

SPRING 2026

# NETA WORLD™

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## COMMISSIONING AND ACCEPTANCE TESTING:

The Foundation of Electrical System Lifecycle Management

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# FROM A YEAR OF GREAT PROGRESS TO A FUTURE OF ENDLESS POSSIBILITY

*As we open 2026, I am proud to reflect on what was one of the most consequential years in NETA's history. In 2025, our Association advanced its mission of promoting safety, reliability, and technical excellence across the electrical power testing industry at a time when our work has never been more critical.*

Last year marked the release of ANSI/NETA ATS–2025, strengthening the technical foundation for acceptance testing at a moment when construction schedules are accelerating and system complexity is increasing. We also welcomed the publication of NFPA 70B–2026, which aligns powerfully with our standards by providing a complementary framework for long-term electrical maintenance programs. Together, these milestones represent a major step forward in reinforcing a true lifecycle approach to electrical system reliability from initial energization through decades of operation.

Equally important in 2025 was the continued growth of our membership, the expansion of technician training and certification programs—specifically the DOL-approved apprenticeship program—and the rising recognition of NETA-accredited companies as the gold standard for independent electrical testing. As digital infrastructure, renewable energy, battery storage, and mission-critical facilities expand worldwide, NETA's role in defining consistent, defensible testing practices has never been more visible or more valued.

The articles in this issue of *NETA World* reflect both the progress we have made and the challenges ahead. The feature on commissioning and acceptance testing as the foundation of lifecycle management reinforces why our standards matter—not just as technical documents, but as essential tools for protecting people, assets, and operations over the long term. And the in-depth examination of ANSI/NETA standards in data center acceptance testing highlights how our industry is adapting to AI-driven growth, modular construction, and unprecedented project timelines without compromising safety or quality.

You will also find valuable insight into transformer factory acceptance and field commissioning, underscoring the importance of baseline testing, documentation, and experienced interpretation in preserving critical assets. The case study on upgrading a line relay without an outage offers a practical reminder that innovation, teamwork, and rigorous testing can extend the life of existing infrastructure while maintaining reliability for customers and communities.

A cornerstone of our year ahead will be PowerTest 2026 in Nashville, TN. Hopefully you are reading this article while attending. Powertest continues to stand as the premier technical conference and exposition for the electrical power testing industry. Building on the strong momentum of recent years, PowerTest 2026 will bring together practitioners, engineers,



NETA'S ROLE IN DEFINING  
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NEVER BEEN MORE VISIBLE OR  
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## PRESIDENT'S DESK

manufacturers, educators, and industry leaders for an unmatched program of technical education, hands-on learning, and peer collaboration.

I encourage every member to participate whether as an attendee, presenter, exhibitor, or sponsor and to help make PowerTest 2026 another defining moment for our Association and our industry.

Looking ahead to 2026, NETA will release the updated edition of ANSI/NETA ETT 2025, *Standard for Certification of Electrical Testing Technicians*, ensuring that technician qualifications continue to reflect the highest levels of professionalism and technical rigor. NETA will also introduce a new ANSI-approved standard, ANSI/NETA EMW2026, *Standard for Qualification of Electrical Equipment Maintenance Workers for Electrical Power Equipment & Systems*®. This important addition directly supports NFPA 70B®, *Standard for Electrical Equipment Maintenance*®, and fulfills the qualification requirements for Qualified Electrical Equipment Maintenance Workers (QEMW) outlined in that standard.

As we move into 2026, NETA's priorities are clear. We will continue to evolve our standards to keep pace with emerging technologies, support the development of the next generation of technicians, and expand our educational offerings to meet the needs of a rapidly changing industry. We will also strengthen collaboration with allied organizations and standards bodies to ensure alignment, clarity, and consistency across the broader electrical ecosystem.

Most of all, we will remain focused on our core purpose: helping our members deliver safe, reliable, and resilient power systems in a world that increasingly depends on uninterrupted electricity. The work you do often under tight schedules, complex conditions, and immense responsibility makes a tangible difference every day.

Thank you for your commitment to excellence, your engagement with NETA, and your continued support of our shared mission. I look forward to what we will accomplish together in 2026.



**Dan Hook, President**  
InterNational Electrical Testing Association

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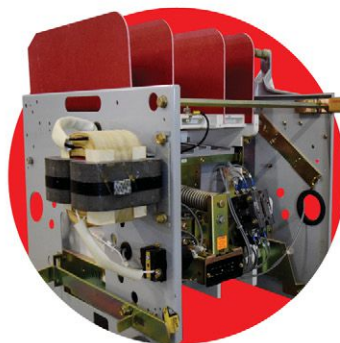


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# KEN VESCOVI:

## PROBLEM SOLVER WITH A PASSION FOR TEAM BUILDING

This issue of *NETA World's* “Insight and Inspiration” series features Ken Vescovi, Vice President Power—Electrification and Power Solutions, at ABM, where he is responsible for the operation and financial management of ABM Electrical Power Solutions, LLC, and ABM Electrical Power Services, LLC, both NETA Accredited Companies. These responsibilities extend to every aspect of the business, including strategic business and growth plan development, SME technical oversight and approvals of large projects, oversight and development of the technical training team, and the best part, building the team by opening new avenues for recruitment and partnerships. Prior to beginning his career, Vescovi earned a BS in mathematics from Youngtown State University in Youngstown, Ohio.



**NW:** What attracted you to the electrical industry?

**Vescovi:** What first attracted me to the electrical industry was the security of the utilities. I was looking for a career, not just a job, and I knew that everyone relied on power generation. I thought this could be an industry where I could grow for years. I am a problem solver at heart, which is why I have always loved math. I also love understanding how things work, especially anything in

technology, and knowing that every little wire and component plays a specific role in allowing a device to function properly.

When I began my career in the power generation industry, I was instantly pleased to find that my troubleshooting and problem-solving skills were challenged daily. However, when I was introduced to NETA testing, I gained a much greater appreciation and understanding of how all of these components and systems worked together, and I knew I had found my career.

**NW:** What was your path to your current position?

**Vescovi:** While I was attending Youngstown State University, I began working full-time at Pennsylvania Biodiesel Inc. as an Instrument & Controls Technician. I calibrated field instrumentation and worked with the Delta V control system to ensure proper batch processing. I worked there until I finished my degree and found a new home as a Generation Specialist with First Energy Generation Corp, where I was introduced to NERC compliance.

I held various roles at First Energy and worked in small coal-fired subcritical generation facilities as well as on super-critical units, and I was fortunate enough to also support their combustion turbine and hydro plants. During that time, I would hire and work with NETA Accredited Companies to ensure that the plants were NERC-compliant and met all required PRC standards. This is when I met the ABM team from Pittsburgh, Pennsylvania.

After working with the team for a few years and seeing the coal-generation plants being decommissioned, I knew it was time for me to apply for the Project Manager position in Pittsburgh, and in November 2015, I was hired as the Pittsburgh Project Manager responsible for acceptance testing and utility projects. Our team expanded and nearly doubled over the next two-plus years, and I was fortunate enough to step into the newly created Operations Manager role.

The biggest challenge of my career came in 2020, when I was promoted to General Manager for Pennsylvania and Ohio in March. This couldn't have come at a more challenging time due to the environment surrounding COVID; however, our team was resilient and continued to excel even in this most difficult of times. We were fortunate enough to have a maintenance backlog that could not only sustain our current workforce, but even allowed us to expand and continue to grow our team.



In 2023, I was promoted to Area General Manager and became responsible for ABM Electrical Power Solutions, LLC. This is where I was introduced to the Mid-Atlantic data center corridor and the vast amount of work our team was executing in data centers. The Power Solutions Team has grown at an accelerated pace over the last two years, and in November

2025, I was promoted to Vice President of Operations and am now responsible for ABM's two NETA Accredited Companies: ABM Electrical Power Solutions, LLC and ABM Electrical Power Services, LLC.

**NW:** How does being a NETA Accredited Company change how ABM sells and delivers?

**Vescovi:** Being a NETA Accredited Company significantly enhances ABM's credibility and marketability. Our customers know that being NETA accredited means ABM technicians have gone through rigorous technical and safety training and will provide the highest standard of quality and service. That means our customers do not look at ABM as another commodity service provider; we are now looked at as a trusted technical authority and advisor. As a NETA Accredited Company, we are not just there for the project; we are a partner that will support the entire lifecycle of our customers' electrical systems and personnel.

**NW:** Can you explain the difference between NETA-compliant testing and testing by non-NETA electrical service providers?

**Vescovi:** There are five main points that differentiate NETA-compliant testing and testing by non-NETA electrical service providers.

1. NETA-compliant testing provides independence and objectivity and prevents any influence on testing outcomes.
2. NETA technicians are certified by standard tests, qualified by NETA Accredited Companies to the highest standards in the electrical industry, and required to continuously complete education to stay up to date on all NETA standards. There are other standardized certifications in the industry, but they are not tied to company accreditation and do not offer the independent evaluation NETA can provide.

3. NETA-compliant testing must follow ANSI-approved NETA standards, while non-NETA service providers can choose to follow any standard (IEEE, NFPA, etc.) or internal procedure.
4. Calibration and equipment quality is paramount and must be maintained to NETA standards. There is no specific requirement for non-NETA service providers.
5. NETA companies and NETA-compliant testing are regularly audited and must meet the strictest standards for safety, technician education, calibration, quality, and many other requirements. Non-NETA service providers are not held to any specific industry-wide audits or standards.

**NW:** How has the electrical testing landscape changed now that NFPA 70B is a mandatory standard?

**Vescovi:** NFPA 70B–2023 is now a formal standard, so the biggest change is that preventative maintenance is no longer an option. It is now mandatory for all facilities. The new required inspection, testing, and maintenance intervals mean that most facilities are seeing an increase in volume and frequency over previous maintenance programs.

This is prompting many facility managers to create formalized electrical maintenance programs that may have not been in place previously, and NETA Accredited Companies are well-positioned to provide these services with uniquely qualified technicians who are viewed as the boots on the ground experts. NFPA 70B also requires strict documentation to ensure compliance, which is easily attained by a NETA Accredited Company through its standard operating procedures.

The biggest challenge is the number and frequency of mandatory tests required to meet NFPA 70B. When coupled with the increase of data center and infrastructure projects across the industry, there are not enough certified technicians to maintain every facility.

**NW:** Describe a time you declined work or adjusted scope due to safety concerns.

**Vescovi:** There have been many times throughout my career when we have adjusted scope due to safety concerns, and I am sure many in the NETA community can relate. One that stands out happened a few years back when I was a project manager working with an oil and gas company on one of their shutdowns.

It was January in Pennsylvania, and there was snow on the ground. Our team was hired to perform maintenance on the de-ethanizer substation and associated switchgear down to their 480-V MCCs. We had written up the method of procedure (MOP) for a complete shutdown of the de-ethanizer substation and all associated downstream gear. I went with our lead NETA Level 3 Technician to walk down the outage work with the customer and discuss the MOP about a week before the shutdown. The customer informed us that we needed to change the MOP and keep power on to the downstream 480V MCCs to keep the heat trace on and prevent their pipes from freezing during the 12-hour shutdown. The lead NETA technician and I formulated a plan to provide multiple generators and create separate isolated backfeeds for each motor control center (MCC) as required by the customer.

Multiple safety representatives from both companies reviewed and critiqued the plan, which was finally approved and put into action during the outage. The plan worked flawlessly, except we found an issue where one of the MCC feeds did not match the prints. The team immediately stopped work, traced back, and verified where the additional cabling was going,

and they were able to isolate before backfeeding an unintended system. Once this was corrected, the team was able to successfully complete the full outage with no safety issues or incidents.

**NW:** Which energy trend do you think will most affect NETA companies in the future?

**Vescovi:** It is hard to deny the impact of the number of new data center sites coming online every month across the country. With current projections lasting decades into the future, the biggest issue is where will we get the power.

Many newer sites are being built with co-generation on site, which works great if you have a fuel source nearby. Even old coal-generation plants are being converted to alternate fuel sources to repower and support data centers. The biggest energy trend driving utilization of NETA companies right now and heading into the future is the massive amount of energy being consumed by these data centers, and the excessive number of generation, distribution, and transmission upgrades needed to support them.

“Technical curiosity, disciplined problem-solving, electrical safety, and a deep commitment to people are just a few of the values that drive every NETA Accredited Company,” Vescovi concludes. “As the power industry evolves, strong NACs, built with intention and supported properly, are the companies that will ultimately ensure the long-term success of the power industry. I’m proud to have worked for a NAC for the past 10 years, and I look forward to many years of team building and problem solving in the power industry. [NW](#)”

# THE MOST DANGEROUS ELECTRICAL TASK YOU DO EVERY DAY?

BY RON WIDUP, *Vector Power*

We work around electricity every day.

We are exposed to hazards every day.

But what's the most dangerous task YOU do every day?



*Switching Operation*

## DANGEROUS TASKS

### The Starting Point: Turn It Off!

My guess is you treat switching operations like surgery—plan the task, determine the proper shutdown sequence, see which loads are affected, check the one-line diagrams, verify the labels, double-check the switching order, figure out the lockout/tagout needs, and execute the tasks.

Dangerous? It can be, but you have likely put a lot of brain cells into the situation to help minimize risk.

### The Part in the Middle: Gotta Test It Now

Circuit breakers, medium-voltage cables, power transformers, protective relays, switchgear lineups—you have switched everything off, so the testing part is probably routine. You're qualified, you know what you're doing, you execute the tasks.

Dangerous? Not as much—but there are elements of risk.



*Portable Meter Use*

## **The Last Part: Turn It Back On!**

Put it all together, account for all your tools, double- and triple-check the cable connections, restore the settings if you moved them, and clean up the mess. It's time to step back and turn it back on.

Dangerous? Shouldn't be...You did, after all, check everything out. Just make sure you aren't in front of the gear or next to the transformer when you do turn it back on.

## **THE MOST DANGEROUS TASK?**

OK—we turned it off, we tested the equipment using the NETA standards, and we turned it back on when we were done. So what is the most dangerous task in all of that?

## **Testing for voltage using portable test instruments.**

Arguably, NFPA 70E® doesn't treat switching as the riskiest moment in electrical work. Your real exposure shows up in using portable meters to test and verify energized electrical conductors and circuit parts.

That includes testing for the absence of voltage, testing for the presence of voltage, troubleshooting, load checks, verifying lockout scenarios, proving circuits before touching them...anything involving portable test instruments.

You do this work every day. You also have opportunities to take more shortcuts here than anywhere else.

# THE NFPA 70E AND NETA

These exposure combinations will likely put you closer to an arc or shock event than a breaker operation or a switching procedure, not to mention how many times a day you might (or should) be doing this.

Portable metering steps place your hands and body closer to energized parts than switching ever does.

- You lean in.
- You open covers.
- You reach into unknown conditions.

## NFPA 70E COVERS IT

NFPA 70E®, *Standard for Electrical Safety in the Workplace*®, centers your risk right here, and it addresses the process for verifying the absence of voltage in a few key sections. The primary procedure for verifying absence of voltage is detailed in Section 120.6, and it is supported

by additional test instrument requirements in 110.6(E), as well as lockout/tagout procedural elements in 120.5(B)(6).

Section 120.6, *Process for Establishing and Verifying an Electrically Safe Work Condition*, details step-by-step procedures, including:

- Using an adequately rated portable test instrument
- Testing each phase conductor or circuit part, both phase-to-phase and phase-to-ground

Section 110.6(E) *Operation Verification*, provides guidance on verifying the test instrument's operation on a known voltage source before and after testing for the absence of voltage.

Let's look at a few common scenarios that lead to injury when testing for voltage.

## Scenario One: What About Those Instrument Ratings?

Portable test instrument ratings and misapplications are likely a failure point nobody plans for, even though a portable meter is part of your PPE arsenal. NFPA 70E requires test instruments to be “adequately rated” for the environment and the use.

Many field failures of portable meters come from:

- CAT II meters used on CAT III or IV systems
- Leads with cracked insulation
- Fused leads replaced with solid wire.
- Meters not reverified after drops or rough handling
- Using the wrong voltage class of meters

When meters fail, they can fail violently, and they can become ignition sources.

And think about this: You protect your hands and face with PPE, but you will trust an unverified test instrument that is just inches



*Voltage Test*

from an exposed (and possibly energized) electrical component!

## Scenario Two: Live-Dead-Live Is Not a Ritual, It's a System Test

If you follow NFPA 70E, the standard requires live-dead-live circuit verification (Section 110.6(E) *Operation Verification*).

Many times, this simple, but very important, task is treated as a box to check on the paperwork—unless you make it an ingrained part of your safety DNA.

Think about these typical activities:

- You are going to touch a (possible) known live source
- You test your circuit
- You do your work

Most failures hide in actions that you do not check:

- You do not confirm your meter works before the dead test (live-dead-live)
- You skip the second live source verification (live-dead-live)
- You test at one point instead of all of the conductors you are about to work on
- You trust (ASSume!) the disconnect orientation without confirming which is line and which is the load.

When you touch a circuit part that you believe is dead—and you haven't followed the necessary steps to verify all of it—this is where shock injuries happen!

## REMEMBER THIS: DON'T MAKE TEMPORARY PROTECTIVE GROUNDS THE MISSING CONTROL POINT

OK, you've tested the system for absence of voltage (70E requires us to test for the absence of voltage "at each point of work.") and you have locked out everything. What needs to happen before you actually work on the equipment?



*Temporary Grounds*

You should be placing temporary protective grounds on large systems after testing for voltage...and I'll bet you rarely ground the smaller systems down the line. NFPA 70E addresses temporary protective grounding as a requirement, not an option, so be careful here.

Those requirements are addressed in Section 120.6(8) *Process for Establishing and Verifying an Electrically Safe Work Condition*, where 70E tells us that temporary protective grounding equipment is required where there is a possibility of induced voltages, stored electrical energy, or the potential for contact with energized conductors during the work.

An increase in the risk of injury shows up when:

- Induced voltage sits on isolated conductors.
- Backfeed appears through control circuits.
- Capacitors have a residual charge.
- Parallel feeders share stray voltages.
- Temporary generation is misapplied.
- Tie breaker or alternate feed circuits are coming from a different source.

You test it once, and you remove your rubber insulating gloves. You ASSume the circuit is safe. But what about all of the touch points? Did you map all of the possible scenarios, even on the smaller circuits? Did you sweep all of the exposed conductors and circuit parts? It's "the other parts" that can sneak up and get you with unexpected energy that finds your hands and body.

## WRAP IT UP: DO THESE FIELD CORRECTIONS AND REDUCE RISK

Challenge yourself to do these simple tasks to reduce risk and improve your safety DNA when it comes to testing circuits with portable instruments:

- Use the correct PPE for circuit verification work.
- Inspect portable meters and leads every day, before every use.
- Replace any lead that shows wear. No exceptions!
- Use properly rated meters only. Match the environment.
- Execute a complete live-dead-live process every time.
- Place temporary grounds on conductors after verification on medium- and high-risk systems—and be thorough in analyzing where to place them, including the higher-risk low-voltage circuits.
- Do not remove rubber insulating gloves until temporary protective grounds are in place.
- Test. Before. Touch.

These risk controls cost very little, don't take much time....and ultimately can prevent a high percentage of electrical injuries related to metering tasks.

## WHAT'S THE FINAL MESSAGE?

You might perform switching tasks a few times a week, maybe a few times a month. You probably do NETA performance testing on electrical equipment all the time. But throughout these processes, you should be performing portable metering checks/tasks dozens of times a day....placing you in harm's way each time.

Real exposure often happens in the work you treat as routine....the task that feels normal often causes the most injuries. Don't let testing for the absence of voltage become routine.

When you think about it, you don't need more rules. You need vigilant discipline where your hands and body are exposed the most, especially when using portable test instruments.

So stay sharp, keep on your game, and test before touch! **NW**



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# ON TRANSFORMERS WITH ELECTROSTATIC SHIELDS

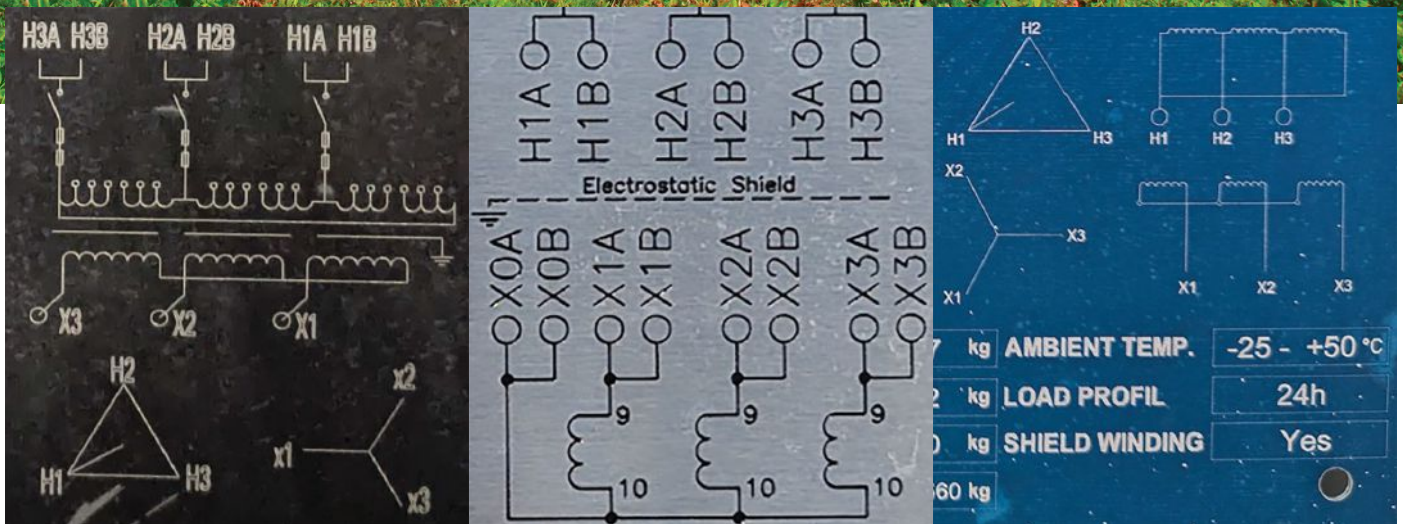
BY MICHAEL LABELIT, *RESA Power*

If you've worked on transformers in renewable energy circuits, as I have for the past six months, you've likely seen many—perhaps most—equipped with electrostatic shields, grounded copper or aluminum sheets wedged between the high- and low-side windings. The existence of these shields inside transformers is normally (but not always) readily identifiable via the unit data plates (Figure 1). Some affirm the presence of a shield with a grounded, dotted line running between the windings; others label the dotted line with “Electrostatic Shield” or “ESS”; others indicate the shield with a simple “Yes.”

These shields are designed to protect loads from overvoltage transients that are common in renewable circuits. While these features may enhance the integrity of renewable circuits, they sow confusion among test technicians due to their unique effect on power factor test results.

## **LOW CHL CAPACITANCE**

As Khanali and Jayaram (2015) state, “The main functionality of the electrostatic ground shield is to capacitively decouple the primary and secondary windings. The advantage of this method is suppressing the transfer of high-



**Figure 1:** Data Plates for Shielded Transformers

frequency contents of voltage generated on each side of the transformer to the other side.”

This works, they say, because “the electrostatic shield basically acts as a capacitive filter to prevent the transfer of critical voltage components onto the secondary side.” This capacitive decoupling manifests itself as (much)

lower high-side to low-side (CHL) capacitance compared to that of unshielded transformers.

Table 1 represents power factor test results recently gathered on a 4,200-kVA, 35.4-kV/480-V delta-wye, shielded Hitachi transformer. Observe the exceedingly low capacitance of the CHL insulation.

**Table 1:** Hitachi Shielded Transformer Test Data

Insulation	V [kV]	I [mA]	Loss [W]	PF*TCF [%]	TCF	Cap (pF)
CH+CHL	10.001	42.032	1.679	0.400	1	11149.600
CH	10.000	41.046	1.674	0.408	1	10888.100
CHL (Measured)	10.000	0.974	-0.003	-0.027	1	258.420
CHL	*	0.986	0.005	0.052	1	261.500
CL+CHL	1.000	122.196	4.853	0.397	1	32413.949
CL	1.000	121.226	4.856	0.401	1	32154.650
CHL (Measured)	1.000	0.975	-0.006	-0.063	1	258.534
CHL	*	0.969	-0.003	-0.030	1	259.299

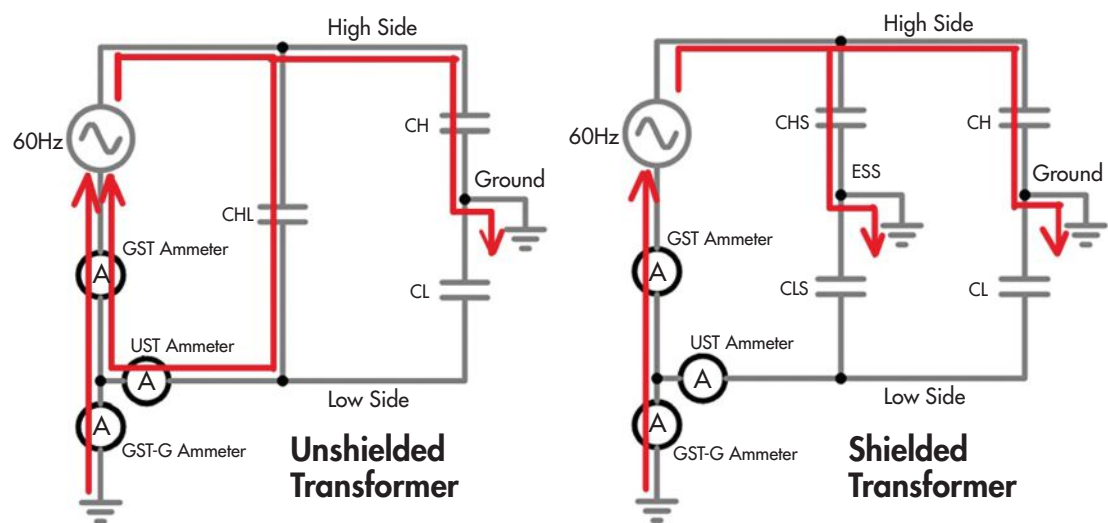
**LOW CHL CURRENT AND WATTS LOSS**

The difference between the grounded specimen test (GST), the grounded specimen test with guard (GST-G), and the ungrounded specimen test (UST) is the current the test set is measuring.

- The GST applies a voltage across CHL and CH, then measures the current through both CHL and CH.
- The GST-G applies the same voltage across both insulators, but measures only the current through CH.
- The UST applies the same voltages, but measures only the current through CHL.

All current wants to return to its source. The electrostatic shield provides a low-impedance path for current flowing in either winding to return to the source via ground, instead of to the other winding (Figure 2). As a result, when voltage is applied between the high and low sides during testing, current that would normally flow through CHL (as measured by the UST ammeter) flows instead through ground (as measured by the GST-G ammeter) through the high side to ground insulation (CH) and the high side to shield insulation (CHS).

Some current still flows from the high side to the low side, but it is minimal. This explains the low CHL current measurements in Table 1.



**Figure 2:** Current Paths in Shielded vs. Unshielded Transformers

It also explains the low CHL watts losses because the insulation watts loss  $W$  is the product of the test voltage  $V_T$ , the total current measured  $I_T$ , and the power factor  $PF$ , or  $W = V_T(I_T)(PF)$ . As total current  $I_T$  decreases, so must watts losses  $W$ .

### NEGATIVE POWER FACTOR

Power factor is a function of *cosine* ( $\vartheta$ ). Angle  $\vartheta$  is the angle between the test voltage  $V_T$  (or the resistive current  $I_r$ ) and the total current  $I_T$  (Figure 4). For a power factor to be negative, the angle between the applied voltage and total current would have to be above 90 degrees and below 270 degrees. For example, if angle  $\vartheta$  equals 120 degrees, then the power factor equals *cosine* (120 degrees) equals -0.5.

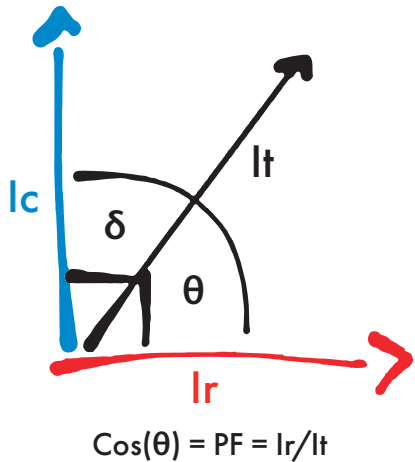


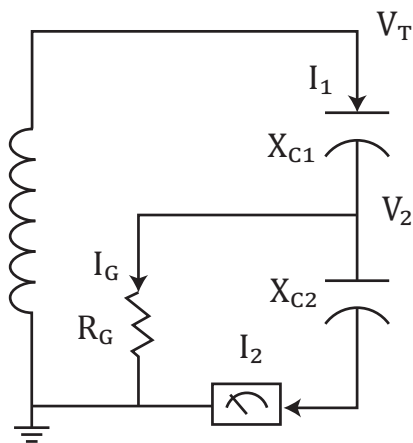
Figure 3: Power Factor Angles (Labeit 2023)

Negative power factors are impossible. Real power cannot exceed apparent power; resistive current cannot exceed total current. Negative power factor **measurements**, however, are a well-documented phenomenon.

A common cause of negative power factor measurements is an unknown path for resistive current back to the source, typically via ground. How this is possible can be explained as follows. Suppose a technician performs a power factor test on an asset as illustrated in Figure 4.

The technician may think that the asset is composed simply of one capacitive layer, but suppose a surreptitious path  $R_G$  for resistive current  $I_G$  back to the source exists somewhere in the middle of the asset. Such a path would split the single capacitive layer of the asset into two distinct, capacitively reactive layers,  $X_{C1}$  and  $X_{C2}$ . The power factor test set calculates the power factor by measuring the phase angle between the test voltage  $V_T$  and the current that enters its ammeter,  $I_2$ .

But if the current that is supposed to enter the ammeter instead bypasses the ammeter on its way back to the test set, that current being  $I_G$ , the test set will erroneously calculate the power factor. The test set sees the true test voltage, but it does not see the true total current,  $I_2 + I_G$ , otherwise known as  $I_1$ . It only sees  $I_2$ .



$$V_2 = V_T \times \frac{X_{C2}}{\frac{X_{C1}X_{C2}}{R_G} + (X_{C1} + X_{C2})}$$

$$I_2 = V_2 / X_{C2} = \frac{V_T}{\frac{X_{C1}X_{C2}}{R_G} + (X_{C1} + X_{C2})}$$

Figure 4: Negative Power Factor Model (Pong, 2022)

Let's use some numbers. Suppose  $V_T$  is 100V,  $X_{C1}$  and  $X_{C2} = 100\Omega$ , and  $R_G = 1000\Omega$ . In that case, the current  $I_2$  that flows through the test set ammeter using the equation in Figure 5 will be:

$$= \frac{100}{\frac{(-100i)(-100i)}{1000} + (-100i - 100i)}$$

$$= -\frac{10}{401} + \frac{200}{401}i$$

This value of  $I_2$  converts to  $0.499A \angle 92.86^\circ$  when switching from rectangular to polar coordinates. The test set sees this amperage, concludes that angle  $\vartheta$  equals  $92.86^\circ$ , and calculates the power factor as cosine ( $92.86^\circ$ ) equals  $-0.0499$ . Behold, negative power factor!

The key in this erroneous calculation is the ammeter placement. If the ammeter was between the test set and the ground connection, it would intercept all current  $I_1$ , including resistive current  $I_G$ , and the power factor calculation would instead be:

$$= \frac{100}{(1000^{-1} + (-100i)^{-1})^{-1} - 100i}$$

$$= \frac{10}{401} + \frac{201}{401}i$$

polar  $\left(\frac{10}{401}, \frac{201}{401}\right) \rightarrow r = \sqrt{\frac{101}{401}} \quad \theta = \arctan\left(\frac{201}{10}\right)$

$$\cos\left(\arctan\left(\frac{201}{10}\right)\right) = \frac{10\sqrt{40501}}{40501}$$

This value simplifies to a power factor of 0.0497.

In the case of a shielded transformer,  $X_{C1} + X_{C2}$  represents the capacitive reactance of CHL, and  $R_G$  represents the electrostatic shield acting as a path back to the source that splits CHL into two capacitances. Because the shield redirects the vast majority of the current from the UST ammeter to the GST-G ammeter during power factor tests, USTs tend to render small or even negative values for CHL, as is evidenced by Table 1. Pong (2002) has a highly

recommended and masterful discussion on this topic.

## WHAT TO DO?

Power factor measurements from USTs on shielded transformers are of limited value, though, as Pong (2002) indicates, they can reflect changing conditions of the shield ground connection. Capacitance measurements from USTs remain sound examples of trendable parameters; their changes over time are worth noting. The same applies to GST-G tests of CH and CL power factors and capacitances; these remain valid as well. [NW](#)

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- [3] Pong, L. (2002). Review of Negative Power Factor Test Results and Case Study Analysis," *70th International Conference of Doble Clients*, Boston, Massachusetts, USA.



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# USING THE KD-10 TO PROVIDE 78 OUT-OF-STEP TRIPPING PROTECTION FOR A LARGE GENERATOR

BY STEVE TURNER, *Consultant*

Typically, multi-function numerical generator protection relays are now used to provide out-of-step tripping (OST) for large unit-connected generators. However, some users prefer to maintain older existing infrastructure, such as electromechanical relays. 78 OST protection must meet PRC-026-2 Criterion A of Attachment B requirements as follows:

*PRC-026 Criterion A of Attachment B indicates that a 78 impedance-based out-of-step protection function should not trip during a stable power swing when the relay characteristic is completely within the unstable power-swing region. The unstable power swing region is formed by the union of three shapes in the impedance plane:*

- 1. Lower loss-of-synchronism circle based on a ratio of the sending-end to receiving-end voltages of 0.7*
- 2. Upper loss-of-synchronism circle based on a ratio of the sending-end to receiving-end voltages of 1.43*
- 3. Lens that connects the end points of the total system impedance bounded by varying the sending end and receiving-end voltages from 0.0 to 1.0 per unit, while maintaining a constant system separation angle across the total system impedance, where the system separation angle is defined as follows:*
  - At least 120 degrees, or*
  - An angle less than 120 degrees where a documented transient stability analysis shows the expected maximum stable separation angle is less than 120 degrees.*



PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/IMANTSU

a single zone of phase distance protection for all three phases. Figure 1 shows the one-line diagram for this particular application. The relay is located on the high side of the two parallel GSUs and measures the total current flowing into the adjoining 230-kV system.

The relay is located at the bus on the high side of the parallel GSUs. Therefore, set the reach to see the equivalent GSU impedance ( $X_{TR}$ ) plus the saturated generator direct axis transient reactance ( $X_d'$ ) as shown in Figure 2.<sup>[1]</sup> Care

*All generation is in-service, and all transmission BES elements are in their normal operating state when calculating the system equivalent impedance.*

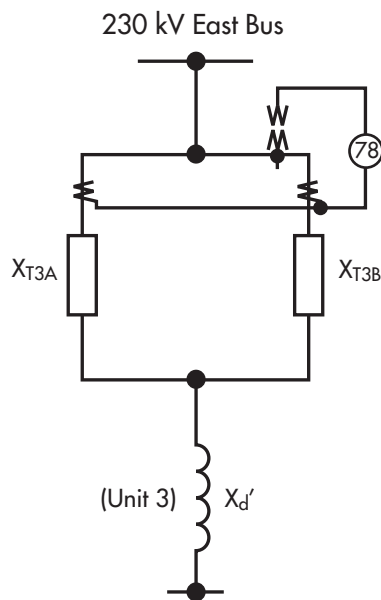
*Saturated reactance is used for all machines.*

*Criterion A provides a basis for determining if the 78 function should not trip during a stable power swing having a system separation angle of up to 120 degrees, with the sending end and receiving end voltages varying from 0.7 to 1.0 per unit.*

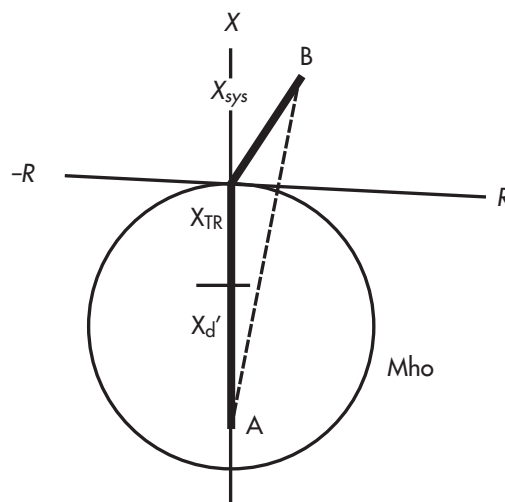
*It can be challenging to set electromechanical relays properly for this type of application, and the level of protection provided typically cannot match the corresponding protection provided by numerical relays.*

## APPLICATION

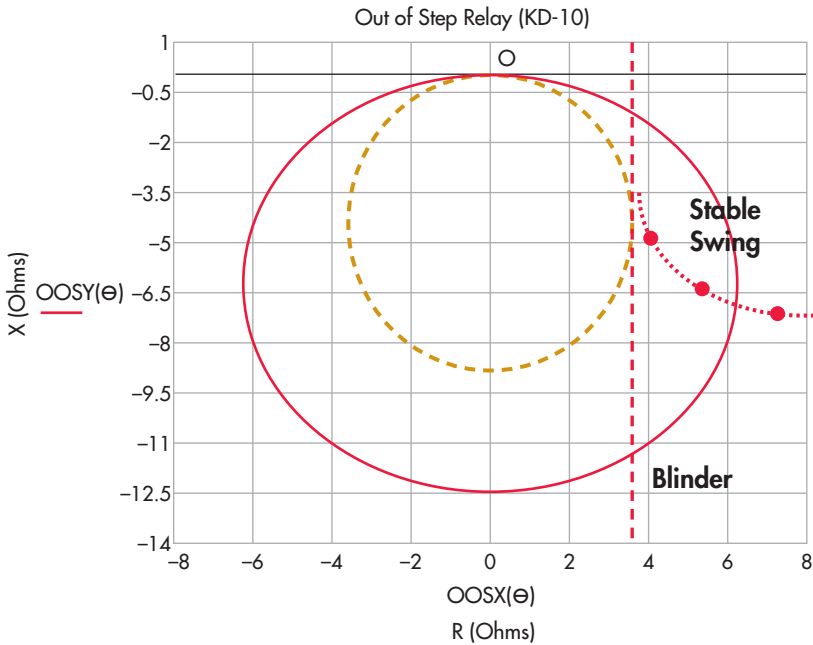
This example demonstrates how to set an existing KD-10 electromechanical distance relay for this application. The KD-10 relay is a polyphase compensator-type relay that provides



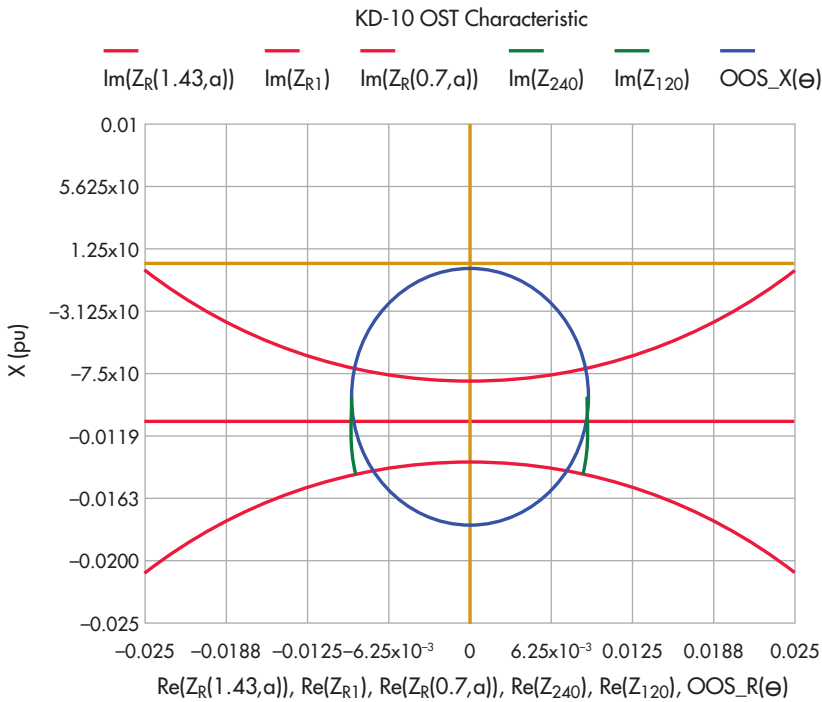
**Figure 1:** Single-Line Diagram



**Figure 2:** R-X Diagram for KD-10 Relay



**Figure 3:** KD-10 Operating Characteristic



**Figure 4:** KD-10 Operating Characteristic

must be taken to use the correct base when calculating the total impedance to determine the proper reach, which is the 230-kV system, not the generator.

Figure 3 shows the actual Mho characteristic that was calculated for this application. One of the main drawbacks to using the KD-10 for this application is that there are no blinders to keep the operating characteristic from operating during a stable swing. Therefore, the reach must be pulled back if necessary, which can compromise the protection. Unstable swings travel through either the generator or the GSU for large machines. The blinder shown in Figure 3 is for illustrative purposes only.

Figure 4 shows the actual Mho characteristic for the application. The reach was pulled back until it met the PRC-026-2 requirements.

## CONCLUSION

This article demonstrates some of the inherent advantages offered by numerical protection relays. [NW](#)

## REFERENCES

- [1] Reimert, Donald. (2017) *Protective Relaying for Power Generation Systems*. 1st ed. CRC Press, page 304.



**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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# SAFETY TIPS FOR CIRCUIT BREAKER MAINTENANCE AND TESTING

BY PAUL CHAMBERLAIN, *Asplundh Electrical Testing, LLC*

Breaker testing and maintenance can expose personnel to many types of hazards. Mitigating them can be achieved in various ways. First, it must be verified that the personnel are qualified to perform the required tasks. The person doing the work must recognize and understand the hazards that may be encountered while performing the tasks.

To better understand the many hazards involved with testing and maintenance of breakers, let's look at the sources that contribute to each hazard and consider ways to mitigate the risk.

## **PREPARE FOR THE JOB** **Conduct Job Prep and** **Pre-Job Brief**

Locate and review all service bulletins, maintenance documents, and manuals before beginning work.

Perform a pre-job brief with everyone who can affect the work or could be affected by the work on-site.

## **Recognize Hazards**

Human error is simply when a person (or persons) makes a mistake.

Checklists are a great way to engage the mind and avoid mistakes. To help prevent human

error, follow a procedure or checklist while performing any task. If one doesn't exist, create one.

Mistaken identity of equipment is a common cause of mistakes and accidents due to inaccurate labeling and incorrect one-line diagrams, etc. Equipment nomenclature must be verified and re-verified upon approaching a piece of equipment. Perform a self-check and a peer-check to ensure that the task is being performed on the correct equipment.

## **Select Personal Protective** **Equipment**

Before beginning work, select the appropriate personal protective equipment (PPE). The selection must be based on NFPA, OSHA, or CSA regulations for the class of breaker to be serviced. These regulations indicate the level of protection required to prevent electrical shock and protect personnel from an arc-flash.



PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/CHALEPHOTO

Note that the information will be based on the known values of the short circuit current, the clearing time in cycles, and the minimum working distance. If those factors are unknown, more information must be gathered prior to performing the work to ensure personnel safety.

### Isolate the Equipment

We often work around equipment that looks the same as other equipment.

Identify and flag the equipment being worked on to mitigate the risk of human error. Flagging can also be used to indicate a component that is not operating as expected, even when it is not visually apparent that it is not functioning normally. Flagging can take many forms, including signage, tags, and labels, depending upon the company or client's policy and procedures.

Barricade off a safe work zone to prevent other workers from inadvertently entering the work area. This ensures maintenance and testing are conducted in an area under the control of the people performing the work.

### CONTROL ENERGY

Failure to properly perform lockout and/or tagout (LOTO) contributes to many injuries when performing maintenance on breakers.

#### Electrical Energy

Controlling the electrical energy of a breaker is the first and most obvious hazardous energy source that can cause injury.

- Electrically de-energize the breaker. Ensure the breaker is disconnected from all sources of power.



- Once de-energized, verify that the breaker is at a zero-energy state using the manufacturer's approved method.
- Test the measuring device against a known source, then check for zero energy on the de-energized equipment, and then test the detection equipment against a known source again. This will verify that the test device was functioning properly during the check. Testing for voltage requires its own level of personal protective equipment (PPE) depending upon the voltage and the test procedure, following NFPA, OSHA, and/or CSA requirements.
- Connect grounds where and if applicable. Refer to OSHA 29 CFR 1910.269, NFPA 70E Section 120.6, or CSA for specific guidance on grounding locations and ground sizing required for the task, and follow the manufacturer's suggested practices. Personal protective safety grounds should be utilized when the equipment could contact energized components or when induced voltages or stored electrical energy exist.
- Tag out the equipment and notify all personnel in the work area.

## Other Energy Sources

Electrical energy isn't the only energy that requires control and LOTO.

Breakers contain a large amount of mechanical energy. This energy must be dissipated before servicing to prevent serious injury. Once the breaker's mechanical energy has been discharged, it is also advisable to lock out and tag out the charging mechanism if feasible. Ensure that remote operating handles are tagged in a local or manual mode. This will prevent someone from inadvertently operating the breaker.

Gravity (potential energy) must also be controlled. The sheer size and weight of larger breakers make them difficult to rack in and out or to maneuver around. Mechanical lifting devices may be necessary to move the breaker to an area where it can be serviced. This type

of energy does not necessarily require lockout/tagout, but it is an important hazard to consider.

Be aware of pressurized equipment or vessels. If pressurized equipment/vessel requires access, ensure the unit is depressurized, and the source of the pressure is disabled. The source of the gas or pressure must also be locked out/tagged out.

## OTHER HAZARDS

### Chemicals

Chemicals can be a hazard when maintaining various types of breakers. Sulfur hexafluoride (SF<sub>6</sub>) gas is used as an insulator in some applications, and care must be taken with damaged breakers that exhibit arcing, which can form a byproduct of sulfur pentafluoride, an extremely toxic gas. Additionally, SF<sub>6</sub> is denser than air, so it will displace oxygen in lower-lying areas, similarly to carbon monoxide. Ventilation must be used if the gas may become trapped.

### Lubricants and Cleaners

Some lubricants and cleaners pose a respiratory and skin irritant hazard if used in enclosed areas or on bare skin. Knowledge of the chemicals being used, reading the label, and checking the safety data sheet is advised to identify any potential health effects. When using some cleaners, personal protective equipment such as nitrile gloves, safety glasses, a face shield, and respiratory protection may be necessary.

### Asbestos

Asbestos may be a hazard in some older breakers. Learn to properly identify its presence or the equipment that may have contained it. Do not handle or disturb asbestos unless you are properly trained.

## CONCLUSION

When performing maintenance and testing on circuit breakers, we must recognize and take precautionary actions to avoid hazards.

1. Gather and review all applicable service advisories, bulletins, manuals, and maintenance documents for the equipment being serviced.



2. Perform a pre-job briefing.
3. Utilize all appropriate PPE for the task.
4. Use flagging and barricades.
5. Use peer-checking and self-checking to prevent mistakes.
6. De-energize, verify zero energy, and lockout and/or tagout the equipment.
7. Install grounds where applicable.
8. Utilize written procedures to ensure a step is not skipped or missed.
9. Be familiar with the chemicals used and associated hazards.

Following these steps can lead to a safer work environment while performing maintenance and testing of breakers. [NIV](#)



*Paul Chamberlain has been the Safety Manager for Asplundh Electrical Testing, LLC (formerly American Electrical Testing Co., LLC), a subsidiary of Asplundh Engineering Services, LLC since 2009. He has been in the safety field since 1998, working for various companies and industries. Chamberlain received a BS from the Massachusetts Maritime Academy.*



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## ACCEPTANCE TESTING AND COMMISSIONING

BY MORGAN GIENI, *Magna IV Engineering*

Electrical equipment is selected by a design engineer for a specific purpose. This includes operating within the manufacturer's specifications, as well as how it functions within the system.

For newly installed equipment, it is important for NETA Certified Technicians to critically verify that all aspects of the equipment work as intended to ensure proper and reliable operation of the electrical system.

1. During commissioning of a new circuit breaker, which of the following should be verified against the engineered single-line diagram?
  - a. Contact operation timing
  - b. Nominal current
  - c. Contact resistance
  - d. Insulation resistance
2. During acceptance testing, a single line may indicate the CT ratio plus which of the following?
  - a. BIL rating
  - b. Insulation rating
  - c. Percent accuracy
  - d. C classification
3. When testing the relay, breaker, and current transformers after commissioning, which overall test can be performed to ensure all devices function together?
  - a. Wiring check
  - b. Primary current injection
  - c. Burden check
  - d. Tightness verification
4. Which transformer rating can be verified during commissioning and then added to the single-line diagram?
  - a. Percent impedance
  - b. Voltage ratio
  - c. Phase shift
  - d. Tap position

5. Which cable test applies a higher voltage for acceptance testing and a lower voltage during maintenance?
  - a. Phasing check
  - b. Withstand
  - c. Insulation resistance
  - d. Shield resistance
  
6. When commissioning protective relays, which verifications would NOT need to be confirmed to be accurate on the single-line protection diagram?
  - a. Tripping indication
  - b. Relay name
  - c. Firmware version
  - d. ANSI device numbers

7. When commissioning circuit breakers and protective relays, which of these checks does NOT ensure they operate together?
  - a. Functional trip
  - b. Primary current injection
  - c. Schematic control checks
  - d. Confirming the same manufacturer

See answers on page 128.



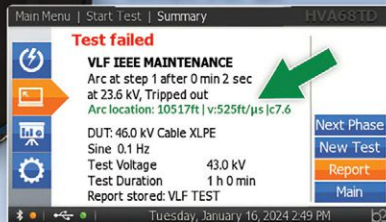
**Morgan Giени, CET, PSE**, is the Technical Support Lead — Technical Field Services (TFS) at Magna IV Engineering. He is a Certified Engineering Technologist through ASET — The Association of Science & Engineering Technology Professionals of Alberta and a Power System Electrician. Giени has extensive knowledge and experience regarding the commissioning, repair, and maintenance of electrical power systems equipment. He has spent the past few years of his career building technical training programs, providing technical support, and mentoring field service employees. Giени holds NETA Level IV Senior Technician Certification and is on NETA's Technical Resource Committee.



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# SUBSTATION SAFETY: ARE YOU ROCK SOLID?

BY JACOB RIOUX, *Hood Patterson & Dewar*

Substation design typically calls for two to six inches of aggregate (crushed rock) as a top layer upon completion of construction. This layer serves several purposes, including improved vehicle access, reduced erosion, and suppression of vegetation. Another significant function of this layer is to provide personnel safety by increasing the allowed (maximum permissible) touch and step potential values versus native soil. When the aggregate becomes a critical part of the site's safety, knowledge of the aggregate's composition and properties is required.

## ROCK MATTERS

In June 2023, the IEEE PES Substations Committee released a technical report titled Testing and Application of Crushed Aggregate for Use as a Resistive Substation Surface Layer, which has been incorporated into the new IEEE Std. 81-2025. This guideline provides a deep dive into all the factors regarding aggregate application. One of the main questions raised is whether the aggregate used at a site has a known resistivity. In our

experience, the answer is no. Utilities typically use a locally available aggregate for which the resistivity is untested and unknown.

Along with the unknown resistivity value of the aggregate, additional site factors come into play, including compaction, erosion, contamination from native soil, organic matter, and vegetation, along with environmental considerations such as temperature, moisture, herbicides, and salt treatment. All these components play a



*This older distribution substation has minimal rock with a lot of grass and weeds—precisely what you want to avoid.*

role in the resistivity and effectiveness of the site's rock layer. Once the aggregate has been compromised, a site can become unsafe for personnel if it's not remediated. We've been in hundreds of existing substations and have rarely found the aggregate maintained to the required depth or condition.

### CHALLENGES WITH ROCK

Limestone aggregate is used frequently as it is readily available, but limestone resistivity is lower than granite. Surprisingly, river rock is as high or higher than granite in resistivity (based on our lab test results). However, since it is a round rock, it isn't easy to walk or drive on, making it a less-than-ideal choice. It is critical to thoroughly wash the chosen aggregate to remove all fines, adhered clay, and silt. Washed rock raises the front-end cost but improves (increases) its resistivity and performance in the field. AASHTO #57 (¾ inch to 1 inch in size) is the most commonly specified rock size for use in substations.

From our experience, the biggest challenge for new substations is ensuring that the contractor lays down the right thickness of clean

aggregate inside and outside the station. For the substation exterior, a design specification typically calls for four-inch or larger rock three to six feet around the perimeter of the substation fence. This provides better erosion control and makes it more difficult for a person or animal to approach the fence.

### SAFETY FIRST

An ideal substation design intends to have the grounding system stand on its own with minimal assistance from outside grounding sources. Years ago, this was easier to achieve when line-to-ground fault currents were lower. However, this goal is more challenging as electrical systems have become more robust.

Today, during the design process, we depend more and more on exterior ground sources, transmission line overhead shield wires (OHS), and distribution neutrals to lower the system ground impedance by providing alternate paths for the fault current to return to its source. This lowered system ground impedance will, in turn, lower the resultant site ground potential rise (GPR). The substation will still require installation of a highly resistant aggregate layer



*Regular inspections to maintain the rock layer depth are critical to substation safety.*

to increase the safety factor, i.e., the allowable touch and step voltages.

**TESTING ROCK RESISTIVITY**

In November 2025, the IEEE PES Substations Committee released IEEE Std. 81-2025, *IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Surface Potentials of a Grounding System*. Per this newest version of IEEE 81 Section 11, Annex E, and Annex F, we now have guidelines for testing the

aggregate resistivity of substations. This is significant because most ground grid designs default to a crushed aggregate resistivity of 2,000–3,000 ohm-meters ( $\Omega$ -m), which is likely a conservative assumption that results in over-engineering the ground grid. Testing the aggregate resistivity will allow a more accurate design of the ground grid. Conversely, lower assumed aggregate values can result in measured touch potentials exceeding the overly conservative calculated permissible values.

**Table 1:** *Regional Aggregate Resistivity Samples*

	West (New) ( $\Omega$ -m)		Southeast (Old) ( $\Omega$ -m)		Midwest (New) ( $\Omega$ -m)		Northeast (New) ( $\Omega$ -m)	
Dry Test	64,285	110,354	637,272	215,603	661,577	648,068	1,215,176	2,927,622
Saturated with Water	3,170	3,677	30,847	27,052	8,955	8,695	22,847	22,570
Drained 1 Minute	3,122	3,579	34,737	29,417	10,181	9,538	22,074	22,597
Drained 2 Minutes	3,055	3,512	40,788	31,691	10,185	9,819	22,127	24,211
New Water & Drained 2 Minutes	3,846	4,330	47,870	33,175	9,835	9,864	23,068	26,094
Range	3,055–4,300 $\Omega$ -m		29,417–47,870 $\Omega$ -m		9,538–10,185 $\Omega$ -m		22,074–26,094 $\Omega$ -m	

SOURCE: HP&D REGIONAL AGGREGATE RESISTIVITY TEST DATA

IEEE Std. 80-2013, *IEEE Guide for Safety in AC Substation Grounding*, outlines “typical surface material resistivities,” but our testing has revealed that the data is incomplete and may not be indicative of aggregate values nationwide. As shown in Table 1, regional samples vary widely; hence, it is necessary to test your aggregate not only per region but also per site, as many factors can affect aggregate resistivity and, therefore, substation safety. Not all utilities in a region may be using the same type of stone, so the values shown in the table are for a specific region, utility, and site.

### ROCK STEADY

Ideally, aggregate resistivity testing should be conducted during the design process to ensure a cost-effective yet safe aggregate layer; however, this may not be possible or practical. To verify that the aggregate resistivity meets design criteria during the new substation commissioning, the aggregate should be tested according to IEEE Std. 81-2025.

Maintenance is essential for all substations. Using aggregate as a top layer is one of the most effective and cost-efficient methods to enhance safety. If a utility incorporates an aggregate top layer as part of a substation’s safety design, it must implement a rigorous inspection and maintenance program. Retesting the resistivity of the aggregate every five years is recommended to ensure that the site continues to meet the design safety criteria for touch and step voltages, and additional aggregate will likely be necessary. [NW](#)



**Jacob Rioux** is a Grounding Specialist at Hood Patterson & Dewar, Inc. With a background in substation design and testing, Rioux provides substation and facility grounding system testing and safety analysis. He also performs soil resistivity testing and grounding system design for new construction.

His client base includes electric utilities and industrial and commercial facilities. He provides grounding articles, training, and presentations for conferences and clients nationwide. Rioux has a BS in mechanical engineering technology with a minor in electrical engineering technology from the University of Maine.

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# COMMISSIONING AND ACCEPTANCE TESTING: THE FOUNDATION OF ELECTRICAL SYSTEM LIFECYCLE MANAGEMENT

BY JOEL GILLEY, *Electrical Reliability Services, Inc.*

Electrical power systems—from data centers and hospitals to industrial plants, utilities, and commercial complexes—are the foundation of modern facilities. Because these systems serve as critical infrastructure, they must operate safely, reliably, and efficiently at startup as well as through decades of service. Ensuring long-term performance demands a lifecycle-oriented strategy, beginning with rigorous commissioning and acceptance testing of all electrical components and systems.

Standards play an essential role in this endeavor by providing objective, consistent procedures for verification, testing, and documentation. The InterNational Electrical Testing Association (NETA) defines detailed standards for acceptance and ongoing maintenance testing. Additional standards, such as NFPA 70B from the National Fire Protection Association (NFPA), provide specific guidance

on maintenance programs, administrative procedures, and safety management over the system's life.

By combining NETA's technical rigor with complementary maintenance guidance, facility operators can feel confident that their electrical infrastructure will perform as intended from initial energization through long-term operation.



PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/EASYTURN

Commissioning standards are typically dictated by the owner's project requirements (OPR).

*Why standards matter: Applying documented standards reduces subjectivity, ensures consistent, repeatable testing methods, and provides a traceable record, supporting safety, reliability, and long-term performance.*

## WHAT IS ELECTRICAL COMMISSIONING AND ACCEPTANCE TESTING?

Electrical commissioning is a systematic process of inspecting, verifying, testing, and documenting newly installed or retrofitted electrical systems to ensure they are safe, reliable, and perform as designed before going fully operational. Benefits of a well-executed commissioning process include safer and more

reliable facility systems, greater efficiencies, lower cost of operation, a higher possibility of achieving construction scheduling and budget goals, and a well-planned and organized handover to the facility staff that leaves them with the knowledge and resources to successfully operate the building as intended in the design.

- Commissioning bridges the gap between construction and operation by confirming compliance with standards and operational needs.
- Acceptance testing, typically a prerequisite for commissioning, focuses on evaluating individual components and subsystems prior to initial energization. Its purpose is to confirm that each piece of equipment has been installed correctly, performs within the manufacturer's tolerances, and meets the project's design or contract requirements.

Together, commissioning and acceptance testing serve multiple purposes: They promote integrated system performance, document as-built conditions, and generate baseline data that serve future maintenance and lifecycle management. This combination is particularly critical for new installations, major retrofits, or system expansions where undetected installation errors or latent faults could lead to safety incidents or operational failures.

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*Electrical commissioning vs. acceptance testing: ECx focuses on a process that begins with reviewing the design and typically ends with integrated systems testing, while acceptance testing ensures component-level readiness for each piece of critical equipment before energization.*

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## Commissioning and Acceptance Testing → Maintenance

The sequence of acceptance testing verified as part of the commissioning process builds confidence in the installed equipment. Once commissioning is complete and handed off, it falls on facilities to ensure ongoing operations. This is where maintenance testing ensures continued system integrity, operational reliability, and data-driven maintenance decisions.

In the commissioning process, all critical equipment undergoes thorough documentation review, physical inspections, and verification. The commissioning process typically includes the development of a commissioning plan, creation of project-specific checklists and test scripts, visual and mechanical inspections, electrical acceptance testing, and documentation of test parameters, results, and final approved settings for energization.

Acceptance testing confirms that individual equipment and subsystems—switchgear, transformers, cables, UPS units, transfer switches—are installed correctly and function properly. This step verifies compliance against manufacturer tolerances,

design specifications, and standards, preventing latent defects or mis-installations from entering service.

Once the system is energized and operational, maintenance testing becomes the cornerstone of long-term system health. Maintenance testing may include periodic inspections, functional tests, thermographic surveys, partial-discharge or insulation testing on cables and switchgear, protective-device checks, and other condition-based diagnostics. These activities help identify degradation, abnormal conditions, or wear before they lead to failures or safety hazards.

The documentation and baseline data generated during commissioning and acceptance testing provide the reference point against which all future testing is measured. Having this as-built and as-energized record greatly improves the effectiveness of maintenance programs. It streamlines test interpretation, facilitates trend analysis, and supports equipment health tracking over time.

## THE ROLE OF STANDARDS

A robust lifecycle-oriented approach to electrical systems involves a seamless progression from initial installation through long-term operation, each phase supported by appropriate standards and documentation.

### ANSI/NETA Standards

ANSI/NETA standards provide a rigorous framework for electrical commissioning, acceptance, and maintenance.

ANSI/NETA ECS-2024, *Standard for Electrical Commissioning of Electrical Power Equipment & Systems*, provides guidance for verifying that newly installed or retrofitted systems meet design and performance requirements. ECS-2024 covers low-, medium-, and high-voltage systems, with an emphasis on integrated system-level performance including protective devices, interlocks, and alarms. It ensures systems are ready for energization and provides a baseline for long-term maintenance.



## ANSI/NETA STANDARDS AT A GLANCE

- ECS–2024: Electrical Commissioning Specifications for Electrical Power Equipment and Systems
- ATS–2025: Acceptance testing; component-level verification and readiness
- MTS–2023: Maintenance testing; preventive and predictive inspections for in-service systems

- ANSI/NETA ATS-2025, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*, specifies field tests and inspections before energization and final acceptance. It covers modern equipment such as battery energy storage systems (BESS), photovoltaic (PV) systems, uninterruptible power supplies (UPS), and medium-voltage cables. Compliance with ATS-2025 ensures each component is installed correctly, performs to specification, and is safe for operation.
- Maintenance testing, guided by ANSI/NETA MTS–2023, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*, defines procedures for periodic in-service inspections and predictive testing. Commissioning and acceptance testing data provide a reference point for MTS-2023, enabling operators to detect degradation, identify emerging issues, and plan maintenance effectively.

Together, these standards establish a lifecycle approach linking initial verification with long-term reliability.

## Complementary Guidance from NFPA 70B

While ANSI/NETA standards provide detailed technical requirements for commissioning, acceptance, and maintenance testing, facility operators receive additional guidance on maintenance program structure, administration, and long-term compliance. This is where additional standards—notably from the National Fire Protection Association (NFPA)—complement NETA’s technical scope.

For example, NFPA 70B-2026®, *Standard for Electrical Equipment Maintenance*®, defines the administrative and organizational aspects of an electrical maintenance program (EMP): scheduling of regular inspections, establishing written maintenance procedures, training and qualification of maintenance personnel, recordkeeping of maintenance history, and ensuring safety compliance during maintenance activities.

By combining the ANSI/NETA technical standards with an NFPA-style maintenance program structure, facility owners and operators achieve a comprehensive, standards-based approach to their electrical system

maintenance. NETA addresses which tests to perform and how, while NFPA-level guidance helps define when, by whom, and under what programmatic and safety framework maintenance should occur. The result is a lifecycle-focused strategy that supports safe, reliable, and efficient operation from day one through decades of service.

*Editor's note: 70B® and Standard for Electrical Equipment Maintenance® are registered trademarks of the National Fire Protection Association, Quincy, MA.*

## Benefits of a Standards-Based Approach

Adopting a standards-based methodology provides multiple significant benefits for facility operators and stakeholders.

- **Safety.** By verifying installation integrity, protective device coordination, alarm and interlock functionality, and system compliance before energization, commissioning and acceptance testing mitigates the risk of electrical accidents, equipment failures, and latent hazards. Regular maintenance testing helps detect insulation degradation, loose connections, or other developing issues before they lead to catastrophic failures.
- **Reliability.** Facilities designed and tested under NETA standards and maintained under a consistent program are less likely to suffer unexpected downtime. By capturing baseline data and performing periodic assessments, operators can proactively identify wear or stress on components, make informed maintenance decisions, and avoid unplanned outages.
- **Compliance and due diligence.** Many regulatory bodies, insurers, and facility owners now expect documented evidence of proper commissioning, testing, and maintenance. Applying widely recognized standards like ANSI/NETA and NFPA 70B provides

defensible documentation in support of safety, regulatory, and contractual obligations.

- **Lifecycle cost management.** Baseline data collected during initial testing and system commissioning establishes a reference point for future performance and maintenance, enabling predictive maintenance, better budgeting for repairs or replacements, and more strategic asset management. Over time, this can significantly reduce the total cost of ownership and extend the useful life of critical infrastructure.

## Evolving Standards

Standards evolve to remain relevant for modern electrical systems, including BESS solutions, PV installations, UPS units, and more complex medium-voltage installations. By aligning commissioning and testing practices with current standards, facilities can accommodate modern technologies while preserving safety, reliability, and maintainability

## CONCLUSION

Electrical commissioning and acceptance testing are not optional extras—they are critical foundational steps in the lifecycle management of electrical power systems. The standards published by NETA provide comprehensive, objective, technically rigorous guidance that ensures equipment and systems are installed correctly, tested thoroughly, and maintained effectively throughout their operational life.

When combined with the complementary maintenance-program guidance in NFPA 70B, this standards-based methodology delivers a holistic, lifecycle-oriented approach. It ensures that electrical systems are safe, reliable, efficient, and capable of meeting evolving demands over decades of service.

For facility owners, engineers, maintenance managers, and commissioning professionals, applying these standards is not merely a best practice; it's foundational to achieving operational excellence, safety, and long-term

value from electrical infrastructure. Ultimately, commissioning, acceptance, and maintenance testing are not isolated activities, but connected stages of a comprehensive lifecycle strategy that protects people, assets, and operations. [NW](#)

[4] National Fire Protection Association. NFPA 70B-2026®, *Standard for Electrical Equipment Maintenance*®. Editor's note: NFPA 70B-2026 was released in November 2025.

**REFERENCES**

- [1] ANSI/NETA ECS-2024, *Standard for Electrical Commissioning of Electrical Power Equipment & Systems*.
- [2] ANSI/NETA ATS-2025, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*.
- [3] ANSI/NETA MTS-2023, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*



*Joel Gilley currently serves as Director of Commissioning Services at Electrical Reliability Services, Inc., where he oversees commissioning operations and delivery. Gilley is a commissioning and operations leader with over two decades of experience supporting complex mechanical and electrical systems across mission-critical and industrial environments. His work has focused on commissioning execution, operational oversight, and supporting the teams responsible for system validation and performance. Before ERS, Gilley spent 12 years at Primary Integration as a Project Manager, following earlier technical roles as a Senior Technician at TAC and a Final Test Technician at Applied Materials. His background combines hands-on technical experience with long-term leadership in commissioning and project execution.*

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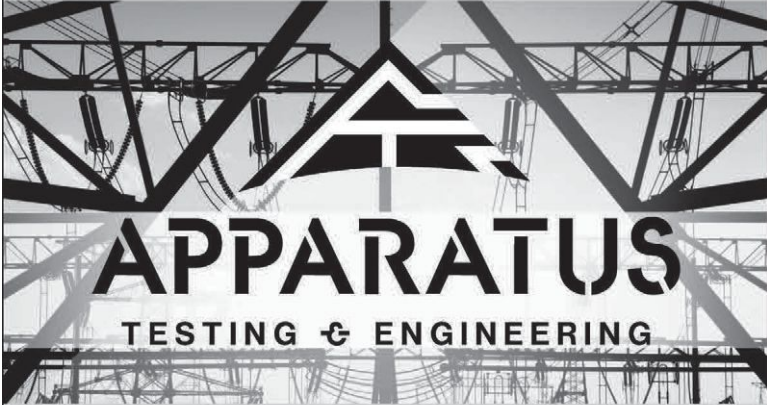
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# ANSI/NETA STANDARDS IN DATA CENTER ACCEPTANCE TESTING


BY ROBERT HILL, *Vector Power*

The rapid expansion of AI-driven data center construction has introduced new challenges to an already demanding electrical testing and commissioning industry. Data centers are being built at an unprecedented speed and scale, driven by the growth of artificial intelligence workloads, cloud computing, and global demand for uninterrupted digital services.

Accelerated schedules, dense electrical infrastructure, and heightened performance expectations now place extraordinary pressure on acceptance testing and commissioning teams. These teams are tasked with verifying that complex power systems are in an acceptable condition while identifying and resolving deficiencies without jeopardizing aggressive project timelines. While construction methods and delivery models continue to evolve, compliance with

ANSI/NETA testing specifications remains critical to safety, reliability, and long-term system performance.

Over the past several years, data center construction has become one of the largest and fastest-growing segments of work for ANSI/NETA acceptance testing companies. Facilities that once took years to design and construct are now being delivered in months, often with multiple



buildings simultaneously constructed on a single campus. As this trend continues, technicians are increasingly required to adapt to new construction strategies, modular designs, and off-site fabrication methods while maintaining the intent, rigor, and documentation requirements of NETA standards.

## ACCEPTANCE TESTING

Acceptance testing is the first critical step in verifying proper system operation. During this phase, individual components and devices are tested to identify deficiencies such as loose connections, improper torque values, incorrect wiring, damaged insulation, or defective apparatus. These deficiencies are not uncommon on large projects where thousands of devices are installed under tight schedules by multiple contractors. Acceptance testing serves as the primary opportunity to detect these issues before the equipment is energized and placed into service.

On large data center projects, mismatches between coordination study documentation and installed equipment labeling are frequently encountered. Breaker designations, panel names, and feeder identifiers may differ between drawings, studies, and physical equipment. Correlating these discrepancies across hundreds—or thousands—of devices is a significant undertaking, yet proper coordination is essential to correct system operation. Incorrectly labeled or mis-coordinated devices can result in nuisance tripping, loss of selective coordination, or failure to clear faults as intended.

To meet schedule demands, many owners now elect to have switchgear assembled off-site and delivered as completed substations or modular skids. Medium-voltage and low-voltage skids are increasingly manufactured with breakers installed, cables pre-terminated, and protective devices programmed prior to delivery. While this approach reduces on-site construction time and improves quality control in a controlled environment, it introduces new challenges for acceptance testing once the equipment arrives at the data center.

PHOTO: © ISTOCKPHOTO.COM/PORFOLIO/QUANTIC69



**Photo 1:** *A Modular Skid Assembled in the Factory*

Low-voltage modular skids (Photo 1) are typically mounted on elevated steel frames, often more than 12 inches above grade. This configuration can significantly restrict access for high-current test equipment, lifting devices, and test leads. Physical access limitations can make traditional primary injection testing difficult or, in some cases, impractical. One effective approach is to perform component testing on the warehouse floor before skid assembly. Testing breakers, protective relays, and other devices before assembly allows technicians to perform thorough inspections and testing without the spatial constraints imposed by the skid structure.

After skid assembly, the common bus can be tested to verify continuity, proper connection of bus joints, and the absence of shorts or grounds. Acceptance testing performed at skid facilities is often faster, cleaner, and more efficient; however, it must be carefully coordinated with the owner, the engineer of record, and the testing firm to ensure that test scope, documentation, and responsibilities are clearly defined.

Testing equipment before final installation can reduce the effectiveness of acceptance testing



**Photo 2:** *This bolt-in LVCB (a) cannot be removed due to the (b) enclosure wall.*

if not properly managed. Errors introduced during final assembly, transportation, or field installation may go undetected if testing is completed too early. For this reason, the ideal scenario is to perform acceptance testing once equipment is installed in its final position and before it is energized. This approach ensures that any issues resulting from handling, installation, or final connections are identified and corrected.

### Low-Voltage Circuit Breakers

When data centers contain thousands of low-voltage circuit breakers requiring primary injection testing, even a small failure rate can generate a substantial number of deficiencies. A one-percent failure rate across several thousand breakers may result in dozens of devices requiring repair, replacement, or further investigation. Reconciling these issues under aggressive schedules can quickly become overwhelming, particularly when equipment availability, replacement parts, or manufacturer support are limited.

Some clients do not approve of off-site testing or require all devices to be retested at the destination. In certain cases, bolt-in low-voltage circuit breakers (Photo 2a and 2b) cannot be removed once installed due to enclosure design or skid configuration. Removing these breakers can be extremely difficult and time-consuming, often requiring partial disassembly of the enclosure or surrounding equipment.

In these situations, and only with full client knowledge and approval, alternative test methods such as primary current verification may be considered. This method uses a smaller current source to verify current transformers and control wiring by measuring primary current at the trip unit, followed by secondary injection of the trip unit itself. Because this approach is not a NETA-approved test method, it must be clearly documented and approved by the customer as a deviation from standard testing requirements. The objective remains unchanged: Verify that equipment is functional, reliable, and safe to energize without causing damage.



**Photo 3:** *Low-Voltage Circuit Breakers in Just One Electrical Room*



**Photo 4:** *Numerous Power Distribution Units Installed in an Electrical Room*

Another major challenge in data center acceptance testing is verifying short-circuit and coordination settings across large populations of low-voltage circuit breakers (Photo 3).

A single electrical room may contain hundreds of devices (Photo 4), and this number multiplies rapidly across a multi-building campus. While verifying breaker functionality



**Photo 5:** *Transformer Fault Showing Internal Damage*



**Photo 6:** *Equipment Damage from a Catastrophic Fault*

is essential, improper coordination can result in nuisance tripping, loss of redundancy, or failure to isolate faults appropriately.

### Faults

The destructive potential of electrical faults (Photo 5) is well documented. Even something as minor as a loose control wire can initiate a severe fault if it contacts an energized bus.

Internal faults within switchgear or transformers can cause extensive equipment damage (Photo 6) and pose serious hazards to personnel. While modern arc-resistant designs and safety procedures reduce risk, the most effective protection is identifying and correcting deficiencies during acceptance testing.

Acceptance testing requires diligence across all equipment types, including current transformers, potential transformers, protective relays, uninterruptible power systems, generators, and large generator step-up transformers. Technicians are often the final safeguard before energization. While the responsibility is significant, ANSI/NETA standards provide the structure and guidance necessary to perform this work safely and effectively.

Despite intense schedule pressure, adherence to standards is critical. These standards exist to protect personnel, equipment, and system reliability. Compromising testing scope or quality to meet a schedule increases the risk of failure, unplanned outages, and unsafe conditions. Safety must always remain the highest priority.

## COMMISSIONING

Acceptance testing verifies individual components, but commissioning proves overall system functionality. Commissioning validates that all components operate together as an integrated system from the primary voltage source through final distribution. This process requires a more in-depth approach, greater attention to detail, and close coordination between testing technicians, engineers, contractors, and owners.

Commissioning activities often include functional testing of protection schemes, verification of control and communication circuits, breaker and relay coordination checks, and operational testing of system sequences. These activities are time-consuming but essential to ensuring that systems perform as designed under normal and abnormal operating conditions.

A significant portion of commissioning occurs in the substation yard. While physically smaller than the data center itself, substations control the entire power supply feeding the facility. Proving protection schemes, communication paths, breaker failure logic, and trip circuits is a substantial undertaking that requires careful planning and execution.

Commissioning begins where acceptance testing ends, but it is not merely an extension of component testing. It requires a system-level mindset, where technicians must understand how protective devices, control systems, communications, and power sources interact across multiple voltage levels. This is particularly challenging in modern data centers, where electrical systems are intentionally complex and highly redundant by design.

A fundamental objective of commissioning is verifying that the system responds correctly to both normal and abnormal operating conditions. This includes loss of utility power, generator startup, UPS transitions, load transfers between distribution paths, and fault conditions at various locations throughout the system. Each of these scenarios must be validated to ensure that failures are isolated properly and do not propagate beyond their intended boundaries.

## Protective Relays

Protective relaying and control schemes are a major focus during commissioning. Even when relay settings have been reviewed and verified during acceptance testing, functional testing is required to prove that protection operates as intended in the field. This includes verifying trip paths, breaker failure, logic, lockout relays, and interlocking schemes. A single missed wire, incorrect polarity, or misrouted fiber connection can defeat an otherwise well-designed protection system.

Communication systems add another layer of complexity. Modern data centers rely heavily on digital communication between relays (Photo 7), meters, controllers, and building management systems.



**Photo 7:** Protective Relays Using Fiber Outputs to Control the Automation



**Photo 8:** *Commissioning a Service Entrance in a 138-kV Substation*

IEC 61850, Modbus, DNP3, and proprietary protocols are used, often in combination. Commissioning must verify not only that devices communicate, but also that they exchange the correct information with the correct devices, using the correct logic and priorities. A communication failure may not immediately trip a breaker, but it can prevent alarms, inhibit automated sequences, or delay fault clearing during an emergency.

Perhaps most importantly, commissioning serves as the final opportunity to identify latent issues before the facility is energized and placed into service. Once a data center goes live, correcting deficiencies becomes significantly more difficult and costly. Unplanned outages, even brief ones, can have far-reaching consequences for owners and end users alike.

Commissioning requires experience, discipline, and a thorough understanding of both equipment and system behavior. ANSI/NETA standards provide critical guidance, but successful commissioning ultimately depends on skilled technicians working collaboratively with engineers, contractors, and owners. When performed correctly, commissioning delivers confidence that the electrical system is safe, reliable, and ready to support the mission-critical demands of modern data centers.

A 138-kV service entrance yard (Photo 8) illustrates the scope of these challenges. Commissioning efforts must confirm system operation from downstream low-voltage equipment back to the utility point of connection. Proper staffing and teamwork are essential, as no single technician can address every aspect of a system of this size and complexity.

## CONCLUSION

As reliance on digital infrastructure continues to grow, the importance of reliable power systems cannot be overstated. Acceptance testing and commissioning play a direct role in ensuring that data centers operate safely, reliably, and as intended throughout their service life.

Acceptance testing is critical for identifying defects that could lead to system failure, but it is only one part of the overall process. Commissioning completes system validation by proving functionality under real-world operating conditions. Adherence to ANSI/NETA standards is essential, even under the most demanding schedules, because personnel safety and system reliability depend on it.

ANSI/NETA standards are founded on the principles of safety and equipment reliability. Proper testing ensures safe operation of electrical devices and dependable system performance. As NETA technicians, we have a fundamental responsibility to deliver systems that are safe, reliable, and ready to energize. [NW](#)



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# IMPROVING CONNECTIONS: TRANSFORMER FACTORY ACCEPTANCE AND FIELD COMMISSIONING TESTS

BY JOHN J. FOSCHIA, *Doble Engineering*

It is often observed that discontinuities exist between factory acceptance and field commissioning tests of power transformers. Ideally, the two test sessions are well-coordinated, allowing measurements captured at the transformer manufacturer to be easily replicated once the transformer is prepared for service.

No two transformers are identical, and if segments of a transformer's history are unavailable, those responsible cannot make the most informed decisions. In some instances, baseline factory tests are not repeatable. This article discusses observations of the gaps between these two test sessions and provides recommendations to improve the communication of expectations and results throughout this process. It is intended for technicians, engineers, procurement personnel,

and asset managers involved in developing transformer purchasing specifications, factory acceptance testing, field commissioning testing, and final acceptance of the transformer.

## **WHY DO WE PERFORM OFF-LINE ELECTRICAL TESTS?**

An incredible amount of time, energy, and resources is devoted to performing and analyzing off-line electrical tests of power



PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/WILLIAMLUQUE

apparatus. While it is easy to discount these tests as one box checked in the process of commissioning or maintaining an expensive piece of critical infrastructure, the reality is much more comprehensive.

Electrical apparatus—specifically transformers and bushings—can be considered living beings that age and deteriorate over time, each with unique life experiences. Properly analyzing off-line electrical testing is not accomplished solely through software algorithms and numerical calculations. Assessing condition based on the equipment's responses to electrical interrogation is a skill that requires experience and familiarity with the failure mechanisms that end (or shorten) an asset's life.

Electrical testing is a reliable means of assessing the condition of a transformer's insulation system, electromagnetic circuit, and physical properties. Within a relatively short time,

the health of these integral structures can be evaluated by applying electrical stresses with portable equipment. Experience has demonstrated that if a transformer's response to an electrical interrogation shows a change, failure or deterioration mechanisms can often be predicted. Depending on the nature of the issue, remedial options may be available. Interpreting these changes allows for proactive intervention—an ideal opportunity in an environment of increasing transformer criticality.

## WHAT EXPERIENCES DID A TRANSFORMER HAVE AT THE BEGINNING OF ITS LIFE?

### Design and Construction

In transformer factories, raw materials are manipulated and constructed, pursuant to an engineered design, to form a highly efficient

apparatus. Material or design insufficiencies can plague a transformer's reliable operation. Performing factory acceptance testing challenges the design, materials, and construction, ideally identifying defects before the transformer leaves the factory.

## **Factory Acceptance Testing**

Factory-performed tests of transformers and bushings are driven by industry standards such as IEEE and IEC, as well as company purchasing specifications. A significant effort is focused on developing and enhancing these requirements based on experience and technology improvement. The combination of industry standards and purchasing specifications ideally results in the delivery of not only a reliable asset, but also a collection of records that future test results may be compared against.

For distribution- and power-class transformers built in accordance with IEEE Std. C57.12.00, the manufacturer should provide certified test reports to the purchaser, and many purchasers condition the shipment of the transformer on the approval of the transformer's certified test report. This report gives the purchaser an opportunity to identify any concerns with the test records and request remedial action, if warranted. While all transformers should be manufactured with the same attention to detail, the additional tollgate of test-report approval necessitates that the manufacturer properly audit the test records.

## **WHAT IF THE REQUIRED FACTORY TESTS FAIL TO DEMONSTRATE THAT REPAIRS WILL RESULT IN A RELIABLE TRANSFORMER?**

There are instances where the minimum factory acceptance test requirements cannot detect specific defects. With small distribution transformers built according to IEEE Std. C57.12.00, insulation resistance, insulation power factor and capacitance, and dissolved gas analysis are not required unless specified. Only Class II power transformers require routine partial discharge testing, one of the best

indications of insulation quality. Regardless of the transformer class, some defects might go undetected during factory acceptance tests. True transformer defects will later be identified through the electrical acceptance or maintenance tests, dissolved gas analysis, initiation of the transformer protection scheme, or eventual failure.

## **WHAT IF THE TRANSFORMER FAILS THE FACTORY ACCEPTANCE TEST?**

While failing to pass a factory acceptance test is not an ideal situation, the objective of performing these tests is to identify an unacceptable condition. It is not a far reach to understand that high demand, supply-chain constraints, and skilled-labor shortages do not align with quality objectives. When a transformer fails a factory acceptance test, some level of investigation and repair/replacement activity is undertaken to remediate the condition before repeating the tests. Minor defects, such as a loose connection, an inoperable de-energized tap changer, or a conductor's clearance to ground might be easily repaired without removing the core and coil assembly from the tank. In severe cases, winding or construction defects may require removing the core and coil assembly from the tank for investigation, repair, or replacement. Best practice is to involve the transformer purchaser and their subject matter experts, in this process to ensure that appropriate repairs are made and an acceptable retest plan is prescribed.

## **Preparation for Shipment**

The steps in preparing a transformer for shipment depend largely on its dimensions, weight, transportation permitting restrictions, and purchasing specifications. A distribution transformer may be cleaned and packaged for local transportation after completing the factory acceptance tests without requiring significant attention. On the other hand, transporting a large power transformer to its destination may require the removal of its insulating liquid and partial disassembly. In some cases, transitioning high-voltage

autotransformers and/or transformers with buried delta windings to operational condition may require internal modifications.

### Transportation

The opportunity for damage increases as the number of transportation modes increases. While smaller shipments from local manufacturers may require brief highway transportation, large power transformers may require a notoriously rugged ride on a railcar. In North America, a significant number of transformers are purchased from international manufacturers, requiring cross-ocean shipment in addition to rail and/or road transportation. Each transportation mode and each transition between transportation modes incurs additional risk to the transformer's condition.

Critical damage can result from shipments hitting bridges, hard railcar humping, and rough placement onto the transformer's foundation. Any breach of the transformer's internal atmosphere introduces an opportunity for insulation to be compromised. Impact recorders, visual inspection, and electrical test comparisons are critical in evaluating the quality of the transformer's journey.

### On-Site Assembly

Once the transformer is placed onto its permanent or temporary foundation, assembly efforts are often required to bring it into operational condition. Locations that do not involve environmental considerations are rare, as most transformers requiring assembly are located outdoors, exposed to the whims of Mother Nature.

Significant exposure to a humid atmosphere, improper control of foreign material (i.e., tools and hardware), and negligent behaviors during confined-space entry may introduce opportunities to compromise the insulation. Parts might not have shipped with the transformer, and if they are available, they may not fit, leaving those tasked with assembly without access to the drawings and documentation necessary for the design's intended assembly. In an ideal world, all

transformer components are fully assembled before final field assembly. Any field fabrication efforts or poorly guided attempts at assembly can risk the transformer's reliability.

### FIELD ACCEPTANCE TESTING A NEW, FULLY ASSEMBLED TRANSFORMER

The technician or engineer who receives a new transformer in the field may not be aware of its history. The certified test report and native (electronic) test files may not be accessible or may have been communicated only to another department within the purchaser's organization. The engineering team responsible for new equipment purchases may not have a robust interface with those tasked with operating and maintaining the transformer. If the technician or engineer is performing contract work for an asset owner, yet another layer of abstraction may conceal the transformer's history.

In the realm of field acceptance testing, strange electrical test results may be encountered, especially for new installations, when testing during a transportation interval, or when grounding systems are not yet in place. New substations or industrial facilities may accept new transformers without the supporting infrastructure in place. These challenging situations are often managed on an individual basis by establishing a reference ground.

In many instances, unexpected test results are representative of the transformer, but hours may be spent establishing appropriate ground references, mitigating environmental conditions, and verifying that the test instrumentation is operating properly.

Herein lies an opportunity for improvement. The transformer's baseline results may not be accessible to the individual tasked with interrogating its acceptability at its final destination, if the baseline results even exist.

If baseline results are available, were the conditions in which the results were obtained properly documented, and can they be replicated in the field? Several frequently

encountered factors result in differences between field acceptance and factory acceptance test results:

- Tap changer positions and switches/link-boards used for modifying dual-voltage or vector relationships can introduce differences when comparing many of the typical electrical tests.
- The presence, absence, or difference of insulating fluids between the two test sessions can introduce discrepancies. As of this publication, the IEEE standards do not require testing a transformer with the operating fluid it is designed for, and variations in the permittivity of the insulating fluid can introduce differences in the capacitive behavior of an insulation system, thereby influencing the electrical test results.
  - For example, a KNAN-rated transformer designed for use with natural ester fluid may be tested in the factory with mineral oil because handling and storing natural ester fluid can be a challenge to efficient factory throughput. Additional equipment, labor, and cost may be required to perform factory acceptance testing with an alternative fluid.
  - In another example, a shipping-condition sweep frequency response analysis (SFRA) test is required before and after transporting the transformer from the factory to its foundation. However, the manufacturer may have performed the shipping SFRA test when the transformer was filled with mineral oil, while the post-transport test may be performed while the transformer tank is filled with dry air.
- Bushings are an inherent contributor to a transformer's insulation system, and they play a role in the electrical test results. In some situations, the transformer in the field may have different bushings than those used for factory acceptance tests. Some examples include:
  - The original bushings were damaged during preparation for shipment at the factory or during transportation.
  - The original bushings were kept at the factory for performing factory acceptance tests of a sibling transformer for the same asset owner.
  - The original bushings were subjected to a service advisory and required replacement.
- The magnetic state of the transformer core is often a source of unexpected test results or changes from benchmark results. Testing a transformer's electromagnetic circuit may be impacted by the core's magnetic state. Factors influencing the magnetic state of the core include:
  - Prior DC winding resistance measurements without a subsequent attempt at demagnetizing the core
  - Inadequate demagnetization
  - Overvoltage conditions/saturation of the core
  - Switching operations
- The connections associated with delta windings may be the source of discrepancy when comparing field and factory test results. Delta windings are often incorporated as stabilizing windings that are not loaded externally but are present (buried) for harmonic suppression. The delta winding may be configured depending on the transformer's stage of life:
  - The delta winding is closed, and all three corners of the delta are made accessible for factory acceptance testing.
  - The delta winding is closed and grounded internally to the transformer (externally inaccessible).
  - The delta winding is closed, and one corner is made accessible through one bushing. This corner could be grounded or ungrounded during any of the electrical tests.

- The delta winding is open, and one corner is made accessible through two bushings.
- The delta may be closed by connecting the two external bushings.
- The delta may be open or closed during any of the electrical tests.
- The delta corner may be referenced to ground or left floating during the electrical tests.

## FREQUENTLY USED ELECTRICAL TESTS SUSCEPTIBLE TO INFLUENCE

### Turns Ratio and Phase Relationship

The turns ratio and vector relationship are a result of the transformer’s winding connections and tap changer positions. Minor influences due to the opening or closing of a delta-connected winding may be observed. Differences in the insulating fluid and bushings are not expected to cause differences in the turns ratio and phase relationship test results.

### DC Winding Resistance

Tap changer positions and winding configurations will, in most cases, influence the measured resistance as turns are removed or added to the current-carrying circuit. In some cases, designs incorporate isolated series transformers (boosters) where the DC winding resistance measurements will not be affected by changes to the on-load tap changer position. These cases are easily identifiable by reviewing the transformer nameplate.

While the presence and configuration of a delta stabilizing winding may affect the process of obtaining measurements, the DC

winding resistance measurements of a given winding should not be affected in most cases. Differences in bushings, provided there are secure connections between the winding and the bushing, are not expected to influence the DC winding resistance measurements.

### Overall Power Factor and Capacitance

Changes to the insulating fluid of a transformer will result in a change in the overall capacitance. For example, a transformer tested with mineral oil will inherently have higher capacitance than a transformer filled with dry air. Note that overall tests performed in the absence of its intended insulating liquid should be tested at a reduced voltage to prevent insulation damage.

For example, consider the overall capacitance measurements of the two-winding, 230-kV to 13.8-kV YNyn, 100-MVA transformer shown in Table 1. This transformer was filled with mineral oil in the factory and with natural ester fluid in the field. The increase in the insulating liquid’s permittivity will cause the overall capacitance to increase. The magnitude of the increase will vary for each insulation system, depending on the volume of contributing insulating liquid.

Tap changer, dual-voltage, or vector-relationship connections can result in differences of overall capacitance, depending on the design of the transformer.

If the transformer is assembled with bushings that have a significantly different C1 capacitance than those used during factory acceptance tests, those differences will contribute to changes in the overall insulation capacitance referenced to ground potential.

**Table 1:** Overall Capacitance vs. Fluid Type

Insulation System	Overall Capacitance Measurements (pF)		Percent Change
	Mineral-Oil Filled	Natural-Ester Filled	
CH	4631	4929	+ 6.4%
CHL	6414	8494	+ 32.4 %
CL	17638	22257	+ 26.2 %

The test setup of the transformer that has a delta winding that is unloaded in operation is very important. Transformers that have a loaded delta tertiary winding (with all three corners accessible) should be tested as a three-winding transformer; this approach results in six unique insulation systems.

In a transformer with only one corner of the delta tertiary accessible, inconsistency in test practices has been observed. The transformer is ideally tested as a three-winding transformer; however, it could be tested as a two-winding transformer if the delta tertiary is grounded during the test. Variations in these configurations will result in different overall capacitance measurements.

### Single-Phase Exciting Current and Loss

Tap changer positions will play a role in the behavior of the exciting current and losses under single-phase excitation. Changes to the energized winding's number of effective turns will change the magnetic flux, thereby changing the exciting current and losses. The tap position of lower-voltage windings (i.e., an on-load tap changer on the LV winding) may cause intentional loads during this open-circuit test, resulting in a change to the measured exciting current and losses. Such intentional loads include preventive autotransformers used with reactive-type on-load tap changers and/or series transformers.

As demonstrated in Table 2, the effects of residual magnetism are commonly observed during the single-phase exciting current and loss measurements. Efforts to demagnetize the transformer core are often successful at

reducing the impact of the core's magnetic state. Notably, the core's magnetic state is constantly changing, even without external influence, due to the effects of magnetic viscosity.

The presence and connections of a delta stabilizing winding may influence the behavior of the exciting current and losses, notably the capacitive component of the exciting current. For this reason, extracting the exciting current components and evaluating the purely resistive watts measurement is encouraged.

While differences in insulating liquid (i.e., mineral oil vs. natural ester) are not expected to produce any observable differences in the exciting current and loss results, caution should be observed if attempting to perform single-phase exciting current and loss tests when the transformer is empty.

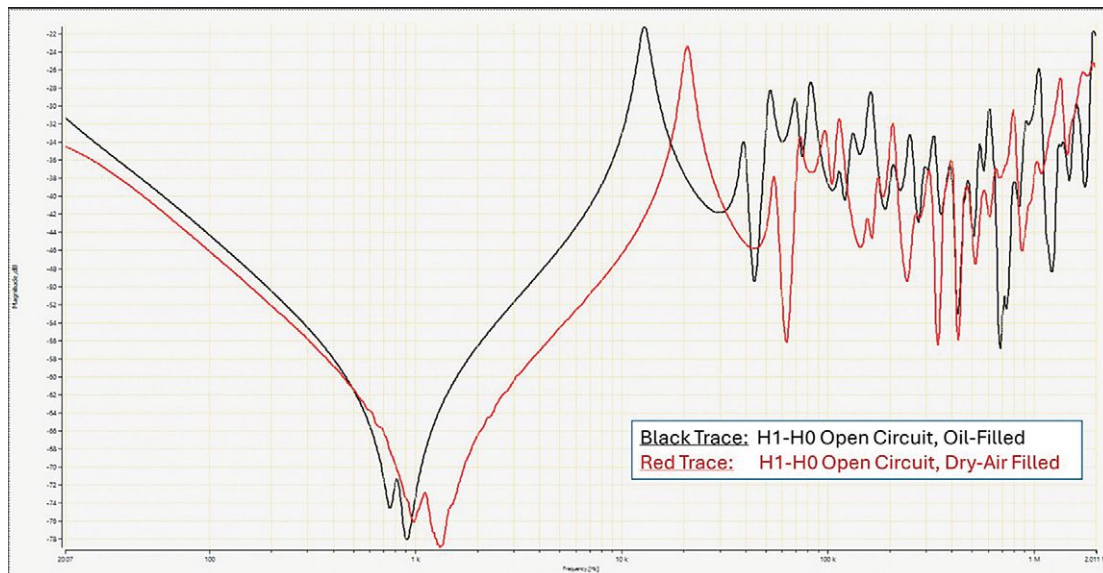
### Leakage Reactance and Loss

The leakage reactance results are dependent on the tap changer positions of the transformer. The impedance of the transformer changes as the tap changer positions change, influencing the reactance measurement. Neither the presence nor the absence of insulating fluid, differences in bushings, nor the presence or configuration of a stabilizing tertiary winding are expected to change the measured leakage reactance.

While the first iteration of low-voltage leakage reactance measurements is often compared against the factory-measured impedance measurements, it must be recognized that differences in flux distribution exist. For a three-phase transformer, the factory impedance measurements are made using a three-phase

**Table 2:** *Impact of Core's Magnetic State*

Test Session	[H1-H3] Measurements @ 10 kV	
	Exciting Current (mA)	Losses (W)
Before DC Winding Resistance	5.27	21.80
After DC Winding Resistance	8.91	38.94
After Demagnetizing	5.28	21.84



**Figure 1:** HV Open Circuit Response of a YNyn Transformer Tested in Empty and Oil-Filled Conditions

power source, whereas the field measurements are most often made using a single-phase source. Note that per-phase measurements are preferable, if feasible, because the reactance measurements of the individual phases can be compared to further investigate winding deformation.

### Sweep Frequency Response Analysis

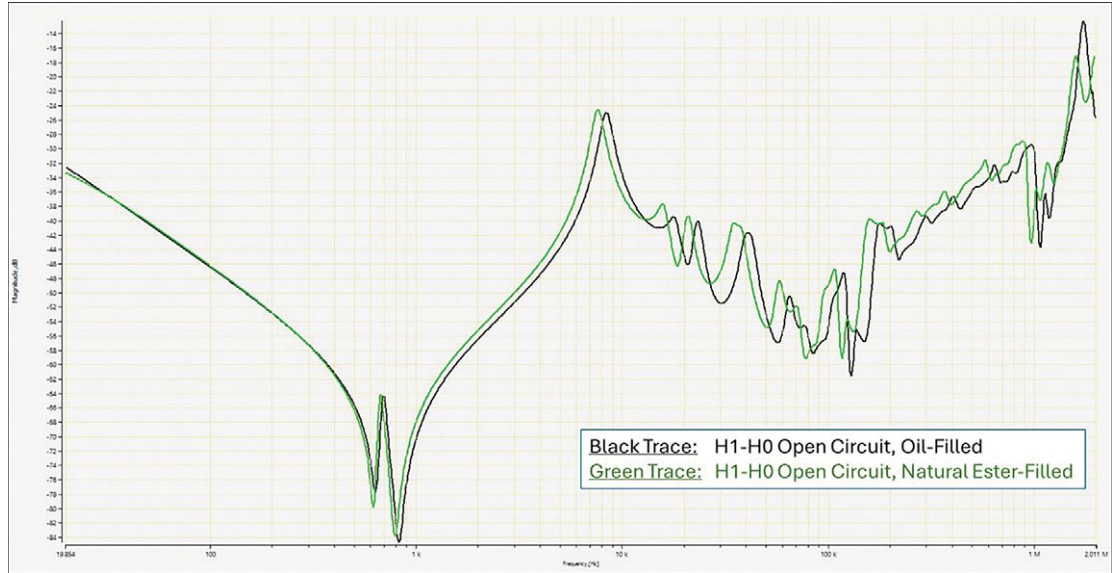
Sweep frequency response analysis (SFRA) may be the most sensitive test to all the aforementioned factors because it interrogates both the inductive and capacitive nature of the transformer. Changes to the frequency response in the lowest frequency region are often encountered due to differences in the magnetic state of the core; however, significant changes may be indicative of an issue within the transformer's electromagnetic circuit. Like the aforementioned tests, differences in tap changer positions, delta winding configurations, and connected bushings contribute to differences in the frequency response of the transformer under test.

As described with overall capacitance measurements, differences in the permittivity of the insulating fluid will cause a change to the capacitive behavior of the transformer, resulting

in a shift of the resonance frequencies of the transformer's frequency responses. Expectations are more easily established if the condition of the transformer under test is well-detailed in the test records.

Figure 1 demonstrates a situation where the manufacturer performed a shipping-condition SFRA, but with the tank filled with mineral oil. After the transformer was received in the field, SFRA measurements were repeated with the transformer tank drained. Changes to the frequency response, particularly the resonance frequencies, are expected for this difference in insulating medium. Because air has a relative permittivity lower than mineral oil, the frequency response is expected to shift towards higher frequencies.

In Figure 2, the SFRA tests were made on the same transformer while the core and coil assembly was immersed in different insulating liquids. Knowing the difference in insulating liquid sets an expectation of frequency response shift. For example, because the relative permittivity of natural ester is higher than that of mineral oil, it is expected that the trace shifts toward lower frequencies. If this situation was not documented in the test records, suspicions of physical change may be justified.



**Figure 2:** HV Open Circuit Response of a YNyn Transformer Tested with Mineral Oil and Natural Ester

## RECOMMENDATIONS

When considering the sources of discrepancies during electrical tests, how might these challenges be alleviated? Our objective is to assess the health of the transformer, and we are aided by being able to replicate the exact configurations in which baseline results were established.

The following recommendations are provided to ensure efficiency in the process of assessing a transformer’s condition in the field as compared to its factory benchmarks.

1. If an asset owner’s transformer acceptance and maintenance testing protocol includes electrical tests exceeding minimum industry standards, request that these tests be performed at the factory to establish reliable benchmarks to which future results may be compared. IEEE standards for new power and distribution transformers do not require tests such as leakage reactance and sweep frequency response analysis.

Measurements of exciting current and losses are generally performed in nominal tap changer positions, unless otherwise specified; however, many field test plans

include tests in at least half of the on-load tap changer tap positions. Purchasing specifications that require the transformer to be factory-tested with its intended fluid of operation may be warranted.

2. Factory test specifications for tests also performed in the field should be explicit and, if necessary, should prompt further discussion between the purchaser and manufacturer. If an asset owner’s maintenance testing protocol requires a test to be performed in a specific manner, the best time to establish expectations of future behavior is while the transformer is undergoing factory acceptance tests. Requesting a test by name, without identifying the specific tap changer and configuration requirements, may not provide the expected records. It is of critical importance that the tap positions and all pertinent connections and configurations are noted.

Ideally, electronic test records are provided to reduce administrative work during field acceptance testing. Evaluating and comparing tests, such as SFRA, by reviewing paper or PDF reports is challenging, and defects may

go undetected when analyzing flattened or paper records. Tools incorporated in many testing software packages assist in comparing test records.

3. Develop communication to ensure that operations and maintenance personnel have access to the factory results and history of incoming transformers.

Factory test reports, factory failure reports, and electronic test records are ideally made available to the appropriate parties. Not only does this history provide a full perspective of the transformer's infancy, but it also provides clues as to what issues could be experienced during the remaining decades of the transformer's life.

## CONCLUSION

Numerous risks challenge the successful creation, delivery, and commissioning of new transformers. The objective of the factory and field commissioning tests is to ensure that the transformer will operate reliably and that there have been no unintended changes throughout its early life. Test records developed at the transformer manufacturer are preferred benchmarks against which future test sessions are compared. These records should be properly detailed and made available to the teams tasked with receiving and evaluating the transformer at its final destination. The reliability of critical infrastructure is best served by the sharing of information and informed decision-making. **NW**

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**John J. Foschia** has been a Principal Client Service Engineer at Doble Engineering since 2021, following eight years with SPX Transformer Solutions, where he most recently served as Product Test Manager. His experience includes factory acceptance testing and quality control of power transformers in addition to diagnostic testing and condition assessment of high-voltage electrical apparatus. Foschia is currently an Assistant Secretary for the Doble Transformers Committee and has participated in several IEEE Transformer Committee working groups. He received BS degrees in electrical engineering and computer engineering from North Carolina State University.



# UPGRADING A LINE RELAY WITHOUT AN OUTAGE

BY BIBEK KARKI, *IPS PowerServe*

With electromechanical and solid-state protective relays now obsolete and nearing the end of life, upgrading to microprocessor counterparts is paramount for the reliability of power systems. Microprocessor relays provide advanced communication, monitoring, and automation capabilities along with all basic protection and control platforms.

Raising awareness among customers about the importance of a relay upgrade is vital in the overall contribution to power system reliability. Line relay upgrade projects involve not only the customer, but the utility provider as well. These highly technical projects tend to be more complicated and involve more than one entity. Relay upgrade projects can yield maximum

benefits if carried out as a team effort among the customer/end user, engineering firm, commissioning agent, and the utility provider.

This article presents a case study of a line relay upgrade project that lay dormant for 15 years and was revived in 2021. The line relay was installed and wired in 2004, but



was never commissioned or put in service. After the new relay was tested and commissioned, a functional check and testing were performed on its associated DC circuit. End-to-end testing was completed with the utility provider, and the relay was prepared to be put into service. The process was unique: All testing and commissioning were performed while the substation was energized.

This article focuses on the steps taken to isolate the relay and maintain power system reliability, as well as the procedures performed to gather onsite data and raise the customer's awareness of the importance of upgrading. The detailed procedures to complete the upgrade process, challenges faced, and lessons learned are also outlined.

## INTRODUCTION

Protective relays are an integral part of the power system; they ensure protection for equipment during fault conditions. If these protective devices are installed, engineered, programmed, and maintained properly, they keep our power system safe and reliable.

It is critical to upgrade protective relays to the current technology and standards. Many

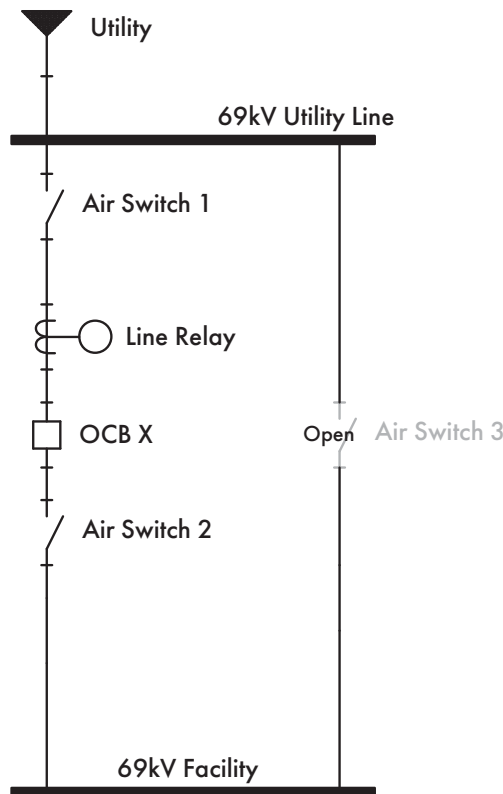
electromechanical and solid-state relays are becoming obsolete, which means upgrading them is inevitable, through unplanned failures or during planned outages.<sup>[1]</sup> Older protective relays near the end of life cannot be relied upon for equipment protection. Instead of providing system protection and reliability, these relays now become a liability.

Older electromechanical line relays have limited functionality and capability, which is another challenge when integrating them with new microprocessor relays installed by the utility provider. System integration is especially challenging in the case of line relays, since these relays usually protect the same transmission line. Most advanced relays can detect and interrupt the fault more quickly than their electromechanical counterparts. Microprocessor relays also provide advanced communication and automation abilities. This means the relays can be used to gather data for

event analysis, power quality monitoring, and diagnostics, all contributing to power system reliability.

Relay upgrade projects require meticulous project planning that includes gathering field data, communicating with all stakeholders early and often, and preparing testing and commissioning plans. This process was especially important in this project because it involved reviving an existing incomplete project and included line relaying. Most relaying schemes and configurations impact one power system or entity; line relaying affects more than one power system because a line connects two or more entities. In most cases, the other end of the line is a utility provider, as was the case in this project.

Another project highlight was raising awareness about the importance of relay upgrade, as the process that was undertaken was more significant compared to the actual on-site testing and commissioning process.



**Figure 1:** Main Incoming Power Substation Single-Line Diagram<sup>[2]</sup>

## PROJECT BACKGROUND AND SCOPE OF WORK

The current incoming power for the customer’s plant is supplied by a 69-kV switchyard (Figure 1) that consists of a 1200-ampere (A) main incoming oil circuit breaker (OCB), six step-down power transformers, six OCBs on the primary side of these transformers, and the associated substation that houses protective relaying and metering circuits. All transformers are protected by advanced microprocessor transformer differential protection relays as primary and electromechanical overcurrent relays as a backup.

The main OCB—called Breaker X for the remainder of this article—has microprocessor relays for overcurrent protection and line protection in conjunction with the utility company. There are also three air switches in addition to the main incoming OCB. The way these air switches were designed was critical to this entire testing and commissioning project.

### Project Background

Currently, two electromechanical relays (KD-10s) in the facility’s substation provide primary protection. These relays only provide phase-to-phase and three-phase protection and operate in different zones: Zone 1 and Zone 2. Zone 1 protects up to 80% of the line to the utility substation #1 and operates instantaneously for a fault on the line. Zone 2 protects the rest of the line, but before it opens breaker X, there is a 40-cycle delay. This is too much time for clearing a fault. With a new microprocessor relay and communication to the utility company, the clearing time could be reduced to three or four cycles.

The new microprocessor relay will provide the same functions as the two KD-10s, as well as phase-to-ground protection. Since it is believed that approximately 70%<sup>[3]</sup> of faults on an electrical system are line-to-ground faults, this protection for the facility is critical. The two KD-10s will remain in service and provide backup to the new microprocessor relay.

The microprocessor relay currently installed in the substation provides no protection since the trip cutoffs are lifted; this relay has been left in this state for many years. During the initial site visit, we were told that the initial relay upgrade project was carried out sometime around 2003–2004. This was the date and timeframe mentioned during site visits and in the drawings.

The relay upgrade included new microprocessor relays and associated test switches to provide isolation for trip outputs, currents, and potential inputs. The system has two test switches. The top test switch shown in Figure 2 is designated for the currents and voltage; the bottom test switch is designed for the trip circuits.

During the initial design and upgrade process, this relay was intended to communicate over radio controls to the utility company. An antenna and radio frequency transmitter in the substation were installed but never commissioned or used in all these years because communicating over the radio was not considered reliable. The utility company has installed a fiber communication cable between its substation and the facility's substation. This newly installed fiber should alleviate any concerns about the reliability issues for communicating between this relay and the utility relay.

### Scope of work

The main scope of this project was to reboot this relay, which has been dormant for several years, and make the system fully functional so the relay upgrade project could be implemented in the plant's power system reliability. We have an excellent relationship with the operations and maintenance (O&M) and engineering teams for this facility. Both of these teams asked for our assistance with two specific requests:

- Create a feasibility and plant reliability (MV relaying) report to convince their upper management to implement this project.



**Figure 2:** Existing Relaying Protection before Project Execution

- Prepare the testing and commissioning plan, including end-to-end testing with the utility.

Thus, the end goal of this project was to integrate the microprocessor line relay into the plant's power system in conjunction with the utility company to improve the plant's reliability.

### PROJECT PLANNING AND PREPARATION

This was not a typical relay upgrade project. The initial goal involved preparing a feasibility study on the project itself as well as educating

plant upper management on the importance of this project and how it could be executed successfully. After all commercial items were taken care of, there was productive communication with plant engineering and the O&M team, and the utility company was brought into the conversation. The utility company was very collaborative and provided its full support.

### Site Visit, Data Collection, and Findings

The plant facility engineering and O&M teams were instrumental in providing most of the existing project drawings and documents. The site visit was performed for an entire week. The main intention of the site visit was to gather hard copies of all drawings, download relay settings, verify the relay wiring, verify the test switch position, and similar tasks.

I have always believed in site visits, and customer interaction is the best way to execute any relay commissioning project. Non-intrusive data collection was performed on site. We communicated with the existing microprocessor relay, downloaded relay settings, and provided them to the customer and the utility company. The relay was enabled and seemed to be working fine, although there were some questionable wiring connections in the back of the new relay and a couple of wire jumpers. Some modifications had been made on the system, but had not documented in the as-built drawings. All changes were redlined in the drawings, and baseline voltage measurements were performed in the DC trip circuits.

### Presentation to Plant Upper Management

After concluding the week-long data collection process, a detailed feasibility report was created and presented to the facility's upper management. Several facility leaders, the engineering and O&M teams, and utility company representatives participated. A few of the meeting highlights are provided here:

- The biggest risk of not improving the system is that when there is a fault on the line between the utility's substation and the facility, the utility company may open the breaker on their end while the mill's generators continue to feed the same fault. This is because the protective relays on the mill's incoming breaker (OCB X) have to perform independently and take longer to operate. This could cause substantial damage to the generators and electrical system.
- All testing and commissioning tasks could be performed without any power interruption to the facility. One of the main reasons this project was not completed despite several past attempts was that the power could not be shut down. Note that the term "outage" typically means turning the power off; however, in this article, outage does not imply any power interruptions; it simply refers to the testing and commissioning task.
- A microprocessor relay has a wider variety of protection functions, including Zone 1 through Zone 4 protection schemes and neutral and ground overcurrent protections. KD-10 has limited capability.
- The microprocessor relay provides various communication parameters and input monitoring capability, including sending relay failure and loss of communication alarms. None of these is possible with KD-10.
- For the utility breaker trip at the utility substation, the utility trips the breaker at the substation and sends a direct trip (DT) signal to the microprocessor relay, which trips OCB X at the customer switchyard. This relay would also send a signal to the load shed system, initiating the load shed scheme. This event would be captured in the sequential event recorder to assist with troubleshooting.

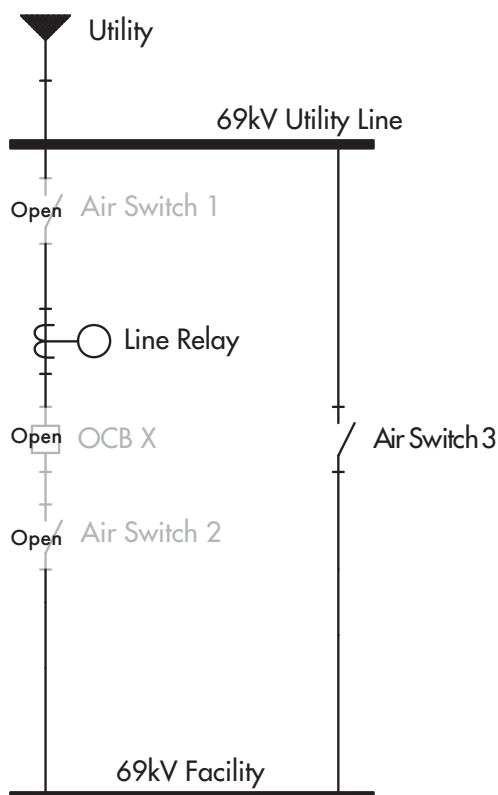
The meeting was very interactive. Every possible effort was made to describe the importance of this project and the methods of

effective project execution. A frame of detailed isolating, relay testing, commissioning, and end-to-end testing was presented. A few weeks after the site visit and presentation, we were notified that the plant had provided notice to proceed with the testing and commissioning items of the project.

### Main Incoming OCB and Relaying Circuit Isolation

A detailed plan was prepared for isolating the microprocessor relay and OCB X from the main incoming power system. OCB X was part of the isolation so that all DC functional trip checks<sup>(4)</sup> could be performed on the entire OCB control scheme along with relay testing. A few main highlights of the system isolation plan are provided here:

- Feed the plant through the bypass switch, close air switch #3, and open air switches #1 and #2. The facility would prepare these switches for operation.
- Isolate breaker failure trips, direct trips, breaker failure initiates, and load shed initiates from the microprocessor relay to OCB X using test switches XA and XY. Open all knife switches first in test switch XA, and then XB. Turn the 43 CO breaker failure cut-off selector switch to the OFF position. This provides two isolation points in a trip circuit.
- Disable the bus differential tripping scheme using test switch XB. Pull the knife switch named TRIP first, then all current inputs. This should prevent any trips on the 86B bus differential lockout relay and consequently on all OCBs.
- Disable undervoltage (27) from the 69-kV bus using the isolation switches at the bottom of the 27 Westinghouse CV-2 relay. Switches #1 and #10 will be pulled, and this relay won't be able to send any trips to OCBs.
- Work with the facility to disable all DCS trips and handle any load shedding manually.



**Figure 3:** Main Incoming Power Substation Single-Line Diagram<sup>(2)</sup>

## COMMISSIONING AND TESTING PLAN

### Switching Order

An additional switching order was prepared to help the facility switch air switches. The facility now has a step-by-step procedure to follow when bypassing incoming breaker OCB X, using kirk-keys to ensure that the procedure is performed in the correct step-by-step order. Existing relay settings were reviewed, and recommended settings changes with minor modifications were sent to the customer and the utility company.

A detailed switching order was created for the initial pre-testing circuit isolation and as a post-testing plan for restoring the circuit to as-found condition. Some of the detailed steps from the switching order are provided in Table 1.

This switching order, which contains several chronological steps, was peer-reviewed internally and provided to the customer for further feedback and review. The switching

**Table 1:** *Snippets of the Switching Order*

Print	Sheet	Name	Step	Activity	Completed
672-E-027 REV 4	01 of 03	OC8-07 PLC	6.1	Measure and record OC8-07 Terminal 57 _____	
672-E-027 REV 4	01 of 03	OC8-07 PLC	6.2	Measure and record OCS-07 Terminal 58 _____	
672-E-027 REV 4	01 of 03	8PS PLC	6.3	Measure and record OC8-07 Terminal 83 _____	
672-E-027 REV 4	01 of 03	8PS PLC	6.4	Measure and record OC8-07 Terminal 84 _____	
672-E-027 REV 4	01 of 03	OC8-07 21 & 8F Schematic (TCL)	7.0	Review Bypass Sync Circuit	
672-E-027 REV 4	01 of 03	Bypass Sync	7.1	Measure and record OCS-07 Terminal 82 _____	
672-E-027 REV 4	01 of 03	Bypass Sync	7.2	Measure and record OCS-07 Terminal 07 _____	
672-E-030 REV 6	01 of 01	Une & UV Relays	8.0	Review Panel 4 SEL-321 CT & VT Input	
672-E-036 REV 4	02 of 02	Panel 4 - 8F & SEL Distance Wiring Diagram	8.1	Measure Voltage in SEL and record TSI (A) to TSI (0) / Label Device SA _____	
672-E-036 REV 4i	02 of 02	Panel 4 - 8F & SEL Distance Wiring Diagram	8.2	Measure Voltage in SEL and record TSI (B) to TSI (0) / Label Device SA _____	

order was provided to the utility company for review and comments. After subject matter expert (SME) and technical reviews, the final version of the switching order was provided to all affected parties. It also included the step number, drawing references, drawing title, and switching activity, such as opening test switches, measuring voltages, etc.<sup>[4]</sup>

### On-Site Relay Testing

Part of the commissioning plan was to retest the new relay, verifying its parameter settings with the associated trip levels and functions, including the function with the utility company initiating a trip command for our incoming breaker OCB X when their feeder breaker opens.

A mirrored-bits communication scheme was used, which means that the utility company will send bits reflecting the open/closed status of their breaker. This is a common way of communicating between substations. When the relay receives the open bit because of a detected fault and trip command from the utility substation, the facility's OCB X should trip as well. The utility should not be allowed to reclose the facility's tripped breaker. After the utility company has reclosed its breaker, the powerhouse operator will reclose OCB X when synchronized with the generators.

### Commissioning

After a few attempts to schedule onsite testing, a date was secured to perform onsite tasks. The switching order was followed to isolate the circuit. The relay apparatus testing was performed according to NETA standards, minor wiring changes were made, and DC functional trip checks were accomplished. The DC trip checks were performed for all circuits from the relay to the OCB X. All tests were successful and went as planned.

### End-to-End Testing

End-to-end testing was performed with the utility provider. Some complications were noticed with the utility company commissioning team. During the end-to-end testing, an actual utility-initiated trip command was planned. This means the utility will actually trip their feeder breaker at their substation, and it will be verified that the facility's incoming breaker OCB X will trip as well. The utility company ran into some technical difficulties and was not able to simulate and send the fault to the customer's circuit. Despite several attempts, they could not send the trip signal. After several hours of troubleshooting and meetings with the customer and utility company, a consensus was reached to restore the system to normal configuration and complete the end-to-end testing at a later date.

This project was also an opportunity to perform preventive maintenance and testing on all three air switches and test the DC schematic circuit for the OCB. A light form of preventive maintenance, such as visual and mechanical inspection, lubing connection points, etc., was performed on air switches. DC functional trip checks were performed on the OCB control circuit. These tests are vital from the regulatory standpoint and to extend equipment life span.

## FUTURE WORK AND LESSONS LEARNED

In addition to the goal to complete the relay upgrade project that was started several years ago without any power interruption or cold outage, another important project goal was to create a trusted and verified switching order for the main incoming OCB X so that the facility could perform preventive maintenance and testing in the future. The facility was very pleased with the way the project was carried out and the goals that were achieved. A few months later, the facility was able to replicate the power isolation process and complete the testing with the utility. This system is now fully functional and operational.

One of the important lessons learned was that projects like this require meticulous and detailed planning, effective communication, attention to detail, and perseverance. Raising awareness of stakeholders about the importance of their asset, the need for periodic preventive maintenance, and a timely update/upgrade goes a long way in making our electrical system safe and reliable.

## CONCLUSION

Protective relays are the backbone of the protection, automation, and control for medium-voltage systems. They are critical to power system performance and reliability; thus, utmost importance should be given to the proper maintenance and upgrade of these relays. It is our responsibility to not just perform the preventive maintenance and testing/commissioning of power systems, but also to make our customers aware of the necessity and impact this could have on

their system reliability. Using engineering brainpower and harnessing the advancement in technology, we can keep our electrical system reliable and extend its lifespan. [NW](#)

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# DETECTING INSULATION DEGRADATION USING DFR: A CASE STUDY

BY YASH GODHWANI and CHANAKYA PATEL, *Megger*

Medium- and high-voltage cables are among the most vital electrical assets in modern power systems, delivering electricity to millions of households year-round. Yet, when it comes to diagnostic testing during commissioning or maintenance, many cables remain untouched with modern diagnostic tools.<sup>[1]</sup>

Dielectric frequency response (DFR), a well-known diagnostic technique in the transformer and oil-filled cable industries, measures dielectric losses over a broad frequency range and evaluates the moisture content of oil-paper insulation. Important insights, such as aging condition, water treeing, and thermal aging, can be obtained by using the same technology on medium- and high-voltage XLPE cables. By tracking the insulation state of cables over time, from commissioning to mid-age, DFR provides a supplementary method.

A more sensitive evaluation of insulation aging is made possible by the technology's capacity to measure the dissipation factor and capacitance discretely over a broad frequency range (from

1 mHz to 1 kHz) in an off-line setting. This enables asset owners to schedule interventions before issues arise. When compared to VLF tan-delta testing, which only provides measurements over one frequency, DFR's wide frequency sweep provides meaningful insights that help distinguish between various aging effects and emphasize the impact of accessories.

This can be further divided into three categories: bulk insulation state, thermal aging, and water intrusion in the insulation. The location of these flaws can subsequently be determined by using localizing methods such as partial discharge. Performing a frequency domain spectroscopy (FDS) test first provides clearer partial discharge results that can



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help the asset owner determine whether the focus should be on bulk insulation, thermal degradation, or water ingress.

This article presents a case study demonstrating the application of DFR for commissioning and maintenance diagnostics on critical medium-voltage cables, highlighting its advantages, limitations, and role in a comprehensive asset management strategy.

## DFR METHODOLOGY

Frequency domain spectroscopy (FDS), also known as dielectric frequency response (DFR), is a low-voltage diagnostic technique used to evaluate the dielectric behavior of high-voltage insulation. A small sinusoidal excitation—typically 200 V peak-to-peak—is applied over a wide frequency range from the millihertz

to kilohertz regions. The resulting current is measured to characterize polarization and conduction phenomena within the insulation. Under an applied AC field, dielectric polarization arises from electronic, atomic, dipolar, and interfacial mechanisms, each associated with distinct relaxation times. The measured current response in the frequency domain is expressed as:

$$I(\omega) = j \omega C(\omega) U(\omega)$$

Where  $U(\omega)$  represents the applied sinusoidal voltage,  $I(\omega)$  is the measured response current, and  $C(\omega)$  denotes the complex capacitance of the insulation system. The complex capacitance is generally formulated as:

$$C(\omega) = C_0 \left[ \varepsilon'(\omega) - j \left( \varepsilon''(\omega) + \frac{\sigma_0}{\varepsilon_0 \omega} \right) \right]$$

Where  $C_0$  is the geometric capacitance,  $\epsilon'(\omega)$  is the real component of permittivity reflecting energy storage,  $\epsilon''(\omega)$  is the imaginary component associated with dipolar relaxation losses,  $\sigma_0$  denotes the DC conductivity of the insulation, and  $\epsilon_0$  is the vacuum permittivity. The dielectric dissipation factor, or loss tangent, which serves as an indicator of dielectric losses relative to energy storage, is obtained as:

$$\tan \delta(\omega) = \frac{\epsilon''(\omega) + \sigma_0/(\epsilon_0\omega)}{\epsilon'(\omega)}$$

This demonstrates that low-frequency losses are dominated by conduction, whereas higher frequencies reflect dipolar and interfacial polarization. In XLPE insulation, moisture significantly affects the dielectric response, increasing low-frequency tan delta due to enhanced orientation and interfacial polarization. This sensitivity allows DFR to detect moisture ingress, thermal and electrical aging, and semiconductor degradation with high precision. By spreading physical phenomena across the frequency axis, DFR enables reliable condition assessment of MV/HV polymeric cable systems.

## FACTORS AFFECTING XLPE INSULATION HEALTH

Cross-linked polyethylene (XLPE) is the preferred insulation for MV and HV power cables due to its high dielectric strength, thermal stability, and efficient manufacturability.<sup>[5][6][18]</sup> However, the long-term reliability of XLPE is strongly influenced by electrical, thermal, mechanical, moisture-related, and environmental stresses, each of which progressively alters its microstructure and degrades dielectric performance.

### Electrical Stress

Electrical overstress is one of the most dominant aging mechanisms in XLPE. Field enhancement at imperfections—including contaminants, voids, rough semicon interfaces, and installation defects—initiates partial discharges (PD). Each PD event induces localized heating and bond scission, gradually forming electrical trees that propagate toward failure. Tan delta increases disproportionately with voltage as conduction paths develop inside treed regions.

### Thermal Stress

Thermal loading accelerates chemical and mechanical deterioration in XLPE. Operation near the rated conductor temperature (90°C) or continuous load cycling induces non-uniform expansion between the conductor, XLPE, and semicon layers. This thermal mismatch causes interfacial shear stress, leading to micro-void formation and PD initiation sites. Elevated temperatures also enhance charge injection. Thermal loading accelerates chemical and mechanical deterioration in XLPE insulation. Operation near rated conductor temperatures or repeated load cycling induces differential thermal expansion between the conductor, XLPE insulation, and semiconductive layers. This mismatch generates interfacial shear stress, which promotes micro-void formation and creates conditions favorable for partial discharge inception.<sup>[7]</sup>

### Mechanical Stress

Mechanical loading during installation, operation, or ground movement induces residual stresses and micro-cracks that serve as PD and moisture-entry sites. Thermal-mechanical fatigue is intensified by differential expansion between conductor and insulation. Li et al. reported that optimized 70L–30H polyethylene blends maintain 10–15% higher modulus at 120°C than XLPE, improving fatigue resistance.<sup>[19]</sup> Experimental investigations have demonstrated that thermal cycling in MV cable joints produces significant variations in interfacial pressure between XLPE insulation and elastomeric materials. Such pressure variations persist after repeated temperature cycles and contribute to the formation of voids and weak spots at material interfaces, thereby increasing susceptibility to partial discharge activity.<sup>[14]</sup>

### Environmental and Chemical Factors

UV radiation causes surface oxidation and chain scission in exposed XLPE.<sup>[2]</sup> Chemical pollutants, acidic soils, and heavy-metal ions accelerate hydrolysis, oxidation, and stress cracking.<sup>[17]</sup> High humidity (>85%) increases surface leakage and corrosion in joints, altering dielectric response.<sup>[11]</sup> Long-term environmental aging lowers crystallinity, increases amorphous

content, and produces more polar defects, causing DFR spectra to show elevated low-frequency tan delta due to enhanced conduction and interfacial polarization.<sup>[2][6][8]</sup>

## VLF TAN-DELTA TEST LIMITATIONS

VLF tan-delta testing is widely used to evaluate the condition of extruded MV cable insulation, such as XLPE and EPR, but several inherent limitations affect diagnostic interpretation.

- Because VLF operates near 0.1 Hz—far below the 50/60-Hz service frequency—the dielectric response becomes dominated by slow polarization, depolarization, ionic conduction, and space-charge effects, often inflating tan delta relative to operational conditions.<sup>[12]</sup>
- Field measurements are also highly sensitive to temperature, humidity, and surface moisture, since cables rarely reach thermal equilibrium during testing.<sup>[11][12][14]</sup>
- Thermal-cycling studies demonstrate that rising temperature alters interfacial pressure in joints due to differential expansion between the semiconductive and insulating layers.<sup>[11]</sup>
- Aged insulation may further exhibit nonlinear voltage-dependent tan delta behavior due to space-charge accumulation and localized field distortion.<sup>[5][6][14]</sup>

- Because 0.1-Hz testing requires long stabilization times, measurements are sensitive to polarization drift and leakage currents.<sup>[4][12]</sup>
- In long cable circuits, total capacitance may exceed VLF equipment capability, reducing achievable test voltage and accuracy.<sup>[1][10][15]</sup>

## INTERPRETING FDS RESULTS FOR MV CABLES

The DFR master curve framework provides a structured method to interpret dielectric-loss behavior across multiple decades of frequency. Each master curve represents a characteristic  $\tan \delta(f)$  response associated with a specific insulation condition—unaged, thermally aged, moisture-degraded, or accessory-influenced. This approach was formalized in the wide-band FDS study by Naderian Jahromi et al.<sup>[3]</sup> that analyzed more than two decades of published XLPE dielectric measurements by Werelius,<sup>[2]</sup> Hvidsten,<sup>[4]</sup> Drapeau,<sup>[5]</sup> Banerjee,<sup>[6]</sup> and Liu. Their work demonstrated that different aging mechanisms dominate at different frequencies, enabling a zone-based categorization scheme for MV XLPE cable diagnostics.

The XLPE insulation response can therefore be segmented into five diagnostic frequency zones (Figure 1), each corresponding to a dominant physical mechanism and distinct degradation behavior (Table 1). This zonal segmentation

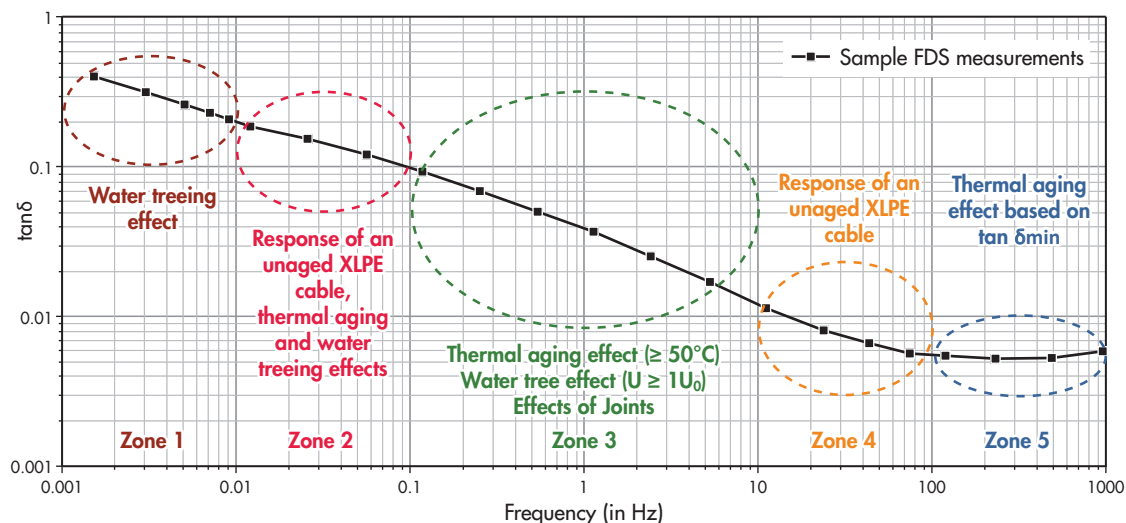


Figure 1: DFR Assessment Curve<sup>[3]</sup>

**Table 1:** Frequency Zone for DFR Interpretation

Zone	Frequency Range (Hz)	Dominant Diagnostic Effect
1	0.001–0.01	Water treeing, severe moisture ingress
2	0.01–0.1	Unaged response and initial thermal aging
3	0.1–10	Thermal aging ( $\geq 50^{\circ}\text{C}$ ), water treeing ( $U \geq U_0$ ), and joint influence
4	10–100	Unaged response region (dipolar polarization stable)
5	100–1000	High-frequency region used for estimating $\tan \delta_{\min}$ and aging temperature

allows utilities to evaluate tan delta trends with respect to the underlying aging process rather than relying solely on a single-point VLF tan delta at 0.1 Hz.

**CASE STUDY: COMPARATIVE INTERPRETATION OF DFR SIGNATURES FOR MV XLPE CABLE**

This case study presents a zone-by-zone comparison of frequency domain spectroscopy (FDS/DFR) measurements performed on an aged medium-voltage cable termination (Figure 2). Cable terminations and splices contain multilayer structures that significantly influence electric-field distribution, and non-uniform fields over time can accelerate degradation and lead to insulation failure. Prior research shows that improper workmanship, incorrect stress-

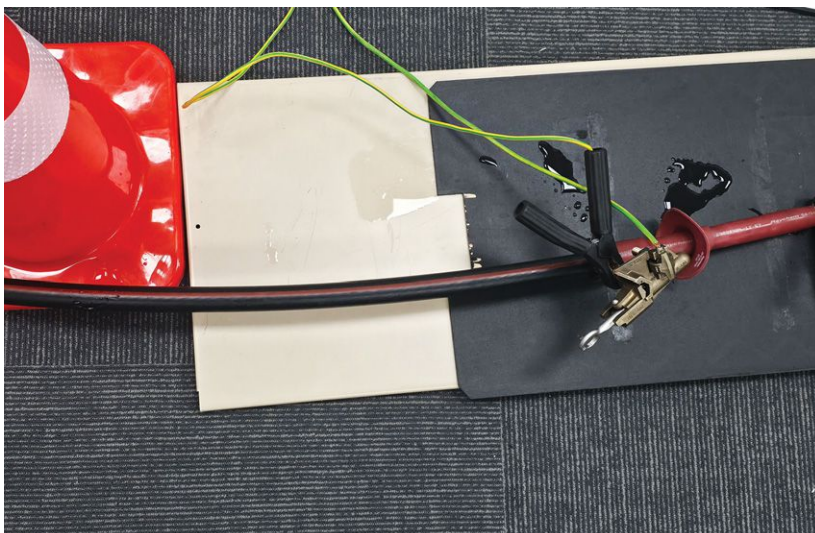
cone positioning, knife cuts, and contaminants frequently cause weak points in terminations, resulting in elevated electric stress, partial discharge, and premature aging.<sup>[7][5]</sup> Thermal degradation is another major contributor, especially when accessories experience localized heating or are improperly installed, as commonly reported in field-aged heat-shrink terminations.<sup>[18]</sup>

To replicate these real-world ageing conditions, a deliberate pinhole was created just before the mastic/stress-control tube (Figure 3), allowing controlled moisture ingress into the XLPE–semicon interface—an approach consistent with established methodologies where artificial voids or holes are introduced to simulate moisture-driven deterioration in cable insulation systems.<sup>[7]</sup>

Additionally, the cable jacket was intentionally ruptured, and another pinhole with moisture ingress was introduced (Figure 4) to reproduce field-aged insulation behavior.

When the actual DFR curve is mapped onto this framework (Figure 5), several termination-specific observations become clear. At ultra-low frequencies ( $<10$  mHz), the measured tan delta reaches approximately 4–5%, far higher than what is typically expected for a well-sealed, dry termination. This behavior strongly suggests moisture presence inside the termination enclosure or migrating along the XLPE surface, causing ionic conduction and interfacial polarization.

In the 10–100 mHz range (Zone 2), the curve steadily declines but remains elevated,



**Figure 2:** Laboratory Setup Used to Simulate Moisture Ingress and Termination Defects in an MV XLPE Cable

indicating a combination of thermal and moisture-driven dielectric relaxation. The slope observed in this region resembles laboratory data from thermally stressed termination samples, where warming of the stress-control tube and semicon layers increased low-frequency losses.

Mid-frequency behavior (0.1–10 Hz) shows a defined tan delta minimum around 0.3–0.4%. Comparing mid-frequency with the master curve<sup>[3]</sup> clearly shows a normal curve with a minimum difference, proving that the cable and termination have not experienced any high temperature above 50.

At higher frequencies (100–1,000 Hz), the upward trend in the DFR curve corresponds to thermal activation and semicon resistivity effects typically observed in cable terminations. Installation-related defects—such as improper wrapping of the yellow stress-control tape, incorrect semicon cutbacks, conductor-interface heating, and overheating of the heat-shrink tube—create localized regions of elevated electrical stress.

Furthermore, semiconductive layers exhibit strong temperature-dependent resistivity behavior, with resistivity rising significantly as temperature increases.<sup>[9]</sup> Because stress-control tubing and semicon materials are more temperature-sensitive than bulk XLPE, even moderate heating steepens the high-frequency conduction slope, a phenomenon consistent with the positive temperature coefficient (PTC) behavior observed in semicon shields.<sup>[9]</sup> This aligns with research showing that terminations often fail due to a combination of workmanship errors and thermally activated interface defects, which amplify dielectric losses across the frequency spectrum.<sup>[7]</sup>

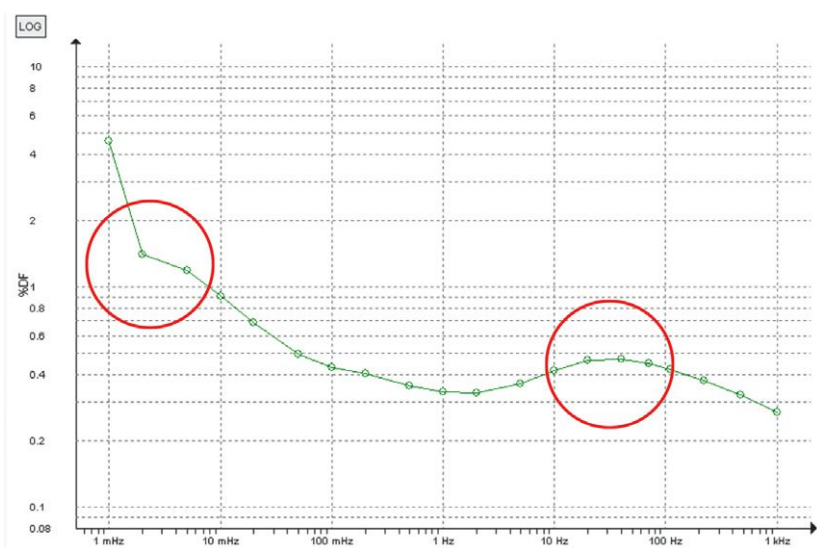
In summary, the DFR curve indicates that the termination exhibits moisture ingress and early-stage moisture ingress near the XLPE/stress-cone interface, accompanied by thermal effects and moderate interface aging, while the bulk XLPE remains functional.



**Figure 3:** Artificial Pinhole Defect Introduced in Cable Jacket Near Termination



**Figure 4:** Deliberate Jacket Rupture with Exposed Semiconductive Layer and Applied Moisture



**Figure 5:** Frequency Response Analysis of Cable Termination and XLPE Insulation

## CONCLUSION

This study demonstrates that frequency domain spectroscopy (FDS) or dielectric frequency response (DFR) provides a significantly deeper and more discriminative assessment of MV XLPE cable insulation compared to traditional single-frequency tan delta measurements. By examining the dielectric response across several frequencies, the method separates the dominant aging mechanisms—thermal degradation, moisture diffusion, electrical stress, water-tree formation, and accessory-related influences—into distinct spectral zones with identifiable signatures. The development of master curves for unaged, thermally aged, water-treed, and joint-influenced conditions enables a structured interpretation framework that utilities can apply consistently in field diagnostics.

Importantly, this study reinforces the practical diagnostic value of FDS for cable-system asset management. The zone-based interpretation scheme allows engineers to:

1. Isolate accessory-related anomalies from bulk insulation aging
2. Distinguish reversible temperature effects from irreversible degradation
3. Assess the progression of water-treeing long before breakdown strength is critically reduced

This enables more accurate condition classification, improved prioritization of cable replacement or rejuvenation, and the potential to significantly reduce in-service failure rates—outcomes that mirror utility case studies reported in the literature.

Overall, frequency-swept dielectric response emerges as a powerful, non-destructive tool for evaluating MV XLPE cable health. As measurement equipment continues to advance—and as more field data is incorporated into refined master curves—FDS is poised to become an integral element of predictive maintenance strategies across modern distribution networks.

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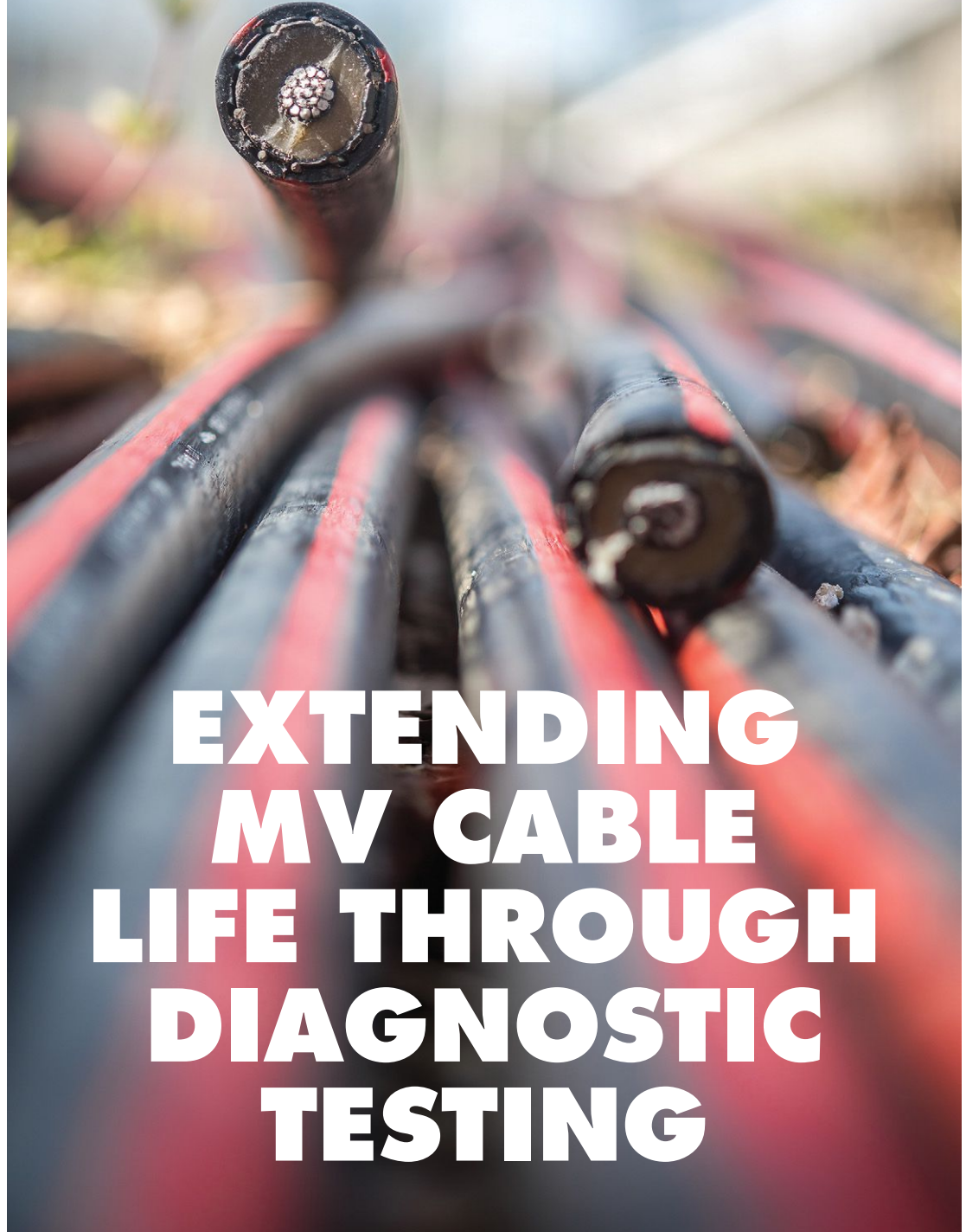
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# EXTENDING MV CABLE LIFE THROUGH DIAGNOSTIC TESTING

PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/CHUYN

BY NILSON BARONI JR and DANIEL BENTO, *Baur USA Corp*; DANILO DE SOUZA, USMT,  
and RAFAEL MORGADO, *Baur Brazil*

The decision to replace a medium-voltage cable is rarely straightforward. It involves high costs, plant downtime, mobilization of field crews, and a direct impact on the reliability of the electrical system. For many years, the dominant practice has been to adopt simplified criteria, generally based solely on cable age: Once a certain number of years has passed, replacement is planned.

However, experience shows that operating time, by itself, is an imperfect indicator of the end of life. There are very old cables in excellent condition, as well as relatively young cables that exhibit accelerated degradation due to factors such as load profile, thermal stress, environmental conditions, and poor installation quality.

### FIELD DIAGNOSTIC TESTING

This is why field diagnostic testing is becoming increasingly important as a central tool for safely extending the life of cable service. Diagnostic testing directly measures the electrical behavior of the insulation and the integrity of the metallic shield rather than assuming that all segments of an installation age the same way. Based on these data, it is possible to determine whether a cable can remain in service, requires only periodic monitoring, or truly demands immediate intervention.

Evaluating the service life of medium-voltage cables begins with understanding their construction. Unlike low-voltage cables, which typically include only a conductor and insulation, medium-voltage cables incorporate several functional layers. These layers include the conductor, inner semiconducting layer,

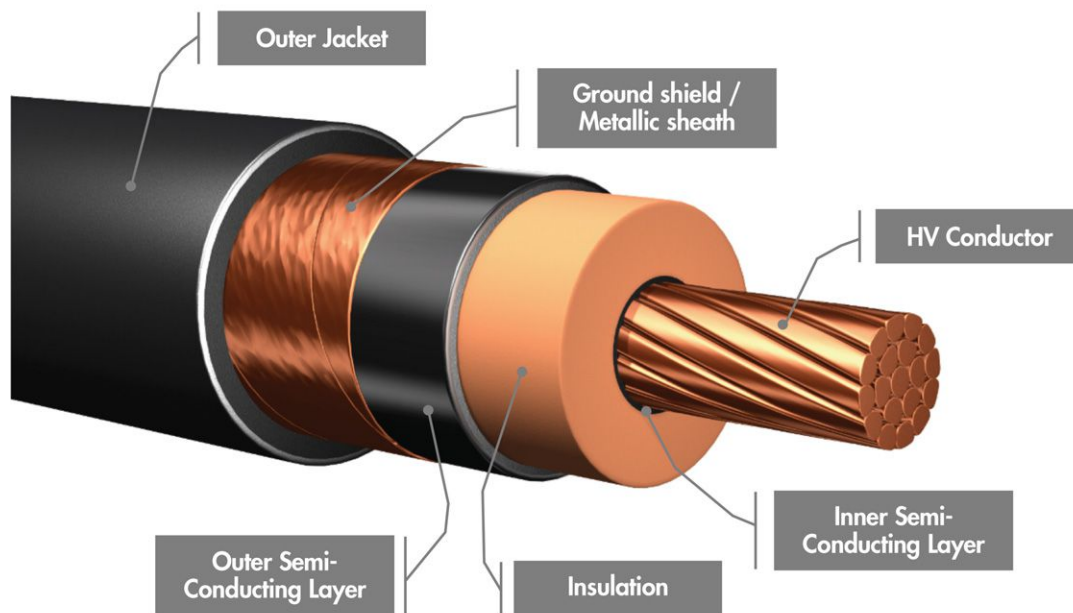
insulation, outer semiconducting layer, metallic shield, separator, and outer jacket (Figure 1).

Over the years, polymeric insulation has been subject to the formation of water trees as well as other dielectric aging mechanisms. The metallic shield may experience corrosion and discontinuities, which can compromise control of the electric field and its ability to conduct fault currents. When these two elements remain in good condition, it is common for the cable to continue operating well beyond the frequently cited typical service life of 25 to 30 years under nominal load.

Thus, the more important question is not, “How old is the cable?” but rather “What is the actual condition of the insulation and the shield?” Diagnostic testing exists precisely to answer this second question.

### VLF Tan Delta Testing

Over the last few decades, very low frequency (VLF) tan delta testing has become one of the reference methods for assessing the insulation condition of extruded cables. The principle is straightforward: Every insulated cable can be modeled as a capacitor, in which part of the current is purely capacitive and



**Figure 1:** Typical Structure of a Medium-Voltage Cable

part is associated with dielectric losses. The tan delta value represents the ratio between these components; the higher the value, the greater the losses and, in general, the worse the condition of the insulation.

Testing at VLF offers two decisive advantages. First, it allows the application of voltage levels representative of cable operation without inducing destructive stress, unlike some direct-current tests that can accelerate material degradation. Second, combining parameters such as the mean tan delta at 1  $\mu\text{m}$ , the standard deviation (SDTD), and the tan delta ( $\Delta\text{TD}$ ) between different voltage levels provides a highly sensitive picture of the degree of aging.

International guides, such as IEEE 400.2, associate test results with three decision categories:

- Cables with no need for action
- Cables requiring future studies or monitoring
- Cables in a condition requiring action, meaning with a high probability of failure

By translating numerical test results into critical classes, the method converts an abstract electrical quantity into operational information that is useful to asset managers.

### Time Domain Reflectometry

Time domain reflectometry (TDR) complements insulation assessment by examining the metallic shield. By injecting short-duration pulses and observing the reflections along the cable, it is possible to identify significant discontinuities in the shield, typically associated with regions of high resistance caused by corrosion or breakage.

Practical experience and the IEEE 1617 standard itself demonstrate that the technique is sensitive to more severe damage, typically above approximately 25% of the shield cross-section. This makes TDR particularly useful for identifying critical segments that may compromise fault performance and the overall system integrity.

Combined with tan delta testing, TDR enables the classification of cables in terms of both dielectric failure risk and their ability to perform their function of conducting short-circuit currents. In this context, extending service life is acceptable only if both functions remain adequately preserved.

### CASE STUDY: ASSESS 207 CABLES IN AN INDUSTRIAL PLANT

The practical application of this approach can be illustrated by a diagnostic testing campaign carried out at a large industrial facility in the interior of São Paulo. In total, 207 medium-voltage cables (13.8 kV) were evaluated over a few days using VLF/tan delta and TDR testing, which involved a field team as well as specialized data preparation and analysis.

Although the company's headquarters had already determined that the cables should be replaced, since many of them were approaching the projected service life of about 30 years, the local unit adopted a more cautious strategy. Before committing to a high-cost, large-scale replacement program, it decided to conduct a few days of diagnostic testing to evaluate the actual condition of the insulation and the metallic shield. This approach enabled the decision to be based on objective data, thereby avoiding premature replacements and accurately identifying which cables truly required immediate attention.

The tan delta results, interpreted in accordance with IEEE 400.2, showed the following distribution:

- Approximately 55% of the cables were classified "no action required."
- Approximately 18% to 19% were classified "future study needed."
- Approximately 28% were labeled "action required."

In parallel, 51 TDR tests were performed, and no anomalies consistent with severe shield degradation (greater than 25% loss of metallic shield cross-section) were detected. This

reinforced that the primary concern at that moment was centered on insulation condition.

A particularly relevant finding was that 108 cables, many of which were among the oldest in the plant (with more than 30 years of service), presented results consistent with acceptable operating conditions. In a maintenance strategy based solely on age, most of these cables would have been automatically included in replacement plans. However, diagnostic tests showed that they could remain in service safely, postponing the need for intervention.

At the other end of the spectrum, 57 cables were identified as having a high probability of failure, supporting recommendations for the replacement of sections, splices, and terminations, especially in circuits most critical to the industrial process. Between these two extremes, an intermediate group of cables was classified as “future study needed,” indicating the value of repeating measurements within one to two years to track the evolution of tan delta and determine the most appropriate moment for intervention.

The main advantage of this approach is that it organizes cable population into three well-defined groups:

1. **Good cables with results falling within the “no action required” range** can have their service life effectively extended, remaining in operation until degradation indicators begin to approach alert thresholds. In many cases, this means gaining several additional years of service without compromising reliability.
2. **Cables requiring monitoring are classified as “future study needed”** if the results indicate signs of aging, though not yet at a critical level. For this group, the diagnostic test transforms uncertainty into a plan: a baseline is established, and a schedule of future tests is defined. If the next campaign shows stable tan delta values, operation can continue; if significant progression occurs, replacement can be scheduled before failure.

3. **Cables requiring action with a high probability of failure**, indicated by elevated MTD,  $\Delta$ TD, and standard deviation values, are often accompanied by automatic test interruption for safety reasons. In these cases, the diagnostic test does not extend service life; rather, it anticipates the decision and prevents the end of life from manifesting as an unplanned outage.

In all scenarios, the cable’s service life ceases to be a statistical assumption and becomes a variable managed through data.

### LIFE EXTENSION WITH OPERATIONAL SAFETY

Extending the service life of cables does not mean postponing the problem. The central point is that by systematically measuring the condition of the insulation and the metallic shield, the company gains access to objective risk indicators. Instead of scheduling large-scale replacements of cables that are still in good condition, it directs resources toward those that truly present a higher probability of failure.

In the case study, this meant keeping more than 100 cables in service that, under an age-based maintenance strategy, would otherwise have been replaced automatically. At the same time, the 57 critical cables were identified and prioritized. The direct consequence is a smoother investment curve, fewer unplanned outages, and greater availability of the plant’s power assets.

From an engineering perspective, there is an additional benefit: The measurement history enables the comparison of how different circuits respond over time to the same operating conditions. This helps identify systemic installation issues, drainage problems, and sections that are more exposed to moisture or mechanical stress, guiding mitigation measures that extend far beyond simply replacing a cable.

Tan delta and TDR testing, when performed as isolated actions, already provide value. However, their true potential emerges when they are incorporated into a predictive maintenance

program with periodic retesting, database updates, and integration with investment planning.

In this perspective, each campaign functions as a high-resolution snapshot of the cable population. Comparing successive campaigns reveals the aging rate of each section. Cables that remain stable may have their retesting interval extended, while those showing accelerated degradation are given priority for replacement or localized repairs.

Over time, the combination of diagnostic data and operational history allows the question, “How long can this cable continue operating?” to shift from a conservative guess to a technically grounded answer. In other words, diagnostic tests convert theoretical service life into managed service life.

This experience demonstrates that it is possible to combine technical rigor, extended cable life, and reliability. Instead of making decisions based solely on age, the company evaluated 207 cables individually using methods consolidated in international standards, obtaining a detailed map of its medium-voltage network. Based on this map, it was able to keep dozens of older cables in operation, monitor those in intermediate condition, and take decisive action where the risk was elevated.

## CONCLUSION

By doing so, the company optimized investments, avoided failures, and created the foundation for a continuous improvement cycle. Each new test enhances the data set, improves the understanding of aging in service, and makes future planning more accurate. In this way, diagnostic testing is not merely a one-time health check but also a strategic tool for safely extending the service life of medium-voltage cables while strengthening the reliability of industrial electrical systems. [NW](#)

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# THE ROLE OF UV TECHNOLOGY IN EXTENDING ELECTRICAL EQUIPMENT LIFESPAN

BY SHEYNA REIZES, *OFIL Systems*

Electrical equipment forms the backbone of modern industrial and utility operations, including power generation, transmission and distribution networks, renewable energy facilities, manufacturing plants, and hyperscale data centers. As global demand for reliable and uninterrupted power continues to rise, capital budget constraints and extended lead times for critical components are forcing organizations to place greater emphasis on maximizing the operational life of existing assets.

## THE IMPORTANCE OF EXTENDING ELECTRICAL EQUIPMENT LIFESPAN

In this context, extending equipment lifespan is no longer viewed as a purely maintenance-driven objective, but rather as a strategic business requirement tied directly to operational resilience, financial performance, and long-term infrastructure planning.

Modern asset management strategies increasingly focus on extracting maximum value from installed equipment through advanced diagnostics, predictive maintenance, and condition-based monitoring. This shift reflects both economic realities and the growing complexity of electrical networks, where equipment failures can have cascading operational and regulatory consequences.

## RISING PRESSURES ON POWER INFRASTRUCTURE

Over the past several decades, electrical infrastructure has been subjected to steadily increasing operational stress, driven by multiple converging factors:

- **Aging asset populations**, with a significant portion of transformers, switchgear, cables, and rotating machines operating at or beyond their original design life
- **Higher and more dynamic load profiles**, resulting from the electrification of transportation, the rapid expansion of renewable generation, and the exponential growth of energy-intensive data centers



- **Environmental and climatic challenges**, including more frequent and severe weather events such as heat waves, wildfires, hurricanes, flooding, and airborne contamination
- **Stricter regulatory oversight and reliability requirements**, with tighter performance indices for service continuity and system resilience

These external and internal stressors accelerate insulation aging, thermal cycling, mechanical fatigue, and contamination-related degradation in electrical equipment. Without corresponding evolution in inspection and maintenance methodologies, the probability of unexpected failures increases significantly.

## FINANCIAL IMPACT OF ASSET LONGEVITY

Replacing major electrical assets requires substantial capital expenditure and long project timelines. Extending the operational life of these assets delivers measurable financial and operational advantages:

- **Reduced capital expenditure (CAPEX)** by deferring or eliminating the need for premature asset replacement
- **Lower operating expenditure (OPEX)** through targeted, condition-based maintenance rather than blanket time-based interventions
- **Minimized unplanned downtime**, protecting production output, service reliability, and contractual service-level agreements
- **Improved total cost of ownership (TCO)** across the full lifecycle of electrical assets

In addition, insurance and risk exposure are directly influenced by asset health-management practices. Insurers increasingly recognize the value of predictive and non-destructive diagnostic technologies, as they reduce the likelihood of catastrophic failures, secondary damage, and fire-related incidents. Utilities and industrial operators that adopt advanced condition monitoring often benefit from more favorable insurance terms, lower

risk premiums, and improved long-term insurability due to reduced loss profiles and stabilized risk exposure.

For utilities and large industrial facilities, each additional year of reliable operation from critical assets can translate into millions of dollars in avoided replacement costs, reduced outage penalties, and improved system reliability.

## THE POTENTIAL-FAILURE CURVE

The potential-failure (P-F) curve (Figure 1) is a foundational reliability engineering model that describes how faults in electrical equipment develop over time. Rather than viewing failure as a sudden event, the P-F curve shows that most failures are the result of progressive degradation that can be detected long before the equipment stops functioning.

- The horizontal axis (X-axis) represents time or operational exposure, typically expressed as operating hours, load cycles, switching operations, or calendar time.
- The vertical axis (Y-axis) represents the asset condition or resistance to failure, which reflects the health of critical elements such as insulation systems, mechanical integrity, and thermal stability.

As time progresses along the X-axis, the asset's condition shown on the Y-axis gradually declines. This degradation is rarely linear and is most often represented by a non-linear or exponential curve, reflecting the accelerating nature of aging and damage mechanisms in electrical equipment.

## Defining the P and F Points

Two critical points define the model:

- **Point P – Potential Failure** is the moment at which a defect becomes detectable through appropriate diagnostic technologies, even though the asset is still operating within acceptable performance limits.
- **Point F – Functional Failure** is the point at which the asset can no longer perform its intended function, resulting in forced outages, safety risks, or equipment damage.

The time between these two points is known as the P-F interval. This interval represents the practical window available to detect, diagnose, and correct developing faults before they evolve into full failure.

## How the P-F Curve Applies to Electrical Assets

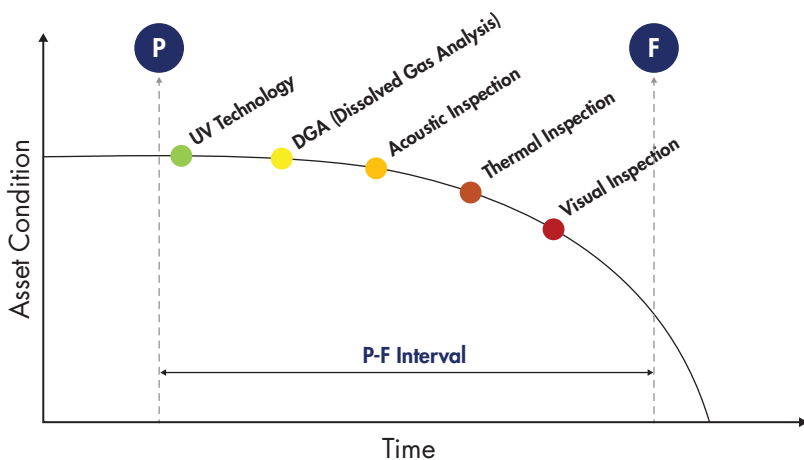
Failures in electrical systems rarely occur instantaneously. They develop through progressive mechanisms such as:

- Insulation aging and degradation
- Partial discharge and corona activity
- Thermal overstress and localized heating
- Mechanical loosening and fatigue

These processes start far in advance of functional failure and may remain invisible without advanced diagnostic tools. The P-F curve conceptually explains when different technologies can detect these phenomena and how early intervention is possible.

## The Strategic Role of Advanced Inspection Tools

While the P-F curve explains how failures develop over time, it does not, by itself, prevent



**Figure 1:** *The Potential-Failure (P-F) Curve*

failure. The practical value of the model lies in the ability to observe and measure real-world physical and electrical phenomena that occur along this degradation path. Without appropriate diagnostic tools, the early stages of failure remain invisible, and the opportunity to intervene within the P–F interval is lost.

This is where modern inspection technologies become essential. Each technology is designed to detect specific physical signatures—electrical, thermal, acoustic, visual, or chemical—that appear at different stages of the degradation process. By aligning inspection tools with the stages defined by the P–F curve, asset owners can transform a theoretical reliability model into a practical, data-driven maintenance strategy that actively extends equipment life and improves system reliability.

### Solar-Blind UV Imaging

Position on the P–F curve: Very close to Point P

Solar-blind ultraviolet (SBUV) imaging detects electromagnetic emissions in the 240–280 nm wavelength range, where natural sunlight is filtered by the atmosphere. This enables the detection of faint ultraviolet photons generated by corona partial discharge, surface partial discharge, and arcing that are often early warning signs of potential faults (Figure 2). Such detections can take place even under daylight conditions.

SBUV cameras are designed as bi-spectral imaging devices, operating at two spectral bands: the solar-blind UV-C band and the visible light band. They produce output images by merging UV and visible light imagery, thereby presenting a comprehensive view of the observed scene.

Solar-blind UV technology can detect faults such as:

- Local electric field intensification caused by improper design or installation
- Early-stage insulation stress
- Contamination-driven discharge activity

- Microdefects on energized hardware, mechanical damage, breaks, cracks, broken strands, loose components, and more.

Because corona and surface PD are typically among the earliest measurable symptoms of electrical degradation, SBUV operates extremely close to Point P, often identifying defects long before heat, sound, or visual damage appears.

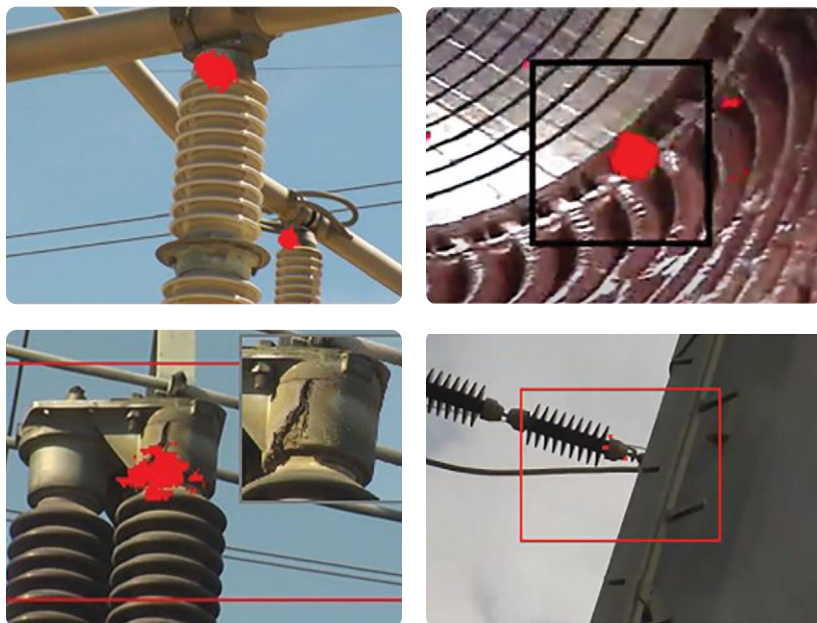
### Dissolved Gas Analysis (DGA)

Position on the P–F curve: Very close to Point P (for oil-filled equipment)

DGA is a chemical diagnostic technique applied primarily to oil-filled transformers and bushings. It detects fault-generated gases dissolved in insulating oil (Figure 3).

Key diagnostic gases include:

- **Hydrogen (H<sub>2</sub>).** Indicates partial discharge and corona, often linked to insulation defects or moisture ingress.
- **Acetylene (C<sub>2</sub>H<sub>2</sub>).** Signals high-energy arcing and represents a critical fault condition



**Figure 2:** Corona PD Indicating the Presence of Malfunctions



**Figure 3:** *Dissolved Gas Analysis Oil Sample*

- **Carbon Monoxide (CO) and Carbon Dioxide (CO<sub>2</sub>).** Reflect the thermal degradation of paper insulation.
- **Methane (CH<sub>4</sub>).** Associated with low-temperature thermal faults and overheating components.
- **Ethylene (C<sub>2</sub>H<sub>4</sub>) and Ethane (C<sub>2</sub>H<sub>6</sub>).** Indicate thermal decomposition.

DGA provides internal visibility of electrical and thermal faults that are completely inaccessible to external inspection. Because gas generation begins

at the very earliest stages of fault activity, DGA is considered one of the closest technologies to Point P for sealed, oil-filled systems.

**Acoustic and Ultrasonic Inspection**

Position on the P–F curve: Mid-range between P and F

Acoustic and ultrasonic techniques (Figure 4) detect high-frequency sound emissions produced by:

- Partial discharge and arcing
- Mechanical looseness and vibrations
- Gas leaks

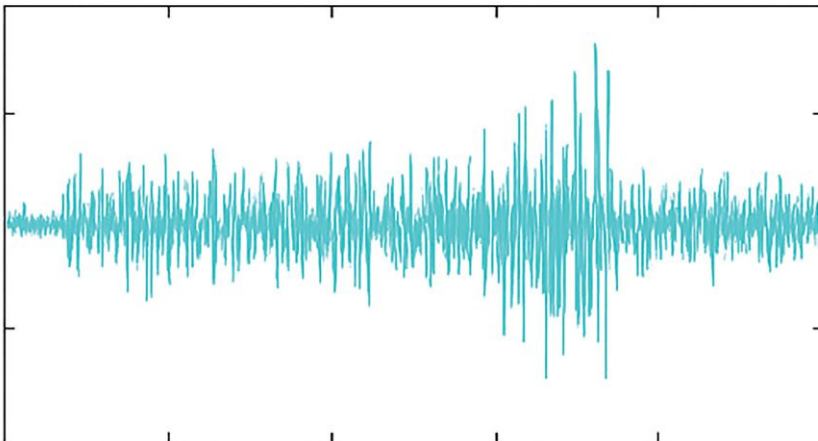
These methods are particularly effective in enclosed environments, such as switchgear. However, audible and ultrasonic emissions usually occur after electrical or chemical degradation has intensified, placing these tools further from Point P and closer to mid-to-late stages of the P–F interval.

**Infrared Thermography**

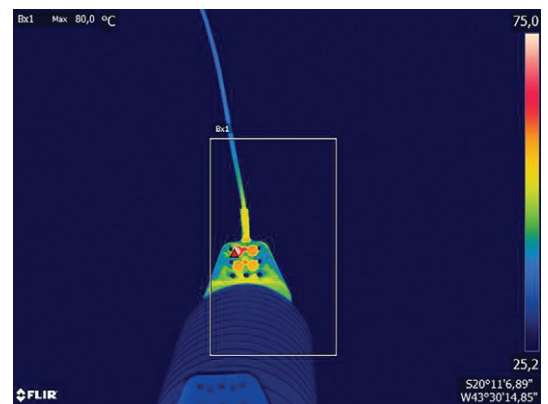
Position on the P–F curve: Middle to late stages

Infrared (IR) thermography identifies temperature anomalies caused by:

- Resistive heating at poor electrical connections (Figure 5)
- Conductor overload
- Phase imbalance
- Insulation breakdown progressing to thermal loss



**Figure 4:** *Acoustic Signal Analysis*



**Figure 5:** *Thermal Camera Hotspot Detection*

Thermal signatures generally appear after electrical stress and partial discharges have been active for some time. As a result, IR thermography is positioned further along the P–F curve, detecting faults typically in the late stages of degradation.

### Visual and High-Resolution RGB Inspection

Position on the P–F curve: Close to Point F

Red-green-blue (RGB) Visual inspection detects:

- Cracks and fractures
- Burning and carbonization
- Corrosion and contamination buildup (Figure 6)
- Deformation and mechanical damage



**Figure 6:** *Visual Discovery of Corrosion on Insulator*

These are typically late-stage symptoms, appearing only after significant damage has already occurred. As a result, visual inspection is positioned closest to Point F, where corrective actions tend to be reactive, urgent, and costly.

## CASE STUDIES: USING UV TECHNOLOGY TO PREVENT FAILURES AND EXTEND ASSET LIFESPAN

### How UV Technology Extends Lifespan

Electrical assets rarely fail without warning. Long before a transformer flashes over, a switchgear panel trips, or an insulator shatters, the equipment enters a silent deterioration

phase—often beginning with small, localized electrical discharges that gradually weaken insulation systems.

UV cameras detect corona and surface partial discharge at their very earliest stages—often months before damage becomes visible through other inspection methods. By revealing microscopic defects, poor assembly practices, installation errors, contamination, moisture-related stress, and emerging insulation breakdown, UV inspection allows operators to intervene long before these issues escalate.

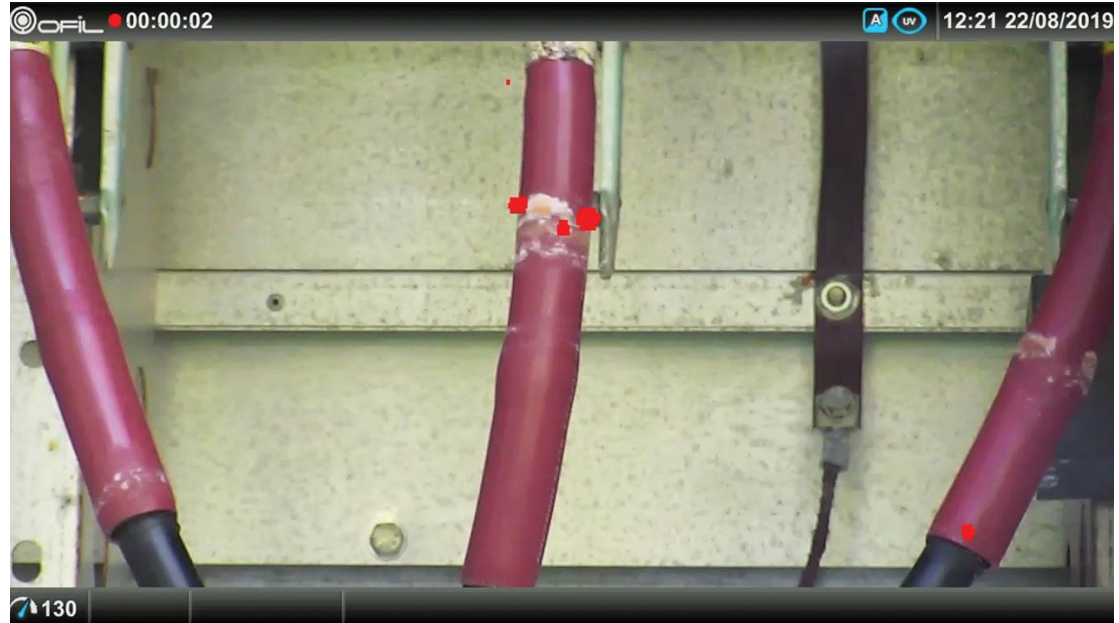
Every hour that partial discharge remains active accelerates insulation aging, erodes surfaces, increases electric field stress, and shortens the usable life of the asset. Interrupting this process early prevents irreversible damage, avoids unexpected outages, and maintains asset integrity for many additional years. In many documented cases, a single UV inspection has prevented failures that would have required costly replacements or extensive repairs.

The following case studies illustrate how utilities and industrial facilities have used UV technology to identify hidden defects, prevent failures, avoid major financial losses, and—most importantly—extend the operational life of critical electrical equipment.

### CASE 1: Preventing Partial Discharge in Medium-Voltage Switchgear (European Utility)

A large European utility experienced a series of unexplained outages associated with medium-voltage switchgear. Initial root-cause assumptions focused on extreme cold-weather operating conditions, as the failures appeared during winter periods. However, the recurring nature of the events suggested an underlying equipment integrity issue.

An extensive inspection campaign was conducted using solar-blind UV corona cameras. The survey revealed that approximately 30% of the inspected switchgear population, most of which had been in service for only about 10 years, exhibited active partial



**Figure 7:** UV Corona Camera Assessment of Switchgear

discharge (Figure 7). UV imagery revealed concentrated discharge activity along cable terminations and insulation surfaces, visible in inspection imagery as distinct UV emission clusters (red detection zones).

Further technical analysis determined that the root cause was not environmental temperature but improper cable installation practices that introduced mechanical stress and microscopic air gaps in the insulation system. These defects created localized electric field intensification, initiating partial discharge inside the cable insulation. Over time, the persistent PD activity accelerated insulation aging, leading to repeated protection trips and line outages.

**The Challenge: Preserving Asset Lifespan**

The primary challenge was not only to stop recurring outages, but also to prevent premature aging and early end-of-life of relatively young assets. The switchgear population was only around 10 years old, yet signs of accelerated insulation degradation were already present due to installation-related defects. Without early detection, these assets would have suffered irreversible dielectric damage, forcing early replacement years ahead of their intended service life.

The utility’s objective shifted from reactive repair to stabilizing and extending the operational life of the existing asset base.

**The Outcome: Life Extension Through Early Intervention**

By using UV inspection to detect partial discharge at an early stage, the utility was able to:

- Eliminate the root causes of accelerated aging
- Restore the insulation integrity before irreversible damage occurs
- Re-standardize installation practices to protect long-term asset health
- Introduce UV inspections as a permanent life-extension strategy

This approach extended the usable lifetime of the affected switchgear, delaying capital replacement cycles and preserving asset value.

**CASE 2: Extending Substation Insulator Lifespan in a Chemical Production Facility**

During a scheduled condition assessment of a chemical production facility’s high-reliability substation, a solar-blind UV inspection was performed on critical insulation components

operating under continuous load. The site required exceptionally high power quality and continuity due to the sensitivity of the production processes and the safety constraints of the operating environment.

Although no visible damage or thermal anomalies were detected, the UV inspection revealed persistent corona discharge activity concentrated around the metal cap of a critical insulator (Figure 8).

The discharge pattern was stable and repeatable, indicating a structural defect rather than a transient environmental effect. Detailed analysis suggested the presence of a micro-gap between the insulator cap and the insulating body. This gap was likely introduced during installation or developed over time due to mechanical stress, thermal cycling, and structural tension on the line. The gap created a localized electrical field intensification, producing continuous corona activity along the insulator surface. This condition initiated progressive material erosion at the edge of the insulating material.

Environmental exposure significantly accelerated the degradation process:

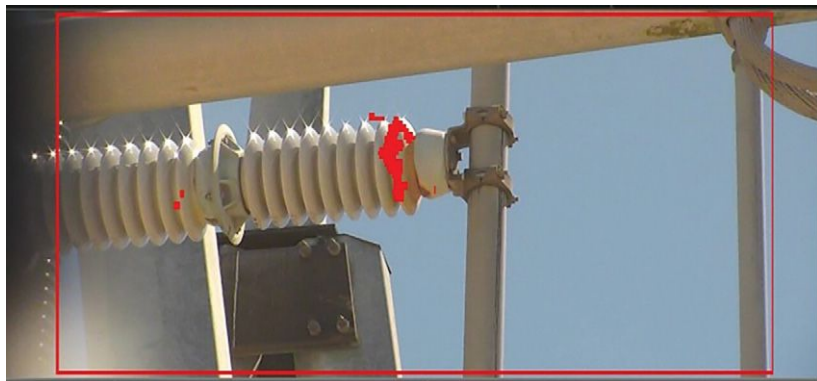
- Rainwater penetrated the micro-gap.
- Moisture reduced surface insulation resistance.
- Repeated wet–dry cycles increased surface tracking and erosion rates.

Although the insulator was still operational, the combination of continuous corona, moisture ingress, and surface degradation placed the asset on an accelerated path toward early end-of-life.

### The Risk to Asset Lifespan

If left undetected, the defect would have resulted in:

- Rapid loss of dielectric strength
- Increased likelihood of flashover
- Structural weakening of the insulator body



**Figure 8:** *Corona Discharge Activity on a Critical Insulator*

### Corrective Action and Life Extension Outcome

Based on the UV inspection results, the facility implemented a proactive replacement program before functional failure occurred:

- The affected insulator was replaced at a direct cost of approximately \$1,800.
- Mechanical installation procedures were updated to eliminate tolerance gaps.
- A periodic UV inspection program was introduced to monitor similar components.

This proactive approach prevented the defect from progressing into irreversible damage and preserved the long-term integrity of the substation infrastructure.

### Return on Investment and Lifecycle Impact

A failure at this location would have forced an emergency shutdown of critical production processes. The facility estimated that such an event would have resulted in:

- Production losses
- Complex and hazardous restart procedures
- Increased safety risk to personnel
- Potential damage to adjacent electrical infrastructure

The estimated avoided financial impact exceeded \$350,000, achieved through a

relatively low-cost early intervention. More importantly, the early action extended the expected service life of the substation assets, delaying capital replacement and preserving system reliability.

## CONCLUSION

Electrical degradation is a gradual process, and the P-F curve demonstrates that the greatest opportunity to preserve asset life lies in detecting faults at their earliest stages. By integrating solar-blind UV imaging with complementary diagnostic tools such as DGA, infrared thermography, acoustic measurements, and visual inspection, operators gain coverage across the full degradation process, from the first microscopic signs of discharge to the later stages of physical damage.

Real-world cases clearly show that early detection not only prevents catastrophic failures but also slows insulation aging, stabilizes asset condition, and extends the usable life of critical electrical infrastructure. As utilities and industrial facilities face increasing reliability demands and constrained replacement budgets, adopting early-stage inspection technologies becomes essential for achieving long-term resilience, safety, and lifecycle cost reduction. [NWW](#)



*Sheyna Reizes is Vice President of Product at OFIL Systems. She has broad experience in B2B product management across multiple industries and works closely with cross-functional teams, including R&D, sales, and marketing. She holds a BS in mechanical engineering from Tel Aviv University and an MBA from The Open University of Israel.*



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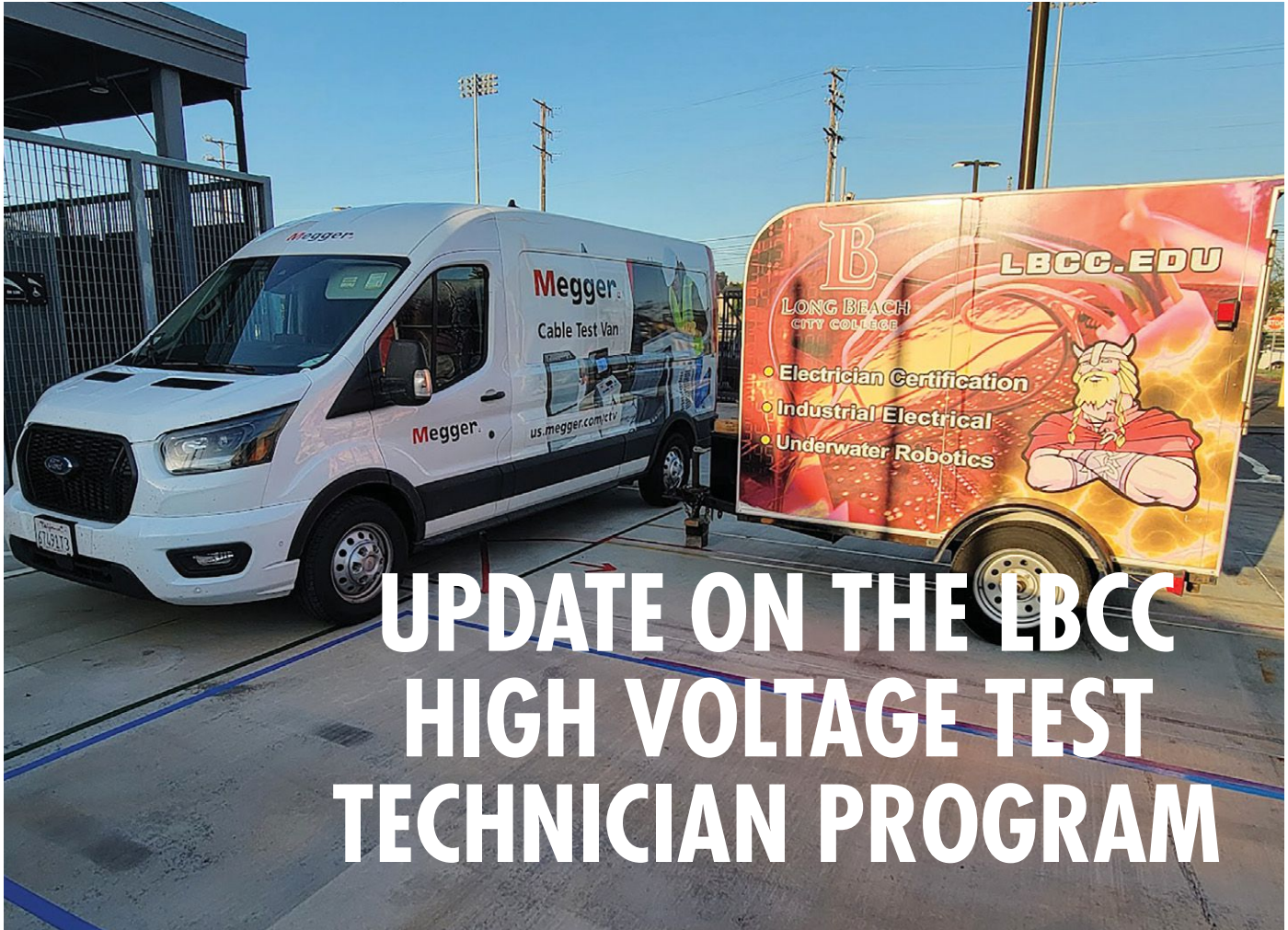
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# UPDATE ON THE LBCC HIGH VOLTAGE TEST TECHNICIAN PROGRAM

*Megger Cable Test  
Van at Long Beach  
City College*

BY NENO PASIC, *Tony Demaria Electric, Inc.*

## **PART 1: A RETROSPECTIVE ON DEVELOPMENT, MILESTONES, AND IMPACT**

Since its inception, the partnership between Long Beach City College (LBCC), Tony Demaria Electric, Inc. (TDE), and NETA has created a rare and impactful educational model for training high-voltage test technicians. Now entering its eighth academic year, the program continues to stand as a national example of how local institutions, accredited industry partners, and professional associations, as well as the individuals' enthusiasm, dedication, and volunteering, can collaborate to address skilled labor shortages through a curriculum aligned with ANSI/NETA MTS, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*.

This article provides a retrospective on the program’s development, key milestones, enrollment trends, graduate outcomes, and instructional challenges encountered and overcome along the way.

## PROGRAM ORIGINS: BUILDING A CURRICULUM FROM THE GROUND UP

The concept for the LBCC High Voltage Test Technician (HVTT) program began taking shape in 2013. Recognizing a critical need for qualified electrical testing technicians, TDE approached LBCC with the idea of developing a curriculum that could feed directly into the workforce pipeline. From the start, the initiative was fueled by close collaboration between TDE and LBCC faculty, with guidance and curriculum frameworks provided by NETA.

As detailed in the Summer 2017 issue of *NETA World*, the program was designed to blend academic instruction with applied training and was the first of its kind to formally align its core courses with the ANSI/NETA ETT, *Standard for Certification of Electrical Testing Technicians*. After years of curriculum development, administrative vetting, working with the State of California Education Department, and industry review, the program officially launched the first NETA Electrical Power Testing Technician (EPTT) course for the Fall semester of 2018. This year is the 10th anniversary of the memorandum of understanding between LBCC and NETA for the NETA-developed Electrical Power Testing Technician (EPTT) Curriculum.

## KEY MILESTONES IN PROGRAM EVOLUTION

Since launch, the program has continued to evolve, with new milestones shaping its identity and reach:

- **2018–2019.** Two foundational EPTT courses launched, serving as a pilot for curriculum structure and instructional delivery.
- **2019.** Enrollment doubled, as noted in the Fall 2019 edition of *NETA World*. Positive industry reception, student

success stories, and strong faculty engagement contributed to this surge.

- **2020.** The program faced its first major disruption during the COVID-19 pandemic; however, instructors quickly pivoted to hybrid formats. Despite the challenges, continuity was maintained.
- **2023–2024.** As presented at PowerTest 2024, the program enrolled its largest cohort to date. Vendor engagement grew substantially, with Intellirent, Doble Engineering, Megger, and others offering direct classroom support, test equipment, and equipment demos.

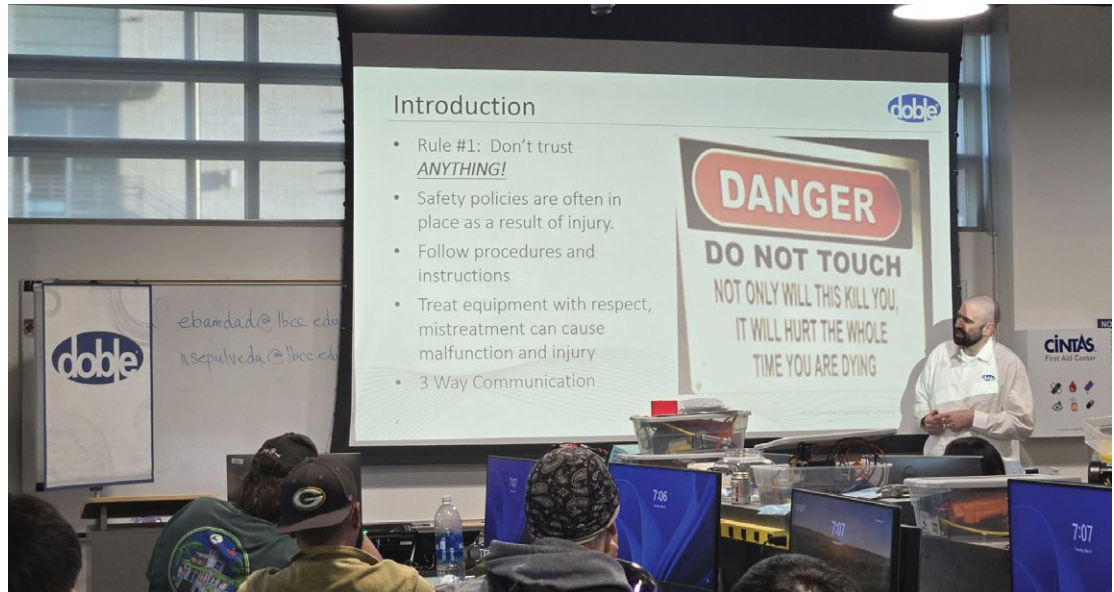
From a curriculum standpoint, each course adheres to ANSI/NETA MTS, which serves as the primary instructional material and textbooks for all classes. The curriculum has been continuously refined to reflect real-world testing scenarios and include updated safety procedures, PPE use, and equipment operation.

## ENROLLMENT TRENDS AND GRADUATE OUTCOMES

The program has seen consistent enrollment growth, fueled in part by industry demand, targeted outreach, and word-of-mouth. Initial



*Long Beach City College Pacific Coast Campus, Home of the High Voltage Test Technician Program*



*On May 14, 2025, Doble Engineering once again brought high-voltage testing technology directly to students in the High Voltage Test Technician and Electrical Technology program, part of LBCC's NETA-approved university curriculum.*

cohorts ranged from 12–15 students per semester. Recent classes have grown to 20–24, with a higher retention rate than in earlier years.

Anecdotally, many graduates have secured employment within weeks of completing the program. While some have joined NETA Accredited Companies such as TDE, others have pursued roles at utilities, electrical contractors, and engineering firms. LBCC's Career Services and the direct pipeline created by TDE and other employers have played a crucial role in this success.

The PowerTest 2024 presentation highlighted success stories, including graduates who progressed to NETA Level 2 certification within 18 months of employment—further evidence of the program's impact.

## INSTRUCTIONAL CHALLENGES AND LESSONS LEARNED

Despite the many successes, the program has also faced persistent instructional challenges:

- **Pace and Scope.** The ANSI/NETA standards provide a robust but dense

foundation. Teaching complex concepts, like insulation resistance, power factor, and protection systems, to students without prior industry experience demands careful pacing and contextualization.

- **Hands-On Limitations.** Due to equipment cost and availability, replicating field testing conditions in the classroom has required creative solutions. This includes vendor partnerships for demo units.
- **Instructor Support.** Recruiting instructors with teaching ability and high-voltage field experience has been difficult, especially since all program courses take place on weekday evenings. Faculty continuity is essential for student engagement and curriculum fidelity.

Over time, the program addressed these issues by adopting a team-teaching approach, improving LMS support, integrating real test reports into assignments, and incorporating vendor-led demos into course modules. These adjustments have proven critical to student comprehension and engagement.


## FROM CURRICULUM TO CAREER: A GROWING COMMUNITY

Beyond its academic structure, the program has fostered a growing community of alumni, employers, and instructors who continue to refine and support its direction. From Day 1, intellirent has been an LBCC program supporter, providing a variety of test equipment and instruments each semester at no charge, including round-trip shipping. The LBCC program remains the only program in the United States providing coursework directly aligned with the ANSI/ NETA standards at the community college level.

The program now also plays a role in shaping national workforce training discussions. With the U.S. Department of Labor’s 2025 approval of NETA’s National Guidelines for Apprenticeship Standards, programs like LBCC’s are poised to serve as key local implementation partners.

## WHAT’S NEXT? PART 2: LOOKING AHEAD

Part 2 of this article, to be released in the Summer 2026 edition of *NETA WORLD*, will examine what’s next for the LBCC High Voltage Test Technician Program, including:

- Potential strategies to integrate the new NETA apprenticeship model into LBCC’s structure
- Program replication opportunities
- Summary of lessons learned from the program adoption
- Deeper employer partnerships and mentorship models
- A forward-looking view of training, technology, and technician needs in the high-voltage testing space
- An interview with an LBCC High Voltage Test Technician program graduate who was hired by a NETA Accredited Company 

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*Neno Pasic is a NETA Accredited Representative and Tony Demaria Electric (TDE) Chief Information Officer. Neno has been working with TDE for over 24 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, 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 the 2021 NETA Outstanding Achievement Award and the 2025 NETA Excellent Service Award.*



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# SYNC OR SINK: THE CRUCIAL ROLE OF PTP IN DIGITAL SUBSTATIONS

BY CHRIS LARRIVÉE, *OMICRON Electronics Corp. USA*

In power system protection, time has always been central—from coordinating relay trip times to selecting algorithms and schemes with the fastest trip times for fault clearing. Historically, however, time synchronization was largely an afterthought serving SCADA and event logging. That has changed with today's digital substations.

This article explains how precision time protocol (PTP) based on IEEE Std. 1588 enables protection-grade synchronization and provides a practical blueprint for designing, validating, and commissioning a substation timing architecture.

## TIME SYNCHRONIZATION IN SUBSTATIONS

In power system protection, time has always been critical—from coordinating relay trip times to selecting algorithms and schemes that minimize fault clearing time. Historically, however, time synchronization was largely a nice-to-have, an afterthought serving SCADA

and event logging in the substation. That has changed with today's digital substations. In earlier generations, each relay received analog current and voltage from instrument transformers, digitized these measurements locally, and made tripping decisions on its own sampling clock and settings. Now, relays may process signals that arrive already digitized and time-stamped by other microprocessor devices.

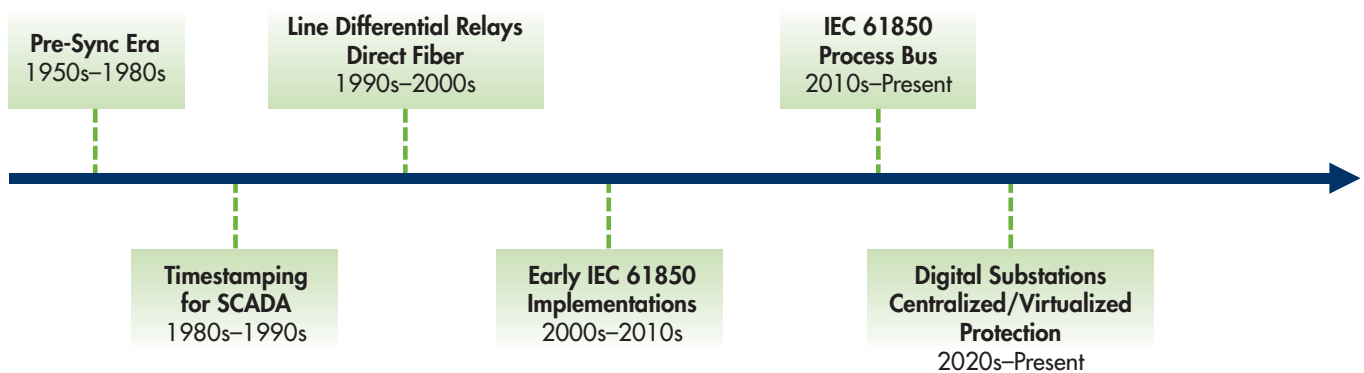
When multiple digitally time-stamped signals traverse the station communications fabric and converge in a protection relay, we must ask whether all signals are aligned to the



PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/WATCHARAPHONG

same sampling interval and remain free of unacceptable errors from device clock offsets or network delays. More precisely, what level of inaccuracy is acceptable for protection purposes, and how should synchronization accuracy and status be monitored so that certain elements that depend on this are inhibited when sync status is lost or degraded?

As soon as the protection architecture depends on a time-synchronization scheme, that scheme itself becomes part of the protection concept. If the timing system fails or degrades, so does the greater protection system. Furthermore, does it become a single point of weakness, or has robustness and redundancy been deliberately engineered?



**Figure 1:** *History of Time Synchronization in Substations*

The timeline (Figure 1) shows how time moved from a background detail to a core element in digital substation designs. Until the 1980s, relays used local clocks, and time was mainly for event logging. In the 1990s, digital line differential relays over direct fiber offered better protection for the line than traditional schemes, but precise time alignment between terminals was required. However, this time sync was typically over direct fiber and not station-wide. In the 2010s, with IEC 61850 process bus and sampled values, timing shifted to a station-wide service often synchronized globally through a GPS antenna, passed through Ethernet switch hardware, and finally to the end device's internal clocks, enabling multiple IEDs to be synchronized to a common time reference.

## FROM LEGACY TO DIGITAL: WHAT CHANGED AND WHY IT MATTERS

Time synchronization has played a role in substations for a long time. What has now changed is the reason devices need to be synchronized to support the level of accuracy and availability. Historically, better time sync means better correlation of event records and SCADA logs. In digital substations, it directly affects how protection functions interpret and compare data.

With many modern schemes, protection elements depend on synchronized, time-stamped signals for proper functionality. When signals

are time-stamped by different devices and later realigned in the relay, any synchronization error rides along with the data. If that error exceeds the element's tolerance, the comparison can be biased enough to cause misoperation. Therefore, the synchronization status must be monitored, and selected functions must be blocked if necessary. At the same time, certain protection functions are not sensitive to the synchronization status of devices, such as overcurrent.

A practical approach is to actively monitor the synchronization status and/or accuracy and block only those protection functions that rely on tight synchronization, leaving others in service and re-enabling sync-dependent functions once acceptable conditions are restored. This remains consistent with the traditional goal of power system protection: Balance reliability with availability.

We often say a substation has “one clock (or two),” but in fact every microprocessor device—relays, merging units, gateways—has its own internal clock. The so-called substation clock is simply the dedicated time source whose primary role is to maintain high-accuracy time, distribute it to all those device clocks, and act as the reference clock for all synchronized devices.

For this article, we will refer to this network of clocks and the infrastructure it runs on as the substation timing system. Different time-sync

**Table 1:** *Time Synchronization Classes*

Time Synchronization Class	Accuracy [ $\mu$ s] Synchronization Error	Application
TL	>10 000	Low time synchronization accuracy — miscellaneous
T0	10 000	Time tagging of events with an accuracy of 10 ms
T1	1 000	Time tagging of events with an accuracy of 1 ms
T2	100	Time tagging of zero crossings and of data for the distributed synchrocheck. Time tags to support the point on wave switching.
T3	25	Miscellaneous
T4	4	Time Tagging of samples or synchronized sampling respectively
T5	1	High precision time tagging of samples with respectively high synchronized sampling

SOURCE: IEC 61850-5 EDITION 2.1 PAGE 68

**Table 2:** Synchronization Protocols Used in Substations

Mechanism	Medium / Distribution	Typical enddevice accuracy (order of magnitude)
PTP (IEEE 1588)	Layer2 Ethernet with boundary/transparent clocks	$\leq 1 \mu\text{s}$ in a properly engineered station LAN
IRIGB (unmodulated/DCLS)	Point-to-point copper or fiber; fanout via distribution amplifiers	$< 100 \text{ ns}$ at clock port; $\sim 10\text{--}50 \mu\text{s}$ typical end-to-end once distributed
1PPS (pulsepersecond)	Direct electrical pulse (often from a GNSS receiver)	$\sim 100 \text{ ns}$ to UTC common (nsclass possible with high-end receivers)
NTP / SNTP	IP over Ethernet (LAN/WAN)	$\sim 1 \text{ ms}$ on LAN under good conditions; 10s of ms over internet

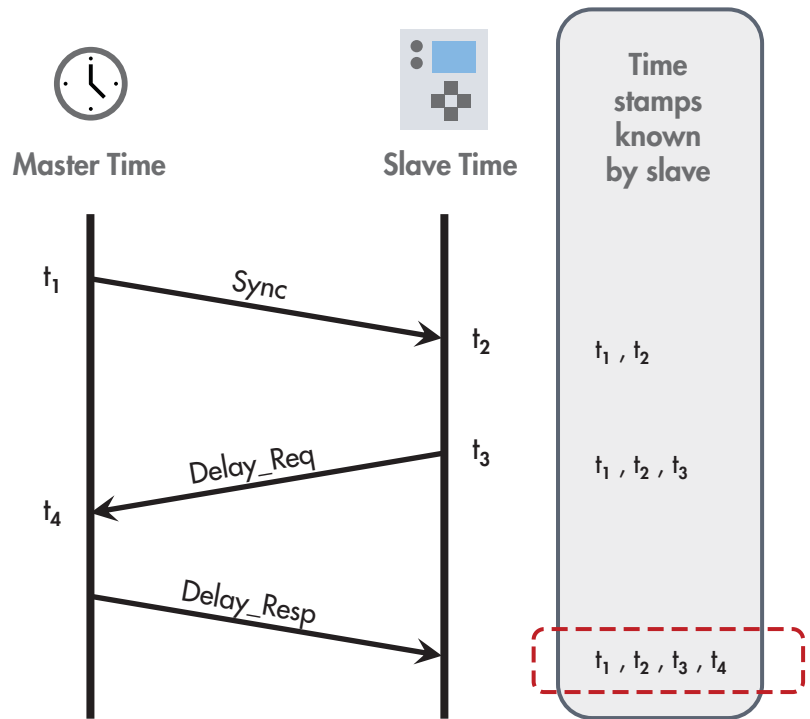
protocols such as IRIG-B, NTP, PTP, and 1PPS are used in substations. These protocols (Table 2) offer varying levels of accuracy, different mechanisms for distributing periodic synchronization messages, and different media on which the messages are sent.

Precision time protocol (PTP) has proven to be an ideal protocol for modern substations due to its accuracy and the fact that this packet-based protocol uses Ethernet as a medium, which is already present in modern substations. However, a system designer must ensure that the equipment is PTP-capable as well as tried and proven. As we've all come to learn, multi-vendor standards can be interpreted differently by different vendors.

### PTP IN POWER SYSTEMS: THE ESSENTIALS

Precision time protocol (PTP), defined in IEEE 1588, was first published in 2002 as a protocol for synchronizing clocks in networked measurement and control systems. It is a packet-based method that distributes a common time reference over an Ethernet network. The reference clock in a PTP system is the grandmaster clock, typically synchronized to a GPS (or other GNSS) time source.

Within a PTP domain, the grandmaster periodically sends sync messages (often at one-second intervals in power profiles, though the rate can be configurable). The receiving devices, known as ordinary clocks or slave clocks, use these sync messages along with follow-up and delay-request and response messages to



**Figure 2:** Precision Time Protocol Delay\_Req Delay\_Resp Mechanism

calculate the time offset from the grandmaster and the mean path delay through the network (Figure 2). Once these quantities are known, each device can steer its local oscillator so that its internal time tracks to the master time.

With  $t_1, t_2, t_3, t_4$  time stamps obtained and known by the slave clock, it can then calculate the mean path delay on the network between itself and the master. Note, this delay will be affected by the physical location of the end device on the network and influenced by the hardware that the messages must pass through.

## Delay times

Forward delay (master → slave):

$$d_{\{ms\}} = t_2 - t_1$$

Reverse delay (slave → master):

$$d_{\{sm\}} = t_4 - t_3$$

Average path delay:

$$d_{\{avg\}} = \left(\frac{1}{2}(t_2 - t_1) + (t_4 - t_3)\right)$$

## Offset

$$offset = t_2 - (t_1 + d_{\{avg\}})$$

## Time of Slave Clock

$$t_{\{slave, new\}} = t_{\{slave, current\}} + offset$$

This synchronization mechanism runs continuously in the background, maintaining a high level of sync accuracy. In addition, another mechanism is running in the background to identify which clock will act as the grandmaster in implementations where multiple potential masters exist. This mechanism is defined as the best master clock algorithm (BMCA), which compares the values listed in Table 3 to determine whether a new grandmaster is elected.

Priority 1 and Priority 2 (Table 3) are configurable settings to influence a preferred clock to act as the grandmaster; other inherent or measured values and settings reflect the performance and status of the clock.

## PROTECTION-GRADE ACCURACY: WHAT IS GOOD ENOUGH?

In protection, very-high synchronization accuracy is required so that samples can be realigned into the same time interval. What does “accurate enough” mean in practice? First, consider the sampling interval. IEC 61850-9-2LE and its successor, IEC 61869-9, specify 80 samples per cycle for 60-Hz systems:

$$60\text{Hz} \times 80 \text{ samples per cycle} = 4800 \text{ samples per second}$$

$$\frac{1}{4800\text{Hz}} = 208.33\mu$$

Therefore, the sampling interval is 208.33 μseconds

The sampled values containing digitized current and voltage measurements are therefore sampled and published 4,800 times per second with an interval of 208.33 μseconds and transported over the station communications fabric. Finally, devices subscribe to these values and use them in their protection algorithms for tripping decisions (protection relays).

With most protection relays requiring 16–32 samples per cycle for algorithms (differential, distance), 80 samples per cycle are deemed sufficient for protection purposes with room for error. Therefore, adding a higher resolution would require higher processing and network bandwidth capabilities, with no real benefit for the overall performance of the protection system.

**Table 3:** Best Master Clock Algorithm to Elect the Grandmaster

Best Master Clock Algorithm	
Priority 1	User defined setting to influence selection of master
Clock class	Enumerated list of clock states, lower number the better
Clock accuracy	Enumerated list of accuracy ranges (21 hex indicates <100ns)
Clock Variance	Indicating the frequency stability of the clock
Priority 2	User defined setting to influence selection of master
Clock Identity	64 bit unique number of MAC Address

When these sampled values reach the protection relay, two things must be true:

- (1) They are reassembled in the exact order they were taken, and
- (2) The reference clocks of the measuring devices (merging units) and the receiving devices (protection relays) are aligned closely enough that the relay places each value back into the same 208.33  $\mu$ s window.

If either condition is not met, the relay may end up comparing samples that were not taken at the same instant, and the resulting error can appear as a real difference in magnitude.

To ensure the sampled values frames are realigned in the proper order, IEC 61850 defines the `smpCnt` or sample count field, which is present in every sampled values frame. This field is a numerical value between 0 and 4,799 for each sample taken within a one-second interval. The publisher of this sample assigns the `smpCnt`, and the subscriber uses this value to reorganize the samples in the proper order.

To validate that the reference clocks of each device are accurate enough with respect to one another, we must rely on PTP. PTP synchronizes clocks to a common time reference (the grandmaster clock) and, in the power profiles, effectively defines the maximum acceptable offset as 1  $\mu$ s for a synchronized device. Therefore, in a synchronized state, 2  $\mu$ s is the maximum possible offset between two clocks. An additional field in sampled values defines the synchronization status of the merging unit at the time it took the sample. The `smpSynch` field is defined as one of the following numbers:

- 0 = internally synchronized
- 1 = local synchronization
- 2 = global synchronization

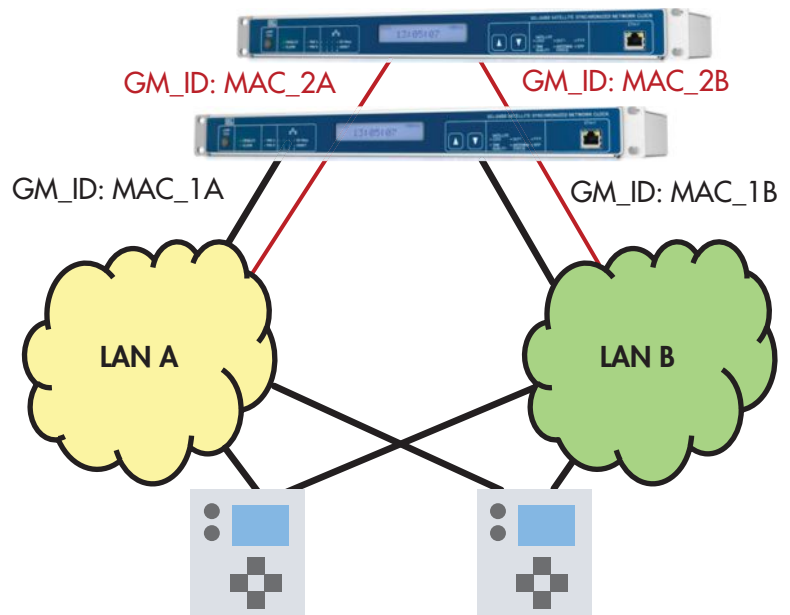
According to IEC 61850, a properly functioning digital substation implementation will rely on a well-synchronized substation timing system, achieved through precision time protocol. This

substation timing system is a sub-system of the protection system, and just as other subsystems, including the protection settings or wiring, must be carefully designed, tested, and monitored, so must the substation timing system.

## DESIGNING A SUBSTATION-GRADE TIMING ARCHITECTURE

Designing a substation-grade timing system requires careful engineering so that time synchronization does not become the Achilles heel of the overall protection scheme. Hardware must be selected from reputable vendors with proven, standard-compliant PTP implementations. The architecture should avoid single points of failure by providing redundant time sources and redundant paths. In protection, redundancy is a proven means of enhancing reliability; the same philosophy applies to the timing infrastructure.

Beyond hardware, correct operation depends on a solid understanding of the relevant PTP profiles for power systems (for example, IEEE C37.238 and IEC/IEEE 61850-9-3) and consistently configuring those profiles across clocks, switches, merging units, and protection relays. Parameters such as domain numbers, delay mechanisms,



**Figure 3:** Redundant Substation Clocks Connected to PRP Networks

message rates, BMCA priorities, and holdover behavior must be coordinated so the timing system remains accurate enough under both normal and contingency conditions. If the accuracy is lost or degraded, then the protection settings must disable certain elements. This can be done by internal logic in the relay, configurable logic, or settings.

Figure 3 shows an example of a redundant substation timing system with two potential master clocks, redundant paths over the parallel redundancy protocol (PRP), and redundant ports on the end devices. A designer must understand how the devices handle redundancy.

## COMMISSIONING WORKFLOW: HOW TO ENSURE IT WORKS, AND WHAT HAPPENS WHEN IT DOESN'T

At this point, it should be clear why the substation timing system must be treated as an integral part of the greater protection system. Before critical power system protection can go into service, it must be rigorously tested to prove it is fully operational and will perform its functions if it is called upon in case

dangerous faults appear on the power system. It must also avoid any mis-operations that may lead to unnecessary power outages. Because the substation timing system underpins many of these functions, it must be tested, commissioned, and its failover scenarios verified before allowing the overall protection scheme to go into service.

A practical workflow to verify operation includes:

- Step 1: Verify that grandmaster clocks are active, and performance is satisfactory.
- Step 2: Confirm switches are properly configured and are not introducing unsatisfactory delays.
- Step 3: Confirm end devices are synchronized and display this state.
- Step 4: Perform a failover scenario: clocks switch over to the new time source, and alarms are displayed properly (ideally locally and to SCADA).
- Step 5: Perform protection tests with a synchronized test set, confirming that appropriate protection elements are blocked when devices lose synchronization and re-enabled when sync is restored.

The screenshot displays a network analyzer interface titled "PTP Sniffer - DANEO - Remote (CB077F)". It is divided into two main sections: "PTP sources" and "PTP timeTransmitters".

**PTP sources table:**

Status	Port	Protocol	Domain
✓	A	IEEE 802.3	0
✓	B	IEEE 802.3	0

Below the table, the status is indicated as "Usable".

**PTP source details:**

Delay mechanism	Peer-to-Peer
Announce interval	1 s
Sync interval	1 s
Other peers	1
Best timeTransmitter available	True
Packet errors	0

**PTP timeTransmitters details for 1@20-B7-C0-FF-FE-00-F6-6E (Best timeTransmitter):**

Power profile GM ID	--
Power profile version	--
MAC address	20-B7-C0-00-F6-6E
VLAN ID	not present
VLAN priority	not present
GM identity	20-B7-C0-FF-FE-00-F6-6E
GM priority 1	128
GM priority 2	128
GM clock accuracy	WITHIN_100_NS (0x21)
GM clock class	PRIMARY_REF_PTP (6)
GM clock variance	18465
Qualified	True
Alternate	False
TLV count	0
UTC offset	37
UTC offset valid	True
Leap 59	False
Leap 61	False
Time traceable	True
Frequency traceable	True
PTP time scale	True
Time source	GPS (0x20)

At the bottom of the interface, there are buttons for "Restart", "OK", and "Cancel".

**Figure 4:** PTP Sources Displayed Using Network Analyzer with Grandmaster Details

To perform Step 1 and Step 2, a tester will need insight into the timing statistics of the network, which can be achieved using a network-analyzing tool with PTP capabilities.

In Figure 4, the PTP sources on ports A and B of the analyzer show available grandmasters on the network and display their details. With this information, we can confirm the presence of PTP sources on LAN A and LAN B of the substation network. We also get details on the configuration, PTP profile, grandmaster ID, VLAN, grandmaster priority 1 and 2, clock accuracy, clock class, clock variance, etc. This information is also key if ever the substation timing system is not functioning, and the tester must troubleshoot.


For Step 3, we must have information on the mean path delay (Figure 5) discussed earlier, as an unsatisfactory mean path delay can be introduced by network switches or other network components. This time is measured and calculated by an end clock and is not advertised by the grandmaster.

The same network analyzer shows the mean path delay over the network, which is measured and not advertised by the master clock. With this knowledge, we can pinpoint whether the grandmaster clock or the network is malfunctioning.

## VERIFYING SYNCHRONIZATION STATUS AND FAILOVER

Step 3 and Step 4 can be performed in the same test plan. Step 4 is only applicable if there is clock redundancy and will require the main clock to be removed from the network, disabled, or forced into inferior status according to the BMCA.

One of the greatest benefits of the shift toward digital substations is the amount of information available to system operators and test engineers. As traditional signals are moved into digital form and transmitted over the network, they

Time			
	Local	2026-01-05	22:06:53
	UTC	2026-01-06	03:06:53
	TAI	2026-01-06	03:07:30

PTP details - Port A	
<b>Synchronization status</b>	
Status	TimeReceiver
Offset from timeTransmitter	18 ns
Peer mean path delay	99 ns
Steps removed	1

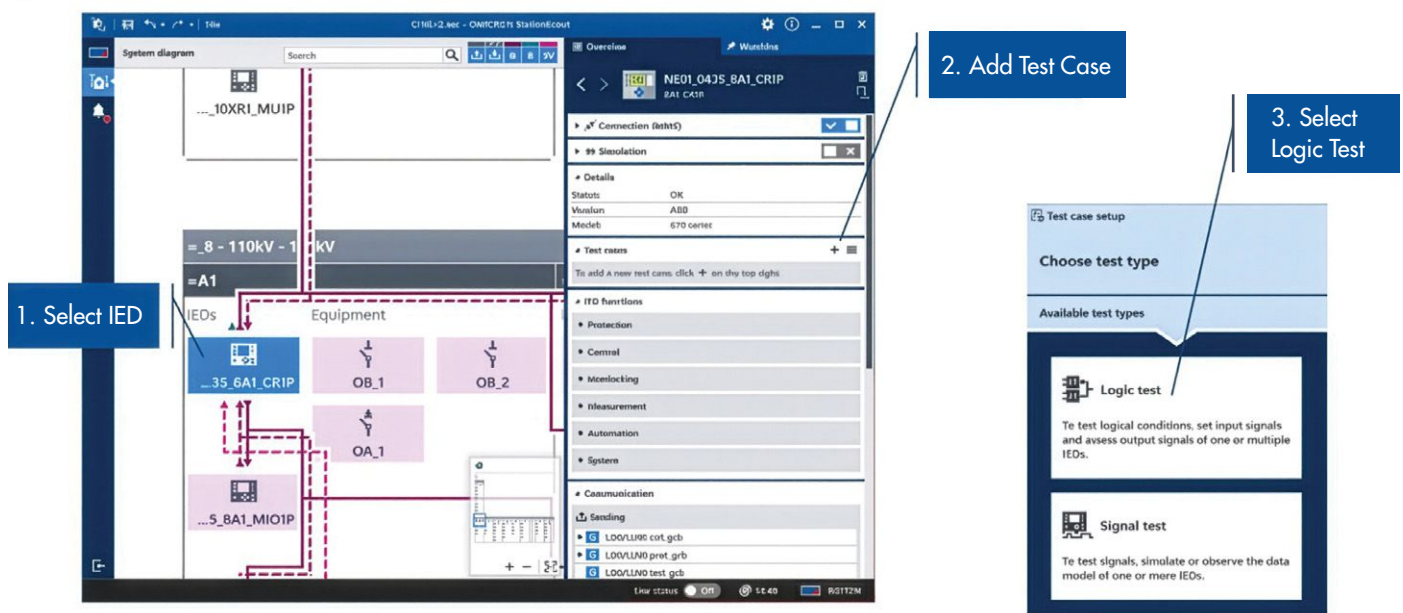
**Figure 5:** Satisfactory Peer Mean Path Delay Leading to an Unsynchronized End Clock

carry valuable information on the status, health, and quality of the signals themselves.

A great example of this, specifically for monitoring the synchronization status of devices, is the time master supervision logical node (LTMS) function defined in IEC 61850:

### 6.4.5.4 Time Supervision

*Time supervision is the function responsible for communicating the status of the time synchronization function of an IED. The logical node LTMS has been introduced for that purpose. It allows to know important*



The screenshot displays the software interface for testing and commissioning IEC 61850 devices. On the left, a system diagram shows various IEDs (e.g., \_35\_6A1\_CRIP, \_5\_BA1\_MIOIP) and equipment (e.g., OB\_1, OB\_2, OA\_1) connected to a bus. A callout '1. Select IED' points to the IED selection area. The central panel shows the 'Overview' for a selected test case 'NE01\_0475\_8A1\_CRIP', with a callout '2. Add Test Case' pointing to the test case list. The right panel shows the 'Test case setup' dialog, where 'Logic test' is selected, with a callout '3. Select Logic Test' pointing to the selection button. The 'Logic test' description reads: 'To test logical conditions, set input signals and assess output signals of one or multiple IEDs.'

**Figure 6:** IEC 61850 Testing and Commissioning Software for Time Sync Verification

*conditions with regard to time synchronization as the status of the communication channel with the time source of the time accuracy class according to IEC 61850-7-2.*

The synchronization status of all devices in the substation can be checked locally in a manual process, but test tools also allow us to build test plans (Figure 6) to verify station-wide synchronization in a more automated manner.

To verify synchronization, the IEC 61850 test software can poll each IED (merging units and protection relays) to verify its synchronization status via the LTMS logical node. Instead of verifying this individually in a time-consuming manner, the system configuration language (SCL) file can be exported from the configured project and imported into the test software. This is yet another advantage of testing in digital IEC 61850 environments. Based on the imported SCL file, we can select the LTMS logical node from the signal list for each IED. Once this is configured, we can refer to it as our substation timing system test plan and perform the test.

A report (Figure 7) is then generated showing the synchronization status of each device from the signal list. The test plan can also be saved and used as a template. This will serve well once it is time to fail over from the primary time source and see how the substation timing system reacts.

Earlier in the article, it was mentioned that redundancy should be implemented in the substation timing system to avoid a single point of failure in the greater protection system. Redundancy that has not been tested and proven is not true redundancy. This means that if redundant master clocks are installed to take over and act as a grandmaster in the event of a failure on the primary grandmaster, we must simulate this failure, witness the secondary clock takeover, and finally witness that all devices switch their internal time reference to the secondary clock. This can be done by reusing the same test plan, utilizing the LTMS logical node, and verifying the new GM Identity or MAC address displayed in Figure 7.


**20 Test case status check – Passed**

Test type: Logic  
 Automated control: Off  
 Automated assessment: Off

**21 Step 1 – 2024-02-22 15:17:40.251-05:00 – Passed**

**Signal assessment**

Signal	Timestamp	Value	Expected value
Go Src Ref NE01_435_10XFR1_MIO1PSYS/A LGOS1.GoCRef		NE01_035_10XFR1_XR1 PLD0/LLN0.INSERV_gcb	NE01_435_10XFR1_XR1PL D0/LLN0.INSERV_gcb
Subsc. status NE01_435_10XFR1_MIO1PSYS/A LGOS1.St	2024-02-22 14:34:48.130- 05:00	True	True
Time Src NE01_435_10XFR1_MIO1PSYS/A LTMS1.TmSrc	2024-01-30 15:28:15.459- 05:00	EC4670FFFE0AC364	EC4670FFFE0AC364
Time sync. status NE01_435_10XFR1_MIO1PSYS/A LTMS1.TmChSt	2024-01-30 15:28:01.459- 05:00	True	True
Process Bus A link status NE01_435_10XFR1_MIO1PSYS/R CHLCCH3.ChLiv	2024-01-30 15:28:05.459- 05:00	True	True
Process Bus B link status NE01_435_10XFR1_MIO1PSYS/R CHLCCH3.RedChLiv	2024-01-30 15:27:57.459- 05:00	True	True
Station Bus link status NE01_435_10XFR1_MIO1PSYS/S CHLCCH1.ChLiv	2024-01-30 15:27:55.459- 05:00	True	True



**Figure 7:** Automated Test Report Generated with Sync Status

Synchronization status (SmpSynch):	Synchronization status of the CMC	
Optional fields	Synchronization status of the CMC	
Grandmaster Clock ID (Gmidentity):	0 - Internal synchronization 1 - Local synchronization 2 - Global synchronization Custom value	
Sample mode (SmpMod):	Not used	
Sample rate (SmpRate):	Not used	

**Figure 8:** Configuration of *smpSynch* Flag for Sampled Values in Test Universe Protection Testing Software

## TIME SYNCHRONIZATION CONSIDERATIONS FOR PROTECTION TESTING

Step 5 will be performed in conjunction with the traditional relay testing. Consideration must be taken when performing protection testing in digital substations concerning the substation timing system. First, the protection relay under test must have all protection enabled and therefore must be in a synchronized state. The relay will likely require the sampled values produced by a test set to be synchronized (*smpSynch* flag = 1 or 2).

For this reason, it is often beneficial to synchronize the protection test set to the substation clock to obtain truly synchronized simulated sampled-value streams for test purposes. Additionally, since this is for testing, it is possible to force the value of the *smpSynch* flag to any of the allowable values shown in Figure 8.

It is important to ensure that appropriate protection elements are blocked under certain loss-of-synchronization conditions. Relay vendors handle this differently, and behavior may vary depending on the relay firmware version, but this is typically a mix of configurable settings, inherent functionality, and custom logic. This creates room for errors, so how the relays will block protection elements under loss-of-sync conditions must be understood and verified during commissioning.

## CONCLUSION

In modern digital substations, time synchronization is no longer an accessory for SCADA and event logs; it is a core part of

how sampled values, GOOSE messages, and protection relays work together. The substation timing system—grandmaster clocks, PTP configurations, time-aware switches, as well as relay logic and time-sync parameters—has effectively become a subsystem of the overall protection system, and it needs to be engineered with the same care as any part of the protection scheme.

Precision time protocol (PTP) provides the accuracy and flexibility needed to keep device clocks aligned in this environment, but good hardware alone is not enough. Designers must understand the relevant profiles (such as IEEE C37.238 and IEC/IEEE 61850-9-3), coordinate settings across the network, and avoid single points of failure by using redundant clocks, redundant paths, and appropriate supervision of synchronization status.

If something fails over, you want to know about it. When this is done well, the substation timing system supports reliable fault clearing and predictable protection performance, even during disturbances. It should never introduce a single point of failure.

Finally, the timing system must be verified and maintained. Commissioning workflows should include checks of the grandmaster performance, device synchronization status, and behavior during failover. The same test plans can be reused after firmware changes, network modifications, or device replacements, and tools based on IEC 61850 (including LTMS and automated test reports) make it practical to repeat these checks. In short, if digital substations are going to depend on time

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synchronization, then designing, testing, and documenting the substation timing system must be a standard part of putting protection schemes into service. [NW](#)

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**Chris Larrivée** joined OMICRON in 2020, where he is an advocate and specialist in the digitalization of substations and is highly involved in IEC 61850. He previously built six years of hands-on commissioning and testing experience in the power industry, managing and contributing to projects across Canada, the United States, Europe, and Africa. Larrivée holds an advanced diploma in electrical engineering technology from Algonquin College, a BS in electrical engineering from the Limerick Institute of Technology, and an MS in engineering from the University of Ottawa.

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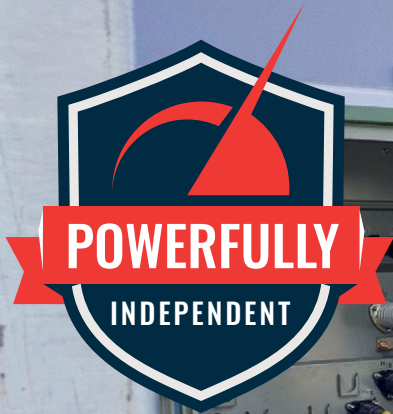
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# AEMC INSTRUMENTS: PRECISION ENGINEERING PAIRED WITH OLD-SCHOOL SERVICE

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



**KRISTY FORD**

This ongoing *NETA World* series focuses on the thought leadership behind these successful companies. For this issue's CAP Spotlight, we talked to Kristy Ford, Marketing Director for AEMC® Instruments (Chauvin Arnoux® Inc., d.b.a. AEMC® Instruments), where she leads marketing, digital strategy, and technical communications for North and South America, Australia, and New Zealand.

“At AEMC, we are passionate about AEMC’s people, leadership, and products,” Ford explains. “We believe that our combination of robust instruments, real-world training, and accessible, knowledgeable support is what truly sets the company apart. Our focus is on pairing solid engineering with clear communication and old-school customer service so crews can work safer, smarter, and with more confidence.”

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

**Ford:** One thing that often surprises people is how much AEMC does beyond just building great instruments. Yes, AEMC Instruments

is known for precision electrical test and measurement, but we're also very focused on what happens after the tool leaves the box.

We provide accredited training to help people deepen their field skills, and we engineer OEM versions of our instruments and custom solutions when the standard catalog model isn't the right fit. At the end of the day, our job is to give technicians the right tools and the confidence to use them.

We're also in the process of expanding our portfolio here in the U.S. to include auxiliary relays, analog transducers, and panel meters—just to name a few. These products have been

# CORPORATE ALLIANCE CORNER — CORPORATE ALLIANCE SPOTLIGHT

working quietly in the background for decades in European nuclear plants and rail applications through our sister company, Chauvin Arnoux Energy, and now we're bringing that same engineering heritage to the U.S. market under the AEMC name, with the same focus on reliability and long-term support.

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

**Ford:** I'm proud that in 2025, a real person still answers the phone at AEMC.

Whether you call tech support or customer service, you get a human being who actually knows the instruments and can help you sort out what's going on. That may sound small, but when you're standing in a substation or a plant and the clock is ticking, it's huge.

We hear it all the time: "You actually picked up," and "You knew exactly what I was talking about." It's a bit old-school, but it's very intentional. Fast, knowledgeable support is a big part of why people stay with us.

**NW:** What are the biggest challenges facing your customers right now?

**Ford:** There's a lot of pressure in the field today—aging infrastructure, smaller crews, and more compliance and documentation demands. Technicians are being asked to keep systems running, stay safe, prove it on paper, and somehow do it all faster. They really don't need another complex interface or confusing setup screen.

Our focus at AEMC is to make things simpler and safer with instruments that set up quickly, give you readings you can trust, and help you get through testing and reporting without a lot of extra steps. The goal is pretty simple: Help them save time and money and let them get back to keeping the lights on and the plants running.

**NW:** Going forward, what challenges do you see for the industry?



OUR FOCUS AT AEMC IS TO MAKE THINGS SIMPLER AND SAFER WITH INSTRUMENTS THAT SET UP QUICKLY, GIVE YOU READINGS YOU CAN TRUST, AND HELP YOU GET THROUGH TESTING AND REPORTING WITHOUT A LOT OF EXTRA STEPS.

**Ford:** I see three big challenges.

- 1. Aging infrastructure plus rising complexity.** Crews are maintaining legacy systems while integrating renewables, EV loads, and modern protection schemes. Nothing is "simple" anymore.
- 2. Lean teams, heavier compliance.** Fewer people are doing more work, with more reporting and proof required. No one has time for rework because a test process or instrument wasn't clear.
- 3. A lot of data, not always usable.** We're collecting more measurements and waveforms than ever, but decisions still have to be made quickly with confidence.

That's where we see our role: Reduce the noise, reduce the steps, and give people tools that get set up quickly, can capture the right data the first time, and produce reports you can hand to a client or an Authority Having Jurisdiction (AHJ) without a rewrite. Precision, speed, and safety must move together.

# CORPORATE ALLIANCE CORNER — CORPORATE ALLIANCE SPOTLIGHT

**NW:** Is this a good time to be in the electrical power testing business?

**Ford:** It's a phenomenal time. Electrification is accelerating across the board. AI-driven data centers are popping up everywhere, along with ongoing grid modernization and a renewed focus on nuclear for a clean, reliable, low-carbon source. All of that depends on power quality, protection, grounding, and maintenance you can trust. If you can test it, verify it, document it, and do it safely—you're not just in demand, you're essential!

**NW:** What advice do you have for young people entering the field?

**Ford:** I would boil it down to a few things:

- **Nail the basics.** Grounding, bonding, insulation testing, power quality, protection coordination—those fundamentals will carry you throughout your whole career.

- **Be serious about safety.** Live NFPA 70E, understand arc flash risk, and don't cut corners. The best tech is the one who goes home safe every single day.
- **Get hands-on as soon as you can.** Certifications (NETA, etc.), time with instruments, and real-world job sites will teach you things no book can.
- **Learn to explain things clearly.** If you can write a clean report and talk calmly to a customer or AHJ, you'll stand out quickly.
- **Stay curious.** Digital workflows, connected instruments, and data analytics are only going to grow. Lean into them.
- **Find a mentor—and eventually be one.** This industry runs on knowledge being passed down.

“If you show up with humility, a good work ethic, and respect for the craft and the risks, there's a lot of opportunity ahead of you,” Ford offers. [NW](#)

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When uptime is critical, uncertainty is not an option. Power systems are becoming more complex, expectations for performance continue to rise, and even minor disruptions can create significant operational and safety risk. In high-demand environments, reliability depends on expertise, speed, and clear accountability before issues escalate.

# GLOBAL ENERGY TRANSITION: WHAT WILL IT MEAN FOR ELECTRICAL TESTING?

BY KEVIN G. SARB, *Ducker Carlisle*

The global energy system is undergoing a fundamental shift that will reshape how electricity is generated, distributed, and managed over the coming decades. Electrification is accelerating across transportation, manufacturing, and digital infrastructure, while clean and renewable sources are rapidly expanding their share of global power generation.

For the electrical testing community, this transition is not theoretical. It is already changing the complexity, configuration, and risk profile of the systems that must be tested, commissioned, and maintained.

Ducker Carlisle's most recent *Global Energy Transition Outlook* examines how the world's energy mix is evolving under three scenarios: Net Zero Emissions, Announced Pledges, and Stated Policies. The report identifies five core

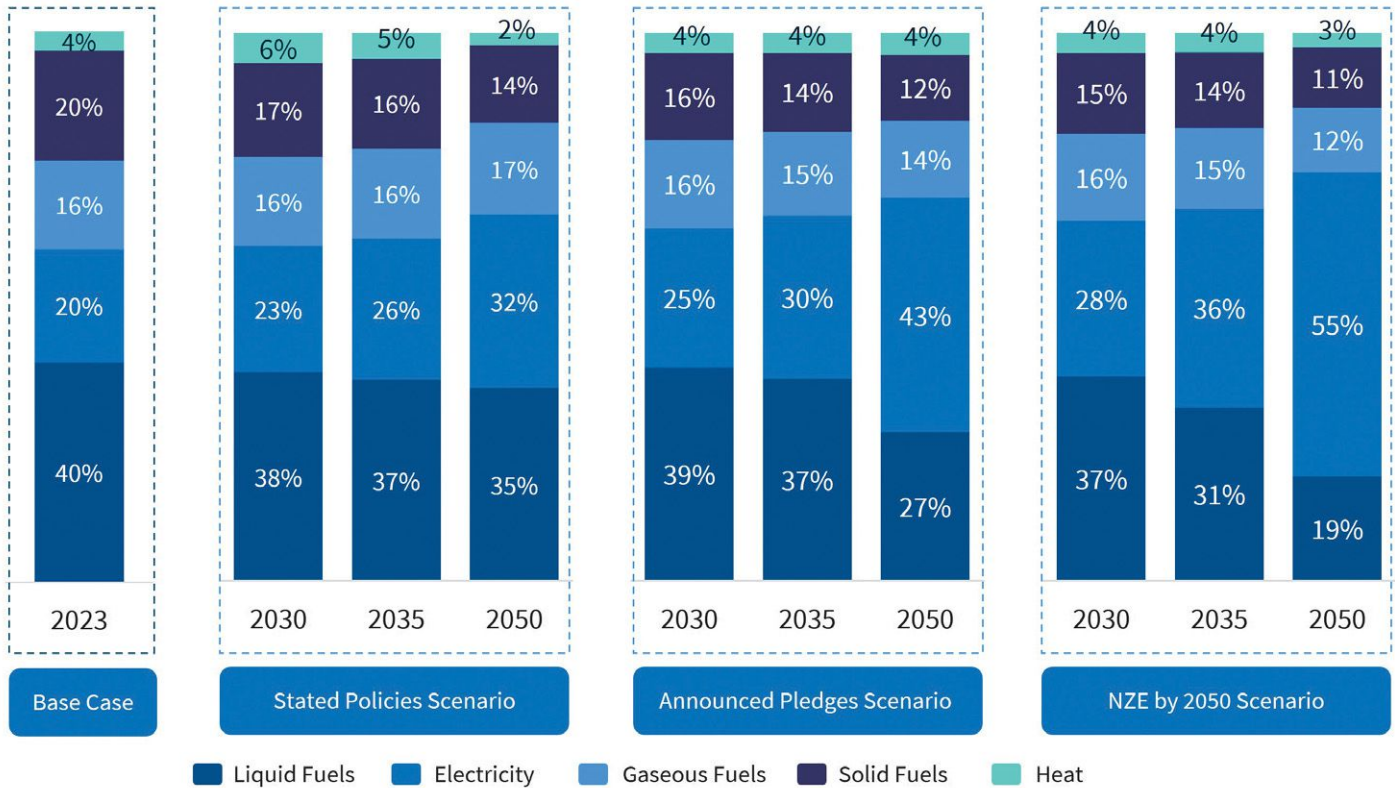
findings that define the direction of travel. Together, these trends point to a future where electrical testing expertise will be more critical than ever.

## **ELECTRICITY'S EXPANDING ROLE IN THE GLOBAL ENERGY MIX**

Today, electricity accounts for roughly 20% of global energy consumption, with the majority still coming from liquid, gaseous,

PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/LOOPS7

### Share of Energy in Total Final Consumption by Type by Scenario



**Figure 1:** *Shifting Global Energy Consumption Mix*

and solid fuels. That balance is changing rapidly. By 2050, electricity is expected to represent at least one-third of global energy use and potentially as much as 55%, depending on policy and technology outcomes (Figure 1).

This shift reflects broad electrification across the economy. Electric vehicles, electrified industrial processes, data centers, and distributed energy systems are all contributing to rising demand. From a testing perspective, this growth places increasing pressure on generation assets, substations, protection systems, and distribution infrastructure that were not designed for today’s load profiles or operating dynamics.

### CLEAN AND RENEWABLE GENERATION BECOMES THE MAJORITY

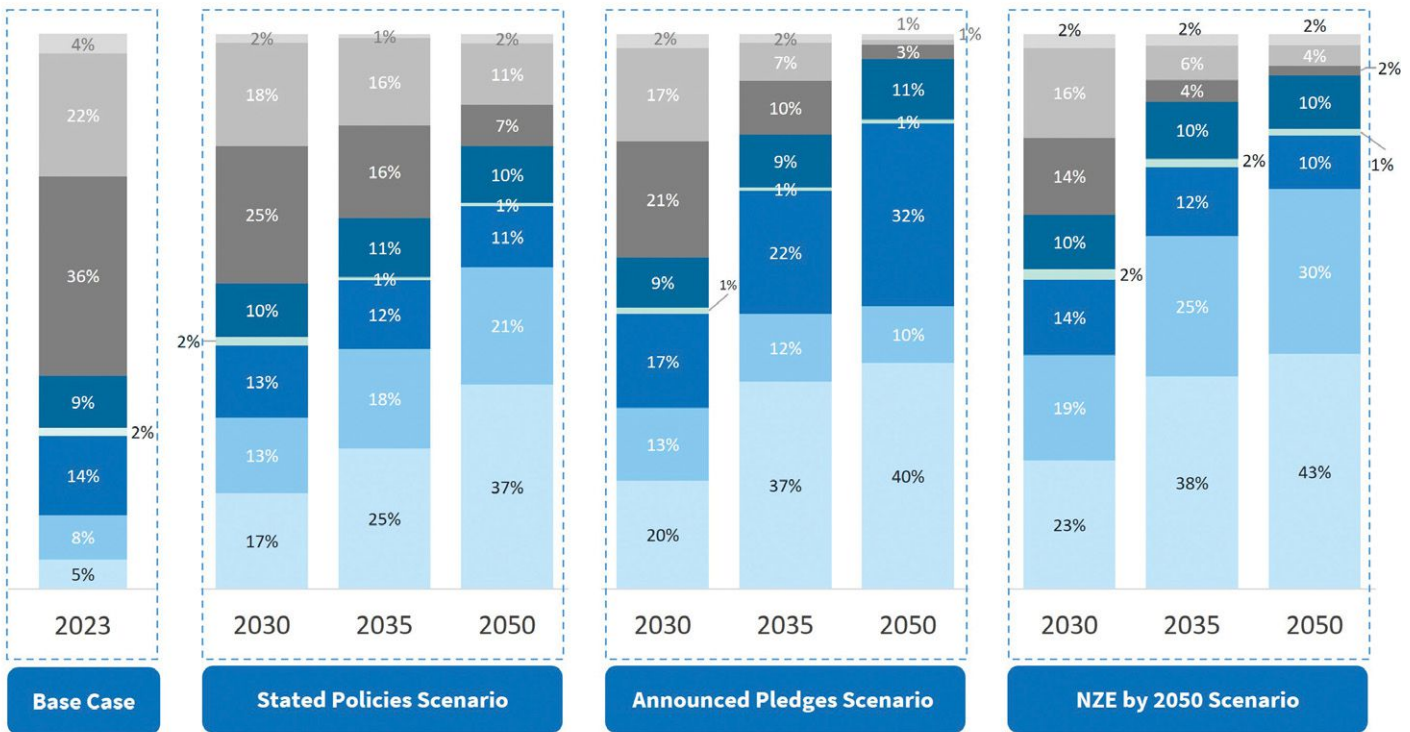
As electricity demand grows, the sources used to generate that power are also changing. Clean

Today, electricity accounts for roughly 20% of global energy consumption, with the majority still coming from liquid, gaseous, and solid fuels.

and renewable sources are projected to supply between 67 and 88% of global electricity by 2035, up from 38% in 2023 (Figure 2). This expansion is driven by a combination of government policy, energy security concerns, and improving economics for renewable technologies.

While the shift to clean power is essential, it introduces new challenges for grid stability. Variable generation from wind and solar requires more sophisticated protection, control, and coordination across the grid. For testing

**Share of Electricity Generation by Source by Scenario, TWh\***

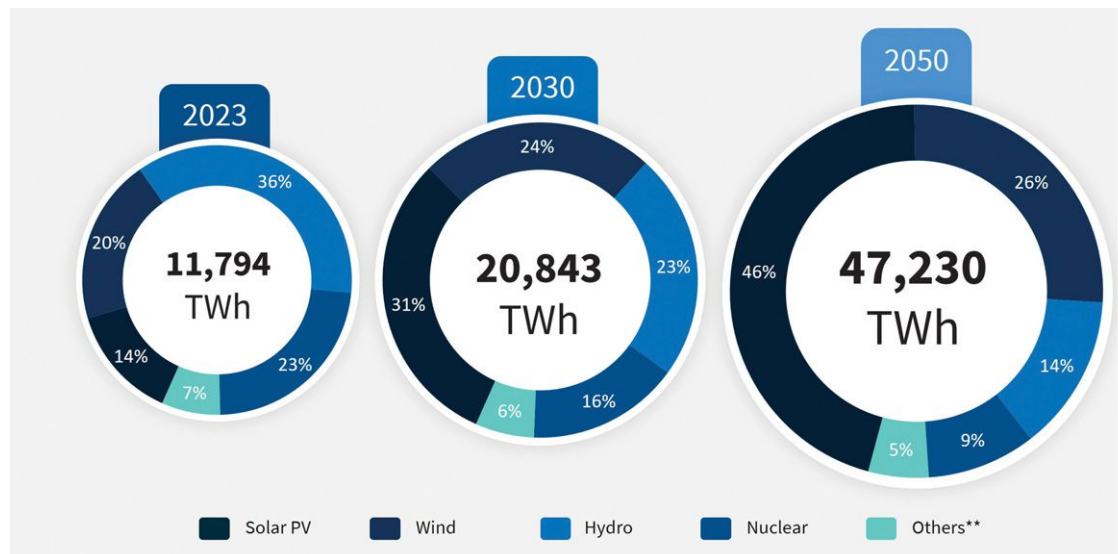


**Figure 2:** Shift from Traditional to Clean/Renewable Electricity Sources in Any Projected Scenario

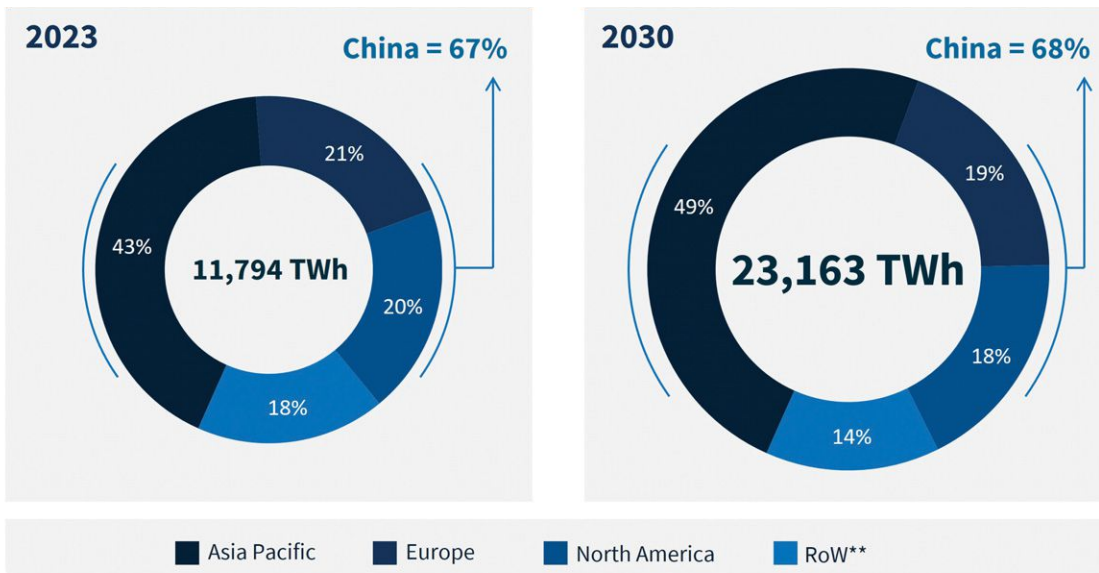
professionals, this means validating systems that must operate reliably under a wider range of load conditions, fault scenarios, and dynamic operating states than in traditional centralized generation models.

**SOLAR AND WIND DRIVE RENEWABLE GROWTH**

Solar photovoltaic (PV) will be the fastest-growing clean energy source, expanding from 14% of global clean electricity generation today



**Figure 3:** Solar GPV and Wind Expanding Share of Global Renewable Energy Sources



**Figure 4:** Clean Electricity Generation by Global Region

to more than 30% by 2030 and nearly 50% by 2050 (Figure 3). Wind power will also grow, reaching approximately 25% of clean generation and holding relatively steady beyond that point.

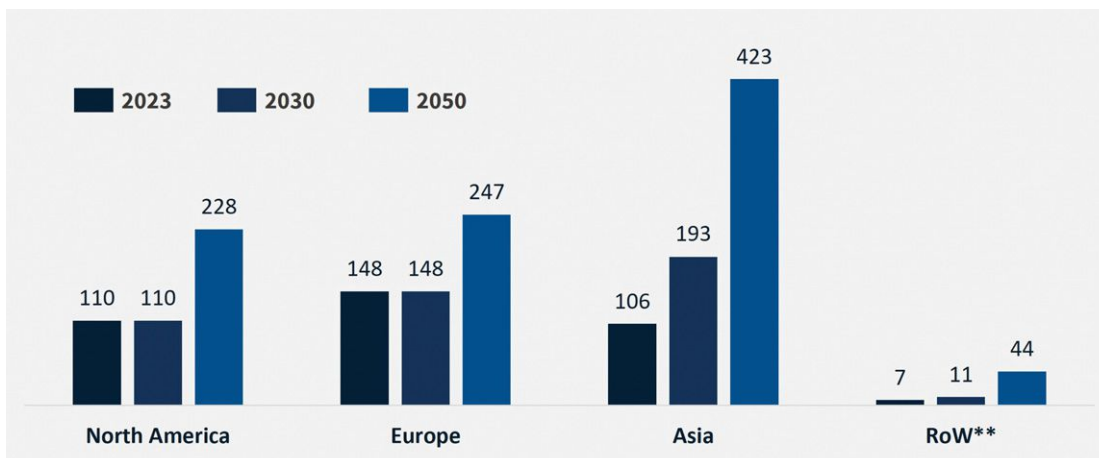
The rapid deployment of solar and wind is supported by declining costs and strong policy momentum, particularly in China and the European Union. However, these technologies are inherently intermittent. Their integration into both transmission-scale and behind-the-meter systems increases the importance of proper testing of inverters, protection schemes, grounding systems, and power quality controls.

### ASIA PACIFIC LEADS CLEAN ENERGY DEVELOPMENT

Geographically, the energy transition is not evenly distributed. By 2030, the Asia Pacific region will account for nearly half of all global clean electricity generation, with China alone representing more than two-thirds of that total (Figure 4).

The region is also projected to have nearly double the nuclear electricity-generating capacity of Europe or North America (Figure 5).

This concentration of investment reflects aggressive industrial growth, government



**Figure 5:** Nuclear Electricity Generating Capacity by Global Region

support, and long-term energy planning. It also underscores the global nature of equipment standards, testing methodologies, and best practices. As systems are deployed at scale in Asia and exported globally, alignment on testing rigor and performance validation becomes increasingly important.

## TECHNOLOGY AND POLICY AS ENABLERS

Achieving a cleaner global energy mix will require more than generation capacity. Battery energy storage systems, advanced energy management platforms, and grid modernization are all essential enablers (Figure 6). Storage systems help manage variability, while digital controls optimize dispatch, protection, and efficiency across increasingly complex networks.

Many electrical grids remain under-invested and were not designed for high penetrations of distributed and variable generation. As a result, significant capital investment and policy support will be required. From a testing standpoint, this creates demand for new skill sets, expanded commissioning scopes, and deeper system-level understanding rather than asset-by-asset testing alone.

## WHAT THIS MEANS FOR ELECTRICAL TESTING

The convergence of renewable generation, energy storage, and advanced control systems is fundamentally changing how power systems are designed and operated. These systems must function as integrated ecosystems rather than

### Battery/Storage Capacity



- Current battery storage technology is not sufficient; various newer and innovated technologies in consideration, including hydrogen storage and flow batteries
- Government regulation and incentives needed in short term to get new technologies off the ground and lower costs

### Grid Capacity & Resiliency



- Aging grid and related components, especially in transmission, cannot handle higher and more fluctuating loads in a future cleaner, more electrified world
- Investment in grid capacity and resiliency will be required; however, there are significant bottlenecks in new grid connection projects for renewables

### Energy Management



- Monitoring & controls for load balancing and management
- Hybrid, integrated systems including wind/solar plus storage to balance load
- Artificial Intelligence (AI) may have a significant role

“The cost of getting storage implemented cancels out value prop of solar. We get requests to price storage and more times than not, the costs are too high.”

- Executive Director, Renewables, Major Utility

“We don’t see LI ion as the longer-term solution. We’ve looked at flow batteries. The future will probably be a mix of LI ion, flow batteries, thermal storage, or hydrogen storage.”

- VP Global BD, Major Wind Manufacturer

“Queues are bottlenecked. There’s not enough supply to go around, but demand continues to increase. There are still supply chain constraints, still transmission constraints.”

- Executive Director, Renewables, Major Utility

“Majority of the circuits are 30-40 years old. As load increases and fluctuates, you must account for the transmission level to connect the load.”

- Sr. Power Systems Design Consultant

“How to balance and manage the variability of the resources is critical. You need smart management.”

- Sales Executive, Major Wind Manufacturer

“Next markets to be developed will be storage, grid, and energy management systems. That is where complex system integration will have to come as complexity increases in the grid.”

- VP Global BD, Major Wind Manufacturer

**Figure 6:** Key Analysis Findings to Enable a Clean Energy Future

isolated components, and each configuration can be highly customized.

Behind-the-meter and microgrid installations are a clear example. As utilities work through grid constraints and connection backlogs, large electricity users—including hyperscale data centers—are increasingly deploying on-site generation and storage to meet near-term power needs.

These systems often combine natural gas generation, solar PV, battery energy storage, and sophisticated energy management software.

Testing and commissioning these hybrid systems requires expertise across multiple technologies and operating modes. Electrical testing professionals must validate not only individual assets, but also system interactions, protection coordination,

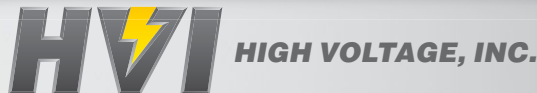
control logic, and response under abnormal conditions.

## CONCLUSION

As the energy transition accelerates, demand for electrical testing will continue to grow, both in volume and complexity. Firms that invest in technical capability, training, and system-level expertise will be well-positioned to support this next phase of grid evolution.



*Kevin G. Sarb is Managing Director at Ducker Carlisle, leading the Industrials Practice with a focus on energy, climate technologies, and commercial excellence. With 20 years of management consulting experience, he helps industrial clients design growth strategies and build commercial capabilities that deliver measurable results. Sarb holds degrees from the University of Notre Dame, the University of Michigan, and the University of Chicago Booth School of Business.*



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Computer control - wireless



80 kVdc Hipot/Megohmmeter  
1 instrument - 2 tests

# ELECTRIC VEHICLES: THE GLOBAL SHIFT TOWARD SUSTAINABLE TRANSPORT

BY KHALED SHADI MORSHED, *Commissioning Services International*

In today's world, electric vehicles are advancing rapidly, fueled by breakthroughs in battery technology, increasing global awareness of environmental sustainability, and national efforts to reduce dependence on fossil fuels and lower carbon emissions. As a result, electric vehicles are becoming a key solution for the future of global transportation.

The urgency for cleaner transportation has never been greater. Rising pollution levels and the environmental impacts of conventional fuel consumption make sustainable alternatives essential. Electric vehicles offer not only a greener mode of transport but also a quieter, smoother driving experience and lower long-term operating costs, positioning them as both practical and strategic choices for modern mobility.

The concept of electric vehicles is not new. In 1880, British engineer Thomas Parker introduced one of the first practical electric vehicles, demonstrating that electricity could serve as a clean and efficient alternative to internal combustion engines. His pioneering work laid the foundation for the electric mobility we see today.

## THE IMPORTANCE OF ELECTRIC VEHICLES

The world today is striving to reduce carbon emissions from various sectors, with the transportation sector bearing a significant responsibility in addressing this issue due to its high levels of greenhouse gas emissions. This has prompted countries to adopt sustainable solutions, primarily the expansion of electric transportation.

The importance of electric vehicles lies in their role as a key solution to the environmental challenges associated with the transportation sector. They contribute effectively to reducing carbon emissions and air pollution, in addition to their high energy efficiency compared to conventional vehicles. These vehicles also help



*Excursion in a 19th-Century Motorized Carriage Cab*



ILLUSTRATION: © WWW.SHUTTERSTOCK.COM/G/ELNUR

reduce reliance on fossil fuels and support the transition to renewable energy sources, thus enhancing the long-term sustainability of transportation systems.

Low emissions are among the most prominent advantages of electric vehicles, as they produce significantly less greenhouse gases compared to gasoline or diesel cars. In Europe, studies indicate that electric vehicles emit between 17% and 30% less of these gases, which contributes to reducing the carbon footprint of the transportation sector and supports the achievement of the goal of reducing carbon dioxide emissions from cars by 55% by 2030.

In September 2023, the European Commission published a draft document outlining the impact of conventional and electric vehicles on

carbon emissions. The document focuses on the potential of e-fuels to reduce greenhouse gases, noting that they currently reduce emissions by 70% compared to conventional fuels. Analysis indicates that gasoline-powered cars will emit approximately 61 grams of CO<sub>2</sub> equivalent per kilometer by 2035, while electric vehicles will produce only about 13 grams when fully charged, making them the more environmentally friendly option.

## **THE MARKET FOR ELECTRIC VEHICLES**

The global electric vehicle market has undergone a significant transformation in recent years, driven by a growing interest in environmentally friendly solutions and a shift away from fossil fuels. This shift is attributed to several factors, most notably technological



advancements in battery systems, the expansion of charging networks, and government initiatives to support the adoption of electric vehicles. Furthermore, increased consumer awareness regarding the importance of reducing carbon emissions has prompted manufacturers to expand their electric vehicle production lines to meet rising demand.

electric vehicles, more than the total global sales just two years earlier.

In Europe, sales growth slowed slightly due to the reduction or removal of subsidies in several countries, while EU CO<sub>2</sub> emission targets for vehicles remained unchanged between 2023 and 2024.

Meanwhile, electric vehicle sales in the United States continued to rise, although the growth rate dropped to about a quarter of the previous year's level.

Outside these three major markets, however, EV sales experienced strong momentum, increasing by nearly 40% to reach 1.3 million vehicles, approaching the U.S. total of 1.6 million electric vehicles.

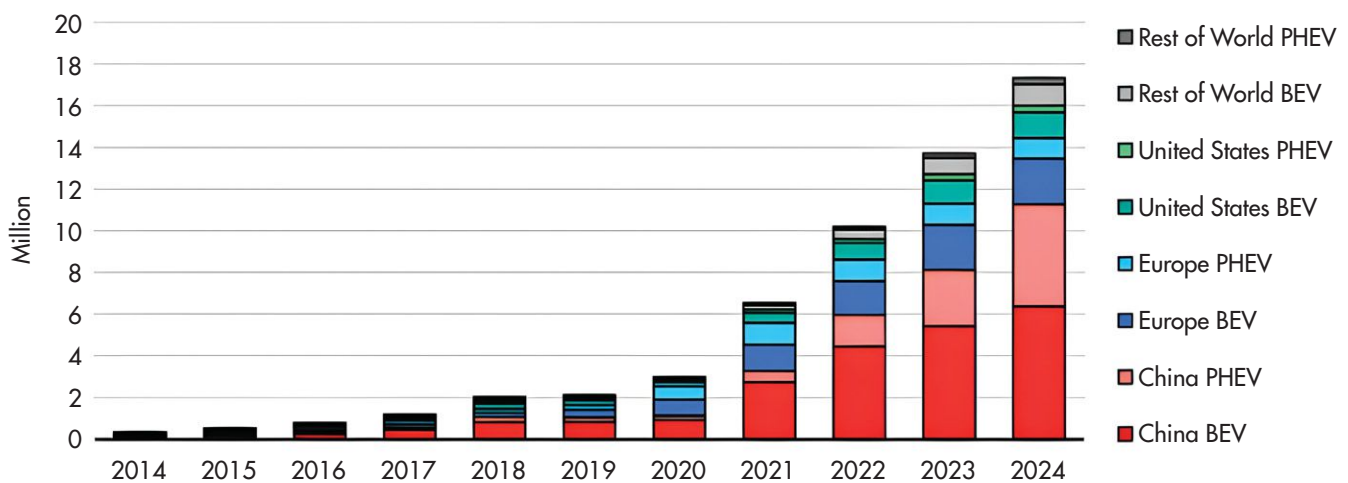
## THE GLOBAL ELECTRIC VEHICLE MARKET HAS UNDERGONE A SIGNIFICANT TRANSFORMATION IN RECENT YEARS, DRIVEN BY A GROWING INTEREST IN ENVIRONMENTALLY FRIENDLY SOLUTIONS.

In the International Energy Agency's 2024 annual report, global electric vehicle sales surpassed 17 million units, reflecting an increase of more than 25% compared to the previous year. Notably, the additional 3.5 million vehicles sold in 2024 alone exceeded the total global EV sales recorded in 2020.

China maintained its leadership among major markets, with sales exceeding 11 million

### LEADING NATIONS IN EV ADOPTION

One of the most important reasons for the increasing growth in electric vehicle adoption is the role of governments through supportive regulations and policies. These include tax incentives and the development of charging infrastructure.



Notes: BEV= battery electric vehicle; PHEV = plug-in hybrid vehicle. Includes new passenger cars only.  
Sources: IEA analysis based on country submissions and data from the European Automobile Manufacturers Association (ACEA), European Alternative Fuels Observatory (EAFO), EV Volumes and Marklines. IEA\_ CC BY 4\_0.

**Figure 1:** Global Electric Car Sales 2014–2024



PHOTO: © ISTOCKPHOTO.COM/PORTFOLIO/3ALEXD

### *Electric Cars Charging*

#### **Norway**

Norway has achieved an unprecedented milestone in electric vehicle sales, bringing it a significant step closer to eliminating petrol and diesel cars from its new car market.

According to data from the Norwegian Traffic Information Council (OFV), electric vehicles accounted for approximately 95.9% of all new car registrations last year, with the figure rising to 98% in December alone, compared to 88.9% at the end of 2024.

Norway also set a new record for the number of new passenger cars registered, with 179,550 vehicles registered during the year, representing a 40% year-on-year increase and surpassing the previous record set in 2021. These figures reflect Norway's position, despite being an oil-producing nation, as a global leader in sustainable transportation.

#### **United Arab Emirates**

Public policy is a key element in driving the UAE's move towards electric mobility. The

**THE UAE HAS ALREADY CONVERTED 20% OF ITS FEDERAL GOVERNMENT VEHICLES TO ELECTRIC POWER AND INITIALLY SET A TARGET OF HAVING AT LEAST 30% OF PUBLIC SECTOR VEHICLES AND 10% OF ALL VEHICLES ON THE ROAD BE ELECTRIC OR HYBRID BY 2030.**

country has already converted 20% of its federal government vehicles to electric power and initially set a target of having at least 30% of public sector vehicles and 10% of all vehicles on the road be electric or hybrid by 2030. This target was supported by a range of incentives, such as free registration, free parking, and reduced charging and road tolls for electric vehicles.

In 2023, at the 28th Conference of Parties (COP28), the UAE announced that its 2050 goal is for 50% of all vehicles on the road to be electric or hybrid, along with tripling the country's renewable energy generation capacity.

## USA

The U.S. government directly supports the adoption of electric vehicles not only in the general market but also within government fleets. Through the Federal Energy Management Program (FEMP), federal agencies are provided with guidance and assistance for purchasing and installing electric vehicle charging equipment and electric vehicles, aiming to expand charging infrastructure and enhance energy efficiency in government fleets.

In the United States, the share of electric vehicles in total new car sales is still growing gradually. In 2025, electric vehicles accounted for approximately 7.9% of total sales; when considering both electric and plug-in hybrid vehicles, the share reached around 9.7%. At certain points in 2025, the share even reached 10.5% of total sales, indicating a clear increase despite strong competition from conventional vehicles.

infrastructure is a barrier to everyday use and long-distance travel; and technical challenges related to electricity grids, such as ensuring grid stability during peak hours and standardizing charging across different vehicles and outlets, remain.

The study indicated that overcoming these obstacles requires governments and manufacturers to expand support not only for the vehicles themselves but also for the supporting infrastructure and technologies to ensure that EVs become more accessible and appealing to consumers.

## CONCLUSION

Electric vehicles are no longer a futuristic concept; they are becoming an integral part of the global transportation landscape. Technological advancements, environmental concerns, and government policies have all contributed to their rapid development and adoption. From the pioneering work of Thomas Parker in the 19th century to the modern electric mobility initiatives in countries like Norway, the UAE, China, and the United States, it is clear that innovation and supportive regulations play a crucial role in shaping the future of transportation.

Despite this growth, several challenges remain, including high initial costs, range anxiety, insufficient charging infrastructure, and technical limitations in electricity grids. Addressing these obstacles will require coordinated efforts from governments, manufacturers, and consumers, not only to expand EV adoption but also to ensure sustainable energy use and environmental benefits.

Ultimately, electric vehicles represent a strategic pathway toward reducing carbon emissions, improving air quality, and achieving a more sustainable transportation system worldwide. As countries continue to implement supportive policies and as technology evolves, the shift toward electric mobility is poised to accelerate, paving the way for a cleaner and more efficient future. [NW](#)

**DESPITE GLOBAL GROWTH, SEVERAL CHALLENGES REMAIN, INCLUDING HIGH INITIAL COSTS, RANGE ANXIETY, INSUFFICIENT CHARGING INFRASTRUCTURE, AND TECHNICAL LIMITATIONS IN ELECTRICITY GRIDS.**

## CHALLENGES HINDERING THE SPREAD OF ELECTRIC CARS WORLDWIDE

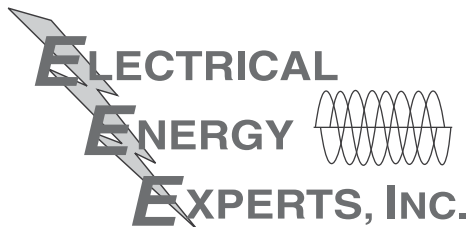
Despite the rapid global growth of electric vehicles (EVs), several key challenges hinder their widespread adoption. A study by the Massachusetts Institute of Technology (MIT) on the challenges of expanding EV adoption identified several major obstacles. Initial purchase costs remain high compared to conventional cars, primarily due to battery prices; some consumers worry about running out of battery charge before reaching their destination, especially in areas lacking charging stations; the lack of charging

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**Khaled Shadi Morshed** received his BEng. degree in Electrical Engineering from Balqa' Applied University, Jordan. He is currently working as an Electrical Engineer at Commissioning Services International (CSI), where he is involved in testing, commissioning, and power system analysis. Khaled is also a NETA Level 3 Certified Electrical Testing Technician, demonstrating his expertise in advanced electrical testing and commissioning procedures.



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*A N S W E R S*

1. **b. Nominal current.** Feeder breakers and main circuit breakers may fit the same cell but have different current ratings. Although cell interlocks sometimes prevent placing the wrong breaker in the cell, the single-line diagram will indicate the intended current rating and must be verified during commissioning.
2. **d. C classification.** For example, a C200 rating indicates that if the CT were producing 20 times nominal current, and the rated burden was connected to the terminals, it would be able to accomplish it by building 200 V across the terminals with a maximum 10% error. This ensures the CT has enough VA to measure large fault currents and reproduce them on the secondary circuit without saturating. This voltage is verified during the CT saturation test.
3. **b. Primary current injection.** By injecting a known amount of current through the CT primary, a technician can verify that the proper phase displays the amount of current on the relay or meter. This proves that the CT ratio, wiring, and relay programming are all correct. They may also prove the functionality of the CT isolator switch during the test.
4. **a. Percent impedance.** The transformer impedance is generally known before manufacturing; however, the measured impedance is usually stamped on the nameplate. The engineer may request this information so that it can be added to the drawing during commissioning activities. This value is used to calculate the maximum fault current the transformer can provide.
5. **b. Withstand.** During acceptance testing, a higher voltage is recommended to stress the cables more than during maintenance. This proves the insulation doesn't have any unacceptable deficiencies before initial energization, which can be covered by warranty. For maintenance, the intent is to ensure continued operation, but the voltage level and stress on the insulation are lower than during acceptance testing.
6. **c. Firmware version.** All others should be indicated accurately on the drawing. This includes the device(s) the relay trips, the name of the relay, and the ANSI device numbers, including active protection elements.
7. **d. Confirming the same manufacturer.** Sourcing a breaker and relay from different manufacturers is very common. However, primary current injections, functional trip checks, and schematic control checks all prove multiple items together as a system. [NW](#)



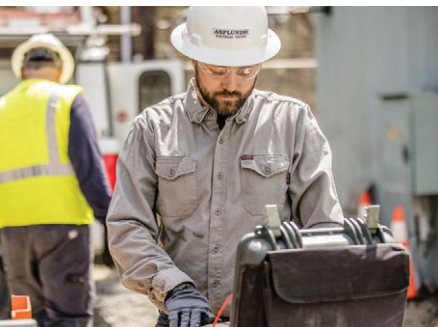
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- The Electrical Safety Immersion Experience delivers hands-on demonstrations featuring the latest electrical safety technologies to test and expand your knowledge.
- Covering 800 sq. ft. of the PowerTest26 Trade Show floor, this interactive zone features continuous safety demos with additional demos throughout the hall.
- Each demo includes a quick quiz that earns points toward your overall safety score.
- Track top performers on the Safety Immersion Leaderboard. The 1st, 2nd, and 3rd place winners take home cash prizes.



**CBS Arc Safe** — Arc-Safe Remote Racking Demo



**3M** — Cable Sensor Technology Demo



**Eaton** — Virtual Reality Training Demo

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- **Vector Power** — Safety Training
- **3M** — Cable Sensor Technology
- **IRISS** — IR Widows and System Monitoring Devices and Software
- **National Safety Apparel** — Electrical Safety PPE
- **Eaton** — Virtual Reality Training
- **CBS Arc Safe** — Arc-Safe Remote Racking Equipment
- **NETA** — Safety Corner Quiz
- **AVO Training** — NFPA 70 Electrical Safety Training
- **Schneider Electric** — Fault Detection Software
- **Eaton** — OT Cyber Security
- **OFIL** — UV Discharge Detection Technology and Software
- **EPS** — Virtual Reality Training

A nighttime city skyline with numerous skyscrapers illuminated. Overlaid on the scene are numerous vertical light trails in shades of blue, cyan, and magenta, creating a sense of digital connectivity and data flow. The trails vary in length and intensity, some appearing as thin lines and others as thicker, more prominent streaks.

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**EPIC26** — *The Electrical Power Innovations Conference*, hosted by NETA, offers a comprehensive, interactive, and future-focused experience—blending education, collaboration, innovation, and strategic insights geared specifically for power-sector professionals. It's an immersive environment to learn, connect, and lead in the evolving electrical power landscape.

The electrical power industry is undergoing a profound transformation driven by escalating power demand, technological advancements, regulatory changes, and the global push toward sustainability. In this dynamic environment, EPIC26 serves as a critical platform for professionals to stay ahead of the curve.

## A HUB FOR INNOVATION AND KNOWLEDGE

EPIC is designed to bring together thought leaders, engineers, manufacturers, power providers, and service suppliers to explore cutting-edge technologies shaping the future of power systems. From grid modernization and renewable integration to digitalization, AI, and cybersecurity, the conference addresses the most pressing challenges and opportunities in the power sector.

### Bridging Industry Silos

One of EPIC's most significant roles is fostering collaboration across traditionally siloed areas—operations, IT, and engineering. By creating an environment for open dialogue, the conference enables cross-sector partnerships that accelerate innovation and improve system reliability.

### Empowering the Workforce

With sessions focused on skill development, automation, and AI, EPIC equips professionals with the tools and knowledge needed to adapt to emerging technologies. This emphasis on workforce readiness ensures that the industry can meet future demands effectively.

### Networking and Collaboration

EPIC is not just about learning—it's about connecting. Attendees gain access to a diverse network of peers and experts, creating opportunities for collaboration that extend well beyond the conference.

In essence, EPIC plays a pivotal role in shaping the future of the electrical power industry by combining education, innovation, and strategic foresight. For professionals committed to driving progress, attending EPIC is not just an option—it's a necessity.



## Join Power Professionals for a meeting of minds...

- ▶ Knowledge-Sharing Symposiums
- ▶ Cutting-Edge Future-Focused Presentations
- ▶ Leadership Networking and Cross-Sector Collaboration
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## EPIC26 – The Future of Power

The electrical power industry is at a crossroads. Accelerating power demand, rapid technological advancements, evolving regulatory landscapes, and the global push toward sustainability are reshaping how power is generated, transmitted, and consumed. In this era of transformation, the NETA-hosted Electrical Power Innovations Conference (EPIC) stands as a vital forum for industry professionals to gain insights, share knowledge, and prepare for the future.

### DRIVING INNOVATION IN ELECTRICAL POWER

EPIC26 is more than a conference—it is a catalyst for innovation. The event brings together engineers, manufacturers, power providers, service suppliers, and thought leaders to explore emerging technologies and strategies that will define the next decade of power system management. Topics such as grid modernization, renewable integration, digitalization, AI, and cybersecurity dominate the agenda, ensuring attendees leave with actionable knowledge.

By focusing on cutting-edge solutions, EPIC26 empowers organizations to adapt to challenges like power reliability, aging infrastructure,

increasing demand for clean energy, and the complexities of distributed generation. These discussions help attendees identify opportunities for growth and resilience in a rapidly changing market.

## **Bridging Industry Silos**

One of EPIC's most significant contributions is its ability to break down silos within the industry. Traditionally, operational technology (OT) and information technology (IT) have operated in separate spheres. EPIC fosters collaboration between these domains, creating a unified approach to power system management. This integration is critical as utilities and service providers embrace smart grids, IoT-enabled devices, and advanced analytics.

Through expert presentations, interactive panels, and workshop discussions, EPIC encourages dialogue that leads to practical solutions. Attendees gain insights not only from experts but also from peers facing similar challenges, making the conference a hub for collective problem-solving.

## **Strategic Insights for Long-Term Success**

Beyond technical expertise, EPIC offers strategic perspectives that help power professionals and organizations plan for the future. Sessions delve into emerging

technologies, market trends, regulatory developments, and economic forecasts, equipping attendees with the knowledge needed to make informed decisions. Whether it's understanding the impact of smart grid technology, renewable mandates, or preparing for workforce evolution, EPIC provides a roadmap for navigating uncertainty.

Industry leaders share best practices on capital investment, research and development, and service expansion. These insights are invaluable for executives and managers tasked with steering their organizations through periods of disruption and growth.

## **Empowering the Workforce**

The electrical power sector faces a pressing challenge: workforce readiness. As automation, artificial intelligence, and digital tools become integral to operations, professionals must acquire new skills to remain relevant. EPIC addresses this need through sessions focused on training, skill development, and workforce planning.

By highlighting strategies for attracting and retaining talent, EPIC ensures that organizations can build teams capable of meeting future demands. This emphasis on human capital complements the conference's technical content, creating a holistic approach to industry advancement.



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## Networking and Collaboration Opportunities

EPIC is not just about learning—it's about connecting. The conference attracts a diverse audience, including standards development organizations, equipment manufacturers, utilities, engineering firms, investment groups, and service and testing agencies. This diversity

creates opportunities for partnerships that extend beyond the event itself.

Networking sessions, informal meetups, and collaborative workshops allow attendees to forge relationships that lead to joint ventures, research collaborations, and business development. In an industry where innovation often depends on cooperation, these connections are invaluable.

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NETA is pleased to host the EPIC Conference with a clear purpose: to bring together stakeholders from across the electrical power ecosystem and foster collaboration with the goal of shaping the future of the power industry. Please plan to join NETA and your future-focused colleagues for an EPIC event! [NW](#)

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## 51 CORNERSTONE

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## ABM

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Booth 208

### RavenVolt

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The electrical testing industry is rapidly evolving as microgrids and battery storage become essential for resilience and energy independence. ABM is expanding to meet this demand through key acquisitions. RavenVolt, a leader in turnkey microgrid solutions, integrates solar,

storage, and generation to deliver reliable, efficient power for commercial clients. Their capabilities strengthen ABM's role in supporting advanced energy infrastructure. We also recently acquired QUS, a UPS and battery services company, enhancing our technical expertise in critical power and complex battery systems. Together, these additions position ABM to better serve our clients across the changing power and testing landscape.

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## AEMC INSTRUMENTS

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CBS ArcSafe, a Group CBS company, introduces the RSK-CSH-W Chicken Switch Hitter, a wireless remote switching kit for dual-pushbutton and control switch applications. The device enables operators to safely perform multiple switching tasks with a single tool from up to 100 feet away, outside the arc flash boundary. It magnetically attaches to switchgear with no equipment modifications or downtime required. An integrated laser alignment system, motor, and dual adjustable linear actuators ensure precise, reliable operation across equipment from multiple OEMs, including ICCB, ACB, VCB, and MCC applications.

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Booth 903

and the HIPODirect mobile app, compatible with view-share-upload reports. This is the most accurate current measurement and guard circuit designed to eliminate stray leakage currents.

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The SPI2000 is a highly portable high-current test set that can deliver up to 20,000 amps. The main unit can test a 600-amp breaker by itself, and boosters can be added to test up to 2000-amp breakers. The SPI2000 will provide more compliance voltage and current than any other test set in this category. The test set can be used in manual mode or in automatic mode, where you enter a current, and the test set finds the current and runs the test.

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### OFIL DayCor Luminar X

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OFIL DayCor Luminar X is a high-performance ultraviolet (UV) camera designed for corona partial discharge detection in electrical utilities, transmission and distribution networks, substations, switchgear, rotating machines, and more. Engineered with enhanced sensitivity, Luminar X enables reliable inspections at long distances of up to 700 ft, reducing the need for close proximity to energized equipment and improving operator safety during substation and powerline inspections. The camera combines solar-blind UV detection with a high-resolution visible channel to support accurate

fault detection and pinpointing. When integrated with the Gridnostic software platform, Luminar X supports structured data organization, efficient post-inspection analysis, and streamlined reporting across the full inspection lifecycle.

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## OMICRON

*omicronenergy.com*

Booth 103

### CPX200

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The CPX200 is OMICRON's innovative new multifunctional test set designed for electrical maintenance and acceptance testing. Combining multiple commonly used tests into a single lightweight (65 lbs total) and highly portable platform, the CPX200 simplifies service provider workflows while improving efficiency and ease of use. The CPX200 can test transformers, circuit breakers, and instrument transformers, and serves as a highly capable current-injection test set. Built with the needs of service providers in mind, the CPX200 delivers powerful field performance through an integrated hardware and software ecosystem, marking a key industry innovation.

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## POWER MONITORING AND DIAGNOSTIC TECHNOLOGY LTD. - PMDT

*powermdt.com*

Booth 220

### PMDTiSmart Series Intelligent Wireless Online Partial Discharge Monitoring System

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Is the operational reliability and insulation condition of your power assets well tracked? PMDTiSmart delivers the solutions. PMDTiSmart is a wireless, easy-deployment, real-time online monitoring solution for substations. The smart TUT (TEV/Ultrasonic/Temperature), UHF, HFCT, and AE sensors feature low power consumption and fast, non-intrusive installation with no shutdown required. Combined with cloud-based diagnostics and flexible local or remote access, PMDTiSmart identifies partial discharge (PD) risks early, protects assets, reduces outages, and significantly lowers maintenance costs.

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## PROGUSA

[progusa.net](http://progusa.net)

Booth 720

### DV Power Handheld and Portable Test Instruments — New for 2026

---

DV Power is expanding its portable test lineup with six new handheld instruments designed for field crews that need speed, accuracy, and long battery life. New offerings include a three-channel circuit breaker and coil timer with advanced PC software, a 300-A micro-ohmmeter with all-day Li-Po battery operation, and a compact WRT/TTR combo unit for transformers up to 8 MVA. Also featured are a new 250-VAC, 25-A winding resistance tester and the CVA500 portable CT/PT/CVT test set with automatic tap sequencing and IEEE/IEC-based measurement methods.

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## QUALUS

[qualuscorp.com](http://qualuscorp.com)

Booth 1003

### QualU training

---

Qualus is excited to share what's happening in 2026 at the New Product Forum. We are a NETA Administratively Approved Provider, which means you can get your NETA credits with Qualus University Training in 2026 and beyond. We're also announcing a special seminar giveaway at the forum, but you must be present to win. To top it off, we'll showcase both of our training centers, and you can design your very own custom trucker hat with us and Rancher Hat Bar at Booth 1003.

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## RAYTECH

[raytechusa.com](http://raytechusa.com)

Booth 626

### Raytech TR4

---

The Raytech TR4 is the next generation successor to the TR-Mark III 250V, three-phase ratiometer. Features include advanced diagnostics like frequency response of stray losses (FRSL) and short circuit impedance, fully integrated into one portable instrument. The TR4 supports phase-shifting

transformer testing and requires only a single test setup. Measurements are performed using an internally generated, adjustable test voltage of up to 250 VAC. The TR4 offers flexible power options, operating on either line voltage or an external power bank. Integrated tap control enables automated test sequences make it well-suited for field and laboratory transformer diagnostics.

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## UTILITY RELAY COMPANY

[utilityrelay.com](http://utilityrelay.com)

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---

Utility Relay Company is proud to introduce AC-PRO-ML®, our direct replacement trip-unit modernization kit for the Schneider MasterPact NW, NT, NS, PowerPact, and ComPact families of LV circuit breakers. Reuse existing sensors and simply replace Micrologic with AC-PRO-ML. Ratings plugs and add-on modules are no longer needed. All the features and convenience you've come to depend on from AC-PRO will now be available as a direct replacement Micrologic upgrade. Modernize your future with AC-PRO. Simply.

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## VOYTEN ELECTRIC

[VoytenElectric.com](http://VoytenElectric.com)

Booth 209

### RL and SPB Breakers

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## INRUSH ELECTRICAL TECHNOLOGY RECOGNIZED AS NETA ACCREDITED COMPANY



Inrush Electrical is a North America-based electrical engineering and technical field services firm specializing in power system studies, protection and control, SCADA, and automation. Inrush supports utilities, data centers, oil and gas, renewables, and industrial clients with end-to-end solutions. Inrush delivers reliable, defensible results aligned with NETA, NERC, and utility best practices.

Inrush believes in a vendor-neutral approach to client problems and strives to provide best-in-class engineering solutions. With core competencies in power system studies, major equipment, P&C, and SCADA design and

development, Inrush can take a project from concept to completion, providing a full turn-key solution.

Inrush provides NETA-aligned commissioning, acceptance testing, maintenance, and troubleshooting of low-, medium-, and high-voltage systems. A key differentiator is Inrush's in-house protection and control and SCADA laboratory, used for relay configuration validation, end-to-end protection scheme testing, and communications engineering. The lab supports IEC 61850 system design and testing, including GOOSE messaging, MMS, time synchronization, and network architecture

validation, as well as SCADA protocol simulation. This controlled environment enables factory-style testing, mis-operation analysis, and realistic training scenarios prior to site deployment, reducing field risk and improving overall system reliability.

“Being a NETA Accredited Company means our testing and commissioning practices meet the highest independently verified industry standards. For utilities, data centers, and industrial facilities, it provides confidence that safety, reliability, and accuracy are built into every test, every report, and every decision affecting critical electrical infrastructure,” states Ankur Trigunayat, VP Corporate, Inrush Electrical

“NETA extends a warm welcome to Inrush Electrical Technology Ltd,” says Dan Hook, President of CBS Field Services and current NETA President. “We applaud the important role our NETA Accredited Companies play in advancing the electrical power systems industry and its safety. Achieving NETA accreditation is indicative of Inrush’s accomplishments as an organization.” [NW](#)



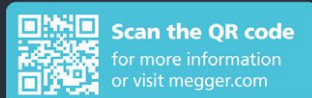
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## MID-CITY ELECTRIC TECHNOLOGIES JOINS NETA'S QEMC PROGRAM LEADERS



NETA is pleased to welcome Mid-City Electric/Technologies as a Qualified Electrical Equipment Maintenance Company (QEMC). The company achieved certification by participating in NETA's new Qualified Electrical Equipment Maintenance Company (QEMC) and Qualified Electrical Equipment Maintenance Worker (QEMW) programs, launched in 2024 to respond to new requirements for electrical equipment maintenance based on NFPA 70B-2023®, *Standard for Electrical Equipment Maintenance*®. The new requirements make proper electrical equipment maintenance mandatory and enforceable.

Mid-City Electric offers comprehensive electrical and tele-data service, specializing in new construction and service work across commercial, healthcare, data center, and industrial markets. Mid-City has one of the largest electrical service departments in

Columbus, with more than 20 estimators and project managers and over 600 field staff.

Headquartered in Westerville, Ohio, Mid-City serves Columbus and the surrounding area and is looking to expand. "I believe recognition as a QEMC will become a benchmark that customers actively seek for preventative maintenance—just as they rely on NETA-certified contractors for their testing needs," says Service Operations Manager Chris Lang. "This certification reinforces our core value of being customer-focused," he continues. "By proactively pursuing and earning this certification early in its introduction to the market, we demonstrate our commitment to prioritizing our customers' best interests and safety above all else. We take pride in delivering exceptional service and ensuring our customers' facilities are cared for by the most highly trained technicians in the industry."

A trusted partner in the Central Ohio community, Mid-City has been a family-owned business for more than 65 years and has recently transitioned to an employee-owned company. Treating people like family is a principle they live out every day with their employees and customers, and the company is often rewarded for its values. In 2025, CEO Brian Dew was honored with a Fellowship in the Academy of Electrical Contracting at the 2025 NECA convention. He also received the 2025 Builder's Exchange Cornerstone Award. Formerly known as the Man of the Year award, this honor originated in 1954 and was developed to recognize a prominent industry professional who exemplifies outstanding service and commitment to the local construction community. Mid-City's James Dew won this award in 2006.

"NETA is proud to recognize Mid-City Electric/Technologies as a new NETA Qualified

Electrical Equipment Maintenance Company (QEMC)," says Chasen Tedder, NETA QEMC and QEMW Committee Chair. "NETA QEMC-recognized service providers are ensuring their Qualified Electrical Equipment Maintenance Workers (QEMWs) align with new NFPA 70B requirements and lead the way in meeting the growing demand for electrical power system maintenance services." [NW](#)



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## C&H ELECTRIC RECOGNIZED AS QUALIFIED ELECTRICAL EQUIPMENT MAINTENANCE COMPANY



NETA has named C&H Electric as a Qualified Electrical Equipment Maintenance Company (QEMC). The company achieved certification by participating in NETA's new Qualified Electrical Equipment Maintenance Company (QEMC) and Qualified Electrical Equipment Maintenance Worker (QEMW) programs, launched in 2024 to respond to new requirements for electrical equipment maintenance based on NFPA 70B-2023®, *Standard for Electrical Equipment Maintenance*®. The new requirements make proper electrical equipment maintenance mandatory and enforceable.

Headquartered in Waterbury, Connecticut, C&H Electric has been serving critical facilities across the state since 1967. The company focuses on environments where reliability, safety, and uptime are essential, including major healthcare systems and hospitals, manufacturing and industrial facilities, and higher education, laboratory, and research institutions.


C&H Electric joined NETA as a QEMC as part of its long-term mission to become the employer of choice for electricians in Connecticut. That mission is built on three core pillars: providing strong career advancement opportunities, long-term stability, and meaningful work that contributes to the community. By building out its electrical maintenance and testing capabilities and aligning with the leading, standards-driven organization in the industry, C&H is creating new technical career paths for its teammates while strengthening the company's ability to deliver reliable, recurring services to its customers.

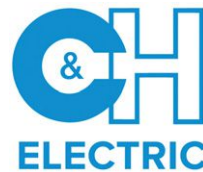
"Association with NETA and participation in the QEMC program allows us to continue growing our technical skillsets and service capabilities," said Bill Concannon, Principal of C&H Electric. "That directly supports our people by creating long-term career opportunities, supports our customers by improving uptime and safety, and supports our

communities by strengthening the reliability of critical facilities.”

C&H Electric’s current maintenance and testing services include infrared thermography, ultrasonic testing, updates to electrical one-line diagrams, arc flash hazard analysis, NFPA 70E training and consulting, and auditing and development of electrical safety programs and electrical maintenance plans. These services help customers improve safety, reduce unplanned downtime, and maintain compliance with evolving industry standards.

Recognized as a mission-critical commercial electrical contractor, C&H Electric specializes in the design, construction, and maintenance of electrical distribution systems. The company’s project and service teams work closely with facility owners, engineers, and general contractors to deliver solutions that prioritize reliability, compliance, and long-term system performance.

“NETA is proud to recognize C&H Electric as a new NETA Qualified Electrical Equipment Maintenance Company (QEMC),” says Chasen Tedder, NETA QEMC and QEMW Committee Chair. “NETA QEMC-recognized service providers have ensured their Qualified Electrical Equipment Maintenance Workers (QEMWs) align with new NFPA 70B requirements. C&H and the other QEMC companies lead the way in meeting the growing demand for electrical power system maintenance services.” 



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## COGBURN ELECTRIC NAMED QUALIFIED ELECTRICAL EQUIPMENT MAINTENANCE COMPANY



From humble beginnings in 1975, Cogburn Electric has grown into a trusted name in specialized electrical contracting. For five decades, they have powered industries, illuminated communities, and energized innovation with precision and pride for five decades, leaving a 50-year legacy of excellence in general contracting.

Founded on the principles of quality workmanship and exceptional customer service, Cogburn's electrical contracting business has grown to become a thriving enterprise. Their unwavering dedication to serving their clients, community, and team members remains at


the forefront. From going the extra mile to ensure customer satisfaction to creating a positive work environment for team members, Cogburn is committed to excellence.

Cogburn's core values are to lead with compassion and respect for others; utilize integrity and professionalism in all they do, and value going the extra mile. Since its first day in business in 1975, the company has made relationships and integrity its signature art. Voted the best of Marion 2024 for electricians, Cogburn has a passion for helping people. "Our core focus is to provide the best electrical services we can to our clients, and

we're confident we have the experience needed to help you get your system back up and running," explains President Scott Ruth.

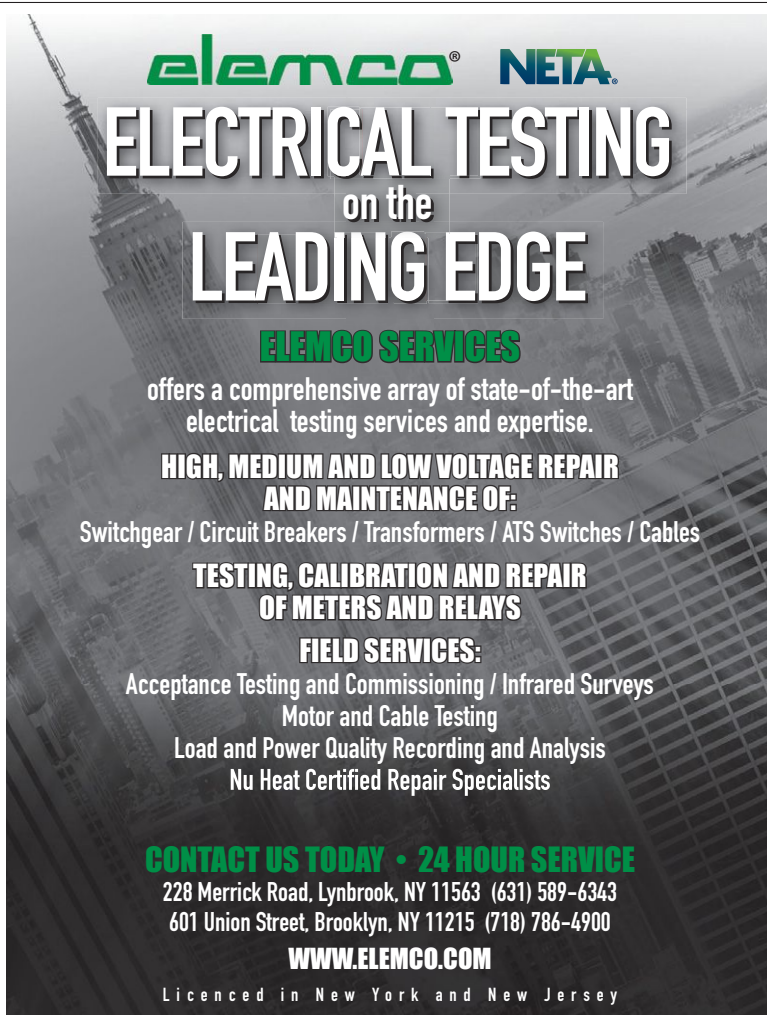
"It is our honor to officially become a QEMC contractor and help support NETA contractors and our clients with compliance in the NFPA 70B space," Ruth continues.

"NETA is proud to recognize Cogburn Electric as a new NETA Qualified Electrical Equipment Maintenance Company (QEMC)," says Chasen Tedder, NETA QEMC and QEMW Committee Chair. "NETA QEMC-recognized service providers are ensuring their Qualified Electrical Equipment Maintenance Workers (QEMWs) align with new NFPA 70B

requirements and lead the way in meeting the growing demand for electrical power system maintenance services." 



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# ANSI/NETA STANDARDS UPDATE

## ANSI/NETA ETT-2026 STANDARD REVISION APPROVED

The revision of ANSI/NETA ETT-2022, *Standard for Certification of Electrical Testing Technicians*, was approved by the American National Standards Institute (ANSI) on December 1, 2025. The updated edition of ANSI/NETA ETT-2026 is scheduled for release at PowerTest 2026 and replaces the 2022 edition. 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.

## ANSI/NETA EMW-2026 NEW STANDARD APPROVED

ANSI approved 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.



# SPECIFICATIONS AND STANDARDS ACTIVITY

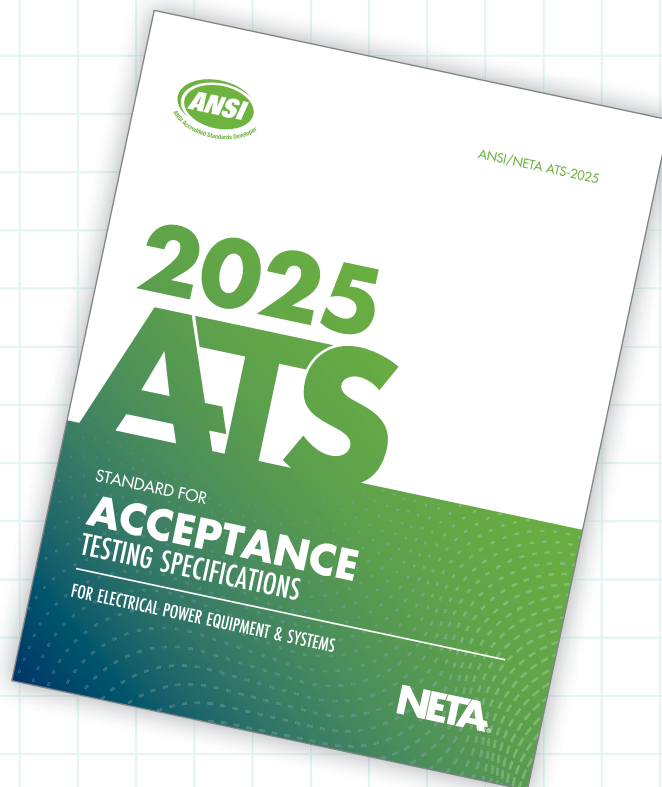
Key updates in the 2023 edition included a comprehensive overhaul of the Cables section and the introduction of a new section addressing Electric Vehicle Charging Systems, reflecting evolving technologies and industry needs. ANSI/NETA MTS-2023 is available for purchase at the NETA Bookstore at [www.netaworld.org](http://www.netaworld.org).



## ANSI/NETA MTS-2023 REVISION UNDERWAY

The next revision cycle for ANSI/NETA MTS-2023, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*, is underway. To support this process, the NETA Standards Review Council will convene a series of working groups composed of subject matter experts from across the industry. These working groups are to pilot a new approach to early-stage comment review. This beta initiative will also serve to refine procedures in preparation for the upcoming revisions of other ANSI/NETA standards. The ballot pool canvassing process begins in the Spring of 2026.

ANSI/NETA MTS-2023 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.



## ANSI/NETA ATS-2025

ANSI/NETA ATS-2025, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*, received formal approval from the American National Standards Institute (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.

# SPECIFICATIONS AND STANDARDS ACTIVITY

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

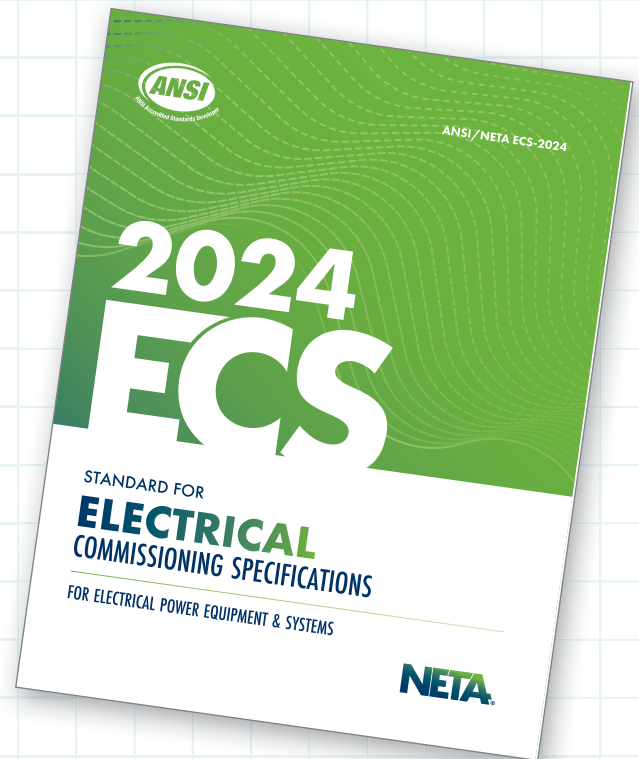
A notable revision in ANSI/NETA ATS-2025 is found in Section 7.4.D.2.a-b., Metal-Enclosed Busways. This update introduces separate formulas for low-voltage and medium-voltage systems and replaces the previous nominal 1,000-foot run length with the actual busway length in feet, enhancing the applicability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

ANSI/NETA ATS-2025 is available for purchase through the NETA Bookstore, offered in bound print, PDF download, and a Redline PDF (with all changes highlighted) download.

## 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). [NW](#)

## 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](http://www.netaworld.org). To get involved, recommend revisions, or be considered for ballot pools, please visit <https://www.netaworld.org/standards/standards-development> or contact the NETA office at 888-300-6382.



ANSI/NETA EMW-2026

# 2026 EMW



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# 2026 ETT



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- Updated Detailed Content Outline (DCO) for Levels 2-4
- Minor changes to Training Requirements

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# IEEE PES ICC COMMITTEE REPORT

BY CHASEN TEDDER, *Hampton Tedder Technical Services*

The IEEE Power and Engineering Society (PES) Insulated Conductor Committee (ICC) met on October 26–29, 2025, in Amelia Island, Florida.

The IEEE Power and Engineering Society (PES) Insulated Conductor Committee (ICC) creates standards for low-, medium-, and high-voltage power distribution cables. NETA's ANSI/NETA standards heavily reference the IEEE standards to provide guidance on voltage test levels, durations, and acceptable criteria.

It is important not only to stay up to date on the latest changes and know when the changes are coming, but also to guide the IEEE documents to incorporate more of a field perspective on how and when to perform the testing.

### IEEE 400.0

- IEEE 400.0 (omnibus) was just published two years ago; there were no meetings this time.
- IEEE 400.1 (DC testing PILC) was discussed, outlining that it will continue. There were a couple of presentations on IEEE 400.2 (VLF), which was released last year.
- IEEE 400.2 (VLF) will begin the process of a rewrite next year. The version recently passed was reaffirmed to ensure it didn't expire.

- 400.3 (offline PD) did not have a meeting.
- 400.4 (DAC) is in the process of active revision and needs to ballot by next year. The committee is actively reviewing this document amid a lot of test equipment manufacturer influence. There is a lot of discussion regarding DTS, DAS, and DSS, which monitor temperature, acoustics, and strain on power cables in real time. Real-time monitoring seemed to be a big topic.

### Other Topics

Interest was gauged for a new standard on the diagnostic testing of terminations and joints. The group discussed whether another document is needed to provide an overview of other test methods.

### Action Items

No follow-up actions are required. Consistent participation to allow for voting would help.

The IEEE PES ICC Committee's next meeting is April 27–29, 2026. [NW](#)



*Chasen Tedder is an Electrical Field Engineer at Hampton Tedder Technical Services. In addition to acting as a Principal on the IEEE PES ICC Committee, he is the 1st Vice President on NETA's Board of Directors and serves on the Membership Application Review Committee, Conference Committee, and Standards Review Council.*

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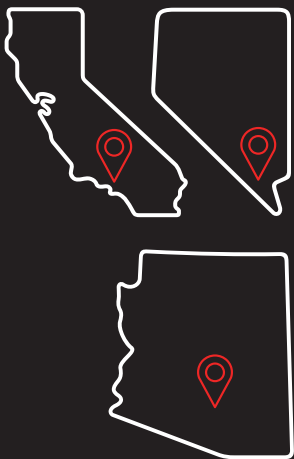
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United States of America  
(832) 467-4446

## **Accessible Consulting Engineers, Inc.**

- www.acetesting.com*
- Irvine, CA 92618-3201  
United States of America  
(951) 808-1040
  - Corona, CA 92882-7158  
United States of America  
(951) 808-1040
  - Edmonton, AB T6E 0P5  
Canada  
(403) 697-3747

## **Advanced Testing Systems**

- www.advtest.com*
- Bethel, CT 06801-2858  
United States of America  
(203) 743-2001

## **Alpha Relay and Protection Testing, LLC**

- www.arptco.com*
- Billings, MT 59102-7460  
United States of America  
(406) 671-7227

## **AMP Quality Energy Services, LLC**

- www.ampqes.com*
- Decatur, AL 35601  
United States of America  
(256) 513-8255
  - Nashville, TN 37210-2125  
United States of America  
(629) 213-4855

## **Apparatus Testing and Engineering**

- www.apparatus-testing.com*
- Rancho Cordova, CA 95742-6822  
United States of America  
(916) 853-6280
  - Pleasanton, CA 94588-8017  
United States of America  
(916) 853-6280

## **Applied Engineering Concepts**

- www.aec-us.com*
- Pasadena, CA 91103-3046  
United States of America  
(626) 389-2108
  - San Diego, CA 92126  
United States of America  
(619) 822-1106
  - Quebec, QC G1V 0B9  
Canada  
(800) 398-3052

## **ARM CAMCO, LLC**

- www.armcamco.net*
- Ebensburg, PA 15931-4111  
United States of America  
(814) 472-7980

## **Asplundh Electrical Testing, LLC**

- www.asplundhtesting.com*
- Foxboro, MA 02035-2873  
United States of America  
(781) 821-0121
  - South Windsor, CT 06074-2931  
United States of America  
(860) 648-1013
  - Baltimore, MD 21227-1564  
United States of America  
(717) 804-7808
  - Boonton, NJ 07005-1942  
United States of America  
(973) 316-1180
  - Brentwood, NY 11717-1265  
United States of America  
(631) 617-5330
  - Allentown, PA 18104-9158  
United States of America  
(484) 538-2272
  - Croydon, PA 19021-6051  
United States of America  
(215) 826-9400

## **BEC Testing**

- www.bectesting.com*
- Farmingdale, NY 11735-1402  
United States of America  
(631) 393-6800

## **BIC Switchgear Services, Inc.**

- www.bicswitchgear.com*
- Irondale, AL 35210-1210  
United States of America  
(205) 951-5455

## **Blue Runner Switchgear Testing, LLC**

- www.bluerunnerswitchgear.com*
- Cave City, KY 42127-9481  
United States of America  
(270) 590-4974

## **Brosz Technical Services**

- www.brosz.net*
- Markham, ON L3R 8C3  
Canada  
(905) 472-6660

## **Capitol Area Testing, Inc.**

- www.capitolareatesting.com*
- Crownsville, MD 21032-0259  
United States of America  
(443) 370-8583

## **CBS Field Services**

- www.cbsfieldservices.com*
- Sumner, WA 98390-9690  
United States of America  
(253) 891-1995
  - Phoenix, AZ 85040-3832  
United States of America  
(602) 426-1667
  - Chino, CA 91710-9026  
United States of America  
(602) 426-1667
  - Lakeland, FL 33811-1785  
United States of America  
(810) 720-2280
  - Concord, NC 28027-4344  
United States of America  
(619) 672-5217
  - Nashville, TN 37207-5534  
United States of America  
(615) 394-6011
  - Salt Lake City, UT 84104-6533  
United States of America  
(888) 395-2021
  - Vancouver, WA 98661-1261  
United States of America  
(888) 395-2021

## **Control Power Concepts**

- www.controlpowerconcepts.com*
- Las Vegas, NV 89120-2791  
United States of America  
(702) 448-7833
  - Phoenix, AZ 85024-1106  
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(702) 448-7833
  - Boise, ID 83713-8995  
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(702) 448-7833
  - Spanish Fork, UT 84660-5675  
United States of America  
(702) 448-7833

## **CSI Commissioning Services**

- www.csicx.com*
- Dubai, United Arab Emirates  
(+971) 4 888 6446
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  - Cairo, Egypt  
+20 221 928040
  - Riadh, Saudi Arabia  
+966 11 235 7522
  - Doha, Qatar  
+974 4480 5902

## **Elecserv Electrical Testing Co.**

- www.elecserv.com*
- Brooklyn, NY 11231-3308  
United States of America  
(718) 705-4500

## **Electek Power Services, Inc.**

- electek.ca*
- Sarnia, ON N7T 2E5  
Canada  
(519) 383-0333
  - London, ON N6L 1A4  
Canada
  - Sudbury, ON P3A 5K7  
Canada

## **Electric Power Systems, Inc.**

- www.epsii.com*
- Saint Louis, MO 63132-1316  
United States of America  
(314) 890-9999
  - Phoenix, AZ 85043-2354  
United States of America  
(480) 633-1490
  - San Diego, CA 91126  
United States of America  
(858) 566-6317
  - Pleasanton, CA 94588-8560  
United States of America  
(415) 683-7789
  - Santa Ana, CA 92705-4648  
United States of America  
(714) 714-7226
  - Riverside, CA 92503-4804  
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(619) 972-4075
  - Centennial, CO 80112-3851  
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(720) 857-7273
  - Sanford, FL 32771  
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(407) 578-6424
  - Norcross, GA 30092  
United States of America  
(770) 416-0684
  - Burr Ridge, IL 60527-7559  
United States of America  
(815) 577-9515
  - Indianapolis, IN 46256  
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  - Gonzales, LA 70737-4759  
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(225) 644-0150
  - Cockeysville, MD 21030  
United States of America  
(443) 689-2220
  - Riverview, MI 48193-4250  
United States of America  
(734) 282-3311
  - Brooklyn Park, MN 55428  
United States of America  
(763) 315-3520
  - Kansas City, MO 64117  
United States of America  
(816) 241-9990
  - Saint Louis, MO 63132-1316  
United States of America  
(314) 890-9999

- Raleigh, NC 27615  
United States of America  
(919) 322-2670
- Manchester, NH 03109-5606  
United States of America  
(603) 657-7371
- Albuquerque, NM 87113-1663  
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(505) 792-7761
- North Las Vegas, NV 89115  
United States of America  
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- Brunswick, OH 44212  
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- West Chester, OH 45069-3806  
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- Coraopolis, PA 15108-9307  
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- Nashville, TN 37211-3121  
United States of America  
(615) 834-0999
- Sugar Land, TX 77478  
United States of America  
(713) 644-5400
- Richardson, TX 75081  
United States of America  
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- New Braunfels, TX 78130-5189  
United States of America  
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- Salem, VA 24153-5120  
United States of America  
(540) 375-0084
- Glen Allen, VA 23059  
United States of America  
(804) 526-6794
- Vancouver, WA 98682-2447  
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(855) 459-4377
- Green Bay, WI 54304-5640  
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(920) 632-7929

#### **Electrical & Electronic Controls** *eecontrols.com*

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United States of America  
(423) 344-7666

#### **Electrical Energy Experts, LLC** *www.electricalenergyexperts.com*

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(262) 255-5222
- Oak Brook, IL 60523  
United States of America  
(847) 875-5611

#### **Electrical Equipment Upgrading, Inc.** *www.eeu-inc.com*

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United States of America  
(912) 232-7402

#### **Electrical Reliability Services** *www.electricalreliabilityservices.com*

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- Chandler, AZ 85286-1691  
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- Carlsbad, CA 92010-6634  
United States of America  
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- Pleasanton, CA 94566-3119  
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(925) 485-3400
- Santa Fe Springs, CA 90670-7358  
United States of America  
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- Denver, CO 80221-2900  
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- Fort Myers, FL 33966-1244  
United States of America  
(239) 693-7100
- Marietta, GA 30067-9319  
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(770) 541-6600
- Sulphur, LA 70665-6905  
United States of America  
(337) 583-2411
- Geismar, LA 70734-3423  
United States of America  
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- Shreveport, LA 71129-3003  
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- Omaha, NE 68138-4008  
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(402) 861-9168
- Albuquerque, NM 87113-1861  
United States of America  
(505) 822-0237
- Sparks, NV 89431-6070  
United States of America  
(775) 746-4466
- Las Vegas, NV 89118-6851  
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(702) 597-0020
- Milwaukie, OR 97222-8853  
United States of America  
(503) 653-6781
- North Charleston, SC 29418-2833  
United States of America  
(239) 693-7100
- Pasadena, TX 77503-2337  
United States of America  
(281) 241-2800
- Allen, TX 75002-8738  
United States of America  
(972) 788-0979
- Sandy, UT 84070  
United States of America  
(801) 561-0987
- Fife, WA 98424  
United States of America  
(253) 736-6010

#### **Electrical Test Tech LLC**

- www.electricaltesttech.com*
- Lanham, MD 20706-4357  
United States of America  
(877) 388-0911

#### **Electrical Testing and Maintenance Corp.**

- www.etmcorp.net*
- Memphis, TN 38118-6313  
United States of America  
(901) 566-5557

#### **Electrical Testing Solutions**

- www.electricaltestingsolutions.com*
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United States of America  
(920) 420-2986

#### **Electrical Testing, Inc.**

- www.electricaltestinginc.com*
- Rome, GA 30161-3894  
United States of America  
(706) 234-7623

#### **Electro Test, LLC**

- www.electrotest.pro*
- Wahiawa, HI 96786  
United States of America  
(808) 321-2028

#### **Elemco Services, Inc.**

- www.elemco.com*
- Lynbrook, NY 11563-2622  
United States of America  
(631) 589-6343
- Brooklyn, NY 11215-1033  
United States of America  
(718) 786-4900

#### **EnerG Test, LLC**

- www.energtest.com*
- Kennett Square, PA 19348-1734  
United States of America  
(484) 731-0200

#### **Ener-Phase Solutions**

- www.enerphase.com*
- 5045 11th St. SE  
Calgary, Alberta T2H1M7  
Canada  
(403) 873-8500

#### **EPS Technology**

- www.eps-technology.com*
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(203) 679-0145
- Rockaway, NJ 07866-4051  
United States of America  
(732) 636-2426

#### **Field Service Specialists, LLC**

- www.fssofix.com*
- Houston, TX 77033  
United States of America  
(832) 416-0020

#### **Forefront Electrical Testing Co.**

- www.forefronttesting.com*
- Elk Grove Village, IL 60007-2215  
United States of America  
(630) 484-3428

#### **GERS**

- www.gers.com*
- Weston, FL 33331-3603  
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(954) 384-8925

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+5724897000
- Mexico City, Mexico 11300  
+525555354093
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- Bogota, Colombia  
(571) 485-7100
- Sheffield, England S6 2SA  
+44 7595540063
- Barranquilla, Colombia  
+57 310 382 5834

#### **Giga Electrical & Technical Services, Inc.**

- www.gigaelectrical-ca.com*
- Commerce, CA 90040-2413  
United States of America  
(323) 255-5894

#### **Grubb Engineering, Inc.**

- www.grubbengineering.com*
- San Antonio, TX 78212-3743  
United States of America  
(210) 658-7250

#### **Hampton Tedder Technical Services**

- www.httstesting.com*
- Montclair, CA 91763-6129  
United States of America  
(909) 628-1256
- Phoenix, AZ 85009-1359  
United States of America  
(480) 967-7765
- Las Vegas, NV 89118  
United States of America  
(702) 452-9200

#### **Harford Electrical Testing Co., Inc.**

- www.harfordtesting.com*
- Joppa, MD 21085-3409  
United States of America  
(410) 679-4477

#### **High Potential Testing LLC**

- www.hp-testing.com*
- Bensalem, PA 19020-5815  
United States of America  
(609) 313-1299

#### **High Voltage Maintenance Corp.**

- www.hvmcorp.com*
- Dayton, OH 45414-3525  
United States of America  
(937) 278-0811
- Cheshire, CT 06410  
United States of America  
(203) 949-2650
- Elk Grove Village, IL 60007-2400  
United States of America  
(847) 640-0005
- Greenwood, IN 46143  
United States of America  
(317) 322-2055

- Louisville, KY 40299-3820  
United States of America  
(859) 371-5355
- Walpole, MA 02081-2541  
United States of America  
(508) 668-9205
- Hanover, MD 21076  
United States of America  
(410) 279-0798
- Novi, MI 48375-2422  
United States of America  
(248) 305-5596
- New York, NY 10119  
United States of America  
(718) 239-0359
- Mentor, OH 44061  
United States of America  
(440) 951-2706
- Pittsburgh, PA 15205-1206  
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(412) 747-0550
- New Berlin, WI 53151-3549  
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(262) 784-3660
- United States of America  
(859) 371-5355

#### **Industrial Electric Testing, Inc.**

[www.industrialelectrictesting.com](http://www.industrialelectrictesting.com)

- Jacksonville, FL 32256-2746  
United States of America  
(904) 260-8378
- Hallandale Beach, FL 33009-4029  
United States of America  
(954) 456-7020

#### **Infinity Technical Services Division, Inc.**

[www.infinitytsd.com](http://www.infinitytsd.com)

- Gaffney, SC 29341-1409  
United States of America  
(833) 873-4897
- Raleigh, NC 27617-4775  
United States of America  
(833) 873-4897
- Belmont, NC 28012-1479  
United States of America  
(833) 873-4897

#### **Infra-Red Building and Power Service, Inc.**

[www.infraredbps.com](http://www.infraredbps.com)

- Braintree, MA 02184-2409  
United States of America  
(781) 767-0888

#### **Inrush Electrical Technology Ltd.**

[www.inrush.inc](http://www.inrush.inc)

- Edmonton, AB T5V1K7  
Canada  
(888) 426-9119

#### **IPS PowerServe**

[www.ipspowerserve.com](http://www.ipspowerserve.com)

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- Irondale, AL 35210-3701  
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(877) 343-6490
- Livermore, CA 94551-8521  
United States of America  
(559) 275-2171

- Carson, CA 90810  
United States of America  
(310) 549-5673
- Fresno, CA 93722-6418  
United States of America  
(559) 275-2171
- Lakeland, FL 33810-7804  
United States of America  
(813) 425-7300
- Las Vegas, NV 89118  
United States of America  
(888) 296-0625
- St-Jean-sur-Richelieu, QC J2W 2H1  
Canada  
(514) 316-8512
- Lewisville, TX 75057-2301  
United States of America  
(972) 420-0157
- Pasadena, TX 77507-1071  
United States of America  
(800) 420-0157
- San Marcos, TX 78666  
United States of America  
(800) 420-0157

#### **JET Electrical Testing, LLC**

[www.jetelectricaltesting.com](http://www.jetelectricaltesting.com)

- Lawrenceville, NJ 08648-2332  
United States of America  
(609) 285-2800
- Hamilton, NJ 08619-3314  
United States of America  
(609) 285-2800

#### **KT Industries, Inc.**

[ktiengineering.com](http://ktiengineering.com)

- Los Angeles, CA 90065-2919  
United States of America  
(323) 255-7143

#### **LND Technical Services LLC**

[lndts.com](http://lndts.com)

- Houston, TX 77024-1546  
United States of America  
(406) 369-5330
- Albany, NY 12206-2937  
United States of America  
(281) 407-6488
- Ho Chi Minh City, Vietnam

#### **M&L Power Systems, Inc.**

[www.mlpower.com](http://www.mlpower.com)

- Old Bridge, NJ 08857-1980  
United States of America  
(732) 679-1800

#### **Magna IV Engineering**

[www.magnaiiv.com](http://www.magnaiiv.com)

- Edmonton, AB T6X 0X2  
Canada  
(780) 462-3111
- Fort McMurray, AB T9H 4A6  
Canada  
(780) 791-3122
- Calgary, AB T2Z 3V6  
Canada  
(403) 723-0575
- Grande Prairie, AB T8V 3J3  
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(780) 791-3122

- Langley, BC V2Y 0G9  
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- Penticton, BC V2A 6M2  
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(778) 476-5833
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(250) 857-5960
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#### **Midwest Engineering Consultants, Ltd.**

[www.midwestengr.com](http://www.midwestengr.com)

- Moline, IL 61265-6954  
United States of America  
(309) 764-1561

#### **MTA Electrical Engineers**

[www.mtaee.com](http://www.mtaee.com)

- Escondido, CA 92029-1337  
United States of America  
(760) 658-6098

#### **New York Electrical Power Services LLC**

[www.nyeps.com](http://www.nyeps.com)

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United States of America  
(718) 433-4084

#### **North Central Electric, Inc.**

[www.ncetest.com](http://www.ncetest.com)

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United States of America  
(215) 945-7632

#### **Pace Technologies, Inc.**

[www.pacetechologies.com](http://www.pacetechologies.com)

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Canada  
(780) 450-0404
- Calgary, AB T2C 5S7  
Canada  
(780) 450-0404
- Kelowna, BC V1X 8C8  
Canada  
(250) 712-0091

#### **Pacific Power Testing, Inc.**

[www.pacificpowertesting.com](http://www.pacificpowertesting.com)

- San Leandro, CA 94577-5542  
United States of America  
(510) 351-8811

#### **Pacific Powertech Inc.**

[www.pacificpowertech.ca](http://www.pacificpowertech.ca)

- Port Coquitlam, BC V3C 6N2  
Canada  
(604) 944-6697

#### **Phasor Engineering**

[www.phasorinc.com](http://www.phasorinc.com)

- Mercedita, Puerto Rico 00715  
(787) 844-9366

#### **Potomac Testing**

[www.potomactesting.com](http://www.potomactesting.com)

- Crofton, MD 21114-2051  
United States of America  
(301) 352-1930
- Carmel, IN 46032-5807  
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(301) 352-1930
- Troy, MI 48083-2236  
United States of America  
(301) 352-1930
- Jeffersonville, OH 43128-1091  
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(301) 352-1930

#### **Power Critical Services, LLC**

<https://pwrsvcs.com/>

- Mansfield, TX 76063-2721  
United States of America  
(833) 541-2472
- Centennial, CO 80112-4232  
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(833) 541-2472
- Houston, TX 77066-5204  
United States of America  
(833) 541-2472

#### **Power Engineering Services, LLC**

[www.pe-svcs.com](http://www.pe-svcs.com)

- Converse, TX 78109-2041  
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(210) 590-6214
- Mauldin, SC 29662-2414  
United States of America  
(800) 328-7382

#### **Power Solutions Group, LLC**

[www.powersolutionsgroup.com](http://www.powersolutionsgroup.com)

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- Bay Minette, AL 36507  
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(215) 937-4652
- Bakersfield, CA 93308-5100  
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(661) 589-0400
- Rocklin, CA 95677-4031  
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- Riverside, CA 92501-2248  
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(800) 462-3157
- Centennial, CO 80112-3947  
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(303) 799-1273
- Middletown, CT 06457-1588  
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(860) 635-9777
- Bethel, ME 04217-4908  
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- Moncure, NC 27559-9165  
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- Liberty, SC 29657-9426  
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(864) 540-8434
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- Pearland, TX 77581-1901  
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(346) 221-2165
- La Porte, TX 77571-4639  
United States of America  
(281) 826-3781
- Kennewick, WA 99338  
United States of America  
(937) 506-8444

#### **Power Systems Professionals, Inc.**

[www.powerpros.net](http://www.powerpros.net)

- McClellan Park, CA 95652  
United States of America  
(866) 642-3129

#### **PowerX**

<https://powerxco.com>

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- Wendell, NC 27591-9708  
United States of America  
(919) 365-9775
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- Austin, TX 78754-4126  
United States of America  
(855) 776-9379
- Grand Prairie, TX 75050-1255  
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(855) 776-9379
- Chantilly, VA 20151  
United States of America  
(855) 776-9379
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United States of America  
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#### **Praetorian Power Protection, LLC**

[www.praetorianpower.com](http://www.praetorianpower.com)

- Everett, WA 98208  
United States of America  
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