading, you never learn how the other two compare, and you can't be certain whether you've found a problem or made a mistake. A bad result is a question, and the rest of the data is the answer.



Figure 9: *Damaged Control Wiring*



Figure 10: *Switch Rod Damaged*



Figures 11: *Bugs in Ground Switch*





Figures 7 and 8: *Damage Found with IR Survey*

TRANSFORMER INSULATION DIAGNOSTICS

Today, power factor testing can tell us more. When test sets began sweeping across a range of frequencies, there was often pressure to run only the 60 Hz point and move faster. I held to the sweep in most cases. Yes, it takes a little longer, but it shows far more. On one customer's transformer, the H2 bushing's 60 Hz power factor was elevated enough to fail on its own. The sweep added detail: H1 and H3 stayed flat near 0.2% from 15 to 400 Hz, while H2 climbed to about 3% at 15 Hz. The two acceptable bushings made the third stand out, and the low-frequency rise gave the customer a stronger case for replacing it. The pushback is nearly always time, but we have the time it takes to get the data that lets the customer make an informed decision about the safety and reliability of their system.

A 15 to 400 Hz sweep is only the start. Dielectric frequency response (DFR) measures from well below 1 Hz upward, and the shape of the curve shows how much moisture the insulation holds. That matters because most of a transformer's moisture lives in the paper, not the oil. One case study I reviewed described a 150 MVA unit with about seven tons of cellulose and 70 tons of oil. At 40°C, the oil held about 1.1 kg of water, and the paper about 210 kg. An oil sample can look acceptable while the paper is wet, and moisture moves between them with temperature, so one result at one moment can't settle the question. At 70°C, dry insulation supports roughly 100 years of life; at 3.4% moisture, about 15 years, an 85% loss.

BEYOND PASS/FAIL TESTING

Vacuum bottles show the same shift away from pass/fail. In nearly 30 years, I've had two circuit breakers fail the AC high-pot integrity test. It gave us a go/no-go answer and nothing else. Previous passing results couldn't tell us how long those bottles had been degrading. Magnetron atmospheric condition (MAC) testing, built on the Penning discharge principle, measures the actual pressure inside each bottle. Compared against the Paschen curve and trended across periodic tests, the readings show pressure rising and let us plan a replacement instead of finding out the hard way (Figure 12).

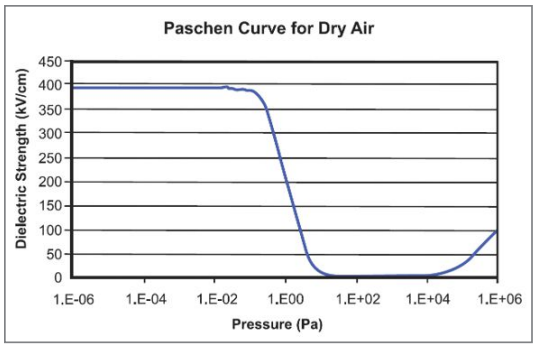


Figure 12: *Paschen Curve*

Relays have taken two paths. Electromechanical relays still need constant attention to stay on their time/current curves. They can drift and require adjustments or upgrading to a modern replacement. With microprocessor relays, we worry less about the protective elements and logic once a substation is properly commissioned, so testing has moved toward pass/fail: verify metering, inputs, and outputs. This is where a tempting shortcut hides. On one test, a relay failed to operate its 86 lockout. It was determined after investigation that the 86 had been improperly reset, which burned out its coil. We found it by exercising the output and protective element through to the controlled device, the 86, not just watching the relay's output (Figure 13).



Figure 13: *Burned 86 Coil*

ANSI/NETA MTS, *Maintenance Testing Specifications for Electrical Power Equipment*, says to check relay outputs, preferably by operating the controlled device. It leaves verifying each protection element optional. The required tests mostly tell us whether the equipment passes, and the optional ones tell us how it is aging. The tools are already in the standard. If you're using them, I'd like to hear what you're seeing.

CONCLUSION

Reliability is built into a substation, not assumed. It happens the same way at every stage: someone chooses to collect the data and act on it. At acceptance, that means proving the system as a whole and protecting the time to do it. In service, it means treating an alarm, a warm connection, or an odd noise as information to act on, not to dismiss. In maintenance, it means taking advantage of available technology to determine how equipment is aging, not just whether it meets industry standards.

Each stage hands something to the next. The baseline captured at acceptance is what makes a sweep-frequency response fingerprint meaningful years after a fault. Inspections show maintenance where to look. Maintenance results tell the owner where to act before a failure does. A deviation caught at any of these points is one that never gets the chance to become normal.

The tools will keep improving. The question beneath every test stays the same: is this result telling us what we need to know? Asking it, and taking the time to answer it, is how we keep the people and equipment on these systems safe, and it is why we go out to test. NW

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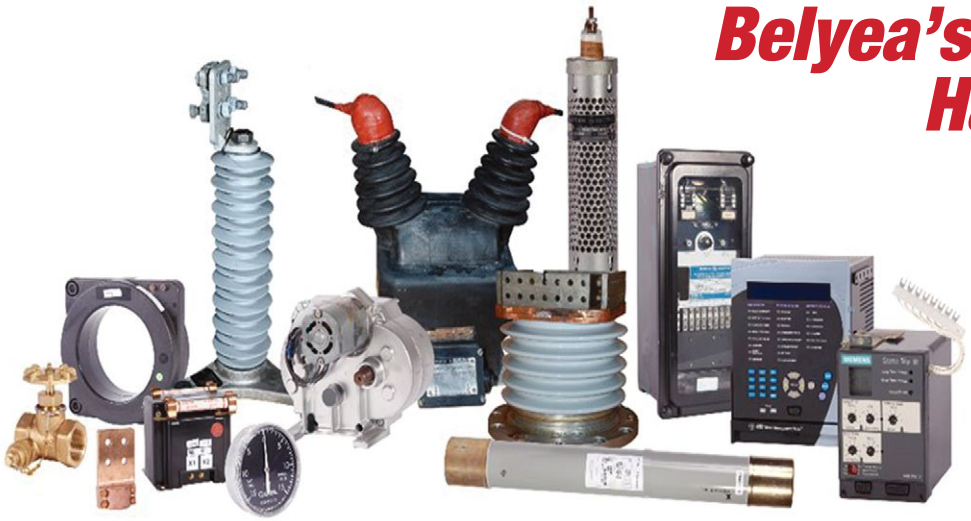
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Mose Ramieh *is Vice President of Business Development at CBS Field Services. A former Navy man, Texas Longhorn, Vlogger, CrossFit enthusiast, and slow-cigar-smoking champion, Ramieh has been in the electrical testing industry for more than 25 years. He is a Level IV NETA Certified Technician with an eye for simplicity and utilizing the KISS principle in the execution of acceptance and maintenance testing. Over the years, Ramieh has held positions ranging from field service technician, operations, sales, and business development to company owner. To this day, he claims he is on call 24/7/365 to assist anyone with an electrical challenge. That includes you, so be sure to connect with him on the socials.*

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POWER EQUATIONS FOR GENERATOR UPRATES

BY STEVE TURNER, *Consultant*

Power equations are very useful. For example, they help ensure that specific North American Electric Reliability Corporation (NERC) Protection and Control (PRC) standards remain satisfied when a generator's power output is uprated.

Assume for this particular example that the following generator real power output is to be uprated from 1,220.58 MW (P_1) to 1,241 MW (P_2). The pertinent nameplate original power output data is as follows:

1,356.2 MVA (S_1) @ 0.9 PF lagging (PF_1)

While the real power output is to be significantly increased, the nameplate values shown above are to be held constant; that is, S_1 never changes. Here is how to calculate the original real power output for a power factor of 0.9 lagging:

$$P_1 = S_1 * PF_1 = 1{,}220.58 \text{ MW}$$

Calculate the net gain in real power output as follows:

$$\Delta P = P_2 - P_1 = 20.42 \text{ MW}$$

The power factor must increase to generate the additional real power output ΔP:

$$PF_2 = \frac{P_2}{S_1} = 0.9151$$

Calculate the change in reactive power (Q) as follows:

$$\Delta Q = Q2 - Q1 = -44.26 \text{ MVar}$$

This loss in reactive power must be absorbed from the grid.

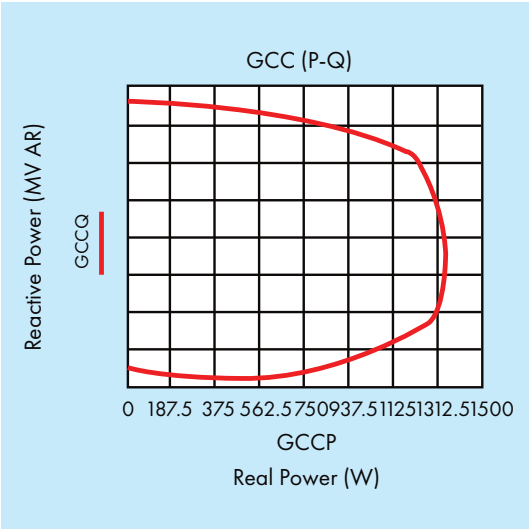


Figure 1: *Generator Capability Curve (GCC)*

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Assume this generator is protected by a 51V, voltage-restrained phase time overcurrent relay. Check NERC PRC-025-2, *Generator Relay Loadability*, to ensure 51V still complies.

CONCLUSION

51V has an effective tap of 8.614 A secondary; the relay will not pick up during periods of heavy load as defined by this particular NERC PRC (that is, the pickup is greater than the maximum load current). Thus, no setting changes are required. NW

$CTR = 8000 \quad VTR = 200 \quad V_{nom} = 24\ kV_{LL}$

$$V_{PRC} = 0.85\frac{V_{nom}}{VTR} = 102\ V\ secondary$$

$$P_{nom} = P_2 = 1{,}241\ MW$$

$$Q_{PRC} = 1.5 * P_{nom} = 1{,}861.5\ MVar$$

$$S_{PRC} = P_{nom} + Q_{PRC}j = 1{,}241\ MW + 1{,}861.5\ MVar*j = 2{,}237.245\ MVA$$

$$I_{PRC} = \frac{|S_{PRC}|}{V_{PRC} * VTR * CTR * \sqrt{3}} = 7.915\ A\ secondary$$



Steve Turner *is a Consultant at Sargent & Lundy. He was previously in charge of system protection for the Fossil Generation Department at Arizona Public Service Company for five years. Turner formerly held positions at Beckwith Electric Company, GEC Alstom, SEL, and Duke Energy, where he developed the first patent for double-ended fault location on overhead high-voltage transmission lines and was in charge of maintenance standards in the transmission department for protective relaying. He has BSEE and MSEE degrees from Virginia Tech University. Turner is an IEEE Senior Member and a member of the IEEE PSRC and has presented at numerous conferences.*

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DRUG AND ALCOHOL POLICIES
DO YOU MANAGE THEM?

BY PAUL CHAMBERLAIN, *Asplundh Engineering Services*

In roles with many different companies, I have overseen drug and alcohol programs and employee testing (called a Designated Employer Representative, or DER). The regulation of illicit substances or even prescribed drugs can be complex for most organizations, depending on what they do and where they work.

In my home state, recreational marijuana use is legal. However, this is regulated state-by-state (Figure 1). Many states abide by the federal standard for substance abuse, which still includes marijuana, and federal law requires testing for drugs of concern in certain professions, such as commercial drivers and airline pilots. Some states allow it only as medication, requiring a medical card to purchase. Others allow testing only in certain situations (such as New York and California). Some specific tasks considered safety sensitive may also require testing.

With recreational or medical marijuana use being legalized in many states across the United States, workplaces should review their health and safety or human resources policies regarding alcohol and drug use—and if the workplace does not have a policy, it's high time to create one.

THE IMPORTANCE OF A DRUG AND ALCOHOL POLICY

What if your job is considered safety-sensitive, such as working with live-line voltages, and a coworker shows up for their shift smelling like a distillery? Or if you're a supervisor and an employee calls to tell you their driving license was suspended over the weekend, and they'll be unable to show up for work without a ride? What exactly are employers, supervisors, and coworkers supposed to do when someone they are depending on in their workplace is clearly under the influence of alcohol or drugs? It's a sensitive subject that affects many.

According to the Substance Abuse and Mental Health Services Administration (SAMHSA), an agency in the Department of Health and Human Services, illegal and illicit drug use is increasing and becoming a growing workplace hazard to worker safety.

AN ISSUE OF SAFETY

Impaired workers can cause serious injury or damage to themselves, fellow employees, or expensive components or equipment. Developing a comprehensive workplace drug and alcohol policy along with a testing procedure is essential for any workplace that has people working with hazards or equipment

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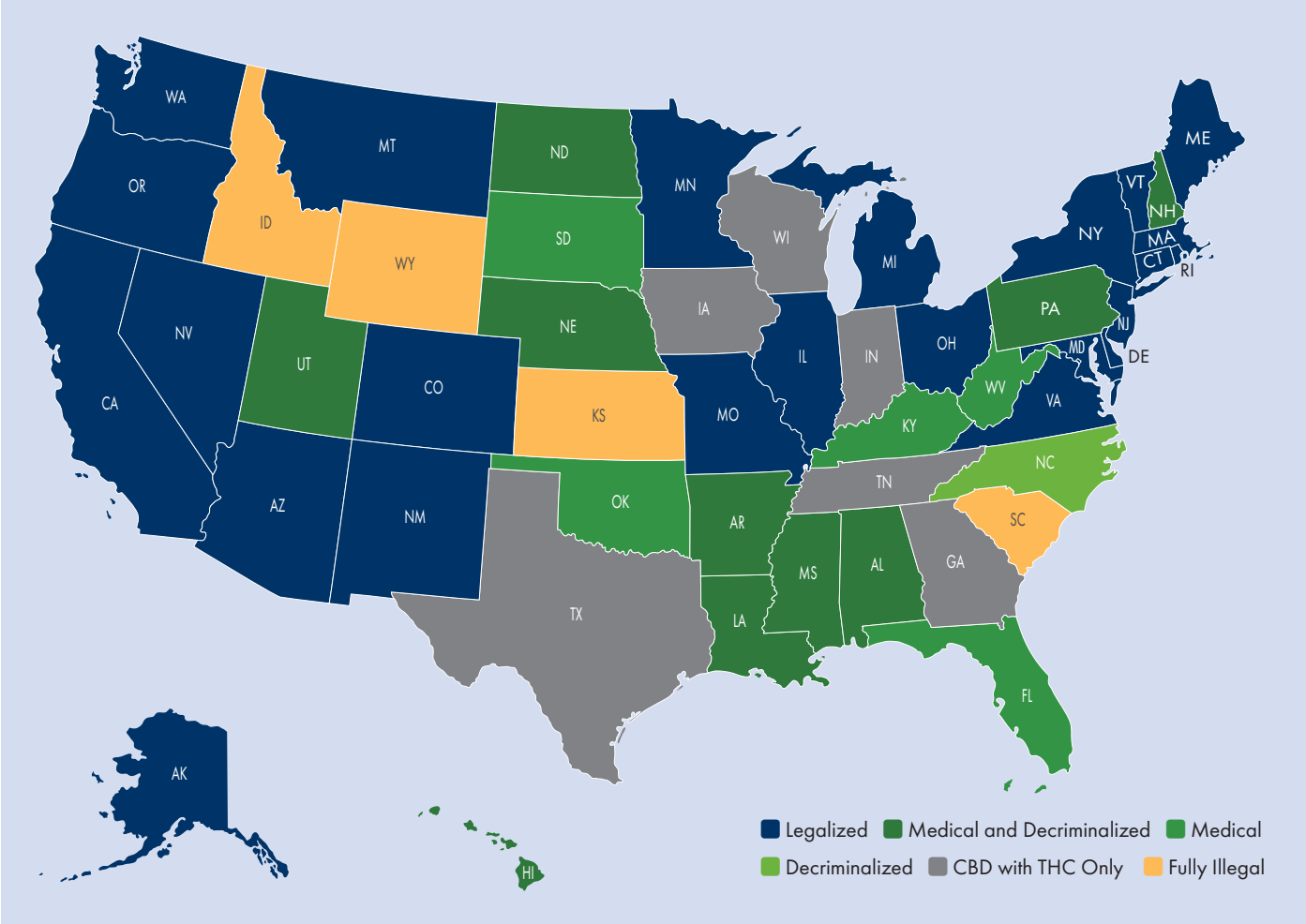


Figure 1: *Marijuana Legality by State*

that would make the employee considered safety sensitive. Resources like *www.samhsa.gov/workplace* can help organizations' policy makers develop such a program.

Once such a program is developed, notification and training of all employees is essential. It is suggested that a third-party company be contracted to assist with random selections, testing, and analysis. These companies can buffer a workplace from potential lawsuits that may occur should an employee be terminated from employment for a positive drug or alcohol test.

Managers who will be responsible for administering any program should go through additional training on how to manage it. There may be reasonable suspicion or post-accident drug and alcohol testing training, or training on how to give proper notice to an employee should they be selected for a random test.

Employees should also be regularly reminded that some prescription or even over-the-counter drugs may affect their performance. Certain cough medicines, pain medications, and many others may have detrimental effects. The company should appoint a DER to not only maintain the records (which must be kept confidential) of drug testing, but also to be a resource when it comes to questions regarding these drugs.

FIT FOR WORK VS. THE HANGOVER EFFECT

Statistics show that when it comes to alcohol and other drugs, we cannot underestimate the influence of our behavior while off the job. Many incidents occur the morning after

The following are some of the statistics on substance use in the U.S. as of 2025:

ALCOHOL USE

- **Overall Drinking Rates.** Only 54% of American adults say they drink alcohol, with 44% describing themselves as total abstainers.
- **Monthly Use.** According to federal data from the National Survey on Drug Use and Health (NSDUH), roughly 129.1 million Americans aged 12 and older (about 44%) reported using alcohol in the past month.
- **Binge Drinking.** Among those reporting past-month alcohol use, 56.8 million (44.0%) reported binge drinking, representing a decline down to roughly 19.5% of the total U.S. population aged 12 and older.
- **Health Perceptions.** Concern over health risks surged; 66% of 18- to 34-year-olds and 50% of 35- to 54-year-olds view moderate drinking as bad for health.

ILLICIT DRUG USE

- **Past-Year Use.** This rose from 62.0 million people (22.2%) in 2021 to 69.8 million people (24%) by 2025.
- **Most Common Substance.** Marijuana remains the most widely used illicit drug, with over 61.5 million past-year users in the U.S.
- **Youth Trends.** Declines were reported among adolescents regarding tobacco, alcohol, binge drinking, marijuana, and overall illicit drug use.
- **Increases.** Past-year illicit drug use, hallucinogen use, and marijuana use/disorder showed overall increases across the broader population compared to 2021 baselines.

FENTANYL AND OPIOID MISUSE

- **Past-Year Use.** Approximately 0.3% (768,000 people) reported use in the past year.
- **Overall Opioid Misuse.** About 2.4% of the population aged 12 or older (about 7.1 million people) misused opioids in the past year.
- **Downward Trend.** Overall opioid misuse showed a decline compared to previous years, dropping from 9.1 million (3.2%) in 2021 down to 7.1 million in 2025.

SUBSTANCE USE DISORDERS

- **Past-Year Use.** Around 15.3% of people aged 12 or older (about 44.6 million individuals) experienced an SUD in the past year. This rate shows a decrease from 16.7% in 2021.
- **Treatment Trends.** Fewer than 1 in 5 people (16.0%) who needed substance use treatment actually received it in the past year.

when blood alcohol levels may still be high. When a worker is hungover, and the senses are dulled from the ill effects of too much alcohol or drugs in the system, it's the prime time for workplace incidents to occur, especially if that worker operates machinery or equipment in a safety-sensitive industry such as ours.

Research has found there is a correlation between the frequency of being hungover at work and other workplace events, such as feeling sick at work, sleeping on the job, and having problems with tasks or coworkers. It has been shown that employees with substance abuse issues may frequently become tardy or have increased missed days of work (sick, vacation, or just never clocked in). This can become an operational issue for managers, as they must continue backfilling positions to ensure the work is completed on time.

In one study, the hangover effect was demonstrated by pilots tested in flight simulators. There was still evidence of impairment 14 hours after pilots reached blood alcohol concentrations (BACs) of between 0.10% and 0.12%, and pilots were still significantly impaired eight hours after reaching a BAC of 0.10%. This study shows that impairment can continue well after substance use ends and may also lead to increased employee absences.

CONCLUSION

Every individual in the workplace has a personal responsibility to ensure their own safety and the safety of others. Part of that responsibility is to encourage and help someone with an alcohol or drug problem seek assistance through an employee assistance service or a supervisor. If that individual is putting themselves or others in danger, you have a responsibility to report that individual to a supervisor or leader. The adage "You are your brother's keeper" is accurate in this case. The employee may not only be preventing injury to their coworker but also preventing injury to themselves or others.

Based on usage statistics and constantly evolving legislation, the guiding principles

of alcohol and drug policies continue to include a shared responsibility for safety, an understanding of how behavior on and off the job affects safety, and balancing safety and privacy interests.

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QUIZ

NO. 154

HIGH-VOLTAGE UTILITY VS HIGH-VOLTAGE INDUSTRIAL

BY MORGAN GIENI, *Magna IV Engineering*

Utility generation is held to high standards to ensure consumers receive clean, reliable power. However, industrial facility owners must take care to limit their impact on the grid. As NETA Certified Technicians, we must be aware of the required quality standards as they pertain to both utility and industrial applications.

1. In IEEE Std. 519, *Harmonic Control in Electric Power Systems*, where is the strict boundary line located where a utility must provide clean voltage, and where an industrial facility must limit the current harmonics they inject back into the grid?
   a. At the main utility generator terminals
   b. At all primary VFD terminals
   c. At the panel feeding individual variable speed drives inside the user's facility
   d. At the point of common coupling, where the utility connects to the industrial customer

2. Why do power quality standards treat utilities and industrial plants differently regarding harmonics?
   a. Utilities are responsible for controlling current harmonics, while industrial plants must control voltage harmonics.
   b. Industrial plants only care about voltage harmonics because they do not use electronic equipment.
   c. Utilities must control voltage harmonics, while industrial facilities must control current harmonics.
   d. Utilities do not have to follow any harmonic standards, but industrial plants do.

3. Industrial facilities often run heavy machines, such as arc furnaces and large motors, that start and stop rapidly, causing lights to dim and brighten. Which standard and metric are used by utilities to test and measure this effect?
   a. IEEE 1547 using Total Rated Demand Distortion (TDD)
   b. IEEE 1453 using Short-Term Flicker Severity and Long-Term Flicker Severity
   c. NEMA MG1 using the Motor Derating Factor
   d. NFPA 70E using Incident Energy Analysis

4. According to IEEE 519, how does the utility's short-circuit ratio (Isc/IL) affect an industrial site's allowed current distortion limits?
   a. A higher short-circuit ratio means the grid is stronger, allowing the site to operate with higher percentages of current harmonics.
   b. A higher short-circuit ratio means the grid is weaker, requiring the site to operate with lower percentages of current harmonics.
   c. The short-circuit ratio only matters for utility generation and has no impact on current distortion limits for a site.
   d. A lower short-circuit ratio allows the owner to ignore all high-frequency harmonic limits.

5. How does power quality data collection on a site differ when comparing requirements from utility standards versus collecting data while troubleshooting using a power quality meter on a site?
   a. Utility measurements are taken at higher voltages and require larger meters.
   b. Utility measurements capture large power consumption and require way more memory.
   c. Higher voltage means lower current. Current probes within a site distribution network must be large primary-current-rated sensors.
   d. Utilities require continuous, highly accurate 10-minute-average windows for at least a week, while industrial troubleshooting often uses fast, millisecond-level snapshot triggers.

6. Which standard specifically states how utility-scale generation (like wind farms, solar farms, or traditional power plants) must ride through grid disturbances and control voltage, which differs from industrial consumer standards?
   a. IEEE 519
   b. IEEE 1547
   c. NEC Article 430
   d. OSHA 1910

7. What is the likely root cause difference between unbalance in utility generation versus an industrial network?
   a. Utility unbalance is caused by three-phase generators; industrial unbalance is caused by running too many lights.
   b. Utility unbalance is usually due to unevenly distributed single-phase customers on the grid lines; industrial unbalance is usually due to large, unequal single-phase loads or failing equipment inside the user's facility.
   c. Utilities never experience unbalance because transformers automatically fix it before it reaches a user's facility.
   d. Utilities are typically unbalanced due to an unstable generator, and industrial unbalance is caused exclusively by using solar panels on the roof.

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Morgan Gieni, CET, PSE, *is the Technical Support Lead Technical Field Services (TFS) at Magna IV Engineering. He is an ASET Certified Engineering Technologist and a NETA Level 4 Certified Senior Technician and is on NETA's Technical Resource Committee.*

See answers on page 109

THE COST OF A POOR CONNECTION

LESSONS FROM A VLF TESTING FAILURE

BY BRANDON SEDGWICK, *Hood Patterson & Dewar*

Very-low-frequency (VLF) testing is a valuable tool for verifying the condition of medium-voltage cables. However, the quality of the results depends heavily on proper setup, careful monitoring, and a clear understanding of what the test is evaluating. When test configurations introduce unintended equipment into the circuit or when terminations are not fully seated, the test can shift from a diagnostic exercise to a destructive test. The following example highlights how a seemingly minor setup issue can escalate quickly, creating costly repairs and reinforcing the importance of proper test procedures.



Figure 1: *This transformer bushing was damaged during the VLF test.*

During VLF testing of a 35 kV cable, while the cable was connected to the bushings of an associated oil-filled transformer, the testing firm severely damaged both a transformer bushing (Figure 1) and the cable termination (Figure 2). Because the transformer had not been energized outside this test, the evidence suggests the damage resulted from a loosely seated cable termination that created an air gap between the surface of the bushing resin and the termination body.

That condition likely caused internal arcing at the connection point between the bushing and cable termination. The testing appears to have continued for an extended period because the test



Figure 2: *The cable termination was also damaged during the VLF test.*

data was not being actively attended to by the technician. An attentive technician would have observed the poor results and aborted the test before the damage became significant. After the incident, the bushing and cable termination components required replacement and re-testing, which caused avoidable and unnecessary costs for the client, project delays, and a serious quality-control concern for the testing firm.

LESSONS LEARNED AND BEST PRACTICES

This incident underscores that successful VLF testing depends on more than the test itself; it requires disciplined preparation, careful equipment isolation, active monitoring, and the ability to identify when test results indicate a problem that requires the test to be stopped. The following best practices can help reduce the risk of preventable damage and improve the reliability of test outcomes.

1. Avoid connecting cables to a transformer during VLF testing, as transformer insulation leakage current can mask cable deficiencies and compromise test interpretation.
2. Do not subject transformer internals to VLF test voltages. If cables are too short to test individually, connect the three-phase conductors together instead of testing through the transformer.
3. Continuously monitor the test set and data throughout the test, so failing readings can be identified, and the test can be stopped before significant damage occurs.
4. Configure the VLF test set to trip off immediately when arcing is detected rather than allowing the equipment to continue operating through a fault condition.
5. Confirm all cable-to-cable connections are fully seated, tightly connected, and properly lubricated with grease to prevent air intrusion at the termination interface.
6. Document and acknowledge testing errors promptly so corrective action can begin quickly, and the client relationship is protected.

VLF testing is a powerful diagnostic tool, but its value depends on proper execution from setup through interpretation of final results. This incident is a reminder that small oversights in termination, isolation, or monitoring can quickly become expensive equipment failures. By verifying every connection, appropriately isolating equipment, configuring test settings properly, and responding immediately to abnormal test data, testing teams can prevent avoidable damage, protect client assets, and deliver accurate, reliable results. NW



Brandon Sedgwick, PE, is President of Hood Patterson & Dewar, where he oversees offices in five states and leads a large team that includes registered Professional Engineers (PEs), degreed engineers, and skilled test technicians. He manages projects for critical facilities and infrastructure, functions as an owner's representative, provides factory witness testing, and leads forensic investigations. With extensive experience in both newly constructed and live-site facilities, Sedgwick specializes in functional performance verification and troubleshooting of complex electrical distribution systems, as well as commissioning of integrated building systems.

NETA SAFETY COMMITTEE

PUTTING SAFETY INTO PRACTICE

NETA's strength has always depended on industry professionals willing to share their experience for the benefit of the electrical testing community. The NETA Volunteer Spotlight recognizes these individuals, highlighting the knowledge, perspectives, and commitment they bring to the association and the industry.

For this issue, *NETA World* turns the spotlight on the NETA Safety Committee, whose members bring decades of combined field, operational, training, and environmental health and safety experience to their work.

SAFETY COMMITTEE

The Safety Committee helps ensure that safety remains fundamental to the work performed by NETA Accredited Companies and NETA Certified Technicians. The committee develops and modernizes NETA's minimum safety guidelines for electrical testing, evaluates safety programs, and considers the safety implications of emerging testing methods, equipment, and industry practices.

That work requires more than understanding requirements on paper. Committee members draw on experience in field testing, operations, training, safety program development, standards activities, and leadership to help ensure guidance remains practical and applicable to the conditions that electrical testing professionals encounter every day.

The Safety Committee is chaired by Scott Blizard from Asplundh Electrical Testing, whose involvement with NETA spans numerous committees and industry standards activities. Joining him in this Volunteer Spotlight are committee members Dan Hook from Group CBS, Paul Chamberlain from Asplundh Engineering Services, Shelley Baber from Eaton, and Virginia Balitski from Magna IV Engineering. Their backgrounds differ, but their responses share a common theme: Volunteering provides an opportunity to give back, learn from peers, and help make the electrical testing industry safer and stronger.Here, they share their experiences as NETA Volunteers.



Scott Blizard



Dan Hook



Paul Chamberlain



Shelley Baber



Virginia Balitski

***NW:* What motivates you to dedicate your time, expertise, and energy to NETA?**

Blizard: My father, Charles K. Blizard Sr., was instrumental in my early involvement in NETA. He believed that giving back to the industry would help it grow and that participating in NETA would benefit not only our organization, but also the industry as a whole. That philosophy has stayed with me throughout my career.

Hook: Working in electrical field testing with CBS Field Services, I saw firsthand how much shared safety guidance matters, both to protect crews and to keep testing programs consistent across the industry. Joining the Safety Committee was a natural way to put that field experience to use and help shape guidance testing professionals rely on every day.

Chamberlain: My company was heavily invested in NETA and its success, so it made sense to contribute my knowledge and expertise where needed. Over time, volunteering has also given me the opportunity to help influence NETA's direction and contribute to its continued success.

Baber: Throughout my career, I've seen the impact that strong industry standards and collaboration can have on safety, reliability, and business performance. NETA brings together professionals committed to doing things the right way and continuously improving the industry. Volunteering allows me to contribute while helping ensure safety remains foundational to the work we do.

Balitski: I wanted to give back to NETA and the electrical industry that has provided me with important professional growth over the years. NETA offered an opportunity to contribute based on my experience and background, with the hope of helping strengthen the industry and support its professionals.

***NW:* What experience or perspective do you bring to the Safety Committee?**

Blizard: I've had the opportunity to work as an electrician, a NETA Certified Technician, an operational manager, and eventually Vice President and COO of American Electrical Testing Co., LLC. I also helped create AETCO's first safety manual in the 1990s and worked on NETA's early minimum safety guidelines. That progression has given me both field and leadership perspectives.

Hook: Because CBS Field Services is a day-to-day field testing operation, I bring a practical, on-site perspective. When considering new testing methods and equipment, such as VLF cable testing, I think about how they actually work under field conditions. That helps keep guidance realistic and usable as well as technically sound.

Chamberlain: My background includes environmental remediation, heavy construction, trucking, and safety management. I also helped design a complete safety program from the ground up for an international corporation. That broader experience helps me consider concerns outside the typical scope of a testing company and contributed directly to my work on NETA safety program guidelines.

Baber: For more than 25 years, my career has centered on environmental, health, and safety leadership within electrical utility and service organizations, from frontline responsibilities to corporate EHS positions. That experience helps me understand both safety and operational perspectives and reinforces the importance of keeping employees at the center of decision-making.

Balitski: My transition from a field role to work focused on training and safety has been an asset. Field experience, participation in standards activities, and leading training initiatives have helped me understand different areas of the industry and how to bring people together toward a common goal.

***NW:* What would you tell someone considering becoming a NETA volunteer?**

Blizard: It's the people you meet along the way and the opportunity to work and collaborate toward a common goal. Volunteering allows you to learn, have a voice in the organizations you participate in, and contribute to their improvement.

Hook: It's an opportunity to affect change where it may be needed and bring practical field experience into the conversation. The lessons learned while doing the work can provide an important perspective when developing guidance for the industry.

Chamberlain: It's not just what you know, but who you know. Volunteering with an organization connected to your industry introduces you to people you might not otherwise encounter. Those relationships can become valuable resources when your organization faces a difficult problem or unfamiliar challenge.

Baber: The opportunity to learn from and collaborate with some of the best people in the industry is unmatched. Volunteering isn't only about contributing expertise; it also brings new perspectives, expands professional networks, and provides an opportunity to help shape the future of the profession.

Balitski: I have truly enjoyed volunteering and contributing in any way I can. Together, volunteers can make a real impact and help shape a future for the industry that we can all be proud of.

***NW:* Why is volunteer involvement important to NETA's future?**

Blizard: Organizations like NETA must rely on their members and volunteers to remain industry leaders. Being able to have a voice in the present while helping the organization prepare for the future is a privilege. I believe in leaving an organization better than when you joined it and helping provide a foundation for the next generation.

Hook: Volunteering brings field experience into the work NETA does. It also creates relationships among testing professionals, manufacturers, and engineers who may not otherwise work together. Those connections allow people to compare experiences, solve safety challenges, and collaborate on broader industry initiatives.

Chamberlain: Volunteers choose to contribute because they care about the organization and its success. That personal investment brings passion to the work and helps NETA continue moving forward.

Baber: NETA's strength comes from the expertise and commitment of its volunteers. Industry professionals share their knowledge, experience, and time to advance standards, education, and best practices. That engagement helps NETA remain relevant, practical, and responsive to the industry.

Balitski: Volunteer involvement brings together diverse perspectives and expertise that help move NETA's programs and initiatives forward. Ultimately, that benefits everyone working in the electrical industry.

Who will be recognized in the next Volunteer Spotlight? Watch for it in the Spring 2027 issue of NETA World. NW





POWER QUALITY RISKS

INDUSTRIAL VS UTILITY

BY VINCENZO PAGLIUCA, *The Hartford Steam Boiler Inspection and Insurance Company*

Maintaining power quality is a shared goal of utility power systems and industrial and commercial electrical infrastructure. However, the responsibilities and methods for achieving this objective differ substantially. Utility providers focus on ensuring reliable and efficient transmission and distribution of electricity to the grid, while industrial and commercial facilities prioritize power quality to protect sensitive equipment and maintain operational continuity.

Despite these differing contexts, both environments require careful management of power quality to help prevent disturbances, reduce or mitigate equipment damage, and minimize downtime. Understanding the distinct challenges and responsibilities in each setting is crucial for implementing effective power quality risk management strategies, ultimately supporting the overall reliability, resiliency, and efficiency of the electrical supply chain.

10.6 Power Supply to Voltage Sensitive Equipment Computers and Sensitive Equipment

Customers who use computers, microprocessor-controlled equipment, solid slate devices, x-ray equipment, or other voltage sensitive electronic equipment should consider the installation of auxiliary devices designed to protect this equipment from power disturbances. These power disturbances may be in the form of voltage sags or swells, temporary loss of power, or any other deviation from normal. The Customer may have to safeguard this equipment by the application of line filters, solid state line-voltage regulators, transient suppressors, isolating transformers, uninterruptible power supply (UPS) systems or motor generators. Utillity distribution systems normally operate between certain voltage limits as established by National Standards and state rules. The Company should be contacted for further guidance.

Electric utilities typically have a clause in their Specifications for Electrical Installations 2020 (ESB 750) from the National Grid 2020 Green Book that requires the customer to protect their sensitive electronic equipment.

COVER IMAGES COURTESY OF MATT ROBINSON, SIGMA-C POWER SERVICES

From an insurance risk perspective, coverage helps mitigate the negative consequences when electrical losses occur. Equally important, insurance engineers perform risk analyses and assist in making recommendations that help prevent or control losses, provide equipment testing, develop maintenance and monitoring guidelines, and assist with the awareness and application of industry standards such as IEEE and ANSI/NETA.

Power quality issues in utility infrastructure and industrial and commercial facilities pose significant risks to equipment, operations, and ultimately, the bottom line. While utility providers and facility owners share the goal of maintaining reliable power supply, their respective risk exposures and mitigation strategies differ. Insurers must consider the unique challenges and responsibilities in each environment, including the potential for equipment damage, business interruption, and liability claims. By understanding the distinct power quality risks and consequences in utility infrastructure versus industrial and commercial facilities, insurers can develop targeted risk management and loss control solutions, such as tailored policies and premium structures, to help mitigate these risks and support the resilience of their clients' operations, ultimately reducing the likelihood and impact of power-related losses and business interruption.



Special power line conditioning equipment may be needed by the customer to improve the utility-supplied power quality. Line conditioners, voltage regulators, and uninterruptible power supplies help comply with equipment manufacturers' closer supply tolerance limits.

INDUSTRIAL AND COMMERCIAL POWER QUALITY

Power quality monitoring can play a critical role in mitigating risk for insurers and their clients. By providing real-time insights into power disturbances, such as voltage sags, swells, and harmonics, power quality monitoring systems can help identify the potential for equipment damage and business interruption risks. This data can be used to elaborate risk assessments, develop targeted mitigation strategies, and optimize insurance policy terms and conditions.

Additionally, power quality monitoring can facilitate proactive maintenance, reducing the likelihood of equipment failures and subsequent claims. From an insurance perspective, the benefits of power quality monitoring include reduced claims frequency and severity, improved risk selection, and enhanced client risk management capabilities, ultimately leading to more accurate premium pricing and improved profitability. By leveraging power quality monitoring data, insurers can better manage power-related risks and provide more effective risk transfer solutions for their clients.



Power quality meters can be installed at the main service equipment and communicate critical information and programmed alarms to a central monitoring location.



Power quality issues from surges destroy sensitive and costly electronic equipment and circuit boards. Equipment damage in a facility results in extended business interruptions and financial losses.

UTILITY AND GRID-RELATED POWER QUALITY

Power quality monitoring and mitigation are crucial for ensuring the reliable and efficient operation of electrical grids, particularly when interconnected with renewable energy sources, industrial facilities, commercial buildings, and data centers. One effective way to help mitigate power quality issues is by utilizing advanced devices such as static compensators (STATCOMs) and other power electronic devices on the transmission side. For distribution, devices such as capacitor banks can provide substantial power factor correction that may help the power quality. While traditional STATCOMs are deployed at the transmission level to maintain grid stability across large regions, distribution or D-STATCOMs operate at much lower medium-voltage levels—typically between 4 kV and 35 kV. They are usually installed near commercial, industrial, or renewable energy sites to solve localized power quality issues.

MONITORING POWER QUALITY RISK

Before mitigating power quality issues, it is essential to monitor and identify the problems. Power quality monitoring involves collecting data on various parameters such as:

1. **Voltage:** Magnitude, phase, and harmonic distortion
2. **Current:** Magnitude, phase, and harmonic distortion
3. **Power factor:** Lagging, leading, or unity
4. **Frequency:** Deviations from the nominal frequency
5. **Harmonics:** Presence and magnitude of harmonic frequencies
6. **Flicker:** Voltage fluctuations that can cause light flicker

This data is typically collected using power quality analyzers (PQAs) as well as phase measurement units (PMUs, also known as synchrophasors), which can be installed at various points in the grid, such as substations (for overall grid performance), transformer stations (individual transformer performance), and load centers (PQ monitoring at the point of consumption).

DISTRIBUTION-LEVEL MITIGATION

Here are some design and integration methods that help reduce or potentially mitigate power quality issues at the distribution level:

- **Power factor correction.** Inductive loads like cooling motors and transformers drag down the power factor by drawing lagging reactive current. Capacitor banks supply leading current, pulling the overall power factor closer to unity (1.0). D-STATCOMs can assist dynamic power factor correction, saving facilities from costly utility penalties.
- **Voltage support.** Drawing excessive reactive power causes voltage drops across transmission lines. Injecting capacitive VARs directly reduces this voltage drop, maintaining a more steady-state voltage. Advanced D-STATCOMs can compensate for phase imbalance, protecting local three-phase motors from overheating.
- **Capacity liberation.** Reducing apparent power (kVA) requirements can increase the available capacity of existing transformers and lines, allowing the grid infrastructure to support higher real power (kW) loads.
- **Loss reduction.** Supplying reactive power locally means less total current needs to travel from the generator through the transmission lines. Because power loss is calculated as I^2R, lowering the current (I) directly slashes thermal losses.



Micro Phase Measurement Unit Installed in a Microgrid Application

Micro PMUs provide ultra-fast monitoring for power quality, data analytics, and control of internal power system components with very high-speed data sets. They withstand greater variations in bulk power reliability because the short-duration transients die out too quickly for transmission-grade PMUs. They also operate at reporting rates of 100 to 200 frames per second, capturing rapid changes that traditional supervisory control and data acquisition (SCADA) systems miss..



A capacitor bank at the distribution-level voltage (pole-top cap bank, utility side) is an excellent way to provide voltage support

TRANSMISSION-LEVEL MITIGATION

As advanced power electronic devices, STATCOMs can mitigate power quality issues by injecting or absorbing reactive power, thereby regulating the grid voltage and improving power factor. STATCOMs can be used to:

1. Compensate for voltage fluctuations by injecting or absorbing reactive power to regulate the grid voltage
2. Improve power factor by injecting or absorbing reactive power to improve the power factor, reducing the strain on the grid
3. Reduce harmonic distortion by filtering out harmonic frequencies and improving the overall power quality
4. Provide reactive power support during periods of high demand or when the grid is under stress

In addition to STATCOMs, other devices can be used to mitigate power quality issues. Active or passive power filters filter out harmonic frequencies and improve power quality. Uninterruptible power supplies (UPS) provide backup power during outages and regulate the output voltage. Capacitor banks (capacitive) regulate the output voltage during periods of voltage sag. Reactor banks (inductive) regulate the output voltage during periods of voltage swell. And energy storage systems (ESS) are used to store excess energy generated by renewable sources and stabilize the grid frequency.

Leading and Lagging Power Factor Impacts

Leading and lagging voltage conditions can have significant impacts on transmission system operation and stability. Leading voltage (capacitive PF) can cause overvoltage conditions, leading to insulation failure and equipment damage, and reduce the transmission system's stability margin. Lagging voltage (inductive PF) can cause undervoltage conditions, leading to reduced transmission capacity and increased losses, and increase the transmission system's stability margin.

Interconnection with the Grid

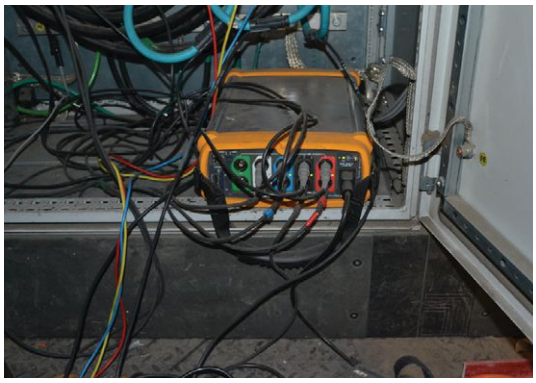
When connected to the grid, power quality monitoring and mitigation devices can help ensure that power quality meets grid codes and standards. This is particularly important when connecting renewable energy sources, such as solar or wind power, to the grid. By using STATCOMs and other power quality mitigation devices, the grid as well as the industrial location can be protected from power quality issues caused by the variable output of renewable energy sources, switching associated with the grid, or other independent power-producing industrial locations.

THE DIFFERENCES BETWEEN INDUSTRIAL AND GRID

Power quality mitigation strategies can vary significantly between industrial locations and the grid due to differences in their electrical infrastructure, load characteristics, and operational requirements. Some key differences include:

1. **Local power quality issues.** Industrial facilities often have localized power quality issues, such as voltage sags, swells, or harmonics, caused by equipment startup, shutdown, or malfunction.
2. **Load characteristics.** Industrial loads can be highly variable, with large motors, drives, and other equipment that can cause power quality disturbances.
3. **Islanded operation.** Industrial facilities may operate in islanded mode, with their own generation and distribution systems, which can affect power quality.
4. **Customized solutions.** Industrial facilities often require customized power quality mitigation solutions, tailored to their specific load characteristics and operational requirements.
5. **Focus on equipment protection.** Industrial facilities prioritize equipment protection, as power quality issues can damage sensitive equipment and disrupt production.

Common power quality mitigation strategies in industrial locations include using active filters to mitigate harmonics and other power quality issues; implementing voltage regulation systems to maintain a stable voltage supply; using power conditioning units to regulate the output voltage and current; and installing UPS systems to provide backup power during outages and regulate the output voltage.



Portable power monitoring equipment can be used when no permanently installed monitors are available.

When it comes to the grid, key differences include:

1. **Wider geographical scope.** Power quality issues on the grid can affect a larger geographical area, impacting multiple customers and facilities.
2. **Diverse load characteristics.** The grid serves a diverse range of customers, from residential to industrial, with varying load characteristics and power quality requirements.
3. **Standardized solutions.** Grid operators often implement standardized power quality mitigation solutions, which can be applied across multiple locations.
4. **Focus on grid stability.** Grid operators prioritize grid stability, as power quality issues can affect the overall reliability and efficiency of the grid.

THE MEETING POINT: DATA CENTERS AND THE GRID

As data centers continue to grow in size and complexity, their high power-density requirements pose significant challenges for power quality. To address these challenges, data centers are adopting advanced mitigation strategies, including the use of enhanced STATCOMs (E-STATCOMs) and other equipment. An E-STATCOM is an advanced power electronics grid-stabilization device that combines a traditional STATCOM with a short-term energy storage system, typically supercapacitors or batteries, to manage both grid voltage and frequency simultaneously. This allows it to exchange both reactive power and real (active) power with the grid.

Traditional STATCOMs primarily manage reactive power by injecting VARs when voltage drops and absorbing inductive VARs when voltage rises. For highly variable loads such as AI data centers or renewable generation, E-STATCOMs can absorb or inject real power to smooth fluctuations seen by the grid.

Trends in Data Center Power Quality

1. **High power density.** Data centers are experiencing increasing power densities, with some facilities reaching up to 20 kW per rack.
2. **Variable load profiles.** Data centers have variable load profiles, with power demands changing rapidly due to factors like cloud computing, artificial intelligence, and machine learning.
3. **Renewable energy integration.** Data centers are incorporating renewable energy sources, such as solar and wind power, into their energy mix, which can introduce new power quality challenges.
4. **Grid connectivity.** Data centers are increasingly connecting to the grid, which requires them to ensure power quality to avoid disrupting the transmission and distribution grid.

Power Quality Mitigation Strategies for Data Centers

1. **E-STATCOMs.** These are being used to regulate voltage, improve power factor, and mitigate harmonics.
2. **Active power filtering.** Active power filters are being used to mitigate harmonics and other power quality issues.
3. **Energy storage systems.** Energy storage systems, such as batteries, are being used to stabilize the grid frequency and voltage.
4. **Advanced power management systems.** These are used to monitor and control power quality in real time, optimizing energy efficiency and reducing power quality issues.

Benefits of Power Quality Mitigation Strategies

1. **Improved power reliability.** Power quality mitigation strategies ensure reliable power supply to data centers, reducing downtime and data loss.
2. **Increased energy efficiency.** By optimizing power quality, data centers can reduce energy waste and improve overall energy efficiency.
3. **Enhanced grid stability.** Power quality mitigation strategies help reduce the risk of grid instability and power outages.
4. **Compliance with grid codes.** Data centers can ensure compliance with grid codes and standards, avoiding penalties and fines. The Federal Energy Regulatory Commission (FERC) has ordered the North American Electric Reliability Corporation (NERC) to propose changes to its rules. Specifically, NERC must update its registry criteria to include computational-load entities in the mandatory reliability framework. This change aims to enhance the reliability of the energy grid.
5. **Cost savings.** By reducing energy waste and improving power reliability, data centers can achieve significant cost savings.

CONCLUSION

Power quality is all about ensuring that the electrical supply meets the specifications of the connected utilization equipment. This requires attention at the transmission and distribution grid level as well as at the customer level, such as industrial locations or power-intensive data centers.

The utility company has an obligation to deliver "coarse-tuned" electricity to the customer service point. This is the demarcation point where the utility-owned electrical equipment ends and the customer-owned electrical equipment begins. The utility-supplied service must be within voltage, frequency, and balance tolerances. It must also be reliable and not negatively impact business continuity.

The customer must evaluate whether the coarse-tuned utility supply is adequate for the connected equipment. When the coarse-tuned utility supply does not meet the connected supply specification, the customer must provide additional equipment to correct for power quality deficiencies. This may involve the use of voltage regulators, surge protection, harmonic filters, phase loss relays, under or overvoltage

protection relays, and in many cases, UPS systems and backup generators.

Understanding these roles, responsibilities, and mitigation strategies will assure that power quality remains efficient, stable, and helps to avoid electrical equipment losses and unnecessary business interruptions. NW

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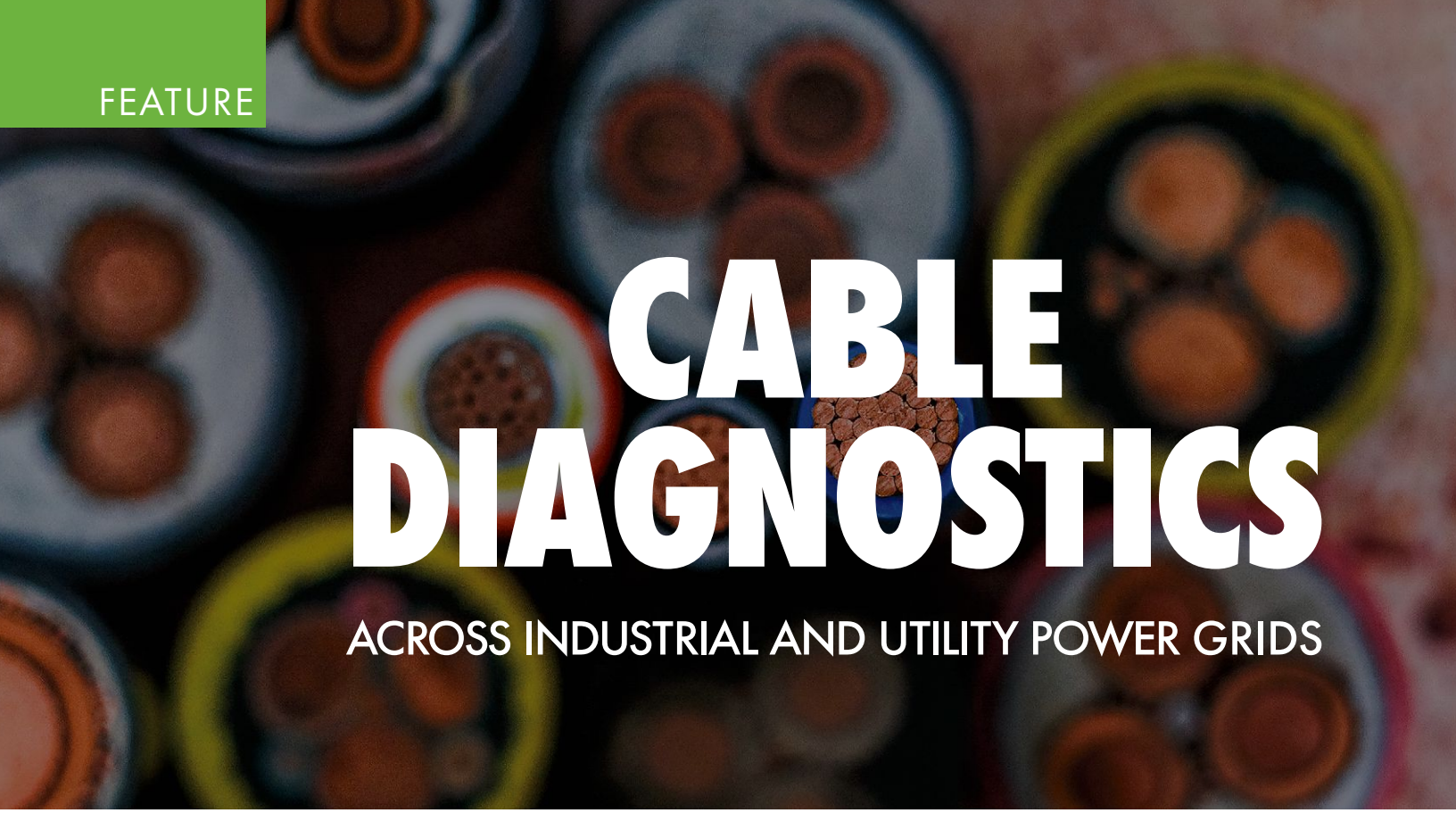


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FEATURE



CABLE DIAGNOSTICS

ACROSS INDUSTRIAL AND UTILITY POWER GRIDS

BY NILSON BARONI JR AND DANIEL BENTO, *Baur USA Corp,*
and MARCELO PLANTIER, *Baur Brazil*

Industrial electrical networks and utility grids share common elements: transformers, circuit breakers, protection relays, busbars, and insulated cables. Despite this, they differ profoundly in architecture, criticality, fault exposure, maintenance philosophy, and diagnostic strategies. A failure in an underground cable is more than the physical or functional loss of an electrical component; it can abruptly interrupt a continuous industrial process or leave thousands of consumers without power, resulting in massive financial losses and severe regulatory penalties. This duality necessitates engineering approaches that are carefully tailored to the operational realities of each facility.

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The evolution of testing techniques has radically transformed the maintenance paradigm for these critical infrastructures. Traditional methods, such as DC insulation resistance measurement and DC withstand voltage testing, continue to play specific roles in preliminary verification but have shown significant limitations in detecting intrinsic defects associated with dielectric degradation. These tests have been progressively complemented by non-destructive techniques that determine the actual aging state of the insulating material and the location of defects: dissipation factor or tan delta (tan δ), partial-discharge (PD) detection and localization, time-domain reflectometry (TDR), and assessment of outer sheath integrity.

CIGRE, through its Technical Brochure TB 924 (2024), which is dedicated entirely to condition assessment and asset management of medium-voltage networks, consolidates the state of the art in these practices. The document explicitly identifies very low frequency (VLF tan δ) voltage testing, PD monitoring, damped AC (DAC) voltage testing, TDR, and outer sheath testing as priority tools for predictive diagnostic actions. CIGRE advocates that the selection of a methodology cannot be standardized generically; rather, it must result from a weighted assessment of the insulation type (XLPE, EPR, or PILC), service age, transient profile, and the circuit's operational criticality.

TWO REALITIES: INDUSTRY AND ELECTRIC UTILITIES

The first fundamental distinction between the two environments lies in physical scale, power topology, and the primary mission of the electrical circuit. An industrial plant operates concentrated circuits within private geographical boundaries, where the integrity of the medium- or high-voltage supply is inextricably linked to the continuity of the manufacturing, refining, or mining production chain. In contrast, distribution utilities manage branched networks that extend for tens or hundreds of kilometers across urban and rural areas, subject to continuity metrics and regulatory penalties for widespread supply interruptions.

This infrastructural divergence dictates entirely different maintenance strategies. While the engineers in industry settings focus primarily on preventing a single production line stoppage, which can cost millions per hour of downtime, the utility balances maintenance costs against the management of regulatory and statistical risks across a vast array of circuits. Figure 1 summarizes the technical and operational distinctions between these two environments.

As shown, the number of assets in a manufacturing setting is limited, yet the severity of any incident is critical. Industrial

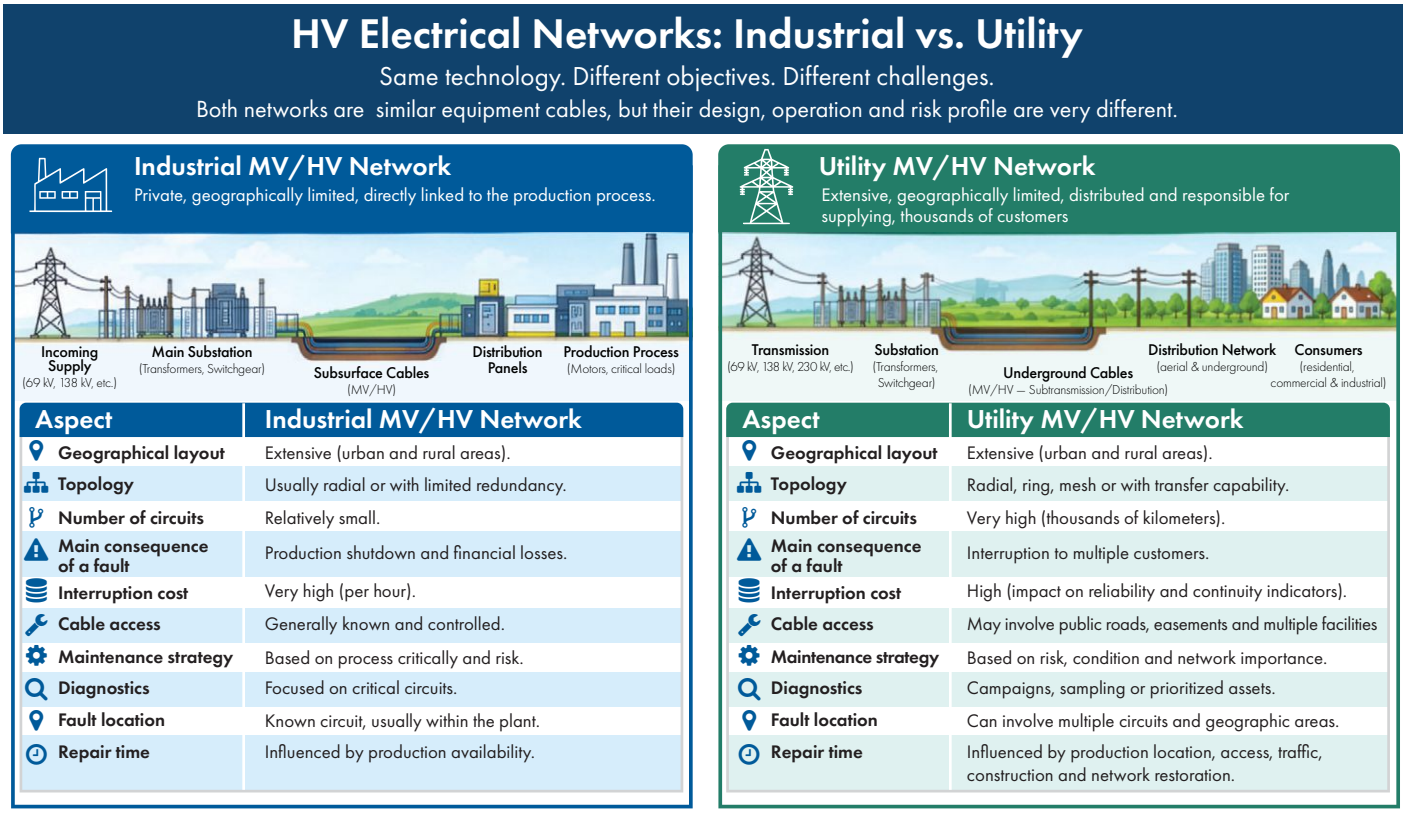


Figure 1: *Technical-Operational Comparison Between Industrial and Utility Networks [AI-Generated Image]*

risk analysis must quantify the direct financial impact of plant operational downtime, necessitating robust contingency plans and predictive maintenance routines focused on maintaining operational availability.

Conversely, for utility companies, treating the asset fleet uniformly is unfeasible. Management must process analytical variables (such as insulation type, manufacturer, thermal loading regime, splice density, soil corrosivity, DEC/FEC reliability indices, and emergency switching capability) while aligning diagnostics with strategic asset management principles. In this context, the following ANSI/NETA standards establish the criteria for these activities: ANSI/NETA ATS-2025, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*, specifies parameters for the acceptance and commissioning of new circuits, whereas ANSI/NETA MTS-2023, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*, defines tolerances and mandatory tests for evaluating equipment in continuous service.

THE VULNERABILITY OF INSULATED CABLES

The greatest challenge for technical teams is that dielectric deterioration in insulated conductors occurs silently within the cable layers and their accessories. A medium- or high-voltage feeder can operate continuously under rated current and voltage conditions without externally measurable thermal changes or protection alarms, even as micro-cracks, treeing, or delamination progress within the polymeric material, eventually leading to a total loss of dielectric strength.

The agents triggering this degradation form a complex matrix of interrelated multifactor stresses. Key mechanisms include thermal aging caused by overloads or continuous thermal cycling; moisture ingress through punctured sheaths, inducing the formation of water trees (electrochemical treeing); internal PDs within microscopic voids; manufacturing imperfections; and mechanical damage resulting from excessive tension or improper bending during installation. Additional issues include continuity failures in semiconducting and metallic screens, galvanic corrosion of copper tapes or wires, degradation of the grounding system, and frequent accidental external damage from uncontrolled excavation and civil works along underground circuit routes.

Field studies and statistical analyses consistently indicate that the system's weakest link is rarely the continuous conductor itself, but rather its joints and terminations. The field installation of cable accessories introduces human variability into the electrical system: imprecise cutting of semiconducting layers, contamination by conductive particles or moisture, incorrect positioning of the stress control element, and improper torque application at mechanical connections create points of severe local electric field gradients. CIGRE emphasizes that, despite the rigorous factory quality control mandated by product standards, the field assembly and connection process necessitates mandatory commissioning tests before the systems are handed over for energization.

TESTS WITH DIFFERENT OBJECTIVES: ACCEPTANCE, MAINTENANCE, AND DIAGNOSIS

A common misconception in underground cable management is the tendency to group testing methodologies under a single operational category, disregarding the specific technical purpose of each test procedure. To ensure system reliability and avoid unnecessary operational costs or accelerated insulation degradation during testing, industry guidelines categorize verification routines into three distinct areas: acceptance, periodic maintenance, and predictive dielectric integrity diagnostics.

Acceptance tests, suggested by ANSI/NETA ATS-2025 and IEEE 400.2-2024, *Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)*, focus on accurately determining whether a newly installed cable, along with its splices and terminations, has been assembled according

to design specifications and is ready for initial energization. This process aims to identify installation-related damage and accessory assembly defects by applying controlled overvoltage and supplementary dielectric strength tests prior to handing the asset over for commercial operation.

Meanwhile, periodic maintenance tests, structured according to ANSI/NETA MTS-2023, aim to verify that circuits in continuous service maintain the functional compliance required for ongoing operation. In this context, tracking historical data is fundamental: a single, isolated data point does not reveal the structure's aging rate, whereas a comparative analysis of historical parameters allows for predicting when the system is approaching the end of its service life. Unlike pass/fail approaches, diagnostic tests aim to determine the level of insulation degradation, the defect phenomena present, and their physical locations along the cable. This specialized category encompasses techniques such as dissipation factor (tan δ), PD characterization, TDR, frequency-domain reflectometry (FDR), DAC voltage monitoring at VLF, and tests of outer metallic sheath integrity. While a withstand voltage test merely verifies whether the insulation withstands the applied electrical stress, predictive engineering diagnostics quantify the intrinsic condition of the insulation and enable preventive decision-making prior to catastrophic in-service failure.

MAIN DIAGNOSTIC TECHNIQUES: VLF, TAN DELTA, AND PD

The development of VLF voltage testing technology represented a fundamental evolutionary milestone in enabling field testing for shielded power cable systems. IEEE 400.2-2024 establishes the technical parameters for conducting tests at frequencies typically in the 0.1 Hz to 0.01 Hz range, covering everything from withstand tests to advanced integrated diagnostic measurements of dielectric losses. The basis of this technique relates to the cable's capacitive charging current, represented by the expression:

$$Ic = 2\pi \cdot f \cdot C \cdot V$$

Where the operational quantities are duly described by:

- *Ic:* System capacitive charging current, expressed in amperes (amp)
- *f:* Frequency of the sinusoidal waveform applied during the test, expressed in hertz (Hz)
- *C:* Total equivalent capacitance of the cable circuit under test, expressed in farads (F)
- *V:* RMS test voltage applied to the conductor, expressed in volts (V)

Since the magnitude of the charging current is directly proportional to the test frequency, reducing the excitation from 60 Hz to 0.1 Hz reduces the required current and the apparent power output of the source by a factor of 600. This frequency reduction enabled the development of more compact, lightweight equipment, thereby allowing testing of longer underground circuits at higher test voltages. In accordance with IEEE 400.2-2024, it is essential to distinguish between the VLF withstand test (pass/fail) and VLF diagnostics, the purpose of which is to assess the degree of insulation degradation.

In this context, tan delta (tan δ) diagnostics quantify dielectric losses due to conduction and polarization within the insulation system, expressed by the scalar relationship between the components of the total current:

$$tan\ \delta\ = \frac{Ir}{Ic}$$

Whose physical components represent:

- *Ir:* The resistive component (active dielectric losses) of the current, in amperes (amp)
- *Ic:* The pure capacitive component of the reactive current, in amperes (amp)

In sound dielectric systems, resistive losses are low, resulting in tan δ values that are very low and stable across voltage increases. The presence of moisture, conductive voids, contamination,

and widespread water treeing increases conductivity and dielectric loss, significantly raising the dissipation factor and the variation in tan δ between applied voltage levels (tip-up). The tan δ test reflects the overall condition of the insulation along the entire cable section but cannot pinpoint the exact location of an isolated, localized defect. For this very reason, it is standard practice to complement the tan δ test with PD analysis.

PDs are localized events of microscopic dielectric breakdown occurring at internal discontinuities, voids, delamination, or conductive points within the insulation or at accessory interfaces where the electric field gradient exceeds the local dielectric strength. Continuous PD activity erodes the polymer matrix, damages the insulation material, and transforms electrochemical trees into electrical trees, a mechanism that culminates in dielectric insulation failure, ultimately leading to circuit breakdown. In accordance with IEEE 400.3-2022, *Guide for Partial Discharge Field Diagnostic Testing of Shielded Power Cable Systems*, investigations must record the apparent discharge magnitude (in picocoulombs, pC), the inception (PDIV) and extinction (PDEV) voltages, and the phase-resolved PD (PRPD) pattern. For utility and industrial networks, mapping the spatial locations of PD sources within joints and terminations ensures accuracy in scheduled repair decisions.

FAULT LOCATION AND COVERAGE INTEGRITY

It is crucial that asset managers do not confuse diagnostic engineering (preventive/predictive maintenance) with fault location techniques (corrective maintenance). Diagnostics assess the physical degradation state of an energized line to estimate its remaining service life and prevent unwanted contingencies; conversely, fault location is initiated after a system failure, with the line de-energized, to determine the precise coordinates of physical damage for the maintenance team. Indiscriminate excavation near underground cable networks results in excessive civil work costs, the risk of accidental damage to adjacent circuits, and unacceptable downtime.

The engineering workflow established by IEEE 1234-2019, *Guide for Fault-Locating Techniques on Shielded Power Cable Systems*, comprises three sequential stages:

1. **Preliminary electrical fault classification:** Identifying phase-to-phase or phase-to-ground faults and gathering historical circuit data (e.g., number of splices, previous faults, cable route) using voltage tests (breakdown voltage), TDR, Wheatstone/Murray resistive bridges, or transient oscillation methods (such as the arc reflection method).
2. **Instrumental pre-location:** Narrowing the fault area to a specific window along the route's topographic profile using TDR or bridge measurement methods (Murray or Glaser).
3. **Precise pinpointing:** Performed using acoustic ground sensors combined with electromagnetic detectors to capture the mechanical pulse generated by controlled discharges from surge generators ("thumpers").

In scenarios involving intermittent faults—where dielectric integrity is restored after the circuit is disconnected and the short circuit only re-emerges under higher stress and full operating voltage—the fault-location technology must be selected based on the fault dynamics rather than merely circuit voltage compatibility, ensuring the use of appropriate methods and equipment.

Concurrently, verifying the integrity of the outer sheath (whether semiconducting or PVC/PE insulating) is crucial for the operational longevity of the grounding and protection systems for medium- and high-voltage conductors. Continuous groundwater ingress in direct contact with shielding tape leads to corrosion, loss of conductive cross-section, and dangerous fluctuations in induced potentials along the cable route. Periodic sheath integrity testing, which involves the application of a controlled DC potential between the metallic shield and the ground, identifies punctures and damage

caused by external mechanical factors, enabling localized repairs before moisture can reach and contaminate the cable's primary insulation.

FROM PREVENTIVE TO CONDITION-BASED MAINTENANCE

The traditional management paradigm based on fixed time intervals is proving increasingly inefficient for modern electrical infrastructure. Two feeders with identical technical specifications and installation dates can exhibit vastly different integrity profiles: one operating under light load, with no intermediate splices and installed in a well-drained tray, while the other has undergone severe overcurrent cycles, contains multiple splices, is located in an area with aggressive groundwater infiltration, and has a history of outages. In this context, chronological age, while relevant, is merely an indirect indicator of the asset's state; it is insufficient to capture the complex degradation mechanisms that truly determine operational condition and failure risk.

The transition to condition-based maintenance (CBM) and risk-based maintenance (RBM) integrates data on age, overvoltage events, daily loading parameters, splice history, and results from structured diagnostic tests. The value of these tests lies primarily in tracking historical trends; a dissipation factor (tan δ) value that is acceptable under ANSI/NETA MTS-2023 and IEEE 400.2-2024 may still indicate imminent risk if it has tripled over a mere 12-month period of operation.

The technical definition of a healthy cable goes beyond simply passing a momentary withstand test. A healthy system exhibits design dielectric parameters consistent with its history of service, operational criticality, and remaining useful life under current regulatory standards. This distinction enables utility companies and large industrial complexes to shift from a corrective and reactive cycle (failure → location → excavation → emergency repair) to structured predictive planning (diagnosis → degradation identification → risk assessment → scheduled intervention), thereby reducing costs and maximizing asset availability.

MANAGEMENT ARCHITECTURES

Implementing a cable management program in an industrial setting involves a governance approach focused on five sequential stages:

1. **Detailed technical inventory:** A comprehensive record of circuits, lengths, insulation polymer types, manufacturers, installation years, and the quantities and technologies of terminations and splices
2. **Process criticality matrix:** A weighted scoring of failure impacts regarding operational safety, hourly production losses, and replacement costs
3. **Preliminary screening:** Conducting rapid screening tests to identify circuits suspected of aging
4. **Specialized diagnosis:** Performing comprehensive tests, such as tan δ, PD, TDR, and cable jacket integrity tests, on the screened lines
5. **Action plan:** Deciding between continued operation under monitoring, scheduled repair, or section replacement

For electric utilities, this process requires analytical adaptation to handle thousands of kilometers of network. Corporate asset databases integrate outage histories with insulation types, manufacturers, installation environments, and diagnostic sampling campaign results, all categorized by priority. This data flow informs planning systems and regulatory investment plans (CAPEX and OPEX), in accordance with the guidelines found in CIGRE TB 924 (2024) and CIGRE TB 912 (2023) regarding the condition assessment and lifecycle management of underground cables.

Operational dynamics for contingency mitigation also reflect these architectural differences. At the manufacturing plant, the protocol requires a rapid team response: isolating the circuit, locating the fault via TDR/pinpointing, repairing the splice or damaged section, performing post-repair tests, and restoring the production load. In the distribution network, conversely, a

topology with transfer capability enables service to priority customers via remote switching operations—carried out before the faulty circuit is even investigated—thereby transforming the physical grid architecture into a direct maintenance resource.

HIGH-VOLTAGE CABLES: SPECIFIC METHODS

The transition from medium voltage (MV) to high voltage (HV) and extra-high voltage (EHV) introduces technical constraints that prevent the simple transposition of conventional MV testing methods. HV cables feature significant lengths, high phase capacitance, complex accessories with precise electric-field control, and cross-bonded sheath-grounding systems designed to mitigate circulating currents induced along the circuit.

For HV and EHV circuits, CIGRE TB 912 (2023) and IEEE 400.4-2015, *Guide for Field Testing of Shielded Power Cable Systems Rated 5 kV and Above with Damped Alternating Current (DAC) Voltage*, advise against pure DC testing due to the risk of space charge injection and retention within the insulating polymer, which can precipitate dielectric breakdown upon re-energization. Preferred methods in these cases include AC resonance testing at power frequency or near-power frequency, high-power VLF systems, and, notably for operational application, DAC testing, as standardized by IEEE 400.4-2015.

The DAC method operates by applying a slow DC charging ramp followed by the near-instantaneous switching of the cable onto a calibrated test circuit inductance, exciting damped sinusoidal oscillations in the range of tens to hundreds of hertz. This process simulates power-frequency electrical stress without transferring excessive heat to the dielectric, enabling synchronized measurements of losses and PDs using compact field equipment. The choice of method must take into account the voltage class, span length, insulation technology, grounding complexity, and the permissible stress level for each circuit.

MATRIX OF METHODS AND TECHNICAL GUIDELINES

Structuring testing programs requires objective criteria for selecting diagnostic tools. Improper application of a technique can waste financial resources without identifying the root cause of dielectric degradation or subjecting already weakened sections of the insulation to unnecessary electrical stress. Table 1 summarizes the nine main testing methodologies for medium- and high-voltage insulated cables, outlining their respective technical objectives, data obtained, and recommended application scenarios.

The matrix establishes objective criteria for defining technical inspection routines. Newly executed splices require commissioning inspections focused on PDs and outer sheath tests, capable of identifying assembly deviations before the circuit is delivered for commercial operation. In turn, older lines demand integrated evaluations by VLF tan δ, aiming to monitor the rate of evolution of volumetric degradations resulting from service time and load cycles of the system.

CONCLUSION

Underground networks in industrial environments and distribution utilities operate based on similar electrotechnical principles, yet they require distinct maintenance philosophies due to their architecture and the consequences of potential failures. In the manufacturing sector, the priority is ensuring supply continuity for continuous production lines, where the cost of downtime outweighs the investment in advanced predictive diagnostics. In the distribution sector, management focuses on balancing service availability for the community, regulatory continuity targets, and the efficient allocation of maintenance and network expansion budgets.

The management of medium- and high-voltage insulated cables should not be limited to isolated checks of operation under nominal conditions. A structured maintenance policy aims to determine the degree of insulation degradation, the rate at which it progresses,

Table 1: *Practical Matrix of Test Methods for Insulated Medium and High Voltage Cables*

Test Method	Technical Objective	Information Obtained	Typical Use Scenario
Insulation Resistance (IR / PI)	Quick preliminary check of primary dielectric strength	Ohmic resistance and polarization index under direct current	Basic screening during commissioning and post-failure testing
VLF Applied Voltage (Withstand)	Insulation integrity verification using test overvoltage	Binary pass/fail response for the installed system	Commissioning and acceptance following installation or repair work
Dissipation Factor (VLF Tan)	Quantification of dielectric losses within the insulation volume	Widespread degradation, presence of moisture, and arborescence	Overall condition assessment and predictive management of aging cables
Partial Discharge (PD)	Detection of micro-defects and localized dielectric stress points	PD level (pC), defect location, and phase angle (PRPD)	Detailed inspection of joints, terminations, and insulation integrity
Damped Alternating Voltage (DAC)	Diagnosis of PDs and losses under alternating voltage conditions	Detects, measures, and locates partial discharges	Long medium- and high-voltage circuits and HV cable commissioning
Time-Domain Reflectometry (TDR)	Mapping of impedances and discontinuities along the route	Length, splice position, branches, open circuit, and low-impedance faults	Physical circuit registration and pre-location of faults
Acoustic Localization (Pinpointing)	Precise identification of the physical coordinate of the fault	Acoustic and electromagnetic signal emitted at the point of rupture	Final localization phase prior to excavation and repair
Outer Sheath Integrity (Sheath Test)	Assessment of the physical condition of the outer sheath and metallic shielding	Presence of mechanical punctures, water ingress, and earth leakage	Commissioning and periodic maintenance of underground ground beds
AC Resonant Test (AC Hi-Pot)	High-power power-frequency withstand test	Dielectric strength under an alternating waveform equivalent to the mains supply	Mandatory acceptance and commissioning of HV and EHV systems

the mechanisms involved, and the probability of failure during continuous operation. Modern predictive maintenance tools—such as VLF testing, dissipation factor analysis, PD monitoring, time-domain reflectometry, and cable jacket testing—provide the technical data necessary for this assessment.

The modernization of generation, transmission, and distribution sectors, as well as industrial plants, stems from the transition from corrective and reactive maintenance models to CBM and RBM strategies. Transforming field measurements into health and probabilistic risk indicators enables engineering teams to plan interventions before unplanned faults occur, thereby preserving the service life of underground assets that are strategic to national grid reliability.

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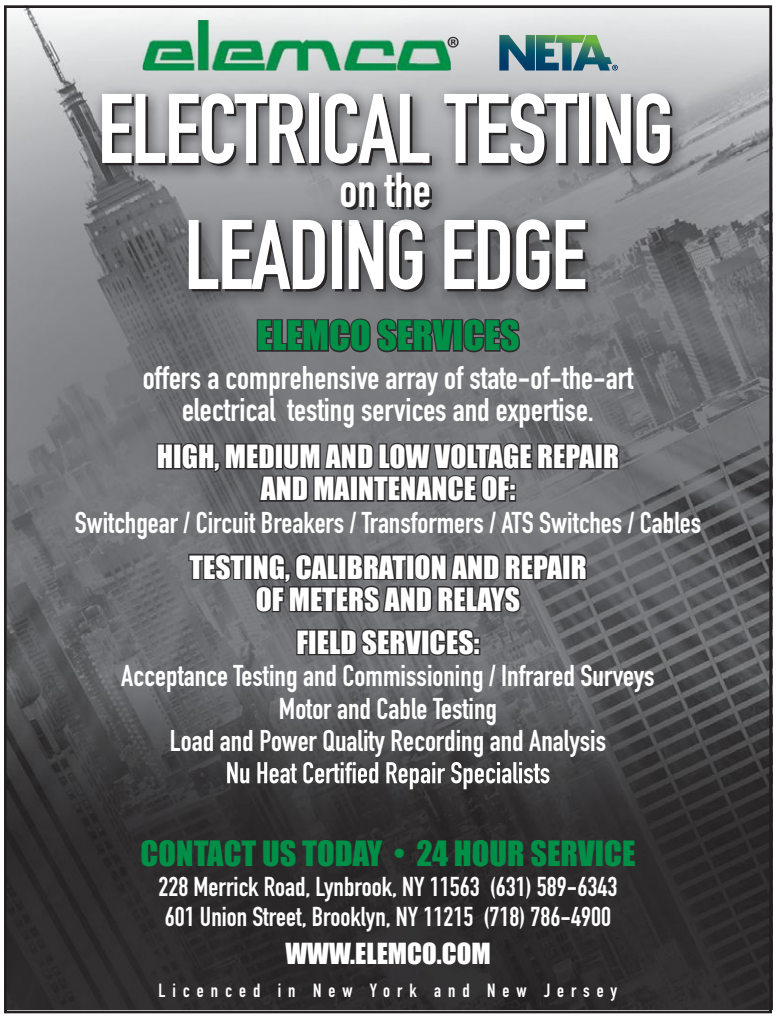
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SMART MONITORING BRINGS POWER QUALITY CLARITY

BY MELVIN LIWAG, *Orlando Utilities Commission*

Power quality is a cornerstone of reliable electrical service, particularly for large commercial and industrial customers. Poor power quality can lead to costly disruptions, equipment damage, and operational inefficiencies, making it essential for utilities to ensure consistent and clean power delivery. According to the Electric Power Research Institute (EPRI), poor power quality costs U.S. businesses more than $145 billion annually.

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Power quality events can halt entire production processes, often occurring 20 to 30 times per year, with a one-second outage costing industrial and digital economy firms $1,477 per second. A paper by Sharmistha Bhattacharyya and Sjef Cobben of the Technical University of Eindhoven in The Netherlands shows 70% of power quality issues occur on the customer side because of equipment operation and wiring, with the utility often shouldering the blame for poor power quality.

The technology to spot power quality problems and their causes—no matter whose side the issue is on—plays an integral role in preventing future interruptions and outages as well as providing accurate information to forge a solid partnership with the customer.

ENGINEERING FOR RELIABILITY

Orlando Utilities Commission (OUC) is the 14th largest municipal utility in the U.S. and has long prioritized reliability, serving more than 242,000 metered accounts, including 32,000 commercial and industrial clients, in Orlando (Orange County) and St. Cloud (Osceola County). OUC's 418-square-mile (1,083-square-kilometer) service territory includes significant installations such as an international airport, nationally recognized tourist attractions, major health care facilities, and large-scale manufacturing and supply chain operations.

For nearly six years, OUC provided uninterrupted power to a large manufacturing plant in Orlando, thanks to infrastructure designed for maximum reliability. The plant was served by three dedicated underground feeders and 10 three-phase transformers, eight of which were 2,500 kVA units. These transformers were part of an engineered system featuring automation capabilities, such as auto-transfer switches that could switch to backup power sources within two seconds of a disruption. This setup was critical, as it ensured the manufacturer could operate without interruption—even during hurricanes and daily thunderstorms common in central Florida.

However, that changed in 2022 when the manufacturer experienced unexpected partial power outages and low-voltage events. These events caught the utility off guard, as the system had previously withstood numerous challenges—including Category 3 and 4 hurricanes such as Irma, Ian, and Idalia—as well as many tropical storms, without issue.

UNCOVERING THE CAUSE

OUC began a thorough investigation to pinpoint the cause, deploying temporary data loggers and pulling historical data from meters to discover why certain transformers were blowing fuses. While these tools were effective for basic monitoring, the utility needed more detail to diagnose the complex power quality issues. Because two meters were connected to the customer's 10 transformers, providing data every 15 minutes, and the data loggers only held two weeks of data, OUC installed two power quality meters to gather more precise data.

With access to more data points, the utility discovered that three transformers linked to the outages were overloaded. However, it still required more information to understand the root cause of the issue. Seeking to understand the partial outages better, the utility visited with the plant engineer and discovered the manufacturer had recently installed an 800-hp compressor and an entire process line wired to a fully loaded transformer. Each time the compressor started, it brought the transformer well above its current rating and caused bayonet fuses inside the transformer to blow several times.

OUC continued using its older monitoring equipment and discussed transferring loads with the customer to improve load balance. At the same time, the utility discovered a solution that could obtain a real-time view of the customer's power quality issues, especially the load profile, which could potentially help the utility to be more proactive and prevent problems.



Three-Phase Padmount Transformers for Commercial and Industrial Load



OUC Crews Installing a DTM Unit

REAL-TIME MONITORING

OUC learned from another utility about the distribution transformer monitor (DTM) and AI-driven asset management platform that it uses. During a planned outage, OUC installed the DTM units on the three overloaded transformers.

The impact was immediate, providing OUC with real-time transformer load monitoring, voltage, internal pressure, temperature, and dozens of other monitoring capabilities upstream, downstream, and in the transformer. For example, OUC can now monitor the customer's load profile and see current spikes when a process starts. The utility can detect sags and harmonics, determine the origin and cause, and address them before outages occur or transformers are damaged.

Shortly after the units were installed, the manufacturer experienced another outage over the Christmas and New Year's holidays. This time, OUC was equipped with real-time data, leading to a rapid diagnosis. An engineer was able to access the asset management platform from a laptop at home, pinpoint the cause down to the specific transformer and circuit—a blown bayonet fuse—and coordinate a swift response to restore power.

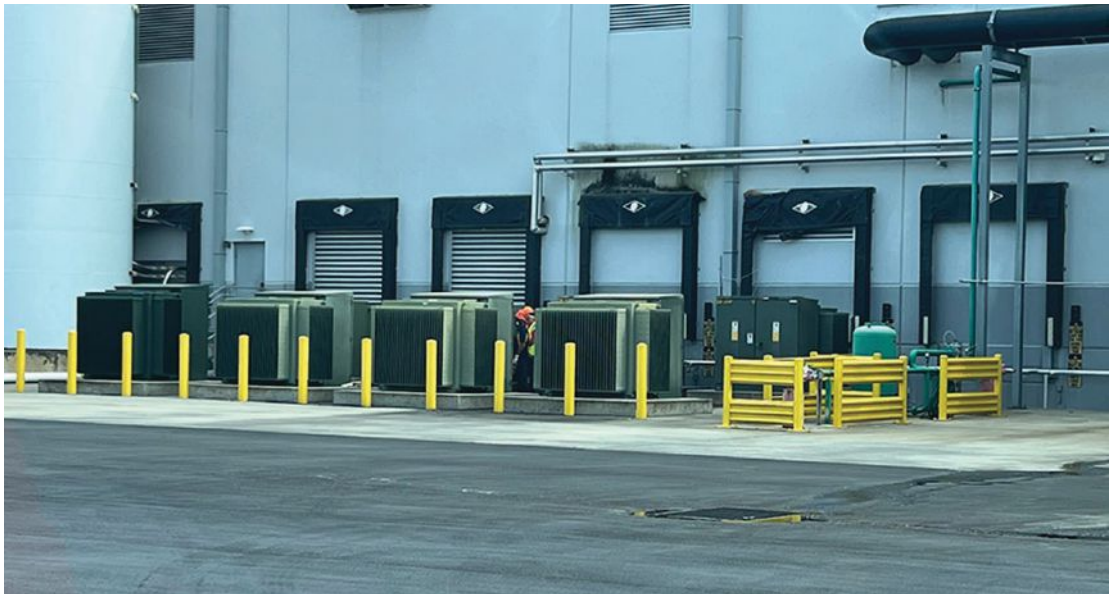
The information helped guide the field technician to the right transformer to replace the fuse without having to waste time inspecting all 10 transformers and coordinating with the customer to reenergize.

INSIGHTS FOR BETTER SERVICE

With real-time monitoring units, OUC can provide customers with valuable insights. For example, the ability to monitor overloaded transformers enables the utility to provide this information to the customer to improve load balancing. In turn, this improves reliability and extends the useful life of assets.

OUC can measure a wide range of grid and transformer health factors by monitoring primary current, secondary current, and secondary voltage 7,800 times per second to gain a more accurate picture of power quality issues. This enables measuring frequency, power factor, sags, swells, harmonic distortion, transients, and critical transformer health data such as temperature, pressure, load, pole tilt, and impact. Health reports are delivered every two minutes, and alerts are sent immediately by text or email.

OUC's power quality team works closely with the manufacturer of its DTM units,



Commercial Transformers at a Manufacturing Facility

establishing alert thresholds and reports while keeping the utility updated when new analytics capabilities are released.

CONTINUED EXPANSION AHEAD

Building on the success of the real-time monitoring units at the manufacturing plant, OUC plans to expand the technology to other commercial and industrial customers. Future deployments include applications at a new theme park with rides and hotels, and possible deployments at a growing number of small satellite emergency room (ER) facilities, where reliable power is critical.

ER facilities require a high level of power quality due to the sensitive nature of imaging equipment. This can be challenging because some facilities must be served with overhead feeders, making them susceptible to weather, vegetation, and wildlife. With new monitoring and analytics capabilities on distribution transformers, the utility's power quality team is focused on the feeders to improve reliability.

The journey from a sudden power quality issue to a successful resolution demonstrates how continuous transformer monitoring can strengthen reliability and innovation. By embracing advanced monitoring technologies, OUC can ensure its customers receive the reliable service they depend on. As the utility looks forward, it sees the continued expansion of smart monitoring solutions playing a crucial role in maintaining and enhancing the reliability of Orlando's power grid. NW

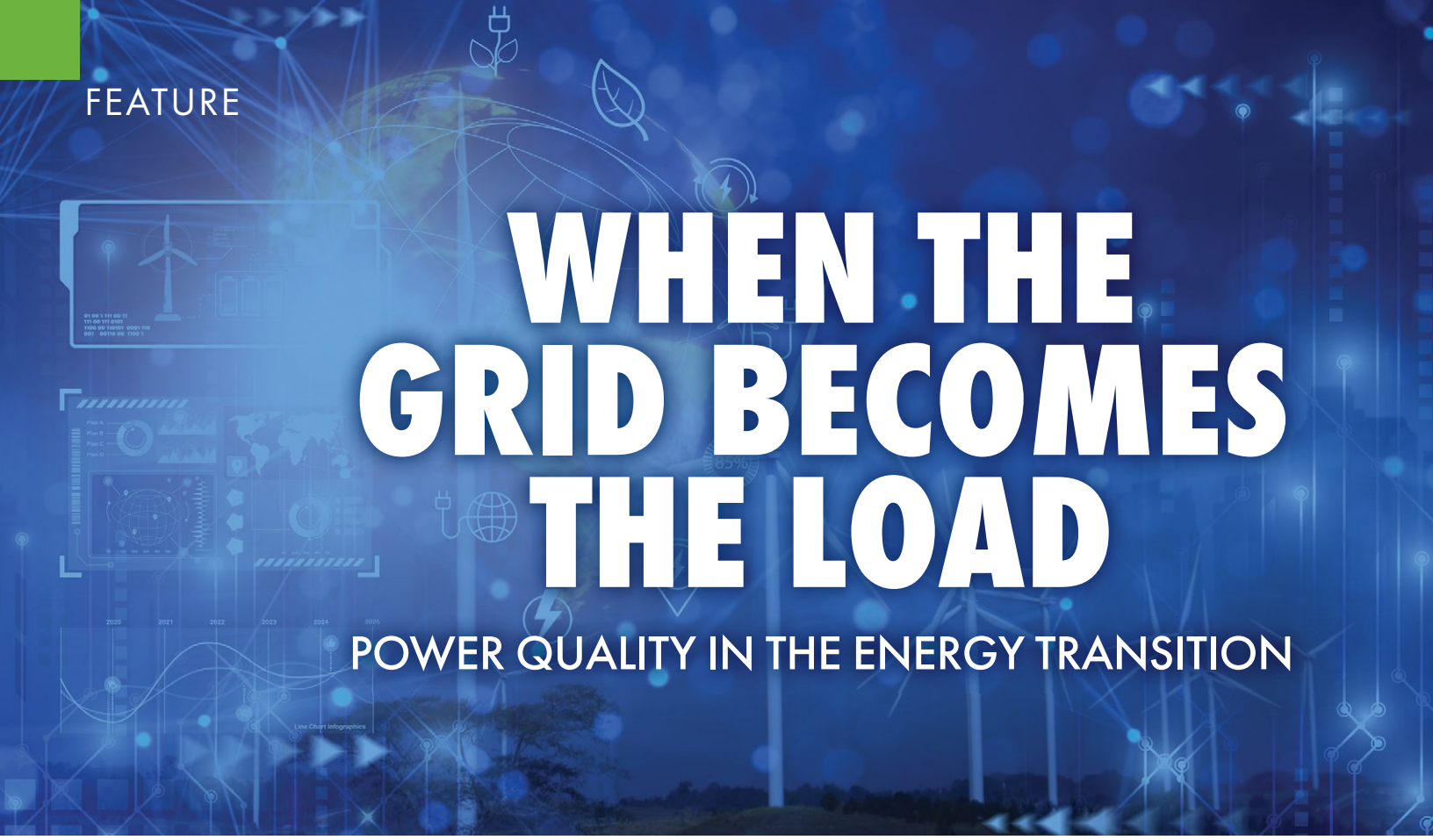
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WHEN THE GRID BECOMES THE LOAD

POWER QUALITY IN THE ENERGY TRANSITION

BY HOWARD W. PENROSE, *MotorDoc*

Power quality investigations commonly begin with events such as equipment trips, overheated transformers, unexplained relay trips, or electric machine failure. We measure voltage and current and evaluate harmonics, unbalance, transients, power factor, and other conditions to determine their effects on equipment. That work remains necessary. Changes in generation, distribution, storage, and power electronics require us to examine more of the connected system to understand how these technologies affect the electrical network as a whole.

A battery energy storage system (BESS) illustrates the challenge. Charging draws active power; discharging supplies it. Its power electronics may also supply or absorb reactive power to support voltage or respond to torsional or frequency oscillations. Each condition changes current through the converter, transformer, and connecting circuits. The response depends on equipment capability, control settings, and conditions of the connection.

Similar interactions occur across wind and solar plants, industrial facilities, data centers, and coordinated distributed resources. Equipment responds to the electrical system while influencing it—the relationship described by this article. Testing personnel must connect that behavior with equipment condition and reliable operation, and be able to identify conditions that existed when investigating an event.

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CONSIDER THE COMPLETE PLANT

An inverter-based resource (IBR) interfaces generation or storage with the AC system through power electronics. Examples include solar photovoltaic generation, BESS, and many wind turbine designs. A distributed energy resource (DER) is connected within a distribution system and may use inverter-based or rotating-machine technology. These terms may overlap, but they describe different characteristics.

A virtual power plant (VPP) coordinates geographically distributed generation, storage, and controllable demand. Resources can occupy different feeders and may not necessarily be one electrical plant. High-voltage direct current (HVDC) systems transfer power through DC circuits and converters and inverters. For a two-terminal link, one AC terminal receives active power while the other delivers it, subject to losses. Converter and inverter technologies, controls, filters, and network conditions determine the local response.

IBR and DER are often discussed as individual generators. However, the grid sees the combined installation: transformers, collector circuits, auxiliaries, reactive compensation, protection, and controls. The plant may supply or consume active power, and supply or absorb reactive power. An inverter specification cannot establish the completed plant's behavior as generation, load, or both. Figure 1 illustrates the shared network.

After sunset, a solar plant's auxiliaries can still consume electricity, energized collector circuits can affect reactive exchange, and a co-located BESS may charge. Measurements and models must represent that operating condition, even though the site is called a generating plant.

Thousands of individually compliant devices may respond to one dispatch signal or voltage disturbance. Their combined power change can affect feeder voltage. VPP operators need resource locations, local constraints, timing, and communications status alongside aggregate megawatts. Verify that local controls and limits take precedence as intended when an aggregate command cannot be delivered.

THE INFORMATION GAP BECOMES A TESTING PROBLEM

Incomplete original equipment manufacturer (OEM) control documentation and incomplete design and construction records leave owners, testing personnel, and grid operators without a reliable description of the plant. Records should identify available and enabled functions, limits, control priorities, and the installed configuration. Factory capability, an entered setting, and verified plant response are different things.

These gaps affect planning and operating models. Omitted functions, assumed settings, unavailable equipment, or construction changes can separate predictions from field performance. A mathematically correct model

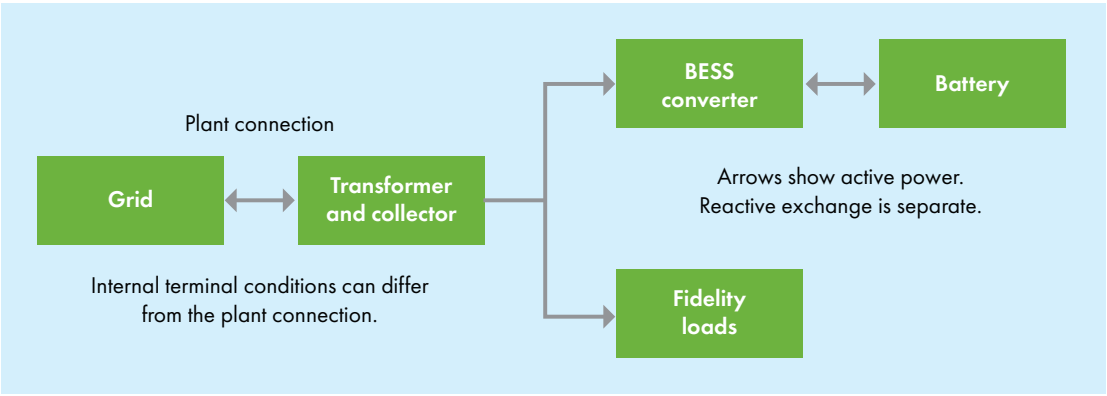


Figure 1: *Active power exchange in a shared BESS network, where the facility branch represents nonregenerative loads and reactive exchange is separate. Internal and interconnection conditions can differ.*

may describe a plant that was never built in that configuration.

The consequences include errors in expected voltage regulation, reactive-power capability, disturbance response, and power exchange with the local and bulk grids. The joint North American Electric Reliability Corporation (NERC) and Texas Reliable Entity (RE) investigation of the 2022 Odessa disturbance identified the importance of models reflecting actual modes, controls, settings, and protection. This makes documentation quality an operational issue, not simply a project closeout task.

Independent testing helps verify that what was specified, installed, configured, and demonstrated aligns. Proprietary code need not appear in routine reports, but functional behavior, limits, and model information must support performance assessment. Record unknown behavior as an unresolved limitation.

ACCEPTANCE AND COMMISSIONING HAVE COMPLEMENTARY ROLES

NETA's emphasis on independent testing and consensus standards is directly relevant to these installations. ANSI/NETA ATS-2025 addresses suitability for initial energization and includes sections for BESS and solar photovoltaic systems. ANSI/NETA ECS-2024 addresses commissioning and system performance verification against the owner's project requirements and basis of design. These activities provide complementary evidence about equipment condition and the completed installation.

Inspect the installation, evaluate insulation and connections, verify instrument transformers, test breakers and relays, and confirm wiring and interlocks using applicable procedures. Converter controls cannot compensate for defective terminations or incorrectly connected current transformers. Correct ratios, polarity, and phase identification underpin power and protection measurements.

Then evaluate the assembled system. A relay may pass individually while a plant controller initiates an unexpected response. A converter may meet factory specifications while the plant cannot deliver the required reactive power at the interconnection. Identify those interfaces and assign responsibility for evaluating them.

Field testing organizations need not redesign the plant or perform every stability study. They must communicate exceptions to responsible engineers and operators. Tie acceptance to the equipment, operating condition, and requirement evaluated.

BESS MUST BE TESTED ACROSS OPERATING MODES

A BESS includes batteries, power conversion, battery management, controls, protection, and supporting electrical equipment. Its AC behavior changes with charging, discharging, reactive duty, and transitions. Testing at one steady discharge point cannot establish performance across that range.

For a 10 MVA converter at nominal voltage, assume balanced fundamental-frequency operation and neglect distortion. The idealized limit $P^2 + Q^2 \leq S_rated^2$ leaves 6 Mvar at 8 MW. P is active power, Q reactive power, and S_rated the assumed apparent-power rating. At 10 MW, no reactive margin remains. Figure 2 shows this shared capacity, not an OEM capability curve. Actual limits depend on voltage, temperature, DC conditions, and control priorities. Transformers and collector circuits further affect plant capability.

When a voltage disturbance calls for reactive current near the converter's current limit, what governs allocation? Does active power decrease? Does reactive current take priority, or do battery controls restrict the response? Document and verify these functions through appropriate tests or studies. Megawatts alone are insufficient.

State of charge limits sustained response even when instantaneous power capability is adequate. Temperature and unavailable battery racks impose further restrictions. Connect AC measurements with battery state, commands, active limits, and equipment availability.

Test representative charging, discharging, low-output, and permitted reactive conditions. Near zero active power, reactive current can still produce losses. Evaluate transformer temperature against root-mean-square (RMS) current, reactive duty, ambient conditions, and loading history. Reversed active-power flow alone does not establish an abnormal condition.

Consider an illustrative trip: a voltage sag precedes rising reactive current, falling active power, and a converter alarm. Investigate current allocation and converter limits. A battery-management restriction preceding the AC change suggests a different sequence. Neither proves root cause; compare time-aligned records with enabled logic.

CONTROLS AND PROTECTION DETERMINE THE RESPONSE

Grid-following controls generally synchronize to an existing voltage waveform and regulate current or power relative to it. Grid-forming controls establish an internal voltage reference and regulate their interaction with the network. The distinction describes dynamic behavior, not simply the energy source. The NREL grid-forming research roadmap discusses both the potential support and the integration challenges.

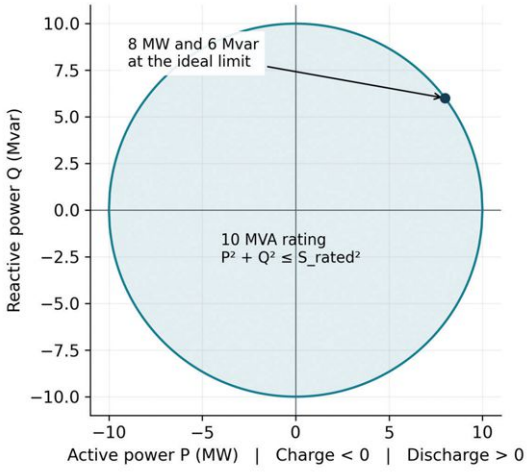


Figure 2: *Idealized converter capability at nominal voltage, neglecting distortion. Positive P indicates discharge; positive Q indicates injection. This is not an OEM curve or plant guarantee.*

A grid-forming label does not establish unlimited fault current, islanding, or black start. These depend on equipment, auxiliaries, controls, protection, and the operating envelope. Verify the functions purchased and enabled.

Network impedance matters because converter current changes terminal voltage and therefore controller response. Multiple devices interact through that network. Short-circuit ratio compares available short-circuit capacity with resource rating; state the rating convention used. A weaker connection generally experiences greater voltage change for a given current change. This indicator is neither a complete stability assessment nor synchronous-machine short-circuit ratio.

Fast interactions may require electromagnetic transient (EMT) modeling, coordinated with field measurements. Protection must be represented as well as normal control behavior. Simply relaxing a trip setting to improve ride-through can expose equipment to conditions beyond its capability. The engineering review must reconcile system requirements, equipment limits, protection coordination, and the installed configuration.

PLANT PERFORMANCE CAN IMPOSE INTERNAL STRESSES

Grid requirements may apply at the high-voltage connection while equipment ratings apply at individual terminals. Transformer impedance, collector cables, compensation, and auxiliary demand separate those locations. Meeting the interconnection requirement does not establish acceptable internal component loading.

Synchronous plants also require evaluation of the generators, excitation systems, limiters, step-up transformers, and auxiliaries. Starting, load cycling, and reactive duty can increase thermal and mechanical stress. Elevated voltage relative to frequency increases magnetic flux and can cause heating. Evaluate changed duties against design and present condition.

A data center presents a related concern. Transition of an uninterruptible power supply (UPS) to battery operation can preserve computing while abruptly reducing utility demand. Restoration and recharge create another operating condition. NERC identifies voltage sensitivity and control interactions as large-load concerns. Retain service-entrance measurements alongside UPS status and internal records.

CONNECT POWER QUALITY WITH EQUIPMENT CONDITION

Harmonics, unbalance, transients, and power factor remain useful evidence. Displacement power factor describes the fundamental voltage-current relationship, while true power factor relates active to apparent power and includes distortion effects. Retain harmonic current in amperes as well as percentages; a high percentage at low fundamental current does not necessarily mean a large harmonic burden.

Voltage distortion depends on harmonic currents, existing background distortion, and network impedance. Capacitors, cables, transformers, and filters alter the frequency response. A compensation change can reduce one problem while increasing another. A spectral peak identifies frequency content, but additional evidence is needed to distinguish resonance, switching effects, and control oscillation.

For example, a capacitor stage and network inductance can create a frequency at which distortion is amplified. Changing the stage or feeder configuration changes that frequency. Compare spectra across those configurations and use an impedance study where warranted. A compliant steady-state harmonic result in one configuration does not establish acceptable behavior across all configurations.

Our IEEE, NETA, wind power, and CIGRE work connect electrical signatures with operating conditions and component histories. Corroborate diagnoses against the connected circuit. A signature from one design should not automatically become a universal alarm.

For BESS transformers, combine electrical measurements with thermal inspection, dissolved gas analysis (DGA), fluid type, and loading history. DER transformer DGA standards development emphasizes application-specific information. An abnormal gas result warrants investigation but does not independently identify inverter harmonics as the cause.

CAPTURE THE EVENT AT THE RIGHT LOCATIONS

Routine supervisory control and data acquisition (SCADA) trends establish operating context but may miss a disturbance lasting only a few cycles. Waveform records, relay oscillography, controller logs, and battery-management records provide complementary information when their timestamps can be related. Table 1 shows the evidence needed to reconstruct the sequence.

Use the one-line diagram and symptom to select interconnection and internal measurement points. Account for transformer connections, transducers, and phase relationships; confirm scaling and time alignment. Where practical, retain synchronized voltage and current on both sides of the equipment under investigation.

Choose sampling rate, record length, filtering, and triggering to match the phenomenon. Longer records improve frequency resolution and capture slower oscillations; faster sampling supports higher-frequency investigation. The transducers and complete acquisition chain must have suitable bandwidth. IEC 61000-4-30:2025 includes methods for conducted emissions through 150 kHz in its annexes. A high sampling rate alone does not establish measurement accuracy over that range.

Use approved procedures and appropriately rated equipment. Evaluate disturbances through suitable simulation, laboratory or controlled functional tests, and retained field events. Obtain evidence without creating uncontrolled disturbances on operating installations.

Table 1: *Records needed for disturbance investigation. Timestamps and acquisition settings should be aligned.*

Record	What it establishes	Examples
SCADA and historian	Operating background	Dispatch, trends, equipment availability
Waveform recorder	Electrical event	Voltage, current, distortion, transitions
Relay oscillography	Protection response	Pickup, trip, and breaker sequence
Converter and Battery Management System logs	Control and battery state	Commands, limits, state of charge, alarms

CLOSE THE GAP BETWEEN STUDIES AND FIELD PERFORMANCE

The European Network of Transmission System Operators for Electricity (ENTSO-E) investigation of the Iberian blackout on April 28, 2025, identified interacting factors involving oscillations, voltage and reactive power control, output reductions, and generator disconnections. Its March 2026 findings emphasized the need for improved monitoring, coordination, and data exchange. The lesson for testing is the importance of connecting local behavior with the wider system response.

IEEE 1547-2018 addresses DER interconnection with distribution electric power systems; IEEE 1547.1-2020 specifies associated conformance tests and evaluations. IEEE 2800-2022 addresses transmission-connected IBR, and IEEE 2800.2-2026 provides recommended practices for verifying plant-level conformity. Determine the applicable edition, reference point, interconnection agreement, and project requirements before selecting acceptance criteria. These documents complement equipment testing; they do not make every equipment terminal an interconnection compliance point.

Retain each function's command, mode, settings, measured response, criterion, and disposition of exceptions. Table 2 connects participants with evidence. Compare the installed response with the study, as responsible engineers must resolve discrepancies in equipment, configuration, models, or requirements.

Table 2: *Evidence needed by plant and grid participants. Design and integration records connect installed equipment with models.*

Participant	Main question	Evidence to connect
Utility/system operator	Interconnection response	Synchronized P,Q,V and frequency
Equipment manufacturer	Capability limits	Terminal waveforms, settings, firmware
VPP/plant operator	Commanded vs delivered response	Dispatch, availability, control priorities
Designer/integrator	Installed vs modeled plant	As-built circuits, settings, model revisions
Facility/testing team	Cause and equipment consequence	Local captures, trip sequence, condition

After correction, repeat relevant tests and assess other operating modes. Preserve the final configuration and update models where applicable. Use that maintenance baseline to distinguish deterioration from changed duty or controls. Firmware, compensation, and dispatch changes can justify renewed verification.

Evolving guidance must connect operating experience with interpretation. Reports should explain what was demonstrated, what remains unresolved, and what action follows. A pass/fail entry without an operating context offers little help during the next disturbance.

CONCLUSION

Generation, distributed resources, and storage change the duties that electrical testing personnel must evaluate. The complete plant affects local and bulk grids as generation, load, and a source or sink of reactive power. Individual equipment capability explains only part of that response.

Incomplete control and construction information affect commissioning, maintenance, grid operation, and models. Independent testing connects design with installed performance. Retain sound equipment testing, verify system interfaces, and carry findings into corrective action and maintenance to support safer, more reliable equipment. NW

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ARTIFICIAL INTELLIGENCE IN PRACTICE

LESSONS AND APPLICATIONS FOR NETA ACCREDITED COMPANIES: PART 2

BY NENO PASIC, *Tony Demaria Electric*

In Part 1, published in the Fall 2026 issue of *NETA World*, Valer Banushi and Adis Talovic portrayed a comprehensive perspective on the role of artificial intelligence (AI) in the electrical testing industry. The article offered insights into future applications for NETA Accredited Companies (NACs), while considering opportunities and challenges AI may bring to the electrical testing industry. In Part 2, Neno Pasic touches on AI in everyday business, shares his view on its surprising impact on electrical infrastructure, describes how Tony Demaria Electric, Inc. (TDE), a NETA Accredited Company, has approached implementation, and offers a possible path to AI standardization.

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THE EMERGENCE OF AI

AI is often perceived as a recent technological breakthrough; however, it dates back many decades. The term "artificial intelligence" was first formally introduced at the Dartmouth Conference in 1956, where researchers began exploring how machines could simulate human intelligence. At that time, AI was largely theoretical, constrained by limited computing power and data availability.

Progress occurred in cycles—periods of optimism followed by stagnation—until exponential advances in computing, data storage, and machine learning algorithms over the past two decades, especially the last few years, enabled AI to evolve into a practical, widely deployable tool.

What distinguishes the current era is not simply the existence of AI, but the speed at which industries have adopted it. Technologies that once took years, even decades, to become mainstream are now reaching widespread use in months. AI has quickly transitioned from a specialty capability within technology firms to a standard tool embedded in everyday business applications. From finance and healthcare to manufacturing and construction, organizations are integrating AI into workflows, decision-making processes, and operational strategies at an unprecedented pace.

AI IN EVERYDAY BUSINESS

In March 2024 at The Official Cybersecurity Summit in San Diego, California, I noted and took Professor Richard Baldwin's quote very seriously: "*AI won't take your job. It is somebody using AI that will take your job.*"

The electrical testing industry is no exception. While traditionally grounded in standards-based procedures, engineering expertise, and hands-on field execution, it is now experiencing a measurable shift toward incorporating digital tools that enhance productivity and accuracy. AI's value in this space lies not in replacing human expertise but in enabling faster access to information, improved analysis of large data sets, and more efficient execution of routine tasks.

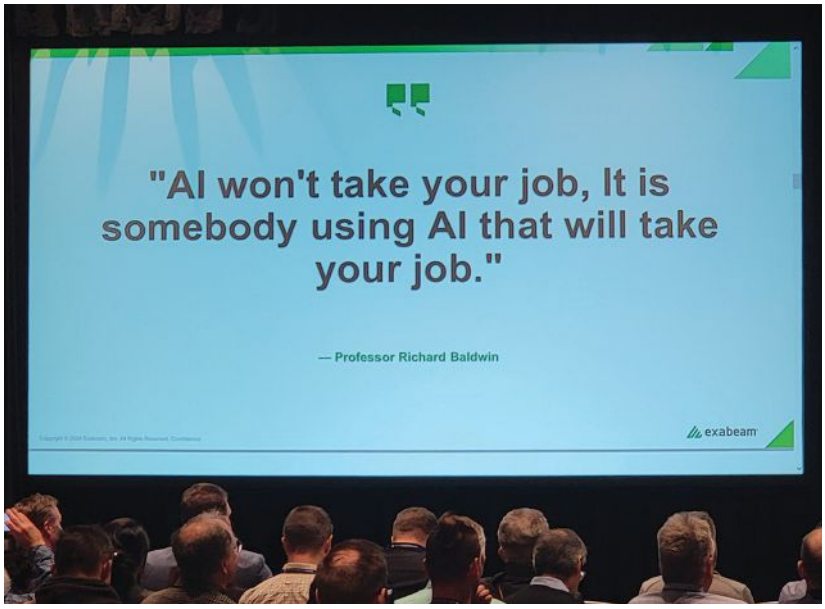


Figure 1: *Professor Richard Baldwin's Presentation at The Official Cybersecurity Summit in 2024*

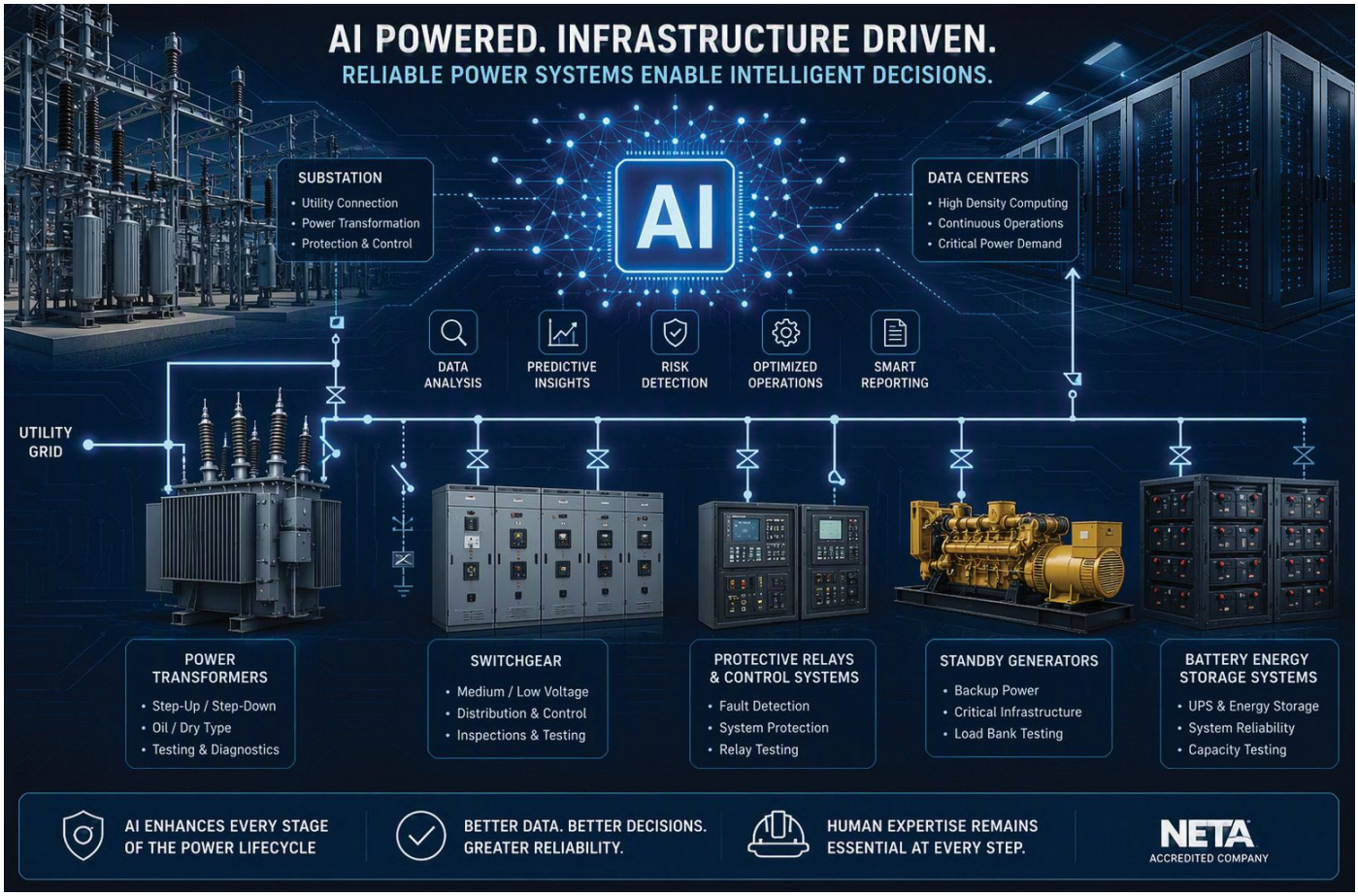


Figure 2: *AI depends on a vast electrical infrastructure, including substations, transformers, switchgear, backup power systems, and data centers. As AI adoption accelerates, NETA Accredited Companies play a critical role in ensuring the reliability and resiliency of the power systems that support it.*

AI'S SURPRISING IMPACT ON ELECTRICAL INFRASTRUCTURE

Much of the public discussion surrounding AI focuses on software, chatbots, and automation. Less frequently discussed is the physical infrastructure required to support AI. Every AI query, image generation request, document analysis, or machine learning model relies on computing resources housed within data centers. As organizations increasingly adopt AI technologies, demand for computing capacity continues to grow, driving significant investment in new data centers and the electrical infrastructure that supports them.

Recent industry discussions have raised questions about whether the pace of AI investment can be financially sustained over the long term. Some analysts point to the enormous capital commitments being made for data centers, advanced processors, cloud computing platforms, and supporting infrastructure. Others argue that AI will ultimately justify those investments through productivity improvements and new business opportunities. Regardless of where those debates land, one fact remains clear: Substantial electrical infrastructure is being designed, constructed, commissioned, tested, and maintained to support AI growth.

For the electrical testing industry, this trend presents significant opportunities. Modern AI-oriented data centers often require large utility interconnections, medium-voltage distribution systems, standby generation, uninterruptible power supplies, protective relaying systems, and increasingly complex monitoring and control networks. These facilities depend on the reliability, safety, and performance standards that NACs have long supported.

In many ways, AI creates a unique relationship with the electrical industry. While AI can help NETA companies review test reports, locate information, and improve operational efficiency, it still depends on reliable electrical systems to function. Every AI advancement ultimately relies on transformers, switchgear, cables, generators, batteries, and power distribution equipment operating as intended. Without reliable power systems, AI cannot exist.

As data center development continues, NACs may find themselves supporting not only the adoption of AI within their organizations but also the critical infrastructure that enables AI to exist in the first place. Whether AI ultimately exceeds expectations or falls short of some of the industry's more ambitious forecasts, the demand for dependable electrical infrastructure and qualified testing professionals will remain essential.

THE TDE APPROACH

At TDE, the approach to AI adoption has been deliberate, structured, and governed by a clear set of principles. Recognizing both the potential benefits and inherent risks of AI, TDE established an internal AI committee to oversee all aspects of AI implementation across the organization. This committee ensures AI is deployed in alignment with company standards, cybersecurity requirements, and the professional responsibilities expected of a NAC.

A key decision made early in this process was to avoid fragmentation by standardizing on a single enterprise AI platform. Rather than allowing multiple unregulated AI tools to be used across departments, TDE has implemented a controlled environment that relies on a single primary AI solution integrated with existing business systems. Others may disagree, but TDE believes this approach simplifies governance, strengthens data security, and ensures consistency in how AI is used across the organization.

The AI committee's role extends beyond governance. It is also responsible for developing and implementing AI agents tailored to specific business processes within TDE. These agents are designed to support both field and office operations by streamlining repetitive tasks, improving access to information, and enhancing decision-making. The committee is also responsible for AI training used within the organization and for gathering and reviewing feedback from AI users.

THE PATH TO STANDARDIZATION

However, practical challenges and exceptions to this standardization exist. Many software platforms already in use—such as Autodesk AutoCAD and Adobe Acrobat—now include embedded AI capabilities as part of their functionality. These built-in tools are accepted as part of the overall ecosystem because they are directly tied to the applications already used in daily operations. The distinction is clear: Externally sourced AI tools are restricted and centrally managed, while embedded AI features in trusted enterprise software are used for their intended purpose.

On the other hand, manufacturers of some technical software, such as PowerDB and Doble, are not planning to deploy such tools yet or at all. They might be testing it, but specific applications make it challenging and even questionable whether such adoption would benefit end users. However, their technical support groups might be implementing AI to help users find answers by crawling their knowledge bases or FAQ sections, or to provide best practices based on historical data and similar cases.

In the field, technicians are often required to reference extensive technical documentation, including standards, OEM manuals, white papers, and historical test data. Locating relevant information within hundreds of pages can be time-consuming and, in some cases, delay critical decision-making. AI-driven tools can significantly reduce this burden by enabling technicians to retrieve precise information quickly and efficiently. Instead of manually searching through documents, technicians can query AI systems to identify applicable procedures, requirements, or troubleshooting steps.

In the office, AI delivers similar efficiencies in administrative and operational processes. AI-supported workflows can accelerate tasks such as analyzing test reports, identifying inconsistencies, and assisting with documentation. This allows engineers and project managers to focus more on interpretation and decision-making rather than manual data processing.

One area where AI has shown immediate impact is in document analysis. Using technologies such as optical character recognition (OCR), which predates AI and has been commercially available since the 1950s, combined with AI-assisted review, large volumes of test documentation can be evaluated in a fraction of the time required by traditional methods. For example, reports that previously required extended manual review can now be assessed quickly to identify discrepancies, missing information, or potential errors. Qualified personnel then verify these findings, ensuring the final output meets the standards required for accuracy and compliance.

Despite these advantages, it is critical to recognize that AI is not infallible. As mentioned in Part 1, one of the most widely discussed challenges associated with AI systems is the phenomenon often referred to as "hallucination," where AI generates information that appears credible but is not based on verified data. In an industry where precision and safety are paramount, relying on incorrect information can have significant consequences.

For this reason, TDE has adopted a strict human-in-the-loop approach. As Banushi revealed in Part 1, AI is treated as an assistive tool rather than a source of authority. Qualified professionals must review and validate all AI-generated outputs before applying them in real-world scenarios, especially in final customer reports or other sensitive and financial decisions. This ensures that the responsibility for decision-making remains with experienced personnel who understand the context, risks, and technical requirements of each situation and are likely to have more intimate knowledge about it than AI could ever have.

The adoption of AI within TDE also reflects a broader trend in how organizations approach technological change. Initial reactions to AI often include skepticism or reluctance, particularly in industries where established processes have been refined over many years. However, once individuals begin using AI

tools and experience their practical benefits, adoption tends to accelerate. This pattern highlights the importance of education, training, and controlled implementation in driving successful integration. I've witnessed this firsthand at TDE as well.

AI AT NETA: SAY HI TO BETTY!

Interest in AI isn't limited to individual NACs. NETA itself is actively evaluating how AI can support its mission and better serve members. As part of its technology initiatives, NETA has tested and completed the first version of "Betty AI," a closed large language model (LLM) built around NETA's technical intellectual property database and intended for use by internal staff and select subject matter experts.

The initiative reflects a deliberate approach like that taken by many NACs: leveraging AI within a controlled environment while emphasizing accuracy, content governance, appropriate limitations, and protection of proprietary information. NETA is also exploring future AI applications that could help members and industry professionals access information more efficiently, including certification resources, technical standards, training materials, conference information, and educational tools designed to support certification preparation and professional development.

Concepts under evaluation include AI-powered study tools to help candidates pursuing NETA certification, as well as AI resources that help conference attendees navigate educational sessions and find relevant information more effectively. These efforts demonstrate that AI is increasingly viewed not simply as a business productivity tool but as a means of improving access to technical knowledge across the electrical testing industry.

As both NACs and NETA itself explore responsible AI adoption, the focus remains the same: improving access to information, supporting better decisions, and enhancing the value delivered to members and customers without replacing the expertise and judgment of qualified professionals.



Figure 3:
AI is transforming business processes in electrical testing, improving accuracy, and supporting better decision-making across field and office operations. [AI-generated image featuring synthetic performers]

CONCLUSION

Ultimately, AI represents a powerful opportunity for NACs to enhance their operations while maintaining the standards that define the industry. By implementing AI in a structured and responsible manner—supported by governance, standardization, and human oversight—organizations can achieve measurable improvements in efficiency, accuracy, and consistency.

At the same time, it is essential to remain grounded in the principles that have long guided the electrical testing profession. Automation cannot replace technical competence, adherence to standards, and professional accountability. Instead, AI should be viewed as a tool that strengthens these principles by enabling professionals to work more effectively and make better-informed decisions. NW



Neno Pasic is a NETA Accredited Representative and Tony Demaria Electric (TDE) Chief Information Officer. Neno has been working with TDE for almost 25 years. He is the NETA Volunteer Engagement Committee Chair, a NETA Training Committee Member, a NETA Promotions and Marketing Committee Member, and an IEEE and NFPA Member. Neno earned a BS in computer information systems and business administration from California State University Dominguez Hills (CSUDH), along with Project Management and Information Technology Management Certificates from the University of California, Los Angeles (UCLA). He received NETA's 2021 Outstanding Achievement Award and the 2025 NETA Excellent Service Award.

Note: AI-generated images created by Neno Pasic using Microsoft 365 Copilot.

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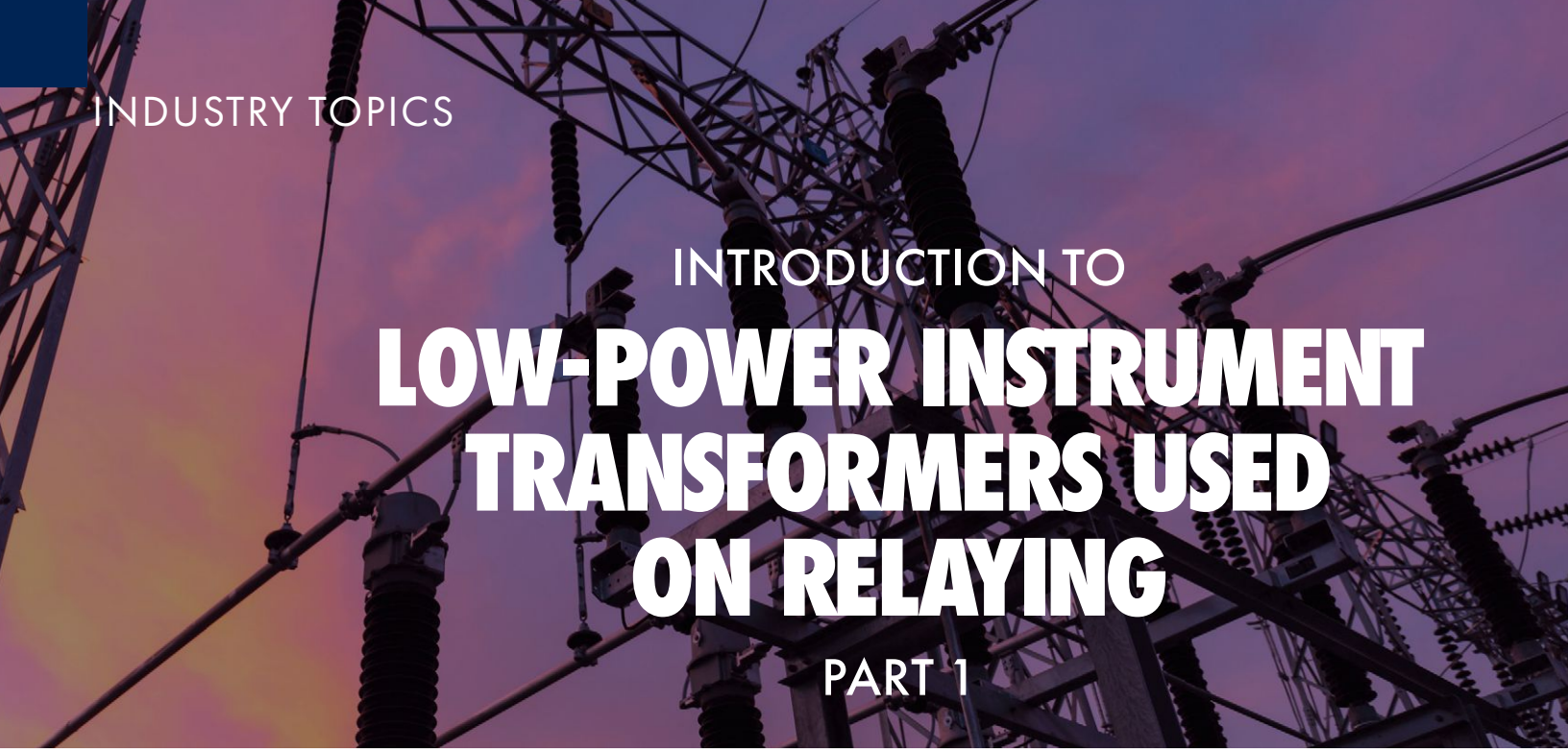
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INTRODUCTION TO LOW-POWER INSTRUMENT TRANSFORMERS USED ON RELAYING

PART 1

BY ABEL GONZALEZ, JACOB LOYD, and DHANABAL MANI, *Doble-Megger*

Originally, instrument transformers, in addition to providing an accurate representation of primary currents at a lower level, had to be able to power electromechanical relays with enough energy to operate them reliably. When microprocessor relays came along, that high power transfer was no longer necessary, yet the industry kept the same types of instrument transformers, because it was simpler to replace just the relay and keep the primary sensors in place. Today, the industry is transitioning from bulky, iron-core inductive transformers to low-power electronic sensors which leverage modern measurement principles to deliver precise signals for digital protective relays [1], [2].

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Doing away with the heavy iron-core assemblies that historically dominated substation hardware, these low-power electronic units free designers to produce significantly more compact switchgear layouts while also reducing the safety hazards that come with working near energized high-voltage conductors [3]. By eliminating magnetic saturation and minimizing the potential for high-voltage open-circuit hazards, these sensors offer enhanced operational safety and increased flexibility in high-density substation environments [4].

Furthermore, by producing millivolt-level analog outputs, these devices facilitate direct integration with intelligent electronic devices, streamlining the transition toward digitized substation architectures in accordance with IEC standards [5], [6]. This evolution toward linear, air-core technology—often utilizing the Rogowski coil principle—removes the constraints of ferromagnetic core saturation, allowing for consistent measurement accuracy across a broad dynamic range of primary currents [7].

Some names used for these devices include non-conventional instrument transformers (NCIT), electronic transformers, low-power instrument transformer (LPIT), low-power current transformer (LPCT), and low-energy analog (LEA) interfaces or sensors. These sensors are specifically engineered to interface with modern relays that comply with IEEE Std. C37.92, *Low-Energy Analog Interfaces between Protective Relays and Power System Signal Sources,* IEC 61869-10, and IEC 61869-11 standards[4].

PRINCIPLES OF SENSOR OPERATION

LPITs rely on diverse physical phenomena to translate high-voltage/current power system quantities into small-signal representations suitable for digital input.

A popular type of current-sensing device is the Rogowski coil, which produces an output voltage proportional to the time derivative of the primary conductor's current through mutual induction. Because the coil lacks a magnetic core, it maintains high linearity across a wide range of currents without the risk of saturation, necessitating an electronic integrator to reconstruct the original current waveform [8].

With Rogowski coils, the voltage output has a 90-degree phase shift relative to the current it measures. This is corrected by integration performed by active or passive circuitry within the sensor head or the relay input stage, which restores the phase relationship. This 90-degree phase shift can affect the testing and needs to be compensated for by the test set when producing signals for the current channels in the relays.

LOW-POWER CURRENT TRANSFORMERS

LPCTs utilize a low-burden magnetic core design that operates in a linear region to provide a scaled-down analog representation of the primary current, effectively minimizing the saturation risks associated with traditional, high-burden secondary windings. These types of current sensors use a burden resistor inserted in the secondary of a current transformer.

An iron-core LPCT, also known as LOPO [9], is fundamentally different from a Rogowski coil because it utilizes a ferromagnetic circuit to measure current. Its design includes:

- **Ferromagnetic Iron Core.** A small, high-precision iron core provides magnetic coupling between the primary and secondary.

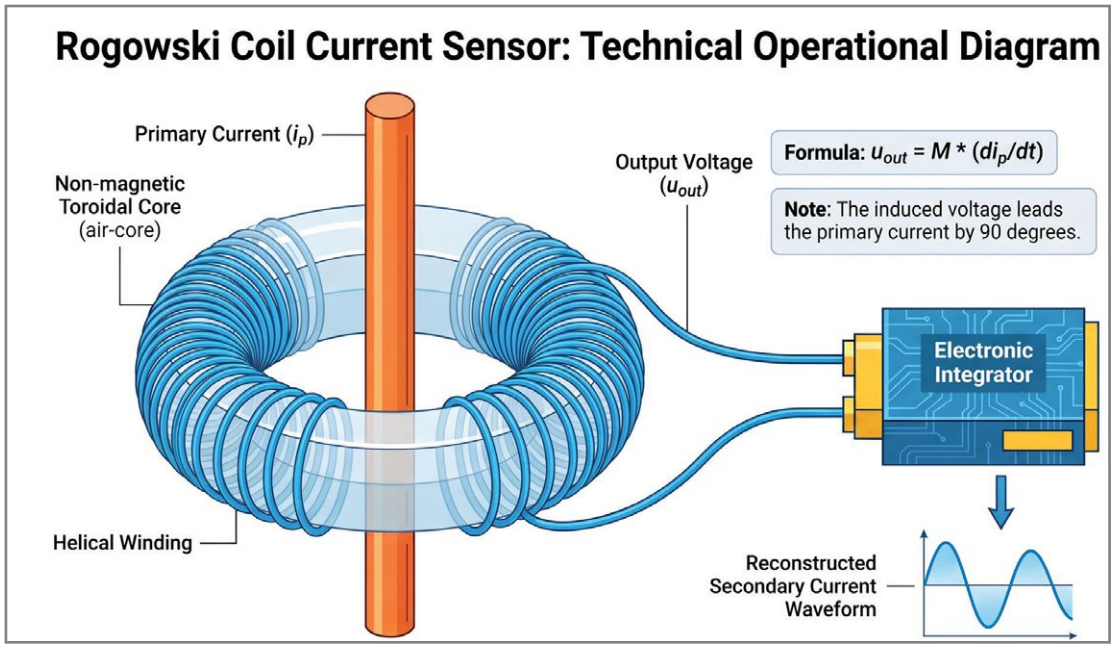


Figure 1: *Rogowski Coil Diagram*

- **Secondary Winding.** The secondary wire is wound around this core with minimized losses.
- **Integrated Shunt Resistor (*Rsh*).** This is the defining feature of the sensor. The secondary winding is internally terminated by a precision resistor, which acts as a current-to-voltage converter.
- **Proportional Output Signal.** The voltage measured across the shunt resistor (*Us*) serves as the output signal. Because it is directly proportional to the primary current (*Ip*), the output waveform matches the primary waveform perfectly.

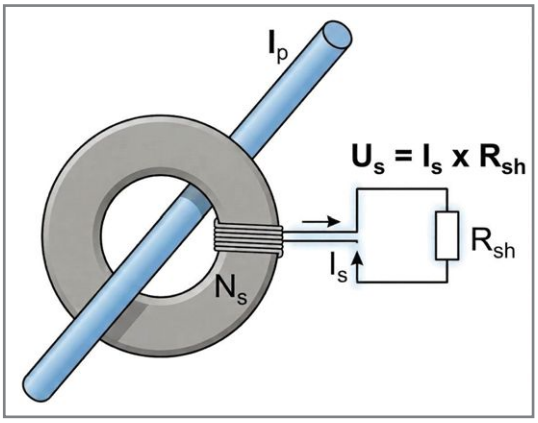


Figure 2: *Low-Power Instrument Transformer*

Comparison to Rogowski coils

While both are considered LPCTs under the IEC 61869-10 standard, they operate on different mathematical principles, as seen in Table 1.

Field Advantages

- **Simplified Testing.** Since the output is proportional and lacks a 90-degree phase shift, specialized test sets do not need to apply complex derivative math to simulate the primary current.
- **Standardization.** These sensors provide a standardized low-voltage analog output (often 22.5 mV, 150 mV, or 225 mV) that is directly compatible with modern relays featuring high-impedance inputs.
- **Safety.** Like all LPITs, the internal shunt resistor ensures there is no risk of hazardous high-voltage spikes if the secondary terminals are accidentally opened while the primary is energized

Optical current transformers are current sensors that operate on the Faraday effect, in which the plane of polarized light passing through an optical fiber is rotated by a magnetic field proportional to the primary current, enabling high-precision measurements without electromagnetic induction [10]. Optical current transformers are expensive, which limits their use to 115 kV and above systems [3].

Resistive current sensors use a shunt resistor placed directly in the primary circuit, converting current into a proportional voltage via Ohm's law, providing a high-precision, non-magnetic alternative for localized sensing [11].

All the current sensors mentioned above convert the current signal into an equivalent

Table 1: *Comparison Between LOPO and Rogowski Coils*

Feature	Iron-Core LPCT (LOPO)	Rogowski Coil
Core Material	Iron (ferromagnetic)	Air (non-magnetic)
Output Type	Proportional to current (*I*)	Derivative of current (*di/dt*)
Signal Processing	No integrator required	Integration required to reconstruct waveform
Saturation	Can saturate at high faults	Inherently non-saturable
Phase Shift	Matches primary phase	90-degree phase lead

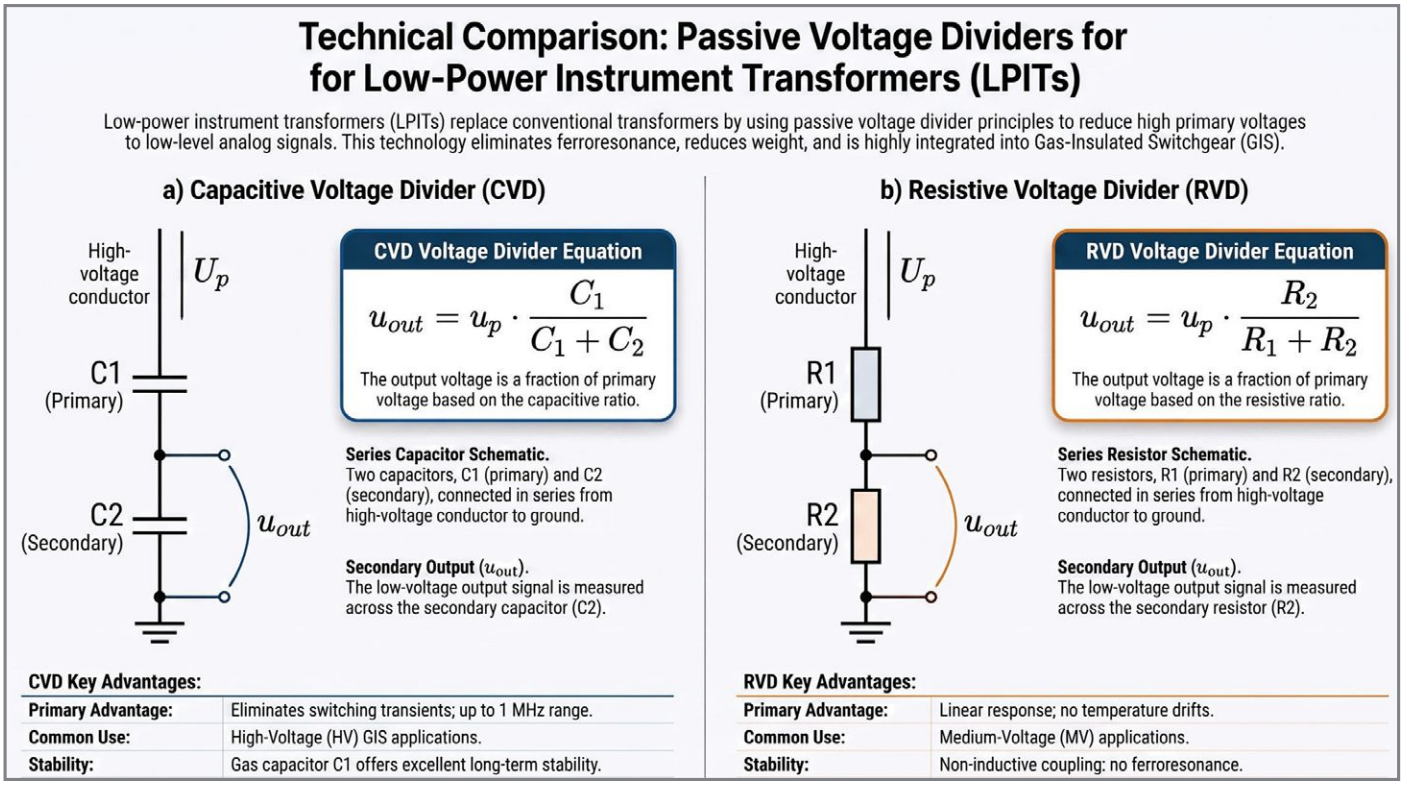


Figure 3: *Capacitive vs Resistive Voltage Dividers*

low-magnitude voltage signal, which is interpreted by the relay as a current input [12].

VOLTAGE SENSORS

Voltage sensing is typically achieved through capacitive divider networks that use a series of capacitors to reduce the high-voltage input to a safe, low-power level suitable for processing [13]. Other voltage-sensing devices use resistive dividers. These resistive voltage dividers operate by forming a simple voltage drop across high-impedance resistors, offering accuracy for steady-state measurements, though they may have transient performance limitations [14].

STANDARDIZED OUTPUT LEVELS FOR LOW-ENERGY ANALOG SENSORS

According to IEEE Std. C37.92-2023, LEA interfaces are standardized into different classes based on their nominal signals and the applications they serve. These nominal levels (1 p.u.) correspond to the rated primary rms value of current (*In*) or voltage (*Vn*) in the measured circuit.

Table 2: *Nominal LEA Output Levels, Maximum Values, and Dynamic Ranges*

Interface Classification	Nominal Output Level (1 p.u. rms)	Maximum Output Value (Peak Instantaneous)	Dynamic Range (Peak Instantaneous)	Notes
Current - Class LV	22.5 mV	1.273 V	0.05 to 40	Widely used industry standard for current measurement
Current - Class HV	200 mV	11.31 V	0.05 to 40	Standard level often used for protection applications
Current - Optional Class LV (Metering)	225 mV	Saturates above 1.273 V	Up to 4	Intended for informational metering applications

Continued — Table 2: *Nominal LEA Output Levels, Maximum Values, and Dynamic Ranges*

Interface Classification	Nominal Output Level (1 p.u. rms)	Maximum Output Value (Peak Instantaneous)	Dynamic Range (Peak Instantaneous)	Notes
Current - Optional Class HV (Metering)	2 V	Saturates above 11.31 V	Up to 4	Intended for informational metering applications
Voltage - Class LV	450 mV	1.273 V	0.05 to 2.0	Standard low-range voltage classification
Voltage - Class HV	4 V	11.31 V	0.05 to 2.0	Standard high-range voltage classification

Table 2 summarizes the common nominal levels, maximum output peak values, and dynamic ranges for current- and voltage-sensing systems.

Key Technical Considerations

- **Dynamic Range.** Current-sensing systems must accommodate a wide dynamic range to capture everything from low-load currents to high-magnitude faults. Voltage-sensing systems focus on a range around nominal system voltage, generally reaching up to twice the rated voltage.
- **Optional Current Outputs.** The optional 225 mV and 2 V outputs are specifically intended for informational metering applications where a smaller dynamic range (4 p.u.) is acceptable.
- **Peak Value Calculation.** The maximum instantaneous values are calculated based on the dynamic range and the peak factor (*rms*×*dynamic range*×2). For example, the maximum output for Class LV Current is 0.0225 V×40×2≈1.273 V.
- **High-Voltage Divider Ratios.** In specific applications such as pole-top reclosers, it is common to use a standardized 10,000:1 ratio to transform primary AC voltage to these lower LEA levels. Regardless of the ratio used, the standard ensures that the relay physically receives signals typically less than 11.31 V peak.

STANDARDIZED CONNECTOR INTERFACES FOR LPITS

Many relay manufacturers now offer dedicated LPIT-compatible inputs that follow IEEE C37.92 and IEC 61869 standards, facilitating seamless plug-and-play integration. An important difference between the use of LPIT and regular instrument transformers concerns the connections at the relay. Instead of using traditional terminal blocks with bolted connections, these sensors utilize specialized low-voltage connectors, such as RJ45 or bayonet-style locking interfaces, to ensure signal integrity and simplify field installation [15]. The backplane of an SEL 787 relay is shown in Figure 4 as an example where E and Z terminals have been replaced by RJ45 inputs for both voltages and currents.

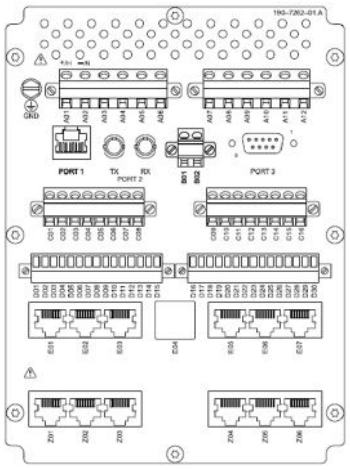


Figure 4: *Backplane of SEL 787 Relay*

Although the most common type of connector used to interface LPITs with modern protection relays is the shielded RJ45 connector, they are not the only type of connector used. According to IEEE Std C37.92-2023, the preferred interface connectors are specifically the RJ45 type and the M12 type.

The specific characteristics and applications of these connectors are detailed below:

1. RJ45 Connectors

- **Widespread Use:** This is the industry-standard connector for most primary distribution applications and is used by major manufacturers.
- **Physical Interface:** Although these connectors are physically identical to standard Ethernet plugs, they are not Ethernet ports and carry point-to-point LEA signals.
- **Cabling:** They typically utilize shielded twisted-pair cables (minimum Cat 5E) to maintain signal integrity and ensure electromagnetic compatibility (EMC).
- **Distance Limits:** Standards such as IEC 61869 limit the use of RJ45 connectors to installations where the distance between the LPIT and the relay is less than 10 meters.
- **Standardized Pinouts:** Both IEEE C37.92 and IEC 61869-6 define specific pin assignments for these connectors to ensure multi-vendor interoperability. For example, a common pinout uses Pins 1 and 2 for current (LPCT) signals and Pins 7 and 8 for voltage (LPVT) signals.

2. M12 Connectors

- **Construction:** The M12 is an 8-way, shielded circular connector that often features a locking nut for secure attachment.
- **Suitability:** Like the RJ45, it is a preferred standard for LEA interfaces, particularly when ruggedness and shielding against environmental factors are required.

3. Legacy and Alternative Connector Types

While RJ45 and M12 are the modern standards, other connectors may be encountered:

- **Twin-BNC:** Some older or specialized IEDs utilize Twin-BNC connectors; adapters are available to convert these to the standard RJ45 interface.
- **Ferrules:** Certain fault-passage indicators or specific product versions may use simple **wire ferrules** for terminal-block connections rather than a modular plug.
- **Terminal Blocks:** For testing and commissioning, LPIT analog terminal blocks may be used to provide a classic secondary analog injection point.

Standardization of these connectors and their pinouts is critical for a "plug-and-play" system, allowing sensors from one manufacturer to be seamlessly integrated with relays from another.

Despite the IEEE C37.92 standard recommendations to integrate a voltage and a current channel in the same connector, some protection relay sensor inputs separate voltage and current channels into different input connectors.

ADVANTAGES OF USING LPITs

In general, LPITs offer significantly improved linearity and accuracy, while eliminating the risks of magnetic saturation and ferroresonance common in traditional iron-core inductive transformers [16]. Table 3 summarizes the advantages of using LPIT over conventional CT and VT.

CONCLUSION

LPITs are not new in the industry, but their use is increasing at a rapid pace due to factors such as flexibility, greater growth potential, increased pressure of digitalization in substations, lower price, and smaller footprint when compared with conventional instrument transformers. NW

Table 3: *Advantages of LPIT vs. Conventional Instrument Transformers*

Category	Primary Advantage	Technical Description
Safety	**Elimination of Open-Circuit Hazards**	LPIT current sensors (LPCTs) like Rogowski coils output millivolt signals, removing the risk of lethal high-voltage spikes if a secondary circuit is opened while energized.
	Ferroresonance Immunity	Because voltage sensors (LPVTs) use passive dividers rather than ferromagnetic cores, they are inherently immune to ferroresonance.
Measurement Performance	**Linearity and Dynamic Range**	Air-core designs ensure no magnetic saturation, allowing a single sensor to accurately measure from nominal values up to 100 kA faults.
	Wide Bandwidth	LPITs provide high-fidelity data accurate up to the 50th harmonic, ideal for power quality and transient analysis.
	Dual Rating Capability	A single sensor can satisfy both high-precision metering (e.g., Class 0.2S) and protection needs (e.g., 5P), reducing hardware requirements.
Physical & Mechanical	**Drastic Size and Weight Reduction**	Eliminating iron cores allows for massive reductions; for example, a sensor might weigh 1.5 lb vs. 38 lb for a conventional unit.
	Switchgear Optimization	Integrated sensors can reduce gas-insulated switchgear (GIS) bay length by 30% and total weight by 25%.
Operational Flexibility	**Software-Defined Ratings**	Unlike fixed-ratio conventional ITs, LPIT primary ratings are configurable via relay software settings, simplifying stock and future upgrades.
	Energy Efficiency	LPITs operate with negligible power losses and eliminate hysteresis/eddy current losses associated with conventional cores.
Environmental & Maintenance	**Sustainability**	LPITs use significantly less copper, steel, and insulation gas (SF6), contributing to a lower carbon footprint.
	Condition-Based Maintenance	Integrated self-check diagnostics allow for continuous monitoring, enabling utilities to move from time-based to condition-based maintenance.
	Simplified Field Testing	LPVTs do not require disconnection during switchgear power-frequency voltage tests, significantly reducing commissioning time.

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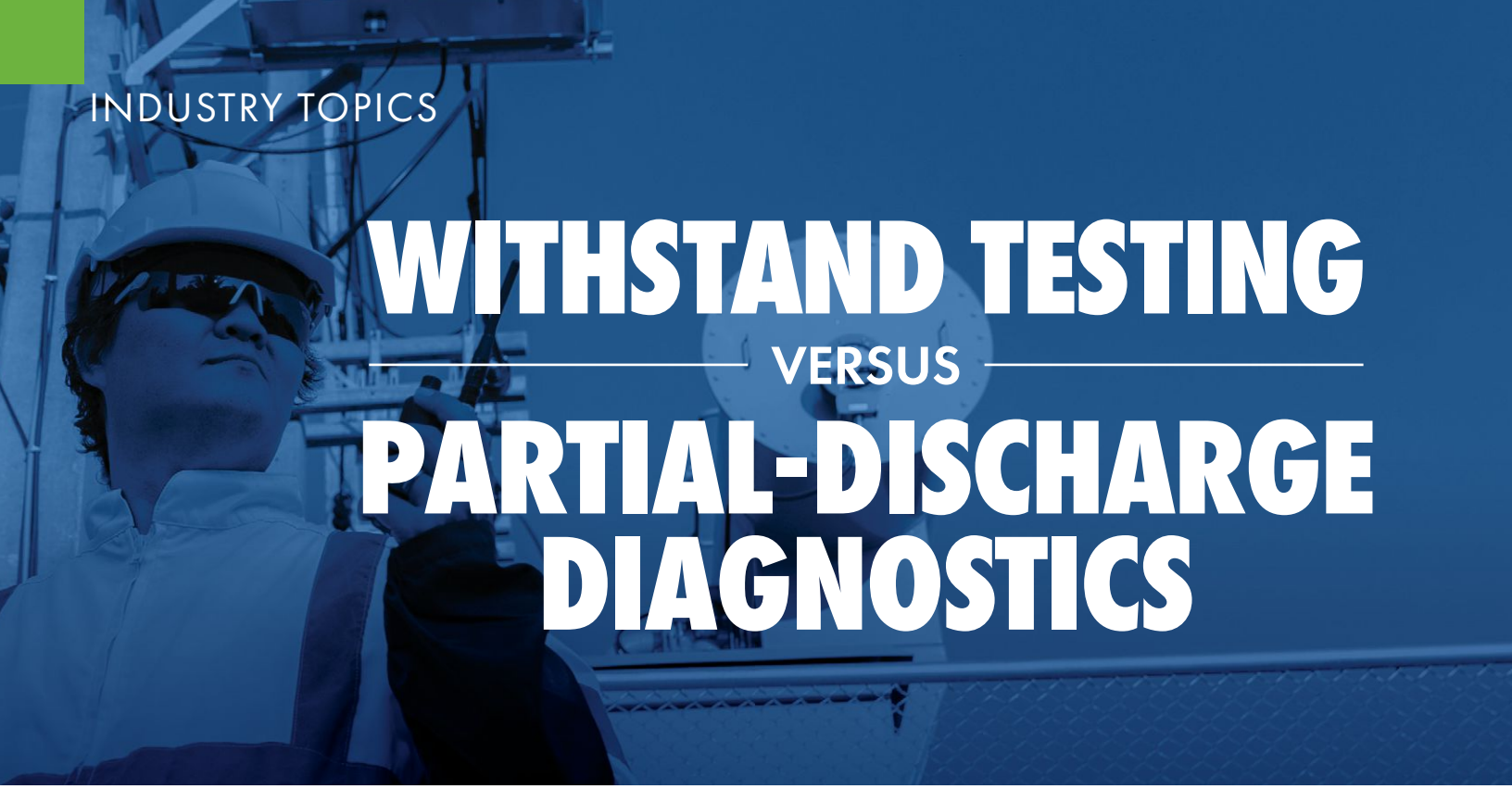
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Dhanabal Mani *is Director of Relay Software Development at Doble-Megger. He led the commissioning of India's groundbreaking 400 kV IEC 61850 substation in Madhya Pradesh while working as the lead commissioning engineer at ABB India Ltd. Dhanabal also worked as an R&D engineer at ABB Ltd in Sweden, developing relay applications. With over 22 years of experience in protective relaying, he has published numerous articles and presented at prestigious international conferences, highlighting his significant contributions to the field.*



WITHSTAND TESTING VERSUS PARTIAL-DISCHARGE DIAGNOSTICS

BY DON GENUTIS, *RESA Power Services*

Very-low-frequency (VLF) withstand testing is a widely accepted method for commissioning and acceptance testing of newly installed medium-voltage cable systems. Many specifications require a one-hour VLF withstand test at elevated voltage levels to demonstrate the integrity of the installed cable system before energization.

However, a simple pass-fail withstand test provides limited information about the condition of a cable system that survives the test beyond the obvious, that the cable can withstand the overpotential. It does not, by itself, identify or locate partial discharge (PD) activity or the insulation defects associated with that activity that may be present during the test. Questions also remain regarding the effect of prolonged elevated-voltage exposure on cable accessories, particularly when partial discharge initiates.

CABLE ACCESSORIES AND ELEVATED-VOLTAGE STRESS

A medium-voltage cable system includes more than the cable insulation itself. Terminations, joints, and separable connectors are often among the most vulnerable components of a medium-voltage cable installation. Field experience and laboratory testing have shown that some accessories may begin exhibiting measurable PD at voltage levels below those used during acceptance withstand testing.

When PD occurs within voids, interfaces, contamination sites, or stress-control defects, localized erosion and electrical treeing may develop. The engineering concern is therefore not simply whether an accessory survives an acceptance test, but whether prolonged exposure above its PD inception level may initiate or accelerate degradation that would not otherwise occur under normal operating conditions.

WITHSTAND TESTING AND DIAGNOSTIC TESTING

A withstand test answers an important question: Did the insulation system survive the specified

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voltage for the prescribed duration? Diagnostic PD testing asks a different set of questions: Is discharge present? At what voltage does it begin? How large is the response? And where is it located?

Damped AC (DAC) PD testing applies a limited number of resonant voltage cycles while simultaneously evaluating the system for PD activity. It should not be viewed as a direct replacement for specification-required acceptance testing. Rather, it can provide diagnostic information regarding cable-system condition and the location of discharge activity while limiting prolonged exposure to elevated stress.

FIELD CASE STUDY

In one case study, four three-phase circuits were evaluated, and three of 24 (12.5%) individual phase terminations exhibited localized PD activity. The 12.5% finding applies only to this limited field sample and is not intended as an estimate of broader prevalence.

The most severe indication was localized to the far-end L3 termination of a 211 m circuit (Figure 1). Partial discharge was evident by 1.3 U0, with approximately 10 nC measured at or below 1.3 U0 and approximately 50 nC during testing from 1.4 to 2.0 U0. The circuit did not satisfy the applicable acceptance criterion.

Before-and-After Verification

The original circuit was reported as failed. After the identified termination was remediated, the repeat DAC PD test found no significant PD positions on any phase (Figure 2). This before-and-after result links the original response to an actionable accessory location and verifies the effectiveness of the repair.

Additional Indications

Two additional circuits satisfied the applicable acceptance criteria, yet each exhibited far-end L1 PD in the 1.4–2.0 U_0 region: approximately 650 pC (Figure 3) and 1,600 pC (Figure 4). IEEE Std. 386-2016, *Separable Insulated Connector Systems for Power Distribution Systems Rated 2.5 kV through 35 kV*, requires separable connectors to have a minimum PD extinction voltage of approximately 1.3 U_0, with PD not exceeding 5 pC at that level. These observations

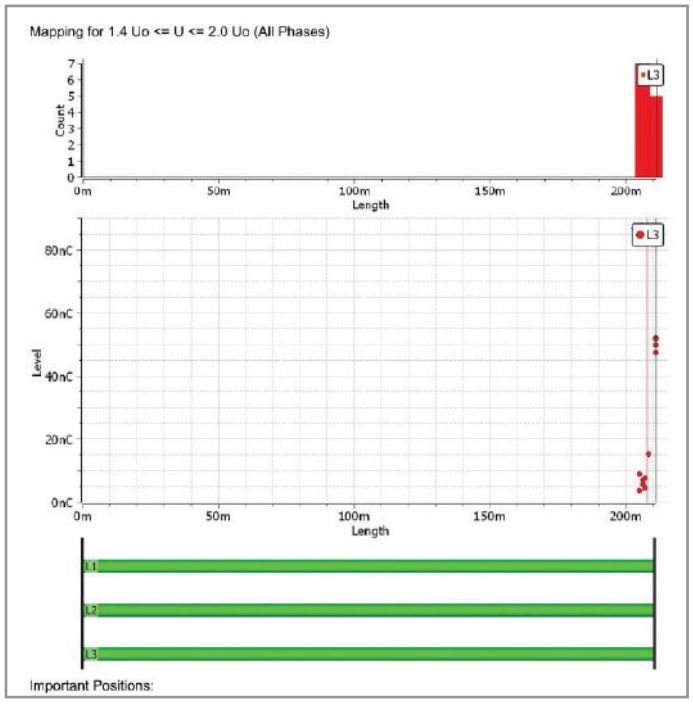


Figure 1: *DAC PD mapping showed localized discharge activity at the far-end L3 termination.*

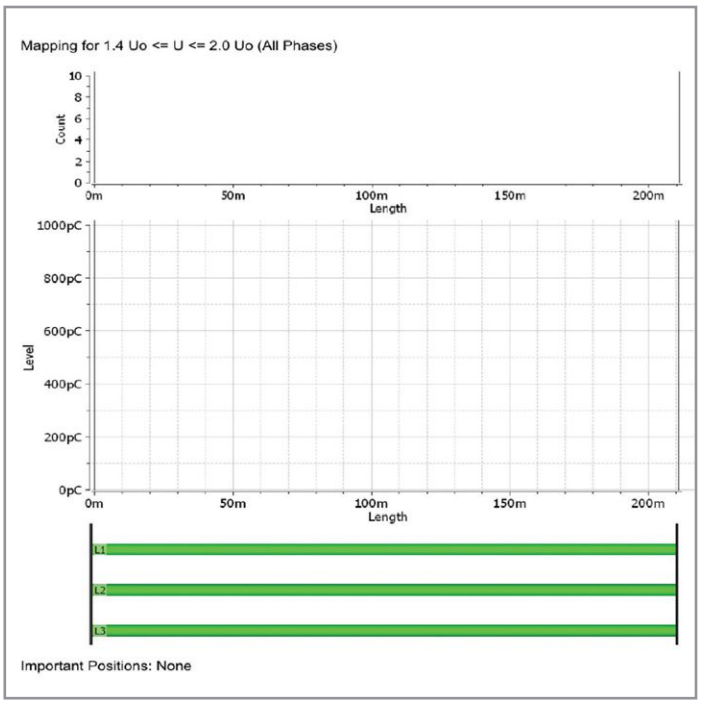


Figure 2: *Retest mapping of the corrected circuit in the 1.4–2.0 U_0 region showed that no important PD positions were identified.*

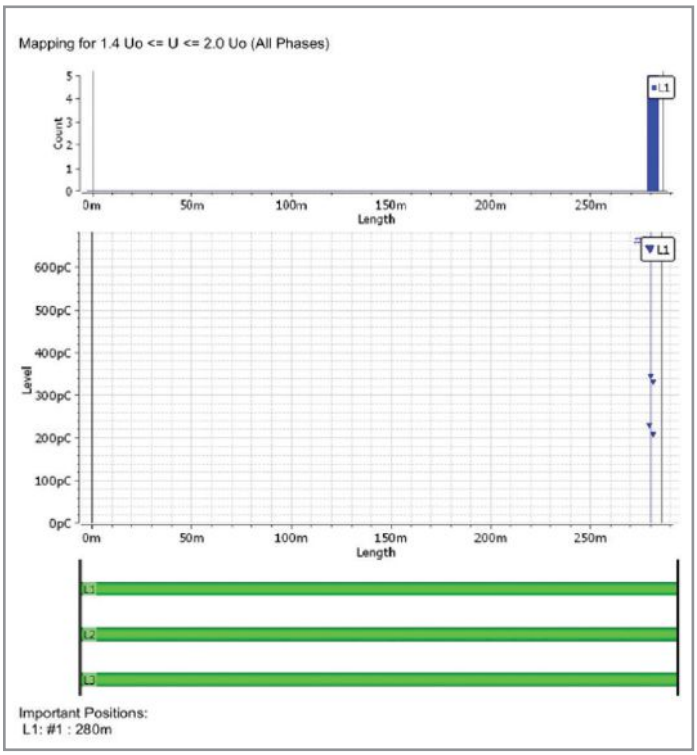


Figure 3: *One circuit showed approximately 650 pC at the far-end L1 termination.*

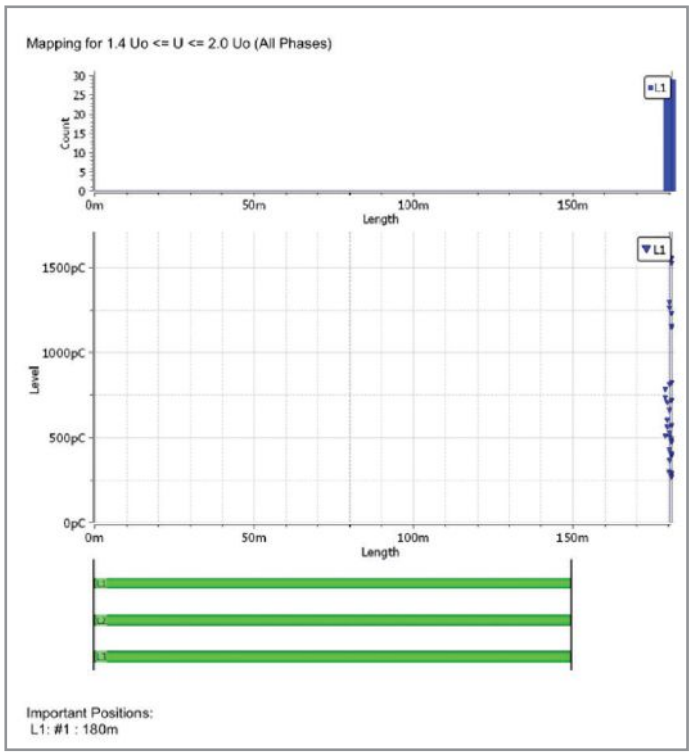


Figure 4: *Another circuit showed approximately 1,600 pC at the far-end L1 termination.*

show that connectors satisfying the applicable PD acceptance-test criteria may nevertheless exhibit substantial discharge activity when subjected to higher voltage stress.

WHAT THE CASE DEMONSTRATES

The case demonstrates two different limitations of a pass/fail result. First, diagnostic PD testing identified and localized a severe termination defect, approaching 50 nC at elevated voltage, which could then be corrected and verified before energization. The field data do not establish when or whether that defect would have progressed to complete failure during a one-hour VLF withstand test. Had the circuit survived the prescribed test, however, the resulting pass indication alone would not have revealed the presence, location, or severity of the underlying PD activity.

Second, two additional terminations exhibited measurable PD at elevated voltage, even though the associated circuits met the acceptance criteria of the applicable testing specification. A successful withstand result, therefore, does not establish that an accessory remained electrically unaffected during the test. Where repetitive PD is present at elevated voltage, insulation degradation may occur, and an existing defect may be worsened even though the circuit ultimately survives the prescribed withstand period. The field data in this case do not quantify the amount of such degradation or establish that a particular accessory would have failed during the withstand test.

During a one-hour VLF withstand test at 2.0 U0, the affected accessories would remain exposed to elevated electrical stress for the prescribed withstand duration.

The value added by DAC PD testing in this case was therefore diagnostic in two important respects. For the most severe indication, it detected and localized the discharge before energization and confirmed that corrective

work removed the identified response. For the two additional terminations, it identified lower-magnitude discharge activity at elevated voltage, even though those terminations satisfied the applicable acceptance criterion. Without diagnostic PD information, those conditions could have remained unidentified while the accessories were subjected to the prescribed elevated voltage withstand duration with partial discharge present.

REPETITION AND DISCHARGE SEVERITY

Once PD initiates at an existing termination defect or interface, continued elevated test voltage can sustain repetitive discharge activity. The field records establish that this can occur at elevated voltage in terminations acceptable at the applicable lower-voltage PD criterion; they do not establish a specific discharge count or quantify resulting damage. Apparent-charge magnitude can be difficult to visualize physically. Published laboratory investigations provide a useful perspective by showing that repetitive PD at substantially lower apparent-charge levels can produce observable insulation deterioration. In one reported insulation system, surface-discharge activity in approximately the 500 pC to 5 nC range was sufficient to continue degradation, with approximately 1 nC associated with permanent damage to cellulose fibers. Other controlled testing of solid epoxy insulation reported progressive deterioration under repetitive PD in approximately the 100 to 1,000 pC range.

These laboratory results are not directly transferable to the specific materials, interfaces, geometry, or electrical-stress distribution of a modern separable cable connector. Apparent charge alone also cannot be used to infer equivalent energy deposition or damage. The studies nevertheless provide a useful physical perspective: Repetitive discharge activity within or along polymeric insulation systems can produce progressive localized degradation, and the rate and significance of that degradation depend strongly on the defect, material, interface, electric-field distribution, and duration of exposure.The comparison is not intended to establish equivalent damage. Rather, it illustrates why repetitive discharge of this magnitude during prolonged elevated-voltage exposure should not be regarded simply as an insignificant electrical indication.

CONCLUSION

One-hour VLF withstand testing remains an established acceptance practice addressed by IEEE 400.2-2024, *IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)*. However, the interaction between elevated acceptance-test voltages and accessory PD performance characteristics deserves careful consideration and further investigation.

The issue is not merely whether the cable system survives the acceptance test. The more important question is whether the test promotes the long-term reliability expected of the system. This raises a further question: When repetitive PD is present during prolonged elevated-voltage exposure, could the withstand test itself contribute to insulation degradation and become counterproductive to the long-term reliability it is intended to support? A successful withstand test alone may not fully characterize the condition or future performance of the cable system when PD is present during prolonged overvoltage exposure. Acceptance testing may therefore benefit from approaches that not only demonstrate insulation survival, but also provide insight into the presence, magnitude, and location of potentially damaging discharge activity. Diagnostic PD methods can add information beyond a simple pass-fail result, while preserving the primary objective of acceptance testing: placing reliable assets into long-term service. NW

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IEEE C57.166-2026

A NEW UNIFIED GUIDE FOR THE ACCEPTANCE AND MAINTENANCE OF TRANSFORMER INSULATING LIQUIDS

BY SCOTT REED, *MVA*

The publication of IEEE C57.166-2026, *Guide for Acceptance and Maintenance of Insulating Liquids in Transformers and Related Equipment*, represents a significant change in how the industry evaluates and maintains insulating liquids. Rather than maintaining separate guides for individual liquid types, C57.166 brings the principal transformer insulating liquids into a single document and, importantly, updates much of the technical guidance used to evaluate liquids in service.

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C57.166 supersedes four existing IEEE guides: C57.106 for mineral oil, C57.111 for silicone liquid, C57.121 for less-flammable hydrocarbon (LFH) liquid, and C57.147 for natural ester liquid. It also introduces synthetic ester liquid, which previously did not have its own IEEE acceptance and maintenance guide. The result is guidance that covers five insulating liquids—mineral oil, LFH, natural ester, synthetic ester, and silicone—within a common framework.

For transformer owners and laboratories, however, C57.166 should not be viewed simply as four older documents combined into one. Numerous technical changes were made during development. This article focuses primarily on how those changes affect the evaluation of in-service transformers.

A COMMON APPROACH TO IN-SERVICE LIQUIDS

One of the most useful changes is the establishment of a common philosophy for evaluating all five liquid types.

C57.166 emphasizes that no single liquid test should be used as the sole criterion for judging

transformer condition. Results should instead be evaluated alongside historical trends, dissolved gas analysis (DGA), electrical testing, and the transformer's overall condition. For example, treating poor-quality liquid without investigating an active gassing condition—or simply dehydrating the liquid when the transformer's solid insulation is known to be wet—may fail to address the underlying problem.

The guide establishes three general conditions:

- Condition I represents a liquid satisfactory for continued use.
- Condition II applies primarily when dielectric breakdown voltage and/or water requirements are not met, and reconditioning, such as filtration or vacuum dehydration, may be appropriate.
- Condition III represents a more severely deteriorated liquid, particularly when properties such as interfacial tension, acid number, and power factor exceed the recommended limits.

These conditions previously existed for mineral oil and were labeled as classes, but they did not exist for the other four fluids. Now, they are also a part of the fluid evaluation and classification for the other four fluid types.

Another important feature is the consistent use of voltage class. The guide's Table 4 establishes in-service thresholds for ≤69 kV, >69 kV to <230 kV, and ≥230 kV. This recognizes that acceptable liquid condition is not necessarily independent of the electrical stresses associated with the equipment in which the liquid is operating.

MINERAL OIL: FAMILIAR BUT AN IMPORTANT CHANGE

Mineral oil users will find many familiar values in C57.166 because the in-service limits in C57.106 were already well developed.

For example, C57.106 established ASTM D1816 dielectric breakdown limits of 23/40 kV at 1 mm/2 mm for equipment ≤69 kV; 28/47 kV for >69 kV to <230 kV; and 30/50 kV for ≥230 kV. It also established power factor limits of 0.5% at 25°C and 5.0% at 100°C, with IFT minimums of 25, 30, and 32 mN/m as voltage class increases. Those values are carried into the unified in-service table in C57.166.

One important change, however, is the disappearance of ASTM D877 from the transformer in-service limits. D877 is no longer an acceptable dielectric test for testing transformer fluids. This is because it has a poor correlation with predicting performance in an actual transformer.

C57.106 still included D877 in its Table 3. C57.166 uses ASTM D1816 for the dielectric breakdown evaluation of both unused and in-service mineral oil and explains that D1816 is more responsive to particles and dissolved water and therefore provides a better evaluation of changes occurring in transformer liquid.

The water limits for mineral oil remain familiar as well: 35 mg/kg (ppm) for equipment rated 69 kV and below; 25 mg/kg for the intermediate-voltage class; and 20 mg/kg for equipment rated 230 kV and above. C57.166 also notes that absolute water content is strongly influenced by liquid temperature and that percent saturation should be considered, particularly at lower temperatures. This is important when interpreting a sample rather than treating the reported ppm value as an isolated pass/fail measurement.

LESS-FLAMMABLE HYDROCARBON: A MAJOR EXPANSION

The changes for less-flammable hydrocarbon (LFH) liquids are more substantial.

C57.121-1998 provided essentially one set of acceptable service-aged values without differentiating among transformer voltage classes. Its Table 4 specified, among other values, D1816 dielectric breakdown minimums of 23 kV at a 1 mm gap and 34 kV at a 2 mm gap, a maximum power factor of 1.0% at 25°C, a maximum acid number of 0.20 mg KOH/g,

a maximum water of 35 ppm, a minimum IFT of 24 mN/m, and a minimum 300°C fire point.

C57.166 places LFH liquids into the same voltage-class structure used for mineral oil.

For ≤69 kV equipment, the 2 mm D1816 minimum increases from 34 kV to 40 kV, and the IFT minimum increases from 24 to 25 mN/m. The 25°C power-factor limit is tightened from 1.0% to 0.5%. More importantly, the guide now establishes increasingly restrictive limits for the >69 kV to <230 kV and ≥230 kV classes. The dielectric values become 28/47 kV and 30/50 kV respectively, while IFT increases to 30 and 32 mN/m.

This is a meaningful change. The older LFH guide treated service-aged fluid largely as one class. C57.166 recognizes that the condition criteria appropriate for a lower-voltage transformer are not necessarily sufficient for higher-voltage equipment.

C57.166 also aligns the LFH acid-number and water limits with the voltage-specific values used for mineral oil. Acid number is limited to 0.20, 0.15, and 0.10 mg KOH/g as voltage class increases, while water is limited to 35, 25, and 20 mg/kg. The 300°C minimum fire point remains an important characteristic of the less-flammable classification. These changes give the owner a more detailed set of reference points for trending an LFH-filled transformer in service.

NATURAL ESTER: DEFINING IN-SERVICE LIMITS

Natural ester guidance has evolved considerably since C57.147-2018.

The earlier guide established dielectric strength and water limits by voltage class but acknowledged significant areas where sufficient service experience was not yet available. Most notably, C57.147 stated that there was insufficient field data analysis to establish reliable recommended limits for dissipation factor. The ≥230 kV values were also identified as provisional.

C57.166 removes that provisional status and provides a much more complete set of in-service criteria.

Natural ester now has a 25°C power factor limit of less than 3.0% for all three voltage classes. The guide also establishes IFT minimums of 10, 12, and 14 mN/m for ≤69 kV, >69 kV to <230 kV, and ≥230 kV equipment, respectively.

Acid number is also formally incorporated into the in-service limits: ≤0.5 mg KOH/g for ≤69 kV and ≤0.3 mg KOH/g for the two higher-voltage classes. Water limits remain 450, 350, and 200 mg/kg as voltage class increases. And C57.166 clearly establishes the continued-use criterion as a viscosity increase of ≤10% from the value measured before energization.

Taken together, these changes move natural ester evaluation beyond the more provisional approach found in the earlier guide and provide utilities and laboratories with a substantially more complete framework for interpreting in-service results.

The differences in allowable water content are particularly important when comparing natural ester with mineral oil. Natural ester can dissolve considerably more water, so the absolute ppm values should not be interpreted using mineral oil experience. C57.166 retains the higher natural-ester water limits while placing them in the same table with the other liquids. This makes the chemical differences visible to the user and reinforces the need to interpret each liquid according to its own characteristics rather than against a single universal set of limits.

SYNTHETIC ESTER: AN ENTIRELY NEW CATEGORY

Perhaps the most significant addition to C57.166 is synthetic ester.

The four predecessor guides contained no corresponding IEEE acceptance and maintenance guide for this liquid. C57.166 now places synthetic ester alongside the other major transformer insulating liquids and references ASTM D8240 for unused-liquid requirements.

The guide also provides useful background on why synthetic ester cannot simply be treated as either mineral oil or natural ester. Synthetic esters are manufactured by reacting a polyol with long-chain carboxylic acids, allowing properties to be tailored through the selection of starting materials. Because transformer synthetic esters are manufactured using saturated acids, they have high oxidation resistance. They also have a much higher water-saturation capability than mineral oil and may hold substantially more water while maintaining dielectric capability.

C57.166 now gives synthetic ester its own in-service limits. Dielectric breakdown follows the same D1816 voltage-class limits applied to mineral oil, LFH, and natural ester. Power factor is less than 3.0% at 25°C. IFT limits are ≥11, ≥14, and ≥16 mN/m, while acid-number limits are ≤1.0, ≤1.0, and ≤0.5 mg KOH/g as voltage class increases. Water limits are 450, 350, and 200 mg/kg.

This provides owners of synthetic-ester-filled transformers with an IEEE framework for routine liquid-condition assessment that previously did not exist in these acceptance and maintenance guides.

The inclusion of synthetic ester also affects routine laboratory practice. The guide identifies ASTM D1816 for dielectric breakdown, ASTM D924 for dissipation factor, ASTM D971 for interfacial tension, ASTM D974 for acid number, and ASTM D1533 for water content, while recognizing that some tests used for other liquids may not be applicable. That distinction is useful because synthetic ester now has defined IEEE reference values rather than requiring the owner or laboratory to extrapolate from mineral-oil or natural-ester guidance.

SILICONE: MODERNIZING OLDER GUIDANCE

Silicone presented a different challenge because C57.111 dated to 1989.

That document specified a 25 kV minimum dielectric breakdown value using ASTM D877, maximum water of 100 ppm, maximum power factor of 0.2% at 25°C, and maximum acid number of 0.2 mg KOH/g for service-aged silicone liquid.

C57.166 retains several of those fundamental condition indicators—most notably the 0.2% power factor, 100 mg/kg water, and 0.2 mg KOH/g acid-number limits for applicable silicone installations—but integrates silicone into the modern test-method framework, including D1816 as the approved dielectric test methodology.

The guide also recognizes that not every test used for hydrocarbon and ester liquids is appropriate for silicone. For example, the guide's Table 4 lists IFT as not applicable. This is an important benefit of the unified format: The user can see not only different numerical limits, but also where applying the same test across every insulating liquid would be inappropriate.

USING C57.166 FOR IN-SERVICE TRANSFORMER EVALUATION

For users of the previous guides, the practical change is that acceptance and maintenance information for the major transformer insulating liquids is now available in one document and presented in a consistent format. Many established limits remain familiar, but C57.166 makes it easier to identify the appropriate tests and limits for each liquid type.

Mineral oil retains the established voltage-class approach with several updates to test practice. LFH liquids now have more detailed voltage-specific criteria. Natural ester includes defined limits for properties that previously had limited field data. Silicone is incorporated into the same framework, and synthetic ester is included with its own acceptance and in-service criteria.

For transformer owners, the guide's Table 4 provides a direct reference for continued-use limits by liquid type and voltage class. The limits are reference points for evaluation and trending, not automatic removal-from-service criteria. Each case should be evaluated individually, and significant changes from

previous test results should be investigated. It is critical that the lab selected to test transformer fluids can distinguish the thresholds for each fluid type. For example, as a service company, it will reflect poorly if a report is submitted that states natural ester fluid failed moisture with a 155 mg/kg (ppm) test value, when the acceptable value is 200 mg/kg or higher, depending on the voltage class.

IEEE C57.166 provides an updated reference for evaluating insulating liquids in in-service transformers. Users familiar with C57.106, C57.111, C57.121, and C57.147 will recognize the technical foundation, but should review the new tables and liquid-specific guidance carefully. Several limits have changed, additional criteria have been established, and synthetic ester has been added as a separate liquid category.



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JON BUCCIARELLI

NETA Corporate Alliance Partners (CAPs) are industry-leading companies that have joined forces with NETA to work together toward a common aim: improving quality, safety, and electrical system reliability.

In this continuing series highlighting NETA's CAPs, the Winter 2026 *NETA World* Corporate Alliance Corner features perspectives from leaders across the electrical power industry. These "View from the Bridge" interviews explore the trends, challenges, and opportunities shaping the future of electrical testing and maintenance.

For this issue's CAP Spotlight, we talked with Jon Bucciarelli, President of SDMyers, a company that has spent more than 60 years helping organizations maintain transformers and other critical electrical assets. As the electrical power industry confronts aging infrastructure, increasing demand, constrained maintenance budgets, and a shortage of experienced technical professionals, SDMyers sees an opportunity to combine decades of field experience with better data, diagnostics, and condition-based asset management.

NW: **What is something readers don't know about SDMyers?**

Bucciarelli: Many people know SDMyers for transformer maintenance, oil testing, inspection services, and safety and reliability products, but they may not know how deeply our purpose shapes the way we operate. For more than 60 years, since Stan Myers started the company, we have worked to help keep electric power reliable while building an organization where people are cared for, developed, and encouraged to reach their potential and use their work for something meaningful.

We see that purpose lived out in practical ways every day. It might be an employee taking extra time to help a customer understand a difficult decision, an experienced professional investing in a newer team member, or people supporting a colleague or community need.



We maintain critical equipment, but ultimately, that equipment supports hospitals, schools, industries, businesses, and homes that depend on reliable power. That connection gives our work a significance we never want to take for granted.

NW: **What recent company achievement or milestone are you particularly proud of?**

Bucciarelli: SDMyers recently celebrated its 60th anniversary. Reaching that milestone reflects the trust of our customers and the dedication of generations of employees who have served them. We have continued to grow and evolve without losing the values and sense of purpose on which the company was founded. No president or leadership team can claim a milestone like this as its own. It belongs to the people who built the company, the employees carrying its mission forward today, and the customers who have trusted us with equipment essential to their operations.

Our work has also evolved considerably. What began with analyzing insulating fluid and servicing transformers has expanded to helping customers organize asset data, prioritize maintenance, educate their teams, and develop longer-range capital plans.

The most meaningful way to honor our history is not simply to celebrate it. We must steward it well by continuing to innovate, making thoughtful long-term decisions, and preparing the next generation to lead with the same principles and values.

NW: **What evolution do you see on the horizon that will have a positive impact on your work?**

Bucciarelli: I see the continued evolution of condition-based asset management having a significant positive impact.

Better data, advanced diagnostics, remote monitoring, and the responsible use of artificial intelligence will help utilities and industrial organizations understand the health of critical electrical equipment sooner and act with greater confidence. This evolution can help organizations move from reactive repairs toward planned, risk-based decisions that improve reliability, safety, and stewardship of capital.

Many customers carry enormous responsibility, often with limited time, limited resources, and little margin for error. A facility might have dozens or hundreds of transformers, but a maintenance budget that cannot

address everything at once. The challenge is determining which assets require immediate attention and which can safely continue operating under appropriate monitoring.

Combining oil-test trends, inspection findings, operating history, loading information, and equipment criticality can provide a much clearer picture of risk and help organizations prioritize their resources.

New inspection methods are contributing to that picture as well. Visual and infrared inspections, partial-discharge inspections, electrical testing, and other diagnostic techniques can provide increasingly comprehensive information about asset health. Used appropriately, this information can help identify risk earlier, direct maintenance budgets where they will have the greatest impact, and potentially prevent unexpected failures.

Technology should strengthen engineering judgment and trusted relationships—not replace them.

NW: What challenges do you see going forward for the industry?

Bucciarelli: The industry is being asked to deliver greater reliability while simultaneously managing aging infrastructure, increasing electrical demand, long equipment lead times, and a shortage of experienced technical talent.

Customers are also being asked to sort through increasing amounts of asset information and decide where to invest limited resources. The challenge is turning all that complexity into clear priorities and disciplined decisions that strengthen electrical power systems over the long term.

At the same time, we cannot overlook the workforce challenge. A tremendous amount of knowledge has been built through decades of hands-on experience, and we cannot assume that knowledge will transfer automatically to the next generation.

The industry must be intentional about teaching, mentoring, and creating meaningful career paths. That could mean pairing a newer technician with a veteran in the field or asking an experienced analyst to explain not only what a test result means, but how that result should influence the next maintenance decision.

In my view, the organizations that navigate the coming years most successfully will be those that invest in both people and technology, remain grounded in their values, and build trusted partnerships before a crisis occurs. NW

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EPIC 26 REPLAY

THE NEXT-GENERATION GRID

MICROGRIDS, BATTERY STORAGE, AND POWER RESILIENCE

BY KENNETH VESCOVI, *ABM Electrical Power Solutions*

The U.S. power grid is being asked to do two things it was never designed to do simultaneously: absorb unprecedented new electricity demand while accommodating a rapidly growing number of distributed resources sending power back in the opposite direction.



Battery energy storage systems support grid resiliency, making proper testing and commissioning essential for safe, reliable operation.

For most of the last century, the model was relatively straightforward: electricity flowed in one direction, from large central generating stations through transmission lines and substations to homes and businesses. Today, that model is giving way to a more dynamic, bidirectional system. Behind-the-meter (BTM) resources—including solar, battery storage, electric vehicles (EVs), microgrids, and on-site generation—can now consume, store, generate, and in some cases return power to the grid.

Regulatory and market changes are accelerating that transition, opening the grid to a wider range of distributed assets and giving customers a more active role in how power is generated, stored, consumed, and ultimately managed. The result is a power system that is becoming more decentralized and considerably more complex.

This transformation is occurring just as electricity demand is accelerating after decades of relatively modest load growth. Data centers

and AI infrastructure, expanding industrial activity, and transportation electrification are placing new demands on a grid already facing transmission, distribution, and generation constraints.

For utilities, facility operators, and large power users, that changes the equation. Cost, availability, and reliability can no longer be treated as separate considerations; all three must increasingly be addressed simultaneously. Distributed generation, storage, and increasingly sophisticated controls offer powerful new ways to do that, but they also introduce more equipment, more interfaces, and more potential points of failure. As the grid evolves, testing and commissioning will become even more critical to ensuring that this new energy infrastructure performs safely and reliably when it matters most.

REGULATION OPENS THE GRID TO DISTRIBUTED ENERGY

One of the most significant catalysts for this transformation was the Federal Energy Regulatory Commission's (FERC) Order No. 2222. Issued in 2020 (and refined in 2021), the rule opened wholesale energy, capacity, and ancillary service markets to aggregate distributed energy resources (DERs). In practical terms, resources such as battery storage, smart building controls, and distributed solar can be aggregated and participate in markets once largely reserved for conventional power plants.

That market access comes with new technical requirements. Aggregated DERs can provide services such as frequency regulation, voltage support, capacity, and reserves, placing greater importance on metering, protection, controls, and coordination at points on the system that historically played little or no role in wholesale power markets.

Several states are moving in the same direction. Illinois built on its Climate and Equitable Jobs Act to expand the Illinois Shines Adjustable Block Program, driving rapid growth in both residential rooftop solar and larger distributed generation projects up to 2 MW. New Jersey expanded its community solar program and interconnection rules as part of its clean energy targets. Connecticut rolled its incentive structure into the Energy Storage Solutions program administered by the Public Utilities Regulatory Authority, pairing distributed generation with battery storage to relieve peak demand.

While the approaches vary by market, the broader trend is clear: more customer-owned energy resources are being connected to systems that were not originally designed around two-way power flow. Together, federal market access and state-level deployment are placing new obligations on utilities to accept generation assets that didn't exist on their systems a decade ago and to build the substation and interconnection infrastructure needed to do so safely.



Trained electrical technicians test and maintain equipment to help ensure safe, reliable power infrastructure.

Utilities themselves are also adapting. The Tennessee Valley Authority (TVA) offers an interesting example. Under its Long-Term Partnership Agreements, TVA has created pathways for participating local power companies to generate a portion of

their own power from distributed resources rather than relying exclusively on centrally supplied electricity. Programs like these reflect a broader shift in grid planning. In the right circumstances, integrating distributed generation can offer a faster or more economical path to additional capacity than relying solely on traditional generation and infrastructure expansion.

NEW TECHNOLOGIES DRIVING THE SHIFT

As regulatory changes open the grid to more distributed assets, advances in generation, storage, and controls are accelerating the transition toward a more decentralized energy system. The opportunity is significant, but so is the complexity: each new technology introduces additional equipment, interfaces, protection requirements, and controls that must operate together as an integrated system.

Microgrids and battery energy storage systems (BESS) are becoming increasingly important components of distributed energy infrastructure. Battery storage can complement distributed solar and participate in demand response and other grid services, while microgrids can combine multiple generation sources with storage and controls to operate independently from the broader grid when needed. These systems also introduce power electronics, inverters, and sophisticated control logic that require specialized commissioning and periodic testing beyond what a traditional generator or transformer may require.



Thermal imaging helps detect electrical issues early, reducing unplanned downtime, protecting equipment, and improving operational reliability.

The growing sophistication of these projects is also changing what it means to bring new energy infrastructure online. A modern microgrid may combine solar, generators, fuel cells, battery storage, switchgear, and a control platform within a single system. Each component may perform as designed on its own, but resilience depends on whether the entire system operates correctly, particularly during transitions between grid-connected and islanded operation. That makes integrated testing and commissioning an essential part of system design and deployment, rather than a final step before energization.

Control and monitoring technologies are the connective tissue that makes this increasingly complex operating model work. Distributed energy management systems, advanced metering, and remote monitoring platforms can coordinate large numbers of distributed assets in real time, helping operators understand how and when those resources should respond. But greater connectivity also raises the bar for communication protocols, cybersecurity, and integration testing—particularly when a digital signal, rather than simply a breaker, may be the difference between normal operation and a fault.

The generation mix itself is also expanding. Fuel cells, for example, can provide firm, continuous power alongside intermittent renewable resources, making them particularly relevant for critical facilities and other high-availability applications.

Linear generators are another emerging option, offering modular, dispatchable generation that can operate either in parallel with the grid or independently. Their growing deployment illustrates the expanding range of technologies

available to serve large or constrained loads, particularly where traditional grid expansion may take years.

Small modular reactors (SMRs) are advancing and could eventually add another source of firm generation for certain large-load applications. While widespread commercial deployment remains some distance away, the technology is advancing—and its eventual adoption will depend not only on technical viability, but also on regulatory approvals and the development of appropriate interconnection, protection, and commissioning requirements.

Together, these technologies point toward a grid with more generation sources, stored energy, sophisticated controls, and more interconnection points than ever before. The challenge is no longer simply generating enough electricity. It is ensuring that an increasingly diverse collection of assets can operate safely, reliably, and in coordination with one another.

THE RISE OF ELECTRIFICATION

The scale of this transformation becomes even more significant when viewed against the growth in electricity demand now confronting the industry. According to the North American Electric Reliability Corporation (NERC)'s most recent *Long-Term Reliability Assessment*, summer peak demand across North America is forecast to grow by 224 GW over the next decade—a 69% increase over the prior year's projection—with winter peak demand growing even faster.

Data centers are among the most visible drivers of that growth, with some projections suggesting they could account for as much as 12% of total U.S. electricity consumption within the next few years. But they are only part of the story. Industrial expansion and transportation electrification are also adding significant new loads. Together, these trends are forcing utilities, grid planners, and large power users to confront a question that was far less urgent during decades of relatively modest load growth: Where will the next increment of reliable power come from?

For some large power users, the answer increasingly includes on-site generation. Where fuel supply, permitting, economics, and site conditions allow, distributed generation can supplement utility power, provide additional resiliency, or help support new loads while traditional generation and transmission infrastructure catches up. Existing generation sites may also offer opportunities for repowering or redevelopment as demand grows.

That demand growth brings the challenge of balancing cost, availability, and reliability into much sharper focus. Large power users can no longer assume that sufficient grid capacity will simply be available when and where they need it—or that the most reliable source will necessarily be the most economical. Increasingly, decisions about where power comes from, when it is consumed, and whether it should be generated or stored on site must account for all three considerations simultaneously.

This is changing the role of the customer as well. Large facilities are no longer simply deciding how much electricity to purchase from a utility. Increasingly, they are evaluating when to buy power, when to store it, when to generate it themselves, and—where market structures allow—when distributed assets can provide value back to the grid.

THE NEW ECONOMICS OF POWER

Those choices are fundamentally changing the economics of power. Today, the cost of electricity increasingly depends not only on how much a customer uses, but also when and where it is consumed, the demands it places on local transmission and distribution infrastructure, and the availability of power within a particular market.

But BTM breaks from that model. Instead of paying into that centralized rate structure and waiting years for new transmission or substation capacity, a customer invests directly

in on-site generation, storage, or a linear generator, trading a long-term regulated-rate relationship for upfront capital costs and self-generated power.

The economics can become more dynamic when distributed assets are aggregated through virtual power plants (VPPs). Depending on market rules and utility programs, these resources may create additional value through peak shaving, demand response, or participation in grid services. In that model, a distributed asset is no longer simply equipment serving the facility behind the meter—it can also become a resource for the broader power system.

The trend is particularly visible in the data center market. According to the Cleanview project tracker, 59 planned data centers representing approximately 90 GW of capacity include BTM power generation—more than 25% of planned U.S. data center capacity. While most of that capacity has yet to be built, the scale of planned investment suggests that BTM generation is increasingly being considered part of the long-term power strategy for large, energy-intensive facilities, rather than simply as a temporary response to interconnection delays.

BTM SHIFTS THE COMPLEXITY

BTM generation is not necessarily a one-size-fits-all alternative to a utility connection, as it comes with its own hurdles.

On the regulatory side, emissions permitting is often the primary bottleneck. Some equipment can trigger air permitting timelines that rival the interconnection queues they're meant to avoid. Fuel storage and delivery permits add further complexity for sites running on diesel, LNG, or hydrogen.

On the engineering side, protection and synchronization are the central technical challenges. A BTM plant that will eventually parallel the grid must be designed and tested to meet utility interconnection standards (commonly governed by IEEE Std. 1547-2018, *Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*) well before that connection is made. This means protective relaying, synchronization checks, and anti-islanding controls all need to be commissioned and verified to the same rigor as a utility-scale asset, even if full grid dependence is not the intent.

Getting these elements wrong can result in equipment damage, safety incidents, or commissioning delays that erase the time BTM generation was intended to save. Commissioning is not necessarily a one-time exercise. Protection coordination studies may need to be revisited as load grows, since a system designed for an initial project phase may require reconfiguration as additional generation or grid capacity comes online.

Simply put, BTM can shift complexity rather than eliminate it—trading interconnection queue risk for a set of testing and commissioning demands that deserve the same specialized attention as any utility-scale plant.

TESTING AND COMMISSIONING

A grid built around one-way power flow from a relatively small number of large generating stations demanded one kind of testing and maintenance strategy. A grid built around bidirectional power flow, distributed generation, storage, sophisticated controls, and unprecedented new loads demands another. As more technologies and points of interconnection are layered onto the power system, testing and commissioning must evolve with them.

This is why NETA accreditation matters even more in an increasingly complex power environment. Asset owners, utilities, regulators, and engineering teams still need confidence that electrical equipment has been tested by qualified professionals and is safe to energize, but answering that question is becoming more complicated as the equipment itself evolves.

Inverter-based resources, battery management systems, protection schemes, and increasingly sophisticated control platforms introduce operating characteristics and potential failure points that did not exist in the traditional one-way grid. For a facility navigating an interconnection,

a utility accepting a new class of generation, or an engineering, procurement, and construction (EPC) firm commissioning a microgrid, consistent testing standards and qualified technicians help ensure that new technology does not become untested technology.

The next-generation grid will be more distributed, more dynamic, and more dependent on technologies that communicate and respond to one another in real time. That creates enormous opportunity, but it also introduces more interfaces, more complexity, and more points where something can fail. The technologies powering the grid may change dramatically; the obligation to prove that they will operate safely and reliably cannot. Policy and market forces explain why this transformation is happening. Testing and commissioning will ultimately help determine whether it works. NW

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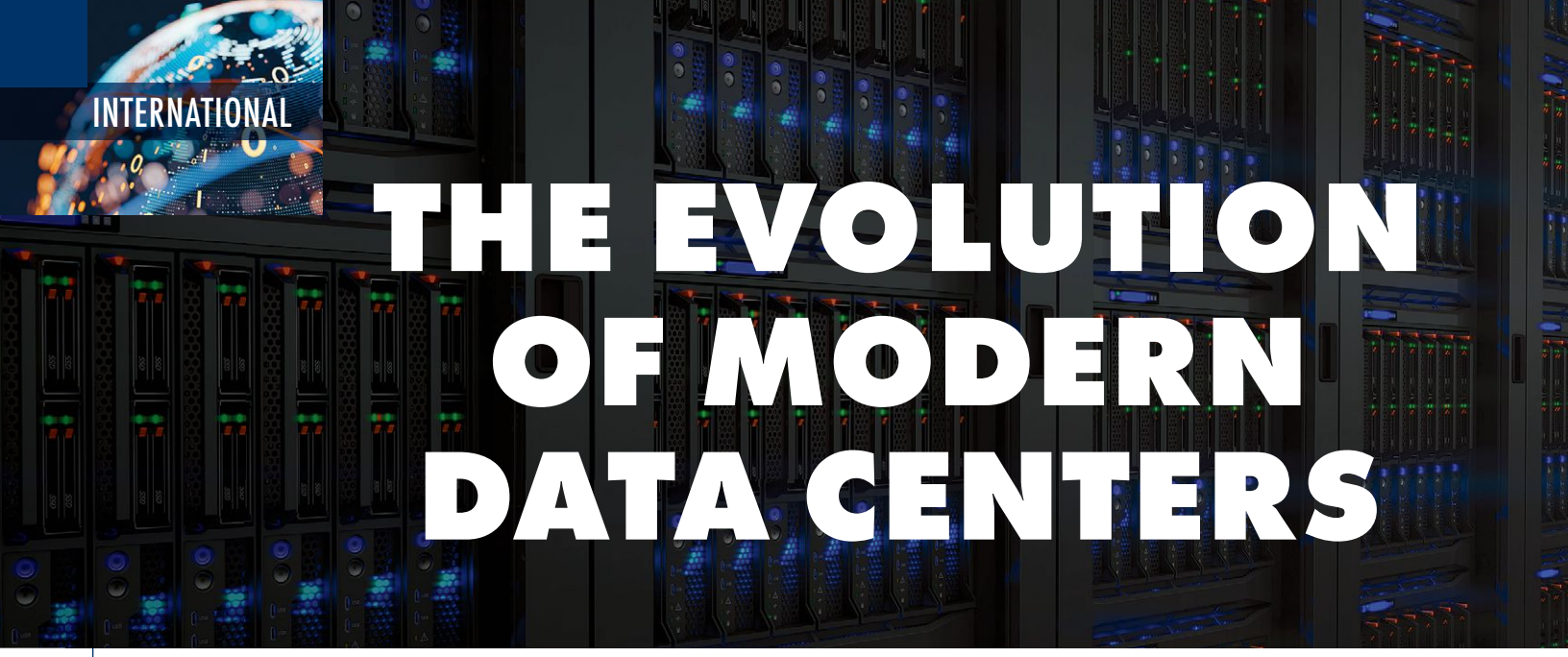
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THE EVOLUTION OF MODERN DATA CENTERS

BY AHMAD NAIMAT, *Commissioning Services International*

Today, data centers have become the essential infrastructure underpinning the digital world. They are responsible for running cloud services, hosting applications, processing data, and supporting artificial intelligence (AI), the Internet of Things (IoT), and other technologies that individuals and organizations rely on daily. With the exponential growth in data volume, the continuous rise in user numbers, and the rapid evolution of digital applications, it is no longer feasible for data centers to continue relying on the traditional approaches of standalone physical servers, manual operations, and limited automation that were common during their inception.

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Over the past several decades, this industry has faced a series of technical challenges, including limited computing resources, low server utilization efficiency, high energy consumption, and the complexity of infrastructure management, alongside a constant demand for faster, more reliable, and scalable services. Overcoming these challenges was not the result of a single innovation; rather, it came through a succession of technological advancements that entirely reshaped the concept of the data center—from simple server rooms through virtualization and cloud computing to hyperscale data centers, accelerated computing, digital twins, and intelligent automation.

As data centers evolved to support increasingly critical and demanding applications, their electrical infrastructure also had to develop to provide greater continuity, reliability, and visibility. The need to maintain uninterrupted operation drove the adoption of increasingly sophisticated power-supply and backup systems, while the growing complexity of data center infrastructure created a need for more advanced methods of monitoring and managing system performance. Technologies such as digital twins and intelligent automation now extend this capability by enabling data center infrastructure to be monitored, analyzed, and managed with greater accuracy and responsiveness.

This article reviews the major phases through which the data center industry has passed, highlighting the drivers behind each stage, and how each development addressed the challenges of the previous phase while paving the way for the next generation of technologies. This evolution has not only transformed how data is processed and managed, but has also fundamentally changed the infrastructure required to keep data centers operating reliably.

FROM SERVER ROOMS TO ENTERPRISE DATA CENTERS

In the early stages of the data center industry's evolution, most organizations relied on small server rooms to run their applications and store their data. These rooms were not designed as integrated infrastructure; instead, they were created to meet specific operational needs, with new hardware added whenever business requirements grew. As a result, servers and storage systems operated in isolation, lacking a unified mechanism to connect them or allow them to share resources efficiently.



The management of these environments relied almost entirely on human intervention. Many processes were executed manually, such as moving backup tapes between devices or locations, in addition to carrying out numerous operational tasks that required the continuous presence of technicians. While this approach was suitable at the time, it was slow, increased the likelihood of human error, and was unable to keep pace with the growing volume of data.

As organizations expanded, data was no longer just files stored when needed; it became one of the most critical assets companies relied on to run their operations and make decisions. Concurrently, servers and storage systems underwent significant development, and multiple manufacturers emerged to offer different solutions and technologies, leading to great diversity in infrastructure within a single organization. It became necessary to connect these disparate systems into a unified network so they could exchange data, share storage resources, and operate as a single, cohesive system rather than remain isolated.

With the increasing number of systems and the complexity of managing them, it became clear that relying on manual operations was no longer a practical option. From here, a new phase began, relying on data center automation, in which storage management, resource allocation, and system monitoring were programmatically managed rather than manually executed. The impact of this shift was not limited to reducing human error; it also improved service delivery speed, increased resource utilization efficiency, and enhanced data storage reliability, while ensuring continuous system uptime.

This transformation had a direct impact on the electrical infrastructure supporting these facilities. As data centers develop from small server rooms into larger, more integrated environments, their electrical systems had to evolve accordingly to support increasing power demands and provide the greater continuity and reliability required for critical operations.

THE FIRST MAJOR REVOLUTION

After organizations transitioned from traditional server rooms to enterprise data centers, a new challenge emerged regarding resource efficiency. At that time, companies relied on purchasing physical servers with high computing capacities to meet the highest expected peak demand, even if that peak occurred only for brief periods. Consequently, most servers operated at a limited fraction of their actual capacity most of the time, while the rest of the resources remained unutilized.

This approach led to significant waste across multiple areas. The problem was not just poor utilization of computing power; it also included higher power consumption, the need for larger physical space in data centers, and rising costs for purchasing, operating, and maintaining a large number of servers. Organizations needed a smarter way to leverage existing resources instead of adding new hardware for every application or service.

This is where virtualization emerged as one of the most critical turning points in data center history. This technology relies on creating virtual computing environments within a single physical server, allowing the server's capacities to be divided into multiple independent virtual servers running simultaneously. This is achieved through a software layer known as a hypervisor, which manages the server's physical resources and allocates them to virtual systems while keeping each environment isolated from the others.

As virtualization technologies matured, the next stage of evolution arrived in the form of cloud computing, which was not just about data hosting or file storage, but rather introduced a new model for building and utilizing digital infrastructure. Cloud computing relies on pooling computing, storage, and networking resources within a flexible environment that can be managed and allocated on demand.

In the past, setting up a new server inside a data center required purchasing equipment, provisioning it, installing cabling, and configuring systems manually—a process that could take days or weeks. With cloud computing, however, it became possible to spin up a new virtual server or scale up computing resources within minutes from anywhere in the world, using software-driven management platforms instead of traditional physical procedures. This transformation changed how data centers are designed and operated, making infrastructure highly flexible and scalable according to business needs.

THE HYPERSCALE REVOLUTION

With the continuous, massive growth of internet usage, data centers were no longer serving just thousands of users; they were required to handle millions of search queries, file download requests, encryption processes, identity verifications, and cloud application tasks simultaneously. With this expanding volume of workloads, relying solely on traditional central processing units (CPUs) has become insufficient to deliver the required performance, efficiency, and speed.

As applications and services grew more diverse, these processors faced an escalating burden. Microsoft was among the pioneers to adopt a new direction, adding field-programmable gate arrays (FPGAs) inside its servers. These chips are distinct in that they can be reprogrammed even after manufacturing, allowing them to be customized to execute specific tasks more efficiently than a central processor. Instead of the CPU bearing all operations, certain tasks were executed directly by the FPGA, which eased the load on the processor, enhanced performance, and reduced latency and power consumption.

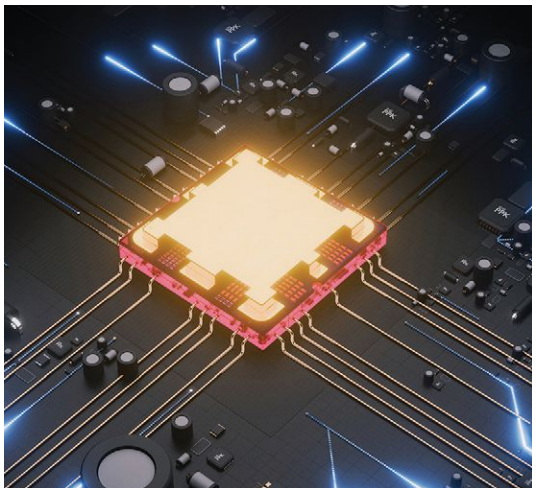
However, the real breakthrough was not just in using these chips but in how thousands of servers were interconnected within the data center. Servers began operating on a high-speed network that allowed workloads to be dynamically distributed across machines. If one server experienced high pressure, a portion of the tasks could be transferred within fractions of a second to other servers with available resources, without the user noticing any impact to the service.

As a result of this intelligent interconnection, the data center was no longer viewed as thousands of separate servers; rather, it began functioning as a single, massive computing unit, sharing its resources and capabilities to process workloads with high efficiency. From this emerged the concept of hyperscale data centers, which rely on the integration of hardware, networking, and software to provide an infrastructure capable of continuous scaling,

running millions of services and serving users simultaneously with unprecedented efficiency and reliability.

WHEN THE CPU IS NO LONGER ENOUGH

As the internet and digital services continued their rapid growth, data centers entered a new phase that differed radically from previous stages. Their mission was no longer limited to



running websites or storing data; they became responsible for processing AI applications, big data analysis, scientific simulations, and high-performance computing (HPC)—applications that require executing billions of mathematical calculations within incredibly short timeframes.

In previous phases, servers relied primarily on the CPU, which is characterized by its ability to execute general tasks and manage operating systems and applications efficiently. However, this type of processor was not designed to handle massive numbers of similar operations simultaneously, which became essential with the rise of AI applications, image and video processing, and big data analytics.

To address this challenge, data centers began adding graphics processing units (GPUs) to servers. Although these processors were originally developed to accelerate graphics rendering, their architecture, which comprises thousands of small cores, made them capable of executing a vast number of parallel operations at the same time. For this reason, they became the optimal choice for running AI applications, training deep learning models, scientific simulations, and other applications that rely on executing massive amounts of repetitive calculations.

With the widespread adoption of GPUs, computing power experienced massive growth, making them the backbone of modern data centers and supercomputers. For instance, the Titan supercomputer required an electrical power capacity of approximately 8.2 MW to run its components, a figure that reflects the scale of energy required to deliver this level of computing performance.

At the same time, major companies did not rely on the GPU alone; they also began leveraging other specialized processors like FPGAs. Instead of the central processor executing all operations itself, certain tasks—such as encryption, data processing, or network acceleration—were offloaded to these specialized chips, alleviating the burden on the CPU and raising the server's overall performance.

This stage marked the beginning of a new era in the data center industry, where the benchmark for advancement was no longer the number of servers inside the facility, but rather the capability to run massive workloads, distribute them intelligently, and leverage specialized processors to achieve the highest possible performance.

THE NEXT GENERATION OF DATA CENTERS

As modern data centers grew increasingly complex, hardware development alone was no longer enough to maintain performance and reliability. These centers now house thousands of servers, cooling systems, power sources, and sensors that generate massive amounts of data every second. The real challenge became not collecting this data but analyzing it and making the right decision at the right time. From here, digital twins and intelligent automation emerged as a new phase in data center evolution, in which management no

longer relies on traditional monitoring but on a live digital model that mirrors the center's actual state and interacts with it continuously.

Digital twins rely on a constantly updated digital replica of the data center that receives data directly from sensors deployed across power systems, cooling units, and servers, and then analyzes it to simulate the center's behavior in real time. For example, cooling systems need to process thousands of temperature, humidity, and airflow readings within fractions of a second. If all this data were sent to remote cloud computing hubs to be processed before sending decisions back to the data center, data latency could delay the response—something highly undesirable in environments requiring instantaneous decisions. Therefore, modern data centers turned toward integrating edge computing with the digital twin, allowing data to be processed within or near the data center itself. This enables instantaneous decisions, such as increasing cooling fan speeds or redistributing thermal loads, before they impact system stability.

The role of the digital twin is not limited to monitoring individual metrics; it relies on understanding the relationship between a vast number of variables simultaneously. This includes not only computing and environmental parameters but also the operating condition of critical electrical assets such as uninterruptible power supply (UPS) systems, transformers, generators, and power distribution equipment. Instead of triggering an alert merely because a component's temperature rises, anomaly detection algorithms can analyze relationships among power consumption, voltage, current, equipment temperature, loading conditions, and other indicators across both IT and electrical infrastructure. If the temperature of a transformer rises while its electrical loading remains within normal levels, for example, the digital twin can identify this deviation from expected behavior and support further investigation of a developing abnormal condition. Similarly, changes in UPS operating parameters, battery condition, or power-system loading can be evaluated together with other facility data to identify patterns that may indicate degradation or an emerging fault. This analysis allows abnormalities to be identified at an earlier stage, enabling corrective action before they lead to equipment failures or unplanned service disruptions.

For digital twins to perform this role efficiently, all data center components must be capable of exchanging data with one another, regardless of their manufacturers. In reality, a facility might house servers from Dell, cooling systems from Schneider Electric, and backup generators from Caterpillar, alongside equipment from other companies. If each company used its own proprietary communication language, integrating these systems would become complex and costly, and organizations might be forced to rely on a single vendor to avoid compatibility issues.

For this reason, modern data centers rely on the concept of interoperability, ensuring that all devices and systems can exchange data and work together even if they are from different manufacturers. This is achieved through the use of open communication standards and protocols, which facilitate the construction of a unified digital twin and give organizations the freedom to choose the best equipment from various companies without being locked into a single vendor or trapped by monopolistic constraints.

Thus, modern data centers are no longer just about operating infrastructure; they have become capable of understanding their own behavior, predicting failures, and making autonomous decisions based on real-time data. This shift marks the beginning of a new phase, moving data centers from human-managed environments into intelligent systems capable of continuous monitoring, analysis, and optimization, making digital twins and smart automation one of the most critical pillars of the next generation of data centers.

CONCLUSION

The evolution of the data center industry was not merely a transition from small server rooms to larger facilities; it was a continuous journey to redefine the concept of digital infrastructure and

how it is designed and managed. From the early days that relied on isolated servers and manual management, the industry has witnessed a series of technological transformations that radically altered how data centers operate. Virtualization and cloud computing helped raise resource utilization efficiency, while hyperscale data centers paved the way to run millions of services and serve users simultaneously. With the emergence of specialized processors, such as GPUs and FPGAs, data centers became capable of handling artificial intelligence and high-performance computing applications with unprecedented efficiency, while energy efficiency surfaced as one of the most critical challenges guiding the design and operation of modern data centers.

At the same time, data center management shifted from relying on traditional monitoring to relying on data and intelligent analytics. Digital twins, automation, and edge computing technologies have enabled data centers to monitor their infrastructure in real time, detect failures before they occur, and continuously optimize the performance of power and cooling systems. The objective is no longer confined to maintaining uptime but has become about achieving the highest levels of reliability, efficiency, and sustainability, alongside the capacity for rapid scaling to keep pace with the growing demand for digital services.

As AI, the IoT, and advanced computing technologies continue to evolve, data centers are expected to enter a new phase that relies even more heavily on autonomous systems capable of making decisions and optimizing their performance without direct human intervention. Therefore, understanding the evolutionary journey of this industry is not just about reviewing its history, but it forms the baseline for understanding future trends and the technologies that will shape the next generation of data centers. Amid this rapid evolution, data centers will remain the foundational pillar of the digital economy and the engine on which various sectors depend to deliver faster, more reliable, and more sustainable services in the coming years. NW

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QUIZ

NO. 154

ANSWERS

1. **Correct Answer: D**
IEEE 519 describes the point of common coupling (PCC) as the place where the utility lines meet the customer's electrical system, where the system owner or operator could offer services to another user. The utility is responsible for keeping the voltage clean up to this point. The user is responsible for making sure its machines do not distort the current back to this point, so neighboring customers do not have affected power quality.

2. **Correct Answer: C**
The utility generates and provides voltage to the user. The user ultimately draws current from this generated voltage source. The utility is responsible for the provided voltage quality and for limiting harmonic voltage; the user is responsible for limiting current harmonics. These limits are explained in IEEE 519.

3. **Correct Answer: B**
IEEE Std. 1453, *Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems*, adopted from IEC 61000-4-15, is used in North America for testing flicker (rapid voltage changes that make lights blink and hurt human eyes). It rates this effect in two ways: Pst (Short-term severity measured over 10 minutes) and Plt (Long-term severity measured over 2 hours).

4. **Correct Answer: A**
The short-circuit ratio (Isc/IL) tells you how strong the utility grid is compared to the size of the connected site, based on normal site loading. A higher ratio means the grid is stronger compared to the site, and it can tolerate a higher percentage of current distortion before the corresponding utility voltage distortion is unacceptable.

5. **Correct Answer: D**
Official utility standards such as IEC 61000-4-30 require Class A-certified meters that log data continuously for seven days at 10-minute intervals to demonstrate legal compliance. Internal industrial testing can be more continuous as well, but is often performed to troubleshoot issues on-site. Technicians will use high-speed triggers to capture events that happen in a fraction of a second.

6. **Correct Answer: B**
IEEE Std. 1547, *Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces,* lists how generation sources must behave. It requires generators to ride through voltage drops without tripping offline, helping keep the whole grid stable. IEEE 519 focuses more on consumer requirements.

7. **Correct Answer: B**
Three-phase power should ideally be perfectly balanced across all three wires. On the utility grid, unbalance happens because houses and small businesses use only one phase, and the utility must try its best to distribute them evenly across the three lines. Inside a user's facility, unbalance happens because heavy, single-phase industrial equipment (like a welding machine) is connected to one line more than the others, or an internal motor is starting to fail.



POWERING THE FUTURE

HOW EPIC26 BROUGHT INDUSTRY LEADERS TOGETHER TO SHAPE WHAT'S NEXT

NETA's 2026 Electrical Power Innovations Conference (EPIC26)—held October 11–13, 2026, in Fort Worth, Texas—brought together the electrical power industry's most forward-thinking leaders for three days of strategic insight, technical exploration, and collaborative problem-solving.

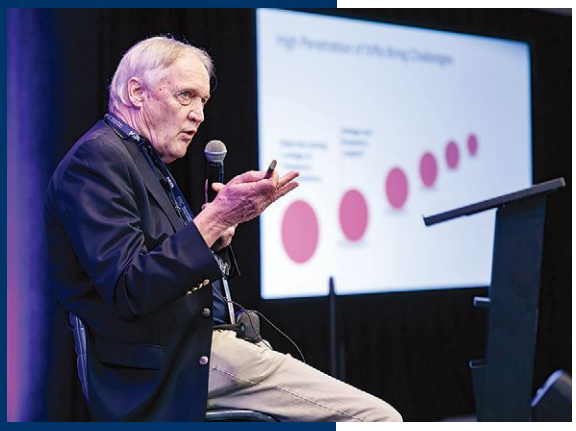
As electrification accelerates, digital systems proliferate, and workforce pressures intensify, EPIC26 served as a vital forum for executives, engineers, educators, and service professionals committed to shaping what comes next in the electrical power industry.

Across keynotes, expert presentations, symposium panels, and hands-on workshops, attendees engaged in candid dialogue about the forces reshaping electrical power systems—and the strategies required to turn industry change into business advantage.









INNOVATION IN A RAPIDLY CHANGING INDUSTRY

EPIC26 proved to be far more than a traditional conference. It served as a catalyst for innovation, uniting thought leaders, engineers, manufacturers, power providers, and service specialists to explore emerging technologies and strategies that are redefining electrical power systems management. EPIC26 addressed the sector's most urgent challenges and cutting-edge opportunities, from grid modernization and renewable integration to digitalization, AI, cybersecurity, and workforce transformation. Participants gained actionable insights from top experts and collaborated on strategies to advance the industry.

For professionals committed to driving progress, EPIC26 offered a rare environment where knowledge, connection, and leadership converged.

KEY THEMES THAT DEFINED EPIC26

The conference centered on three strategic themes that shaped the agenda and guided discussion throughout the event:

- Emerging Technologies Shaping the Future of Energy
- Grid Optimization and Smart Grid Management
- Electrical Power Service Futures: Fueling the Next Generation of Talent

These themes provided a cohesive framework for the three-day conference experience, ensuring attendees could connect technical advancements with organizational strategy, workforce readiness, and long-term planning.

KEYNOTES THAT FRAMED THE FUTURE

EPIC26's Keynote series offered a comprehensive look at the forces reshaping the electrical power industry—from intelligent operations and grid modernization to workforce readiness and AI-driven infrastructure growth.

Hector Perez (Black & Veatch) reframed cybersecurity as a strategic enabler for autonomous OT systems, showing how Return on Mitigation (RoM) strengthens confidence in delegated decision-making.

Mark Carpenter (Oncor) examined how evolving customer expectations, electrification, and inverter-based resources are transforming grid behavior and demanding new tools, analytics, and talent strategies.

Closing the series, David Speidelsbach (Wesco) highlighted how AI is driving explosive growth in data-center infrastructure,

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VECTOR POWER

wesco

underscoring the need for early planning, resilient supply chains, and cross-functional coordination to meet escalating power, cooling, and deployment demands.

Together, these keynotes equipped EPIC26 attendees with a clear roadmap for navigating technological change, strengthening reliability, and building the resilient workforce and infrastructure needed to power what's next.

STRATEGIC INSIGHT FROM INDUSTRY EXPERTS

EPIC26's daily Knowledge-Sharing Sessions brought together more than 20 experts from across the industry. Presentations focused on the technologies, operational strategies, and workforce capabilities shaping the future. Speakers from organizations including 3M, Eaton, GE Vernova, NERC, Siemens, Doble, Hampton Tedder, and Eaton explored advancements in smart sensors, practical OT cybersecurity, microgrid operation and protection, emerging technologies driving the energy transition, and the growing importance of DC power for AI-driven data centers.

Sessions also addressed the training needs required to keep up with evolving skills, including modern equipment and relay testing; advanced monitoring, software, and AI technology; integrated cybersecurity; innovative approaches to workforce motivation and development; and integrating mixed utility and contract test teams.

Together, these presentations reinforced a central theme of EPIC26—the grid is becoming smarter, more connected, and more complex. Organizations must evolve their technology and operations, expand and elevate their service scope, and adapt their strategies for recruiting, developing, and retaining the skilled workforce needed to support the next generation of electrical power systems.

INTERACTIVE DIALOGUE THAT DRIVES STRATEGY

EPIC26's three panel symposiums delivered dynamic, interactive, cross-sector dialogue on the industry's most pressing challenges. Guided by moderators Mark Carpenter (Oncor), Karla Flanagan (Texas State Technical College), and Mark Lauby, (NERC), the panels explored three core themes:

- Grid Optimization and Smart Grid Management
- Service Futures – Fueling the Next Generation of Talent
- Grid Optimization and Smart Grid Management Panel Symposium









WHAT ATTENDEES SAID ABOUT EPIC

"EPIC is crystallizing the vision of a conference that brings together the power industry's brightest minds. While it is still finding its footing, it already has a lot of inertia and is attracting brilliant people."

— Matt Robinson, Director of Safety and Training, Sigma C Power Services

"After more than 35 years in this industry, I still find that the most meaningful moments are the ones you do not plan. At EPIC26, NETA put me in as moderator, and I had the honor of introducing Chasen Tedder, someone I mentored, on a subject that began as my story. Watching that work live on through the next generation is more rewarding than a paycheck. It is a great reminder of why NETA's community matters, and why we invest in people."

— Ken Peterson, NETA Level 4 Senior Certified Test Technician, Vice President of Operations, Power Engineering Services, LLC

"If I had two words to describe NETA's EPIC26, it would be Exceeds Expectations. The presentations were spot-on in terms of preparing for future innovation in the electrical industry. At intellirent, we are proud to be an Anchor Sponsor. It has been an outsanding program."

— Drew Welton, Vice President of Business and Technical Development, intellirent



These sessions created a collaborative forum where participants exchanged real-world insights, challenged assumptions, and identified strategic pathways for the evolving power landscape. Sponsored by Texas State Technical College, a special student-led panel gave EPIC attendees a unique opportunity to hear directly from the next generation of power professionals. Students shared their perspectives on launching careers in the electrical power industry at a time of remarkable growth and transformation, providing valuable insights into the future workforce.

TURNING INSIGHT INTO ACTION

The EPIC26 Workshop Series transformed conference insights explored in the knowledge-sharing presentations into practical action. Workshop participants worked together to translate the themes of the conference into clear, implementable strategies. EPIC workshop groups collaborated in roundtable discussions on approaches for strengthening smart grid management and building the next generation of electrical power talent.

These problem-solving-focused workshops will ensure EPIC26's impact extends beyond the event. The EPIC working groups will meet in the months ahead to develop strategies, partnerships, and action plans addressing the industry's most pressing challenges.

WHAT DID WE ACCOMPLISH AT EPIC26?

Those who gathered at EPIC26 represent a community of strategic thinkers, innovators, and industry leaders committed to shaping the future of electrical power. Through collaboration, knowledge sharing, and the exchange of new ideas, EPIC26 served as a catalyst for progress, helping advance the technologies, standards, and partnerships that will drive a safer, more reliable, and more resilient electrical power industry.

Attendees departed with new insights, stronger connections, and a renewed vision for the future. More than a conference, EPIC26 was a call to leadership and action, bringing together the minds and organizations that will define what's next for the electrical power industry. Through innovation, collaboration, and shared purpose, EPIC continues to build the foundation for the future of power. NW

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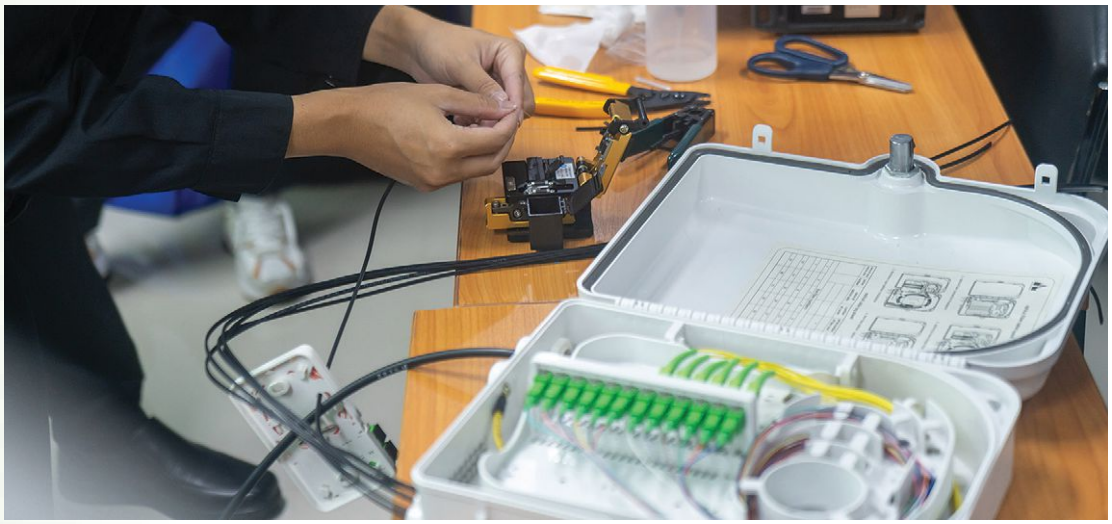
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THE NETA APPRENTICESHIP PROGRAM IN ACTION

Who will train the next generation of electrical testing technicians? For a growing number of NETA Accredited Companies (NAC), the answer is taking shape through apprenticeship.



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Following approval by the U.S. Department of Labor in March 2025, the NETA National Guideline for Apprenticeship Standards (NGS) was introduced to member companies for adoption in September 2025. In its first year, 27 accredited companies have expressed interest, with five working through the adoption process and another five operating fully approved programs.

Behind these numbers are companies welcoming new talent, experienced technicians embracing mentorship, and apprentices building careers in electrical testing. We spoke with participating companies to learn what is working, what challenges they have encountered, and what their experiences can offer others ready to get started.

EXPANDING THE TECHNICIAN PIPELINE

For companies adopting the Electrical Testing Engineering Technician (ETET) apprenticeship, one encouraging early benefit is an additional source of new talent. As the industry faces a shrinking pool of certified technicians and the approaching retirement of experienced professionals, participating NETA member companies have reported bringing on a combined total of 37 apprentices. These additions complement traditional recruiting and training efforts while creating more opportunities for individuals to enter the profession.

Recruitment, however, is only the beginning. The apprenticeship provides a structured

training roadmap aligned with the ANSI/NETA Electrical Testing Technician (ETT) Standard, helping companies guide individuals with little or no electrical experience toward proficiency. For employers, that structure establishes a clear path for developing technicians. For apprentices, it connects the work they do and the concepts they study to their progress in a skilled technical career.

EARLY PROGRESS TOWARD CERTIFICATION

How well does that structured approach prepare technicians for certification and advancement? Early results from Integrated Power Services (IPS), which piloted the program, offer an encouraging perspective. Steve Newton, training manager for IPS, reported that most of his apprentices passed the NETA Level 2 exam on their first attempt. He also observed that apprentices progressed through training more quickly, based on demonstrated competencies, than new technicians recruited from two- and four-year college programs. These observations reflect the experience of one participating company, but they offer a promising example of what a structured apprenticeship can achieve. By connecting instruction with opportunities to demonstrate skills on the job, the program helps make professional growth a deliberate, measurable part of technician development.

MENTORSHIP THAT STRENGTHENS THE ENTIRE TEAM

One of apprenticeship's most valuable advantages is the mentorship built into its approach to learning. By combining structured on-the-job training (OJT) with related instruction (RI), the program creates ongoing opportunities for apprentices to learn directly from experienced technicians.

Mentors help apprentices translate technical concepts into practice, develop sound judgment, and build confidence. They also provide a setting in which apprentices can ask questions, work through challenges, and understand the reasoning behind testing decisions. That exchange helps convey the practical knowledge and experience that classroom instruction alone cannot fully provide. The benefits extend to the mentors themselves.

"This has pushed our senior-level personnel to take a greater interest in what our apprentices are doing and attend some of their classes," noted Matt Robinson, director of safety and training for Sigma C Power Services. That increased involvement creates opportunities for learning across experience levels. Senior technicians take an active role in developing their future colleagues, while apprentices benefit from closer connections with the people whose expertise they are working to acquire. For companies facing the retirement of experienced personnel, these relationships also provide a valuable opportunity to pass along knowledge before it leaves the workforce.

TURNING CHALLENGES INTO PRACTICAL LESSONS

Launching an apprenticeship requires planning, coordination, and sustained attention. The companies interviewed described challenges, but none reported an issue that prevented them from moving forward. Their experiences offer useful guidance for future adopters, particularly in recruitment, instruction, and program administration.

COMMUNICATING THE CAREER OPPORTUNITY

Recruiting apprentices takes more than advertising an available position. Prospective applicants need to understand what electrical testing technicians do, how the apprenticeship supports their development, and what the work requires. Gregory Richmond of Group CBS emphasized the time needed for "… effectively communicating the value of this career opportunity to high school students from smaller communities, particularly when the position requires a significant amount of travel."

For future adopters, the lesson is to make career education part of recruitment. Explaining the training pathway and opportunities for advancement can help candidates see a future in the profession. Discussing travel and other job expectations early also helps them make

an informed decision about whether the opportunity is a good fit.

MAKING TIME FOR RELATED INSTRUCTION

Companies also identified the coordination of related instruction as a challenge. Selecting training resources, identifying instructors, and scheduling learning alongside OJT and field assignments require deliberate planning. An effective approach is to build RI into the training schedule from the outset. Assigning responsibility for coordination and establishing a consistent schedule can help companies give apprentices the time and support needed to connect classroom learning with field experience.

PLANNING FOR PROGRAM GROWTH

As apprenticeship programs grow, so does the work required to manage them. Participating companies noted that programs with approximately 15 or more apprentices can become difficult for one person to administer while also managing other programs or projects. That experience is a useful planning signal rather than a fixed staffing threshold. Companies should regularly assess the time needed to coordinate instruction, maintain records, and monitor apprentice progress. Sharing responsibilities among staff members or assigning a dedicated program manager can help preserve the quality of the apprentice experience as enrollment increases. Planning for that growth early allows companies to build on successful recruitment without overwhelming the people responsible for delivering the program.

GETTING YOUR ETET APPRENTICESHIP STARTED

For companies considering adoption, the first-year participants offered a consistent message: Seek guidance early and build a program your team can support. Participating companies recommended working closely with the apprenticeship office or agency responsible for registration in their state. The paperwork may seem daunting at first, but establishing that relationship early provides a resource for questions about the application and approval process.

Internal planning deserves the same attention. Identify who will oversee the program, which experienced technicians can serve as mentors, and how related instruction will fit into the work schedule. Addressing these questions before apprentices arrive helps translate a written training plan into a workable learning experience.

The NETA NGS provides a foundation aligned with the ANSI/NETA ETT and designed to support broad technician development. As companies prepare their programs, they should identify where their operations may call for adjustments and discuss those needs with NETA and the appropriate registration agency. The goal is to make the program practical for the company while preserving its alignment with applicable apprenticeship and certification requirements. Companies exploring adoption can also benefit from conversations with those already implementing the program. Their experiences with recruitment, mentoring, instruction, and administration offer a starting point for anticipating challenges and making informed decisions.

BUILDING ON THE FIRST YEAR

The first year of adoption has produced encouraging examples of what apprenticeship can bring to electrical testing: new entrants to the profession, early progress toward certification, and greater engagement from experienced technicians. It has also shown that successful implementation depends on the people and planning behind the program. For NACs, the ETET apprenticeship offers a structured way to invest in the technicians who will support their future. Early adopters are already demonstrating how that investment can take shape—and their lessons can help the next group of companies move forward with greater confidence.

If your company is ready to explore an Electrical Testing Engineering Technician apprenticeship, contact the NETA Training Program Manager, Robert Harriman at rharriman@netaworld.org, *to discuss the steps toward adoption.* NW

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WHY INDUSTRY LEADERS CHOOSE NETA ACCREDITATION

For many, accreditation is about gaining a competitive advantage. But it is also a commitment to quality, safety, technical excellence, and investing in the long-term success of both customers and employees. NETA Accreditation validates an organization's dedication to meeting the highest standards in electrical testing and maintenance while creating opportunities for growth, credibility, and professional development.

Here are what these industry leaders say:

"Achieving our accreditation provides assurance to our customers of our quality, experience, and training. We anticipate our accreditation will provide us with many new and exciting opportunities."
– Steve Pioppo, General Manager, QP Testing LLC

"Becoming NETA Accredited is a significant milestone. It reflects our team's commitment to excellence and confirms that our practices meet the highest industry standards. It signals to our clients and partners that we are committed to safety, consistency, and best-in-class technical performance. However, just as importantly, it signals a commitment to our staff and their long-term careers."
– Martin Roy, General Manager, Gemitech Electrotechnical, a RESA Power Company

"NETA Accreditation provides a clear framework for training, certification, and continuous improvement. It gives our technicians and engineers a recognized professional pathway that fosters growth, accountability, and a sense of pride. It validates their expertise, strengthens their professional credibility, and creates opportunities for advancement within a nationally recognized and respected standard."
– Arlan Eliason, President, Ener-Phase

Accredited companies gain a powerful differentiator in today's competitive marketplace. While demonstrating a commitment to technical excellence, NETA Accreditation helps attract and retain motivated professionals, instills pride throughout an organization, and gives customers confidence they are working with a company that meets the industry's most rigorous standards.

If your organization is ready to elevate its reputation, strengthen its workforce, and join a network of industry-leading companies, contact NETA today to learn how your company can become a trusted NETA Accredited Company.

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For a complete listing of NETAAccredited Companies, visit www.netaworld.org

WHY BECOMING A NETA QEMC IS ABOUT MORE THAN NFPA 70B COMPLIANCE

For electrical contractors and facility owners, becoming a NETA Qualified Electrical Equipment Maintenance Company (QEMC) is about more than NFPA 70B compliance. It reflects a commitment to safety, electrical maintenance workforce competency, and industry best practices. For contractors, it strengthens customer confidence and provides a clear competitive advantage. For facility owners, it elevates maintenance programs and qualifies and empowers electrical maintenance personnel.

Here is what our NETA QEMCs say:

"We are excited to earn the Qualified Electrical Equipment Maintenance Company qualification. It demonstrates our commitment to assisting our clients with NFPA 70B requirements."
– Lorne Smith, Executive Vice President at Amteck

"This certification reflects not only where we are, but where we are going. "
– Corey Bard, President, Amteck

"It's a source of pride for our technicians."
– Scott Jackson, Vice President, TEGG Service, Edward G. Sawyer Co.

"Becoming Puerto Rico's first NETA QEMC is a significant milestone—This qualification reflects the alignment of our technical capabilities with the NETA framework."
– Miguel A. Morales, HiPot Engineering

"Recognition as a QEMC will become a benchmark that customers actively seek for preventative maintenance."
– Chris Lang, Service Operations Manager, Mid-City Electric/Technologies

With the ANSI approval and national adoption of NFPA 70B, NETA recognized that demand for qualified electrical equipment maintenance services would grow rapidly. In response, NETA developed the QEMC and QEMW programs to help the industry meet this increasing need.

Consider being a part of the solution.
Interested in becoming a QEMC?
Contact the NETA office @ 888-300-6382.

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Qualified Electrical Equipment Maintenance Company Program (QEMC) and Qualified Electrical Equipment Maintenance Worker (QEMW)

QEMC Program Benefits:

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- NETA Qualified Electrical Worker Verification
- Third-Party Worker Recognition of Expertise

Learn more:
NETAWorld.org/QEMC-QEMW



ELECTRICAL ENGINEERING ENTERPRISES

BECOMES A NETA ACCREDITED COMPANY



NETA welcomes Electrical Engineering Enterprises (EEE) to its growing roster of NETA Accredited Companies (NACs).

Founded in 1999 and headquartered in the greater Tampa Bay area in Florida, EEE provides mission-critical electrical services to customers across the United States. The company operates from three Florida locations and brings together specialized technical expertise with a vertically integrated approach to electrical projects.

Unlike contractors that outsource portions of their work, EEE owns its equipment, employs its own licensed professionals, and manages projects from beginning to end. Its capabilities encompass high-voltage distribution, transformer maintenance, power line installation, and other critical infrastructure services.

Safety is also central to EEE's operating philosophy. The company says every job begins with a formal hazard analysis and a worker briefing, reflecting a safety-first culture that extends beyond basic compliance and becomes part of everyday operations.

According to EEE, changing demands on electrical infrastructure were an important driver behind its pursuit of NETA Accreditation. Customers are installing new infrastructure while simultaneously relying on existing equipment—sometimes beyond its expected service life. These conditions require technicians and test engineers with the knowledge and experience to work safely and effectively across a wide range of equipment.

"Becoming a NETA Accredited Company represents over two years of dedicated commitment and accomplishment," says EEE President Christopher Steele. "It is recognition by an industry-leading standard that our seasoned test engineers' skills and abilities are among the best in the industry."

EEE also sees NETA Accreditation as an important component of addressing one of the electrical power service industry's emerging challenges: developing qualified testing professionals. The company anticipates that the combination of new construction and growing maintenance requirements will contribute to a significant shortage of qualified technicians over the next five years. EEE plans to use NETA's standards and requirements as a foundation for training and developing its next generation of test engineers.

For EEE, NAC status reinforces its commitment to technical development while demonstrating to customers that its test engineers have the expertise to diagnose challenging problems, recommend solutions, and serve as trusted partners.

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CRITICAL SWITCHGEAR SERVICES

BECOMES A NETA ACCREDITED COMPANY



NETA welcomes Critical Switchgear Services, Inc. (CSS) to its growing roster of NETA Accredited Companies (NACs).

Headquartered in Parker, Colorado, CSS specializes in electrical testing solutions for mission-critical, commercial, and industrial facilities. The company's philosophy is straightforward: It does more than test electrical systems; it gives customers confidence that their power systems will perform when they are needed most.

CSS brings more than 50 years of combined electrical infrastructure training to its work and emphasizes personalized, relationship-focused service throughout the testing process. Its customers represent a wide range of markets, including healthcare, education, municipal infrastructure, communications, alternative energy, water treatment, transit, and electrical contracting.

The company provides start-up and acceptance testing as well as preventive maintenance and repair for low- and medium-voltage switchgear, transformers, circuit breakers, protective relays, emergency power systems, battery and DC power systems, grounding systems, and other electrical equipment. Its additional capabilities include infrared scanning, predictive and preventive testing, equipment refurbishment and life-extension services, commissioning, and consulting.

CSS has also performed electrical testing and maintenance on critical infrastructure projects ranging from hospitals and transportation facilities to airports and renewable energy installations. The company's project portfolio includes Denver International Airport, the

Denver VA campus, Denver Union Station, and the Eisenhower-Johnson Memorial Tunnel.

"Becoming a NETA Accredited Company is an important step in the continued growth of Critical Switchgear Services," says Thomas Cervantes. "NETA Accreditation gives us an opportunity to serve customers wherever they operate, pursue larger and more complex projects, and continue building a company recognized for dependable electrical testing and service. Most importantly, it supports our goal of giving customers confidence that their power systems will perform when they need them most."

The accreditation also comes as CSS sees an important challenge developing across the electrical power service industry: finding and developing qualified technicians. The company identified staffing and the availability of skilled technical professionals as the most significant challenges it expects the industry to face over the next five years.

With one location in Parker and a service territory encompassing the United States, CSS enters its next chapter as a NAC with a focus on expanding its reach while maintaining the reliability and customer relationships at the center of its business. NW

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ALL-PRO ELECTRIC BUILDS ON EXPERIENCE WITH QEMC RECOGNITION



All-Pro Electric has joined the growing roster of NETA Qualified Electrical Equipment Maintenance Companies (QEMCs), adding the designation to more than four decades of electrical industry experience.

Based in Haverhill, Massachusetts, All-Pro Electric is a full-service electrical contracting company serving customers throughout New England. The company's team brings more than 40 years of experience in electrical construction and renovation, with projects spanning the commercial, retail, medical, industrial, and educational markets.

All-Pro Electric provides services across the electrical infrastructure lifecycle, from design-build and new construction to renovations and post-completion site maintenance. Its capabilities include electrical service upgrades, lighting design, emergency and backup generators, site lighting, utility work, renewable energy, fire alarm systems, and emergency restoration. The company also works with high-voltage systems, transformers, and overhead and underground utility infrastructure.

A focus on safety and reliability runs throughout the company's operations. All-Pro Electric identifies safety as its top priority for utility work and emphasizes a combination of skilled technical personnel, industry relationships, and individualized customer service. Its service department provides troubleshooting and

electrical support using a fleet of service vehicles and utility equipment, with 24/7 assistance available for customer needs.

Becoming a NETA QEMC provides All-Pro Electric with an opportunity to build on this experience by demonstrating its commitment to established practices in electrical equipment maintenance. The recognition aligns with the company's emphasis on safety, technical expertise, reliable service, and maintaining electrical infrastructure beyond the completion of the initial construction project.

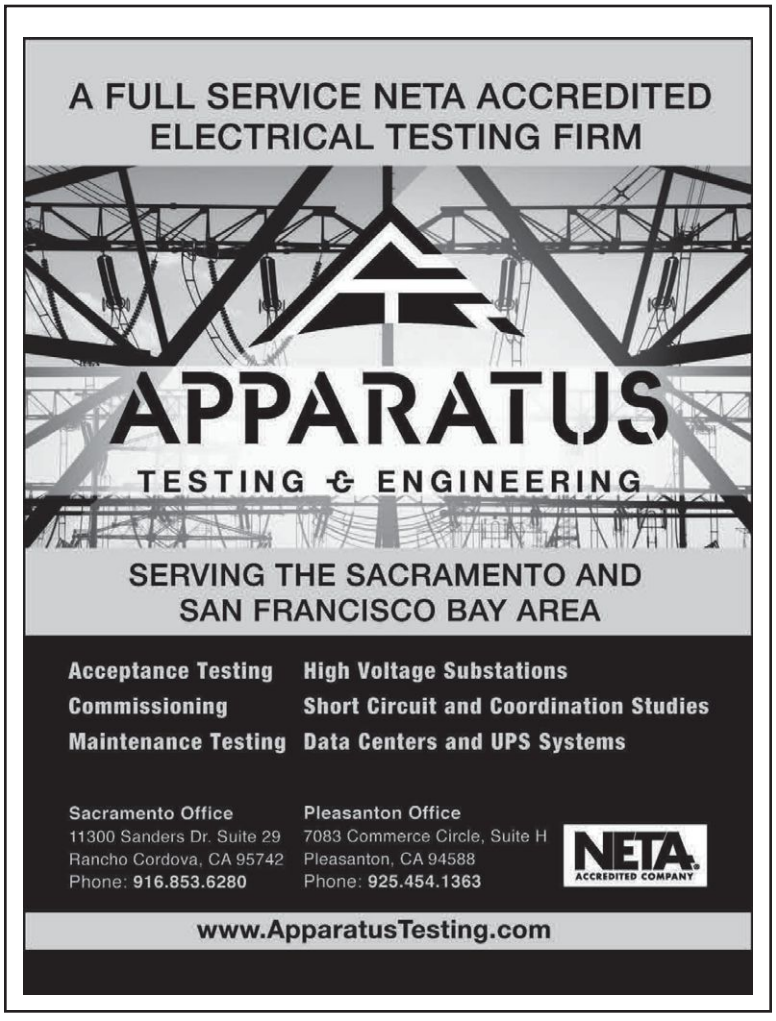
"Achieving QEMC recognition represents an important step for All-Pro Electric as we continue expanding our electrical maintenance capabilities. Our customers depend on their electrical systems every day, and this recognition reinforces our commitment to safety, quality, and reliable service throughout the life of their equipment," says Mike Harrington, founder and CEO of All-Pro Electric.

With its QEMC recognition, All-Pro Electric joins a community of electrical maintenance organizations committed to advancing safety, reliability, and quality in the maintenance of electrical power systems. NW

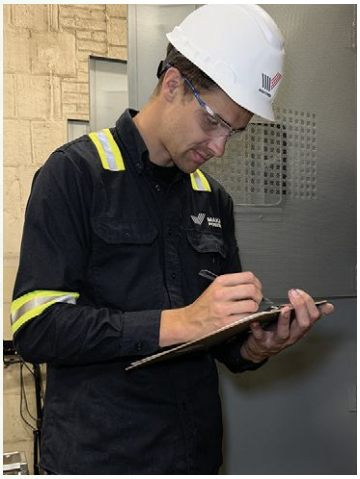
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MAKA POWER
EARNS QEMC RECOGNITION






MAKA Power, a Canadian power reliability company headquartered in Headingley, Manitoba, has joined the growing roster of Qualified Electrical Equipment Maintenance Companies (QEMCs).

Serving industrial, institutional, and commercial facilities across Western Canada, MAKA Power focuses on protecting the electrical infrastructure its clients depend on to keep their operations running. The company combines engineering expertise, electrical apparatus testing, predictive diagnostics, project execution, and proactive maintenance strategies to reduce risk, improve reliability, and minimize unplanned downtime.

At the center of MAKA Power's approach is a philosophy that power system reliability is built through expertise, discipline, and performing the right work before failures occur. Rather than simply responding to problems, the company works closely with clients to understand each facility, its electrical history, operational requirements, and potential risks. This partnership-based approach helps organizations move from reactive maintenance toward long-term reliability strategies.

As a Western Canadian company, MAKA Power also understands the challenges associated with harsh climates, remote operations, aging infrastructure, evolving regulations, and the increasing cost of downtime. Its work is guided by the principles behind the MAKA name: Masterful Workmanship, Accurate Execution, Known Results, and Achieving Excellence.

"Organizations can no longer rely on reactive maintenance or assume that critical electrical

equipment will continue to operate without a disciplined maintenance program," says Matthew Hibbert, CEO of MAKA Power. "Achieving QEMC recognition is not simply an accomplishment; it is a commitment to accountability, professionalism, and delivering safe, reliable, and consistent electrical maintenance services."

MAKA Power says the designation reinforces its commitment to continued investment in its people, processes, and quality systems while providing clients with greater confidence in the reliability of their critical electrical assets.

The company operates from one location in Headingley and serves clients throughout Western Canada. NW

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INTERSTATES
EARNS QEMC RECOGNITION



Interstates has joined the growing roster of NETA Qualified Electrical Equipment Maintenance Companies (QEMCs), marking a new milestone in the company's commitment to electrical safety, reliability, and performance.

Based in Sioux Center, Iowa, Interstates is a full turnkey integrated systems provider for industrial clients. The company supports customers throughout the facility lifecycle, from design and construction through commissioning, maintenance, testing, and modernization.

Interstates traces its roots to 1953 and today works with industrial manufacturing and processing facilities to design, build, automate, maintain, and protect their critical infrastructure and electrical systems. Its capabilities encompass electrical engineering and construction, industrial automation and analytics, maintenance and support, operational technology, prefabrication and manufacturing, and electrical studies and audits. That breadth of capabilities allows Interstates to take an integrated approach to electrical system reliability.

Its maintenance and testing services include breaker injection testing, while its studies and audits practice helps industrial facilities evaluate power distribution systems, identify potential hazards, address aging infrastructure, and plan for future needs. The company also performs power system studies, arc flash studies, grounding audits, and electrical site audits.

For Interstates, achieving QEMC recognition reinforces the role that disciplined electrical maintenance plays in protecting both people and critical facility operations.

"Becoming a NETA Qualified Electrical Maintenance Company is an important milestone for Interstates," says Adam Dittbenner, Instrumentation Manager for Electrical & Instrumentation at Interstates. "It validates the expertise, discipline, and

commitment our teams bring to electrical testing and maintenance, while reinforcing our responsibility to help customers operate safer, more reliable electrical systems."

The designation complements a broader company philosophy centered on understanding customer needs, delivering results, and building long-term relationships. Interstates identifies dependability, integrity, trust, quality, and family among the values guiding its work and describes safety as an integral part of its company identity.

From its headquarters in Sioux Center, Interstates has grown to 14 locations throughout the United States, including regional offices and manufacturing facilities. With QEMC recognition, the company builds on more than 70 years of electrical experience while strengthening its commitment to helping industrial facilities maintain safe, reliable electrical systems throughout their operating lifecycle. NW

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ANSI/NETA STANDARDS UPDATE

ANSI/NETA MTS–2023 REVISION UNDERWAY

The revision of the ANSI/NETA MTS-2023, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*, is underway with an anticipated completion and publication release in March 2027 at PowerTest 2027.

This revision introduced a new Working Group model, bringing together subject matter experts from across the electrical testing industry to conduct early-stage comment review for consideration by the NETA Standards Review Council and the development of three new sections and one reference table. The initiative serves as a pilot program for future standards development activities and will help refine processes planned for the upcoming revision of ANSI/NETA ATS-2025 to begin in the Fall of 2027.



New MTS Content Includes the Following Sections:

- 7.27 Arc Energy Reduction Systems
- 7.28 Battery Energy Storage Systems (BESS)
- 7.30 Wind Turbine Systems
- Table 100.6.8 Voltage Magnitudes and Durations for Offline Cable PD Tests

KEY MILESTONES FOR NETA MTS REVISIONS

Recirculation Ballot Begins
September 18, 2026

Recirculation Ballot Ends
October 18, 2026

Public Comment Period Ends
November 2, 2026

NETA SRC Review of Comments
November 6 - November 8, 2026

Submit ANSI BSR-9 for Approval
End of December 2026

MTS DOCUMENT SCOPE

The ANSI/NETA MTS establishes specifications for field testing and inspections to evaluate the continued serviceability and reliability of electrical power equipment and systems. These specifications help ensure that tested equipment operates within applicable industry standards and manufacturers' tolerances and remains suitable for continued operation.

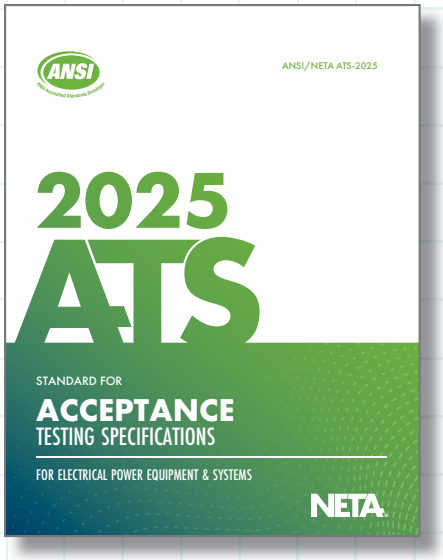
Key updates in the 2023 edition included a comprehensive overhaul of the Cables section and the introduction of a new section addressing Electric Vehicle Charging Systems, reflecting evolving technologies and industry needs. ANSI/NETA MTS–2023 is available for purchase at the NETA Bookstore at *www.netaworld.org*.

ANSI/NETA ETT-2026
NEW STANDARD REVISION APPROVED



The revision of the ANSI/NETA ETT-2022, *Standard for Certification of Electrical Testing Technicians*, was approved by the ANSI on December 1, 2025. Among the key updates is a revised Detailed Content Outline (DCO) for ETT Levels 2-4.

The ANSI/NETA ETT standard defines the minimum qualifications for electrical testing technicians, including requirements for certification, training, and experience. It also outlines the criteria for documenting these qualifications and specifies the standards for an independent and impartial certifying body.



The ANSI/NETA ATS-2025 is available for purchase through the NETA Bookstore, offered in bound print, PDF download, and Redline PDF (with all changes highlighted) download. Photovoltaic (PV), Uninterruptible Power Supply (UPS), and Automatic Transfer Switches (ATS).

ANSI/NETA ATS-2025

The ANSI/NETA ATS-2025, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*, received formal approval from the ANSI on February 20, 2025.

This standard defines the field tests and inspections recommended to evaluate the suitability of electrical power equipment and systems prior to their initial energization. These specifications are designed to confirm that equipment is properly installed in accordance with design requirements, is operational, and performs within applicable industry standards and manufacturers' tolerances.

The 2025 edition introduces significant new content, including:

- Section 7.28 Battery Energy Storage Systems (BESS)
- Section 7.29 Solar Photovoltaic (PV) Systems
- Table 100.6 Medium-Voltage Cables Acceptance Test Values (Tables 100.6.1 – 100.6.6)
- Appendix B Guidance for Circuit Reliability Considerations for Medium- and High-Voltage Cable Testing Methods

A notable revision in the ANSI/NETA ATS-2025 is found in Section 7.4.D.2.a-b. Metal-Enclosed Busways. This update introduces separate formulas for low-voltage and medium-voltage systems and replaces the previous nominal 1,000-foot run length with the actual busway length in feet, enhancing the applicability of testing procedures.



ANSI/NETA EMW–2026 NEW STANDARD APPROVED

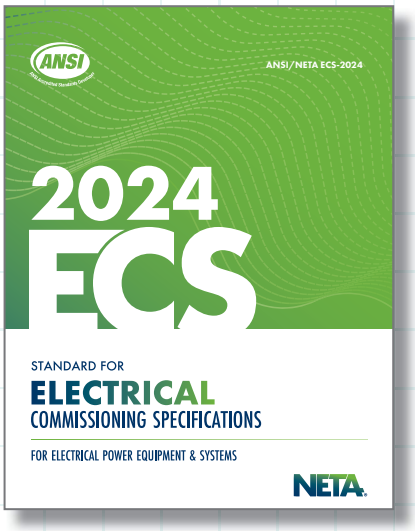
ANSI approved the ANSI/NETA EMW-2026, *Standard for Qualification of Electrical Equipment Maintenance Workers for Electrical Power Equipment & Systems*, on January 6, 2026. This new standard is in support of NFPA 70B, Standard for Electrical Equipment Maintenance, which meets the qualification requirements outlined in that standard for Qualified Electrical Equipment Maintenance Workers (QEMW).

The ANSI/NETA EMW standard defines the minimum requirements for the qualification of QEMWs, including training and experience prerequisites along with the necessary knowledge, skills, and abilities to perform maintenance in alignment with industry best practices, ensuring safety, consistency, and reliability across electrical equipment maintenance practices.

ANSI/NETA ECS–2024

ANSI/NETA ECS-2024, *Standard for Electrical Commissioning of Electrical Power Equipment & Systems, 2024 Edition*, completed the American National Standard revision process. ANSI administrative approval was received on July 2, 2024. ANSI/NETA ECS–2024 supersedes the 2020 Edition.

ANSI/NETA ECS describes the systematic process of documenting and placing into service newly installed or retrofitted electrical power equipment and systems. This document shall be used in conjunction with the most recent edition of ANSI/NETA ATS, *Standard for Acceptance Testing Specifications for Electrical Power Equipment & Systems*. The individual electrical components shall be subjected to factory and field tests, as required, to validate the individual components. It is not the intent of these specifications to provide comprehensive details on the commissioning of mechanical equipment, mechanical instrumentation systems, and related components.



The ANSI/NETA ECS revision includes the following new sections for Source-Specific Systems Commissioning: Photovoltaic (PV), Uninterruptible Power Supply (UPS), and Automatic Transfer Switches (ATS).

***Tania Brammer** is NETA's Director of Technical Operations.*

PARTICIPATION: Comments and suggestions on any of the standards are always welcome and should be directed to NETA. To learn more about the NETA standards review and revision process or to purchase these standards, please visit *www.netaworld.org*. To get involved, recommend revisions, or be considered for ballot pools, please visit *www.netaworld.org/standards/standards-development* or contact the NETA office at 888-300-6382.



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USING THE NETA ETT ROADMAPS TO TRAIN WITH INTENTION

BY DAN HOOK, *CBS Field Services*

Mose Ramieh's article from the Summer 2026 issue of *NETA World*, "Passing the NETA Exam: Train, Don't Cram," makes a critical point: NETA certification exams do not simply measure what someone does every day in the field—they measure how well that person understands the work across the discipline. That distinction matters. Experience is essential, but experience alone is not a preparation strategy.

The NETA Electrical Testing Technicians (ETT) Roadmaps for Levels 2–4 provide a structured way to convert that message into action. Used properly, they help candidates move from generalized experience to deliberate development. They also reinforce an important reality: certification preparation is not a last-minute event. It is a staged process built on safety, technical fundamentals, standards awareness, field exposure, and consistent self-study.

START WITH THE ROADMAP, NOT THE CALENDAR

A common mistake is to begin by asking, "When can I take the exam?" A better question is, "What knowledge, skills, and abilities do I still need to build?" The roadmaps are valuable because they organize preparation by phases and milestones rather than by urgency.

For Level 2, the roadmap presents a typical two-year progression. It identifies prerequisites, experience expectations, supervision requirements, and a phased process that includes onboarding, safety training, electrical fundamentals, hands-on field development, standards awareness, practice testing, and final exam readiness. While individual paths vary based on education, available training resources, and access to fieldwork, the roadmap provides a flexible framework that helps candidates and employers build disciplined progression.

That same principle applies across ETT Levels 3-4 Roadmaps. The roadmap should be treated as a development tool progression, not a checklist to glance at a few weeks before the exam.

USE THE DETAILED CONTENT OUTLINE AS YOUR ANCHOR

Ramieh emphasized that if a subject appears in the Detailed Content Outline, it is fair game on the exam. The roadmaps support that same approach by directing candidates back to the ANSI/NETA ETT outline and its four key domains: Safety, Electrical Testing Fundamentals and Theory, Component Testing, and Systems and Commissioning.

This is where customization begins. A candidate should review the outline and mark three categories:

1. Strong areas — topics regularly performed and well understood
2. Familiar but weak areas — topics seen in the field but not fully understood
3. Blind spots — equipment, standards, math, or theory rarely encountered

That exercise is important because the exam is not limited to the equipment that a company most often tests. Ramieh specifically pointed to common gaps, including unfamiliarity with the apparatus, math skills, and a deeper understanding of the standards. The roadmaps help candidates address those gaps early enough for meaningful improvement.

BUILD THE PLAN IN PHASES

The strongest recommendation from the roadmaps is to prepare in phases. For Level 2, that progression is especially clear:

Phase 1: Initial training and work experience
Focus on company onboarding, required safety training such as NFPA 70E and OSHA, electrical testing fundamentals, and direct hands-on field experience. This is also the time to begin reviewing exam preparation resources and the certification outline.

Phase 2: On-the-job training and knowledge development
Use company training materials, complete NFPA 70B training, and gain practical exposure to acceptance testing, maintenance testing, and commissioning testing. Continue broadening familiarity with related standards such as NFPA, CSA, IEEE, ASTM F-18, and OSHA.

Phase 3: Fundamentals and self-study
Take the practice exam to gauge progress, identify weak areas, attend technical and safety training, and use the certification outline as a study checklist. Mentorship and peer study groups have become especially valuable here.



The NETA ETT Roadmaps provide a structured way for candidates to build on the knowledge, skills, and abilities they need for ETT certification.

Phase 4: Advanced exam preparation
Commit to weekly study hours, retake the practice exam, target weak areas with focused training resources, and continue accountability through study partners or mentors.

Phase 5: Exam execution
Confirm eligibility with the NETA Accredited Representative, schedule the exam, and pursue the final push with realistic expectations. The roadmap notes that not all candidates pass on the first attempt and that growth often comes from gaining more knowledge and experience.

This phased structure supports Ramieh's central message, that training over time is more effective than cramming at the end.

USE THE NETA ETT PRACTICE EXAM AS A DIAGNOSTIC TOOL

One of the most practical tools in the roadmap is the NETA ETT practice exam. It should not be treated as a score to admire or fear. It should be used as a diagnostic.

Ramieh noted that practice exams help identify where a candidate struggles and how questions are structured, but their real value comes afterward in the focused study that follows. He also cited a NETA review showing that technicians who completed the practice exam before the proctored test achieved a 30% higher pass rate than those who did not.

That matters for Level 2, and it matters even more as candidates progress toward higher levels. A good approach is simple:

- Take the practice exam once to establish a baseline.
- Sort missed questions by domain.
- Rebuild weak areas through study, field exposure, and mentoring.
- Retake the practice exam later to measure improvement.

The roadmaps specifically recommend taking the practice exam during the self-study phase and again during advanced preparation. That sequence helps candidates move from broad awareness to targeted readiness.

CUSTOMIZE THE ROADMAP TO THE CANDIDATE

The roadmaps are most effective when they are personalized. A customized plan should account for:

- Educational background
- Access to field assignments
- Available internal training resources
- Current exposure to apparatus and systems
- Strengths and weaknesses in math, theory, safety, and standards

For example, a candidate with strong field exposure but weak math skills may need short, consistent sessions focused on formulas and calculator use. A candidate who routinely works on only one equipment type may need intentional exposure to unfamiliar apparatus and systems. Another candidate may need deeper review of standards foundations and the purpose behind specific tests.

Ramieh's article is especially useful here because it identifies the most common blind spots: safety, math, unfamiliar apparatus, and surface-level understanding of codes and standards. The roadmap provides the timeline; his article helps define where extra effort is often needed.

NETA ETT EXAM PREPARATION SEMINAR

For candidates looking to strengthen their preparation strategy, the NETA Exam Preparation Seminar available through the NETA Bookstore is an excellent supplemental resource. Presented at PowerTest 2026 by Dan Hook and Jim Cialdea, Chair and Vice Chair of the Technical Exam Committee, the seminar offers practical guidance on how to prepare for the next level of NETA ETT certification with greater structure and confidence.

The training covers proven study approaches, effective use of the Detailed Content Outlines, reference lists, formula sheet, exam roadmaps, and the practice exam, along with practical test-taking strategies such as pacing, flagging difficult questions, writing out formulas and circuit sketches, and using field experience and standards study together.

For technicians serious about advancing, this seminar provides direct insight from technical leaders closely involved in the exam process and is a valuable tool for turning day-to-day experience into focused exam readiness.

PRACTICAL RECOMMENDATIONS FOR TECHNICIANS AND EMPLOYERS

To get the most value from the roadmaps, candidates should:

- Review the roadmap at the start of the preparation cycle, not near the end.
- Align training activities with the four exam domains.
- Schedule recurring study time in short, consistent sessions.
- Use the practice exam to identify weaknesses, not just to estimate passing potential.
- Combine classroom learning with hands-on field exposure.
- Build mentorship and peer accountability into the plan.
- Watch the Exam Preparation Seminar from the NETA Bookstore.
- Revisit the roadmap periodically and adjust based on progress.

Candidates should not prepare alone if support is available. The roadmap explicitly points to mentorship, peer study groups, company training resources, on-demand training, and apprenticeship pathways. That is consistent with Ramieh's reminder that while no one else can do the work for you, you do not have to figure it all out alone.

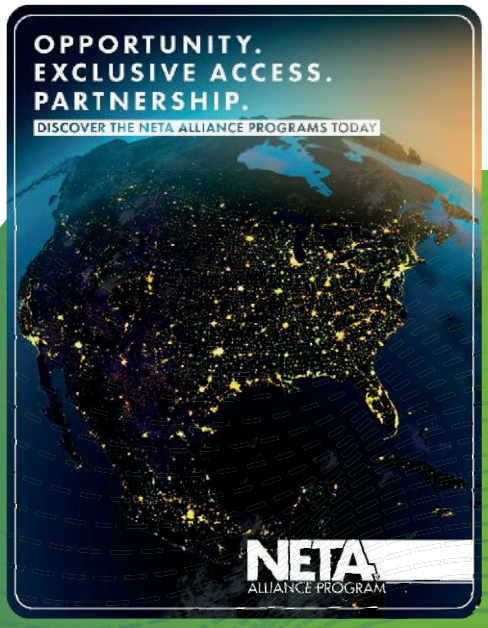
THE ROADMAP IS A TRAINING SYSTEM

The NETA ETT Roadmaps are more than scheduling aids. They are structured preparation frameworks that help candidates develop competence in the same deliberate way the exams are designed to measure it. When combined with the Detailed Content Outline, on-the-job learning, standards-based study, and the NETA ETT practice exam, they provide a practical path from exposure to understanding. That is the real connection to Train, Don't Cram. Candidates who use the roadmaps well are not just studying to pass an exam. They are building the habits, knowledge base, and technical judgment that support safer work, stronger performance, and long-term growth in the electrical testing field. NW



Dan Hook *is NETA President and Chair of the Technical Exam Committee, and Vice President of GCBS Engineering Services and Solutions at CBS Field Services.*

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