

FALL 2026

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GAS RATE-OF-CHANGE ANALYSIS

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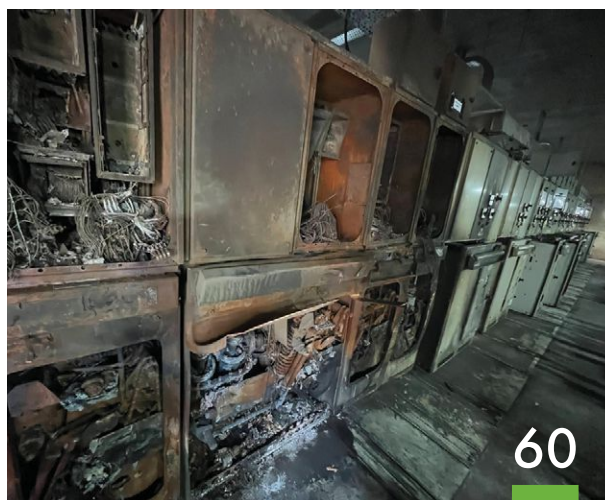


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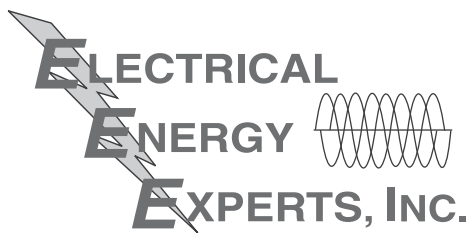
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MEETING THE CHALLENGES OF A CHANGING POWER LANDSCAPE

The electrical industry is in the midst of its most significant transformation in a generation. The rapid growth of EV charging infrastructure, the integration of renewable energy resources, the proliferation of data centers, and the increasing complexity of the modern grid are all reshaping the environment in which our members work every day. This issue of NETA World addresses that transformation head-on.



It is the technician's knowledge, judgment, and mastery that define quality and ensure safety.

Our feature articles this fall cover the spectrum from field safety to standards evolution to advanced diagnostics.

One article tackles the practical hazards posed by EV supply equipment and charging infrastructure, a category of installations that is expanding rapidly and deserves the same rigorous arc flash and shock hazard analysis we apply to conventional electrical systems.

Another examines how the assumptions embedded in decades-old IEEE machinery standards no longer hold in today's operating environment, and what is being done to bring those standards current.

Two additional articles address the shift toward continuous, real-time monitoring: one focused on partial discharge in medium- and high-voltage networks, and one on dissolved gas analysis in transformers serving renewable energy applications. Together, they make a compelling case that condition-based maintenance, driven by continuous data rather than fixed schedules, is becoming the new standard of practice.

The expertise shared in these pages reflects the best of what the NETA community brings to the industry: practical knowledge, field-tested methods, and a commitment to safety and reliability that never wavers even as the technology around us evolves.

I also want to make sure the EPIC Fall Conference is on your radar. Presented by NETA on October 11–13, 2026, in Fort Worth, Texas, EPIC—Electrical Power Innovations Conference—is the premier event bringing together organizations and professionals engaged in exploring future trends that will shape the power industry for decades to come. Meet with industry leaders focused on improving power supply, resiliency, and safety, and gain critical knowledge on emerging technologies, smart grid modernizations, and electrical power service futures. Join us for this unique opportunity to connect with peers across the industry. It is exactly the kind of environment where the topics covered in this issue come to life. I hope to see many of you there.

Visit epicpower.org for details and registration.

With appreciation,

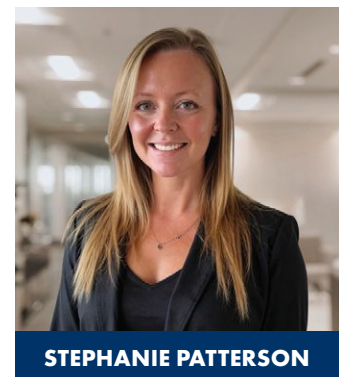
Dan Hook, President

InterNational Electrical Testing Association

STEPHANIE PATTERSON:

LEARNING, LEADERSHIP, AND LASTING IMPACT

This issue of NETA World’s “Insight and Inspiration” series features Stephanie Patterson, Senior Manager, External Training & Partnerships, at Qualus. Patterson leads the strategy, development, and execution of training programs that support industry professionals, clients, and partner organizations. Her responsibilities include managing training initiatives, building and maintaining strategic partnerships, identifying new training opportunities, and ensuring the delivery of high-quality learning experiences that align with industry standards and business objectives. Recently elected to the NETA Board of Directors, Patterson has become a passionate advocate for lifelong learning, mentorship, and attracting the next generation of talent into the profession.



NW: Your career has taken you from operations into workforce development and training. How did that journey unfold?

Patterson: My career has been shaped by a variety of experiences, but one of the most influential was starting as an Operations

Specialist. That position gave me exposure to nearly every aspect of the business. I worked alongside technical personnel, account managers, clients, and company leadership, which allowed me to understand how the electrical power industry functions beyond the work performed in the field.

That operational foundation became incredibly valuable as I transitioned into training and workforce development. Because I understood the day-to-day realities our employees and customers face, I was better able to identify the skills professionals need to succeed and the importance of providing meaningful learning opportunities throughout their careers.

Over time, I realized what I enjoyed most wasn't simply supporting projects—it was helping people grow. Today, I have the privilege of leading training initiatives that connect industry professionals with educational opportunities, strategic partnerships, and workforce development programs that strengthen our industry for the future.

NW: What keeps you passionate about this profession?

Patterson: Knowing that education has a direct impact on people's careers is what motivates me every day. Whether someone is attending their first seminar, preparing for a certification, or stepping into a leadership position, learning opens doors.

Our industry is constantly evolving, and that creates tremendous opportunities for professionals who are willing to continue developing their skills. Being able to play even a small role in someone's professional journey—and seeing the confidence they gain along the way—is incredibly rewarding.

NW: You became involved with NETA relatively early in your career. Did you ever imagine you would one day serve on the Board of Directors?

Patterson: Not at all. I first became involved as the Technician Representative because I wanted to contribute and learn from others in the industry. At that point, I certainly wasn't thinking about serving on the Board.

As my involvement with NETA grew, so did my appreciation for the organization's mission and the people behind it. Serving on the Board is an

incredible opportunity to help shape initiatives that support education, workforce development, and the future of the profession. It's both an honor and a responsibility.

NW: What has surprised you most about your experience with NETA?

Patterson: The sense of community. People certainly recognize NETA for its technical excellence and industry standards, but what has impressed me most is the willingness of members to collaborate and share knowledge. Throughout my committee work, I've had the opportunity to work with professionals who genuinely care about improving the industry and helping others succeed.

“I've been incredibly fortunate to learn from many people over the years. Some were formal mentors, while others were colleagues and leaders who took the time to share their experience, encourage me, or simply answer questions.”

That collaborative culture has reinforced something I've always believed—that our greatest progress happens when experienced professionals invest in the next generation.

NW: You've spoken often about mentoring and professional development. How important have mentors been throughout your own career?

Patterson: I've been incredibly fortunate to learn from many people over the years. Some were formal mentors, while others were colleagues and leaders who took the time to share their experience, encourage me, or simply answer questions.

One lesson that has stayed with me is that leadership isn't about having all the answers.

It's about listening, continuing to learn, and creating opportunities for others to succeed.

I've also learned that many of the best opportunities in my career came through relationships that were built over time. Our industry is filled with professionals who are remarkably generous with their knowledge, and I believe we all have a responsibility to pay that forward.

“As long as we continue investing in education, embracing new technologies, and communicating the value of those resources, NETA will remain an essential organization for professionals at every stage of their careers.”

NW: What do you see as one of the biggest challenges facing the electrical testing industry today?

Patterson: Developing the next generation of skilled professionals. Demand for reliable electrical infrastructure continues to grow, but attracting and preparing enough qualified people remains one of our greatest challenges. That's why education, mentorship, and workforce development have become such important priorities.

We need to continue creating awareness of the rewarding career opportunities available in this industry while making it easier for people to access high-quality training and professional development throughout their careers.

NW: How can NETA continue to remain relevant for technicians and electrical testing professionals?

Patterson: We need to continue to prioritize education and adaptability. Technology is changing rapidly, and our profession has to evolve with it. NETA's strength has always been its ability to

provide trusted technical standards while also responding to emerging industry needs.

As long as we continue investing in education, embracing new technologies, and communicating the value of those resources, NETA will remain an essential organization for professionals at every stage of their careers.

NW: What advice would you offer someone considering a career in electrical testing?

Patterson: Stay curious and take advantage of every opportunity to learn. Build a strong technical foundation early, but don't underestimate the value of networking and mentorship. Some of the most important lessons you'll learn won't come from a classroom—they'll come from experienced professionals who are willing to share what they've learned.

I'd also encourage young professionals not to be afraid to step outside their comfort zone. Every role has something to teach you, and the experiences you gain along the way often prepare you for opportunities you never imagined.

Above all, remember that learning doesn't stop once you enter the profession. The people who continue asking questions, seeking new experiences, and investing in their own development are the ones who will make the greatest impact. [NW](#)



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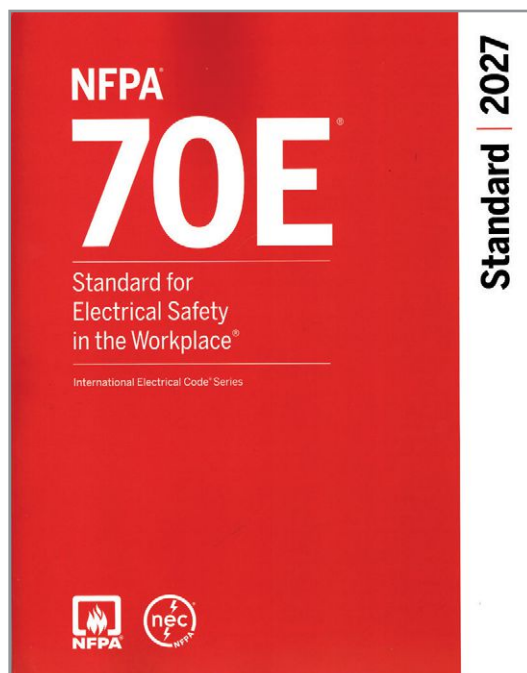
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HISTORY DOES NOT REPEAT ITSELF, BUT IT RHYMES

BY RON WIDUP, *Vector Power*

Often attributed* to Mark Twain, the phrase “*History does not repeat itself, but it rhymes*” seemed appropriate as we look back on our electrical journeys. The 2027 edition of NFPA 70E was recently approved, with an effective date of May 6, 2026, and we are excited about the improvements and enhancements to this very important electrical safety work practices standard.



2027 Edition of NFPA 70E

We highlight a few of the more significant changes in this issue, and a few more changes will be featured in future columns and writings. But speaking of history...

What struck me about the Mark Twain quote ties to a recent visit to NETA's corporate office in Portage, Michigan. There is a lot of history with NETA and its many volunteers in the electrical industry, and this was very evident as we reviewed some of the archived materials found on the shelves.

As an association that has had long-standing input and participation in the development and publishing of standards and work practices in the electrical testing, maintenance, and safety arena, it was evident to me through some of the newsletters, articles, and documents found at NETA that we have, through the course of time, made a difference. So let's take a quick trip down memory lane...

*There is no substantive evidence that Twain made this remark, but he first received credit in 1970, many years after his death.

The earliest strong match appeared in 1965 within an essay by psychoanalyst Theodor Reik titled "The Unreachables."

The phrasing was a bit longer, but the meaning was the same:

*"There are recurring cycles, ups and downs, but the course of events is essentially the same, with small variations. It has been said that history repeats itself. **This is perhaps not quite correct; it merely rhymes.**"*

BACK THEN...

A precursor to *NETA World* was *NETA News*, which first appeared in July 1979.



NETA News, Volume 1, Number 1 (July 1979)

In the October 1979 issue of *NETA News*, the following segment was published:

Maintenance Testing Specs Out Soon

Ernie Showalter, Roundhouse Electric and Engineering Company, and his Technical Committee are making good progress on the NETA Maintenance Testing Specifications. He expects to have a rough draft ready for presentation to the membership by the November [1979] meeting. If any members have in-house specs they feel would be applicable, please forward them to Ernie as soon as possible.

As we look at the historical generation of NETA's original maintenance testing specification in 1979, which led us to the current standard, ANSI/NETA MTS, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*, it's interesting to note that the first edition of NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces*, was also published in 1979 and included only Part I, Installation Safety Requirements.

Two consequential industry documents growing along parallel paths, it seems...

In the 2027 Edition of NFPA 70E: Section 110.3(C):

Speaking of electrical equipment maintenance, a new informational note was added in Section 110.3(C) Condition of Maintenance, which states:

Informational Note: See Informative Annex S for guidance on assessing the condition of maintenance.

This new informational note points to Annex S and NFPA 70B for condition of maintenance and ties work-practice risk decisions to the overall maintenance condition of electrical equipment.

These types of connections between equipment condition and maintenance enhance safety and reduce risk for personnel interacting with the equipment. We have been preaching it for years—you must understand equipment condition to analyze and mitigate the risk!

THE NFPA 70E AND NETA

MORE BACK THEN...

In the October 1979 NETA News, the following segment was also published:

NETA Safety Committee Requests Membership's Assistance

Lyle Detterman, Safety Committee Chairman, with the assistance of Mr. Bob Harrigan, Northeast Electrical Testing, has prepared a preliminary copy of the NETA Safety Guidelines publication. Lyle is distributing a copy to all NETA members requesting comments and/or suggested changes.

Lyle is requesting that each member respond to him before the November membership meeting. Every member's cooperation in helping to complete this important document will be appreciated.

Looking back at history, the NETA Maintenance Testing Specification, NETA Safety Guidelines, and the newly formed NFPA 70E standard were all evolving nicely. This is evidenced by the following article in the December 1979 edition of NETA News:

NFPA 70E Shaping Up

NFPA 70E, Electrical Safety Requirements for Employee [sic] Work Places, which was initiated at the request of the electrical industry when it became obvious that OSHA would not be able to adopt the 1975 or any further additions of the code, is anticipated to consist of four parts. The first part that has now been proposed by OSHA has the title Design Safety Standards for Electrical Systems; Part Two will be Safety Related Work Practices; Part Three will be Safety Related Maintenance Requirements; Part Four, Safety Requirements for Special Equipment. The NFPA Committee on which NETA is represented by JOHN MOORE, ELECTRO-TEST, INC., is now working on Part Two, and it is anticipated that the document will be proposed for adoption at the 1980 annual meeting of the National Fire Protection Association.

In the 2027 Edition of 70E (General)

Just as the NETA Safety Guidelines have evolved over the years, so has NFPA 70E. Many of the changes to the 2027 edition of 70E were editorial in nature. This was done to align

with the revised Manual of Style for NFPA Technical Committee documents and the NEC Style Manual. For example, we had to separate paragraphs with multiple requirements into subsections or lists, and added titles to sections and subsections. The titles of several articles and sections were also revised for clarity.

MORE BACK THEN...

The Winter 1984 edition of NETA News had the following segment:

Flame-Proof Jackets Available from NETA

NETA has acquired a certifiable flame-proof jacket for the field technician. Antiflash Corp. produces material called Panotex 310 with the following characteristics:

- *Will not ignite, hold a flame, or hold a flame afterglow (definition of "flame-proof")*
- *Resists temperatures up to 960 degrees Centigrade (1760 degrees Fahrenheit.*
- *Dry cleans well; washes as wool*
- *Made from Pam/chlorofiber/acrylic/wool*
- *Resistant to splash from all common industrial acids – such as Hydrochloric, Sulfuric, Phosphoric, and Nitric*
- *Resistant to gasoline and acetone*
- *Comfortable to wear; long-lasting, quality-made*
- *Colorfast and attractive*

Panotex 310 is not a chemical treatment of an existing fabric but is custom-made by Coats & Clark of London for the technician subject to a flamelflash environment. Antiflash has made a wind-breaker jacket especially for NETA. It has a zip-out liner and sells for \$55. Qualified members may have the NETA emblem embroidered on the jacket. Orders must be in by January 21. Coveralls, fabric, and other articles of clothing are also available. Contact the NETA office for details.

In the 2027 Edition of 70E: 130.7(C)(14)(b)

Personal protective equipment has improved quite a bit over the past several decades, and while the early days were about flame-proofing and non-melting, we now really understand the

needs (and differences) for arc-rated clothing for electrical workers.

Section 130.7(C)(14)(b) was changed and the PPE conformity assessment revised, as the option to solely use a supplier's Declaration of Conformity to demonstrate compliance of arc-rated PPE was removed. This raises confidence in PPE compliance, and the section now states:

*130.7 Personal and Other Protective Equipment.
(14) Standards for PPE.*

(b) Conformity Assessment. All suppliers or manufacturers of PPE shall demonstrate conformity with an applicable product standard by using one of the following methods:

- (1) Self-declaration under a registered quality management system and product testing by an accredited laboratory and a Supplier's Declaration of Conformity*
- (2) Certification by an accredited independent third-party certification organization.*
Exception: PPE that has been marked with a supplier or manufacturer's self-declared level of conformity prior to the effective date of this edition of the standard shall be permitted.

Informational Note No. 1: See H.4 and ANSI/ISEA 125, American National Standard for Conformity Assessment of Safety and Personal Protective Equipment, for examples of a process for conformity assessment to an applicable product standard.

Informational Note No. 2: See ISO 17065, Conformity Assessment — Requirements for bodies certifying products, processes, and services, for an example of a process to accredit independent third-party certification organizations.

In the 2027 Edition of 70E: 130.2(A)(2)

I mentioned that Dan and I recently visited NETA's corporate office in Portage, Michigan, and whether it's visiting the NETA office, doing energized electrical work, or SCUBA diving, you should always do so with a buddy. (When SCUBA diving, keep a dive knife with you so you can stick your buddy with it if any sharks come around.)

But arguably the most significant change to the 2027 edition of NFPA 70E is a new section, Section 130.2(A)(2). It requires an additional person if an employee is working alone when that worker is at risk of electrical injury because they are performing [justified] energized electrical work. (Key word: justified...because remember—always turn it off if you can!)



1979 NETA NEWS Cartoon

After completing your energized electrical work permit, performing a risk assessment, and determining the required PPE, you will need to

THE NFPA 70E AND NETA

*NETA President
Dan Hook (left) and
Ron Widup Shown
Complying with
Section 130.2(A)(2) at
the NETA Office*



go over all of this with the additional person. The rationale is that an additional person can provide immediate emergency response to the worker in the event of an incident or injury.

The additional person must be trained in contact release methods and must remain outside of the restricted approach boundary or arc flash boundary (whichever is greater) and must observe the work being performed. Another key aspect: Make sure you are both qualified to perform the required task(s)!

This change garnered a lot of discussion during the revision cycle, but when you look at the hazards involved with energized electrical work, it makes a lot of sense to do the work with an additional person.

SUMMARY

We learn from each other in the field, we learn from each other in industry, and we learn from

the subject matter experts who work tirelessly to improve the use and applicability of the 70E standard at each revision cycle. Be sure to get your copy of the new standard at www.nfpa.org.

And finally...speaking of history, one of my favorite historical readings is in Section 115 of the *American Electricians' Handbook*, under the subtitle Measuring, Testing, and Instruments, which states (emphasis added **in bold**):

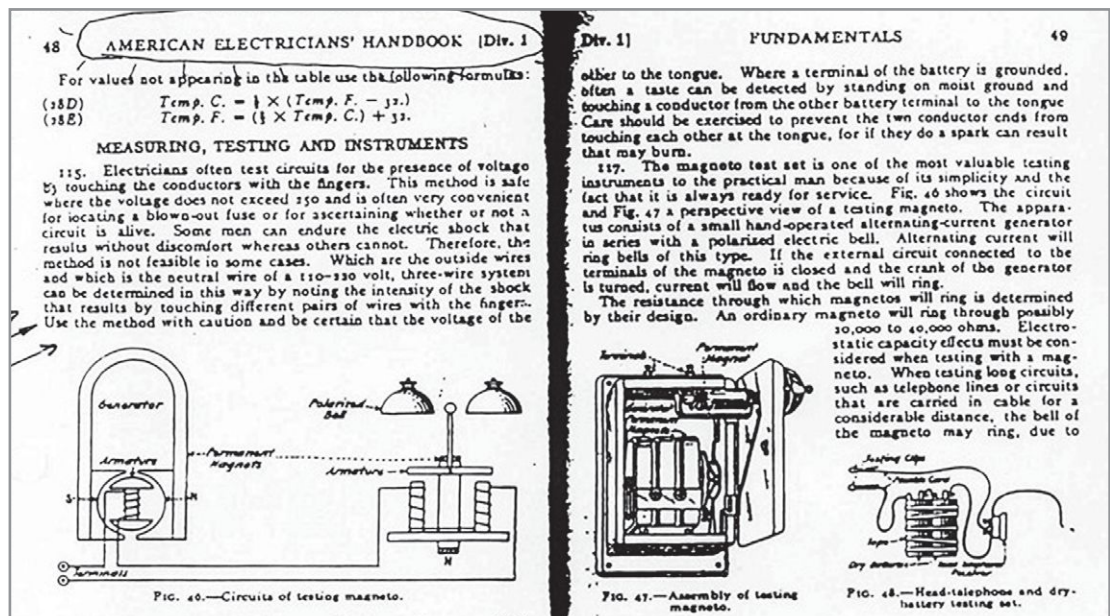
*Electricians often test circuits for the presence of voltage **by touching the conductors with the fingers**. This method **is safe** where the **voltage does not exceed 250** and is often very convenient for locating a blown-out fuse or for ascertaining whether or not a circuit is alive. **Some men can endure the electric shock** that results without discomfort whereas **others cannot**.*

If you did that today, the only part of history that might rhyme would be the curse words flying out of your mouth when you did it. (Don't try this at home, kids!)

Bottom line: Get the new 2027 NFPA 70E, study and embrace the changes, and be safe out there.

And hey, be the smartest person in the room and turn it off – would ya? #testbeforetouch **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.

ON SURGE ARRESTERS AND POWER FACTOR

BY MICHAEL LABEIT, *ASRC Energy*

If you've done power factor testing, you will have noticed that while said testing yields multiple valuable parameters—e.g., watts loss, capacitance, total current, etc.—power factor itself gets the most attention. Indeed, power factor is a critical indicator of electrical equipment performance. However, an important exception to this claim exists, and it exists for surge arresters.



New Surge Arrester Under Test

Power factor is the ratio of resistive current I_R to total current I_T , or I_R/I_T . Total current is a Pythagorean sum of resistive current I_R and capacitive current I_C , where $I_T = \sqrt{I_R^2 + I_C^2}$. Perfect insulation is insulation that permits zero resistive current. In that context, I_C would equal I_T . However, all insulators admit some resistive current, so traditional estimates of equipment condition focus on how far the asset's power factor is from zero. Thus, 0.3% power factor is better than 0.4% power factor, which in turn is better than 0.5% power factor, and so on.

The trouble with using this parameter as a metric for surge arrester condition is that surge arrester capacitance is usually very low. Capacitance C is a function of frequency f and capacitive reactance X_C , where $C = 1/(2\pi f X_C)$. This means that as capacitance decreases at any given test frequency, capacitive reactance rises. As capacitive reactance rises, given any test voltage V_T , capacitive current I_C falls, or $V_T/X_C = I_C$. If capacitive current falls and resistive current is constant, total current falls. If total current falls due to lower capacitive current, power factor rises.

But while rising power factor is associated with equipment degradation, it is traditionally considered problematic when said power factor increase is caused by rising resistive current, not

Table 1: *Power Factor Test Results*

Frequency	Test Voltage	Total Current	Watts Loss	PF Measured	Capacitance
60 Hz	10 kV	0.44 mA	200.08 mW	4.5202%	114.3 pF
60 Hz	10 kV	0.44 mA	225.59 mW	5.0923%	114.4 pF
60 Hz	10 kV	0.23 mA	223.20 mW	9.8844%	56.7 pF

falling capacitive current. The job of insulation is to block resistive current; therefore, comparisons of surge arresters based on power factor results influenced by low capacitive currents will be erroneous.

FIELD SCENARIO

Consider the results for three 36-kV surge arresters tested two years ago (Table 1).

The top two arresters, #1 and #2 were brand-new, while #3 was service-aged. The decision was made to discard arrester #3 because its power factor was higher than those of #1 and #2. In retrospect, this might have been a mistake because of power factor unreliability for arresters.

First, notice that the calculated watts loss of arrester #3 is *between* that of #1 and #2. If arrester #3 was more degraded than its counterparts, we'd expect its watts loss to *exceed* those of #1 and #2.

Moreover, consider the effect of capacitance (Table 2). The capacitance of arrester #3 at 56.7

pF is less than half the capacitances of #1 and #2. As a result, while the capacitive current of #3 is around 228.87 μ A, the capacitive currents of #1 and #2 are approximately 439.55 μ A and 439.43 μ A, respectively. This at least partially accounts for why #3's power factor is so much higher than the power factors of #1 and #2, accounting for test-set measurement error. Meanwhile, the other constituent of power factor, resistive current, is fairly similar across all three arresters.

SUMMARY

The caution against relying on power factor results goes beyond surge arresters. IEEE Std. C57.152-2013, *IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors*, states:

PF calculations should not be used to determine the integrity of insulation if the measured current is less than 0.3 mA. At low measured currents, PF calculations are susceptible to large swings, which could be misleading. Therefore, in those cases, the test results should be evaluated based on current and loss readings.

Table 2: *Currents Tabulation*

Total Current	Resistive Current	Capacitive Current
0.44 mA	19.89 μ A	439.55 μ A
0.44 mA	22.41 μ A	439.43 μ A
0.23 mA	22.73 μ A	228.87 μ A

IN THE FIELD

Low-capacitance assets will be overrepresented among assets with total currents less than 0.3 mA. This means that many SF6 breakers would be subject to this proviso, since they also tend to have low pole-to-pole and pole-to-ground capacitance. This caution against using power factor on low-capacitance assets applies equally to dissipation factor, also known as tan delta calculations. Because $\tan \delta = I_R / I_C$, the same issue of low capacitance causing low capacitive current exists.

The more data you produce, the better. Single tests of arresters are of limited value. The more test results for a given arrester, the clearer the watts loss trend one can develop for the condition of said arrester. [NW](#)

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IEEE. IEEE Std. C57.152-2013, *IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors*.



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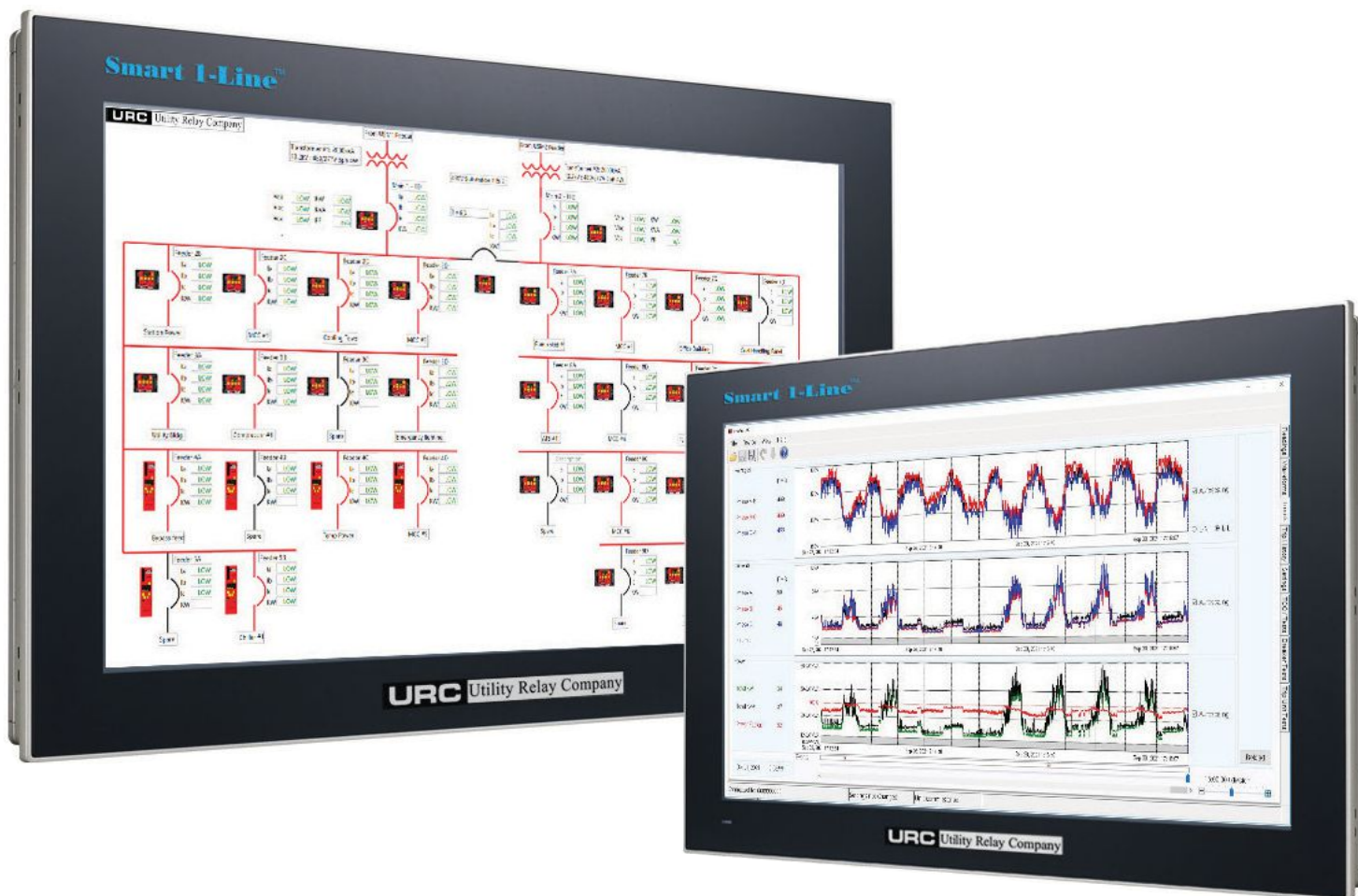


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DESIGNING ADAPTIVE TRIP LOGIC FOR LARGE GENERATORS

BY STEVE TURNER, *Consultant*

Large generators, such as coal-fired and nuclear, are grounded through a high impedance to limit fault current flowing in the stator winding during ground faults. The high impedance is a resistor located across the secondary winding of a single-phase distribution transformer connected from the machine neutral to ground.

Large generators typically have a main set for protection and a backup set. The protection is typically a multi-function generator protection relay. The main and backup protection may or may not be identical. The trip logic typically used is referred to as one-out-of-two (1oo2); if either the main or backup protection operates, then a trip is issued. If either relay fails, then the scheme inherently reverts to one-out-of-one (1oo1) logic.

TWO-OUT-OF-THREE (2oo3) TRIP LOGIC

Nuclear generators are an exception since they are few and far between, while providing the most power output. As such, nuclear generators

tend to have special protection requirements, such as trip logic. This article demonstrates how to apply 2oo3 logic using relay-to-relay communications to assert specific trip outputs. This eliminates the need for much wiring.

The 2oo3 trip logic requires that at least two out of the three main generator protection relays operate for a specific condition, such as an internal stator ground fault (e.g., 64G1). Figure 1 illustrates the relay communications. Each relay must communicate with the other two and vice versa, and each communication link is bi-way. Therefore, each relay continuously knows the status of the other two relays' tripping elements via the communication links.

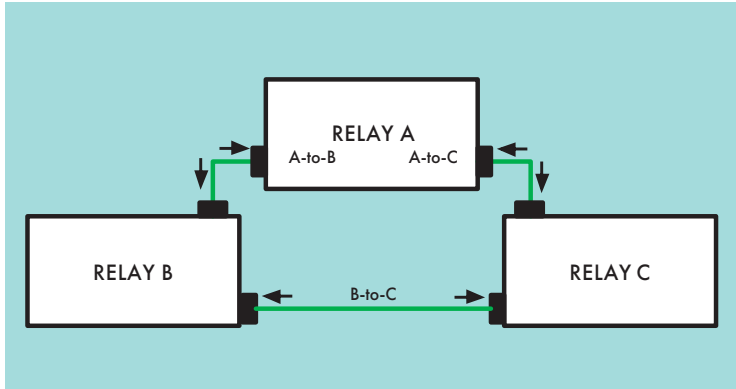


Figure 1: Relay-to-Relay Communication Links for 2003 Trip Logic

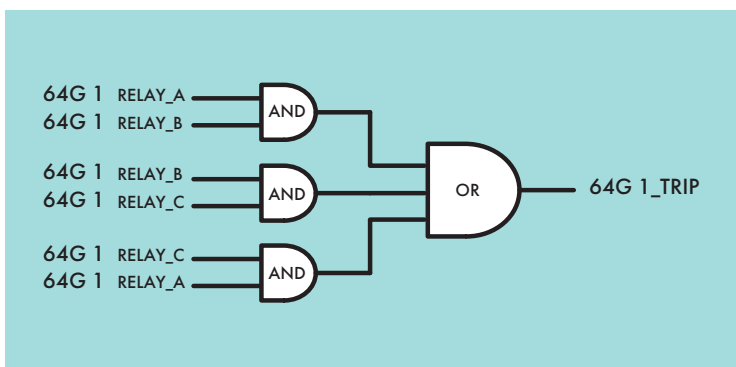


Figure 2A: 2003 64G1 Trip Logic

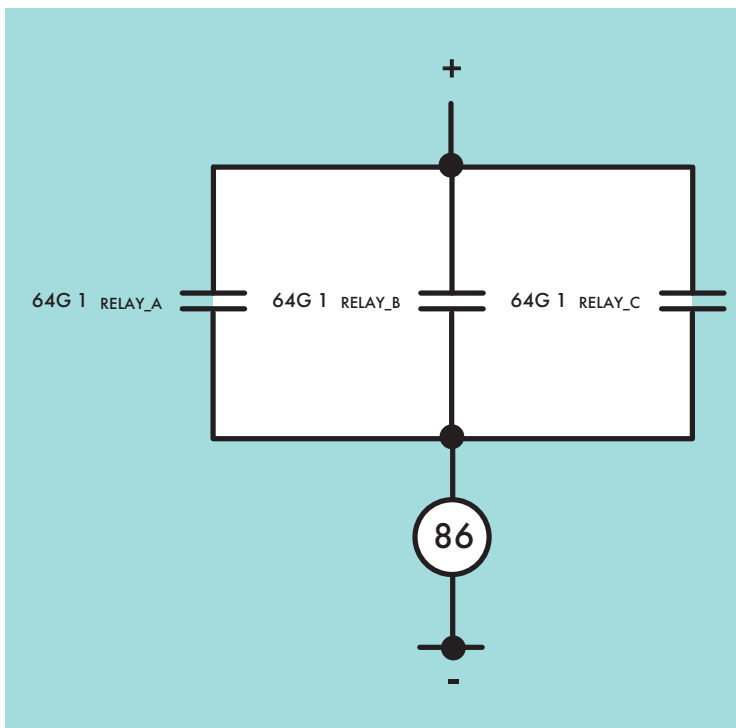


Figure 2B: 2003 External Trip Outputs Wiring Diagram

Two out of the three relays must operate via a particular protection element in order for a trip to be issued, such as 64G1 neutral overvoltage. Figure 2A illustrates this logic.

Each relay has 2003 logic programmed for each specific trip condition (e.g., loss-of-field). The trip contacts for each specific trip from the three relays are wired out in parallel, as illustrated by Figure 2B. Using relay-to-relay communication greatly reduces the amount of wiring required.

ADAPTIVE SCHEME LOGIC

Ideally, each relay should have independent VTs, CTs, and DC batteries; however the vast majority of nuclear power plants were built decades ago. It is rare to ever have three independent sets of batteries. Therefore, two of the three relays must likely be sourced by one battery. The trip logic must automatically adapt if this common battery fails, or else tripping is not possible.

Suppose, for example, that relays B and C are both sourced by the same battery. Figure 3 illustrates how to switch over to a one-out-of-one (1oo1) scheme, relying solely upon relay A until the situation with the defective battery can be remedied.

Normally closed output contacts for relays B and C are connected in parallel with the respective normally open trip output contact. Relay A can independently trip via paths Trip_1 and Trip_3 should the battery sourcing relays B and C ever fail. Each normally closed output contact falls closed when the relay power supply is dead.

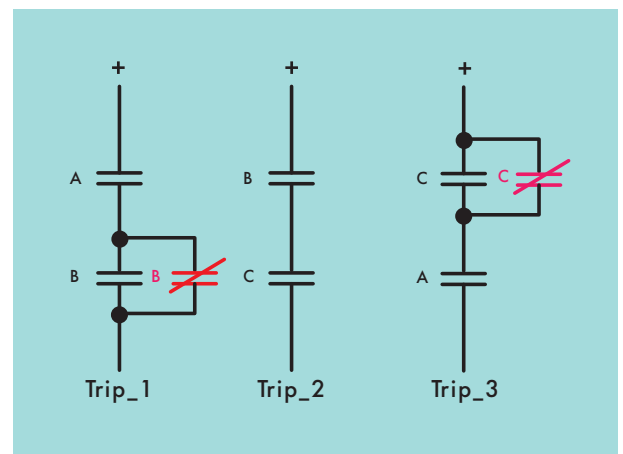


Figure 3: Fail-Safe Adaptive Trip Logic

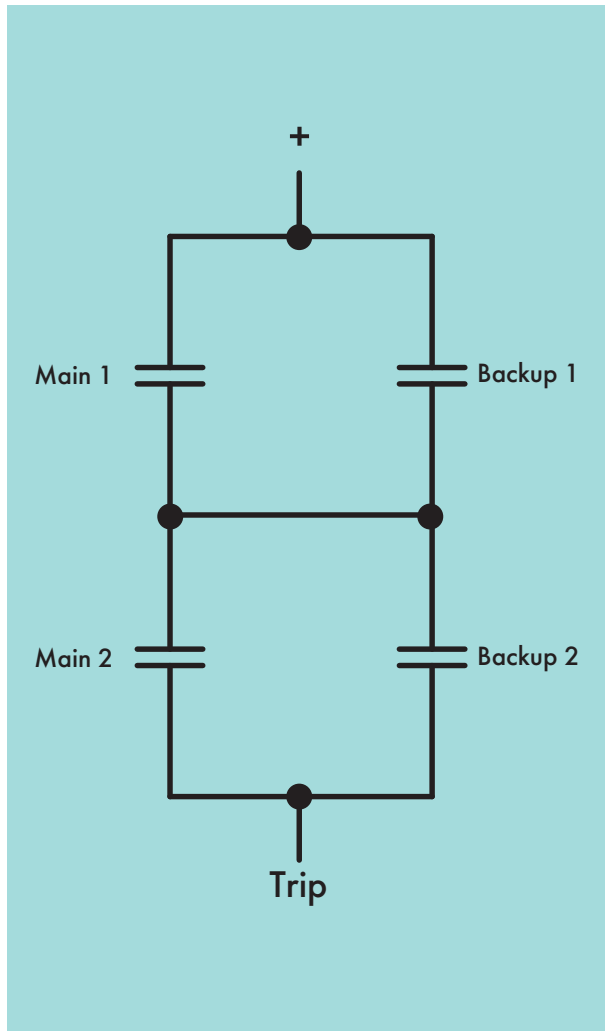


Figure 4: 1002X2 Trip Logic

ONE-OUT-OF-TWO TAKEN TWICE (1002X2) TRIP LOGIC

Another popular trip scheme used is one-out-of-two taken twice, which is simply two one-out-of-two trip schemes connected in series, as illustrated in Figure 4. This scheme is biased towards dependability. This scheme can also be realized using relay-to-relay communication.

Figure 5 illustrates how this trip scheme can be modified so it is adaptive.

The relay alarm output can be realized using programmable relay logic, so extra output contacts are not required, for example:

$OUT202 := (40Z1T \text{ OR } 40Z2T) \text{ OR } (HALARM \text{ OR } SALARM)$

CONCLUSION

This article shows how to realize two trip logic schemes that require three or more relays. One scheme is biased toward security, while the other is biased more toward reliability. Using relay-to-relay communication greatly reduces the amount of wiring required. [NW](#)



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.

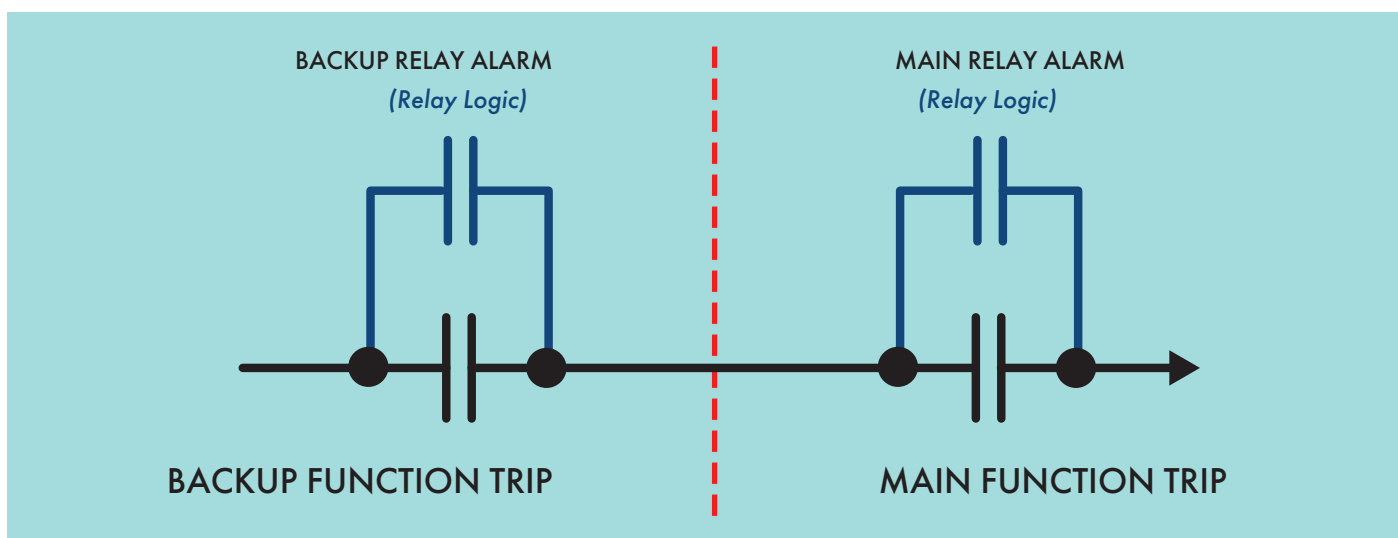


Figure 5: Adaptive 1002X2 Trip Logic



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VEHICLE SAFETY

FOR THE WORKFORCE

BY PAUL CHAMBERLAIN, *Asplundh Engineering Services*

Commuting to and from work by car is a daily routine for most people. Many people are also required to be on the road to a jobsite, client site, the shop, the parts supplier, or anything in between.

One thing that is often overlooked is that driving is one of the leading causes of workplace fatalities. According to the Insurance Institute for Highway Safety (IIHS), there are 40,000–45,000 traffic-related fatalities annually. That number is significant because just one work-related fatality can impact all aspects of the workplace, such as production, insurance costs, and employee morale. To mitigate roadway incidents, it is recommended that companies that require employees to operate a motor vehicle for work purposes develop and administer driver safety programs to manage overall vehicular safety.

Training employees in safe driving techniques will help to reduce the number of vehicular accidents and make the road a safer environment for everybody. The following basic driving skills should be reinforced for employees who drive company vehicles.

TECHNIQUES FOR PROPER BACKING

There are many ways to approach backing vehicles, and no one philosophy is better than another as long as it is used properly every time. Training employees on all these techniques will decrease the likelihood of a backing incident.

1. **No Backing.** Many companies have chosen to use the no-backing approach. This means that vehicles are driven forward through a parking space, allowing them to pull forward out of it. If they are unable to do that, they may back into the space so they can pull out when they leave. The advantage of this approach is that the vehicle will be moving away from potential traffic, not backing into it, thus avoiding the large blind spots that occur when starting the backing maneuver. Drivers initially have a narrow field of vision that widens the farther out of the space the vehicle backs. The opposite is true when backing into the space; the field of vision is large, then it grows smaller as the vehicle gets deeper into that parking space.

Another advantage is that backing into the space upon arrival allows the driver to look over the space prior to backing in. This prevents backing over something on the ground that could potentially damage the vehicle. If the driver approaches the vehicle from the front to get into the cab and back out of a space, they will have no idea what is immediately behind or under the vehicle

unless they walk to the rear and look, which leads to our second technique.

2. **360° Inspection.** Performing a 360° inspection is also a common technique used before backing a vehicle. This means that before every backing maneuver, the driver (or spotter) must walk around the vehicle to ensure there are no obstructions behind or under it. Many companies require employees to place cones at the front and rear corners of the vehicle to enforce this inspection. Sometimes, a second person, the spotter, is used to facilitate this technique.
3. **Use a Spotter.** This technique is commonly used by companies that require employees to travel together in a vehicle at all times. For this to be effective, strict training must be conducted with the driver and the spotter. In many incidents, a spotter has been injured while guiding a vehicle during a backing maneuver. The driver and the spotter must use mutually agreed-upon hand signals, like those in Figure 1, since verbal communication may be impossible.

Drivers must be trained to stop the vehicle every time a spotter is out of sight. A suggested practice is to have the spotter remain in one fixed location on the vehicle (i.e., five feet from the driver's side corner) and never leave that position.

PAYING ATTENTION AND MAINTAINING SPACE

According to the National Transportation Safety Board (NTSB), approximately 1.7 million to 2.5 million rear-end collisions occur annually in the United States. Most of these accidents could have been prevented by simply paying attention to the driving task at hand and increasing the following distance between vehicles.

Paying Attention

Multitasking is a fact of life, and our level of distraction has become increasingly worse with the advent of cellular devices. The incessant need for cell phone activity while behind the wheel has hindered our driving safety. Thirty states and Washington, DC, have enacted hands-free-only laws that state that drivers may talk on the cell phone while driving but may not physically manipulate it (i.e., text, dial, check email, or play games). Nearly all states have banned texting while driving, and some states forbid

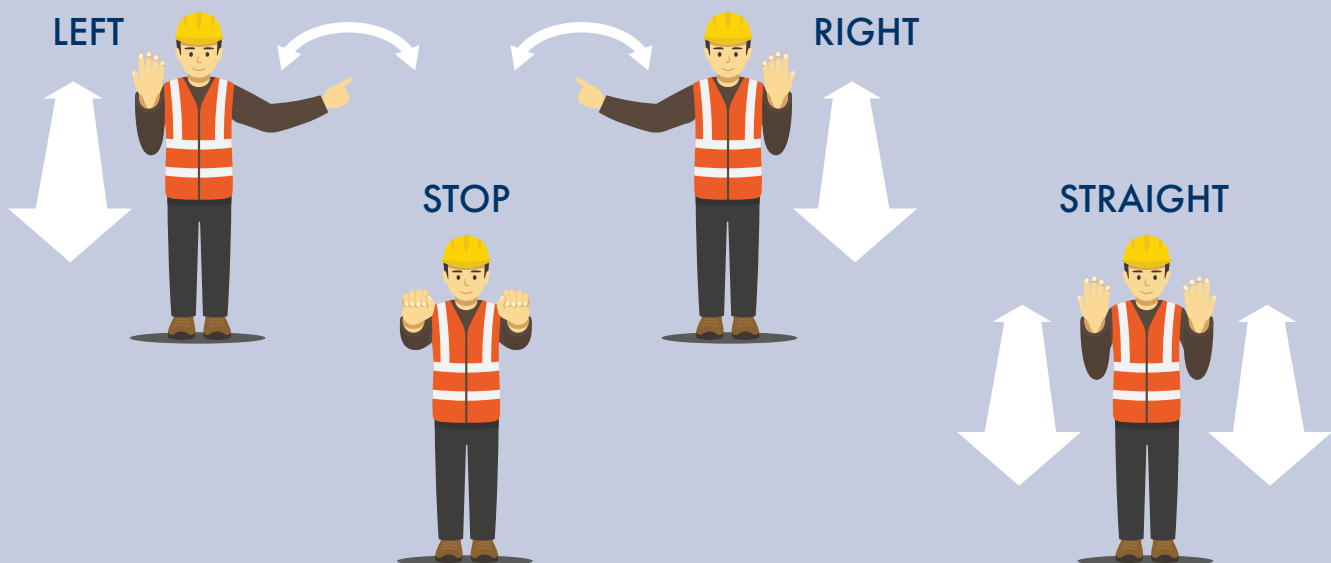


Figure 1: Drivers and spotters should use recognizable hand signals when verbal communication is difficult.

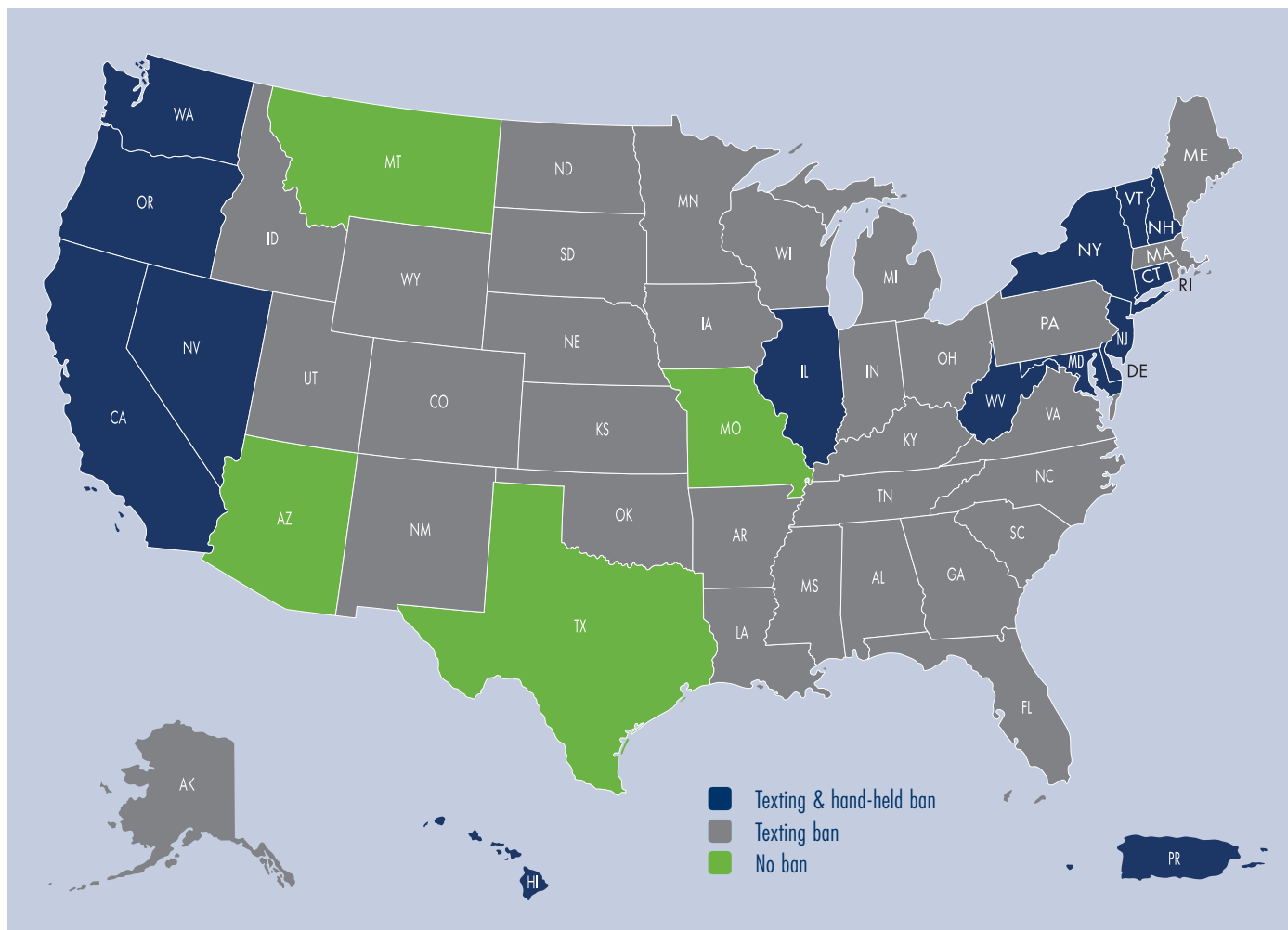


Figure 2: *Distracted Driving Laws by State*

novice drivers from talking on the phone while operating a vehicle even when using a hands-free device. The map in Figure 2 shows the varying levels of distracted driving laws by state.

According to the U.S. Department of Transportation, 18 people are injured every half hour in distracted driving crashes, and one person is killed about every 2.5 hours. Putting down the cell phone and concentrating on the road increases the possibility that a driver will see something that requires them to react, potentially mitigating a collision or other incident.

Maintaining Space

Increasing the space between vehicles by creating a wedge also gives a driver more time to react. The old Yosemite Sam **Back Off** mud

flaps had a message with a purpose: Increasing the space gives drivers more time to react. Think of it this way: A vehicle travels 88 feet per second at 60 mph. If it takes a person one second to see and recognize something, and one second to react and hit the brake, the vehicle has traveled 176 feet before it starts to brake. That does not even account for factors like the weight of the vehicle, the condition of the brakes, tires, and the roadway surface, and more. All of those can impact how long it takes for the vehicle to stop. So, the greater the distance between vehicles, the easier it is for a driver to react and stop the vehicle in time.

STAYING WITHIN SPEED LIMITS

“Speed doesn’t kill; it’s suddenly stopping that does,” as the old saying goes. Speed is

a contributing factor to many accidents. Training drivers to stay within the speed limits (minimum and maximum) helps reduce the likelihood of a crash. It also reduces the severity of a crash, should one occur. Considering the previously mentioned tips, it also helps to increase the cushion between vehicles and decrease a vehicle's stopping distance.

One way to show how driving faster doesn't necessarily get a driver there significantly quicker is by doing some simple arithmetic.

Two drivers are going 200 miles from point A to point B. They travel the same route; the only difference is their speed. Driver A drives at 75 mph, which is 10 mph over the posted speed limit. Driver B drives at the speed limit of 65 mph. Driver A will get to the destination in approximately 2 hours and 40 minutes; Driver B will get there in approximately 3 hours. With less than a half-hour difference for a 200-mile trip, drivers might consider whether the quicker trip is worth the risk.

REQUIRED REST

The Federal Motor Carrier Safety Administration, which regulates commercial motor vehicles (CMV) and their drivers, acknowledges that fatigue reduces reaction time and increases the likelihood of an accident. Because of this, the number of hours CMV drivers may work (driving or not) is regulated and closely monitored.

Even when driving a vehicle does not require a commercial driver's license, drowsy driving can still greatly affect driver reaction time. The difference is that there are no regulations forbidding non-commercial license drivers from operating a vehicle when tired. Employers must monitor the hours an employee works, and employees must be trained to self-police and ensure they do not get behind the wheel while drowsy.

CONCLUSION

There are many ways an employee can get injured, or worse, behind the wheel of a company-issued vehicle or their own. By

training employees and implementing these safety practices, employers can help prevent workplace deaths, which remain the leading cause of fatalities on the job. [www](#)

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

QUIZ

NO. 153

ELECTRICAL EQUIPMENT ADVANCED TECHNOLOGY

BY MORGAN GIENI, *Magna IV Engineering*

The basics of electrical equipment remain constant; however, modern technologies continue to transform how equipment is monitored, controlled, and maintained. To remain industry leaders, NETA Certified Technicians must continuously learn and develop expertise in these advanced solutions.

1. Which online monitoring device is used to detect the development of insulation voids?
 - a. Power monitor
 - b. Partial discharge monitor
 - c. Arc flash sensor
 - d. Corona imaging
2. Which IEC 61850 function is used for fast tripping and binary status information between relays?
 - a. SV
 - b. MMS
 - c. PTP
 - d. GOOSE
3. Which IEC 61850 function is used for publishing analog metering values?
 - a. SV
 - b. MMS
 - c. PTP
 - d. GOOSE
4. Which device can be installed permanently on an oil-filled transformer to provide information regarding overall internal transformer health?
 - a. Hot-spot CT
 - b. Temperature monitor
 - c. Oil monitor
 - d. Vibration sensor
5. On systems with neutral-ground resistors, what protection mechanism can ensure the resistor remains installed?
 - a. Ground current
 - b. Short/open detection
 - c. Voltage rise
 - d. Functional trip
6. Which device in a switchgear main breaker can cause it to trip faster than its coordinated trip time?
 - a. Shunt trip
 - b. Transfer scheme
 - c. Arc flash sensor
 - d. IOC setting
7. What device allows substation event records to be accurate across all relays in the network?
 - a. HMI
 - b. GOOSE
 - c. RAS
 - d. GPS satellite clock



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

See answers on page 134

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GROUNDING TEST REQUIREMENTS AND EQUIPMENT: KNOW BEFORE YOU GO

BY JACOB RIOUX AND LEE HOWARD, *Hood Patterson & Dewar*

The gold standard for grounding testing is IEEE Std. 81–2025, *Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System*. Its purpose is to assist engineers and technicians in obtaining accurate, reliable grounding system measurements and interpreting data for design validation. This standard covers:

- Safety considerations
- Measuring earth resistivity, power system frequency resistance or impedance of the ground system, touch and step voltages, and transient/surge impedance
- Verifying the integrity of the grounding system
- Common test methods, instrumentation characteristics and limitations, and factors that can distort test measurements

In addition to being familiar with this standard, successful testers must also be aware of grounding test equipment options, their pros and cons, and the correct application of each device.

SAFETY FIRST

Many years ago, grounding testing relied on low-current, low-power test equipment, and

sites could often be tested successfully using the fall-of-potential (FOP) method. Today's equipment is much more powerful, and therefore more dangerous. One critical hazard includes induced voltages and current on the test leads due to capacitive and inductive coupling from overhead lines or underground power cables. Voltage can be sourced at a site other than the site under test or from other energized sources in the area, even if the site under test is de-energized.

A written job safety analysis (JSA) with a briefing must be conducted prior to testing. All team members should understand the testing process and potential safety hazards and have the authority to stop work to resolve issues. Test personnel should maintain clearance from the test probes when energized by test sets producing more than 50 V.

DEFINITIONS PER IEEE STD. 81

The new IEEE Std. 81, released in November 2025, covers four new and redefined ground testing terms:

1. The **integrity** test is a measure of electrical continuity between two or more conductive items that, when energized, will become an acceptable path for current conduction with a negligible voltage drop across the elements and their points of interconnection. The test equipment is specified as requiring either a large enough signal to make errors due to power system noise (and other sources) negligible by comparison, or using other means, such as filtering, signal type, and polarity, to adequately reject errors due to site noise.
2. An **impedance** (or resistance) test is a measured value between a ground system and remote earth that can validate the performance of a new or existing grounding system. Some test equipment methods require the site to be isolated to measure impedance/resistance accurately.
3. A **current distribution** measurement is used to validate and determine current splits. The intent is to determine the contribution that each current path makes and calculate its apparent impedance. The test can identify paths that require further investigation and identify potential transfer hazards. This test is limited to evaluating only accessible grounding paths.
4. The existing **current injection test** (CIT) term has a new definition. Per the new standard, this test is an injection of an AC test signal at a frequency different from the nominal power frequency to minimize interference into the grounding system over the following:

Overhead. A transmission feeder line, the preferred method, requires a transmission line outage, which is rarely feasible and adds considerable expense and complexity.

Overland. This test does not utilize an existing conductor and will require deployment of a test lead conductor.

The CIT measures ground potential rise (GPR), touch voltage, step voltage, mesh voltage, and transfer voltage for a response at key locations. It can measure the zone of influence for telecommunication equipment and provide an evaluation of the expected grounding system performance by scaling the measured response to the value expected during a ground fault.

TEST EQUIPMENT SPECIFICATIONS

All of the test equipment presented has the ability to meet the new IEEE Std. 81-2025 test definitions described above. However, each type of test equipment has its advantages and disadvantages, specific requirements, and/or limitations. It must be noted that the site under test may have conditions that render a particular model or brand of equipment inadequate or inapplicable.

VIEW TESTING EQUIPMENT >



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Although AEMC and Megger have been around for a long time and offer newer versions of their test equipment, many pitfalls still exist in today's grounding testing, specifically, limited current output that can't overcome test lead interference (low signal-to-noise ratio). This equipment is:

- Less expensive (\$16K)
- DC power, portable
- 250 mA output—very limiting in field testing, even on small sites
- Output frequency 0–440 Hz
- No user interface data—requires the user to interpret data points in the field to determine validity
- Available for rental

MEGGER DET 2/3 *

- Inexpensive (\$6K)
- DC power, very portable
- 50 mA output—extremely limiting in field testing, even on small sites
- Output frequency 10–200 Hz
- No user interface data—requires the user to interpret data points in the field to determine validity
- Available for rental



Megger
Test Equipment

Image courtesy of Megger



OMICRON
Test Equipment

Image courtesy of OMICRON

OMICRON CPC 100 (OR COMPANO 100) *

- Expensive (\$70K+)
- Training recommended
- Requires AC power for CPC 100 and DC power for COMPANO 100
- Provides real-time data feedback during testing
- Data recorded on tablet/computer
 - CPC 100 = 3 A output
 - COMPANO 100 = 200 mA output
 - CP CU1 = 100 A/50 V or 10 A/500 V output (overhead injection)
- Output frequency 15–400 Hz
- Available for rental



**Safeearth
Test Equipment**

Image courtesy of Safeearth

SAFEARTH AX1 & CS3 *

- Expensive (\$80K+)
- Requires training
- Requires AC or DC battery power
- Data must be recorded by hand—no associated software for field testing (some software for post-test analysis)
- No user interface data—requires the user to interpret data points in the field to determine validity
- 32 A output (overhead)
- Output frequency 40–70 Hz
- Due to training requirements and complexity, not available for rental

SMART GROUND MULTIMETER (SGM) *

- Expensive (\$75K+)
- Requires training
- Requires AC power
- Provides extensive real-time data feedback during testing
- Connected computer records all data
- 16 A output (overland)
- Output frequency 0–250 Hz default. User selectable to 2,000 Hz.
- Due to training requirements and complexity, not available for rental



**SGM
Test Equipment**

Image courtesy of Advanced Power Concepts

TEST EQUIPMENT COMPARISONS *

Based on IEEE Std. 81, the following are direct comparisons of the parameters of the different grounding test equipment:

TURN THE PAGE TO VIEW COMPARISONS THAT COVER THE FOLLOWING CATEGORIES

- Integrity
- Ground Impedance/Resistance
- Current Distribution/Split Factor
- CIT

COMPARE RESULTS OF EQUIPMENT TESTING >

TECH TIPS

INTEGRITY

Equipment	Can Perform	Can't Perform	Notes
AEMC 6472	✓		• DC – very portable • Low current output/signal to noise ratio = low confidence in data
Megger DET2/3	✓		• DC – very portable • Low current output/signal to noise ratio = low confidence in data
OMICRON CPC 100	✓		• Tests at very high current – good signal-to-noise ratio • No phase angle
Safearth CS3	✓		• Fastest but less data • DC – unspool leads as you go • User manually records test points • No phase angle
SGM	✓		• Includes phase angle – Provides additional qualitative data to determine the condition of the bonding conductor • AC – must fully unspool leads to avoid interference • Uses software to identify and reject noise • Software documents every test point with data

GROUND IMPEDANCE/RESISTANCE

Equipment	Can Perform	Can't Perform	Notes
AEMC 6472	✓		• DC – very portable • Low current output/signal to noise ratio = low confidence in data • Remote earth current probe = 5–10x diagonal distance
Megger DET2/3	✓		• DC – very portable • Low current output/signal to noise ratio = low confidence in data • Remote earth current probe = 5–10x diagonal distance
OMICRON CPC 100	✓		• Tests at very high current – good signal-to-noise ratio • No phase angle • Remote earth current probe = 5–10x diagonal distance
Safearth CS3	✓		• Fastest but less data • DC – unspool leads as you go • User manually records test points • No phase angle • Remote earth current probe = 5–10x diagonal distance
SGM	✓		• Includes phase angle • AC – must fully unspool leads to avoid interference • Software documents every test point with data • Remote earth current probe = 2x diagonal distance

CURRENT DISTRIBUTION/SPLIT FACTOR

Equipment	Can Perform	Can't Perform	Notes
AEMC 6472	✓		- Measures with Rogowski coil (1 line at a time, if reachable) and add up to determine split factor - Though not intended for this, per the procedure outlined in IEEE Std. 81–2025, it is capable of performing this test
Megger DET2/3		✗	Doesn't perform this test
OMICRON CPC 100		✗	Doesn't perform this test
Safearth CS3	✓		Measures with Rogowski coil (1 line at a time, if reachable) and add up to determine split factor
SGM	✓		Reports split factor based on measured values

CURRENT INJECTION

Equipment	Can Perform	Can't Perform	Notes
AEMC 6472 & Megger DET 2/3		✗	Doesn't produce enough current for this test
Safearth AX1 & OMICRON CPC 100	✓		Can perform multiple tests at the same time, such as impedance and touch, provided extra manpower and the additional equipment required (OMICRON HGT1 & Safearth MI3) is available
SGM	✓		- Tests at very high current – good signal-to-noise ratio - Includes phase angle

** Information Based on Manufacturers' Websites and Available Brochures*

KEY TAKEAWAYS

The FOP test is still commonly specified, but unbeknownst to most owners, engineers, and testers, it is rarely successful. There is no validation of data nor error reports—all you get is a number. Grounding testing has become much more complicated and expensive than most people realize due to the new standard, test equipment requirements, and time on site.

TECH TIPS

Test personnel must know the grounding test requirements (scope of work) and have extensive knowledge of IEEE Std. 81–2025, including test equipment applications and limitations. Manufacturer training is necessary, particularly with the higher-end test equipment (OMICRON, Sefearth, SGM). Custom equipment training, preferably a combination of classroom and hands-on field testing, is the most inclusive option and essential to successful testing.

The less expensive test equipment, while tempting due to the lower cost, portability, and ease of use, is extremely constrained due to limitations in current output. Only very small, rural, de-energized, isolated sites are likely to be successful. The higher-end test equipment requires a substantial upfront investment in both cost and training and is best considered when many ground testing projects are anticipated, as the learning curve is steep. **ENT**



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.



Lee Howard is a Senior Grounding Specialist with Hood Patterson & Dewar, Inc. With more than 25 years of experience, Howard specializes in the design and analysis of grounding, lightning protection, and surge suppression systems. He speaks at various industry conferences and offers grounding testing and consulting services to a wide range of domestic and international clients, including

electrical utility, industrial, and commercial sites. Howard holds two patents in grounding and lightning protection products. He earned a BS in electronics engineering technology at DeVry University and a Power Systems Certificate from the Georgia Institute of Technology



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NETA Accredited Companies specialize in acceptance testing, maintenance testing, commissioning, and troubleshooting of electrical power systems. Their technicians are trained and certified to identify hidden equipment issues before they become costly failures. Through comprehensive testing of switchgear, transformers, protective relays, breakers, grounding systems, and other critical assets, they help ensure equipment operates as designed and comply with applicable safety and performance standards.



As an independent, third-party, a NETA Accredited Company delivers unbiased assessments that help facility owners make informed decisions regarding maintenance, repairs, upgrades, and risk mitigation. This objectivity is particularly valuable for mission-critical facilities such as utilities, manufacturing plants, data centers, healthcare facilities, and commercial campuses where downtime can have significant operational and financial consequences.

Most important, regular testing by a NETA Accredited Company enhances electrical safety by identifying hazards before they threaten personnel or equipment. The result is improved reliability, reduced outages, extended equipment life, and greater confidence that the electrical power system will perform safely and effectively when it is needed most.

Visit [NETAWorld.org](https://www.NETAWorld.org) for a complete listing of NETA Accredited Companies in your area.

VOLUNTEER ENGAGEMENT COMMITTEE:

FOSTERING PARTICIPATION

NETA offers many volunteering opportunities for interested parties to get involved with the association and share their feedback and expertise. This new Volunteer Spotlight series will feature volunteers across all NETA committees, showcasing their contributions, motivations, and interests. Our first Volunteer Spotlight appropriately features the Volunteer Engagement Committee.

The committee works collaboratively with NETA leadership and all other NETA committees to identify engagement gaps, support recruitment efforts, and enhance communication across the organization. Through these efforts, VEC helps foster participation and sustain long-term engagement in support of NETA's mission. It is one of the youngest NETA committees, established in 2022.

VOLUNTEER ENGAGEMENT COMMITTEE

The Volunteer Engagement Committee (VEC) plays a central role in strengthening member involvement across NETA by ensuring that committees are properly staffed, actively engaged, and positioned for long-term success. At its core, the VEC connects volunteers with meaningful opportunities, aligning individual expertise with organizational needs to support

the Association's continued growth. Through proactive outreach and recruitment, the committee seeks to identify subject matter experts and emerging leaders and create accessible pathways for members to engage in committee work.

In addition to recruitment, the VEC emphasizes accountability, participation, and succession planning across all committees. This includes establishing clear participation expectations, monitoring engagement levels, and helping develop future leadership by identifying individuals who demonstrate consistent commitment to NETA's mission and vision. The committee also supports volunteer recognition and feedback initiatives by highlighting contributions in articles like this new Volunteer Spotlight and continuously improving the volunteer experience.

The VEC is also exploring the idea of organizing a Volunteers Recognition Reception (similar to the Technicians Reception) before PowerTest27 starts, and making it a regular part of PowerTest conferences moving forward. Collectively, these efforts ensure that NETA maintains a strong, engaged volunteer base capable of driving innovation, supporting its members, and advancing the electrical testing industry.

VEC COMMITTEE CHAIR NENO PASIC

Nenad “Neno” Pasic is Chief Information Officer (CIO) and NETA Accredited Representative (NAR) at Tony Demaria Electric, Inc. (TDE), where he has contributed to company operations and industry initiatives for almost 25 years. He serves as Chair of the NETA Volunteer Engagement Committee and is an active member of the NETA Training and Promotions and Marketing Committees.

In his role as VEC Chair, Neno works along with committee members, Kristen Schmidt, Nishat Maredia, and Adis Talović, and NETA office staff Sam Perricone, Amy Williams, and Bryant Philips to strengthen volunteer participation by aligning members with opportunities to engage, improving

communication between committees, and supporting initiatives that drive long-term involvement.

Neno’s motivation for serving is rooted in giving back to the industry that has enriched his personal life way beyond his expectations. Through his work, he has traveled across most of the United States and to nearly 70 countries. While much of his international travel was personal, these experiences would not have been possible without the countless opportunities the industry has provided, further reinforcing his commitment to giving back.

Through his broader work in workforce development and industry partnerships, including collaboration with Long Beach City College (LBCC) and continued work on their High Voltage Test Technician (HVTT) program, currently the only NETA-approved higher education curriculum, Neno continues to support VEC’s mission to build a stronger, more connected, and engaged volunteer community within the electrical testing industry, while contributing to the industry’s most critical challenge—the shortage of qualified technicians—by helping bridge the gap between education and the workforce.



(Left to right): NETA VEC Committee Members Neno Pasic, Nishat Maredia, Sam Perricone, Kristen Schmidt, and Adis Talović during the 2026 NETA PowerTest Trade Show

VOLUNTEER SPOTLIGHT



Neno Pasic

VEC COMMITTEE MEMBERS

In addition to Volunteer Committee Chair Neno Pasic, this Volunteer Spotlight recognizes all three committee members: Vice Chair Kristen Schmidt, member Nishat Maredia, and member Adis Talović, who also serves on the Membership Application Review Committee and the Training Committee.

Here, they share their experiences as NETA Volunteers.

NW: What motivates you to dedicate your time, expertise, and energy to NETA as an organization?

Schmidt: NETA's greatest asset is the people who volunteer their time, energy, vision, and passion. I was fortunate to spend 11 years of my early professional life working with NETA's volunteers in a staff capacity. During that time, I learned so much of what still serves me today. I have always sought to stay connected with this incredible group of people through the years, because they truly make a difference in the lives of others.

Maredia: Globally, we are experiencing incredible growth within the power sector with respect to modernization efforts, new infrastructure, and the need for resilient energy systems to support a wide range of applications. This growth places huge responsibility on testing firms to deliver unbiased testing, providing end-users with confidence and insight into their systems. NETA, as an organization, aligns the tester with its core values of Servant Leadership, Integrity, Safety, Quality, Reliability, and Continuous Improvement.

As NETA responds to rapid technological advances and the associated challenges, it provides a crucial forum for industry professionals to exchange ideas, knowledge, and strategies to navigate the future of the power industry. Volunteering with an organization that plays such an impactful role continues to be a key driving factor for me.

Talović: When I first began attending NETA conferences and committee meetings, I

immediately noticed the depth of knowledge and expertise in the room. Just as important, I saw NETA leadership's genuine willingness to share that knowledge with its members and help strengthen the industry. I have always been passionate about empowering others through knowledge sharing, mentoring, and professional development, and that same energy was clearly present throughout the organization. Because of that, when the first opportunity came to get involved, it felt like a natural next step. I wanted to participate, continue learning, contribute where I could, and share my own experience with others.

NW: What is something unique about your personal industry experience that has been an asset to you as a volunteer for NETA?

Schmidt: I so appreciate knowing the organization's history since its inception in 1972 and having the opportunity to work alongside some of the earliest members while I was on NETA's staff. This perspective reinforces the importance of connecting the future, present, and past to ensure the organization continues to grow and support its mission and vision.

Maredia: By taking on multiple roles during my career, from testing and technical training to business ownership and development, my time across these disciplines has shaped my perspective holistically, and I hope to commit more time to different committees in the near future.

Talović: One unique part of my experience is that I have worked in many different areas of the electrical testing industry. I have seen the industry from the technician's side, the customer's side, and from the perspectives of NETA and testing company leadership. That has helped me as a volunteer because I understand how NETA standards and programs affect people in the real world. I know what technicians deal with in the field, what customers expect from a qualified testing company, and how important it is for the industry to maintain high standards.



Kristen Schmidt



Nishat Maredia



Adis Talović

NW: How does volunteering with NETA touch on other parts of your life?

Schmidt: Volunteering with NETA keeps me in touch with what is shaping my future in the electrical power systems industry, and allows me to integrate that knowledge into my role with USC Power Services, a NETA Accredited Company that I love working for. I am also able to stay connected with people who have become great friends over the past 20 years. To me, that is invaluable; NETA folks are unique in the world of professional associations, and you won't find a better group out there.

Maredia: Volunteering with NETA contributes to many facets because it blends naturally with my professional growth and my personal values. I am connected to the latest developments within NETA, where conversations, committee work, and shared problemsolving all strengthen how I approach my daytoday responsibilities.

Talović: Professionally, volunteering with NETA helps me stay connected to the industry's direction. It keeps me involved with standards, training, certification, and industry challenges beyond just my own company or local market. Personally, it gives me a sense of giving back and makes it meaningful. I came into this industry by learning from others, making mistakes, asking questions, and working hard to improve. Volunteering gives me a chance to help others on the same path. It also connects me with something I value strongly: mentoring people and helping them grow in their careers.

NW: Please share something about your volunteer experience that would encourage others to get more involved.

Schmidt: To quote *The Lorax* by Dr. Seuss, "Unless someone like you cares a whole awful lot, nothing is going to get better. It's not." You don't have to be the smartest person in the room or have all the answers to be a great volunteer. You can simply show up, care about making the industry a better place to work and live,

and share what you know. What you gain in return is an awesome network, new knowledge and expertise, and the opportunity to give something back.

Maredia: I've had the privilege of working with incredible individuals within the Volunteer Engagement Committee. Being part of a team with a strong collaborative spirit, welcoming atmosphere, positive leadership, and a strategic vision has been a fantastic experience. By volunteering, you gain by getting to know the organization, building relationships, and being inspired by the other volunteers' dedication.

Talović: I would tell others that volunteering with NETA is not just about attending meetings. It is about having a voice in the future of the electrical testing industry. When you volunteer, you work with people who care about the same things you do. You also realize that your field experience matters. The lessons we learn on job sites can help improve standards, training, and programs for the entire industry.

NW: Why is volunteer involvement important to NETA's success and mission?

Schmidt: NETA's history is steeped in long hours spent in proverbial smoke-filled rooms, built by men and women who saw a need to standardize an emerging industry. They knew that while they might be competitors in the market, they were stronger together. Today, our volunteers strive to educate the world about why third-party, independent testing firms and the true certification of test technicians are vital to the health, life, and safety of each person working on or around the electrical equipment tested and maintained by our NETA Accredited Companies. Without the time and knowledge shared so selflessly by NETA's volunteers, the organization would struggle to support this mission and its vision to be the worldwide expert in electrical power systems and equipment assessment.

Maredia: Volunteer involvement is essential to NETA's success because the organization is

VOLUNTEER SPOTLIGHT

built on the collective expertise of the industry. NETA's mission—to advance electrical power system safety, reliability, and technical excellence through accredited companies, certified technicians, and ANSI/NETA standards—can only be achieved when professionals actively contribute their knowledge and realworld experience. Volunteers ensure that the standards, exams, and best practices NETA develops stay relevant, practical, and grounded in what's actually happening in the field.

Beyond that, volunteers create the collaborative environment that makes NETA so strong. They bring diverse perspectives, challenge assumptions, and help the organization stay forwardthinking as the power sector evolves. Without volunteers, NETA wouldn't have the depth of insight or the industry connection needed to maintain its leadership role. Their

involvement is what keeps the mission alive, credible, and impactful.

Talović: Volunteer involvement is important because NETA is built on industry experience. The strength of the organization comes from people who are actively working in the field, managing testing programs, training technicians, reviewing standards, and solving real problems every day. Without volunteers, it would be difficult to keep standards practical, training relevant, and programs connected to what is actually happening in the industry. Volunteers bring the field experience, technical knowledge, and leadership needed to keep NETA strong.

Who will be recognized in the next Volunteer Spotlight? Watch for it in the Winter issue of *NETA World*. [NW](#)



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DGA MONITORING FOR RENEWABLE-ENERGY TRANSFORMERS:

GAS RATE-OF-CHANGE ANALYSIS

BY SHAHRYAR FARHANG and VOLNEY NARANJO, *Megger*

Power transformers used in renewable-energy applications are subjected to elevated thermal, electrical, and mechanical stresses due to the dynamic nature of solar and wind generation. Although these transformers are often specifically designed to withstand such operating conditions and achieve their intended service life, they frequently exhibit higher dissolved gas levels and may experience accelerated insulation aging compared to conventional power transformers. As renewable generation continues to expand, understanding the impact of these unique operating stresses on transformer condition assessment is becoming increasingly important.

This article examines the mechanisms that drive gas generation and insulation degradation in renewable-energy transformers and discusses the limitations of relying solely on absolute DGA gas concentrations. Particular emphasis is placed on continuous online monitoring and the importance of dissolved gas rate-of-change (RoC) analysis as a tool for early anomaly detection.

TRANSFORMER STRESS AND DEGRADATION

Power transformers are subjected to several forms of stress throughout their operational life, including thermal, electrical, and mechanical stresses. These stresses accelerate the aging of the solid and liquid insulation system.

Thermal Stress

Thermal stress is typically associated with overloading and cooling-system deficiencies. In renewable-energy transformers, however, thermal aging is often driven by frequent load fluctuations, inrush currents, harmonics, and cyclic loading associated with solar and wind generation. These conditions can accelerate insulation aging, promote oil degradation, and increase dissolved gas generation, ultimately reducing transformer life expectancy.

Figure 1 shows that a 10°C increase in the operating temperature of a transformer can reduce its insulation lifespan by approximately half [1].

Electrical Stress

Electrical stress is commonly associated with switching surges, transient overvoltage, partial discharge, and arcing. In renewable-energy transformers, electrical stress can be further intensified by power-electronic converters, harmonics, frequent switching operations, and fluctuating power generation. These conditions can accelerate insulation degradation, promote partial discharge activity, and increase gas generation, potentially leading to premature insulation failure if not detected early.

Mechanical Stress

Mechanical stress is often caused by sudden changes in current, including inrush currents, fault currents, and frequent load variations. In renewable-energy transformers, these stresses can be intensified by intermittent generation, turbine start-stop cycles, and rapid power fluctuations. Repeated mechanical forces may lead to winding displacement, deformation, or insulation damage, creating weak points that can accelerate aging and increase the risk of future electrical faults.

Moisture

In addition to thermal, electrical, and mechanical stresses, moisture is a major threat to transformer insulation systems. High moisture levels reduce dielectric strength, limit loading capability, and accelerate insulation aging [2].

Figure 2 illustrates the significant impact of increased moisture content on transformer

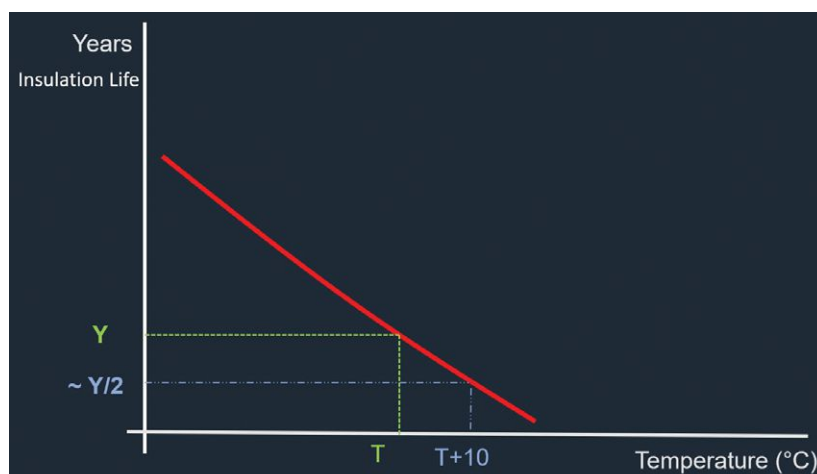


Figure 1: *Aging by Moisture and Heat [1]*

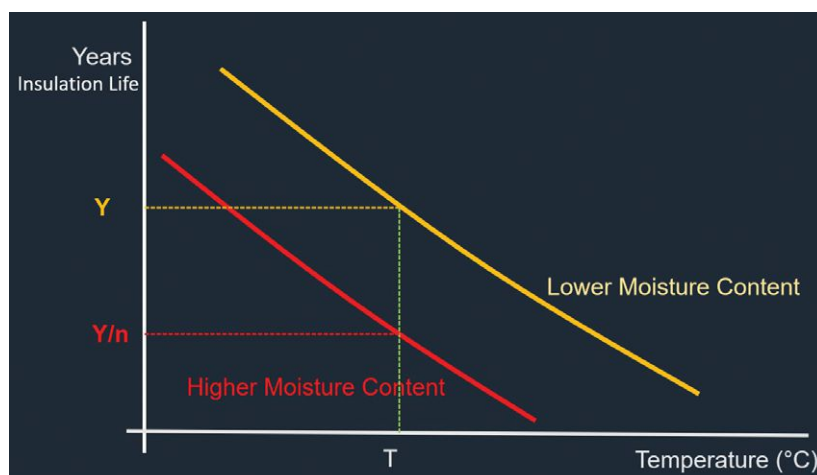


Figure 2: *Aging by Moisture [1]*

insulation life, showing that even relatively small increases in moisture (from 1% to 3%) can dramatically reduce expected transformer lifespan. However, while the focus of this article is on rate-of-change analysis, routine testing and condition monitoring remain essential. Rate-of-change diagnostics should be viewed as a complementary tool.

DGA MONITORING VERSUS OIL SAMPLING

Oil sampling can be compared to a blood test for the human body. Transformer oil carries evidence of insulation aging, overheating, electrical faults, and contamination, making it an excellent indicator of transformer health.



Figure 3: *Installed DGA Monitor vs Manual Oil Sampling*

Oil sampling is typically performed every 6 to 12 months, depending on asset criticality and condition, providing periodic snapshots of transformer health. However, these snapshots may miss rapidly developing events in renewable-energy transformers. In contrast, online DGA monitoring provides continuous trending, enabling earlier detection of changes and developing faults.

RENEWABLE TRANSFORMER CHALLENGES

Renewable-energy transformers are typically subjected to elevated thermal, electrical, and mechanical stresses due to the variable and intermittent nature of solar and wind power generation. While transformers in both solar and wind farms experience these stress mechanisms, their magnitude and dominant characteristics differ between the two applications. Consequently, the resulting aging processes and failure modes may vary.

Table 1 summarizes the key differences in transformer stress profiles in solar and wind farm environments. Conventional oil sampling and dissolved gas analysis (DGA) are valuable for transformer diagnostics, but in renewable-energy applications, dynamic loading can elevate baseline gas levels. This may limit the effectiveness of relying solely on absolute gas concentrations for early fault detection.

ELEVATED GAS LEVELS IN RENEWABLE-ENERGY TRANSFORMERS

A large-scale study of transformer oil samples from wind power plants found hydrogen concentrations significantly higher than those typically observed in conventional transformer applications. Figure 4 illustrates the distribution of hydrogen concentrations observed in the sampled wind-farm transformer population.

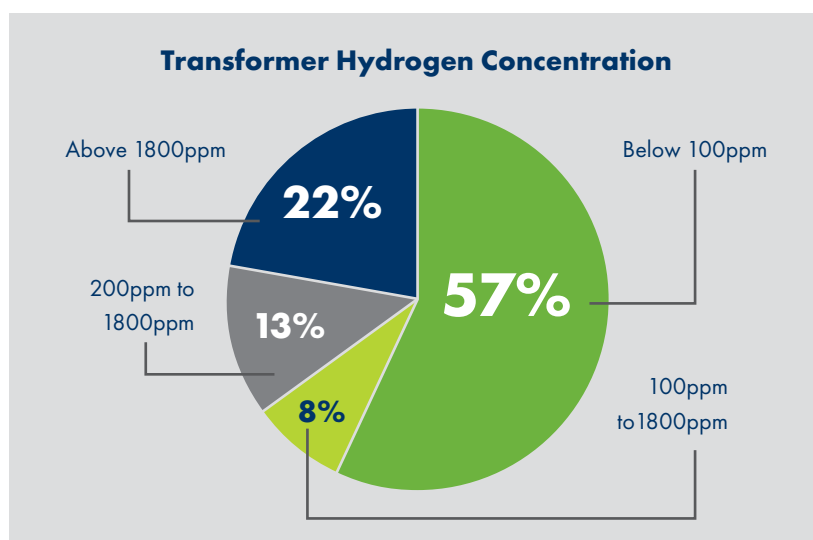
Table 1: *Comparison of Transformer Stress Profiles in Solar and Wind Farms [3]*

Stress Category	Solar Farm Transformers	Wind Farm Transformers
Voltage Fluctuation	Gradual changes due to cloud cover and daily solar irradiance variations	Frequent and rapid changes caused by fluctuating wind speed and turbine operation
Harmonics	Generated by PV inverters; relatively stable operating profile	Generated by power converters; can vary significantly with turbine loading
Thermal Stress	Significant day-night temperature cycling	Variable thermal loading due to changing wind conditions and power output
Mechanical Stress	Generally low; mainly associated with switching operations and load changes	Higher due to turbine start-stop cycles, rapidly changing load, vibration, and transient events
Intermittent Generation	Predictable daily generation pattern with weather-related variability	Less predictable and more dynamic generation profile
Dominant Aging Mechanism	Cyclic thermal aging of insulation caused by daily temperature and loading cycles	Combined electrical and mechanical aging due to frequent load fluctuations and operating transients
Overall Stress Pattern	More predictable, thermally driven stress profile	More dynamic stress profile with stronger electrical and mechanical components

Transformers designed for solar and wind farms are better equipped to withstand thermal cycling, harmonics, and mechanical stresses. However, their unique operating conditions often require a different approach to DGA interpretation.

GAS RATE-OF-CHANGE

Rate-of-change (RoC) analysis is valuable for renewable-energy transformers [5], where normal operation can result in elevated gas levels. By tracking gas-generation rates rather than relying solely on absolute gas concentration, developing faults or abnormal stresses can be identified earlier. As shown in Figure 5, the RoC spikes well before the gas concentration reaches an alarm threshold, providing an early warning of a deteriorating condition.

**Figure 4:** *Hydrogen Concentration of Transformers in Wind Power [3]*

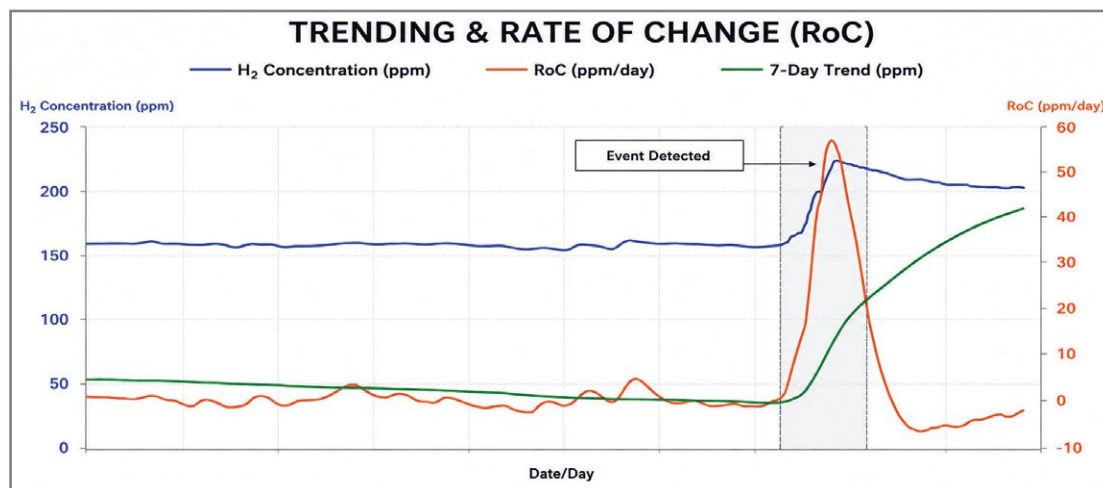


Figure 5: *Trending and Rate of Changes [4]*

Figure 5 demonstrates why RoC can be more informative than absolute gas concentration when monitoring transformers. The chart shows three trends:

- **Blue line:** Absolute gas concentration (ppm)
- **Orange line:** Rate of change (gas generation rate)
- **Green line:** Alarm level or accumulated trend indicator

Before the concentration (blue line) reaches an alarm threshold, the rate of change (orange line) spikes sharply, indicating accelerated gas generation due to a developing fault or elevated operating stress. This provides an early warning even when absolute gas levels remain below critical limits.

Most of the time, DGA interpretation relies on gas formation patterns, absolute gas concentrations, and gas ratios to identify fault types. However, the elevated and fluctuating gas levels commonly observed in renewable-energy transformers can limit the effectiveness of this approach, as seen in Figure 6.

Continuous DGA monitoring can range from single- or few-gas sensors used for fault detection to full-gas monitors used for fault diagnostics. In renewable-energy transformers, early fault detection often provides the greatest

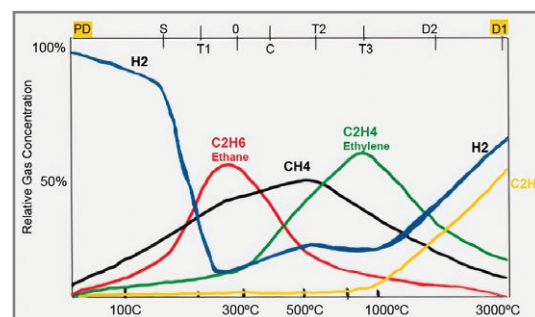


Figure 6: *Gas Formation Patterns as a Function of Temperature and PD [5]*

value, making continuous monitoring and RoC analysis particularly effective tools for asset management. RoC analysis is most effective when used alongside conventional DGA interpretation, historical trending, and other transformer diagnostic information.

LOW-COST DGA MONITORING STRATEGIES

DGA monitors as fault detectors provide an affordable and effective solution for fault detection in renewable-energy transformers, making them well-suited for large-scale deployment across solar and wind sites. These monitors typically measure H₂ and one or two additional gases. To maximize their value, alarm strategies should combine both absolute gas concentration (ppm) and RoC thresholds. This approach improves sensitivity to developing faults while minimizing nuisance alarms, enabling earlier intervention without increasing false alarm rates.

CONCLUSION

Renewable-energy transformers operate under more dynamic thermal, electrical, and mechanical stresses than conventional transformers, often resulting in elevated dissolved gas levels and accelerated insulation aging. While traditional DGA interpretation based on gas concentrations, ratios, and fault-gas patterns remains valuable, these methods may be less effective in renewable-energy environments.

Continuous DGA monitoring, combined with gas RoC analysis, provides earlier visibility of developing faults and abnormal operating stresses. By combining RoC and absolute gas concentration thresholds, asset owners can improve fault detection sensitivity while reducing nuisance alarms. Rather than replacing conventional diagnostic techniques, RoC-based monitoring enhances condition assessment and supports more effective asset management. 

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ELECTRICAL HAZARD RISK ASSESSMENT

ON EV SUPPLY EQUIPMENT AND CHARGERS

BY BIBEK KARKI, *IPS PowerServe*

Electric vehicles (EVs) are a large part of the traffic infrastructure due to the industrial revolution in electrical technology and the paradigm shift in the motor vehicle industry. To support this rapid growth in EVs, the charging infrastructure would need to be designed and implemented at scale. This phenomenon has caused an explosive growth in the design, development, and construction of electric vehicle supply equipment (EVSE).

EVSE refers to the charging infrastructure that safely delivers electrical energy from the power grid to an EV. It includes all the external hardware—such as transformers, overcurrent protective devices (e.g., circuit breakers or fuses), cables, connectors, enclosures (e.g., panel or junction boxes), and control systems—that ensure the proper and safe transfer of electricity for recharging the EV's battery. EVSE could contain all or some of the components, depending on the different voltages and types of charging mechanisms. EVSE is designed to manage and regulate

the electrical connection, provide safety features like isolation and fault detection, and often includes communication protocols to coordinate with the vehicle's onboard charger.

Essentially, while the EV contains its own charging components, the EVSE is the external system that provides the interface between the grid and the vehicle. According to the U.S. Department of Energy, EVSE is not simply a plug or charger; it is an integrated system designed to meet strict safety and performance standards for both the vehicle and the electrical grid.



EVSE with EV Charger and Vehicle [AI-Generated Image]

TYPICAL EVSE AND EV CHARGER SETUPS

EVSE can be found in many different configurations and setups. This depends on the customer's preference on the design, supply power abilities, and location for the EVSE setup. NFPA 70, *National Electrical Code*, Article 625 Electric Vehicle Power Transfer System consists of all EV charging conductors and equipment external to the vehicle, including Level 1, Level 2, and DC Fast Chargers. This is one of the most important references for designing the EVSE. Several other standards—such as UL 2594, *EV Supply Equipment*; UL 2202, *DC Charging Equipment for EVs*; IEEE Std. 2030, *Smart Grid Interoperability*; and IEEE P1547.9, *IEEE Guide for Using Std. 1547 for Interconnection of Energy Distributed Energy Resources with Electric Power Systems*, etc.—can be referred to while designing EVSE. Local city and state jurisdictions should be consulted for meeting and adhering to the code for a robust and effective design.

For the scope of this paper, only Level 2 EV chargers are considered. The EVSE and EV

charger setup and their potential electrical risk assessment methods, data collection, engineering software modeling, and analysis are included. Data was collected by visiting nine different buildings in a large federal facility with this Level-2 charging infrastructure. Each building has at least two charging ports; one building has 16 charging ports. The nameplate information for three-pole 480-V circuit breakers and/or low-voltage disconnect, transformer, 208-V panel, two-pole feeder circuit breakers, and conductor lengths was gathered. Any engineering software capable of modeling short circuit and arc flash hazard analysis can be utilized to create the EVSE power system model and perform risk assessment.

The common design constraint in all of these buildings was typically a 480-V power supply from existing panels. This overcurrent protective device (OCPD) was a thermally magnetic molded-case circuit breaker with no adjustable settings. This OCPD was sized appropriately to protect a dry-type transformer that had a NEMA 3R enclosure. All the transformers were 480-V to 208-V step-down

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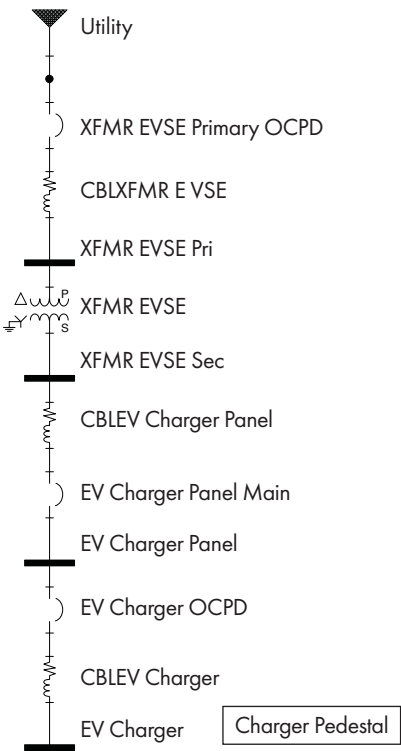


Figure 1: *Single-Line Diagram for an EVSE and EV Charger*

transformers. The downstream of these transformers was connected to a 208-V three-phase panel with a main circuit breaker (MCB). Some of the MCBs had electronic trip units with long time, short time, and instantaneous (LSI) trip settings, and others were thermal magnetic MCBs with fixed instantaneous trip units. All feeder circuit breakers that provided 240-V power to the EV chargers were standard two-pole thermal magnetic MCBs with a fixed trip unit. All the chargers were no farther than approximately 50 feet from the panel. This design configuration is shown in Figure 1.

EVSE AND EV CHARGER ELECTRICAL HAZARDS

EVSE and EV chargers should be installed properly according to applicable standards and OEM instructions. Typically, these pose

hazards similar to those of other electrical equipment, including arc flash, arc blast, and electric shock if exposed to energized components. The batteries in the EV, while charging, may pose additional hazards such as electrical and/or chemical fires and/or chemical exposure. If the charger units are not grounded properly, the charger handle may cause some electrostatic discharge and shock. If the charger cables are not placed correctly after use and sustain any tear in the insulation, this may lead to serious electrocution and arc flash hazards. Most of this infrastructure is located outdoors, so the enclosures should meet the applicable NEMA standards. All of these hazards tend to be serious and multiply when conditions are rainy or wet. Failure Modes and Effects Analysis (FMEA) was performed for the electrical hazards (Table 1).

Hazard	Description	Effect	Severity (S)	Occurrence (O)	Detection (D)	RPN (SxOxD)
Shock / Electrocution	Contact with energized parts due to damaged cables or improper grounding	Severe injury or fatality	10	4	3	120
Arc Flash	High-energy discharge during electric faults	Burns, blindness, fatal injuries	10	3	4	120
Ground Faults	Leakage current from insulation breakdown or moisture	Electric shock, fire risk	8	5	3	120
Overcurrent / Short Circuit	Faulty wiring or connector damage causing excessive current	Fire, equipment damage	7	4	2	56
Improper Isolation	Failure of charger to isolate high-voltage circuits when idle or human error	Shock hazard	9	3	4	108

Table 1: *FMEA for Electrical Hazards*

Notes for FMEA Calculations: Severity (S) = 1 (minor) to 10 (catastrophic) • Occurrence (O) = 1 (rare) to 10 (frequent) Detection (D) = 1 (easy to detect) to 10 (hard to detect) • Risk Priority Number (RPN) = S X O X D

The goal of this exercise was to calculate the risk using numerous factors such as severity, occurrence, and detection. These calculations are based on general industry knowledge. It is recommended to perform FMEA calculations based on the electrical risks from the reader's perspective. These calculations were performed to provide an idea for quantifying the electrical hazards.

ELECTRIC SHOCK HAZARD RISK ASSESSMENT

The electric shock hazard assessment was performed separately for the EV charger and EVSE. For EV chargers, there are no exposed electrical conductors while charging handles are plugged into the charging station. Per OEM and industry standards, power is terminated when not plugged in to charge the vehicle. The charging cord plugs are designed according to the SAE J1772 and UL 2231–2 standards. Since the nominal voltage is 240 V and there are no exposed energized parts, there is no electrical shock hazard.

For the EVSE, there are no exposed electrical conductors. All EVSE components, such as transformers, disconnects (if any), 208-V panel, and cables, are enclosed in an appropriately rated NEMA 3R enclosure (Figure 2). All covers are in place, and all the hardware is fastened per OEM guidelines. When covers are removed, there are shock hazards as listed below:

- Nominal Voltage
= 208 V/240 V
- Limited Approach Boundary
= 42 inches
- Restricted Approach Boundary
= 12 inches

This is derived from NFPA 70E–2024 Edition, Table 130.4(E)(a) Electric Shock Protection Approach Boundaries to Exposed Energized Electrical Conductors. These boundaries are applicable to 208-V, 240-V, or 480-V power systems.

Per this unit's manufacturer, the EV charger has 20-mA charge current interrupting device (CCID) ground-fault detection. A CCID is essentially a smart switch that monitors the flow of current in the charging cable. When the CCID detects a fault, it interrupts the flow of current, thus preventing any further damage. The CCID is typically installed as a part of the charging station's interior controls, working like the GFCI principle. This EV charger also has an open safety ground detection feature, which continuously monitors the presence of a safety ground connection. The cord had plug-out detection features per SAE J1772, and the power is terminated once the charger is removed from the plug.

ARC FLASH HAZARD RISK ASSESSMENT

Like the electric shock hazard assessment, the arc flash hazard risk assessment was performed separately for the EV charger and EVSE. The software model was created for all nine buildings, and incident energy was calculated in the EVSE distribution panel and EV charger. All calculations were performed according to IEEE 1584–2018 and NFPA 70E–2024 for the working distance of 18 inches. Table 2 consists of incident energy and arc flash boundary calculations for the EVSE distribution panel, and Table 3 consists of similar calculations for the EV charger.



Figure 2: Typical EV Charger Pedestal during Charging

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Location/Building	Transformer Size for Power Source (kVA)	Main Circuit Breaker in Distribution Panel	Incident Energy (cal/cm ²)	Arc Flash Boundary (inches)
1	45	ETU (LSI)	5.35	43
2	45	Fixed Inst.	9.64	57
3	112.5	Adjustable Inst.	19.6	94
4	45	Fixed Inst.	4.76	43
5	45	ETU (LSI)	5.35	41
6	75	Adjustable Inst.	11	67
7	45	Fixed Inst.	6.24	47
8*	150	ETU (LSI)	0.07	3
9*	225	ETU (LSI)	0.13	4

Table 2: Arc Flash Hazard Assessment Calculations for EVSE Distribution Panel

Location/Building	Transformer kVA for Power Source	Incident Energy (cal/cm ²)	Arc Flash Boundary (inches)
1	45	0.02	2
2	45	0.02	2
3	112.5	0.07	4
4	45	0.02	2
5	45	0.01	1
6	75	0.54	11
7	45	0.02	2
8*	150	0.38	9
9*	225	0.13	4

Table 3: Arc Flash Hazard Assessment Calculations for EV Chargers

Most buildings have the power system shown previously in Figure 2 with the dedicated transformer for EVSE and then subsequent downstream equipment for EV charger. Building 8 and Building 9 have a different

power system for EVSE as shown in Figure 3. These buildings have a separate EVSE distribution panel but share a common transformer, larger in size compared to the other buildings.

The common trend for all the buildings is that the incident energy in the EVSE distribution panel is directly proportional to the transformer size, where the transformer is dedicated to the EVSE. There was a slight difference in incident energy for the EVSE distribution panel, which had an electronic trip unit in its MCB, compared to the fixed trip unit counterparts. The average arc flash boundary is 48 inches except for the panel being fed by a 112.5-kVA transformer. Most of the EV chargers were about 8 to 10 feet away from the parking lot for all buildings.

The incident energy for all EV chargers was significantly lower than EVSE. This is a typical result found in arc flash hazard calculations since this equipment is downstream of the EVSE transformers. The average incident energy is 0.13 cal/cm², and the arc flash boundary is about 4 inches. Most users are always out of this arc flash boundary while using the chargers, and the charging plug is almost 5.2 inches long, which is outside of the arc flash boundary.

The incident energy and arc flash hazard analysis align with the typical power system hazard analysis. The further downstream we go from the transformers, the lesser the incident energy. Most of the overcurrent protective devices cleared the fault according to their respective fault-clearing times. There were some scenarios where the fault-clearing time was 2 seconds. In other terms, a fault has occurred, the protective device has yet to clear the fault, and it becomes the technician's responsibility for his/her safety to react and leave the arc flash boundary. Based upon IEEE Std. 1584, Annex B.1.2, personnel

working near the fault will react and leave the arc flash boundary within two seconds.

FURTHER WORK

This paper only included Level 2 chargers from certain manufacturers in the analysis. There are several other EV chargers that are different from these in capacity, type, charging mechanism, and design. The plan is to build on this research, gather additional field data, and perform risk-hazard analyses across multiple EV chargers. Another goal is to conduct more research on other possible hazards, such as explosions, electric fires, thermal runaway on batteries, etc. The ultimate goal would be to combine the EVSE, EV chargers, and EVs and calculate/analyze the hazards for the entire system. This field is rapidly evolving with advances in technology, and many variables have been introduced to make it a safer, user-friendly system.

CONCLUSION

EVSE and EV chargers are an essential part of modern technology. They use electrical power on the scale of 208 V/240 V or 480 V with several Amps (40–100) in range, so there are always going to be inherent electrical hazards as with other electrical equipment. This infrastructure should be installed according to manufacturer (AHJ) specifications, and local authority having jurisdiction (AHJ), and well-maintained according to applicable NFPA 70B and/or OEM specifications. Well-maintained EVSE and EV are less likely to have significant failures compared to neglected ones. Like other electrical equipment, they will improve our standard of living and enhance technology if we take care of them and understand the hazards around them. [NW](#)

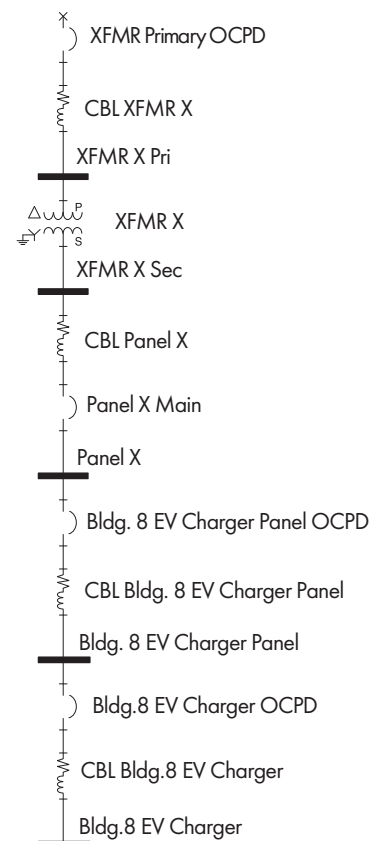


Figure 3: *Single-Line Diagram for an EVSE & EV Charger for Buildings 8 and 9*

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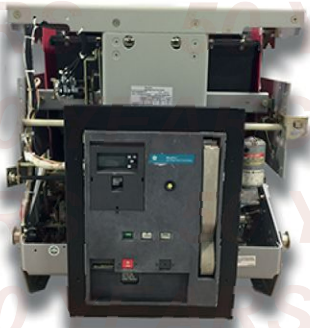

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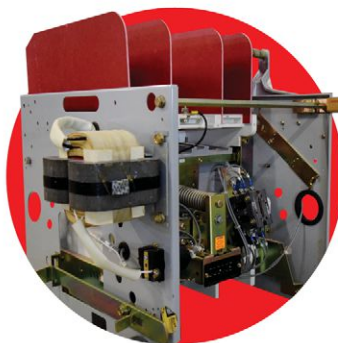


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DEMYSTIFYING ON-LINE PARTIAL DISCHARGE MONITORING

BY BOBBY ELLISON, *IPEC USA*

Reliability and safety are words that come up frequently when discussing modern power networks, and for good reason. Electrical systems today are carrying higher loads, operating with tighter margins, and supporting facilities such as data centers and industrial plants, where downtime is not an option. As a result, operators are placing greater emphasis on technologies that provide early warning of developing issues rather than reacting after a failure occurs.



*Partial Discharge on a
Medium-Voltage Cable*

One technology that has gained significant attention in this context is on-line partial discharge (PD) monitoring. It offers a practical way to continuously monitor the health of medium- and high-voltage power networks without taking assets out of service. While it is difficult to put an exact dollar figure on an outage that never happens, the operational value of avoiding unexpected failures is widely understood. More importantly, knowing the condition of energized equipment in real time helps operators make safer, more informed decisions, protecting people, equipment, and the continuity of operations.

WHAT PARTIAL DISCHARGE IS AND WHY IT MATTERS

Partial discharge is formally defined as an electrical discharge that does not completely bridge the insulation between two conductive parts. In practical terms, PD activity occurs at insulation defects—voids, cracks, contamination, or interfaces—where localized electrical stress exceeds the strength of the material. While individual discharge events may be



Switchgear Failure Due to Undetected Partial Discharge

small, their presence is a well-established early indicator that insulation is degrading.

Left unchecked, sustained PD activity typically accelerates insulation damage and can eventually result in a full dielectric breakdown or fault. This is why PD has long been of interest to those responsible for testing, commissioning, and maintaining electrical assets.

PD can be detected using a wide range of techniques, typically divided between off-line testing and on-line testing. Each method has its place, depending on the asset, operating environment, and maintenance objectives. The focus here is on on-line PD monitoring, which allows condition assessment while equipment remains energized and in service.

A PRACTICAL WAY TO THINK ABOUT PD

A simple analogy helps illustrate the concept. Consider a small leak in a high-pressure pipe. The system continues to operate, sometimes

for quite a while, but the integrity of the pipe has already been compromised. Over time, that leak worsens as stress concentrates around the defect, until the pipe eventually fails—often suddenly and with significant consequences.

Electrical insulation behaves much the same way. Once a void or defect develops, partial discharge activity begins. Environmental and operating stressors such as load changes, temperature fluctuations, and transient overvoltage work against the insulation and accelerate damage.

On-line PD monitoring is intended to detect this leak early, allowing operators to plan repairs, divert load, or schedule outages on their own terms rather than reacting to an unexpected failure.

LOOKING BEYOND A SINGLE ASSET

If we zoom out from a single cable and instead consider an entire interconnected electrical system, the implications of insulation degradation become much easier to appreciate.

Any one defect may seem insignificant on its own, but across a large network, the cumulative risk grows quickly. The consequences are no longer limited to a single failure; they can include extended downtime, widespread damage, and, in the worst cases, serious safety hazards or loss of property.

It is true that electrical grids and facility power systems have operated for decades without the continuous diagnostic tools available today. However, those systems were also designed for very different operating conditions. Load profiles were smaller, equipment was often overbuilt, and reliability expectations were less unforgiving than they are now. Today's electrical infrastructure operates closer to its design limits and is subjected to higher and more dynamic stress than ever before.

The additional stress and dynamic load profiles matter. Load cycling, temperature variation, and transient operating conditions all contribute to increased electrical stress on insulation systems. Once a defect exists, these factors do not remain neutral; they actively worsen it.

Let's go back to the pipe analogy. A small leak under steady conditions may persist for years. Increase the temperature, raise the pressure, and introduce cyclic loading, and that same defect accelerates toward failure. Electrical insulation behaves in much the same manner. A void or imperfection exposed to increased electrical and thermal stress will produce more partial discharge activity and degrade more rapidly over time.

Seen in this context, partial discharge is not abstract, mysterious, or unreliable. It is a measurable, physics-based response to stress within insulation. What has changed over the years is not the phenomenon itself, but our ability to observe it reliably in real operating environments.

When these factors are taken together, the role of on-line partial discharge monitoring in supporting safety and reliability becomes clear. Early adopters, especially those responsible for

large critical facilities, are incorporating this approach into their maintenance strategies, not as a replacement for established practices, but as a practical supplement to them.

ON-LINE PD MONITORING FILLS A PREVIOUSLY UNKNOWN GAP

For operators managing large electrical networks such as data centers, industrial facilities, or utility systems, on-line PD monitoring provides tangible operational advantages. Continuous insight into asset condition allows maintenance decisions to be based on actual system behavior rather than elapsed time alone. In some cases, maintenance intervals can be confidently extended or deferred when condition data confirms acceptable performance. In others, emerging PD activity highlights exactly where attention is needed, enabling targeted shutdowns instead of broad, disruptive outages.

When integrated into existing maintenance or building management systems, PD alarms and condition indicators can flow naturally into established workflows, often autonomously initiating inspections, guiding prioritization, and helping teams respond early rather than react late. The result is a condition-based maintenance approach that focuses time and resources where they provide the most value, while minimizing unnecessary downtime.

Advances in technology have also made on-line PD monitoring far more practical to deploy. Modern systems can be implemented in both new and existing installations. New facilities may incorporate monitoring during construction for optimal coverage, while existing sites can often be retrofitted without major redesign or disruption. Broad compatibility with common switchgear and cable systems has reduced the barriers that once limited adoption, making large-scale deployment a realistic option for many operators. Modern systems allow for installation without taking shutdowns and allow for maintenance access without requiring labor intensive removal of the system.

THE NOISE REJECTION ARGUMENT

One of the most common questions surrounding on-line PD monitoring is straightforward: How do you know it's actually PD and not just noise?

This is a valid concern. In energized environments, particularly in underground medium-voltage cable systems, PD signals can be very small and easily masked by ambient electrical noise from normal system operation, power electronics, and external interference. Historically, addressing this problem required a two-step approach: collecting field data and then relying on off-line expert analysis to separate PD activity from noise. While effective for limited deployments, this method becomes impractical in large facilities where hundreds or thousands of assets must be monitored continuously.

To be viable at scale, modern PD monitoring systems must operate with a high degree of autonomy. That means filtering noise, classifying pulse characteristics, and identifying meaningful events without constant manual intervention. Accuracy is critical, as false positives quickly erode confidence and place an unnecessary burden on maintenance teams.

Reliable autonomous detection depends on both high-quality data and advanced analysis techniques. Modern systems typically employ high sampling rates and sufficient bit resolution to capture the fine detail needed for effective pulse discrimination. This level of fidelity enables advanced signal processing methods to distinguish legitimate PD pulses from background interference.

Over time, trending becomes just as important as individual events. By establishing baselines and tracking changes in activity, monitoring systems can highlight gradual degradation that might otherwise go unnoticed. This long-term perspective allows operators to intervene early, well before conditions become critical.

THE ON-LINE MONITORING STACK

While on-line partial discharge monitoring systems may look different from one manufacturer to the next, the underlying building blocks are largely the same. At a high level, every system comprises three functional layers: sensors, signal processing, and data interpretation (Figure 1). Understanding this basic stack goes a long way toward removing the mystery often associated with PD monitoring.



Figure 1: On-line monitoring systems consist of three functional layers: sensors, signal processing, and data interpretation.

At the lowest level are sensors, which are the components that interact directly with the electrical asset. Sensor form and detection styles vary (Figure 2), but they all work to detect the same physical phenomenon: rapid energy release caused by partial discharge.

Acoustic sensors, which are seen in many on-line monitors and handheld detectors, listen for PD activity by detecting ultrasonic energy produced when a discharge happens. These sensors are typically line-of-sight devices and are most effective when placed close to the source, such as on switchgear or accessible cable terminations.

Transient earth voltage (TEV) sensors detect very-short-duration transients that occur on grounded metal surfaces when PD occurs inside enclosed equipment. These signals are extremely small, comparable in magnitude to static electricity, so these sensors utilize capacitive coupling to make them measurable.

High-frequency current transformers (HFCT) take a different approach. Installed around a ground conductor or cable shield, they detect high-frequency current pulses associated with partial discharge events. Rather than listening or sensing voltage, HFCTs observe how PD activity manifests as current in the grounding system. Examples of these types of sensors can be seen in Figure 2.



Figure 2: *Airborne Acoustic, Transient Earth Voltage, and HFCT*

While the form and placement of these sensors vary, the same purpose is served: converting a physical event into an electrical signal that can be measured.

Translating signals into data is accomplished by transmitting captured analog or digital data to a processing device such as an industrial computer or embedded processor. This step is where much of the historical skepticism around PD monitoring has originated. Raw PD signals, taken alone, often look messy and are easily confused with background noise from normal system operation.

Modern systems address this by digitizing signals at high speed and applying structured processing. The goal is not to capture every fluctuation, but to identify patterns that match known PD behavior while rejecting unrelated interference. In other words, the system is not guessing—it is filtering, comparing, and classifying events based on consistent rules. Depending on system architecture, this processing may take place locally at the device or be supported by centralized infrastructure.

The final layer is interpretation. Rather than expecting operators to interpret raw waveforms, modern monitoring platforms focus on trends, alerts, and condition indicators that fit naturally into existing maintenance workflows. A practical example of this translation is the use of real-time phase-resolved partial discharge (PRPD) heatmaps (Figure 3), where complex signal data is converted into recognizable visual patterns that support consistent interpretation. When PD activity changes over time, the system highlights that shift so it can be investigated before it develops into a failure.

Seen this way, on-line PD monitoring is not fundamentally different from other condition monitoring technologies already in use. Sensors observe a real physical phenomenon, processors clean and organize the data, and the results are presented in a way that supports informed decision-making. Once the technology stack is understood as a whole, it becomes clear that on-line PD monitoring is not guesswork or

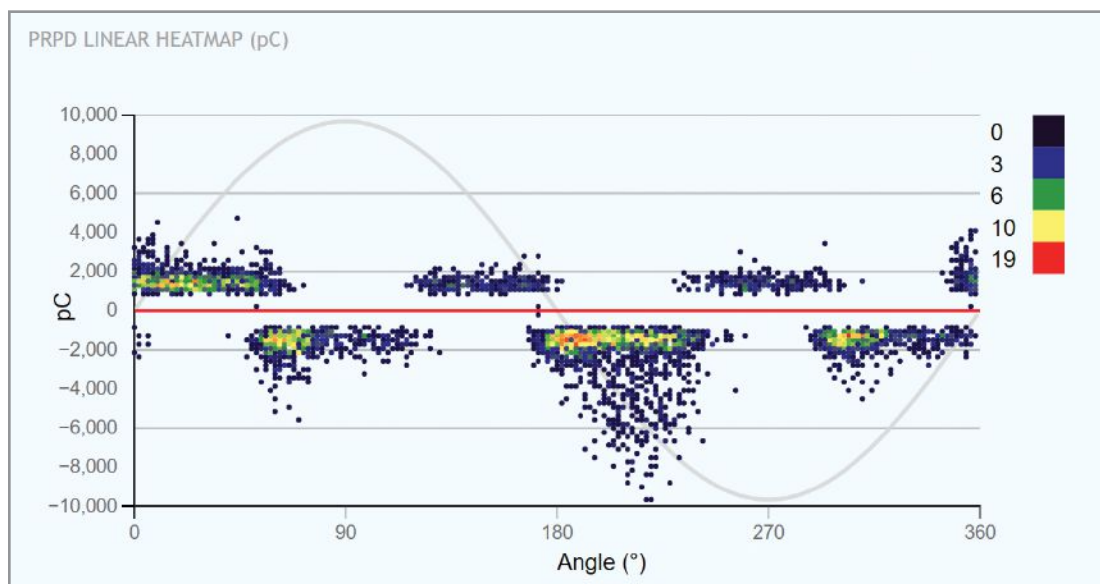


Figure 3: *Phase-Resolved Partial Discharge Map*

black magic, but a structured process of precise data collection and interpretation.

Permanent monitoring is not always practical or necessary for every asset, which is where portable and handheld PD survey instruments continue to play an important role. These tools are particularly useful for screening unmonitored equipment and for locating the physical source of PD activity identified through continuous monitoring.

Handheld instruments (Figure 4) range from simple go/no-go devices to more advanced tools incorporating noise filtering and PRPD pattern analysis. When used as part of a broader condition-based maintenance program,



Figure 4: *Handheld PD Survey Instrument*

they provide a flexible and cost-effective way to extend diagnostic capabilities into the field.

MODERN DATA ANALYSIS

Interpreting PD data still requires experience and a solid understanding of discharge mechanisms and severity. Expert analysis remains essential, particularly when determining root cause and appropriate corrective action. However, modern monitoring platforms increasingly help by summarizing large data sets into clear indicators of asset health and risk.

When applied correctly, this information allows maintenance teams to prioritize inspections, plan targeted shutdowns, and address issues before they escalate into failures. Identifying insulation defects early not only improves reliability but also makes repairs safer, more efficient, and less disruptive.

On-line PD monitoring enhances traditional testing and maintenance by providing continuous visibility into insulation health, enabling earlier, better-informed decisions. When integrated thoughtfully, it supports a holistic approach to electrical system reliability, helping operators meet today's demands while preparing for the challenges ahead.

CONCLUSION

Partial discharge isn't witchcraft—it's a predictable, measurable response to insulation stress. Electrical systems today operate under higher loads, tighter margins, and greater thermal and operational stress than in the past, which accelerates insulation defects once they exist.

What's changed isn't the physics of partial discharge, but our ability to observe it reliably while equipment is energized. On-line PD monitoring gives operators continuous, practical insight into asset condition, allowing maintenance decisions to be based on real behavior rather than tradition or fixed schedules. The result is safer operation, fewer unplanned outages, and more focused, condition based maintenance across large electrical systems. **NW**



Bobby Ellison is a Senior Project Engineer at IPEC with more than a decade of experience spanning critical power systems, field operations, project engineering, and customer-focused technical strategy. He began his career with Cummins Inc., building a strong technical foundation through hands-on work in emergency and critical power environments. Known for his steady leadership approach, technical credibility, and ability to align teams and customers, Ellison brings a pragmatic, execution-focused mindset that consistently turns technical challenges into practical business value.



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A woman with dark hair, wearing a dark blazer over a blue and white striped shirt, is looking down at a tablet computer she is holding. The background is a blurred server room with blue lighting and rows of server racks.

THE EVOLUTION OF STANDARDS TO SUPPORT ADVANCING GRID TECHNOLOGIES

BY HOWARD W. PENROSE, *MotorDoc*

The electric power industry is undergoing the largest transition since widespread energization began more than a century ago. Inverter-based resources, data centers, and rapidly changing load profiles are exposing operating conditions that were never envisioned when many IEEE standards for machinery were originally developed. As a result, IEEE and other standards organizations are revising existing standards while developing new guidance to address these emerging challenges. This article discusses why testing standards are changing, the technical forces driving these changes, and what engineers and technicians should expect as electrical systems continue to evolve.

Many of the changes to electric machinery standards relate to the transition of the grid and the impacts of new loads. While we continue to see advances in materials and designs, the electrification of everything has a significant impact on the reliability of, well, everything.

I've served on IEEE Power Engineering Society (PES) Materials Subcommittee, Motors Subcommittee, and Generator Subcommittee standards since I first became a member of IEEE in 1993. At that time, we were exploring new advances in materials technology and testing technologies, with the backbone of the standards provided by engineers with 30-plus years in the industry, and support from utilities, end users, OEMs, and academics. Effectively, a standards committee or working group is, and was, represented, by as many stakeholders as possible. My service included being a machinery repair and field service technician/engineer, then an academic, then field service and consulting, and an OEM. This provided an interesting viewpoint.

WHY EXISTING STANDARDS ARE BEING REVISITED

Historically, IEEE machinery standards evolved slowly because machine designs, materials, operating environments, and utility systems changed gradually. Today, nearly every assumption surrounding electrical systems, including machinery, is changing simultaneously and dynamically. Utilities are integrating inverter-based resources, industrial facilities are installing variable frequency drives (VFDs) in unprecedented numbers, transportation is electrifying, and hyperscale data centers have become significant non-linear electrical loads. These developments have fundamentally altered the electrical environment experienced by motors, generators, transformers, and associated insulation systems.

IEEE Std. 1415, *IEEE Guide for Induction Machinery Maintenance Testing and Failure Analysis*, originally released in 2006, represented an ambitious effort for its time. Rather than simply serving as another testing guide, its scope extended to selecting appropriate maintenance

tests, interpreting results, investigating failures, and conducting root-cause analysis (RCA). The guide combined visual inspections, more than 40 diagnostic methods, maintenance recommendations, and failure analysis into a single document intended to help engineers determine not only whether a machine had a problem, but also why it had failed and how similar failures could be prevented.

While many users appreciated this comprehensive approach, others questioned whether portions of the document extended beyond what an IEEE guide should encompass. The differing technical philosophies, combined with the rapid evolution of diagnostic technologies and industry practices, ultimately resulted in the guide being administratively withdrawn so that it could be completely restructured rather than incrementally revised.

In many respects, the industry had outgrown the original document. The current IEEE 1415 project is therefore not simply an update but rather an opportunity to retain the original vision while incorporating nearly two decades of advances in machinery diagnostics, condition assessment, and modern power-system operation.

From my perspective as both an original contributor and now chair of the rewrite effort, the discussion surrounding IEEE 1415 demonstrates that standards development is rarely about technology alone. It is about reaching consensus among manufacturers, utilities, service organizations, researchers, consultants, and end users, each bringing different experiences and priorities to the same technical problems.

Those who are familiar with the standards might realize that IEEE Std. 62.2, *IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus – Electrical Machinery*, could be similar. However, IEEE 62.2 focuses on large machines over 3,000 volts, which leaves out specific machines, and it serves as a guide for just the inspection and testing, but not the RCA. This becomes important as the focus of standards development relates to impacts on the modern grid, such that wind turbine generators,

of which more than 96% are induction machines, become a serious consideration. So we extended the scope in IEEE 1415 to include asynchronous power generation.

THE MODERN GRID HAS CHANGED THE RULES

As energy production and distribution have evolved, the standards groups have found the need to evolve with them. Written and published in 2018, IEEE PES-TR69, *Technical Report on Coordination of Grid Codes and Generator Standards: Consequences of Diverse Grid Code Requirements on Synchronous Machine Design and Standards*, is already making major revisions as the makeup of the transitioning grid continues. The operation, stresses, and capabilities of the modern grid have changed dramatically during the past decade. Systems designed around early 20th-century assumptions must now accommodate operating conditions that were never envisioned by their designers.

New testing systems and methods have been introduced into standards and research through organizations such as EPRI, National Labs, and CIGRE, in addition to studies on the impacts of everything from electric vehicles to data centers. This includes concerns about

the impacts of these systems, in addition to cybersecurity considerations, related to mysterious failures of relay systems that were designed around primarily line frequency and lower-order harmonic contributions (up to the 50th). Within recent years, we have just become exposed to supra-harmonic conditions, which are defined as harmonics in the range of 2 kHz to 150 kHz, and associated intra-harmonics that are primarily driven by energy conversion from AC to DC. This does not include conditions that have not yet been discovered or proven.

Perhaps the most significant aspect of this transition is that experienced personnel are retiring while a new generation of engineers and technicians is entering the industry, creating an unprecedented challenge in knowledge transfer. Factors that contribute to this range from the COVID-19 pandemic and what occurred afterward, the focus on computer simulation in academics and engineering, and massive new systems where how they operate is viewed as a trade secret—all hitting at the same time. Add to that how deregulation has impacted generator operation and the amount of time it takes to make adjustments to grid code recommendations.



We have also introduced such technologies as high-voltage direct current (HVDC), which includes converter and inverter switching and related power disturbances, and a variety of independent power sources that play—or don't—by the rules. The discussions at the grid level and in engineering organizations are quite interesting and often more reactive than they have been in the past. This is partly due to the fact that we don't have the data to generate the models that most have become dependent on.

WHAT ENGINEERS ARE SEEING IN THE FIELD

We see this at the power generation side, as synchronous base-load systems age rapidly, new technologies have higher failure rates than expected because of unknowns, systems in buildings and factories fail, and unexplained failures occur in all levels of the electrical systems. We note higher gassing and temperatures in transformers, unexplained relay trips, ferrous materials in generator rotors, electric motors, new lighting systems failing at unexplained frequencies, and far more.

STANDARDS FOLLOW INDUSTRY EXPERIENCE

Standards normally follow conditions. This means that when we are working on these standards, we are looking at the condition and doing several things:

1. **Knowledge transition.** Comparing a standard written in the past 5–7 years, you will note that more explanations concerning the reasons for declarations are provided in the standard. This is the education part, where someone picking up a standard for the first time can have some idea why things are done per the standard.
2. **New standards.** As information is learned and testing methods are incorporated, they are being added to standards. This does leave a lag, as an average non-controversial standard will still take 3–5 years to complete.
3. **Rapid harmonization.** Different standard groups work hard to ensure that standards across organizations, such as between IEEE and IEC, etc., are similar enough not to contradict.

The result of these changes is a new generation of standards that do more than specify test procedures. They provide engineers and technicians with the technical background needed to understand why tests are performed, how the tests should be interpreted, and the capabilities and limitations of each method. This allows testing, inspection, maintenance, and engineering decisions to be supported by sound technical reasoning rather than simply following a procedure.

NEW CHALLENGES DRIVING STANDARDS DEVELOPMENT

Due to the impact of the modern grid, there have been improvements to existing standards, from large generator and motor core inspections to the dissection of coils in electric machines.

At American Clean Power Association (ACP), we had to perform several studies on transformers, as inverter-based (IBR) resource-related transformer gassing did not meet any existing standards. This has resulted in the development of several new standards (in process) based on measurements, experience, and failure rates for these industries. The question of where supra-harmonics are primarily generated has been enough of an issue that several organizations are kicking off studies to look at where they are actually generated, or if they are the result of multiple conditions. This is because bias, assumptions, and misinformation in several standards and peer-reviewed (and non-peer-reviewed) papers continue to propagate opinion over studied fact.

So what have we been doing in the standards arena? A lot. We are updating standards to reflect what is known about existing conditions. New standards are being developed that provide a deeper understanding of the data being obtained in order to make technicians and engineers more effective. We have studies in

place to expand existing and new standards as new information unfolds. We have collaborative work between organizations, including between NETA and ACP on splicing in wind, solar, and battery storage locations (the ACP splicing guide is a best practice, not a standard).

CURRENT IEEE MACHINERY STANDARDS UNDER REVISION

Here's an example of how it is being handled in the standards arena using the IEEE PES Materials Subcommittee as an example (the following is based upon the presentation given at the PES General Meeting in July 2026). The theme relates to new challenges in power generation equipment. This focus is due primarily to the introduction of renewables and data centers, resulting in voltage and frequency issues, reactive power issues, rapid changes in load, and out-of-spec operations.

As mentioned, owners and OEMs both realize that older equipment, and some newer, are experiencing rapid aging across all power generation. The standards within the subcommittee are being adjusted to accommodate the new environment, including:

- Thermal classification of materials: IEEE 117 and 1776 (in working group)
- Testing of electrical insulation systems: IEEE 286 and 433
- Testing of turn insulation (surge testing form-wound equipment): IEEE 522
- Assessing insulation quality and general condition: IEEE 3149
- Maintenance/repair/inspection of machines: IEEE 56, 62.2, 1719
- Testing with direct voltage: IEEE 43, 95, 97 (new)
- Simulated aging of insulation systems: IEEE 1043, 1310, 1553
- Partial discharge measurement: IEEE 1434, 1799, 2465

WHAT THESE CHANGES MEAN FOR ENGINEERS AND TECHNICIANS

A review of these standards and a comparison to even the last versions will demonstrate to the reader that there have been major changes. In

another group, where I chair the new 1415, the work will result in a complete rewrite as we incorporate the changes, test methodologies, and how they are now interpreted. Picking up and referencing an older standard may no longer provide the correct answers, which makes it incumbent upon the engineer or technician to become familiar with the changes when testing and reporting. We have noted significant failures over the past decade resulting from misunderstandings or misinterpretations of the standards or the mistaken belief that something not mentioned in the standard must not be a concern.

Engineers, technicians, and asset owners can no longer assume that guidance contained in decades-old standards fully reflects today's operating environment. Modern power systems continue to evolve rapidly, and standards are evolving with them. Remaining current with these revisions is no longer simply a matter of compliance; it is becoming essential for accurate testing, correct interpretation of results, and reliable operation of critical electrical assets of all types.

For those of us involved in standards development, the objective remains unchanged: Provide engineers and technicians with guidance that reflects real operating experience, supports sound engineering judgment, and continues to improve the reliability and safety of the electrical infrastructure on which modern society depends. [NW](#)



Howard W. Penrose, is President of MotorDoc LLC, a veteran-owned small business, and Founder/CEO of Human Reliability Intelligence Labs. He is Chair of the CIGRE-USNC A1 Study Group (power generation), Chair of IEEE 1415, Chair of ACP transformer

DGA standards, convenor of CIGRE A1.78, and serves on IEEE, ACP, and CIGRE standards and related committees. Penrose also serves on the IEEE PES Grid Code Committee responsible for the power generation section and is a leading researcher in supra-harmonic impacts.

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RESIDUAL VOLTAGE IN POWER CABLES: A LITTLE-KNOWN HAZARD IN FIELD TESTING

BY NILSON BARONI JR AND DANIEL BENTO, *Baur USA Corp*; DANILO DE SOUZA, *UFMT*,
and MARCELO PLANTIER, *Baur Brazil*

Verifying the integrity of power cable insulation is an essential step to ensure the reliability and safety of electrical systems. Applied-voltage tests are widely used before commissioning new cables and during maintenance and diagnostic activities throughout their service life. These tests enable identification of insulation defects, dielectric degradation, or installation issues that could lead to operational failures, supply interruptions, or safety hazards. Therefore, high-voltage testing constitutes a fundamental tool for assessing the dielectric condition of insulated cables in both distribution and transmission systems.

Historically, many of these tests were performed by applying direct high-voltage (DC Hipot), a practice still used in some field routines. However, N. N. Srinivas, et.al. demonstrated that applying direct voltage can induce space charge and dielectric stress in cables with extruded insulation, such as XLPE, potentially contributing to insulation degradation and reducing cable service life.

As a result, the use of alternative methods for testing cables with extruded insulation has been progressively consolidated, particularly very-low frequency (VLF) testing. These methods are currently recommended by major international

technical guides, especially IEEE Std. 400.2, *IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)*, which establishes procedures, voltage levels, and acceptance, maintenance, and diagnostic testing criteria for power cable systems.

The application of low-frequency alternating voltage provides better correlation with the actual operating conditions of the electrical system while also reducing the adverse effects associated with the use of direct voltage in polymeric dielectric materials. In this context, VLF testing has become a widely adopted

practice for assessing the integrity of insulation in field-installed medium-voltage cables.

Regardless of the testing method used, de-energizing the system and applying voltage to insulated cables involves storing electrical energy in the distributed capacitance of the cables. As a result, electrical charges may remain trapped in the insulation after the test source is switched off or even after the circuit is de-energized prior to testing, giving rise to residual voltages.

This phenomenon has significant implications for the safety of field personnel and the integrity of connected equipment. In this context, this article addresses the mathematical modeling of the residual electric field in insulated cables subjected to applied voltage tests, explains the physical origins of residual voltage after the test source is disconnected, presents a numerical model applied to real cables, and incorporates procedures recommended by the IEEE for field testing.

RESIDUAL VOLTAGE IN INSULATED CABLES

Residual voltage in insulated cables corresponds to the electrical voltage that remains in the system after the high-voltage test source is switched off. This phenomenon is not necessarily associated with a cable failure but rather results from the storage of electrical charges in the insulation during the application of the test voltage. In power cables, especially those with polymeric insulation, a portion of this stored

energy may remain in the dielectric after the source is removed, resulting in a potential difference between the central conductor and the metallic shield or grounding system.

From an electrostatic perspective, the cable can be interpreted as a distributed capacitor along its length. During the high-voltage test, electrical energy is stored in the electric field within the insulation, according to the energy-storage equation of a capacitor, as shown in Equation (1). In this relationship, W represents the energy stored in the cable's electric field, C is the cable's equivalent capacitance, and V_0 is the voltage applied during the test.

$$W = \frac{1}{2} CV_0^2 \quad (1)$$

After the high-voltage source is switched off, this energy is not dissipated instantaneously, as the system has leakage resistances and dielectric absorption within the insulation. As a result, energy dissipation occurs gradually, leading to a progressive decay in voltage over time and the formation of a residual voltage in the cable.

Figure 1 illustrates this concept by presenting an analogy between the ideal behavior of the cable as a capacitor and a more realistic equivalent model, in which phenomena such as leakage currents and dielectric absorption influence the dissipation of the stored energy.

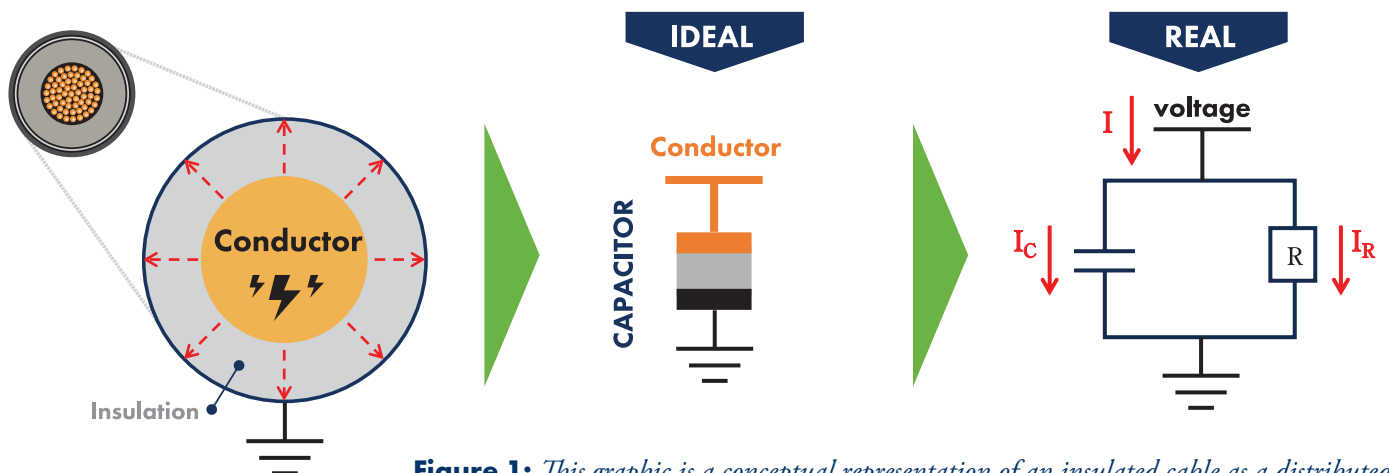


Figure 1: This graphic is a conceptual representation of an insulated cable as a distributed capacitor and the equivalent circuit associated with the residual voltage phenomenon.

Polymeric insulating materials used in power cables, such as cross-linked polyethylene (XLPE), exhibit dielectric absorption due to slow polarization mechanisms and the trapping of space charges within the material. During voltage application, molecular dipoles and charge carriers may align or move in response to the electric field, storing energy in the dielectric. After the voltage source is removed, this process does not reverse instantaneously, and it is characterized by an electrical relaxation regime with multiple time constants (τ_i).

As a result, the voltage decay in the cable does not follow a purely exponential behavior. Under certain conditions, part of the previously stored charge may redistribute internally after the initial discharge, giving rise to the phenomenon known as voltage rebound.

Some factors increase the risk associated with residual voltage:

- **Long cables.** The greater the length, the higher the total capacitance C , and therefore the greater the stored energy. For example, 35-kV cables longer than 1 km may accumulate more than 100 joules, which is sufficient to produce an electric arc or an electric shock.
- **High test voltages.** The stored energy increases with V_0^2 ; therefore, tests performed at $2U_0$ or $2.5U_0$ significantly increase the associated risk.
- **Cables with extruded insulation (XLPE, EPR).** Slow polarization and charge trapping mechanisms cause residual voltage to persist for minutes or even hours.
- **Inadequate termination or connection conditions.** Open or poorly grounded terminations allow residual voltage to lead to electric arcs or shock hazards. Connections near relays, transformers, or electronic equipment may also be damaged.

MATHEMATICAL MODELING OF THE ELECTRIC FIELD

For the quantitative analysis of the phenomenon, the insulated cable is modeled as a coaxial

geometry, consisting of a central conductor and a metallic shield separated by insulation that serves as the dielectric. In this model, a represents the conductor radius, b corresponds to the inner radius of the shield, L is the cable length, and ϵ is the electrical permittivity of the insulating material, defined as $\epsilon = \epsilon_0 \epsilon_r$, where ϵ_0 is the vacuum permittivity and ϵ_r is the relative permittivity of the dielectric.

From this coaxial geometry, the total capacitance of the cable is obtained, as presented in Equation (2), which depends on the permittivity of the insulating material, the cable length, and the ratio between the shield radius and the conductor radius. This parameter is fundamental for analyzing energy storage in the system, since the total capacitance C appears directly in the expression of the electrical energy stored in the cable during the voltage test, as previously presented in Equation (1).

$$C = \frac{2\pi\epsilon L}{\ln(b/a)} \quad (2)$$

When a voltage V_0 is applied between the conductor and the shield, a radial electric field is established within the insulation. The intensity of the field varies with the radial distance r from the conductor's center. This electric field is described by Equation (3), in which $E(r)$ represents the electric field intensity at a point located at a radial distance r from the cable axis, V_0 corresponds to the voltage applied during the test, a is the conductor radius, and b is the inner radius of the shield.

The electric field distribution is not uniform across the insulation, being more intense in regions close to the conductor. Therefore, the maximum electric field, indicated in Equation (4), occurs at the interface between the conductor and the insulating material, when $r = a$. This result is particularly relevant for the analysis of dielectric stress in the cable, since this is the region where the insulation is subjected to the highest electric field level during voltage application.

$$E(r) = \frac{V_0}{r \ln(b/a)} \quad (3)$$

$$E_{max} = \frac{V_0}{a \ln(b/a)} \quad (4)$$

After the test source is removed, the voltage in the cable does not instantaneously drop to zero but instead decays over time due to energy dissipation in the system. In a simplified approach, this behavior can be described by the equivalent RC model of the cable, in which the voltage decay follows an exponential function over time, as represented in Equation (5), where $V(t)$ corresponds to the voltage at time t , V_0 is the initial voltage at the moment the source is disconnected, R represents the equivalent leakage resistance, and C is the cable capacitance.

However, in polymeric dielectric materials, such as XLPE, used in power cables, additional phenomena associated with dielectric absorption and slow polarization are observed and are not fully described by a single RC circuit. In such cases, the residual voltage behavior can be represented as a sum of multiple exponential terms with different time constants (τ_i), as shown in Equation (6). This more comprehensive model explains phenomena observed in practice, such as the partial reappearance of voltage after an initial discharge, known as voltage rebound.

$$V(t) = V_0 e^{-t/RC} \quad (5)$$

$$V(t) = \sum_{i=1}^n V_i e^{-t/\tau_i} \quad (6)$$

Example 1 — 15-kV Cable (8.7/15-kV Class)

For the first example, a medium-voltage cable of class 8.7/15-kV is considered, subjected to an acceptance test using VLF voltage, a method widely employed in field testing to assess the integrity of insulation in cables with polymeric dielectrics such as XLPE or EPR. In systems of this class, the nominal phase-to-ground voltage

is $U_0 = 8.7 \text{ kV}$. During acceptance testing, IEEE guides typically recommend applying $2U_0$, resulting in a test voltage of $V_0 = 17.4 \text{ kV}$. The typical parameters used to estimate the energy stored in the cable are presented below.

- Cable length: 1 km
- Typical capacitance: $0.20 \text{ } \mu\text{F/km}$
- VLF test voltage (acceptance): $2.0 U_0$

The energy stored in the cable during the test can be estimated using the capacitor energy equation, Equation (1). Considering the total capacitance corresponding to 1 km of cable and the applied test voltage, substituting these values into Equation (1) results in the expression presented in Equation (7).

$$W = \frac{1}{2} (0.20 \times 10^{-6}) (17400^2) \approx 30 \text{ J} \quad (7)$$

This result indicates that, even for a single kilometer of a medium-voltage cable, the electrical energy stored during the test can reach several tens of joules. Values of this magnitude are sufficient to produce a perceptible electrical discharge, an electric arc, or a potentially hazardous shock if the cable is handled before the complete dissipation of the stored energy after the end of the test.

Example 2 — 35-kV Cable (20/35-kV Class)

For the second example, a medium-voltage cable of class 20/35-kV is considered, also subjected to an acceptance test using VLF voltage. In this class of system, the nominal phase-to-ground voltage is $U_0 = 20 \text{ kV}$. By applying $2U_0$, the test voltage becomes $V_0 = 40 \text{ kV}$. The typical parameters used to estimate the energy stored in the cable during the test are presented below.

- Cable length: 1 km
- Typical capacitance: $0.18 \text{ } \mu\text{F/km}$
- VLF test voltage (acceptance): $2.0 U_0$

By again applying the capacitor energy Equation (1) and considering the total

RECOMMENDED OPERATIONAL PROCEDURES

1. Before the Test:

- Verify absence of voltage using a voltage absence detector.
- Discharge the cable using a discharge rod suitable for the operating voltage level, maintaining it for the minimum calculated time.
- After resistive discharge, apply direct grounding and keep it connected.
- Disconnect any equipment that may influence residual voltage.

2. During the Test:

- Apply the voltage in accordance with IEEE Std. 400.2 guidelines.
- Monitor current and resistance, if the test equipment includes measurement capabilities.

3. After Voltage Application:

- Discharge the cable using a discharge rod suitable for the test voltage level, maintaining it for the minimum calculated time.
- After resistive discharge, apply direct grounding and keep it connected.
- Measure the residual voltage before allowing access to the circuit.
- It is recommended to maintain discharge and grounding applied for a duration equivalent to multiple time constants ($\geq 5\tau = 5RC$).

capacitance for 1 km of cable, the value in Equation (8) is obtained.

$$W = \frac{1}{2} (0,18 \times 10^{-6}) (40000^2) \approx 144 J \quad (8)$$

This result shows that, for higher-voltage-class cables, the energy stored during the test increases significantly, reaching hundreds of joules. Levels of this magnitude represent a substantial risk of electrical discharge, arcing, or severe shock if the cable is handled before proper discharge and grounding procedures are carried out after the test.

CONCLUSION

Residual voltage in insulated cables subjected to high-voltage testing is an inherent physical phenomenon associated with the capacitive behavior of the system and the polarization mechanisms present in dielectric materials. During voltage application, electrical energy is stored in the distributed capacitance of the cable and within the insulation dielectric. After the test source is removed, this energy is not dissipated instantaneously and may temporarily remain in the system as residual voltage.

The mathematical modeling presented in this work demonstrates that the behavior of residual voltage can initially be described by an equivalent RC model, in which the voltage decays exponentially over time. However, in cables with polymeric insulation, such as XLPE or EPR, additional phenomena, including dielectric absorption and slow polarization, introduce multiple time constants into the electrical relaxation process. This behavior may lead to partial voltage recovery (voltage rebound) after an initial discharge, underscoring the need to consider more comprehensive models when analyzing the phenomenon.

The numerical examples presented for 15-kV and 35-kV cables show that the energy stored during VLF testing can reach tens or even hundreds of joules, even in relatively short cable lengths. Values of this magnitude are sufficient to produce perceptible electrical discharges, electric arcs, or potentially hazardous shocks if the system is handled before the stored energy is completely dissipated.

From an operational standpoint, these results reinforce that the presence of residual voltage should not be interpreted as an insulation failure but rather as a natural consequence of the cable's electrostatic behavior. Nevertheless, it represents a real risk to personnel and equipment if proper discharge and grounding procedures are not followed.

In this context, the safe management of residual voltage must be treated as an integral part of high-voltage testing procedures. Recommended

practices include controlled cable discharge with appropriate resistors, temporary grounding after testing, verification of the absence of voltage with suitable instruments, and the application of operational safety procedures, such as lockout/tagout (LOTO). These measures, aligned with IEEE technical guides and safety standards such as NFPA 70E, are essential to ensure the safety of field personnel, the integrity of equipment, and the reliability of test results. [NW](#)

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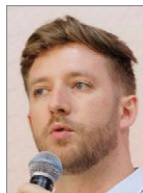
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TECHNIQUES FOR CONDUCTING FALL-OF-POTENTIAL TESTING IN ADVERSE CONDITIONS

BY ANDREAS BURKART, *AEMC Instruments*, and MATTHEW J. ROBINSON, *Sigma C Power Services*

Fall-of-potential (FOP) testing is widely regarded as one of the most reliable methods for evaluating grounding system performance. Under ideal conditions, the procedure is straightforward: Electrodes are driven into the soil at prescribed intervals, measurements are recorded, and resistance values are calculated with a high degree of confidence.

In practice, however, technicians often encounter less-than-ideal environments. Urban and industrial sites often feature sprawling paved surfaces or concrete jungles that prevent the use of conventional driven electrodes. Arriving on-site to find a large parking lot or a fully developed facility footprint is a common scenario—one that presents immediate challenges to standard testing methodology.

Rather than abandoning testing efforts or resorting to destructive measures, such as jackhammering out chunks of the customer's nicely paved roadway, technicians can employ alternative techniques that leverage the physical and electrical properties of these surfaces. With a clear understanding of grounding principles and material behavior, accurate and repeatable results can still be achieved.

This article reviews the fundamentals of FOP testing and presents practical field techniques for conducting tests in environments where traditional electrode placement is not feasible.

FALL-OF-POTENTIAL TESTING

FOP testing is used to determine the resistance of a grounding electrode system to earth, commonly expressed as R_g . This value represents the effective resistance between the grounding system and the surrounding soil mass, and it is a key parameter for assessing a system's grounding provision, mat, or network performance and safety.

The test is performed by injecting a known current between the grounding electrode under test (depending on the test set used, these probes may be tied to the E, X, or C2

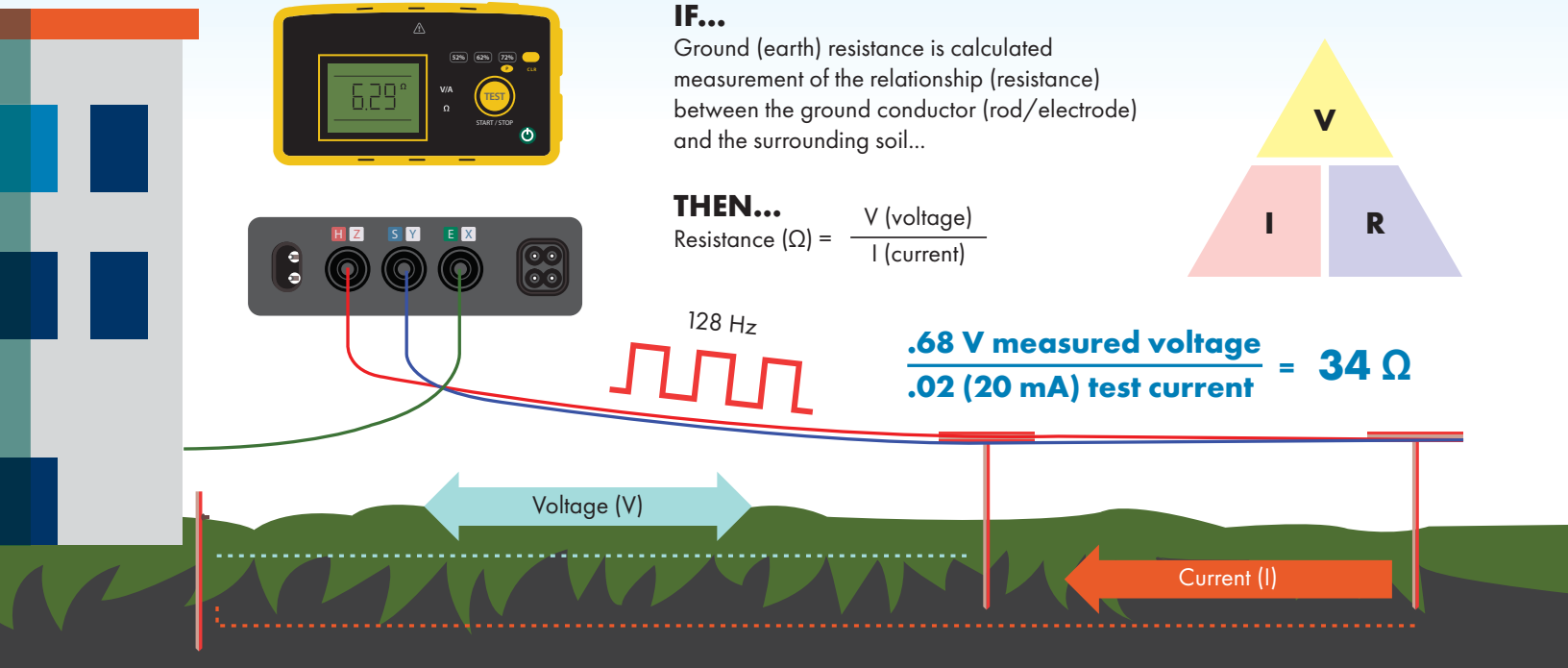


Figure 1: *Fundamental Principles and Setup of Fall-of-Potential Testing*

IMAGE COURTESY OF AEMC® INSTRUMENTS

terminal of the equipment) and a remote auxiliary electrode, often referred to as the current or outer A third electrode (equipment terminal H, Z, or C1). A potential electrode (equipment terminal S, Y, or P), or “walking electrode,” is placed at evenly spaced, linear intervals along the line between the test and auxiliary electrodes. At each position, the voltage between the grounding electrode and the potential electrode is measured. By applying Ohm’s Law, the resistance can be calculated, as seen in Figure 1.

As the potential electrode is moved farther from the grounding system, the measured voltage reflects the diminishing influence of the system’s hemispherical range of influence. Plotting these values typically produces a curve from which a stable resistance value can be identified.

The test setup generally consists of a ground test instrument connected to three electrodes. The grounding electrode is connected directly to the system under test, while the current and potential electrodes are usually metal stakes driven into the earth. In soils that are loosely compacted, moist, and moderately conductive, this process is efficient and reliable. These ideal conditions, however, are not always what a technician encounters on site.

GOING THE DISTANCE

Proper electrode spacing is essential for obtaining accurate fall-of-potential measurements. The distance between the grounding electrode and the current electrode must be sufficient to prevent their respective spheres of influence from overlapping.

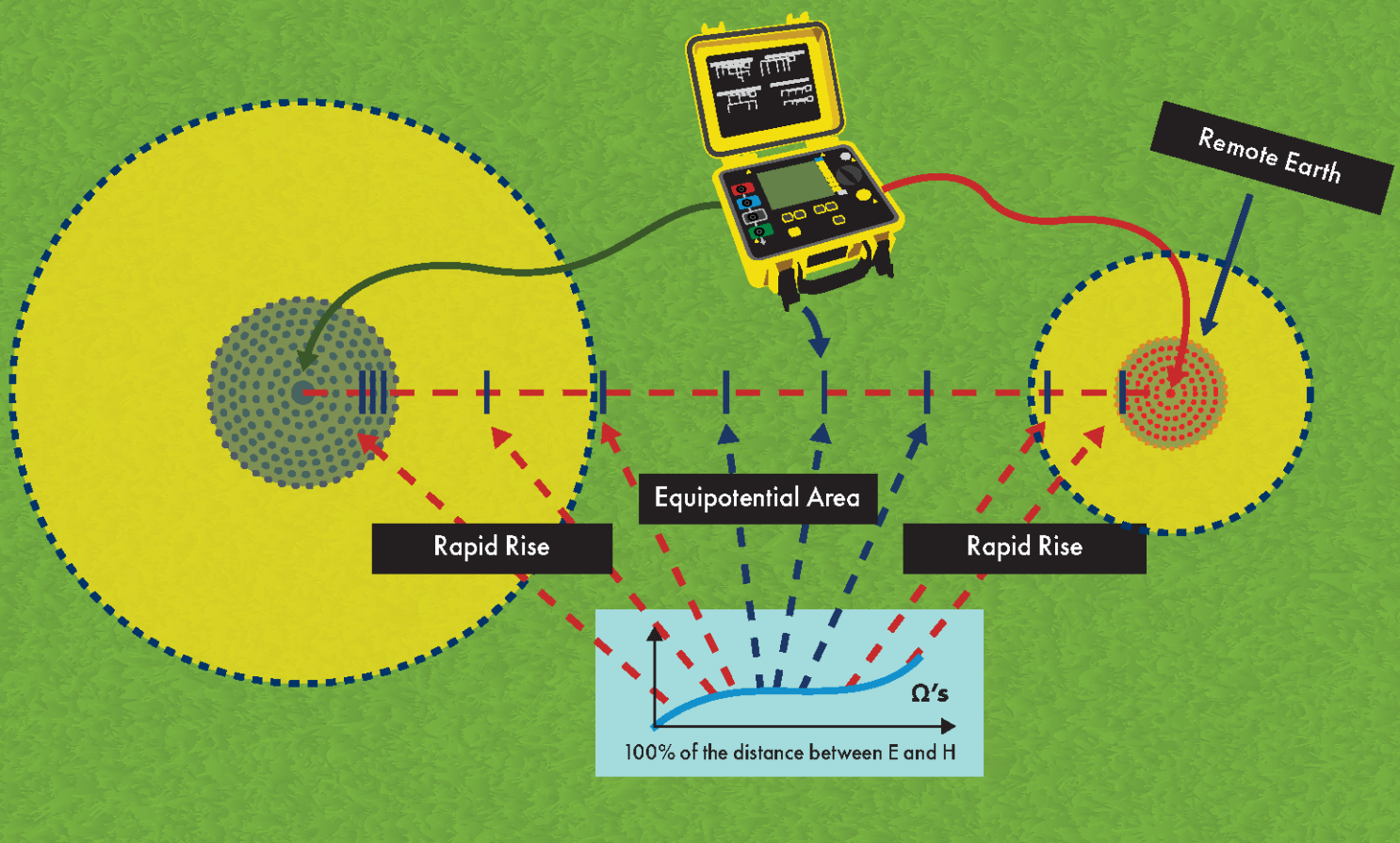


Figure 2: *Fall-of-Potential Ground System and Remote Earth Sphere of Influence*

IMAGE COURTESY OF AEMC® INSTRUMENTS

A grounding system's electrical influence extends outward in a hemispherical pattern (Figure 2), the size of which is determined by several factors, including soil resistivity, electrode geometry, burial depth, and the magnitude of injected current. Larger and deeper grounding systems require greater electrode spacing to fully capture this influence.

In many cases, the required distance can extend several hundred feet, such as when a technician must execute FOP measurements related to transmission and distribution infrastructure and installations. This creates practical challenges, particularly in developed areas where space is limited or obstructed by infrastructure. Additionally, longer test distances may approach the operational limits of the test instrument, particularly in

high-resistance soils where sufficient current injection becomes more difficult.

These constraints are further compounded when the test path must traverse paved or otherwise inaccessible surfaces. Modern facilities are often constructed with extensive paved areas, including parking lots, access roads, walkways, and equipment pads. These surfaces can severely limit the ability to place electrodes at the required intervals.

In some cases, technicians may be able to reroute the test path to reach exposed soil, but such adjustments are not always possible without compromising the geometry of the test. When proper spacing cannot be achieved, the validity of the results may be called into question.

To address this issue, alternative electrode techniques can be used to establish effective electrical contact through paved surfaces. These methods rely on the inherent properties of asphalt and concrete to facilitate current flow when properly conditioned.

Blacktop and Pie Plates

Asphalt concrete (hereafter referred to as asphalt) offers a relatively forgiving medium for alternative testing methods. Asphalt is composed of bitumen—a viscous, petroleum-based binder—and aggregate such as crushed stone and sand. It is typically installed over compacted sublayers that provide structural support.

While new asphalt is largely impermeable, it becomes increasingly porous over time due to environmental exposure, wear, and microfracturing. This permeability allows liquids to penetrate the surface, creating a conductive path when combined with a suitable electrolyte.

The flat electrode method takes advantage of this property. Instead of driving a stake, the technician uses a flat conductive plate—at minimum, the size of a nine-inch, uncoated aluminum pie plate—combined with an electrolyte solution to simulate a ground contact.

The electrolyte solution is also critical. Its purpose is to introduce free ions into the contact area, enabling current flow between the test instrument and the underlying material. While a variety of mixtures can be used, care should be taken to ensure compatibility with the site environment. In some cases, readily available liquids such as sports drinks, lemonade, or even iced tea can provide acceptable conductivity.

A reliable and repeatable mixture includes:

- One part salt
- Two parts pure lemon juice
- Seven parts water (tap water is preferable due to its mineral content)

To perform the test, the technician applies a generous amount of the electrolyte solution to the measurement location and allows it to soak into the asphalt surface. Depending on the condition and age of the pavement, this may take several minutes.

Once the surface is adequately saturated, the flat electrode is placed on the wet area, and the walking electrode lead is connected. The technician then stands on the plate to ensure firm, consistent contact during measurement.

Success with this method depends on maintaining even pressure and ensuring sufficient saturation. When properly executed, the flat electrode method can produce results comparable to those obtained using traditional driven stakes.

Chicken Wire and Ufer Soup

Cement concrete (hereafter referred to as concrete) presents a more complex challenge. Unlike asphalt, well-constructed concrete is only minimally permeable and, when dry, acts as a relatively effective electrical insulator. This can isolate the test setup from the earth below, making conventional approaches ineffective.

Concrete is composed of cement and aggregate, forming a dense, durable material that is not easily penetrated without drilling. Fortunately, its electrical properties change significantly when saturated with water. Under these conditions, concrete exhibits semiconductive behavior due to ionic movement within its pore structure.

The mesh electrode method leverages this phenomenon. Instead of a small contact point, this approach uses a large conductive mesh—such as chicken wire or metal fencing—placed over a water-saturated section of concrete to create a broad contact interface. The mesh should be larger than the flat electrode used for asphalt applications. A size of approximately two feet by two feet is generally sufficient for most testing scenarios.

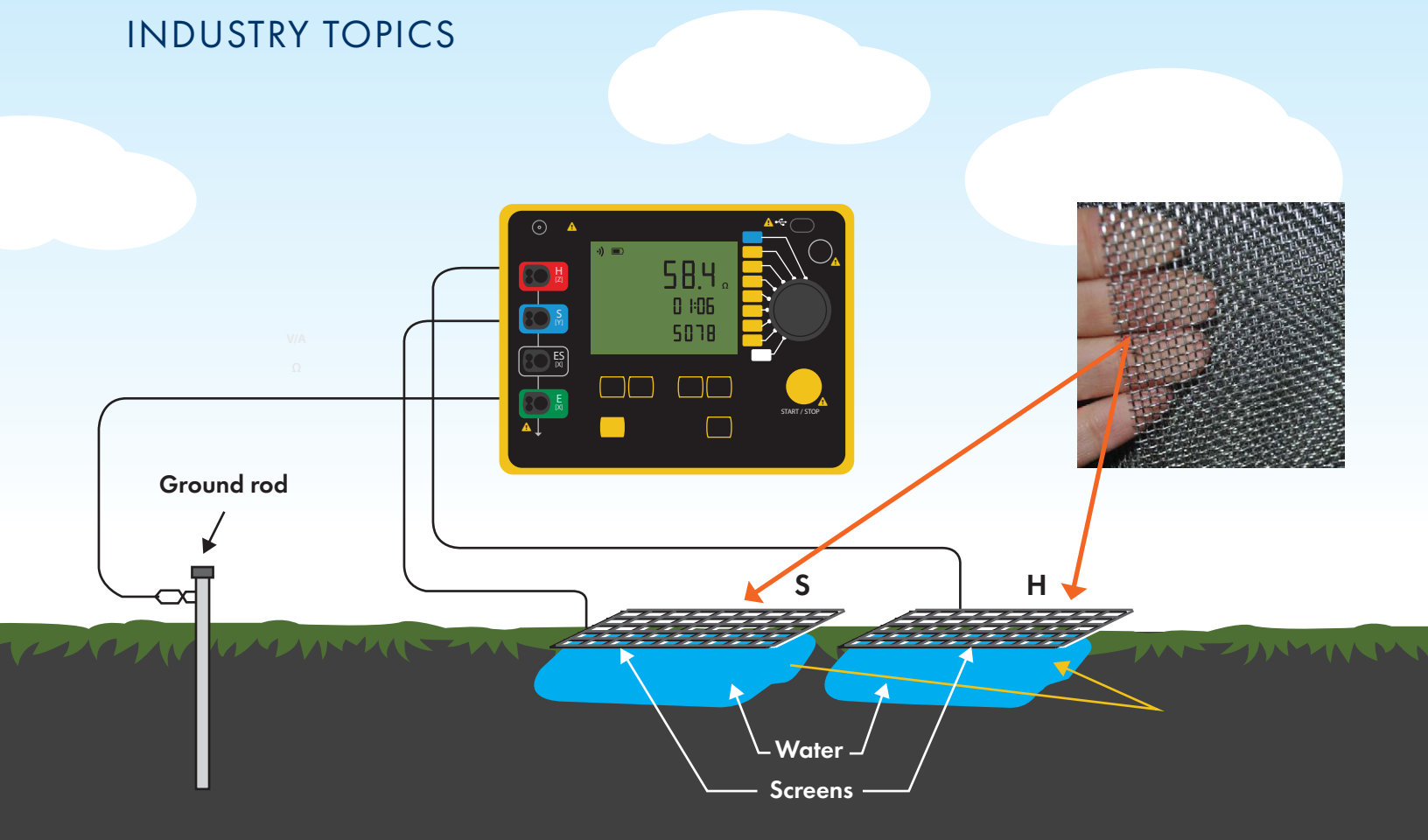


Figure 3: *Mesh Auxiliary Electrode Method*

IMAGE COURTESY OF AEMC® INSTRUMENTS

To perform the test, the technician saturates the target area with a substantial volume of water, typically around one gallon per square foot. Time must be allowed for the water to permeate the concrete thoroughly, which may take several minutes or longer, depending on the material.

Once saturation is achieved, the mesh electrode is laid flat on the surface, and the test lead is connected. As with the flat electrode method, the technician stands on the mesh to ensure consistent contact during measurement. This alternate electrode method can be seen in Figure 3.

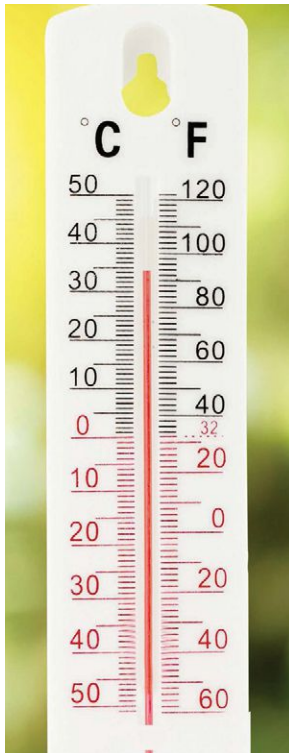
It is important to note that electrolyte solutions should not be used in this method. Introducing additional ions can alter the natural conductive behavior of the saturated concrete and lead to inconsistent results.

CONSIDERATIONS AND LIMITATIONS

While these alternative techniques are effective under the right conditions, they are not universal solutions. Each method has limitations that must be understood to avoid inaccurate results or unintended consequences.

First, the use of electrolyte solutions on natural soil should be avoided. High salt concentrations can damage vegetation and alter soil chemistry, making this approach unsuitable for landscaped or environmentally sensitive areas. Moreover, a properly driven stake in loamy soil remains the most reliable and preferred method for fall-of-potential testing.

Second, both the flat and mesh electrode methods require dense, continuous substrates. Loose materials such as sand, gravel, or riprap do not provide sufficient contact or retention for



°C	°F	Resistivity=Ω-cm
20°	20°	7,200
10°	20°	9,900
0°	32° (water)	13,800
0°	32° (ice)	30,000
-5°	23°	79,000
-15°	14°	330,000

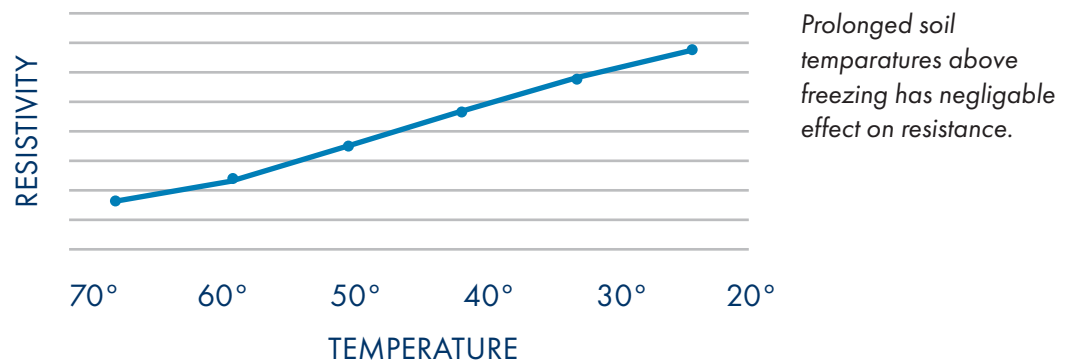


Figure 4: Impacts of Decreasing Temperature on Earth Resistivity and FOP Accuracy

IMAGE COURTESY OF AEMC® INSTRUMENTS

water and electrolytes. In these environments, even conventional testing methods may struggle to produce stable readings. Technicians may need to drive longer rods to reach deeper, more conductive soil layers.

Finally, environmental conditions play a critical role. All ground testing relies on ionic conduction through the earth. When temperatures drop below approximately 35°F, or when subsurface layers are frozen, ion mobility is greatly reduced (Figure 4). Under such conditions, accurate testing becomes difficult or impossible, regardless of the method used.

FINAL THOUGHTS

Fall-of-potential testing remains one of the most reliable methods for evaluating grounding system performance, but real-world conditions rarely align with textbook assumptions. Asphalt parking lots, concrete slabs, and developed

infrastructure often stand between technicians and ideal test setups.

By understanding the material properties of these surfaces and applying alternative techniques such as flat and mesh electrodes, technicians can adapt to challenging environments without sacrificing accuracy. These methods are not replacements for traditional practices, but valuable additions to the field toolkit when standard approaches are not feasible.

Ultimately, successful ground testing depends on sound judgment, attention to site conditions, and a willingness to adapt. By combining fundamental principles with practical ingenuity, technicians can continue to obtain meaningful results, no matter what lies underfoot. [NW](#)

INDUSTRY TOPICS

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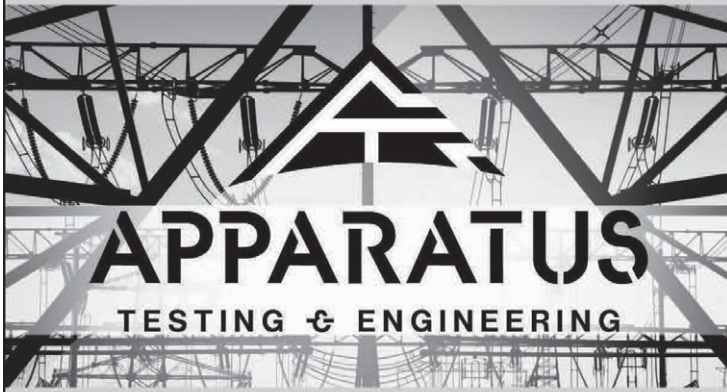


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Matt Robinson is Sigma C Power Services's Director of Safety and Training, an adjunct professor at the Worcester Polytechnic Institute, and a student pursuing his doctorate in engineering at Penn State. His passion lies in education and development of the electrical power workforce, where he uses his position to learn as much as he can from the talented folks that make up what he considers one of the most important and poorly understood industries. Robinson holds a BS and MS in electrical engineering from Northeastern University and NETA 4 and NICET III certification, is a board-certified safety professional, and is part of NETA's Practice Exam Committee.

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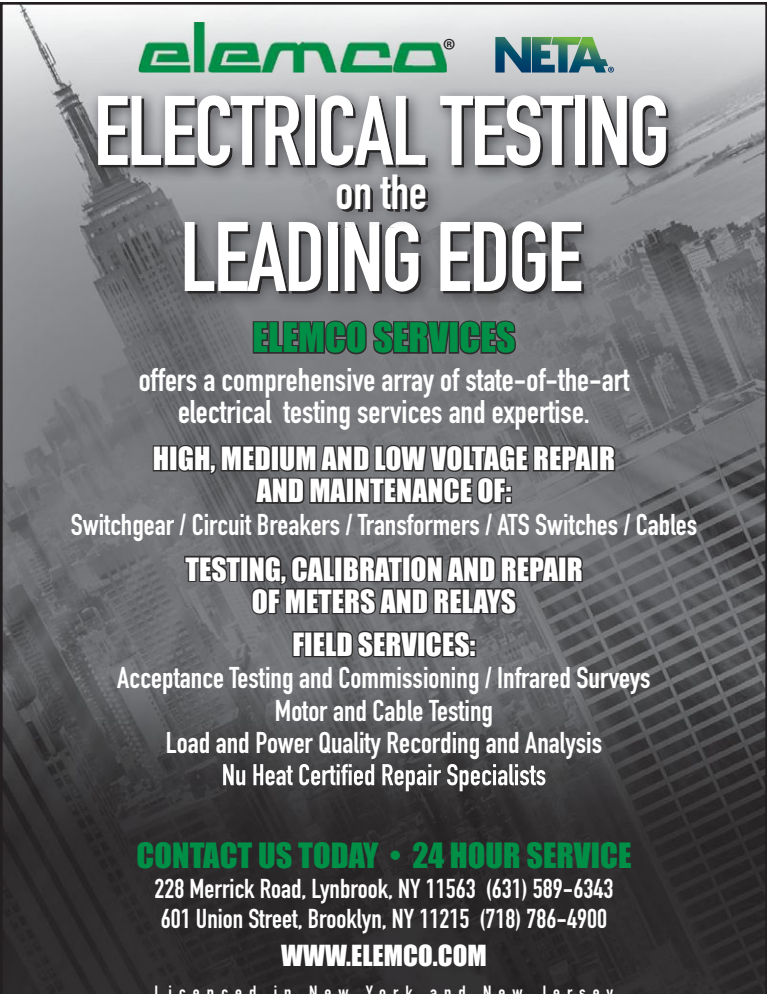
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TRANSFORMER GROUND DIFFERENTIAL ELEMENT BEHAVIOR WITH CT ERROR AND MISOPERATION EVENT ANALYSIS

BY SETH BARNES AND TIM CONDRA, *Tennessee Valley Authority*; JOSHUA HUGHES, *Qualus*;
and AKRAM SAAD, *University of Tennessee at Chattanooga & Quanta Technology*

This paper analyzes the ground differential or restricted earth fault (REF) element for transformer protection and compares its performance against various levels of current transformer (CT) error and saturation. An empirical analysis was performed to determine the limits of today's common digital relays as they experience CT errors. This can help engineers develop general guidelines for designing protection systems related to REF elements. The impact of auxiliary CTs was also examined to determine their influence on element performance. Finally, a real-world misoperation of the REF element due to CT error was evaluated to provide solutions to prevent similar issues.



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REF PROTECTION AND TYPICAL PROTECTION CHARACTERISTICS

At its core, ground differential (87G) protection (REF) is comparable to other current differential protection schemes, where CT placement defines the internal protection zone. However, the value of transformer REF protection is its sensitive detection of ground faults near the neutral of a grounded wye winding. These faults can produce large and damaging circulating currents with minimal impact on the associated phase currents used in conventional transformer phase-percentage differential protection.

To provide protection coverage at the lower end of the transformer wye windings, the REF element commonly uses the transformer neutral current (IN) and the associated transformer terminal bushing or breaker residual current (3I0) via wye-connected CTs. These CTs ultimately define the selective protection zone of this element, and knowing the polarity and phase-angle relationships of the configured CTs can provide a secure method to distinguish between internal and external faults. For this reason, REF elements can provide more sensitive detection of ground faults near the transformer neutral than conventional transformer phase-percentage differential protection, helping to prevent catastrophic fault evolution.

Typical differential CT configurations where polarity faces away from the protected equipment are shown in Figure 1. Assuming no CT saturation, the ideal phase difference between 3I0 and IN is 180 degrees for any external ground current condition. In addition, the 3I0 and IN primary current magnitudes should closely resemble each other.

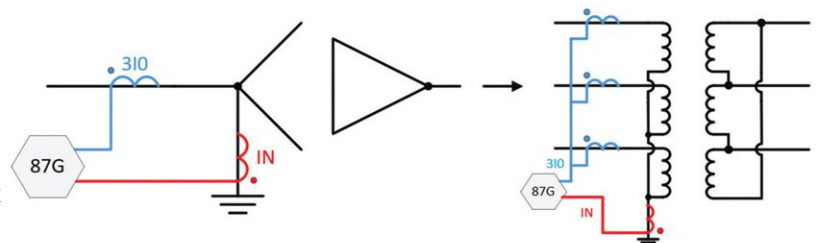


Figure 1: *Simplified REF Protection Scheme Diagram for a Solidly Grounded Wye Winding*

For internal ground faults on the protected winding, the phase difference between 3I0 and IN for the mentioned CT configuration should be closer to 0 degrees. However, unlike external faults, 3I0 and IN primary current magnitudes may vary for internal faults, as the fault sources and impedance to the fault location will be different. Figure 2 and Figure 3 illustrate these correlations for internal and external ground faults based on the CT configuration. These CT relationships, combined with varied vendor algorithms, define the basics of REF protection.

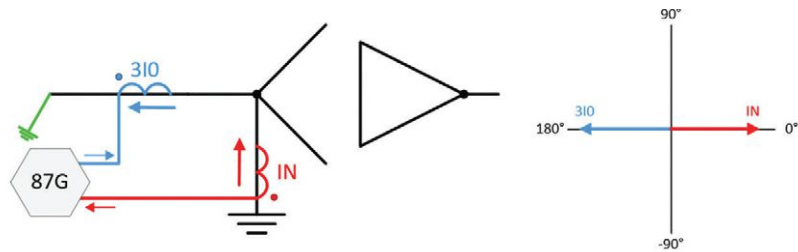


Figure 2: Ideal Phase Relationship between 3I0 and IN for External Ground Faults

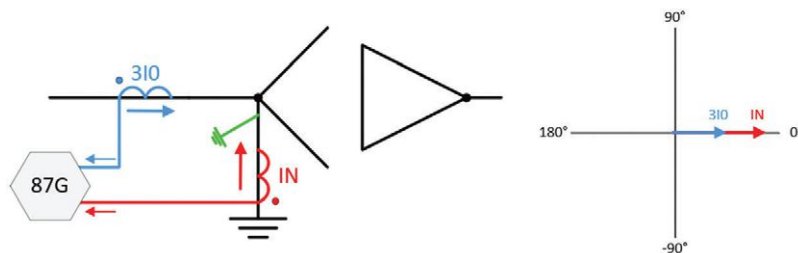


Figure 3: Ideal Phase Relationship between 3I0 and IN for Internal Ground Faults

TESTING REF ELEMENT CHARACTERISTICS

Four microprocessor relays from various manufacturers were tested in a laboratory environment to determine typical REF element characteristics by applying a residual and

neutral current with an angle difference of 0 to 180 degrees. The relays were configured to trip with no delay when the difference between the angles was minimal and restrained when the polarity was opposite.

While each manufacturer's relay operated with varying algorithms, the authors attempted to configure the relays with typical and similar settings for comparison. While Relay #1 and Relay #2 provide directional supervision of the element limited to an angular range, Relay #3 and Relay #4 operate on a percentage differential concept where the slope percent defines the angular area of operation. The REF operating characteristics were additionally normalized for a one-per-unit current pickup for comparison between relays.

If the transformer neutral IN current is set as the reference angle, an external fault occurs when the residual 3I0 current is 180 degrees out of phase and should not result in a REF trip. CT error on the phase CTs results in an angular change to the 3I0 current as it is processed through a microprocessor relay filtering algorithm, shown as the dashed phasor in Figure 4. If the angle change of the residual 3I0 current due to CT error is severe enough, the filtered signal may cross into the internal fault region and misoperate.

Laboratory testing confirmed that the REF element is very secure against single-line-to-ground (SLG) through-faults regardless of the degree of saturation simulated for phase CT inputs. Severe phase CT saturation resulted in a filtered current around 60 degrees offset from an ideal non-saturated signal. Other field events have shown that heavy neutral CT saturation can cause a shift of 45 degrees, but would not be able to shift by more than 90 degrees, which highlights the security of the directionally supervised REF elements.

SOURCES OF CT ERROR

Any protection system requires proper design and analysis to ensure an effective system. Protection engineers are often faced with limitations that require balancing dependability

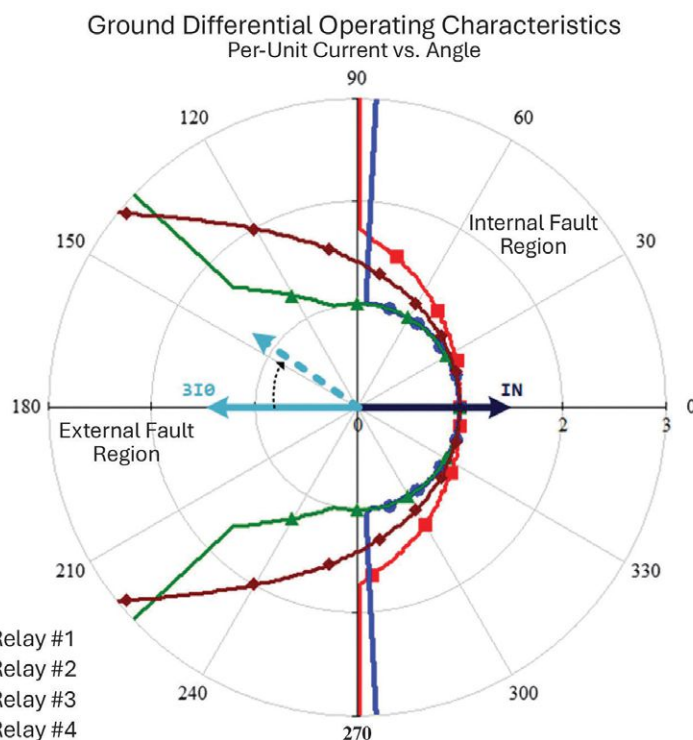


Figure 4: REF Operating Characteristics for Various Microprocessor Relays

Table 1: *Auxiliary CT Performance Data*

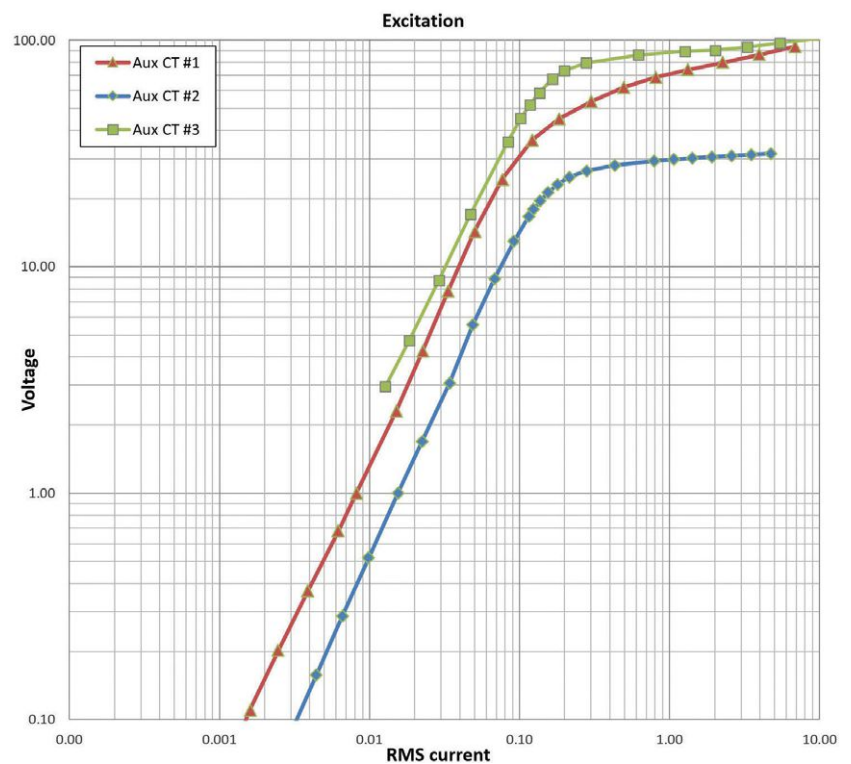
	Auxiliary CT #1	Auxiliary CT #2	Auxiliary CT #3
Ratio	5:5	5:10	7.5:5
CT Primary Resistance	0.240 Ω	0.221 Ω	-
CT Secondary Resistance	0.186 Ω	0.048 Ω	0.206 Ω
Core Voltage at 45-Degree Knee Point	25.9 V	16.9 V	51.8 V
Core Voltage at 30-Degree Knee Point	40.1 V	22.0 V	68.7 V
Accuracy/Classification	-	-	2.5H50
Maximum Available Voltage at Secondary Terminals*	81 V	29 V	79 V

*Limited to 10% CT error at 20 times nominal current with secondary winding voltage drop subtracted.

and security. One example related to transformer protection is replacing an electromechanical (EM) relay with a microprocessor relay. EM transformer differential relays typically do not perform internal compensation for angle shifts produced by the transformer configuration and can require external compensation. For example, a delta-wye transformer protected by an EM differential relay can have CTs wired as wye on the delta side and delta on the wye side to compensate externally for angle shifts. Additionally, auxiliary CTs can be used to help normalize or compensate for the current entering the relay.

As microprocessor relays can numerically compensate for magnitude and angle shifts internally, best practice is to wire CTs directly to the relay in a wye configuration with no intermediate auxiliary CTs. This configuration limits the impedance seen by the system CTs for some fault types, which can reduce CT error. However, a spare CT wire might not be available to convert the three-wire delta configuration to a four-wire wye configuration. Similarly, removing a set of auxiliary CTs in a relay circuit may require installing new wiring at high cost.

A protection engineer must be well-versed in analyzing CT performance when considering the protection system. One popular resource is the CT Saturation Theory and Calculator Excel spreadsheet provided by the IEEE Power System Relaying Committee. However, the performance of auxiliary CTs may not be

**Figure 5:** *Auxiliary CT Excitation Curves*

readily known, as the data, if it were originally available, may have been lost over the years.

The authors were unable to track down factory performance data for most in-service auxiliary CTs. Instead, two common auxiliary CT types used for protective relaying were selected. The nameplate data for these auxiliary CTs provided little information beyond the current ratio. Various CT tests were performed to help understand typical auxiliary CT performance as seen in Table 1 and Figure 5. Auxiliary CT

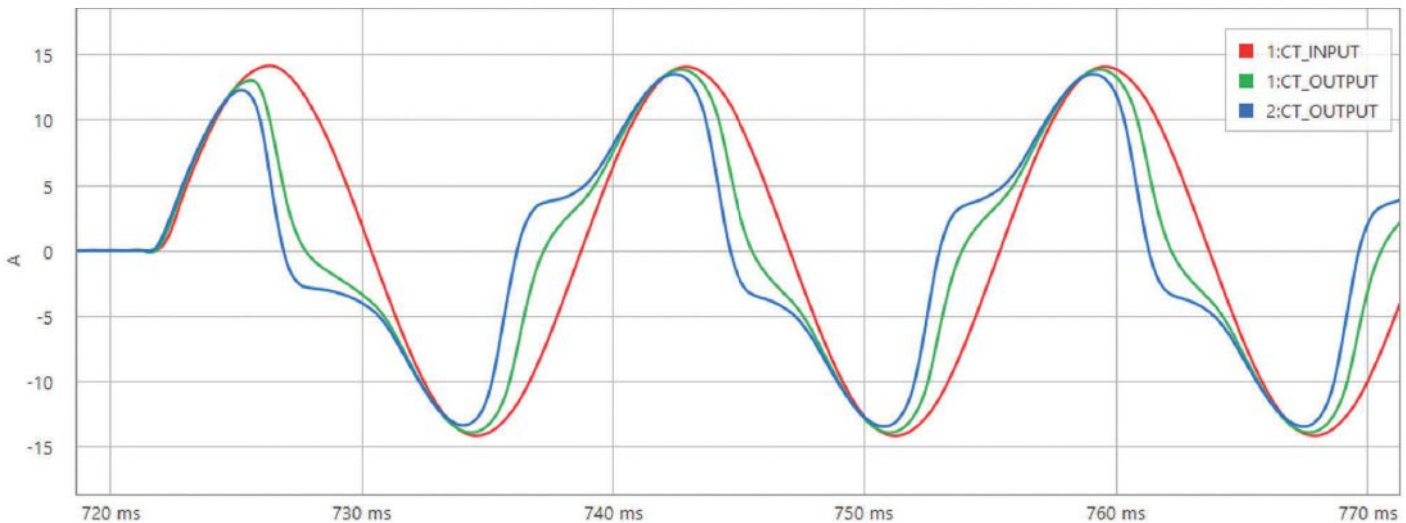


Figure 6: Auxiliary CT Saturated and Replayed Again

#3 was not available for testing, but factory-provided excitation curves and details had been saved from over 50 years ago.

In an additional test on Auxiliary CT #1, the secondary side was loaded with a 10-Ω resistor, and a 10-A symmetrical signal was injected. This required the CT to produce a 100-V secondary, which would be above the CT's capability shown in Table 1. The input signal can be seen in Figure 6 as 1:CT_INPUT. The initial output on the secondary side of the auxiliary CT can be seen as 1:CT_OUTPUT with characteristic saturation.

The authors were curious how the auxiliary CT would respond to a saturated signal as an input, so the 1:CT_OUTPUT signal was replayed back into the CT, with the resulting 2:CT_OUTPUT as the twice-saturated signal measured on the secondary. During CT or event analysis, it may be of benefit to consider one or both primary and auxiliary CTs saturating differently depending on the input signal, level of DC offset, and any remanent flux in the CT.

Once the auxiliary CT performance data is known, it can be analyzed along with the primary CT with respect to the system configuration for transient performance as seen in Hargrave et al.

MISOPERATION EVENT ANALYSIS

The configuration of the transformer relay that misoperated is shown in Figure 7. This microprocessor relay replaced a prior EM percentage-restraint transformer protection relay set with no existing REF protection. Dual relays were installed, providing duplicate protection through the same CT circuits for all elements except the REF element. The A-set relay was wired to the 161-kV neutral, and the B-set was wired to the 46-kV neutral. The 46-kV phase and neutral auxiliary CTs that remained in the secondary circuit were then incorporated into the new 46-kV REF element.

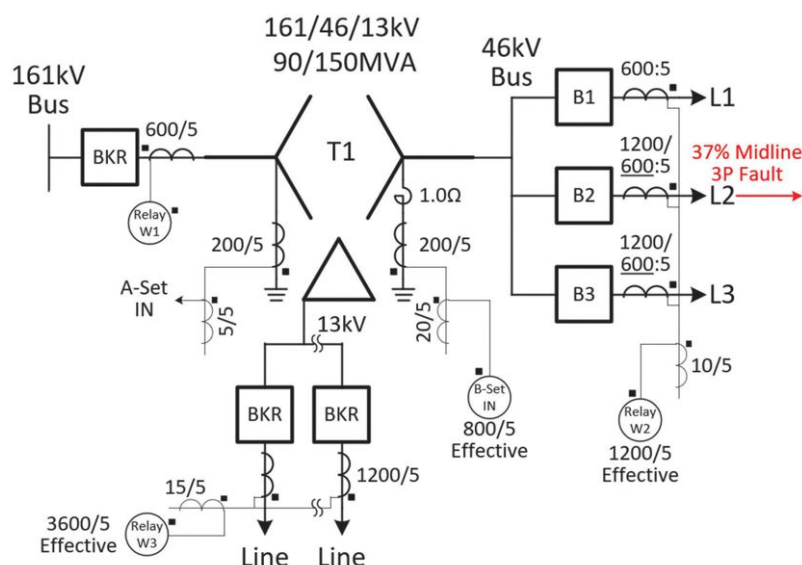


Figure 7: System One-Line and Relay Connections

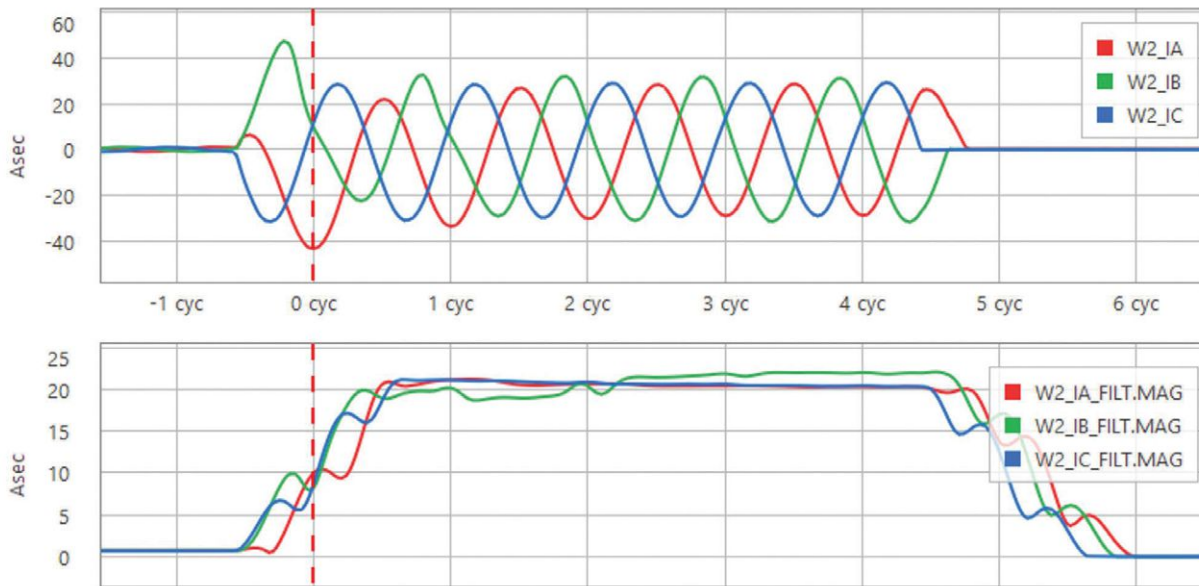


Figure 8: 46-kV Unfiltered Waveform (Top) and Filtered Magnitude (Bottom)

The transformer is a bank of three single-phase transformers; however, the neutral currents are bussed together with a single ground point through a 1- Ω reactor and a single neutral CT. Configurations that sum three neutral CTs from each single-phase transformer require advanced techniques for REF protection. The primary-phase CTs on the 46-kV breakers are all rated at C800, but the faulted line CT is tapped at half the ratio due to the single ratio 600/5 CT associated with Breaker B1, making the CT associated with Breaker B2 an effective C400 rating. A confirmed three-phase fault occurred around 37% down the 46-kV L2 line. While the L2 breaker tripped, the transformer 46-kV REF element operated before the L2 breaker cleared the fault.

The 46-kV B-phase current (W2_IB) shows signs of CT saturation for the first two cycles of the event in Figure 8. The filtered current magnitudes show that the B-phase current was about 10% lower than the other phases when saturated, but 10% higher when not saturated. It is common to think of three-phase faults as perfectly balanced, but system asymmetries can create imbalance and ground current, as shown in this event. In this case, the 46-kV auxiliary B-phase CT had an input signal of about 44 A with some DC offset and

was expected to produce 22 A. As the auxiliary CT was mounted above the relay, the leads between the auxiliary CT and the relay could be considered to have negligible impedance. The microprocessor relay CT inputs also have little burden.

Based on the system model, a similar fault resulted in an estimated X/R ratio of about 5. An impedance of 0.1 Ω would result in an auxiliary CT secondary voltage requirement of under 20 V, assuming no remanent flux in the CT. If the long lead connection from the field and the auxiliary CT primary impedance resulted in a total impedance of 1.6 Ω , the primary CT would need to support a secondary voltage above the 400-V rating. Regardless of whether the primary or the auxiliary CT saturated, this configuration is not ideal and warrants additional security measures for relay protection associated with the 46-kV currents.

The resulting filtered and unfiltered neutral and residual (3I0) 46-kV currents can be seen in the top two graphs in Figure 9. At the beginning of the event, the CT saturation results in a filtered 3I0 that is within 40 degrees of the neutral current, indicating an internal REF trip condition.

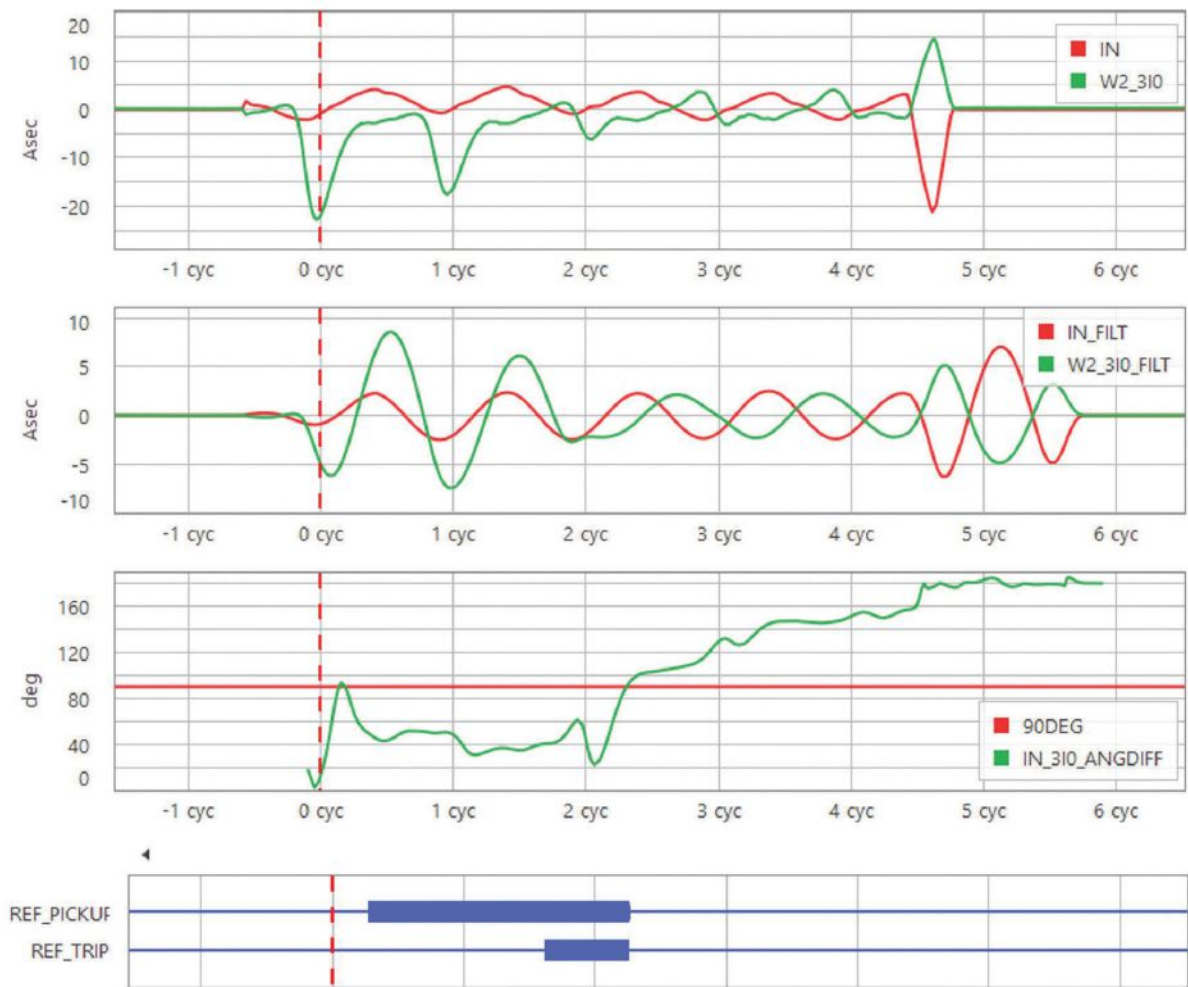


Figure 9: Neutral and 3I0 Current, Angle Differences, and REF Operation

Once the saturation subsides, the angle difference moves to 180 degrees away from the neutral current past the 90-degree threshold, indicating an external through-fault condition. The REF element was also configured to block operation when the neutral current was below 1.2 Asec or the phase residual current was below 0.96 Asec. These thresholds align with a typical 10% imbalance for the transformer MVA rating. During the initial saturated portion of the event, the neutral current measured around 1.9 Asec, and the phase residual current measured 6.0 Asec, permitting the REF element to operate.

Since this misoperation occurred, the breaker with the 600/5 CT was replaced and now supports a 1200/5 ratio. The 10/5 auxiliary CT on the 46-kV phase currents was removed.

Whether the cause of the misoperation was the primary or auxiliary CT, no issues have occurred since the reconfiguration to remove the auxiliary CTs and use a 1200/5 primary CT ratio.

SIMULATION AND TESTING

To better understand how the REF element responds to CT saturation and multi-phase-ground faults, a series of simulated signals was created and played back through a relay configured to operate when the angle difference between the phase-residual and neutral current was less than 90 degrees. The IEEE CT Saturation and Theory spreadsheet was used as the basis for creating a signal that generated an ideal and saturated A-phase current. The spreadsheet was modified to generate an additional ideal B-phase current

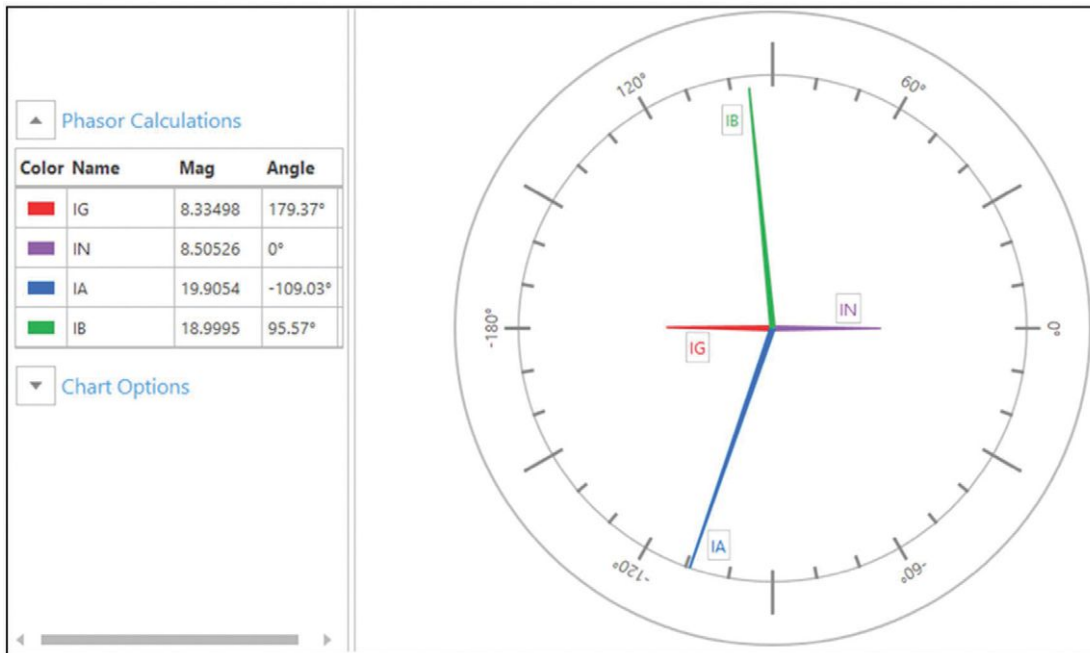


Figure 10: *Phase-Phase-Ground Simulation with No Saturation*

and the resulting ideal neutral current. No current was applied to the C-phase, as it is assumed to be zero for this phase-phase-ground fault type. The magnitude of the B-phase current was set to 95% of the ideal A-phase current, and the B-phase angle was set around 155 degrees. The selection of this angle was derived from the system model by applying a phase-phase-ground fault at the same location as the analyzed event. The resulting signals with no CT error can be seen in Figure 10 with the residual IG current 180 degrees out from the neutral IN current. For this event, the REF element restrains, as IG is 180 degrees from the reference IN.

As the A-phase current saturates, the filtered magnitude reduces, but more importantly, the filtered phase angle leads the ideal current. The latter portion of the positive or negative sinusoid waveform is reduced during saturation, so the peak looks to occur earlier in the filtered waveform, resulting in the leading phase angle. As a CT with an ideal sinusoid input saturates further, the filtered signal peak could shift by only 90 degrees before it crosses into the opposite polarity region. This highlights the security of REF elements set

with a 90-degree characteristic angle for single-phase faults.

When the angle between IA and IB increases beyond 180 degrees due to CT error, the resulting filtered IG angle quickly moves to less than 90 degrees from IN and into the internal REF trip region (Figure 11). One consideration when analyzing CT saturation and phase-phase-ground faults with REF elements is that less CT saturation is required for a misoperation to occur as the angle separation between the two faulted phases increases. For instance, with a 120-degree separation, one phase would need to saturate such that the filtered waveform would shift by over 60 degrees to misoperate. The simulation in this section shows a 155.4-degree separation, which would require the resulting filtered waveform to shift by only 25 degrees for a REF misoperation.

A simple cosine filter model was created to perform relay simulation for unbalanced three-phase faults. Like the fault analysis in the previous section, a three-phase fault with a single phase 10% higher than the others and various levels of saturation was analyzed.

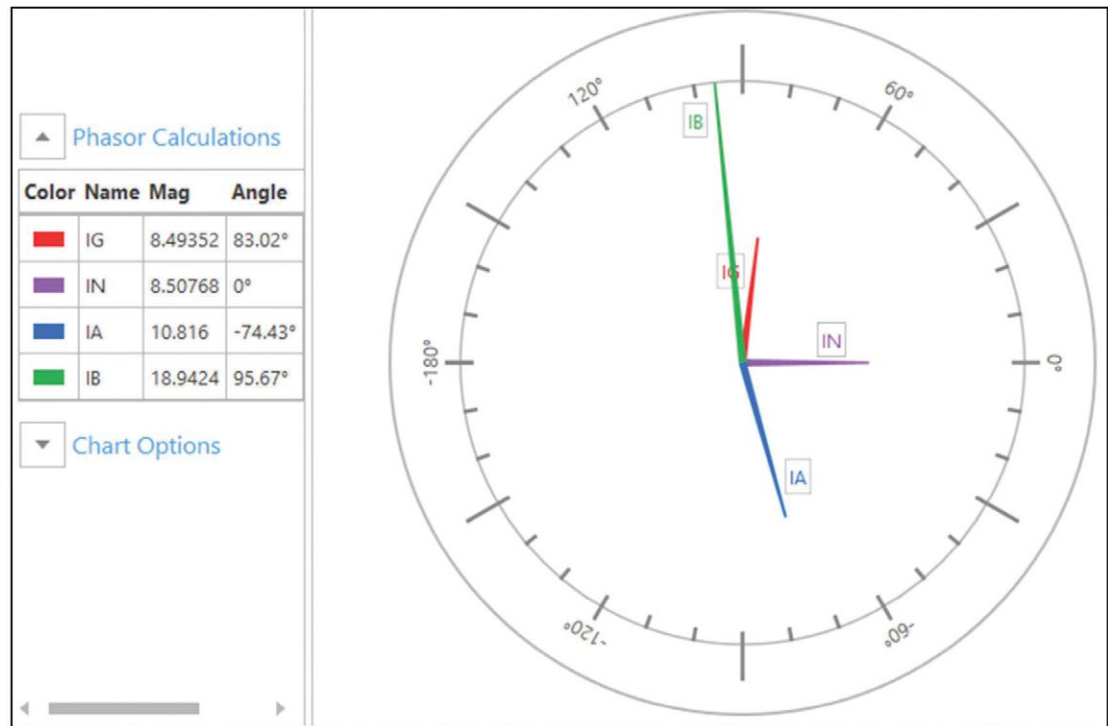


Figure 11: *Phase-Phase-Ground Simulation with Saturation*

When A-phase CT saturates, the missing current creates a large spike in the opposite direction when residually summed to the ground signal (Actual IG in Figure 12). When this signal is filtered, the resulting angle can cause a REF operation with small amounts of CT saturation.

Figure 12 shows CT saturation on the A-phase and the resulting residual IG current on top. The bottom of Figure 12 shows the neutral current IN and the filtered residual IG current. The phasor diagram in Figure 13 from the latter portion of the waveform shows that the angle difference between IG and IN is less than 90 degrees and is in the REF trip region for the waveforms in Figure 12.

Analyzing the waveforms in Figure 12 graphically shows that an unbalanced three-phase through-fault may be more susceptible to REF misoperation due to saturation than a phase-phase-ground through-fault. Both fault types should be considered when designing the REF protection for a transformer if CT saturation is expected.

CHALLENGES AND GUIDELINES FOR REF PROTECTION

When REF misoperations occur, neutral CT polarity is often the cause due to the complexity of properly designing or testing the scheme. CT polarity requirements may vary between relay manufacturers, which can create misunderstanding in the design. Performing 100% testing of the neutral CT polarity to the relay may therefore require alternate test methods, such as primary current injection or analysis of event records triggered by nearby ground faults. While the REF element has shown to be secure for single-phase-ground through-faults, multi-phase-ground through-faults warrant additional analysis.

If CT analysis shows the system may have CT saturation issues for multi-phase-ground faults and physical changes to the system are not available, additional protection security can be implemented. For the fault described in the previous analysis section, negative-sequence blocking logic or a short time delay could have prevented the misoperation.

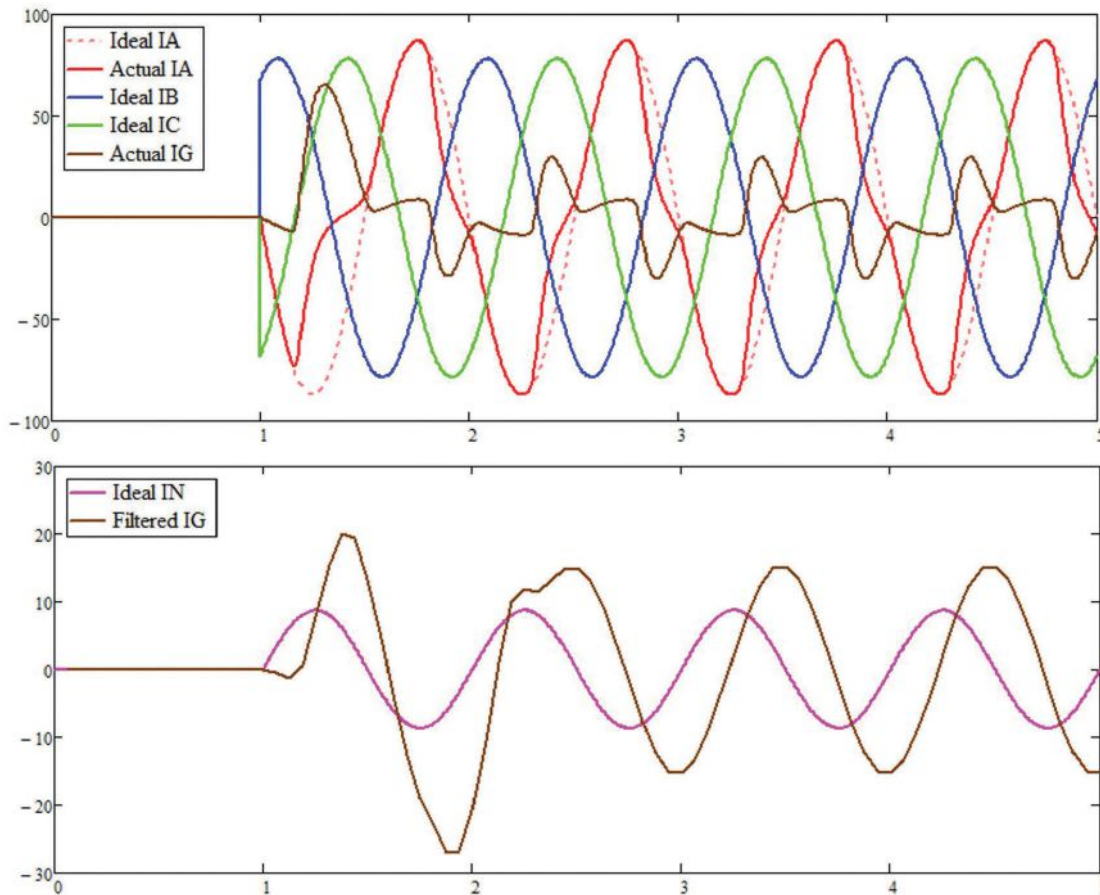


Figure 12: *Unbalanced Three-Phase Fault with Saturation—Waveforms*

Another consideration is to increase the REF current magnitude threshold. Calculations showed that increasing the REF neutral current magnitude threshold from 192 Apri to 300 Apri (10% to 17% of the nominal transformer rating) would have also prevented this REF trip. Das et al discuss the percentage of the winding that is protected by REF by changing the current pickup level, which would reduce the transformer winding protection from 99.3% to 98.9% with the higher current pickup in this case. Das also discusses more advanced security techniques, including blocking the REF element with negative-sequence current to address multi-phase-to-ground through-faults.

From the authors' experiences with fault analysis and testing, a few guidelines can be considered:

1. Ensure the design of the CT polarities for the protection system being considered is understood.

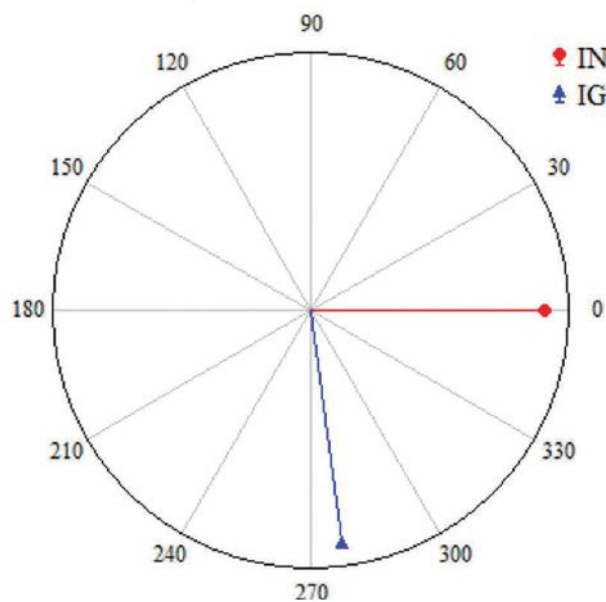


Figure 13: *Unbalanced Three-Phase Fault with Saturation—Phasors*

2. Perform a fault study for phase-phase-ground and three-phase through-faults to determine if CT saturation is applicable for either the phase or neutral CTs, including any auxiliary CTs. Note that a large angle separation between faulted phases on a phase-phase-ground through-fault may require little CT error for a REF misoperation.
3. If CT saturation for the above fault types is of concern, additional security to the REF element may be needed. Increased security options include:
 - a. Consider newer protective relays that can block REF protection based on comparisons of positive- and negative-sequence currents to the residual zero-sequence current to detect CT saturation during a through-fault condition. This blocking logic can also be achieved through custom logic schemes.
 - b. Reduce the sensitivity of the element by increasing the current magnitude pickup. This will reduce the total coverage of the transformer winding. If the REF element is based on a slope characteristic, increasing the slope can also accommodate larger angle shifts.
 - c. Add a time delay or inverse time-overcurrent characteristic to ride through any transient CT error conditions.

SUMMARY

While the transformer REF element is typically secure for single-phase faults, event analysis and laboratory testing have shown that the element is susceptible to misoperation during unbalanced multi-phase-ground through-faults if one of the phase CTs saturates. Fault studies can be performed to ascertain the data associated with these fault types to verify CT performance. This article has presented a real-world REF misoperation event, how it was redesigned, additional considerations to increase security if those hardware changes were not available, and guidelines to help the reader determine when more in-depth analysis is warranted. **NW**

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Joshua Hughes is a Principal Engineer at Qualis, focused on system studies, field system protection services, event root-cause analysis, and technical training. He initially worked as a System Engineer at Tennessee Valley Authority nuclear substations, providing commissioning services, root cause analysis, and system data trending to predict equipment failures. Hughes previously worked at Schweitzer

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A PARTIAL DISCHARGE CASE STUDY FROM AN INSURANCE PERSPECTIVE

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

I have spent many months researching how, as an equipment insurer, to enhance our understanding of underwriting risk by improving the assessment of electrical risk at medium- and high-voltage facilities through predictive analytics.

The answer I found was partial discharge (PD) testing that uses touchless acoustical methods with intrinsic AI capability. Partial discharge is a localized voltage discharge within an insulating medium, often caused by aging, electrical stress, or environmental conditions. It can manifest as surface discharge along insulator surfaces due to contaminants or as internal discharge within insulation material such as cable insulation jackets, often in voids or imperfections, and is caused by moisture and contaminant ingress. This usually appears as treeing, a type of PD in solid dielectrics, such as cable insulation materials, originating from a defect and propagating in a tree-like structure.

PD testing provides an additional method to predict potential issues/failures before they occur. I have seen this phenomenon in several recent substation visits. Alongside a good dissolved gas analysis (DGA) program, PD testing offers an avenue to better and earlier decision-making. Plan the work and work the plan.

PD testing is an effective predictive maintenance technology in medium- and high-voltage substations. The attractive part of PD technology includes AI's ability to provide a comprehensive view of the medium- or high-voltage asset before it becomes a hot spot. Once that switch or piece of switchgear goes hot, the probability of failure increases tremendously.

Now it becomes a reactive maintenance issue and unwanted outage time. Using a predictive approach, such as PD testing, enables the utility or end user to plan accordingly most of the time and take care of the issue well in advance of potential failure. Based on my extensive field experience investigating catastrophic losses, I have synthesized some critical examples and takeaways regarding failure analysis and risk mitigation.

CATASTROPHIC TRANSFORMER FAILURE

This occurred at a substation near an airport, resulting in significant disruption to the power supply and considerable financial losses, including widespread business interruption. The root cause was identified as a preventable failure. Transformers rarely fail without warning. The failed transformer was a 132-kV/11-kV, 40-MVA unit that formed part of the airport's high-voltage electrical distribution network. The substation was responsible for supplying power to the airport's terminals, runways, and other critical infrastructure. The transformer had undergone standard maintenance and inspections, but on the day of the incident, a series of events led to the transformer's failure.

A fault occurred on the 11-kV system, causing a significant increase in current flow through the transformer. The protection and control system responded by tripping the circuit breaker, but the transformer had already suffered significant internal insulation breakdown, which resulted in an explosion and fire that caused extensive damage to the substation and nearby equipment. The investigation into the transformer failure revealed that the root cause was a combination of several factors:

- **Inadequate maintenance.** Although regular maintenance had been performed, it was found that the maintenance activities were not thorough enough to identify and address a growing issue with the transformer's insulation system, including the bushings.

- **Inadequate inspection.** The inspections performed on the transformer did not include a thorough evaluation of the insulation system, which was found to be deteriorating over time. The transformer had not undergone a thorough condition assessment, including manual DGA and acoustical PD testing.

The investigation and analysis of the transformer failure revealed several key lessons that can be applied to prevent similar incidents in the future:

- **Regular and thorough maintenance.** Regular maintenance activities should be thorough and include a detailed evaluation of the transformer's insulation system. Regular manual DGA and acoustical/ultrasound PD testing at a minimum would help prevent such a loss from occurring again. Listen to the undetectable whispers before you audibly hear the screaming.
- **Predictive Maintenance.** A predictive maintenance program (manual on-line PD) should be considered to detect potential issues with transformers before they become major problems. Manual PD testing at a minimum may have helped minimize or prevent this loss as well.



Example of Partial Discharge On or Near a Transformer Bushing
IMAGE COURTESY OF FLIR

TRANSFORMER FAILURE DUE TO PD

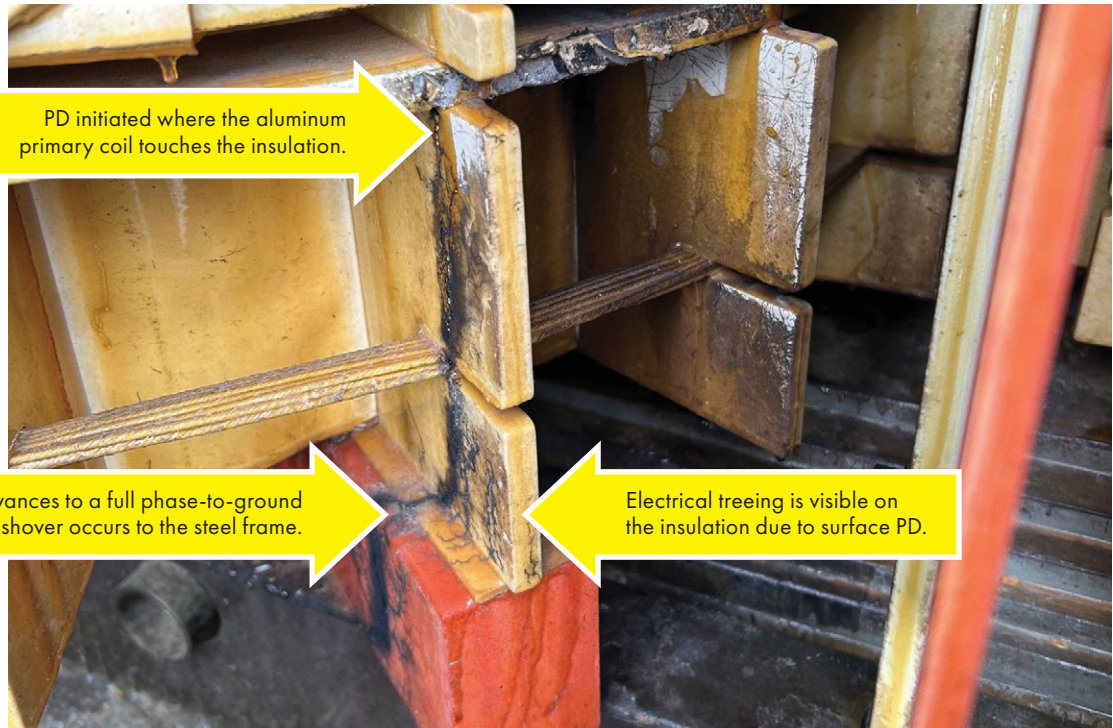
A 2,000-kVA, dry-type transformer failed due to PD on the 13.2-kV primary coil insulation. The failure was due to a damaged ventilation louver on an outdoor transformer enclosure, as the open louver repeatedly allowed water and snow to enter during inclement weather. The moisture, high humidity, and dirt contamination caused the primary coil insulation to break down due to PD. Surface PD tracking and electrical treeing damage were visible on all three primary coil windings and insulation. The surface PD eventually spanned the insulation system to the grounded support steel within the enclosure. The progressive

damage to the insulation resulted in arcing ground faults that destroyed the winding insulation and melted the aluminum primary coil windings.

A review of the damage found that:

- Visual inspection of the roof-mounted transformer enclosure would have detected the damaged ventilation louver.
- Repair or replacement of the bent louver would have prevented water and humidity from soaking into the primary winding insulation and reduced the PD inception voltage.

Periodic, on-line PD testing or manual acoustical imaging equipment would have detected the slowly developing surface tracking.



The internal view of the transformer shows a direct entry point for water and moisture. This is especially true during wind-driven storm conditions.

- Having an NFPA 70B-compliant electrical preventive maintenance program for the roof-mounted transformers would have required periodic visual and electrical inspections.
- Periodic cleaning of dirt from the transformer interior would have reduced the likelihood of surface PD or tracking.

ACOUSTIC PD USE CASES IN SUBSTATION EQUIPMENT

1. **Condition-based maintenance.** Acoustic PD imaging can be used to detect and prioritize maintenance activities for substation equipment, reducing the likelihood of unexpected failures and minimizing downtime.
2. **Fault detection and location.** The technique can help identify and locate faults in substation equipment, such as transformers, switchgear, and bushings, allowing for targeted maintenance and repair.
3. **Insulation condition assessment.** Acoustic PD imaging can assess the condition of insulation materials in substation equipment, enabling utilities to predict and prevent equipment failures.
4. **Commissioning and testing.** The technique can be used to verify the integrity of new substation equipment during commissioning and testing, ensuring that it is functioning correctly and safely.
5. **Predictive maintenance.** By analyzing acoustic PD data, utilities can predict when maintenance is required, reducing the need for scheduled outages and minimizing the risk of equipment failure.
2. **Reduced maintenance costs.** Condition-based maintenance and predictive maintenance enabled by acoustic PD imaging can reduce maintenance costs and minimize downtime.
3. **Improved safety.** The technique can help identify and mitigate potential safety risks associated with partial discharges, such as electrical shocks and fires.
4. **Real-time monitoring.** Acoustic PD imaging can provide real-time, touchless monitoring of substation equipment and power systems, enabling swift response to potential issues and minimizing downtime.
5. **Integration with other diagnostic techniques.** Acoustic PD imaging can be integrated with other diagnostic techniques, such as thermal imaging, vibration analysis, and DGA, to provide a comprehensive understanding of substation equipment and power systems.

In summary, acoustic PD imaging is a valuable diagnostic technique for detecting and locating partial discharges in substation equipment. By leveraging AI and machine learning intrinsic to the PD imager, data centers and utilities can analyze acoustic PD data to predict and prevent equipment failures, optimize operational efficiency, and maintain high levels of uptime. [NW](#)



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BENEFITS OF ACOUSTIC PD IMAGING IN POWER-DENSE MODERN AI DATA CENTERS

1. **Increased uptime.** By detecting and addressing partial discharges, data centers can minimize the risk of equipment failure and maintain high levels of uptime.

ARTIFICIAL INTELLIGENCE IN PRACTICE LESSONS AND APPLICATIONS FOR NETA ACCREDITED COMPANIES:

PART 1

BY VALER BANUSHI and ADIS TALOVIĆ, *RESA Power*

Artificial Intelligence (AI) is rapidly influencing industries worldwide, and the electrical testing field is no exception. This two-part article presents a comprehensive perspective on the role of AI within the electrical testing industry. It offers insights into future applications for NETA Accredited Companies, while considering opportunities and challenges AI may bring to the electrical testing industry.

VALER BANUSHI— IN THE FIELD: SAVING TIME AND ENSURING SAFETY

For a field technician, time and accuracy are paramount. AI agents deployed on mobile devices can act as an interactive technical library, but the operational realities demand perfection.

Imagine a NETA Level 3 Certified Technician troubleshooting an unexpected trip on a complex protective relay system during a high-stakes plant turnaround. Instead of paging through hundreds of pages of OEM manuals in a PDF viewer, the technician queries the AI: *“What are the standard diagnostic steps for a Target 81 fault on an SEL-411L relay under these specific load conditions?”*

When backed by a secure, internal database (a process known as retrieval-augmented generation (RAG), the AI accurately pulls the exact diagnostic sequence from the manufacturer’s latest documentation, cross-references it with recent maintenance logs, and presents a step-by-step testing procedure. It saves the technician hours of manual searching, allowing them to restore power safely and efficiently.

MISAPPLICATION: HALLUCINATIONS

AI hallucinations are a unique phenomenon associated with AI systems. If AI relies on generalized internet training data rather than a strictly controlled internal knowledge database, the results may be unsuccessful.

For example, a technician might ask for the injection testing parameters for a specific legacy medium-voltage circuit breaker. The AI, lacking the exact manual, might stitch together parameters from three similar but fundamentally different breaker models. It might confidently output an incorrect trip curve or suggest a test voltage that exceeds the equipment's insulation rating. If the technician blindly follows this misapplied information, it could result in severe equipment damage or compromised system reliability.

IN THE OFFICE: EMPOWERING PROJECT AND RESOURCE MANAGERS

Behind every successful field operation is a project manager balancing resource allocation, equipment availability, and strict outage windows. Here, AI agents are evolving from simple text generators into planning assistants.

Consider a project manager tasked with planning a week-long, plant-wide shut down for comprehensive NETA maintenance testing. The manager feeds the AI agent the scope of work, the roster of available technicians, including their NETA certification levels, and historical data from previous outages at similar facilities.

The AI agent successfully processes this multivariable puzzle and accurately predicts that testing the facility's aging transformers will take 15% longer than standard baselines, flags a scheduling conflict where two teams need the same primary injection test set simultaneously, and suggests an optimized daily workflow. The result is a highly efficient schedule that maximizes the limited outage window and minimizes costly overtime.

Misapplication: The Context-Blind Schedule

The danger arises when AI misapplies logic by missing crucial, real-world context. For instance, it might generate what appears to be a flawless operational schedule, completely ignoring site-specific safety protocols, including mandatory lockout/tagout (LOTO) clearance delays, union

shift-change rules, or the extra time required to navigate a facility with strict protocols.

Because AI lacks common sense and only understands the data it was explicitly fed, a project manager who takes AI's schedule at face value could quickly find their teams bottlenecked on day one. The result is a blown budget, a frustrated client, and a delayed return to service.

SECURING THE FUTURE: THE HUMAN IN THE LOOP

The integration of AI in electrical testing is inevitable, but its safe deployment requires strict guardrails. NETA companies looking to leverage large language models (LLMs) should adopt the following practices:

- **Closed-loop systems (RAG).** AI should never be allowed to guess answers from the open internet. Systems must be restricted to querying only vetted OEM manuals, ANSI/NETA MTS, *Standard for Maintenance Testing Specifications for Electrical Power Equipment*, ANSI/NETA ATS, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*, and proprietary company data.
- **Mandatory citations.** AI must be required to cite the exact page and document from which it pulled its answer, allowing the technician or manager to instantly verify the source.
- **Human-in-the-loop mandate.** AI must be treated as an assistant, not an authority. It is a tool to accelerate information retrieval, but the final execution,—whether applying test voltage or finalizing a project schedule,—must always rely on the judgment of a certified, experienced professional.

AI is poised to be one of the most powerful tools in a NETA company's arsenal. By understanding the line between accurate delivery and dangerous misapplication, we can harness its efficiency while protecting the safety and reliability that define our industry.



Figure 1: *AI can deliver highly accurate insights when based on verified data, but improper use or incomplete information can introduce significant risks,—reinforcing the need for human validation.*

ADIS TALOVIĆ—OPPORTUNITY, RESPONSIBILITY, AND COMPETITIVE ADVANTAGE

AI quickly evolved from a technology primarily discussed in software and research circles into a practical business tool that is influencing nearly every industry. The electrical testing industry is no exception. As NETA Accredited Companies continue to support the reliability and safety of critical electrical infrastructure, many organizations are beginning to explore how AI can improve operations, reporting, maintenance strategies, and customer service.

Like many emerging technologies, AI has generated both excitement and concern. Some view it as a revolutionary tool capable of transforming asset management and maintenance programs, while others question its reliability and long-term impact on the workforce. The reality likely falls somewhere in between. AI will not replace qualified technicians or engineers, nor the standards that have established NETA as

the benchmark for electrical testing excellence. However, it has the potential to significantly enhance how we collect, analyze, interpret, and present information.

For NETA Accredited Companies, the question is no longer whether AI will become part of the industry, but how to leverage it responsibly to improve safety, efficiency, reliability, and profitability.

TRANSFORMING TEST DATA INTO PREDICTIVE ASSET INTELLIGENCE

One of the most significant opportunities AI presents for NETA Accredited Companies is the ability to transform large volumes of testing data into meaningful asset intelligence. While historical test data has traditionally been used to determine pass/fail results and trend equipment performance, many facilities now possess more information than personnel can effectively analyze.

AI excels at identifying patterns within large data sets. By evaluating historical test results, maintenance records, and operating conditions, AI can detect early indicators of equipment deterioration that may otherwise go unnoticed. This capability supports a shift from traditional calendar-based maintenance to condition-based and predictive maintenance strategies.

By combining electrical test data with asset history and operational information, AI can help identify equipment at the highest risk of failure and prioritize it for maintenance or replacement. As customers increasingly seek actionable insights rather than simply receiving test reports, NETA Accredited Companies that can transform data into meaningful recommendations will be well-positioned to deliver additional value and differentiate themselves in the marketplace.

However, AI is not a replacement for engineering expertise. It is a tool to help technicians and engineers focus their attention where it matters most. Interpreting test results, assessing equipment condition, and developing corrective action recommendations will

continue to rely on the knowledge, experience, and judgment of qualified NETA professionals.

IMPROVING REPORTING AND CUSTOMER DELIVERABLES

AI may also significantly improve one of the most time-consuming aspects of the testing process: report preparation. Many testing projects generate hundreds or even thousands of pages of data. AI-assisted tools can organize findings, identify deficiencies, compare results against historical trends, and assist in developing executive summaries. The value is not simply faster report generation. The real benefit lies in consistency and improved communication that can transform technical test results into information that supports better business decisions.

CHALLENGES THAT CANNOT BE IGNORED

While the opportunities are significant, AI adoption also presents important challenges:

- **Data quality.** AI systems are only as reliable as the information they receive. Inconsistent equipment naming, incomplete records, inaccurate test

results, and poor documentation can reduce the effectiveness of even the most advanced analytical tools.

- **Cybersecurity.** NETA companies frequently work within critical infrastructure environments, including data centers, hospitals, utilities, and manufacturing facilities. Any AI platform handling customer information or electrical system data must be implemented with strong security controls and appropriate oversight.

Perhaps most importantly, professional responsibility remains unchanged. AI can assist with analysis and recommendations, but it cannot replace the experience, judgment, and accountability of qualified technicians and engineers. Customers rely on NETA Accredited Companies for their expertise, independence, and adherence to recognized standards,—not for software.

LOOKING AHEAD

To someone working within the electrical testing industry, AI should be viewed not as a threat to NETA Accredited Companies

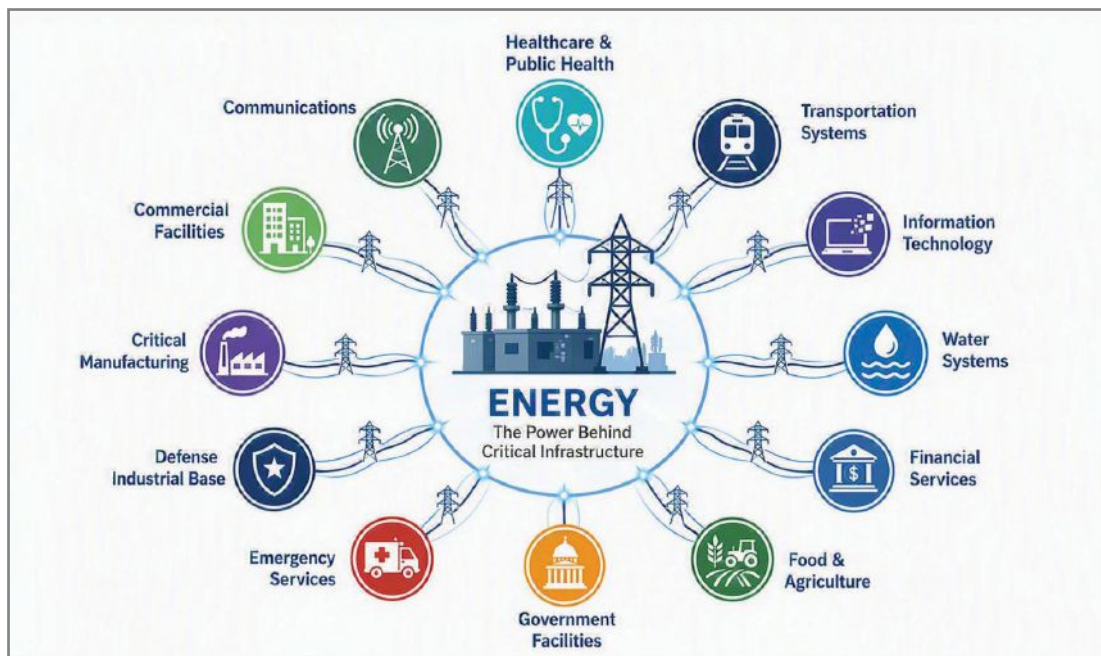


Figure 2: The energy sector provides the electrical backbone required for modern society. NETA Accredited Companies play a vital role in helping maintain the reliability and resiliency of the power systems that support critical infrastructure.

but as an opportunity to enhance the value we provide. The core principles that define NETA,—technical competence, safety, independent testing, and standards-based evaluation,—will remain unchanged. What will change is our ability to extract greater insight from the information we already collect.

The most successful organizations will adopt AI thoughtfully, using it to improve efficiency, strengthen safety programs, enhance customer service, and provide deeper reliability insights. At the same time, they will recognize that no algorithm can replace the expertise of a technician interpreting test results in the field or an engineer making critical reliability decisions.



Figure 3: Artificial intelligence is shaping the future of electrical testing by enabling predictive maintenance, data-driven decision-making, and improved operational efficiency across critical infrastructure.

CONCLUSION

The future of electrical testing will not be driven by AI alone. It will be driven by experienced professionals using advanced tools to make better decisions, improve reliability, and deliver greater value to their customers. For NETA

Accredited Companies, that future presents both challenges and tremendous opportunities.

Coming in the Winter 2026 issue: Neno Pasic shares how Tony Demaria Electric is moving beyond discussing AI to implementing it in day-to-day operations. Learn how a NETA Accredited Company is using AI responsibly to improve productivity, strengthen decision-making, and support both field and office teams,—while maintaining the human oversight essential to our industry. [NW](#)

Note: Images created by Neno Pasic using AI.



Valer Banushi is a degreed Environmental Health and Safety (EHS) executive with twenty years of experience driving EHS, operational excellence, quality assurance, and cultural transformation across the manufacturing, electrical services, and energy sectors. He currently serves as the Vice President of EHS & Operational Excellence at RESA Power. Throughout his career, Valer has successfully designed and scaled comprehensive EHS programs for major North American organizations, leading cross-functional teams and managing rigorous compliance frameworks. Valer holds a BS in occupational health and safety from Northern Illinois University and is an authorized OSHA Outreach Industrial Trainer and certified ISO Lead Auditor.



Adis Talović is an Electrical Engineer and NETA Level 4 Senior Technician with more than 20 years of experience in electrical testing, power system reliability, and engineering leadership. He currently serves as a Lead Power Systems Engineer with RESA Power, where he supports critical power infrastructure projects across a wide range of industries. A graduate of the University of North Carolina at Charlotte, NC, with a BS in electrical engineering technology, Talović has extensive experience leading NETA-accredited operations, developing technical professionals, and driving organizational growth. An active member of the NETA community, he serves on the NETA Membership Application Review, Volunteer Engagement, and Training Committees. He is passionate about advancing the electrical testing industry through mentorship, education, and the practical application of emerging technologies.

THE BUSINESS CASE FOR BECOMING A NETA ACCREDITED COMPANY

Recognized throughout the industry as the gold standard for electrical power system acceptance testing and maintenance, NETA Accreditation validates both a company's technical capabilities and its commitment to safety, quality, and independent service.

NETA Accredited Companies (NACs) play a vital role in advancing electrical power reliability and safety through third-party, independent electrical testing services. Critical facilities, commercial enterprises, industrial plants, utilities, healthcare campuses, and data centers often specify NETA testing services because they require a level of expertise, objectivity, and standards compliance that helps protect their most important electrical assets.

NETA Accredited Companies have built their reputation on adherence to ANSI/NETA standards and the employment of highly qualified NETA Certified Technicians. Their comprehensive knowledge of electrical power systems enables them to identify potential issues before they become costly failures, reduce unplanned downtime, extend equipment life, and improve overall system reliability. Most importantly, their objective, standards-driven approach gives facility owners confidence that maintenance decisions are based on accurate testing, expert analysis, and unbiased recommendations.

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THE ABCs OF YOUR PQA: A FIELD GUIDE TO CONFIGURING POWER QUALITY ANALYZERS

BY GREGG WONG, *AEMC Instruments*

The goal of any good power system is simple in theory: Deliver clean power to the loads it serves. In practice, however, “clean” quickly becomes a relative term. Spend enough time around power quality measurements, and one thing becomes apparent: Many of the disturbances blamed on incoming utility power originate inside the facility itself. Wiring practices, grounding methods, and interconnected loads are often larger contributors to so-called dirty power than disturbances arriving from outside the meter.

Put another way, dirty power is often in the eye of the load. The issue is less the absolute condition of the supply than the susceptibility of the equipment connected to it.

Modern electrical systems complicate this further. Electronic loads have become smaller, denser, and more sensitive to voltage disturbances, while also injecting more distortion back into the system. Manufacturers compensate with increasingly sophisticated protective circuitry, but those protections are

limited by cost, spacing, and thermal design. The result is a power environment where the system intended to support critical loads can become surprisingly hostile to them.

Alongside the evolution of electrical systems, power quality analyzers (PQAs) have become exceptionally capable instruments, combining rapid sampling, harmonic analysis of waveforms, event triggering, and reporting into a single platform. Yet even sophisticated analyzers are only as useful

as their configuration. Understanding the ABCs of power quality analysis—atomy, benchmarking, and capture—provides the framework for configuring the instrument to answer the diagnostic question being asked.

A IS FOR ANATOMY: THE ELECTRICAL SYSTEM AND WHERE TO MONITOR

If you frequent this publication, we do not need to explain the basic anatomy of an electrical system. What is worth examining is where the instrument should be placed within the system, because it is one of the most common misunderstandings about working with PQAs in complex systems. The right answer depends on the question being asked, and the wrong choice of location will limit even the most sophisticated analyzer to missed events or misleading data.

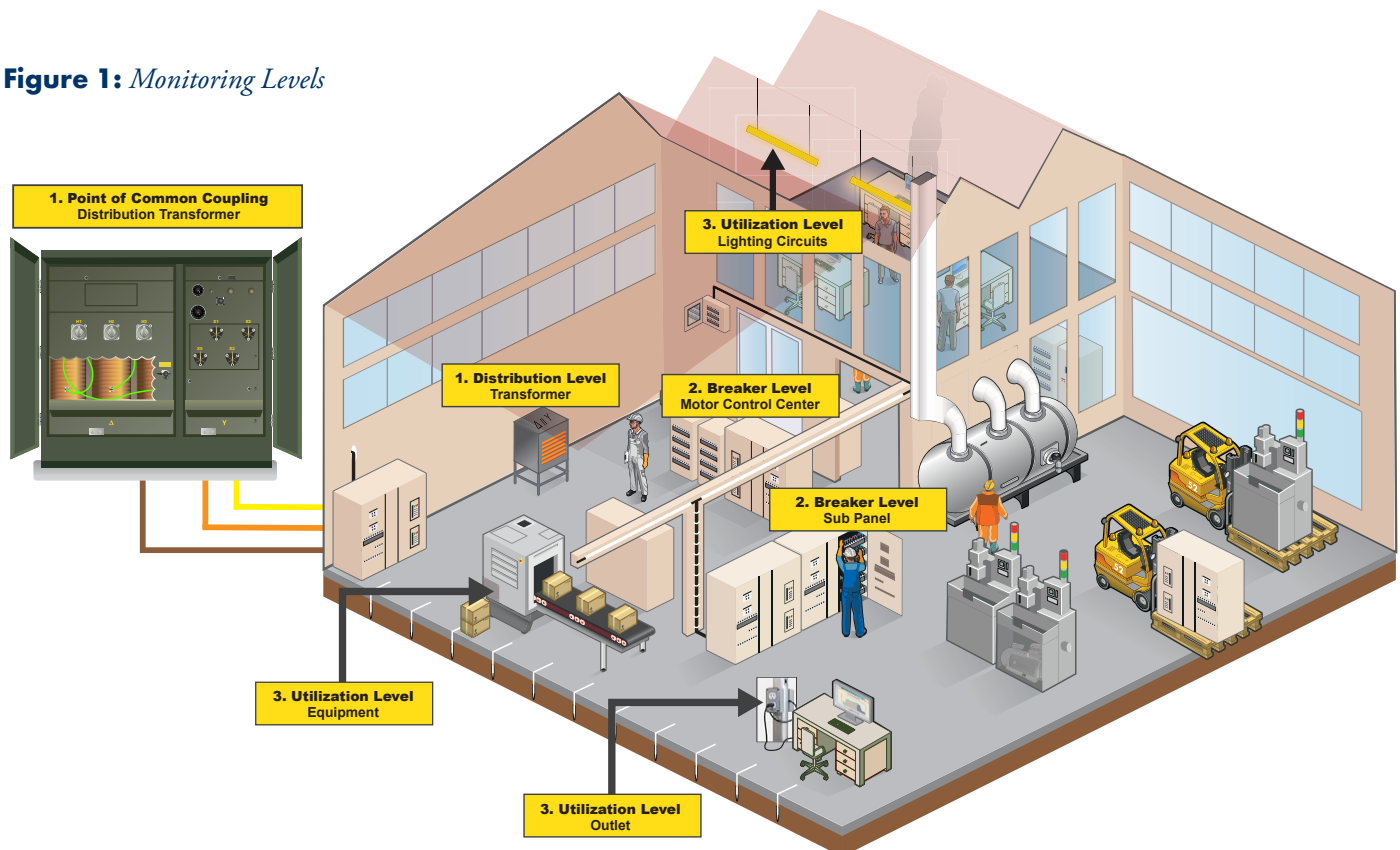
Figure 1 shows the three monitoring levels in a typical facility, from the utility-side distribution transformer down to the outlets, lighting, and equipment that ultimately consume the power.

Point of Common Coupling

The point of common coupling (PCC), sometimes called the service level, is the derived source of power for the facility, typically the secondary of a distribution transformer. Studies at this level capture the entirety of the local electrical network, making it valuable for understanding overall system performance and the facility's interaction with the utility. It is less effective for locating specific internal sources because the contributions of individual loads have already aggregated by the time current and voltage reach the PCC. The PCC is also where the utility's power quality requirements formally apply. Service agreements and tariffs commonly hold the customer to harmonic distortion, flicker, and power factor limits measured at this point, and any question of responsibility for a disturbance is ultimately settled with data recorded here.

Most preset configurations in PQAs are designed against PCC-level references, especially the harmonic compliance limits in

Figure 1: *Monitoring Levels*



IEEE Std. 519, *Standard for Harmonic Control in Electric Power Systems*. The resulting data has value for documenting overall system behavior and for any conversation with the utility, but it is not the optimal starting place when the goal is to locate an internal load behaving badly.

Breaker Level

A study at the breaker level, such as a sub-panel or a motor control center, is better suited to locating circuit-level issues than studying at the PCC. Monitoring here focuses primarily on voltage stability across the branch circuits the panel serves and can reveal patterns spanning multiple loads that would be invisible at any single piece of equipment.

Consider a retrofitted LED lighting system. Before the upgrade, fluorescent tubes failed on a typical maintenance cycle, but new LED fixtures are failing much sooner than their expected end of life. A study at the panel feeding the lighting circuit may reveal overvoltage issues causing LED driver failure, the kind of marginal voltage variations older fluorescent tubes were largely immune to.

Utilization Level

Utilization-level studies have the most diagnostic impact when only a single load is exhibiting problems. Consider a recently upgraded

high-speed printer that begins to misoperate shortly after installation (Figure 2). This is exactly the kind of problem a utilization-level study is designed to resolve. Despite being the easiest of the three monitoring tiers to deploy, utilization-level studies are also among the most consistently underused. Monitoring directly at the equipment terminals establishes the actual electrical environment experienced by the load, including voltage variations that may remain well inside published standards yet still exceed the susceptibility of the connected equipment.

Cascading Studies

One PQA is useful in identifying issues at one level. Several PQAs, deployed simultaneously at different tiers and synchronized in time, tell an entire power disturbance story. Class A instruments include accurate time synchronization, which makes it possible to capture events at multiple monitoring points and analyze them after the fact against a common timeline. Comparing what a single disturbance looked like at the PCC, at a sub-panel, and at the affected load is one of the few ways to determine with confidence whether a problem is being delivered from upstream or generated by something inside the facility. IEEE Std. 1159–2019 formalizes this same monitoring approach by relating the problem scope to the monitoring location, as summarized in Figure 3.



Figure 2: Single-Phase Outlet Power Quality Analysis

Figure 3: *Suggested Monitoring Locations by Problem Scope, Adapted from IEEE Std. 1159-2019, Table 3.*

Problem	Recommended Monitoring Location
A specific piece of equipment exhibits problems related to power quality.	At the equipment connection to the facility's electrical system (e.g., motor control center)
All equipment connected to a branch of the distribution system within a facility exhibits problems related to power quality.	At the branch connection to the facility's electrical system (e.g., motor control center)
The entire facility exhibits problems related to power quality.	Secondary of the transformer serving the facility

B IS FOR BENCHMARKING: CONFIGURING THRESHOLDS FOR THE LOADS BEING SERVED

With the analyzer placed at the right monitoring level, selecting the thresholds to monitor on recorded parameters is the next step. Every parameter a PQA records includes configurable thresholds that determine which events get flagged and which pass unrecorded. Setting those thresholds against published voltage standards alone, such as ANSI C84.1, IEEE Std. 519, or EN 50160 in the European context, can be misleading. Compliance with a published voltage standard does not guarantee a problem-free electrical environment for sensitive loads.

Benchmark Studies

Before configuring a long-form study, one of the most useful steps is establishing a short benchmark recording under normal operating conditions. The goal is not to capture power-related events but to characterize what normal operation looks like at the monitoring location. Capture minimum, maximum, and average RMS voltage per phase, along with RMS current, frequency, and harmonic content, including THD and individual harmonic components where relevant. Cross-reference the recorded trends with operational logs, misoperation reports, or operator observations. The resulting operating envelope becomes the basis for configuring alarm thresholds in the long-form study that follows. See Figure 4 for an example.

WORKSTATION POWER QUALITY STUDY

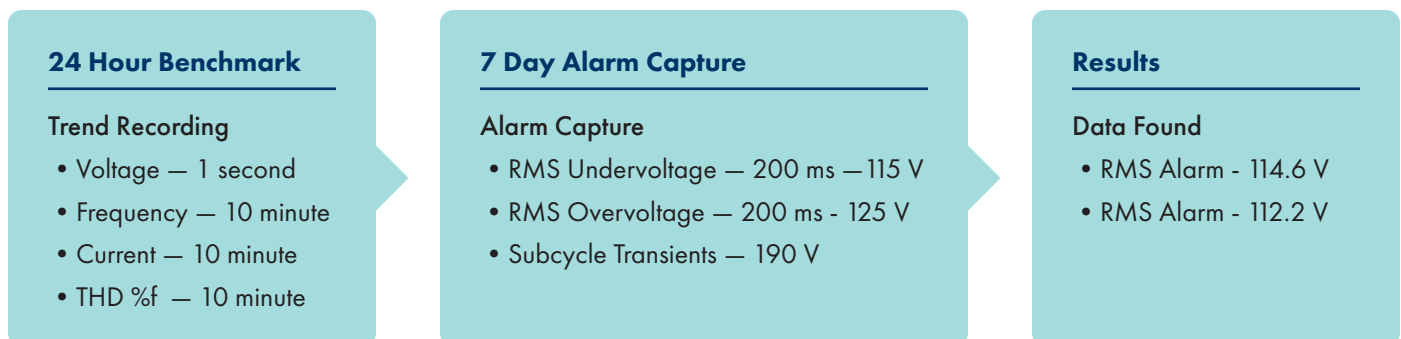


Figure 4: *Basic Power Quality Study Plan and Results*

The benefit of starting with a benchmark study is that it tunes the analyzers' capture to the local environment. A workstation that resets every few hours may be reacting to voltage deviations well inside the published utilization range, which does not trigger the analyzer's default 10% sag threshold. A benchmark study captures the actual operating voltage envelope—perhaps 117 V to 122 V during normal hours—and lets the technician set a sag alarm just outside that envelope, say 115 V, rather than at the default threshold the load would never have hit.

Benchmarking Versus Standards

Most PQAs ship with templates configured against standards such as ANSI C84.1, IEEE Std. 519, or EN 50160. These standards are useful starting points for general power quality assessment, but they are not the right benchmark when the question is whether a specific sensitive load is being treated badly. For that question, load susceptibility—meaning the actual tolerance of the connected equipment—is the critical benchmark. The Information

Technology Industry Council (ITIC) curve, shown in Figure 5, is one widely used susceptibility reference for IT-class equipment. It defines a voltage-versus-time envelope inside which IT-class equipment is expected to ride through without dropout or damage. Equipment manufacturer specifications can be tighter still, and a sensitive load may operate within a window narrower than ITIC predicts.

Parameter Selection

A modern PQA can offer more than 200 selectable parameters in its trend and alarm modes, but capturing every available parameter often produces large reports and junk data rather than diagnostic insight. The temptation is strongest with the long list of calculated power quantities that advanced instruments provide. Values like non-active power, distortion power, and other specialized decompositions of apparent power can be useful in dedicated engineering analysis, but they rarely contribute meaningfully to routine troubleshooting work. They also consume storage and analyst attention that could be better spent elsewhere.

For a basic study, focus on the voltage side. Voltage RMS minimum, maximum, and average per phase, along with voltage THD, will surface most of the disturbances a technician is investigating. Current parameters are worth capturing for specific cases, such as current balance studies or inrush analysis. Defaulting to full current capture across every long-form study tends to inflate data files without adding diagnostic value, because most power quality disturbances are voltage events.

Harmonic Monitoring

Harmonic content (Figure 6) is one of the parameters most likely to produce confusion when analyzer thresholds are configured without considering where the instrument is installed. Preset templates and default analyzer configurations often work well for general voltage monitoring, but harmonic thresholds may not behave the way the user expects.

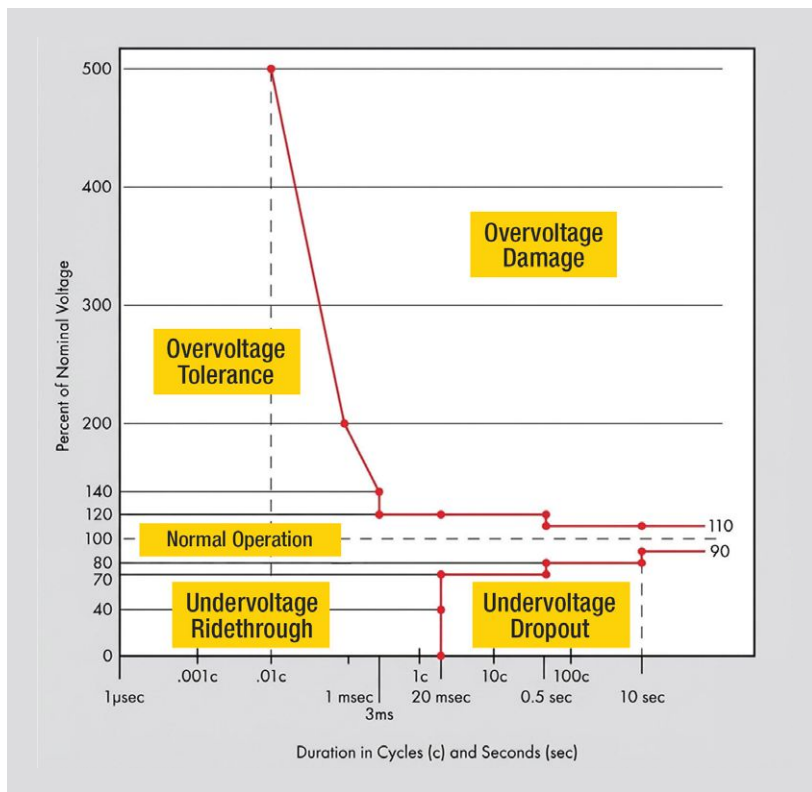


Figure 5: *ITIC Curve*

At the utilization level—close to a nonlinear load such as a VFD, switch-mode power supply, rectifier, or LED driver—current THD of 20% to 40% may be completely routine depending on the topology and measurement location. At the PCC, however, IEEE Std. 519-2022 recommends limiting voltage THD to 8% for systems at or below 1 kV, with individual harmonics limited to 5.0%. Both conditions can be correct because they describe different measurement locations within the system.

Harmonic currents generated by nonlinear loads dilute and partially cancel as they aggregate upstream and mix with other loads. As a result, thresholds appropriate at the PCC can produce nuisance alarms when applied at the utilization level. Benchmark studies and equipment specifications provide a more realistic basis for configuring harmonic alarm thresholds near sensitive or nonlinear loads.

Harmonic flow analysis (Figure 7) can further help identify the source of a problematic harmonic. Modern analyzers capable of synchronous voltage and current sampling can calculate harmonic power flow by harmonic order. Positive harmonic power flow indicates the downstream load is injecting the harmonic, while negative flow indicates the harmonic is arriving from upstream. This technique is particularly useful when determining whether harmonic distortion originates inside the facility or from an external source.

Neutral-to-Ground Voltage as a Threshold

The voltage between neutral and ground should sit near zero on a properly bonded system. Figure 8 shows a sustained neutral-to-ground voltage of approximately 2.5 to 3 V over a 24-hour period. While the system may appear electrically stable from a conventional voltage perspective, elevated neutral-to-ground voltage can indicate an unstable local reference environment for sensitive electronic or communication equipment. Conditions like these are commonly associated with harmonic-rich neutral currents, shared neutrals, or bonding issues and may create problems even

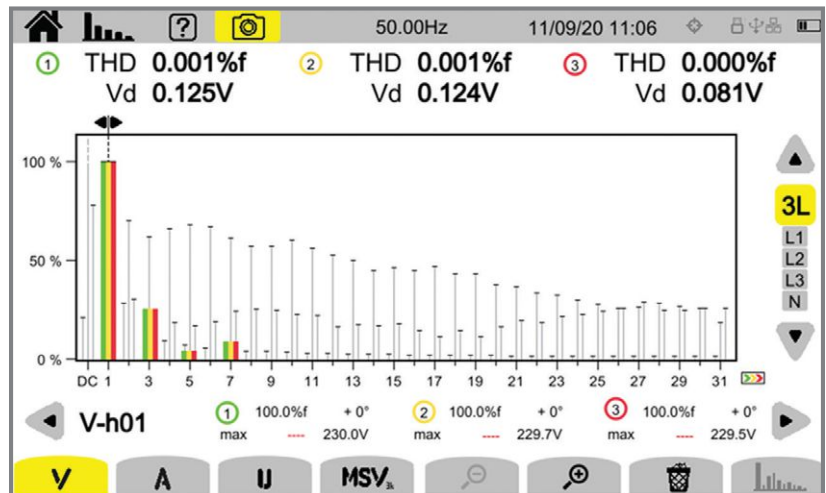


Figure 6: *Harmonic Content*

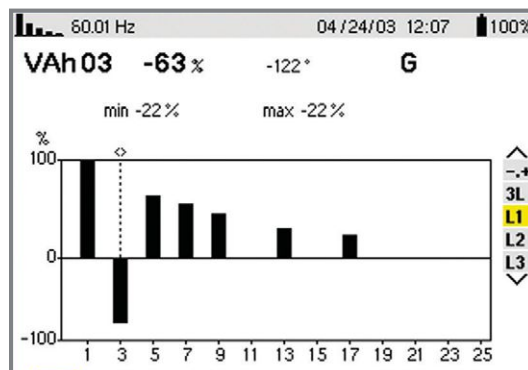


Figure 7: *Harmonic directional analysis shows the 3rd harmonic upstream from the instrument.*

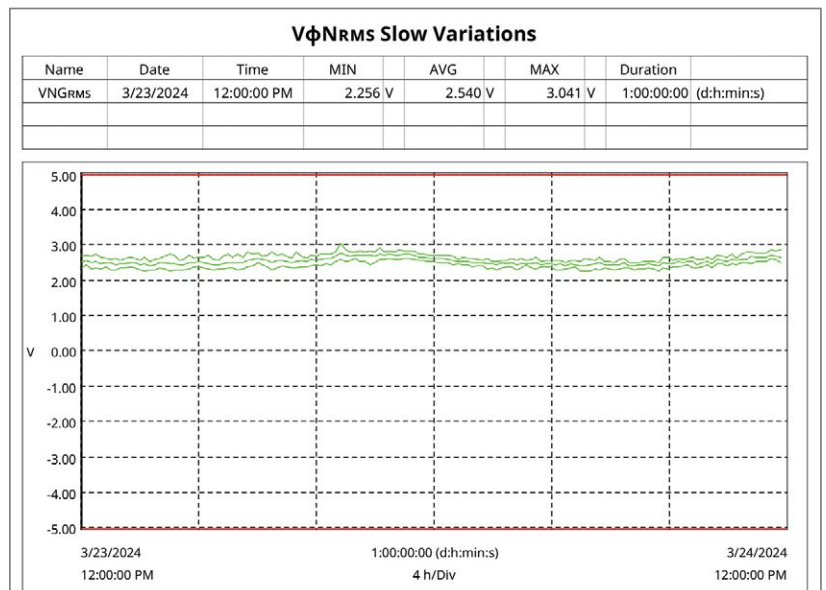


Figure 8: *Neutral-to-Ground Voltages*

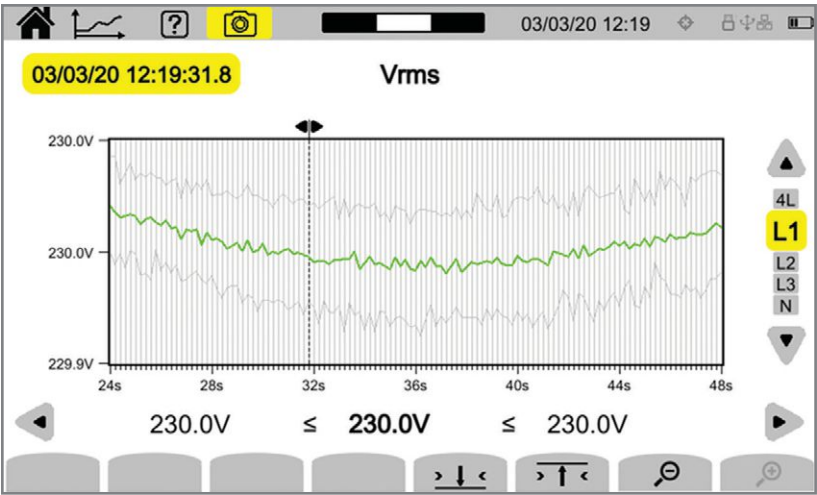


Figure 9: Voltage Trend Recording

when line voltage remains within published standards. IEEE Std. 1100 suggests keeping neutral-to-ground voltage below 1 V at receptacles serving sensitive loads, with tighter thresholds (under 100 mV) for some medical and information-technology installations.

C IS FOR CAPTURE:
RECORDING THE DATA THAT
ANSWERS THE QUESTION

With the analyzer placed at the correct monitoring level and thresholds established through benchmarking, the work shifts to capturing and verifying the presence of power-quality events. The analyzers’ capture configuration—whether continuously, on triggered events, or in some combination—

determines what kind of reporting and analysis is possible when the study is complete.

Capture Modes

Modern PQAs offer four broad capture modes, and choosing the right one is one of the more consequential configuration decisions a technician makes.

Trend mode-type studies (Figure 9) record continuously over a user-defined aggregation interval and are most useful for benchmark studies or long-term operating contexts. Because it records every aggregated value over time, analysis often involves hunting and pecking through large datasets, which makes trend mode better suited to baseline characterization than to event-focused troubleshooting.

Alarm mode (Figure 10) builds on the same trend-recording structure but captures only events that exceed configured thresholds. Instead of producing a continuous operating record, alarm mode generates a smaller, more focused dataset centered on the events of interest.

Transient and inrush modes (Figure 11) are specialized waveform-capture variants of alarm mode. Both trigger from configurable thresholds but record high-resolution waveforms rather than aggregated RMS values. Transient mode is intended for fast events such as switching surges, while inrush mode captures motor or transformer energization.



Figure 10: Alarm Mode Configuration

In practice, most PQAs include pre-configured monitoring studies (Figure 12) that combine trend-mode continuous recording with alarm- and transient-modes operating in parallel to trigger specific events. The trend record provides continuous context, while the alarm, transient, and inrush triggers capture the specific moments that matter at higher resolution. Typically, these monitoring studies are run at the PCC for voltage quality standards, utilizing various standards, but can be adjusted to monitor power quality at breaker and utilization levels.

RMS Aggregation Intervals

Aggregation intervals determine the resolution at which the analyzer summarizes RMS values for the trend record and alarm capture, and choosing the right interval is a tradeoff between resolution and data manageability.

Long aggregation periods, such as 15-minute windows, smooth the data and are ideal for demand studies, load profiling, and long-term trend work where the relevant question is about system behavior over hours or days. Short aggregation periods, such as 1-second or 12-cycle (approximately 200-ms) intervals, give significantly higher resolution.

The captured data at these intervals can be meaningfully compared with the multi-cycle portion of susceptibility references, such as the ITIC curve, manufacturer specifications, or

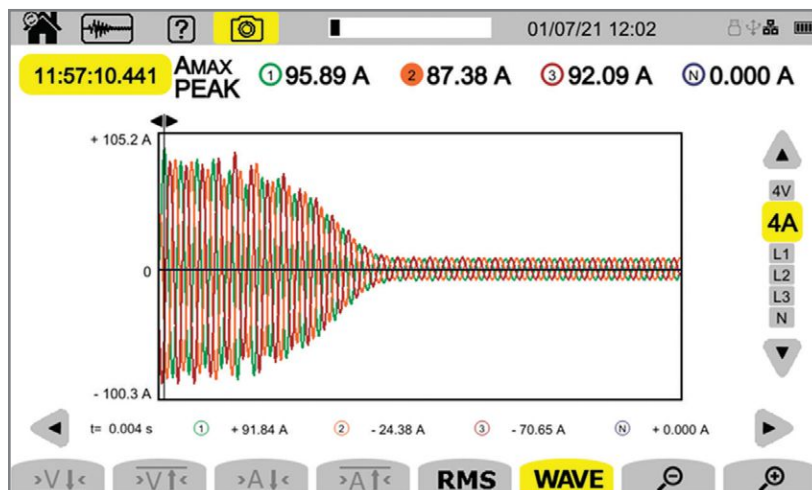


Figure 11: *Inrush Capture Results*

other narrow-window equipment tolerances. A 10-minute aggregation will smooth out a 200-ms voltage sag from the data. A 12-cycle aggregation will register that same sag as a measurable RMS deviation.

For voltage changes that happen faster than the aggregation window can resolve, rapid voltage change (RVC) capture provides a complementary high-resolution method. As defined in IEC 61000-4-30, RVC uses sub-cycle RMS calculations to flag fast voltage shifts that may not exceed the sag or swell thresholds yet still indicate a meaningful disturbance. This bridges the gap between the standard aggregation intervals and the analyzer's waveform-capture modes.

Monitored parameter	Result	Starting date/time	Ending date/time
Slow variations	Test passed	1/27/2024 5:20:00 PM	2/3/2024 5:20:01 PM
Rapid voltage changes (RVC)	No events detected		
Long and short interruptions	No events detected		
Voltage dips	No events detected		
Voltage swells	No events detected		
Transients	Events detected		
RMS	Test passed		
Hz	Test passed		
Unbalance	No results available		
THD & Harmonics	Test passed		
Flicker	Test passed		

Figure 12: *Monitoring Study Results*

Study Duration

The right length for a power quality study is dictated by the timing of the event being investigated. Before setting the analyzer to record, it is worth asking a few diagnostic questions about the symptom: How often does the event occur? Where does it occur? What equipment is being affected? Is the timing correlated with temperature, weather, or a production schedule?

The answers shape how long the study needs to run and when it should run:

- Benchmark studies, as discussed earlier, are short by design and run from 1 hour to 24 hours to characterize normal operation.
- The long-form power quality study that follows ranges from a day to several weeks, depending on the event timing.
- An event recurring every shift may surface within a single day.
- An event tied to weekly production cycles needs at least a week.
- An event correlated with seasonal weather or temperature variation may require a study spanning the relevant conditions, sometimes a month or more.

There is little value in running a long-form study during scheduled downtime, planned outages, or any period when the loads of interest are not operating. The analyzer captures the absence of the problem, not its cause. When in doubt, leave the meter longer, but leave it in place during the conditions when the symptoms actually appear.

Class A and Class S

A brief note on measurement class: IEC 61000-4-30 defines Class A as the reference measurement class, with the tightest specifications on accuracy and time synchronization. Class S is the survey class, which uses the same measurement methods but with looser uncertainty requirements. Most PQ work is well-served by Class S Instruments. The exception is when measurement data may be challenged or used for formal compliance reporting, in which case Class A is the appropriate choice.

FROM DEFAULTS TO DIAGNOSIS

A PQA is a sophisticated diagnostic instrument, but the bulk of its diagnostic value is unlocked by configuration choices made at deployment:

1. Anatomy answers the first question: where to monitor. The right monitoring tier depends on whether the problem is at a single piece of equipment, across a branch circuit, or facility-wide.
2. Benchmarking answers the second question: what to flag. Thresholds informed by a shorter initial study and matched to the susceptibility of the onsite load produce alarm logs that point to the problem rather than to the noise floor.
3. Capture answers the third question: how to record the data. Capture modes, aggregation intervals, and the disciplined use of RMS trends over waveform snapshots determine whether the recorded data answers the question the technician asked.

The configuration that follows from these three questions looks different from the preset templates PQAs ship with. That is the point. Default settings are starting positions, not landing points. The high-speed printer, the retrofitted LED lighting circuit, and the factory facility's interaction with the utility all present different questions, and each requires a PQA configured to answer the specific question at hand. Power quality work begins, and continues, at the most sensitive load. The analyzer's job is to capture the evidence. Configuration is what makes the evidence useful in diagnosing power quality issues.

These measurements do not require exotic instrumentation or a specialist's toolkit. It requires a technician who treats a PQA as an extension of the diagnostic questions already being asked: where the symptom lives in the facility's anatomy, what "normal" looks like at that location, and which capture settings will preserve the evidence when the event finally

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occurs. Approached this way, the ABCs of the PQA turn a box of default settings into a targeted diagnostic instrument and turn weeks of recorded data into a handful of records that explain why the printer locks up, the lighting flickers, or the drive trips. That is the difference between collecting data and finding the problem. [www](#)



Gregg Wong is a Product Manager and technical training professional with AEMC Instruments, specializing in electrical test and measurement applications. He holds a degree in electrical engineering technology and is an AEMC Instruments Certified Technical Trainer, with experience spanning field service, sales engineering, product training, and technical content development. His areas of expertise include ground resistance testing, insulation resistance testing, power quality analysis, and the practical application of electrical testing standards.

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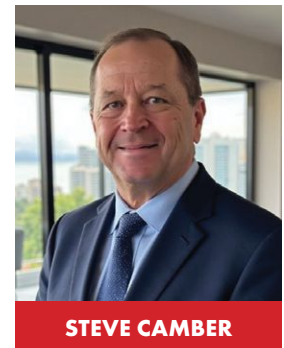
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NETA Corporate Alliance Partners (CAPs) are industry-leading companies that have joined forces with NETA to work together toward a common goal: improving quality, safety, and electrical system reliability.

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



STEVE CAMBER

For this issue, we spoke with representatives from Group CBS, one of North America's largest providers of electrical equipment, engineering, field services, and life-extension solutions. Drawing on expertise across its family of companies, Group CBS discusses how increasing electrical demand, aging infrastructure, and the rapid expansion of AI-driven data centers are reshaping the industry.

NW: What important changes are you seeing in your industry segment?

Camber: The biggest shift we're seeing is the return of meaningful electrical load growth across the North American power grid after nearly a decade of relatively flat demand.

Today's growth is being fueled by transportation electrification, electric heating, industrial electrification, and, perhaps most significantly, the rapid expansion of AI data centers. At the same time, aging electrical infrastructure, lengthy interconnection queues, and increasing grid congestion are slowing the pace of modernization. Traditional resource planning simply wasn't designed for today's combination of accelerating demand and infrastructure constraints.

As one of the nation's largest suppliers of both new and legacy electrical equipment, along with nationwide field service capabilities, Group CBS is uniquely positioned to help customers address these challenges while maintaining reliability during a period of unprecedented change.

NW: What factors are driving these changes?

Camber: Demand-side electrification is the primary driver. More electric vehicles, expanded industrial electrification, increased electric heating, and rapidly growing computing requirements are placing new demands on the grid simultaneously. AI data centers, in particular, have become one of the largest contributors to projected load growth.

Meanwhile, decades of underinvestment in electrical infrastructure are colliding with these new demands. Utilities are responding with significant capital investment programs while balancing customer affordability and increasingly complex supply chains.

One advantage for Group CBS is its extensive inventory of legacy electrical equipment spanning multiple decades. That inventory allows customers to restore service without undertaking expensive redesigns or complete equipment replacements. At the same time, the company's in-house manufacturing capabilities enable modernization projects that increase system capacity while extending asset life.

Another significant driver is the increasing financial impact of downtime. For many industrial facilities, unplanned outages now average more than \$250,000 per hour. As a result, real-time monitoring and proactive maintenance have evolved from optional investments into operational necessities.

NW: How is your organization responding to these changes?

Camber: Our strategy centers on what we call the Power of One—providing utilities and industrial customers with a single, trusted partner throughout the entire electrical power system lifecycle.

Rather than coordinating multiple vendors for engineering, testing, equipment procurement, safety solutions, and emergency response, customers can rely on a fully integrated

organization that supports every phase of an electrical infrastructure project.

Group CBS continues to invest heavily in its nationwide network of NETA Accredited field service operations, engineering resources, and extensive inventory of new, surplus, and reconditioned equipment. Our nationwide service centers also provide life-extension, remanufacturing, and reconditioning capabilities that allow customers to restore legacy equipment while avoiding the cost of complete replacement.

Equally important is our ability to provide emergency response around the clock. With 24/7/365 restoration capabilities, customers can access rapid support wherever their critical assets are located.

Safety remains another major focus. As utilities and contractors perform increasing amounts of high-risk field work to support grid expansion, remote racking and switching technologies are becoming increasingly important for protecting personnel from arc flash hazards.

NW: How will these changes impact the overall electrical power industry?

Camber: Over the next several years, we expect the industry to be defined by the balance between urgency and affordability.

Utilities must expand capacity, modernize aging infrastructure, and improve reliability faster than ever before, all while navigating supply chain limitations, workforce shortages, and financial pressures. Those competing priorities will require thoughtful planning and trusted partnerships.

Automation will also continue to accelerate. As utilities deploy more intelligent monitoring and control technologies throughout their systems, investment in power distribution automation is expected to grow significantly over the remainder of the decade.

At the same time, modernization won't always mean complete replacement. Life-extension

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programs, remanufacturing, engineering expertise, and field services will continue to play a critical role in helping utilities maximize existing assets while making strategic investments that create the greatest value.

NW: How do these changes affect the electrical testing industry?

Camber: Testing is becoming more important—not less.

As utilities seek to maximize the life of existing infrastructure, they need reliable, documented testing to support maintenance decisions and demonstrate equipment condition. Circuit breaker timing, vacuum interrupter testing, arc flash studies, acceptance testing, commissioning, and other diagnostic services have become essential tools for managing risk while maintaining system reliability.

We're also seeing testing evolve from periodic events toward continuous asset management. Real-time monitoring of voltage, current,

harmonics, power factor, and other operating parameters allows organizations to identify developing issues before they become failures. That shift raises expectations for the technicians and engineers responsible for interpreting data and making maintenance recommendations.

Finally, simple growth in electrical infrastructure will continue driving testing demand. Every new interconnection, distributed energy resource, substation expansion, or capital improvement project requires acceptance testing before it can be energized.

As the financial consequences of downtime continue to increase, NETA-certified technicians and licensed professional engineers are increasingly viewed as strategic partners rather than commodity service providers. Thorough testing remains one of the most cost-effective investments utilities and industrial facilities can make to improve reliability, reduce operational risk, and support the growing demands placed on today's electrical power systems. **NW**



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THE TECHNICAL REALITIES OF **Renewable Energy Integration**

As renewable energy continues its rapid expansion, the grid is evolving faster than traditional designs, standards, and maintenance practices can adapt. Inverterbased resources are introducing unfamiliar electrical behaviors that are directly affecting equipment reliability, protection schemes, and testing methods across the industry. Against this backdrop, EPIC26 convenes this October in Fort Worth, Texas, bringing together power professionals to explore how renewable integration is reshaping the grid—and what engineers, technicians, and asset managers must do now to stay ahead of these changes.

Renewable energy is transforming the electrical power landscape at a pace that challenges long-standing engineering assumptions, equipment designs, and maintenance practices. Solar, wind, and energy-storage installations are expanding across North America, driven by decarbonization goals, regulatory incentives, and rising demand for clean power.

Yet behind this momentum lies a complex reality: Renewable energy introduces electrical behaviors that differ fundamentally from those of traditional synchronous generation. These differences are reshaping how transformers, cables, protection systems, and substations must be designed, tested, and maintained. As the industry adapts, electrical service professionals



This article is a collection of excerpts from the PowerTalk Stage Renewable Energy Panel Discussion at PowerTest25.

are encountering both significant challenges and unprecedented opportunities for innovation.

INVERTER-BASED RESOURCES ARE CHANGING SYSTEM BEHAVIOR

At the heart of renewable energy integration is the inverter. Nearly all modern solar, wind, and storage systems rely on inverter-based resources (IBRs) to convert DC or variable-frequency AC into grid-synchronous AC. Unlike synchronous machines, inverters do not inherently produce smooth sinusoidal waveforms. Instead, they rely on high-frequency switching and pulse-width modulation to synthesize AC output. This creates elevated harmonic content—often extending well beyond the traditional 50th harmonic—and introduces high-frequency electrical noise that permeates the system.

These characteristics, combined with the inherently variable and intermittent nature of renewable energy generation, create new stressors

on electrical equipment. Transformers, generators, cables, and insulation systems are exposed to operating conditions that legacy designs were never intended to withstand. The result is accelerated aging, unexpected failure modes, and a growing need for updated engineering practices.

PREMATURE TRANSFORMER FAILURES ARE INCREASING

One of the most visible consequences of inverter-rich environments is the rise in premature transformer failures. Units designed for decades of service are failing in a fraction of their expected lifespan—sometimes within months of commissioning. Several factors contribute to this trend.

Harmonic heating is a major driver. Higher-order harmonics increase eddy-current losses in transformer cores and windings, elevating temperatures and accelerating insulation degradation. Thermal cycling, caused by fluctuating renewable output, further stresses

the insulation system. Many transformers were designed for stable, unidirectional loading, yet renewable installations often require reversible power flow and highly dynamic duty cycles.

In some cases, extremely high harmonic orders—such as the 120th harmonic—have triggered sudden pressure relays or produced alarming dissolved gas analysis (DGA) results. These events underscore the need for improved transformer specifications, more frequent monitoring, and testing practices tailored specifically to renewable applications. As renewable penetration grows, transformer design standards must evolve to reflect the realities of inverter-dominated systems.

INVERTER TRANSPARENCY AND STANDARDS GAPS

A persistent challenge in renewable integration is the lack of transparency in inverter behavior. Many inverters operate as black boxes, with manufacturers restricting access to diagnostic data, especially during warranty periods. This limits the ability of engineers and technicians to analyze system behavior, troubleshoot issues, or validate performance.

Compounding the issue is the absence of unified standards governing inverter response during faults. Traditional protection schemes rely on predictable synchronous-machine behavior, but inverter response is dictated by software logic rather than physics. Without clear standards, protection coordination becomes more complex, and modeling inverter behavior for power flow or short-circuit studies becomes increasingly difficult.

The industry is actively working toward improved standards and greater transparency, but progress is uneven. As renewable installations proliferate, the need for consistent inverter behavior and accessible diagnostic data becomes increasingly urgent.

LIQUID INSULATION CHOICES AFFECT SAFETY AND LONGEVITY

Transformer liquid insulation plays a critical role in renewable environments. Mineral oil, long the industry standard,

has shown poor performance when exposed to partial discharge and high harmonic stress. In such conditions, mineral oil can generate dangerously high hydrogen levels—sometimes reaching tens of thousands of parts per million—creating a significant explosion risk.

Natural ester fluids, such as FR3, offer several advantages. They generate far less hydrogen under partial discharge, tolerate moisture more effectively, and help keep solid insulation drier. These properties improve both safety and transformer longevity. While concerns about viscosity and pour point are sometimes raised, especially in cold climates, the more consequential factors are insulation aging and moisture management. As renewable installations expand, ester-based fluids are becoming an increasingly attractive option for long-term reliability.

DIGITAL SUBSTATIONS AND IEC 61850 ARE BECOMING ESSENTIAL

The integration of renewable energy is accelerating the adoption of digital and hybrid substations built on IEC 61850. These systems replace extensive copper wiring with fiber and IP-based communication, enabling modular, scalable substation designs that can more easily accommodate new renewable sources. Digital substations also offer advanced testing capabilities, such as dedicated test modes that allow technicians to validate relay behavior without affecting live equipment.

IEC 61850 requires technicians to develop new IT-centric skills, including network configuration, data modeling, and cybersecurity awareness. However, digital substations do not replace foundational protection knowledge. Instead, they modernize the tools used to apply it. Technicians still perform metering tests, end-to-end tests, protection function validation, and synchronization checks—just through different interfaces and communication protocols.

PROTECTING INVERTER-BASED RESOURCES REMAINS A CHALLENGE

Protecting inverter-based resources is one of the most active and complex areas of research in modern power engineering. Traditional protection schemes assume predictable synchronous-machine behavior, but inverter response during faults is determined by software logic. This creates significant challenges in modeling, coordination, and system protection.

Key questions include how inverters should contribute fault current, whether they should inject negative-sequence components, and how their behavior should be standardized across manufacturers. Without consistent models, engineers struggle to design reliable protection schemes or conduct accurate short-circuit studies. Industry committees are working to develop standardized inverter models, but the technology continues to evolve faster than standards can keep pace.

CABLES ARE EXPERIENCING HIGHER STRESS AND FAILURE RATES

Cables in renewable installations—particularly wind farms—are experiencing increased stress and higher failure rates. High-frequency switching, thermal cycling, and installation quality issues contribute to partial discharge activity and insulation degradation. Offshore and high-voltage DC cable repairs are especially complex and costly, often requiring specialized vessels and extended outages.

New diagnostic methods, such as online partial discharge testing and low-voltage frequency sweeps, show promise for identifying emerging issues. However, inverter noise remains a significant barrier to accurate assessment. As renewable installations expand, cable testing and monitoring will become increasingly important components of electrical service work.

WORKFORCE DEVELOPMENT IS A CRITICAL PRIORITY

The industry faces a widening skills gap as experienced technicians retire faster than new workers can be trained. Renewable integration requires technicians to master both traditional electrical skills and new digital competencies. Training needs include IEC 61850 communications, a deeper understanding of test-set operation, advanced cable diagnostics, inverter troubleshooting, and specialized safety practices for offshore environments.

Younger technicians may adapt more easily to digital systems, but structured training is essential for all personnel. Workforce readiness will be a defining factor in the industry's ability to support renewable growth.

CONCLUSION

Renewable energy integration is no longer a future challenge—it is already reshaping how electrical systems behave, how equipment fails, and how protection and testing must be performed. From inverter-driven harmonics and transformer stress to evolving protection schemes, digital substations, and workforce readiness, the changes outlined in this article are directly affecting reliability, safety, and day-to-day service work across the industry. Understanding these issues is essential for engineers, technicians, and asset managers who must make informed decisions in increasingly complex environments.

This article offers practical insight into what is changing, why it matters now, and how the industry is responding—setting the stage for deeper discussion and learning at EPIC26 for those responsible for keeping the grid reliable, resilient, and ready for what comes next. [NW](#)

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TRANSFORMER TESTING:

MOVING BEYOND THE PASS/FAIL METRIC

BY KHALED MORSHED, *Commissioning Services International*

Transformer testing should not end when a value is marked acceptable. Each measurement is a diagnostic clue. When insulation resistance, winding resistance, turns ratio, excitation current, and leakage reactance are interpreted together, they create a clearer picture of transformer health and help engineers energize equipment with confidence.

Transformer testing is often viewed as a sequence of individual tasks. In many field reports, each result is recorded, compared with an acceptance criterion, and then marked as acceptable or not acceptable. This approach is necessary for documentation, but it does not always capture the full diagnostic value of transformer testing.

From my experience as an electrical testing engineer, I believe this is only the first layer of transformer testing. In the field, a transformer does not speak directly. It communicates through measurements. A high insulation resistance value, a small winding resistance deviation, a stable transformer turns ratio (TTR) result, or an unusual excitation current pattern can each reveal something about the condition of the transformer. These values are not just numbers in a report; they are diagnostic clues.

This is why transformer testing should go beyond pass or fail. The purpose is not only to prove that a transformer can be energized. The real purpose is to understand the transformer well enough to energize it with confidence.

A transformer is a complete electrical and mechanical system. It includes insulation, windings, magnetic cores, tap changer contacts, bushings, oil, internal supports, and external connections. Because of this, no single test can tell the full story. Each test provides one diagnostic window, and the engineer's role is to connect these windows together to form a complete picture.

MOVING BEYOND THE CHECKLIST

Acceptance and commissioning tests are essential because they confirm that a transformer is ready for service. They also provide baseline data that can be used later

during maintenance, troubleshooting, and life-extension studies. However, the testing process should not stop at checking whether a number is inside or outside a limit.

For example, an insulation resistance test may show a high resistance value, but this does not confirm that the winding connections are correct. A TTR may confirm the ratio, but it does not prove that the winding resistance is balanced across all phases. A winding resistance test may detect a high-resistance joint or tap changer contact issue, but it does not directly evaluate the magnetic core. This is why transformer testing must be interpreted as a group of related measurements.

In practice, the question should not only be: Did the transformer pass the test? The better question is: What does this result tell us about the transformer, and how does it compare with the other test results?

WHAT FIELD TESTING TAUGHT ME

One important lesson I learned in transformer testing is that a normal result should still be understood, not just accepted. During winding resistance testing, the value may appear acceptable, but how the reading stabilizes can also tell the engineer something about the winding, the test connection, and the transformer's magnetic behavior.

In turns ratio testing, an abnormal result does not always indicate the transformer has a defect. Sometimes it points to an incorrect test connection, wrong vector group selection, or a misunderstanding between phase ratio and line-to-line ratio. This is where field judgment becomes important. Standards and acceptance criteria guide the engineer, but experience helps the engineer ask better questions: Is the result logical? Does it match the tap position? Does it match the other phases? Does it agree with the previous test? Does another test support the same conclusion?

For me, this is the real value of transformer testing. It is not only about operating the test equipment. It is about reading the transformer

condition through several connected measurements.

INSULATION RESISTANCE: THE FIRST VIEW OF INSULATION HEALTH

The insulation resistance test (Figure 1) is usually one of the first electrical tests performed on a transformer. It gives an initial indication of the condition of the insulation system between windings and between windings and ground. The test is simple in concept: A DC voltage is applied, and the resistance of the insulation is measured. However, interpretation requires care. The measured value is affected by temperature, humidity, surface contamination, moisture, test voltage, and the condition of the insulation. A low reading may indicate moisture, dirt, insulation deterioration, or leakage paths. It may also be influenced by poor test preparation, dirty terminals, or wet environmental conditions. This is why insulation resistance should be seen as a screening test, not a complete diagnosis by itself. A good insulation resistance value is encouraging, but it does not confirm that the winding geometry, turns ratio, tap changer, or core condition are correct.



Figure 1: *Transformer Insulation Resistance (IR) Testing Connections*

WINDING RESISTANCE: SMALL VALUES WITH BIG DIAGNOSTIC MEANING

Winding resistance testing (Figure 2) measures the DC resistance of transformer windings. The measured values are usually small, but they carry important diagnostic information. This test can help detect loose connections, high-resistance joints, poor bolted connections, defective tap changer contacts, open circuits, and phase imbalance.



Figure 2: *Transformer Winding Resistance (WR) Testing Connections*

One of the most important parts of this test is comparing phases and tap positions. A single resistance value has limited meaning unless it is compared with the corresponding phases, previous results, factory results, or expected design values.

If one phase shows a noticeably higher resistance than the others, the issue might be related to a loose connection or tap changer contact. If one phase shows a much lower resistance, it could indicate a possible shorted turn or incorrect connection. If the values are unstable during the test, this might suggest

poor contact, incomplete core saturation, or an issue in the test connection.

Winding resistance testing also reminds us that field technique matters. Current should be applied carefully, readings should be allowed to stabilize, and the winding should be safely discharged after testing because of the stored magnetic energy in the transformer core.

URNS RATIO TEST: CONFIRMING THE ELECTRICAL RELATIONSHIP

The turns ratio test (Figure 3) verifies that the relationship between the primary and secondary windings matches the transformer nameplate and tap position. This test is critical because an incorrect ratio can lead to incorrect output voltage, circulating currents in parallel operation, protection issues, and system performance problems.



Figure 3: *Transformer Turns Ratio (TTR) Testing Connections*

However, turns ratio testing is not just about comparing a single number with the nameplate ratio. The tester must understand the transformer vector group, winding connection, tap position, and whether the calculation should be based on phase ratio or line-to-line ratio.

A common field issue is obtaining an abnormal ratio because the test connections are wrong or because the selected vector group in the test equipment does not match the transformer. In this case, the transformer itself may not be defective; the problem may be in the test setup. This is why a TTR test should always be interpreted with connection verification.

A correct TTR result supports the conclusion that the number of turns and the voltage transformation relationship are correct. But it does not prove that the contacts are healthy, that the insulation is dry, or that the core is free of problems.

EXCITATION CURRENT: LOOKING AT THE MAGNETIC CORE

The excitation current test, also known as the open-circuit test, provides important information about the transformer core and magnetic circuit. During this test, voltage is applied to one winding while the other winding is open, and the current required to magnetize the core is measured.

The excitation current includes two main components: the magnetizing current and the core-loss current. Abnormal excitation current may indicate core problems, shorted turns, tap changer issues, incorrect connections, residual magnetism, or winding defects.

One important part of excitation current interpretation is comparing the pattern between phases. In many transformers, the middle phase might show a different current from the outer phases because of the magnetic path and core construction. Therefore, the result should not be judged only by looking for identical values on all three phases. The expected pattern depends on the transformer design, connection, and previous test records.

Excitation current is powerful because it can reveal magnetic or turn-related problems that might not appear clearly in insulation resistance or winding resistance tests.

LEAKAGE REACTANCE: DETECTING MECHANICAL MOVEMENT

Leakage reactance, or short-circuit impedance testing (Figure 4), is especially valuable for detecting mechanical changes inside the transformer. When a transformer experiences a short-circuit event, transportation shock, or severe mechanical stress, the winding geometry can change. Even a small movement of the windings can affect the leakage flux path and therefore change the measured reactance.

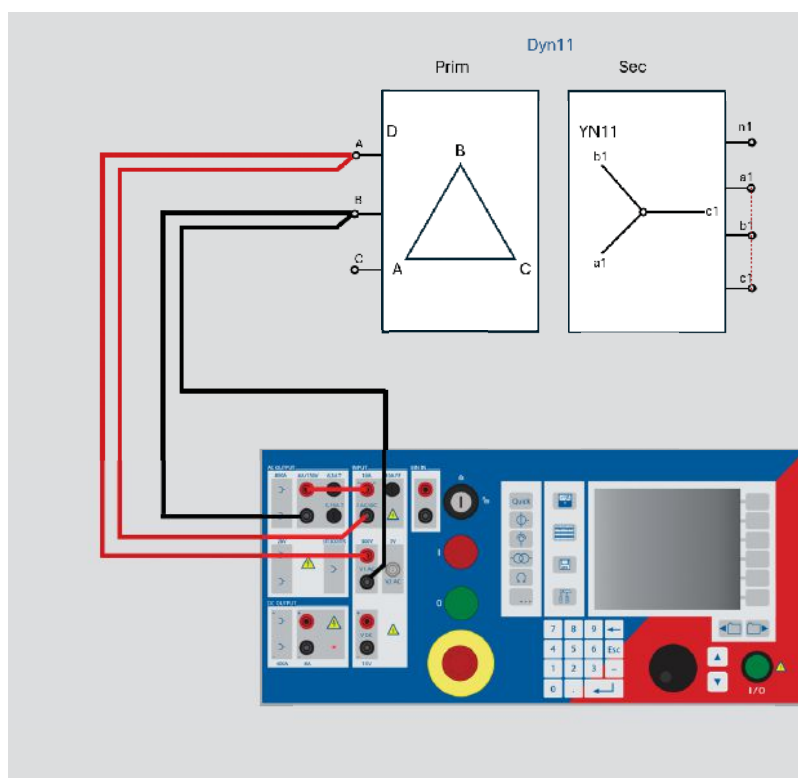


Figure 4: Transformer Short-Circuit Test Connection Using OMICRON CPC 100

This test is important because some mechanical problems might not be visible externally or strongly affect insulation resistance or TTR results. A transformer could appear electrically acceptable in several tests but still have internal winding movement that increases future failure risk.

Leakage reactance results are most useful when compared with factory test results or previous field results. A significant change from the



baseline can indicate winding deformation, displacement, or mechanical damage.

WHY THE TESTS MUST BE READ TOGETHER

The best diagnostic value comes from combining test results. If winding resistance is abnormal on one phase and the turns ratio is also abnormal on the same phase, the problem might be related to the winding or tap changer. If excitation current is abnormal but turns ratio is normal, the issue could be more related to the magnetic circuit, residual magnetism, or core condition. If insulation resistance is low while winding resistance and TTR are normal, the main concern could be insulation moisture, contamination, or surface leakage rather than a winding connection issue.

A transformer test program should therefore connect each test result to a possible transformer subsystem.

Test	Main Diagnostic Area
Insulation Resistance	Insulation condition, moisture, contamination, leakage paths
Winding Resistance	Winding continuity, joints, tap changer contacts, phase balance
Turns Ratio	Number of turns, tap position, vector group, connection correctness
Excitation Current	Magnetic core, shorted turns, tap issues, core-loss behavior
Leakage Reactance	Winding movement, deformation, mechanical displacement

This combined approach helps the engineer avoid two common mistakes: accepting a transformer too quickly because one test looks good or rejecting a transformer too quickly because one result looks abnormal without enough supporting evidence.

THE IMPORTANCE OF BASELINE DATA

One of the most valuable outcomes of acceptance testing is the creation of baseline data. The first field test results become a reference for future maintenance and troubleshooting. Without baseline data, it is much harder to determine whether a future result is normal for that transformer or represents a real change.

For this reason, test reports should include more than final values. They should document test conditions, temperature, humidity, tap position, test voltage, equipment used, connection method, and any unusual observations during testing. Good documentation makes future comparison more reliable.

CONCLUSION

As electrical testing engineers, our responsibility is not only to complete the test sheet. Our responsibility is to understand the condition of the equipment we are testing. Transformer testing provides several diagnostic tools, but the real value lies in connecting the results.

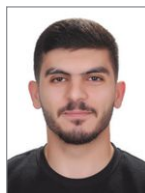
Insulation resistance gives a first view of the insulation condition. Winding resistance reveals the health of winding paths and contacts. Turns ratio confirms the voltage transformation relationship and tap position. Excitation current gives insight into the magnetic core. Leakage reactance helps detect mechanical movement or winding deformation.

When these tests are reviewed together, they allow the engineer to move beyond a simple pass-or-fail decision and toward a deeper understanding of transformer health.

For me, this is what makes transformer testing valuable. It is not just a procedure before energization; it is a diagnostic conversation between the engineer and the transformer. The measurements are the transformer's language, and the engineer's job is to understand what they mean. **nw**

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Khaled Shadi Morshed is an Electrical Engineer at Commissioning Services International (CSI), where he is involved in testing, commissioning, and power system analysis. He received his BEng from Al-Balqa' Applied University in Jordan. Morshed is also a NETA Level 3 Certified Electrical Testing Technician, demonstrating his expertise in advanced electrical testing and commissioning procedures.

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ANSWERS

1. **b. Partial discharge monitor.** Example: When used to monitor online cables, current transformers are placed on the cable shields. A diagnostic test is performed by measuring high-frequency signals from the CT, and the test set plots these events with respect to the system waveform. Based on certain criteria, internal PD activity will produce known patterns, and an assessment can be made.
2. **d. GOOSE – generic object oriented substation event.** These are communication signals published to the network for purposes of protection, such as tripping or other logical actions of interrupting devices during protection events.
3. **a. SV – sampled values.** These are communication signals accurately published to the network to replace wired CT and PT signals. Sometimes there is redundancy, such as two sets of wireless CTs that both publish the same information. Multiple relays may subscribe and receive this information.
4. **c. Oil monitor.** An online oil monitoring device can perform periodic tests to view dissolved gas analysis, water content, and can even estimate the breakdown voltage of the oil. Based on thresholds set, the monitor will flag potential issues and allow the owner to respond and/or correct the issue before failure occurs.
5. **b. Short/open detection.** Manufacturers of neutral grounding resistor (NGR) protection relays can include short and open detection functions. The relay is calibrated to a normal continuity measurement, which includes the resistor and sensing resistor. After that point, if the resistance increases or decreases past the thresholds, the relay will issue a warning indicating a physical resistor connection issue.
6. **c. Arc flash sensor.** When a relay with arc flash sensing detects the presence of light (usually combined with overcurrent for security), it will trip the breaker without delay. A main breaker would normally have a delay to allow downstream breakers to trip first and see if the fault is cleared. The presence of a flash removes the need for the delay and causes an immediate trip.
7. **d. GPS satellite clock.** Relays that reference a common source to set their internal clocks will be highly accurate in reporting event records. This helps the person troubleshooting events understand the exact order, arrival time, and interval time for each event. This can support the conclusion to what caused certain events and if the protection elements operated accordingly. [NW](#)

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When Diagnostics, Testing, and Field Services Come Together:

Sigma C and MVA Collaborate to Help Avoid a Prolonged Outage

In today's power industry, maintaining transformer reliability requires more than a single test or diagnostic technique. The most effective asset management programs combine oil analysis, electrical testing, engineering evaluation, and field service expertise to provide a complete picture of equipment condition.

A recent project at a customer generation plant in New England demonstrates how collaboration between Sigma C Power Services, a NETA Accredited Company, and MVA, a NETA Corporate Alliance Partner specializing in transformer services helps customers identify emerging issues, execute critical repairs, and avoid potentially catastrophic outages.

A PLANNED OUTAGE WITH AN UNEXPECTED DISCOVERY

During a spring outage, Sigma C Power Services was requested to perform comprehensive maintenance testing at the plant, which included testing a 1999 226-MVA generator step-up (GSU) transformer. The transformer is 17.6 kV to 115 kV and contains approximately 14,400 gallons of insulating oil.

As a NETA Accredited Company, Sigma C conducted testing in accordance with ANSI/NETA MTS-2023, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*. The objective of the maintenance program was to verify that the transformer remained operational, within manufacturer tolerances, and suitable for continued service. The maintenance scope included insulation resistance testing, winding resistance testing, turns ratio testing, power factor testing, capacitance testing, and other electrical diagnostic procedures outlined in the ANSI/NETA maintenance testing standard.

OIL DIAGNOSTICS INDICATED A HEALTHY TRANSFORMER

Sigma C utilizes MVA's oil testing laboratory for all oil analysis for its customers. Previous oil test results for this transformer indicated no historical internal faults generating gases. The transformer remained in IEEE Std. C57.104 Status 1 condition and all oil-quality tests met the requirements of IEEE Std. C57.106 for continued service. From an oil diagnostics perspective, the transformer appeared healthy and suitable for continued operation.

This serves as an important reminder that dissolved gas analysis (DGA) is primarily designed to identify faults within the transformer's insulation system, windings, leads, connections, and oil-paper insulation. While DGA remains one of the most powerful predictive maintenance tools available, not every developing problem will generate detectable gas signatures.

That is why a comprehensive maintenance strategy must include both oil diagnostics and electrical testing.

ANSI/NETA TESTING REVEALED A CRITICAL PROBLEM

While the oil analysis showed no indication of internal problems, Sigma C's electrical testing uncovered a significant issue involving the transformer's 115-kV high-voltage bushings.

Power factor and capacitance testing identified deterioration in all three high-voltage bushings. The H1 bushing exhibited the most severe condition, with a power factor value that had increased approximately 168% above its nameplate value. The H2 and H3 bushings also showed significant deterioration, with values exceeding nameplate readings by more than 80%. Under ANSI/NETA MTS-2023 guidelines, these results

warranted investigation and corrective action, and Sigma C recommended replacement of the bushings.

The findings demonstrated exactly why NETA maintenance testing plays such a critical role in transformer reliability programs. Although the transformer oil showed no evidence of an active fault, the electrical condition assessment identified a developing reliability issue that could have eventually resulted in an in-service failure.

Bushing deterioration frequently develops independently of transformer oil conditions that are not detectable through routine DGA. Without the power factor and capacitance testing performed by Sigma C, the condition could have remained undetected until a future failure occurred.



FROM DIAGNOSTICS TO ACTION

Once the failed bushing was identified, the outage quickly shifted from routine maintenance to repair planning.

The power plant had only one spare high-voltage bushing available onsite. While that spare allowed immediate replacement of the most severely deteriorated H1 bushing, the repair itself was far more involved than a simple bushing changeout.

Because of the bushing design, replacing the bushing required draining the transformer. Due to the transformer's age, there was concern that the gaskets would not withstand the vacuum force during final filling of the transformer. The force from the vacuum could flex the tank inward, and if the gasket failed while pulling vacuum, the transformer would be at risk for drawing in moisture that accumulates in the insulation. The second concern is that after re-filling the transformer, leaks could form from where the aged brittle gasketed failed.

The customer understood the risks and made the prudent decision to re-gasket the transformer. Re-gasketing the transformer did not require much additional time, but the outage schedule was already established, and extending the outage would have created significant operational and financial challenges for the facility.

At that point, Sigma C's customer needed more than diagnostics and recommendations. They needed a transformer service company capable of mobilizing immediately and executing the repair within the allocated outage window.

MVA MOBILIZES

After the failed bushing was identified, MVA Services mobilized personnel and equipment to support the repair effort.

Working closely with Sigma C and the plant maintenance team, MVA developed and executed a repair plan that allowed the work to be completed without extending the scheduled outage. The project scope ultimately included:

- Complete transformer re-gasketing
- High-voltage bushing replacement
- Oil circulation and processing within the storage tank
- Heat run under vacuum to dry out the insulation
- Final vacuum and vacuum fill
- Post electrical testing
- Return-to-service support

The transformer was exposed to the atmosphere while performing the repair, and because of the age of the unit, MVA recommended performing a heat run to circulate hot oil while

under vacuum. This process involves filling the transformer to approximately 50% of its oil volume while maintaining a vacuum below 1,000 microns. Once filled, the oil is circulated from the transformer, through oil processing, and back to the transformer until the incoming oil temperature to the oil processing rig is 50°C. At that point, the oil is drained while maintaining vacuum.

After the oil is removed, the transformer will begin final vacuum. The heat run is very important because, as pressure is removed from the transformer while pulling vacuum, the temperature drops within the transformer tank. Eventually, it will fall below 0°C, where it is very difficult to remove moisture from the insulation. By performing the heat run under vacuum, the temperature will be maintained in the core and coil during final vacuum because of the difficulty in transferring the energy to the tank walls. This allows the moisture to continue to flash off from the insulation while under final vacuum. This additional work helped ensure moisture, gases, and contaminants were removed prior to energization.

Despite the compressed schedule and expanded scope, all work was completed within the plant's allocated outage window, allowing the transformer to return to service on schedule.

PROACTIVE PLANNING PREVENTATIVE A FUTURE OUTAGE

While replacing the failed H1 bushing addressed the immediate concern, Sigma C recognized that the issue extended beyond a single component.

Testing results clearly showed that all three high-voltage bushings were exhibiting elevated power factor values. Although only one spare bushing was available during the outage, Sigma C recommended replacing the remaining bushings and advised the customer to immediately order a complete replacement set.

Consistent with challenges experienced by utilities and power producers in recent years, the power plant faced extended lead times for high-voltage transformer bushings. Procuring replacement bushings ultimately took ten months.

After the initial outage, the remaining two high-voltage bushings were replaced during a follow-up planned maintenance outage. As with the original repair, the work required opening the transformer and performing a complete vacuum fill process to ensure the insulation system was returned to service in optimal condition. Because the transformer had undergone a complete re-gasketing and heat run during the initial outage, it was recommended not to perform those steps for the replacement of the other two primary voltage bushings, saving money for the customer.

The value of that proactive planning cannot be overstated. Had the deteriorated bushings remained in service until a failure occurred, the plant could have faced an unplanned outage, extended generation losses, emergency procurement challenges, and potentially significant collateral damage to a critical GSU transformer.

THE POWER OF COLLABORATION

This project highlights the value of collaboration between NETA-certified testing companies and specialized transformer service providers. Each organization brought a unique capability to the project:

Sigma C Power Services

- NETA-certified testing and diagnostics
- Engineering evaluation
- Bushing condition assessment
- Maintenance recommendations
- Long-term asset planning

MVA

- Transformer oil testing
- Dissolved gas analysis
- Oil quality evaluation
- Diagnostic interpretation
- Transformer field services
- Re-gasketing
- Oil processing
- Vacuum filling

Instead, the issue was identified through routine maintenance testing, replacement components were secured before they became critical, and the repairs were completed under controlled conditions. What could have become a major reliability event became a planned maintenance activity.

Together, these capabilities provided the customer with a complete solution—from identifying the problem to executing the repair.

A MODEL FOR RELIABILITY-CENTERED MAINTENANCE

As the transformer fleet across North America continues to age, successful maintenance programs will increasingly depend on combining multiple diagnostic disciplines with experienced field execution.

Testing identifies problems.
Diagnostics help explain them.
Field services solve them.

CONCLUSION

This project demonstrates how ANSI/NETA MTS-2023 testing, transformer oil diagnostics, engineering evaluation, and rapid field execution work together to protect critical assets.

Sigma C's testing program identified deteriorating bushings before a catastrophic failure occurred. Their recommendation to immediately order replacement bushings enabled the customer to overcome extended industry lead times and avoid a potentially prolonged outage. MVA's oil testing confirmed the transformer itself remained healthy internally, while providing the field expertise necessary to execute both the initial repair and the subsequent bushing replacement project.

The result was a successful outage, a repaired transformer, a proactive long-term maintenance strategy, and a happy customer who avoided what could have become a costly and disruptive reliability event. That is the true value of partnership. ●

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

This three-day EPIC event features keynote presentations, knowledge-sharing sessions, workshops, and panel discussions led by industry experts from Black & Veatch, Oncor, NERC, Doble, Siemens, Wesco, Eaton, and Texas State Technical College. More than 20 leading experts will share insights on emerging technologies, grid modernization, and the future of electrical power services.

Discover how the future of electrical infrastructure is becoming smarter, faster, and more connected.

Discover how emerging technologies are helping utilities and service providers navigate one of the most significant energy transformations in history.



EPIC26 KEYNOTES

How do you manage cyber risk when intelligent systems become active participants in operations?

Hector Perez, Black & Veatch, presents the Welcome-Reception Keynote —

From Protecting Assets to Protecting Outcomes: Cyber Risk in the Age of Intelligent OT.

Perez reframes cybersecurity as an enabling design discipline for intelligent operations, not a barrier to innovation. Drawing on realworld industrial scenarios, the session introduces return on mitigation (RoM) as a practical way to connect cyber decisions to operational and financial outcomes that matter: uptime, safety, reliability, and trust.

How will industry leaders develop practical solutions for tomorrow's electric power systems?

Mark Carpenter, ONCOR, offers the Day 2 Keynote — *Powering Progress:*

Past Lessons, Present Realities, Future Solutions.

The electric power grid is undergoing a fundamental transformation driven by evolving customer expectations, regulatory complexity, technological change, and workforce constraints. Carpenter examines how historical transmission and distribution (T&D) lessons inform today's challenges and guide future grid strategy.

Can organizations trust AI-driven operational technologies to make critical decisions?

David Speidelsbach, Wesco, presents the Day-3 keynote, *Scaling Your Supply Chain at Hyper Speed: A Roadmap for the AI Era.*

Speidelsbach explores the trends reshaping the data center market and shares practical strategies for accelerating deployment while mitigating risk. Attendees learn how early planning, supply chain resiliency, and cross-functional partnerships can help align stakeholders to overcome infrastructure challenges and support scalable growth.



KNOWLEDGE-SHARING SESSIONS—EXPERT PRESENTATIONS

Beyond education, EPIC26 offers unparalleled access to a diverse network of professional peers and industry experts, creating partnerships and insights that extend well beyond the conference. EPIC26 stands as a pivotal forum for navigating the evolving electrical power industry—combining innovation, strategic foresight, and crosssector collaboration.

Each day begins with 60-minute presentations exploring the strategic questions organizations must address to capitalize on the electrical power sector's rapid growth and evolving opportunities.

GRID OPTIMIZATION & SMART GRID MANAGEMENT

How are smart sensors transforming installation, commissioning, and maintenance practices?

How Sensors Will Change the Landscape of the Electrical Infrastructure and Installation

The future of electrical infrastructure is smarter, more connected, and increasingly driven by data. Learn how sensors are transforming installation, commissioning, maintenance, and asset management while improving reliability, safety, and energy efficiency across critical facilities and industrial operations.

Pruthish Shah, Segment Leader – Electrical Markets Division, 3M

What are the risks of overlooking the unique realities of electrical infrastructure?

Practical Strategies in OT Environments

This session provides practical strategies for electrical professionals to assess their environment, understand specific risks, and implement protections that truly fit—not just follow the latest trend. Learn how to strengthen resilience without compromising operational priorities.

Matthew Cosnek, Sr. OT Cybersecurity Services Business Development Manager, Eaton

EMERGING TECHNOLOGIES

Which strategies will drive next-generation operation and protection?

Microgrid Operation, Control, and Protection—Part 1 and Part 2

Microgrids are reshaping the future of power resilience and flexibility. GE Vernova's Wayne Hartmann brings insights into one of the fastest-growing areas of the power industry. Learn how advanced operation, control, and protection strategies are enabling smarter, more reliable energy systems.

Wayne Hartmann, Advanced Applications Advisor – NAM, GE VERNOVA

Which emerging technologies will define the future of grid stability and resilience?

Navigating the Energy Transition: Emerging Technologies Address Challenges and Opportunities.

The energy transition is accelerating—but can the grid keep up? Mark Lauby of NERC explores the emerging technologies helping utilities integrate renewables, manage growing loads, and maintain reliability in an increasingly complex energy landscape.

Mark Lauby, NERC Fellow and Chief Engineer, NERC

Why is DC power emerging as a game-changing technology for AI-driven data centers?

The Imperative of DC Power in AI Data Centers: Driving Efficiency, Safety, and Power Density from Grid to Rack

AI is transforming data centers—and power infrastructure must evolve to keep pace. Discover why DC power is emerging as a critical solution for improving efficiency, enhancing safety, and delivering the power density required by next-generation AI applications.

Simon Loo, *Protection and Automation Division Siemens*

ELECTRICAL POWER SERVICE FUTURES

Does today's relay testing workforce have the skills needed for tomorrow's digital substations?

Modernizing the Workforce for Next-Generation Relay Testing

Today's workforce must adapt and acquire new skills to meet the evolving requirements for effective commissioning and testing of modern protection relays. This session provides an overview of protection relay technologies and highlights the specific skills required by testing personnel for each type.

Pedro Quijada, Senior Technical Application Engineer, Doble Engineering

How can organizations attract, develop, and retain the next generation of electrical talent?

The Talent Imperative: Engineering a Resilient Electrical Workforce Now, Tomorrow, and Beyond

Technology alone won't power the future—people will. Siemens' Darwin Newton discusses innovative strategies for recruiting, developing, and retaining the skilled workforce needed to support grid modernization, digital transformation, and the next generation of electrical power systems.

Darwin Newton, Head of Operations, Siemens

What lessons can be learned from more than a decade of implementing a mixed workforce?

Integrating Contract Test Workforce into Utilities

Co-authored with a large utility's Substation Construction and Maintenance Manager, this presentation discusses the implementation of transitioning from a 100% in-house utility test program to a mixed workforce, including the reasons to engage a contract workforce, challenges with bringing on a contract workforce, and the unexpected synergies of a mixed workforce.

Chasen Tedder, Vice President—Utility Testing, Hampton Tedder Technical Services

How can technology revolutionize electrical workforce development, paving the way for a more resilient and capable industry?

New Technologies for Workforce Development Challenges

The electrical workforce faces significant development challenges, including skill gaps, an aging workforce, and evolving industry demands. Addressing these issues is crucial for ensuring a safe, sustainable and efficient future. We will explore innovative solutions to these challenges through the adoption of new technologies.

Alan Lo, Product Manager, Eaton

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PANEL SYMPOSIUMS

The panel discussions will serve as an interactive forum for the exchange of ideas, insights, and experiences. Guided by the interests and priorities of EPIC participants, these sessions will foster meaningful dialogue on the opportunities and challenges shaping the future of the electrical power industry. Leaders and EPIC attendees will come together to collaborate on three central themes:

Grid Optimization and Smart Grid Management Symposium

Moderator: Mark Carpenter, Senior Vice President, Oncor

Electrical Power Service Futures: Fueling the Next Generation of Talent Symposium

Moderator: Karla Flanagan, Associate Vice Chancellor, Texas State Technical College

Emerging Technology: AI, Monitoring, Digitization Symposium

Moderators: Shahyar Farhang, Senior Applications Engineer, Megger, and Pruthish Shah, Segment Leader—Electrical Markets Division, 3M

EPIC26 WORKSHOP SERIES

Building on the insights shared throughout the conference, the EPIC26 workshops will bring participants together to develop actionable strategies, identify key takeaways, and explore future-shaping initiatives. Through collaboration and partnership, attendees will help create solutions that address the industry's most pressing challenges and opportunities. EPIC26 Workshop Focus:

Grid Optimization and Smart Grid Management Workshop

Discussion Leader: Karla Flanagan, Associate Vice Chancellor, Texas State Technical College

Electrical Power Service Futures—Fueling the Next Generation of Talent

Discussion Leader: Mark Carpenter, Senior Vice President, Oncor

EPIC26 IS FOR POWER PROFESSIONALS WHO WANT TO DO MORE THAN KEEP PACE WITH CHANGE—THEY WANT TO LEAD IT.

As AI, grid modernization, cybersecurity, infrastructure demands, and workforce challenges reshape the market, attendees will gain insights needed prepare for what's next.

More than a conference, EPIC26 is an opportunity to turn industry change into business advantage. Participants will leave with practical knowledge, new connections, and a clearer vision for driving innovation, improving performance, and leading their organizations into the future.

**REGISTER
TODAY**

To register for EPIC26 | Electrical Power Innovations Conference and learn more about the three-day program, visit EPICpower.org or contact the NETA office at 888.300.6382. Go here for session details: [Session Agenda—EPIC26 Conference](#)

A photograph of electrical equipment, including insulators and wires, set against a bright green, cloudy sky. The image has a green tint.

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A NEW ERA FOR NETA WORLD

STRATEGIC TRANSITION TO STRENGTHEN OUR INDUSTRY VOICE AND EXPAND OUR REACH

For decades, *NETA World* (NW) has served as the authoritative technical publication for the electrical testing industry, delivering peer-driven knowledge, advancing safety, and reinforcing the standards that define our profession.

As our industry evolves in complexity, scale, and technological advancement, so too must the way we communicate, educate, and connect. In 2026, NETA takes an important step forward by transitioning the publication of *NETA World* to EndeavorB2B.

This transition reflects a deliberate, strategic investment in the future of our publication and, more importantly, in the value we deliver to our members and the broader industry.

PRESERVING OUR FOUNDATION

NETA World's strength has always been rooted in its technical rigor, member contributions, and commitment to advancing electrical testing standards. That foundation will not change.

What will change is our ability to amplify that voice.

By partnering with EndeavorB2B, a publisher with more than a century of experience and a broad portfolio of industry-leading publications, NETA gains access to expanded distribution channels, enhanced production capabilities, and a significantly larger audience within the power and energy sectors.

This positions NW not only as an enhanced member benefit, but as an elevated industry resource with greater visibility and influence.

FROM PUBLICATION TO PLATFORM

The central objective of this transition is to evolve NW from a traditional publication into a multi-platform industry resource, including enhanced digital delivery and user experience.

With enhanced distribution and repurposing of content, *NETA World* will amplify coverage of emerging technologies and electrical power innovations, international developments in testing and maintenance, workforce development and training, and evolving industry standards and best practices. Endeavor's ability to repurpose and redistribute content across multiple platforms ensures that critical insights reach a far wider audience than ever before.



Bryant Phillips,
Executive Director, InterNational
Electrical Testing Association

CONNECTING EXPERTISE PROMISES TO HONOR TRADITION WHILE BUILDING FOR THE FUTURE

For many years, EndeavorB2B and NETA have shared a strong and productive relationship. Through industry-leading brands such as *Electrical Construction & Maintenance (EC&M)* and *Transmission & Distribution World (T&DW)*, we have worked alongside NETA to bring valuable technical expertise and industry insight to electrical professionals across North America. Today, I am excited to share that our partnership is entering an exciting new chapter.

NETA World has long been recognized as one of the electrical testing industry's most respected technical resources. It serves a highly specialized audience of engineers, technicians, contractors, facility managers, and industry leaders who depend on accurate, practical information to support the safe and reliable operation of electrical power systems. Maintaining that legacy is our first priority.

EXPANDING POSSIBILITIES FOR COMMUNITY

We see tremendous opportunities to build upon the strong foundation NETA has created. EndeavorB2B brings decades of experience in content development, audience engagement, digital media, production, events, and industry communications. By combining those capabilities with NETA's unmatched technical expertise, we can expand the ways *NETA World* informs, educates, and connects the electrical testing community.

Readers can expect the same commitment to technical excellence that has defined *NETA World* for years. What may evolve are the ways that content is delivered and experienced. From enhanced digital offerings and expanded multimedia opportunities to new ways of sharing expertise and industry perspectives, our

goal is to create an even more valuable resource for NETA members and the broader electrical power systems industry.

LOOKING AHEAD TOGETHER

What excites me most is the collaborative spirit that has emerged as our organizations come together to produce the first issue under our partnership. This is not just a partnership between two companies; it is a partnership among dedicated teams of professionals who share a common commitment to advancing the electrical testing industry. The opportunities to innovate, educate, and serve our readers will only grow in the issues to come.

We are honored to be entrusted with helping shape the future of *NETA World*. Together with NETA, we look forward to building on its proud tradition while creating new opportunities for growth, engagement, and impact in the years ahead.



Mike Hellmann,
Vice President,
EndeavorB2B

FROM SEARCH ENGINES TO ANSWER ENGINES: **WHAT TO KNOW ABOUT AEO**

For years, organizations focused on search engine optimization (SEO) to improve their visibility online. The goal was straightforward: Rank highly in search results so prospective customers could find your website, products, and expertise.

Today, however, the way people search for information is changing rapidly. Instead of typing a few keywords into a search engine, users increasingly ask complete questions through AI-powered platforms such as ChatGPT, Google AI Overviews, Gemini, and Perplexity. These tools often provide direct answers rather than a list of links. As a result, a new practice has emerged: answer engine optimization (AEO).

WHY AEO MATTERS

Traditional SEO helps content get found. The new AEO discipline helps content become the answer. Rather than simply driving website traffic, the goal is to ensure that AI-powered systems recognize your content as authoritative, trustworthy, and useful enough to include in generated responses.

For companies in the electrical testing and power systems industry, this shift presents both challenges and opportunities. Engineers, facility managers, contractors, and technicians are increasingly using AI tools to research technical questions, compare solutions, and identify qualified service providers. When those users ask questions such as “How often should medium-voltage switchgear be tested?” or “What are

the benefits of partial-discharge testing?” the organizations cited in the answer gain visibility and credibility before a website visit ever occurs.

Fortunately, many NETA Accredited Companies (NACs) already possess one of the most valuable assets in the AEO era: technical expertise.

Answer engines tend to favor content that demonstrates experience, expertise, authority, and trustworthiness. Technical articles, case studies, conference presentations, standards-related discussions, and educational resources all help establish credibility. Companies that consistently share knowledge—not just promotional messages—are more likely to become trusted sources for both human readers and AI systems.

PRACTICAL STEPS FOR NETA MEMBERS

Organizations interested in improving their visibility in answer engines can start with a few straightforward practices:

- Publish educational content that answers common customer questions.
- Use clear headings and subheads that make information easy to understand.

- Support claims with standards, data, and real-world examples.
- Maintain accurate company information across websites and industry directories.
- Encourage subject matter experts within the organization to contribute articles, webinars, and technical presentations.
- Update existing content to reflect current standards and best practices.

The objective is not to game AI systems, but to make valuable expertise easier for both people and machines to find, understand, and trust.

THE FUTURE OF INDUSTRY DISCOVERABILITY

SEO is not disappearing. Search engines remain important, and strong SEO practices continue to support online visibility. However, the rise of AI-powered answer engines represents an evolution

in how information is discovered and consumed. The organizations that adapt early will be better positioned to influence conversations, establish thought leadership, and reach customers at the moment they seek answers.

For NETA Accredited Companies and Corporate Alliance Partners (CAPs), AEO is ultimately about amplifying what the industry already does best: sharing technical knowledge that helps improve the safety, reliability, and performance of electrical power systems. In a world increasingly driven by AI-generated answers, trusted expertise may become the most valuable search ranking of all. [NW](#)

Erin Hallstrom is Director of Content Operations and Visibility, EndeavorB2B.



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NETA ELECTS

STEPHANIE PATTERSON AND KEN PETERSON TO BOARD OF DIRECTORS

NETA's programs, standards, and industry initiatives are powered by people who give generously of their time, expertise, and perspective to serve on NETA's Board of Directors and committees. NETA recently elected Stephanie Patterson and Ken Peterson to serve on the Board of Directors—two professionals whose leadership, service, and commitment to advancing the electrical testing industry reflect the strength of the association's volunteer community.

Both arrive with deep industry experience, a strong connection to NETA's mission, and a practical understanding of the work that electrical testing professionals do every day in the field. Through their work with NETA committees and their contributions within their respective organizations, Patterson and Peterson bring valuable perspective, practical experience, and a shared dedication to supporting the standards, training, and collaboration that will help move the industry forward.

As they begin their Board service, both will also take on important committee responsibilities that connect directly to NETA's mission. Patterson will serve as Chair of the Training Committee and as a member of the Application Review Committee, while

Peterson will contribute to the Promotions and Marketing Committee, Technical Resource Committee, and Training Committee. Together, their committee involvement reflects a hands-on commitment to strengthening member engagement, technical excellence, and the continued development of industry professionals. It is a mix of responsibilities that speaks to both leaders' hands-on commitment to helping NETA grow, support its members, and strengthen the industry's future.

In this Q&A, Patterson and Peterson share more about their paths to the Board, the experience they bring to their roles, and how they look forward to contributing to NETA's continued growth.

STEPHANIE PATTERSON

Senior Manager, External Training and Partnerships, Qualus

NW: What inspired you to get involved with NETA, and what does serving on the Board mean to you?

Patterson: NETA's commitment to quality, safety, and education really aligns with the work we do at Qualus. Getting involved felt like a natural extension of that passion. Serving on the Board is an opportunity to contribute to the continued growth and integrity of the electrical testing industry while helping shape its future alongside other dedicated professionals. I'm extremely honored to be presented with this growth opportunity for me and for NETA.

NW: What role do you hope to play in the Board's work?

Patterson: My vision is to bring a strategic perspective, particularly around training opportunities, member engagement, and industry awareness. My background in power industry training allows me to connect the dots and help strengthen how NETA connects with its members and the broader market. This ensures its value and expertise are clearly understood and accessible. I will also be involved with NETA's PowerTest and EPIC conferences—ensuring both events are purposeful learning and networking opportunities.

NW: What would you like NETA members to know about you—professionally or personally?

Patterson: I have been in this industry for 12 years, which means I've seen some things and learned a lot. Anyone who knows me knows that I believe in “work hard play hard.” My personal goal is to get to know more of the NETA Accredited Companies and NETA members, so if you see me at a conference, please introduce yourself! I enjoy collaboration, connecting with others, sharing ideas, and finding ways to make a positive impact both within my organization and the industry as a whole.



“My vision is to bring a strategic perspective, particularly around training opportunities, member engagement, and industry awareness.”



“I am someone who believes the work matters, and the people doing it matter more.”

KEN PETERSON

VP of Operations, Power Engineering Services

NW: What inspired you to get involved with NETA, and what does serving on the Board mean to you?

Peterson: My involvement with NETA grew naturally out of work, and I was inspired by other men leading the way when I began my NETA journey. Alan Peterson, Jim White, Ron Widup, Scott Bizzard, and Ken Basset were the most influential to me. After more than 35 years in the construction, electrical testing, and commissioning industry, I came to understand that the standards, certifications, and professional community NETA provides are not background noise. They are the foundation that gives this industry its credibility. Serving on the Board is an opportunity to give back in a meaningful way to an organization that has shaped my career and the careers of the people I lead. It is not something I take lightly.

NW: What role do you hope to play in the Board’s work?

Peterson: I bring a field-forward perspective. My work is rooted in operations and building a brand, and I have spent the better part of my career building programs, developing people, and running projects in the real world where standards either hold or they do not. I hope to be a voice for the technician in the field and the company trying to do things the right way, and to help NETA continue connecting its standards work to the practical realities of the industry as we grow our brand together.

NW: What would you like NETA members to know about you—professionally or personally?

Peterson: Professionally, I am a NETA Level 4 Senior Certified Test Technician and VP of Operations at Power Engineering Services, a NETA Accredited Company and Quanta Services operating company based in Texas. I have been involved with NETA events and committees for years, including presenting at PowerTest, and I care deeply about workforce development and certification advancement in this trade. On the personal side, I am someone who believes the work matters, and the people doing it matter more. I am known for chasing steep ski runs, driving on racetracks, and going on some fun 10-k runs when I am not chasing project deadlines, so don’t forget to have fun between projects! [NW](#)



NETA QEMC & QEMW PROGRAM

Companies with Electrical Power System Maintenance Workers are invited.

NETA established the **Qualified Electrical Equipment Maintenance Company Program (QEMC)** and **Qualified Electrical Equipment Maintenance Worker (QEMW)** classification in support of the NFPA 70B maintenance requirements.

This qualification program is in response to the recently ANSI-approved NFPA 70B Standard, making proper electrical equipment maintenance mandatory and enforceable. The new program is intended to meet the anticipated demand for vetted, qualified electrical equipment maintenance contractors and workers.



Why become a Qualified Electrical Equipment Maintenance Company?

Facility owners need to provide proof of their maintenance workers' qualifications. Facility owners hiring electrical contractors will choose service providers based on their ability to verify and be assured of the qualifications of a contractor and its workers. The QEMC and QEMW program provides verification of all maintenance worker qualifications.

QEMC Benefits:

Standard Compliance | NETA Verification | Worker Recognition of Expertise

For Contractors - NETA QEMC & QEMW recognition provides a differentiating advantage over competitors.

NETA IS A **RECOGNIZED LEADER** IN THIRD-PARTY VERIFICATION OF ELECTRICAL POWER SYSTEM MAINTENANCE QUALIFICATIONS

NETA's recognition of your **Qualified Electrical Equipment Maintenance Company** status provides assurance of your organization's electrical power system maintenance experience, and worker qualifications.

NETA's **Qualified Electrical Equipment Maintenance Worker** examination process delivers third-party validation of your field and maintenance workers' qualifications and knowledge.



BECOME RECOGNIZED BY NETA AS A QEMC.

Contact the NETA office to learn more and apply today!

NETA QEMC PARTNERS

WHY HIRE A NETA-VERIFIED QEMC AND QEMW TEAM?

Facility owners, utilities, contractors, and industrial operators need qualified organizations and personnel to perform maintenance in support of NFPA 70B. One of the most effective ways to achieve this objective is to partner with an electrical contractor that is a **NETA Qualified Electrical Equipment Maintenance Company (QEMC)** staffed by **Qualified Electrical Equipment Maintenance Workers (QEMWs)**. These designations provide independent verification that both the electrical contractor and its maintenance personnel have met rigorous qualification requirements established by NETA in support of **NFPA 70B**.

Regular electrical equipment maintenance is essential for identifying deteriorating conditions before they result in equipment failure, safety incidents, unplanned outages, or costly business interruptions.

The QEMC and QEMW Program and gives electrical contractors and facility owners third-party assurance that maintenance work is performed by properly vetted organizations and workers. Ultimately, these designations demonstrate a commitment to excellence in electrical equipment maintenance, helping improve safety, reliability, compliance, and operational continuity for critical electrical power systems.

For information on partnering with a QEMC in your area, contact the NETA office at 888-300-6382 or email NETA@NETAWorld.org.

GEMITECH JOINS THE RANKS OF NETA ACCREDITED COMPANIES



NETA is pleased to welcome Gemitech to its growing network of NETA Accredited Companies. Headquartered in Québec, Canada, Gemitech specializes in providing testing, commissioning, maintenance, diagnostics, and technical support for electrical power systems. As part of Groupe SGE (Société Générale d'Électrotechnique), the company serves a wide range of industrial, commercial, institutional, utility, and energy-sector clients throughout Canada, helping organizations ensure the reliability, safety, and performance of their critical electrical infrastructure.

Gemitech distinguishes itself through its combination of technical expertise, field experience, and commitment to quality. The company offers a comprehensive portfolio of services designed to support the entire lifecycle of electrical assets—from initial commissioning and acceptance testing to preventive maintenance,

troubleshooting, power system studies, and condition assessments. By emphasizing rigorous testing procedures and industry best practices, Gemitech helps customers minimize downtime, improve operational reliability, and enhance workplace safety.

The company's team of highly trained professionals works with medium- and high-voltage other critical power system components. Through its focus on technical excellence and customer service, Gemitech has earned a reputation as a trusted partner for organizations seeking dependable electrical testing and maintenance solutions.

"Achieving NETA accreditation is a significant milestone for Gemitech. It reflects our team's commitment to excellence and confirms that our practices meet the highest industry standards," says General Manager Martin Roy. "This recognition reinforces our mission to deliver safe, reliable, and high-quality services to our clients."

"NETA extends a warm welcome to Gemitech," says Dan Hook, President of CBS Field Services and current NETA President. "NETA

Accreditation is recognized throughout the electrical testing industry as a benchmark for technical competence, quality processes, safety, and adherence to industry standards. By earning NAC status, Gemitech has demonstrated its commitment to maintaining the highest levels of professionalism and technical expertise in electrical testing and maintenance services." **NW**



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ANSI/NETA STANDARDS UPDATE

ANSI/NETA MTS-2023 REVISION UNDERWAY

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

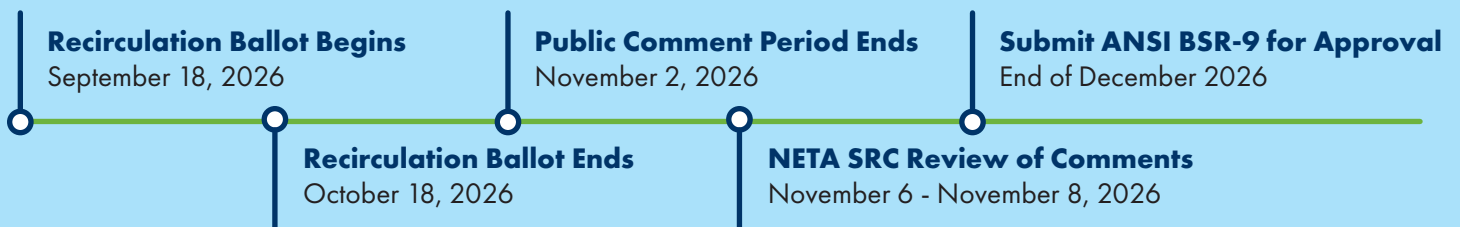
This revision introduced a new Working Group model, bringing together subject matter experts from across the electrical testing industry to conduct early-stage comment review and develop three new sections. The initiative serves as a pilot program for future standards development activities and will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

New MTS content includes the following sections:

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



KEY MILESTONES FOR NETA MTS REVISIONS



MTS Document Scope

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

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

ANSI/NETA ETT-2026 NEW STANDARD REVISION APPROVED

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

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



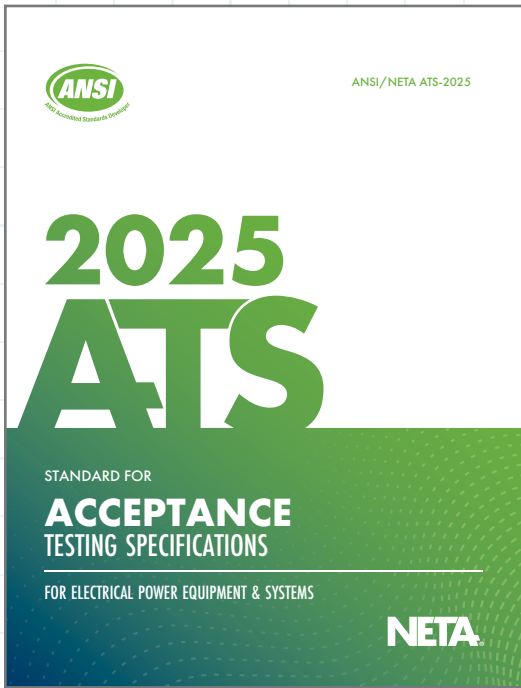
ANSI/NETA EMW-2026 NEW STANDARD APPROVED

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



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.

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.

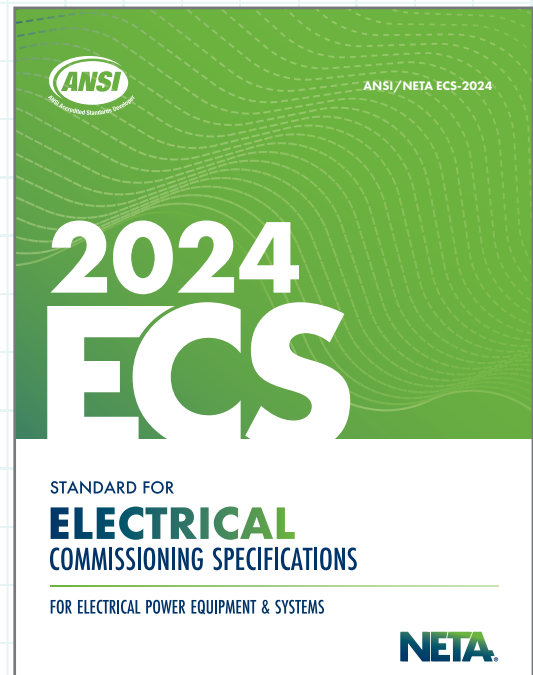
ANSI/NETA ECS-2024

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 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). [NTW](#)

Tania Brammer is NETA's Director of Technical Operations.



PARTICIPATION

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

ADVANCING ELECTRICAL POWER SYSTEM STANDARDS

Electrical industry standards are built by experienced professionals who share their knowledge, review proposed changes, and work together to improve safety, reliability, and system performance. NETA is proud to be part of that process.

Through its Technical Representation Steering Committee (TRSC), NETA participates in the development of standards, codes, and recommended practices that affect electrical testing, maintenance, commissioning, and workplace safety. This involvement helps strengthen ANSI/NETA standards while supporting consistency across the electrical power industry.

WHY IT MATTERS

ANSI/NETA standards are used alongside documents developed by organizations such as NFPA, IEEE, CSA, ASTM, NECA, and NERC. Together, these standards establish the requirements for:

- Electrical safety
- Equipment maintenance
- Test methods
- Equipment application
- Installation practices
- System reliability
- Competency and field evaluation

By participating in these organizations, NETA brings practical field experience into the standards-development process while

staying informed about changes that affect the electrical testing industry.

TECHNICAL REPRESENTATION STEERING COMMITTEE

NETA's Technical Representation Steering Committee coordinates the association's participation on external committees and code panels. The committee identifies priority activities, tracks standards development, and supports NETA representatives serving on technical committees.

The objective is simple: Contribute practical field knowledge that helps improve the standards used throughout the industry.

CURRENT AREAS OF PARTICIPATION

NETA maintains active representation on committees whose work directly affects electrical testing, maintenance, and safety, including:

- ASTM F18; Electrical Protective Equipment
- CSA Z462; Workplace Electrical Safety
- CSA Z463; Maintenance of Electrical Systems
- IEEE C37; Switchgear

SPECIFICATIONS AND STANDARDS ACTIVITY

- IEEE C57; Transformers
- IEEE 400 Series; Medium-Voltage Cables
- IEEE P902; Maintenance and Operational Safety
- NECA
- NFPA 70B; Electrical Equipment Maintenance
- NFPA 70E; Electrical Safety in the Workplace
- NFPA 790; Competency of Third-Party Field Evaluation Bodies
- NFPA 791; Evaluation of Unlabeled Electrical Equipment

NETA also follows other high-impact standards affecting protective relaying, healthcare facilities, distributed energy resources, transformers, overcurrent protection, emergency power systems, grounding, commissioning, and the National Electrical Code.

SUPPORTING BETTER STANDARDS

Participating in standards development helps keep electrical maintenance, testing, installation, and safety requirements aligned across the industry. That leads to:

- Better consistency between standards
- Clearer expectations for owners and operators
- Stronger maintenance and testing programs
- Better integration of safety and reliability
- More effective use of ANSI/NETA standards

As electrical power systems continue to change, coordination among standards organizations becomes increasingly important.

GET INVOLVED!

NETA's technical work depends on volunteers who are willing to share their experience and help shape the future of the industry.

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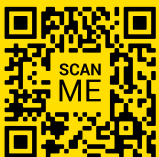


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