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IEEE Electrical Insulation Magazine

A Publication of the Dielectrics & Electrical Insulation Society

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- Rectangular Magnet Wire: A study of thermal aging and oil resistance of various coatings
- Continuous Monitoring: Assessing the condition of medium voltage switchgear

DEIS

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IEEE Electrical Insulation Magazine, a Publication of DEIS

IEEE Electrical Insulation Magazine is involved, together with its sponsoring society, the Dielectrics and Electrical Insulation Society (DEIS), in providing leadership, coordination, and communication among those who are concerned with dielectric phenomena and measurements and with electrical insulating materials, including their behavior as it affects their use in electrical and electronic apparatus. The Magazine is specifically concerned with publishing articles on the development and characterization of the dielectric, chemical, mechanical, and environmental properties of all vacuum, gaseous, liquid, and solid electrical insulation and with utilization of these materials in circuits and systems under conditions of use. The Magazine is not an alternative to the *IEEE Transactions on Dielectrics and Electrical Insulation* for traditional academic research or review papers.

Content

The feature articles are oriented toward the engineer and technologist concerned with the use and application of electrical insulating materials and systems.

Although the subject of an article is not rigidly defined, the style is. Articles must be written in a tutorial or review style, rather than as conference or transactions papers, so that anyone interested in electrical insulation and dielectric phenomena can appreciate and learn about a particular area with which they may not be entirely familiar. If the style of the submission does not fit, then it may be rejected. In general, the length of an article is limited to 8 pages. Authors are required to submit an abstract to the Editor in Chief to ensure relevance of a paper topic before submission of a full paper.

The Magazine articles can express opinions; however, they must be clearly identified as opinion rather than well-documented fact. Commercial subjects can be discussed as long as the article is not perceived as a commercial pitch.

In addition to the technical articles, the Magazine carries features such as new products, industry news, meeting and conference dates, regional news, etc. The Magazine is a vehicle for Society news and, in particular, news regarding the Society-sponsored conferences.

Contributions are sought for all sections of the Magazine. The writing style and requirements vary somewhat for each of the sections. See one of the current issues of the Magazine for the style of the presentation.

Contributions of technical abstracts/articles and all other sections should be sent to:
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FEATURED ARTICLES

Cover: High-frequency-current-transformer sensor on the ground lead of cables connecting to medium voltage switchgear (credit: Muhammad Haziq Bin Ahmad, SP Group, with permission).

DEPARTMENTS

IEEE Electrical Insulation Magazine

A Publication of the Dielectrics & Electrical Insulation Society

The Society's interests lie in materials, measurements, numerical modelling, components, applications, and systems pertinent to dielectrics and electrical insulation. These include solids, liquids, and gases; small-scale systems such as nano-dielectrics and bio-dielectrics; high-voltage and high-field phenomena; and large-scale systems such as high-power insulation applied to electricity generation, transmission, and distribution. The Society supports the basic science of dielectrics and electrical insulation through practical applications and the development of relevant standards.

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Editorial

Sneha Satish Hegde

Chair, IEEE DEIS WIE

IEEE DEIS WIE's Vision for a More Inclusive Tomorrow

IEEE DEIS WIE endeavors to enhance inclusivity and innovation within the domain by empowering students and professionals, inspiring future leaders, and nurturing global connections through various initiatives.

Electrical engineering, and particularly dielectrics and electrical insulation, is a field where female representation is notably low. I have observed this during my own PhD journey, where to date, we have not had a female candidate in this domain in my previous laboratory. This observation reflects a broader societal trend where we see more females in the domain of biology and more males in mechanical and electrical or electronic domains. While efforts have been made in recent years to bridge this gap, we have yet to achieve parity.

However, within DEIS, we have remarkable female pioneers setting examples for future generations. It is our aim to ensure that everyone, not just within DEIS but across all domains, feels celebrated and recognized.

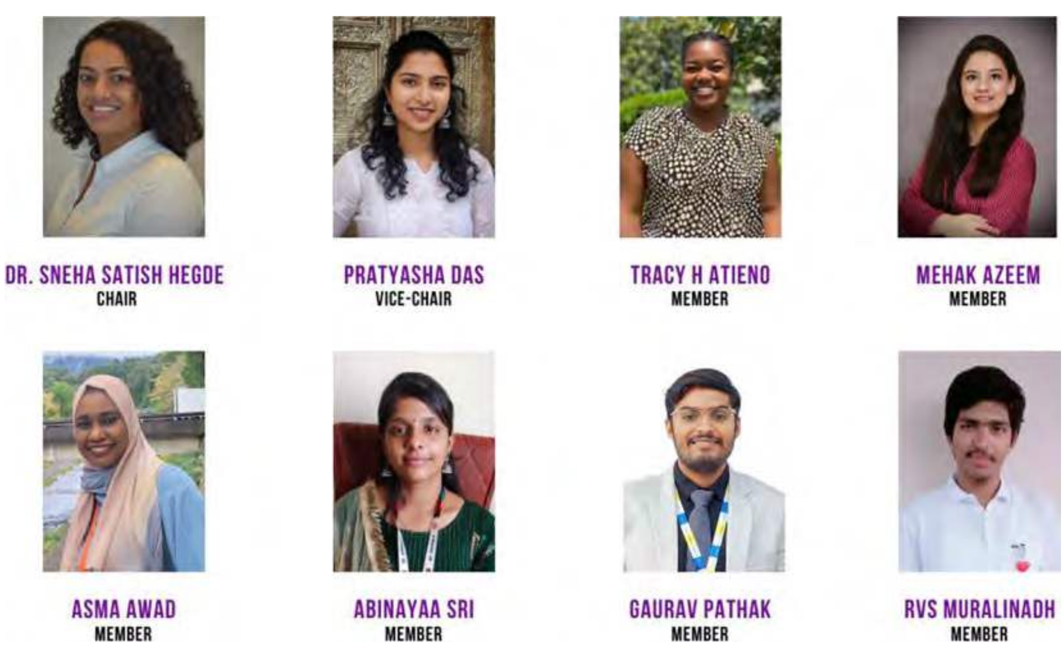
As chair of DEIS WIE, I am dedicated to laying a strong foundation for the future and ensuring increased female participation in DEIS activities and conferences. To achieve this, it is crucial for both students and professionals to understand DEIS's vision and mission and the benefits of being part of this global community.

Unlike many other technical societies, DEIS has a relatively small membership, making visibility a significant challenge. However, since last year, the Young Professionals team under the leadership of Mattewos Tefferi has made commendable efforts in this regard. Now, WIE will also collaborate with them toward the same goal.

In 2024 DEIS WIE is poised for a transformative year, concentrating on advancing inclusivity and innovation in dielectrics and electrical insulation. With plans to expand our network, support women professionals, and nurture future leaders, we aim to have a more substantial impact by collaborating with different IEEE sections, student branches, and other technical societies and councils of IEEE.

Our mission is to disseminate information and engage individuals across the globe through diverse channels, including webinars, workshops, and social media campaigns, to share success stories and opportunities within DEIS WIE, fostering knowledge exchange and inspiration.

A dynamic calendar of events awaits in 2024, providing opportunities for learning, networking, and recognition. From promoting DEIS's vision and mission to establishing new student branch chapters worldwide and facilitating global connections, we will be actively involved. Discussions on women's roles in technology and special sessions at significant conferences underscore our commitment to diversity and inclusion. Through awards and presentations, we highlight the remarkable contributions of women in this domain, advocating for greater diversity and inclusion.



Looking ahead, we envision DEIS WIE flourishing as a symbol of empowerment and excellence in the domain. Through our dedication to diversity, collaborative efforts, and promotion of innovation, we strive to create a brighter, more inclusive future for all.

Meet the individuals driving DEIS WIE forward in 2024. Together, we are forging a future where women excel, and innovation knows no bounds.

Sneha Satish Hegde is currently a postdoctoral researcher at Ecole Centrale Lyon and KAPTEOS. Her research focuses on HVDC, dielectrics, insulators, space charges, partial discharges, electric field mapping, numerical simulations, and so on.

Pratyasha Das is currently a PhD student in electrical engineering at IIT Kanpur, specializing in molecular modeling of nanodielectrics.

Abinayaa Sri T is a BE–EEE graduate from St. Joseph's College of Engineering, Chennai. She is currently working as a data analyst trainee at Latent View Data Analytics, Chennai.

Tracy Hope Atieno is an electrical and electronics engineering student, passionate about social entrepreneurship and empowering women.

Asma Awad is a telecom engineer with extensive experience in network engineering and operations, passionate about leveraging technology for a positive impact.

Mehak Azeem is an application engineer for Invitro Diagnostics and Hematology, STEM motivator, and dedicated volunteer across IEEE Region-10, contributing to uplifting and inspiring young engineers.

Gaurav Pathak is currently working as a Test Engineer at AA ElectroMagnetic Test Laboratory Pvt. Ltd., Gurgaon, Haryana. His specialization includes Telecommunications, IPv6, IoT, Computer Networks.

Venkata Sai Muralinadh Rompicharla is currently working as a flutter developer at Better Analytics Pvt. Ltd., with a strong background in web development and leadership in IEEE initiatives.

Follow us on our social media channels for more updates on the events that we will organize this year.

From the Editor

Mark Winkeler

Editor in Chief
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In reviewing this issue of the magazine, I am struck by its forward-looking nature. The DEIS YP (Young Professionals) and WIE (Women in Engineering) committees are the foundation of our society moving forward. Their enthusiasm and drive will help carry us into the future and achieve our goals. The feature articles in this issue explore materials for potential use in electric vehicles and the implementation of AI for asset management. It was not that many years ago when these types of concepts were limited to the realms of science fiction. It all points to the endless possibilities in the future.

In our editorial from Sneha Satish Hegde, we get her insights into the DEIS WIE committee. Her passionate commitment to making this group a success and vision for the future is inspiring and motivating. Quoting from the editorial, "In 2024 DEIS WIE is poised for a transformative year, concentrating on advancing inclusivity and innovation in dielectrics and electrical insulation." Coupled with the YP group, the future of the DEIS is promising and exciting.

We have two featured articles this month. The first article, "Effect of Thermal Aging on Electrical Performance of Perfluoroalkoxy- and Polyamide-Imide-Coated Coated Magnet Wire," examines the effect of various modes of thermal aging. The first technique exposed the wires under test to automatic transmission fluid. The second method employed steel plates that applied pressure to two strands of wire while under elevated temperatures. In a third test, wires were exposed to salt water at room temperature. These tests have implications for the applicability of wire for use in electric motor applications.

The second featured article is "Implementing Condition Monitoring for Medium Voltage Switchgear for the Distribution Network in Singapore." This article discusses the benefits of condition monitoring of assets. It highlights the challenges of MV switchgear monitoring and how to overcome them. It explores the placement of sensors. It highlights the benefits of on-line monitoring. It also discusses the use of AI to evaluate the patterns of partial discharge. These achieve some predefined goals that include minimizing human intervention. It finishes with real-world examples.

In our regular feature, Young Professionals, Zachary Gibson highlights his journey into the world of electrical insulation and provides advice to new professionals and students.

Our bulletin board features upcoming events and highlights conferences coming up in June: the EIC in Minneapolis, Minnesota, and ICD in Toulouse, France.

The official DEIS website is www.ieeedeis.org. It contains comprehensive up-to-date information on the following:

- The DEIS—its structure, mission, and vision
- IEEE DEIS conferences—directly sponsored IEEE DEIS conferences, to which a DEIS membership discount will apply, are indicated
- *IEEE Electrical Insulation Magazine*—guidelines on the preparation of articles for publication and submission requirements as well as links to find past issues
- *IEEE Transactions on Dielectrics and Electrical Insulation* (TDEI)—the same materials as available for the *Electrical Insulation Magazine* above.
- DEIS educational, professional, and chapter resources
- Career opportunities, latest news, and more

Effect of Thermal Aging on Electrical Performance of Perfluoroalkoxy- and Polyamide-Imide-Coated Magnet Wire

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Key words: electric magnet wire, electric insulation, dielectric properties, polymer insulation, high-voltage breakdown, wire thermal aging, thermal aging, high-performance magnet wire, PFA, PAI

A study of the effect of thermal aging on the dielectric properties of rectangular magnetic copper wire showed the stability of perfluoroalkoxy-coated wire against thermal aging and aging in oil, in contrast to polyamide-imide-coated enameled copper wire.

The insulation of stator winding wires plays the most important role in ensuring the reliable and long-lasting operation of electric motors. Without such magnet wire insulation, it would be impossible for electric generators, electric cars, and other advanced fields of technology to function properly. During normal operation, the wires are affected by many factors: chemical attack (such as oil, secondary insulation, and environment), physical abrasion, thermal overheating, and electrical breakdown. It is therefore critical to select the insulation material that is most resistant to environmental factors and has satisfactory insulating properties. To that end, high-temperature polymers such as polyether ether ketone (PEEK), polyetherketoneketone (PEKK), polyimides (PI), polyamide imides (PAI), polyetherimides (PEI), perfluoroalkoxy (PFA), and others are now the most commonly used.

This article addresses the problem of thermal and chemical degradation of magnet wires with different insulation types and the effect of this degradation on the electrical properties of the wire. Magnet wires with PAI and PFA secondary insulation were included in the study. The PFA wire was found to be stable over a temperature range of 25 to 240°C with no significant loss of dielectric properties or elasticity in air, oil, and salt water. The PAI-coated wire showed a slight decrease in the dielectric properties with increasing temperature and a lower stability of the coating in oil and salt water.

Introduction

The durability and longevity of a rotating electrical machine rely heavily on the reliability of its stator, which consists of a carefully wound magnet wire. The stator winding plays a crucial role in the motor's performance, and any damage to this component is a common cause of motor failure. The stator winding is responsible for generating the magnetic field necessary for the motor to operate. When electric current passes through the winding, it creates a magnetic field that interacts with the rotor to create a rotational motion. However, various factors can contribute to the deterioration of the stator winding over time.

The operating conditions in which the motor is used are an important factor. Extreme temperatures, excessive vibration, and high levels of moisture or humidity can all have a detrimental effect on the stator winding. These adverse conditions can cause an insulation breakdown, resulting in short circuits, overheating, and ultimately motor failure. In addition, the quality of the materials used to construct the stator winding plays a critical role in its reliability. Inadequate insulation materials or poor workmanship during the winding process can weaken the integrity of the stator, making it more susceptible to damage and reducing its lifespan. Factors affecting stator performance fall into 4 categories, the so-called TEAM mechanisms [1]: thermal, electrical, ambient, and mechanical (Figure 1). The composition of the environment, humidity, and temperature have a strong influence on the performance of the wire; all these mechanisms lead to material degradation and loss of dielectric properties. As a result, the life of the electric motor is negatively affected.

A review of several studies on the failures of electric motors [2] agrees, based on the experience of manufacturers, repair centers, and academic studies, that the approximate percentage distribution of the failures in electric motors is as follows: 45% in the bearings, 35% in the stator, 10% in the rotor, and the remaining 10% in other categories.

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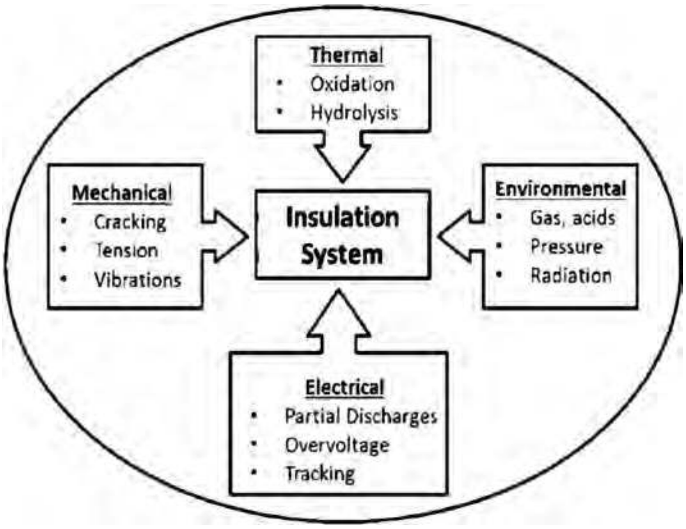

Figure 1. Degradation on mechanisms or factors [2].

Thermal degradation associated with wire overheating is one of the most common causes of electrical breakdown in polymer insulation [3]. It occurs because of increased power at high voltages, which is converted to heat. It is becoming more and more crucial because the current technology trend drives the market toward higher voltage electric machines to increase efficiency. High temperatures can result in the softening of the wire insulation, the degradation of the polymer, and the formation of surface defects. Temperature fluctuations have a critical effect on the integrity of polymer insulation due to the increase in mechanical stress within the polymer. This is especially true for thermosetting polymers.

Chemical resistance is also extremely important in applications where harsh media are to be used, for example, in submersible oil pumps. In this case, the destruction of the wire insulation can lead to immediate failure of the device or significantly reduce its service life.

The main parameters used to measure the electrical properties of a wire are breakdown voltage (BDV), permittivity, and dissipation factor. The goal of modern electrical wire production is to achieve the highest resistance to electrical voltage with the minimum thickness of polymer coating. For this purpose, both thermosets, such as PI, PEI, and PAI, and thermoplastics, such as PEEK, PEKK, and PFA, are used.

Naturally, the thermal and chemical resistance depends directly on the choice of wire insulation. The most commonly used materials are PI, PEI, and PAI, and recently, new high-performance polymers such as PEEK and PFA have also been introduced. Still the most popular on the market are PEI, PAI, and PI applied by the classical enameling technology, which allows a homogeneous coating to be obtained. However, the problem with this technology is the use of highly toxic solvents, which are harmful to both human health and the environment. Thus, the search for an alternative technology for the production of electrical wire is an urgent matter. At present, extrusion can be such an alternative. This method has a wider range of applications; for example, extrusion can be used to apply polymers that cannot be used in traditional enameling technology: PEEK and PFA.

Table 1. Data of basic dielectric parameters for insulating polymers [4]

Parameter	Polymer[1] PAI	PFA
Dielectric loss factor (1.0 E^{-4})	10–310	2–5
Volume resistivity at room temperature, ohm × cm	10^{15}–10^{17}	10^{14}–10^{18}
Permittivity	3.9–4.2	2.1

[1]PAI = polyamide imides; PFA = perfluoroalkoxy.

Two other important properties of the polymeric insulation material are permittivity and dielectric loss. The dielectric permittivity of the medium is a physical quantity that characterizes the properties of the insulating medium and shows the dependence of the electrical induction on the electric field strength. The lower the permittivity, the higher the insulating properties of the medium. A substance possessing a high permittivity exhibits greater polarization when subjected to an external electric field compared with a substance with low permittivity. Consequently, it has the capacity to store a greater amount of energy within itself. Dielectric loss is the amount of energy that is dissipated in an insulation system when it is subjected to an electric field E, causing the dielectric to heat up. The higher the dissipation loss, the higher the temperature rise in the dielectric insulation. This, in turn, can lead to a decrease in the BDV value. The parameters mentioned previously are summarized in Table 1.

In [5], a comparison of the dielectric and mechanical properties of PI films after thermal aging was carried out. The authors concluded that thermal degradation could begin at a temperature of 50 to 100°C below the glass transition temperatures, accelerating significantly at 300°C, leading to an increase in the number of defects. In contrast to PI films, PFA films can reduce the dielectric BDV over time, but simultaneously with the appearance of surface defects, the reverse process occurs: defects are eliminated by the flow of the polymer melt. This is a possible advantage of thermoplastics (PFA) over thermosetting (PI) polymers.

Publication [6] also compared high-temperature PI, poly-P-xylene, and Teflon PFA films for high-voltage power electronics and rocket science applications where even a single insulation breakdown can be critical. Although PI is the most commonly used insulating material, PFA could replace PI in areas requiring greater weathering resistance. Therefore, the authors compared the permeability and dielectric losses of the films in the frequency range of 50 to 100 Hz and at 200°C. The PFA film showed the most stable results regardless of frequency and temperature increase.

At the same time, comparisons of PFA with PTFE and PI, often used in aerospace applications, are known [7]. It should be noted that, according to the model, the exposure temperature that gives an equivalent mass loss to that of PTFE at 250°C is

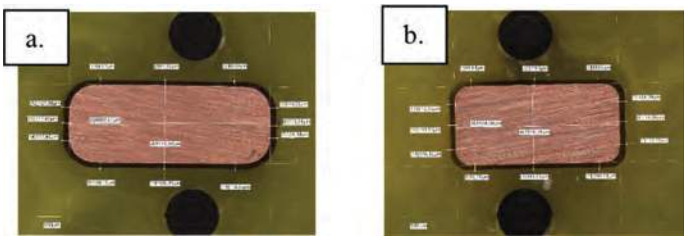

Figure 2. Sections of wire: (a) polyamide imides (PAI) and (b) perfluoroalkoxy (PFA). The wires have the same uniformity of coating.

Figure 3. (left) View of sample and metal plates; (right) view of the sample with bent wire ends, ready for testing.

333°C for PFA. PFA degradation appears to follow simple kinetics, with an activation energy significantly higher than that of PI and PTFE.

Most of the available publications on this topic refer to enameled wires with PI, PAI, and PEI coatings as the most popular coating types. In our article, we conducted a comparative analysis of one of the currently popular PAI coatings and the thermoplastic polymer coating, PFA. The purpose of this study was to investigate the effect of temperature and chemical environmental factors on the mechanical and dielectric properties of a magnetic wire.

Materials and Methods

Materials

Materials used included the following:

- copper wire with PAI insulation (commercially available), cross-section of 4 × 1.5 mm (Figure 2[a]), and coating thickness of 100 µm, manufactured using conventional enameling technology and
- copper wire with PFA insulation by Tre Tau Engineering, cross-section of 3.3 × 1.5 mm (Figure 2[b]), and coating thickness of 100 µm, manufactured using DryCycle technology (patent EP 3518255B1).

Aging in ATF Transmission Oil

Aging tests are performed on the automatic transmission fluid (ATF) used for the magnet wire to evaluate its long-term performance and durability under real-life operating conditions. These tests are essential to ensure the reliability and efficiency of the transmission system, particularly to evaluate oxidation resistance, thermal stability, wear protection, corrosion prevention, and wire durability. The test was carried out in accordance with IEC 60851-4.6 “Resistance to hydrolysis and transformer oil.” The oil selected was Shell Spirax S6 ATF D971. The study was carried out for 2,000 hours at 150°C using 10 wire samples 30 cm in length for each type of wire. Optical microscopy and BDV analysis were used to evaluate the degradation of the samples after aging.

Thermal Aging

Thermal aging tests are performed on magnet wire to evaluate its performance and reliability when exposed to elevated temperatures for extended periods of time. These tests are crucial for the evaluation of the thermal stability, insulation properties, and long-term strength of the wire, ultimately determining its suitability for applications involving significant thermal stress. These tests were carried out in a Memmert UF Plus 108L industrial oven under a wide range of temperatures.

First Test: The first test was for 24 hours at 180°C, 200°C, and 240°C with an applied pressure to ensure consistent contact pressure between the two conductors. This test is not standardized. The mechanical stress is created by using metal plates. Two wires are fastened together on the flat side and clamped between two metal plates with screws (Figure 3[left] view of the sample, 3[right] view of the sample with the ends separated). The screws are tightened with a torque wrench at 2 N × m to achieve an average pressure of 20 MPa. Then the ends of the wires are separated from each other. The insulation is removed from one end of each wire. The samples are then placed in a Memmert oven at specified temperatures. The loss of dielectric properties was investigated using the BDV test.

Second Test: The second test was for 2,000 hours at 260°C for PFA- and PAI-coated wires without additional stress. Similar to the first test, the evaluation of the dielectric properties was carried out with the BDV test.

Stability in Salt Water

This test also comes out of the testing standards. To determine the stability of the wire in salt water, 35-cm-long wire samples bent into a U-shape (as for the BDV test according to IEC 60851-5) were lowered into a beaker containing a 3% NaCl solution so that the liquid covered the middle of the samples. Twenty samples of each type of wire were used for the test. The beaker was covered with foil to prevent evaporation. The samples were kept in salt water for 1,000 and 2,000 hours at 25°C. The results of the test performed were evaluated using the BDV.

BDV Test

The electrical properties of the wire were tested on the Breakdown Voltage Tester (BDV) RDT2-V30 from Rigon Instruments (Italy) according to the IEC 60851-5 standard using steel balls as a conductive medium. Each wire was tested from 5 to 20 times to obtain meaningful statistical data. For hot BDV testing, conventional containers were replaced with Teflon containers holding the same steel balls. The container was placed in an oven for a period of 30 minutes until the set temperature had been reached. The standard temperatures used were 180°C, 200°C, and 240°C. The sample was then immersed

Figure 4. The appearance of samples for the breakdown voltage study with different types of bending with mandrel—flat and edge.

in the steel balls and kept in the oven for 5 minutes. After the time had elapsed, the BDV test was carried out in accordance with the IEC 60851-5 standard.

For the BDV test, different types of bending were used to evaluate the flexibility properties of the wires. The different mandrel diameters were chosen according to IEC 60851-3, which defines the mandrel diameter for flexibility testing in proportion to the copper thickness: for PFA, 6-mm-diameter mandrel for the edge side and 4-mm-diameter mandrel for the flat side; for PAI, 8-mm-diameter mandrel for the edge side and 4-mm-diameter mandrel for the flat side (Figure 4).

Adhesion and Flexibility Test

The tests were performed according to IEC 60851-3-2009+A2-2019 for both wires. A longitudinal cut was made around the circumference of the coating before the wire was stretched. The distance at which the coating began to peel away from the wire was measured in one direction from the cut. In the IEC standard, this test is performed at 15% of the maximum elongation. The standard requires the peel to be less than 1,500 µm.

All photos were taken with a KEYENCE VHX-7100 optical microscope.

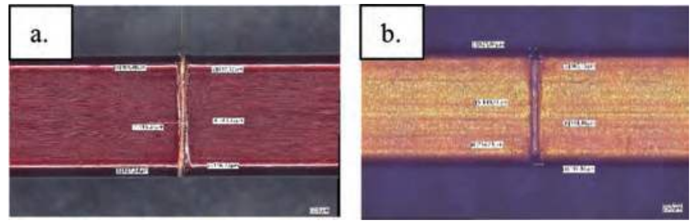

Figure 5. Images of wire samples after the adhesion test: (a) polyamide imides (PAI) wire and (b) perfluoroalkoxy (PFA) wire.

Results and Discussion

Adhesion Test

The test showed comparable results between PAI and PFA coating adhesion to copper wire (Figure 5). For PFA, the peel value ranged from 125 to 214 µm with a mean value of 165 µm. For PAI, it ranges from 116 to 187 µm with an average of 144 µm. These values indicate good adhesion for PFA wire, comparable to that of PAI. According to the IEC standard, the limit is 1,500 µm at 15% of maximum elongation. Therefore, the observed values of 165- and 144-µm peel are 10 times less than the specified maximum. This is rather atypical for a PFA coating, as PFA tends to have difficulty adhering due to the chemical inertness of the polymer.

Voltage Breakdown

Determining the BDV is one of the most common tests for magnet wires. The BDV of an insulator refers to the minimum voltage required to induce electrical breakdown, resulting in a portion of the insulator becoming electrically conductive. This parameter depends on the material, the thickness, the absence of defects in the coating, and the temperature of the wire.

The BDV of the PAI-coated wire showed an almost linear inverse dependence on the temperature increase (Figure 6). The decrease in BDV at 240°C was ~24% (with respect to the room temperature value of 25°C). For the PFA-coated wire, the larg-

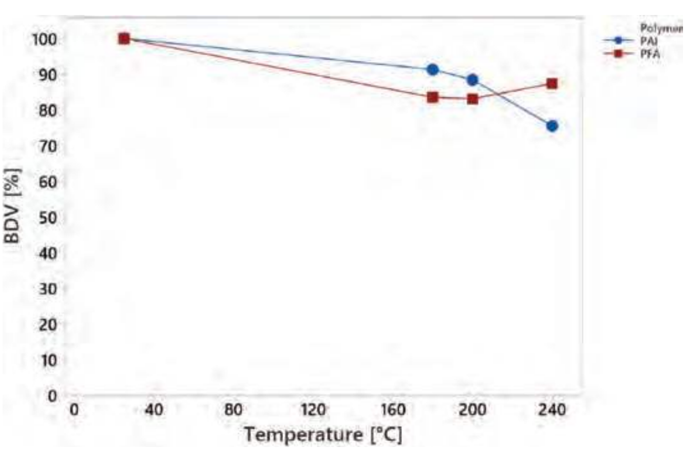

Figure 6. Graph of breakdown voltage (BDV) value variation as a function of temperature for perfluoroalkoxy (PFA) and polyamide imides (PAI) wire samples.

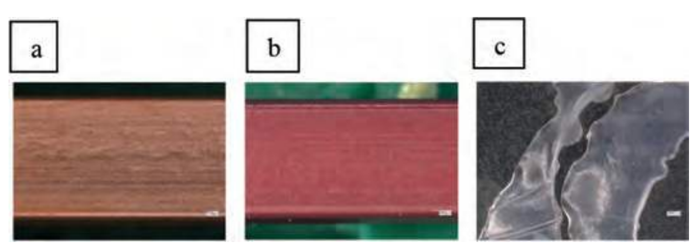

Figure 7. Surfaces of (a) pure copper, (b) copper perfluoroalkoxy (PFA) pored wire after 24 hours at 240°C, and (c) PFA coating after 24 hours at 240°C.

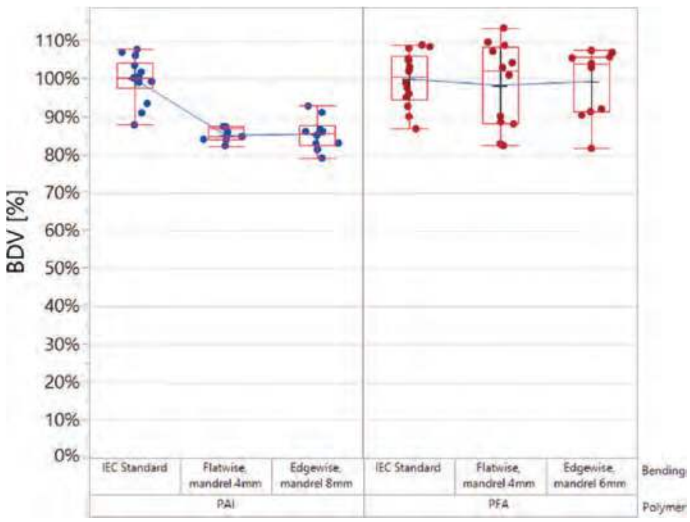

Figure 8. Variation of breakdown voltage (BDV) value depending on the method of bending the specimen. PAI = polyamide imides; PFA = perfluoroalkoxy.

est decrease in BDV was observed at 200°C, which amounted to ~18%, but when it reached the maximum investigated temperature (240°C), the value dropped to 12%. Thus, the pattern of decrease of the studied parameter is not linear; rather, it increases after 200°C. This could be a consequence of processes that could not be identified in the context of this study. Accelerated thermal oxidation at high temperatures could be a possible reason for this BDV deviation. In this case, copper oxides are formed between the copper surface and the polymer layer. Because these substances do not conduct electric current, the BDV can be higher. Another theory to explain why the BDV of PFA increases after 200°C is macromolecular rearrangements in the PFA molecules. These rearrangements could take place because of an increase in the mobility of the polymeric links and their spatial reorientation. This in turn could lead to the formation of a more spatially oriented structure and, for example, an increase in the crystallinity of the polymer. However, this aspect was not thoroughly investigated in this work and should be the subject of further studies.

Figure 9. Comparison of perfluoroalkoxy (PFA) and polyamide imides (PAI) wire before tests.

The validity of the theory correlating the oxidation of the copper surface underneath the PFA coating is confirmed by the following evidence: color change (darkening) of the samples after prolonged heating; darkening of the copper surface and absence of any changes in the polymer coating (Figure 7). PFA has a high oxygen permeability, and oxidation can occur faster in this polymer than in PAI. Copper is reddish in its normal unoxidized state, but it darkens with oxidation: from dark red (Cu_2O) to black (CuO).

The BDV after mandrel bending shows that values are independent of the type of wire bending side (edge or flat). Neither PFA nor PAI wires produce additional coating defects, as indicated by the corresponding BDV values (Figure 8). However, compared with the standard BDV test method, bending with a mandrel reduced the average BDV value for PAI but not for PFA. This may indicate a low elasticity of the PAI coating, which leads to the formation of microdefects and cracks, hence the decrease in value as the bending angle decreases.

Thermal Aging with Additional Mechanical Stress

The thermal aging test (Figure 9) with additional mechanical stress (Figure 10) simulates the operating conditions of a wire in a stator winding of an electric motor that is running at high

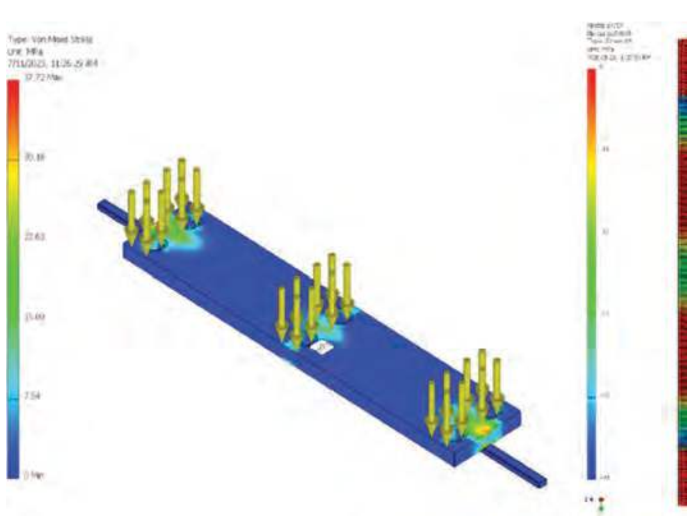

Figure 10. Model of steel plate pressure distribution on the wire and the pressure distribution over the wire itself.

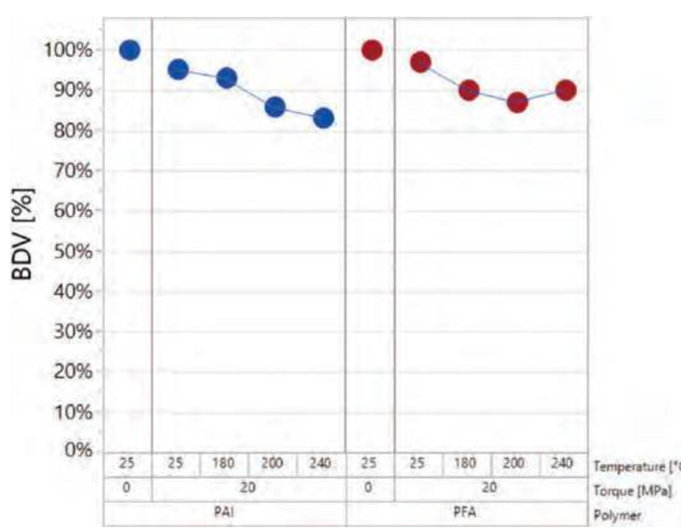

Figure 11. Graph of changes in breakdown voltage (BDV) value for samples with additional stress by steel plates as a function of temperature. PFA = perfluoroalkoxy; PAI = polyamide imides.

Figure 12. Defects of polyamide imides (PAI) wire after thermal aging with additional stress: (a) after 24 hours at 180°C; (b) after 24 hours at 200°C; (c) after 24 hours at 240°C; and (d) wire comparison after 24 hours at 240°C. Perfluoroalkoxy (PFA) wire at the top, and PAI wire at the bottom.

Figure 13. Polyamide imides (PAI) wire after 2,000 hours at 150°C in oil tester.

speed. Although it is not a standardized test (no IEC standard), some motor manufacturers currently use this or similar tests to check the reliability of the wire.

The BDV (Figure 11) result of thermal aging showed a direct correlation with temperature. As the temperature increased up to 240°C, the BDV value decreased for both samples: PAI (Δ13%) and PFA (Δ10%) wires. The slight deviation of the BDV curve of the PFA-coated wire at 240°C may also be a consequence of the standard deviation or the result of the oxidation of the copper surface under the polymer coating as discussed previously.

In addition to the regular decrease in BDV, PAI samples showed a characteristic pattern of delamination of the polymer coating from copper after stress relief. This effect was observed at 180°C, 200°C, and 240°C (Figures 12[a], 12[b], and 12[c]) and was characteristic only of PAI but not of PFA (Figure 12[d]). The PFA coating remained intact after separating the samples at all temperatures. This difference can be explained by the fact that the antifriction properties of PFA are superior to those of PAI, even at high temperatures. Therefore, "gluing" between the wires coated with PFA does not occur.

Thermal Aging in ATF Transmission Oil

Samples of PAI and PFA wires changed color after 2,000 hours at 150°C in the oil tester, from burgundy to black for PAI and from orange to gray for PFA. Many coating defects were found on PAI wire: cracks, voids, and partial absence of coating (Figure 13). No such defects were observed in PFA. Uneven coating color (Figure 14) was one of the defects found in PFA wire.

The flexibility test showed great elasticity during the bending of the PFA wire: there were no cracks, the coating remained homogeneous, and no folds formed at the bending points (Figure 15). In contrast, the PAI wire coating cracked at the bending points, indicating the lack of elasticity of the coating material and the presence of many microdefects (Figure 16). The data obtained for PAI are confirmed by literature (Figure 17) [3], [8].

In addition to visual inspection and testing, the BDV method was used to analyze the electrical properties. The PAI wire, which had a high BDV before the oil aging test, had a BDV retention of 30%. The PFA wire retained approximately 50% of its original BDV values after the oil aging test (Figure 18).

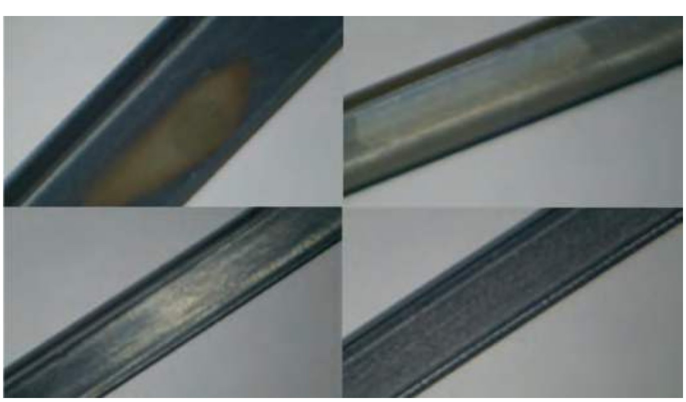

Figure 14. Perfluoroalkoxy (PFA) wire after 2,000 hours at 150°C in oil tester.

Figure 15. Polyamide imides (PAI) wire after 2,000 hours at 150°C in oil tester.

Figure 16. Perfluoroalkoxy (PFA) wire after 2,000 hours at 150°C in oil tester.

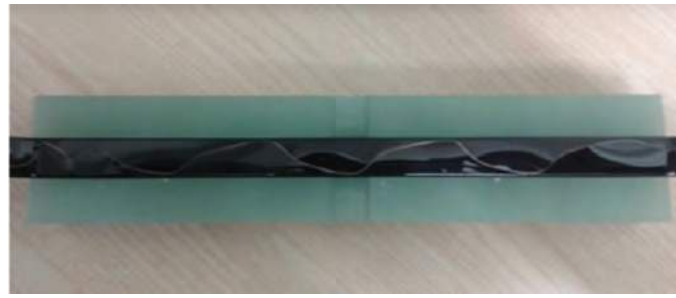

Figure 17. Catastrophic failure of polyetherimides (PEI)–polyamide imides (PAI)–coated wire sample specimen aged at 200°C [9].

Stability in Salt Water

At the end of the tests in salt water, the color and integrity of the samples were unaffected, and no additional defects were detected (Figure 19). This is true for both exposure times: 1,000 and 2,000 hours. The BDV results are presented in the table and visualized in the graph (Figure 20).

The absolute BDV value of the PAI wire before the salt water study was higher than the BDV value of the PFA wire. For the PAI-coated wire, the BDV after 1,000 hours was +11% relative to the original value and after 2,000 hours was −30% relative to the BDV at 1,000 hours. In absolute terms, the difference between the BDV for PAI wire before and after the salt water test was −19%, indicating a decrease in dielectric properties, even taking into account the standard deviation of the data obtained.

For the PFA wire, no significant change in BDV was observed after 1,000 and 2,000 hours of salt water exposure. The absolute change in BDV from 0 to 2,000 hours was +12%. Considering the standard deviation, the stability of the electrical properties of the PFA wire can be confirmed.

The PFA coating showed greater stability in salt water without a significant decrease in the BDV value. In the case of the PAI coating, the decrease in BDV was observed only after 2,000 hours and amounted to 19%.

Conclusions

This article is dedicated to the study of the thermal aging phenomenon of magnetic wires with different types of coatings: thermoplastic PFA and thermosetting PAI. The present study was carried out on commercially available wires with the same coating thickness. As a result, the following were found:

1. Despite having a lower BDV, the PFA-coated wire exhibited superior thermal stability compared with the PAI-coated wire at extremely high aging temperatures.
2. In addition to thermal stability, no loss of elasticity and no delamination of the polymer coating from the copper were observed for the PFA-coated wire. This delamina-

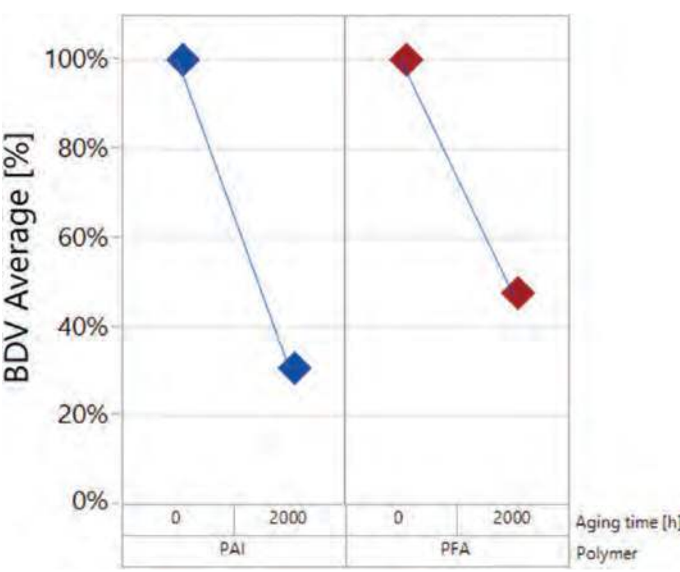

Figure 18. Change of breakdown voltage (BDV) as a result of aging in oil for polyamide imides (PAI) and perfluoroalkoxy (PFA) wire.

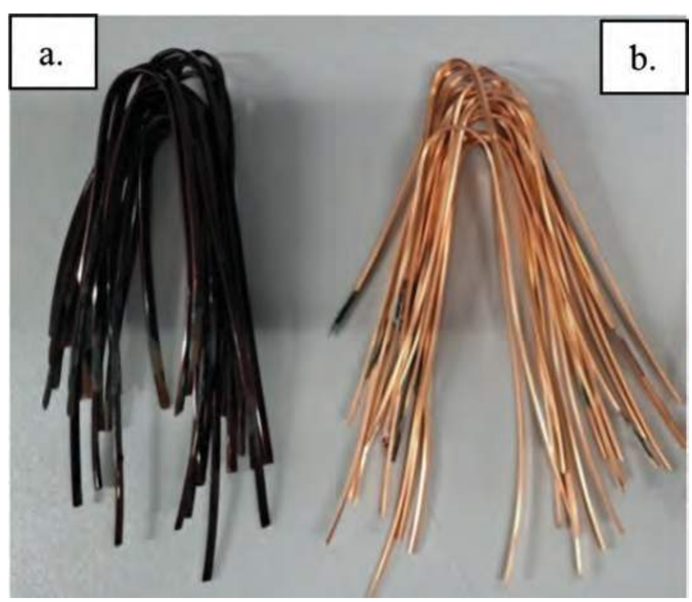

Figure 19. Wire samples after examination: (a) polyamide imides (PAI) and (b) perfluoroalkoxy (PFA) wire.

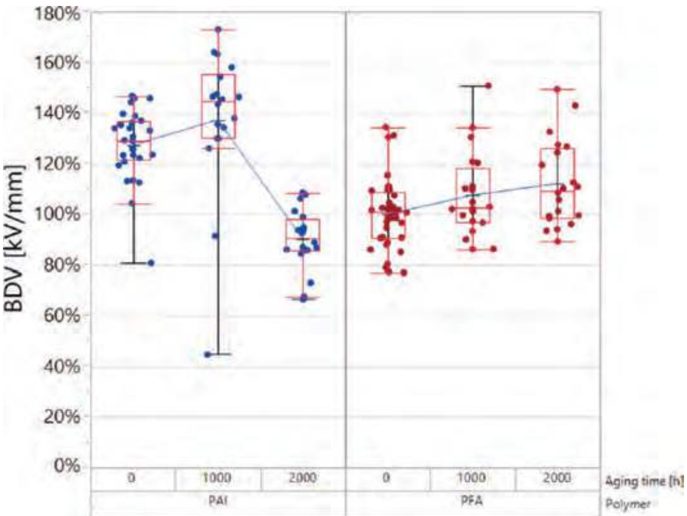

Figure 20. Changes in breakdown voltage (BDV) value of wires after 1,000 and 2,000 hours in salt water. PFA = perfluoroalkoxy; PAI = polyamide imides.

tion and degradation of polymer coating integrity were characteristic patterns for the PAI-coated wire after thermal aging in air, with additional stress, and during aging in oil.

3. The PFA-coated wire demonstrated stability of BDV values after prolonged aging at room temperature. The value decreased for PAI-coated wire, indicating lower barrier properties of the PAI polymer coating.

Based on these findings, the study suggests the potential use of PFA polymer coating for magnet wires instead of PAI coating. Motors equipped with PFA-coated magnet wire can be expected to have extended service life when subjected to various aging stresses. Also, additional performance testing is recommended to confirm service life extension.

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Implementing Condition Monitoring for Medium Voltage Switchgear for the Distribution Network in Singapore

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Key words: condition monitoring, partial discharges, distribution network, medium voltage switchgears, artificial intelligence

This article describes an on-line condition monitoring system for a countrywide distribution network together with the reasons for adopting it, its architecture, the measurement approach, and the case studies obtained during the early stages of its adoption.

Introduction

The use of on-line condition monitoring (CM) systems for assets in the generation and transmission networks has been widely adopted, and it is now a standard practice. It provides the network operators with useful information related to the assets, allowing better management and effective scheduling of maintenance actions, hence improving the power quality and reducing the out-of-service time [1]–[3].

Thanks to CM analyses it is possible to focus on the possible failure locations and evaluate the health status of an asset. Among the CM techniques, partial discharge analysis (PDA) is one of the methods for determining the asset conditions by assessing the status of the insulation systems, which is one of the weak points of any electrical technology.

In the high voltage (HV) market, there are many typologies of CM systems based on PDA, usually focused on a particular asset or insulation technology, and they are designed to provide reliable indications of the status of the insulation materials in use (gaseous, solid, or liquid), each one having different characteristics and failure mechanisms. It is also possible to use complex diagnostic technologies because the overall value of an electrical asset, the cost of repair, and the unavailability justify the cost of the instrumentation.

On the other hand, in the medium voltage (MV) market, the operating conditions are different and it is not usually possible to adopt the same technologies as for HV, leading to the development of measurement approaches not always as effective or accurate as the HV ones and, therefore, not as widespread. There are major obstacles to the diffusion of these systems:

- the vast number of components belonging to an MV network, each one of them being potentially the origin of a fault;
- the relatively low cost of the network parts in comparison to the cost of an effective monitoring system such as those adopted in the HV networks;
- the complexity of the MV networks, for example, the difficulty to keep track of the modifications through the years and to assess the different insulation systems in use, sometimes even mixed;
- the low level of expertise about PDA owned by the field operators, resulting in insufficient exploitation of the diagnostic tools.

Even if these difficulties have limited the applicability and effectiveness of the CM approach on MV assets, it is possible to have standard monitoring solutions focusing on distribution assets [4]–[7]. This approach is used instead of the survey or spot measurement modality, where an operator verifies the presence of PD phenomena by moving through the substation with handheld devices. The latter seems to be the preferred method of analysis, faster even though more prone to false positives and requiring the involvement of operators.

To overcome the issues described previously, a new CM system for distribution networks was designed and developed a couple of years ago, starting from the experience gathered in the transmission and distribution sectors from the licensed electrical utility of Singapore, in cooperation with a company offering CM systems, particularly for HV electrical assets.

The system exploits technologies and measurement techniques developed for the HV electrical apparatuses, and it fits them to a distribution network in terms of features, complexity, and, finally, cost of installation and management [8], [9]. The use of automatic algorithms for data acquisition, elaboration, and analysis reduces the man effort required for daily use.

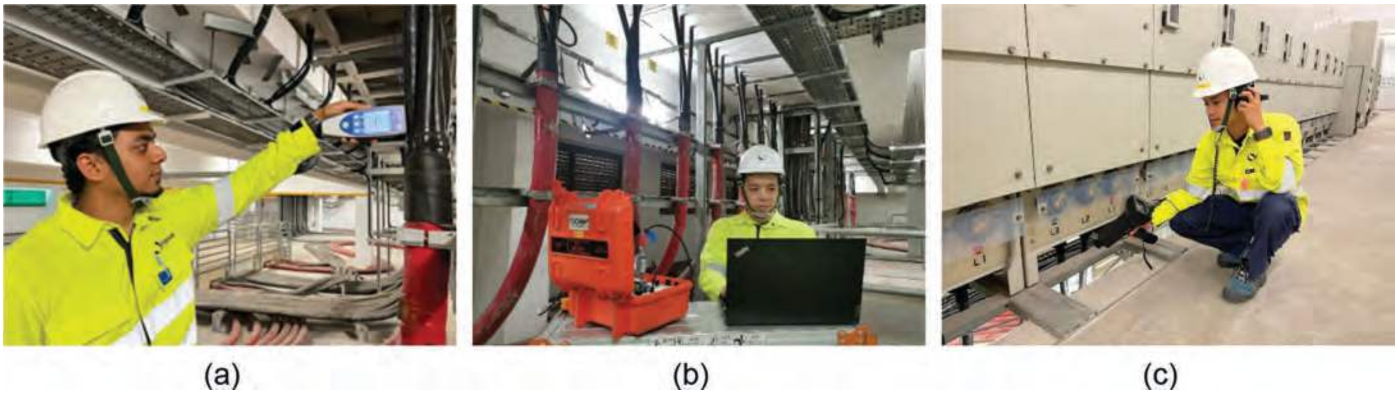

Figure 1. Engineer performing TEV (a), radio frequency (b), and ultrasonic (c) detection.

Moreover, it is one of the first CM systems designed to be country wide, with tens of substations monitored and hundreds of detection points, overcoming challenges related to communication management of a high number of devices, their usability, and the management of the relevant big volume of data.

On-Line CM for the Distribution Network

The transmission network in Singapore has three levels of rated voltages, 400, 230, and 66 kV, whereas the distribution network has a 22- and 6.6-kV level, with the peculiarity that the majority of the cable networks lay underground and the MV switchgears are insulated both in air (AIS) or in sulfur hexafluoride (GIS).

The electrical utility uses CM tools and systems to constantly evaluate the conditions of the network components, which allows effective predictive and preventive maintenance actions by discovering incipient insulation defects that can be rectified before a fault [10]–[13]. There is a standardized CM process established with the primary goal of reducing the failure rate of the electrical components within the grid. It can be summarized into five key steps: (1) detection of abnormality; (2) confirmation of PD, (3) on-line localization of the PD source, (4) off-line localization of PD, and (5) PD defect rectification. Figure 1 shows engineers performing measurements as a survey, with different tools.

When manually performed, the activity is time consuming, and it requires expert personnel, e.g., for correct acquisition and analysis of the detected PD phenomena. An on-line CM system can carry out those tasks with no external help from operators at any time.

In the case of poor performance, false alarms would be raised and a CM expert would be required to manually perform the analysis (described in [14]) to confirm or discard the alarm. Thus, the system described in this article was designed to achieve a high level of accuracy, sensitivity, and robustness, not yet available at the time for CM systems for electrical components of a distribution network.

As summarized in [15], high volumes of published studies were carried out in PD diagnostics using conventional feature extraction, machine learning, and deep learning. The end goal was to have the installed CM system to make the diagnostic process effective and require less intervention from CM experts. On the other hand, an advanced system with artificial intelligence (AI) algorithms and expert systems (ES) implemented on board can support and assist the training and upskilling of the engineers of the distribution utility.

The main goal has been to have an on-line CM system for a wide distribution network having the following characteristics:

- Capability to reduce human intervention using automatic acquisition and signal sources clustering algorithms,
- Capability to automatically reject the high-frequency noise and separate the signal sources of PD phenomena through the shape parameters of the signals [14],
- Selection of hardware filtering when necessary due to environmental conditions,
- Use of AI classification for abnormalities in the measurements,
- Ability to reduce alarm fatigue through AI and ES [16], and
- Provision of in-depth diagnostic processing for confirmation of abnormality.

It is also important to highlight that, despite the level of automation of a CM system, it is the human intervention of the network operators and the constant usage of the CM system that results in maximizing the reliability of the monitored object [16].

Sensors and Their Placement

The on-line CM system focuses the diagnostics on the switchgears inside the distribution substations, where most of the failures are found and from where it is possible to detect defects originating even from far away, with signals propagating through the connecting cables to the sensors installed on the switchgears [17]–[19].

Therefore, at the beginning, an activity described in [20], relevant to the evaluation of the sensitivity of sensors and detection points, has been carried out. The focus was on the propagation of the signals within a GIS switchgear and their frequency content. The comparison was carried out among ultrasonic (US), radio frequency (RF), ultrahigh frequency (UHF), and transient earth voltage (TEV) emissions for different types of defects (internal, surface, and corona) in the various compartments of the switchgear. The airborne US sensor has a sensitivity range

(a) (b) (c)

Figure 2. Installation of sensors and positioning for (a) a high-frequency-current-transformer sensor on the ground lead, (b) TEV sensor on the cable, and (c) ultrasonic airborne sensor.

peaking around 40 kHz, whereas the contact one is in the range of 110 kHz with a wider (80–150 kHz) frequency range. Both the TEV and the high-frequency-current-transformer (HFCT) sensors have been investigated in the RF range (100 kHz–30 MHz). The overall results of the sensitivity study carried out showed the following:

- The TEV sensor installed on the MV cable, close to the termination, is the most sensitive location among the TEV sensors.
- The HFCT wrapped around the ground lead of the switchgear is the most sensitive location for the inductive sensor.
- The US sensors, both airborne and contact, showed poor sensitivity to most of the internal defects in comparison to the other RF sensors, except for external discharges.
- The HFCT in the location described previously is the overall most sensitive sensor.

Figure 2 shows some examples of the positioning of the sensors in the field installations.

Description of the Solution Architecture

To manage the high number of substations and detection points of the project, a multi-level architecture was designed, splitting the geographic layout of Singapore into regions (first level) and each region into substations (second level), each substation into switchboards (third level), if more than one is present in the substation, and finally each switchboard into switchgears (fourth level).

This concept is depicted in Figure 3. Depending on the size of the substations, in each of them one or more *condition monitoring and diagnostic* system (CMD) was installed.

The CMD contains the acquisition devices, and it is connected to the sensors to collect and process data, calculate the historical trends, separate and identify the multiple signal sources, and manage the alarms to be shared with the central monitoring system. The components of the CMD are modular, having a variable number of channels that can be configured based on the number of electrical assets to be monitored in a single substation.

The central monitoring system is the central server that collects all data from remote substations and shares the information. A dedicated human–machine interface, built as a web application, is used to display graphs, historical trends, and all the statistical and alarm values related to the health condition of the insulation systems. The last level, the fourth of the architecture, is at the switchgear level: any switchgear under monitoring is equipped with a triplet of RF, US, and contact temperature sensors connected to the CMD. The communication among the different and remote modules is carried out through OPC-UA, a standard communication protocol.

Acquisition and Data Elaboration Processes

The processes for acquisition and data analysis described in the current section are generic for both RF and ultrasonic channels.

An acquisition occurs at a predefined time interval. An acquisition is defined by configurable timeout and number of pulses: when the maximum number of pulses or the timeout is reached, the data are saved. The standard configuration requires a few thousand pulses related to PD, disturbances, or other signal sources, acquired over a few tens of seconds. Then, the acquired data set is processed onboard the PD detector through the T-F map analysis [21], allowing the separation of signal sources, because different sources have different waveshapes. After the automatic separation into different clusters, the analysis can be performed on every single cluster of data; thus, the identification is not affected by spurious or overlapped phenomena.

Next, the data, processed as described previously, are evaluated in the warning algorithm. Finally, the outcome is a warning severity related to the status of the insulating system.

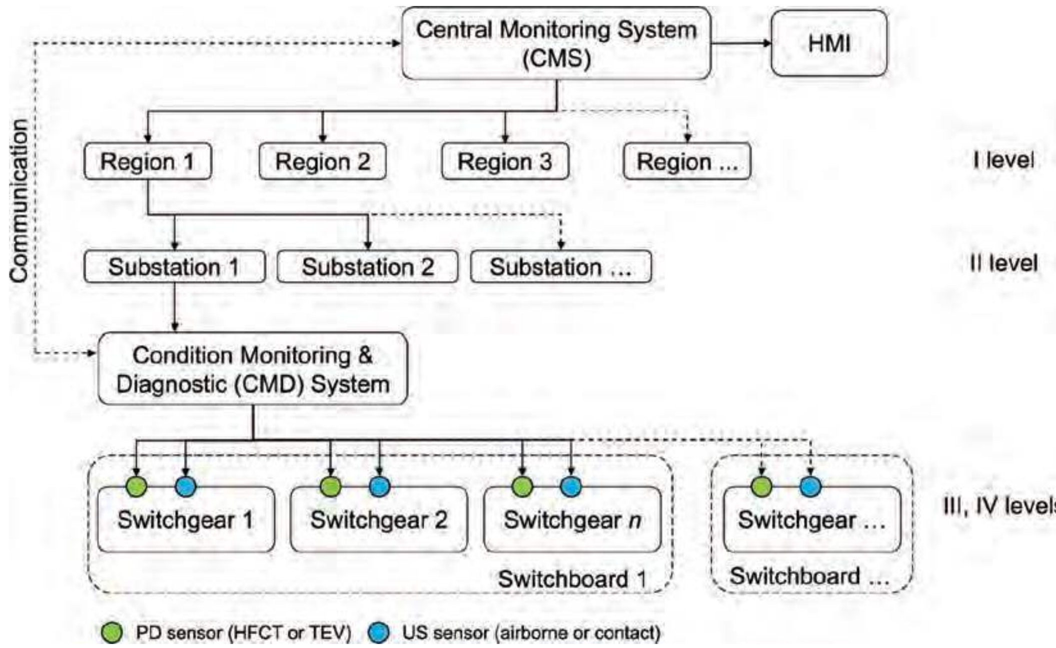

Figure 3. Monitoring system logic architecture.

The measurement steps are graphically described in Figure 4, which displays the conceptual flowchart of the whole process. Each of the steps takes its inputs from the result of the previous one, and it is performed automatically. The outcome is a traffic-light logic that categorizes the health status of the asset into three easy-to-understand levels: red, amber, and green.

Data Acquisition: The signals from each PD channel are sampled and processed directly on board to retrieve information related to the peak amplitude (A), the phase (P) related to the voltage applied, the shape parameters (equivalent time length and frequency) relevant to the acquired waveforms, and the time of occurrence (Ti). The data set may be representative of heterogeneous signals attributed to various sources (different PD, noise, disturbances, and so on), and to have a reliable and accurate identification, the signals belonging to different sources shall be analyzed separately. These signals are saved in the database, and they are available for further evaluation by skilled operators.

In the acquisition stage, to reject the noise, disturbances, or PD of no interest—such as outdoor corona—and thus increase the quality of the acquired data sets, two features of the PD detector can be used: (1) the selectable high-pass 5-MHz hardware filter and (2) the T-F map filters. The hardware filter can be used whenever an overlapping low-frequency noise is present, and the T-F map filters allow selection of zones of the map and the discarding of all the pulses having the shape parameters belonging to the defined areas.

A reliable automatic acquisition parameters configuration algorithm and the capability to filter out the disturbances enhance the quality of data, which is the first step toward obtaining satisfactory responses and avoiding false positive and negative alarms.

Data Elaboration

The data elaboration is the core of the monitoring system, and it has been designed for the current application. The following sections describe each data elaboration step as listed in the elaboration stage.

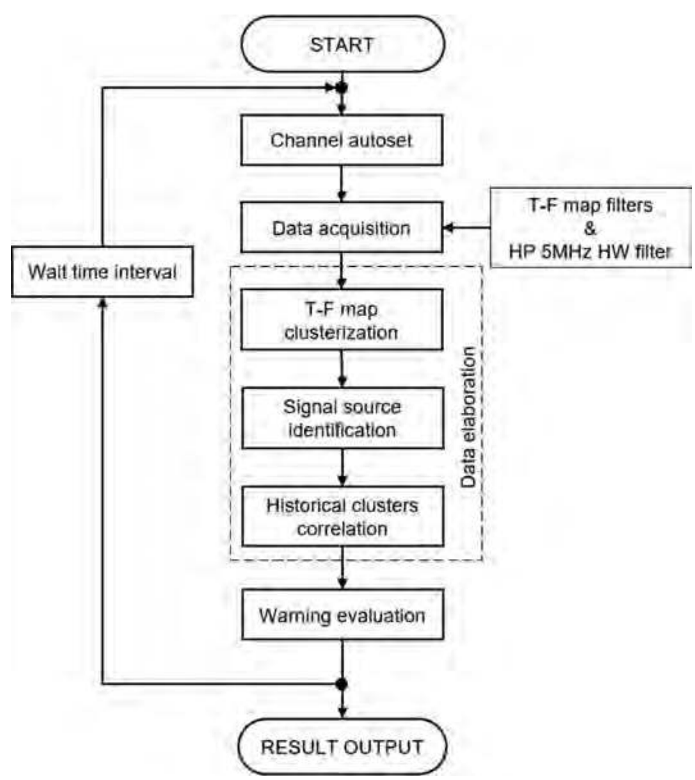

Figure 4. Acquisition process flowchart.

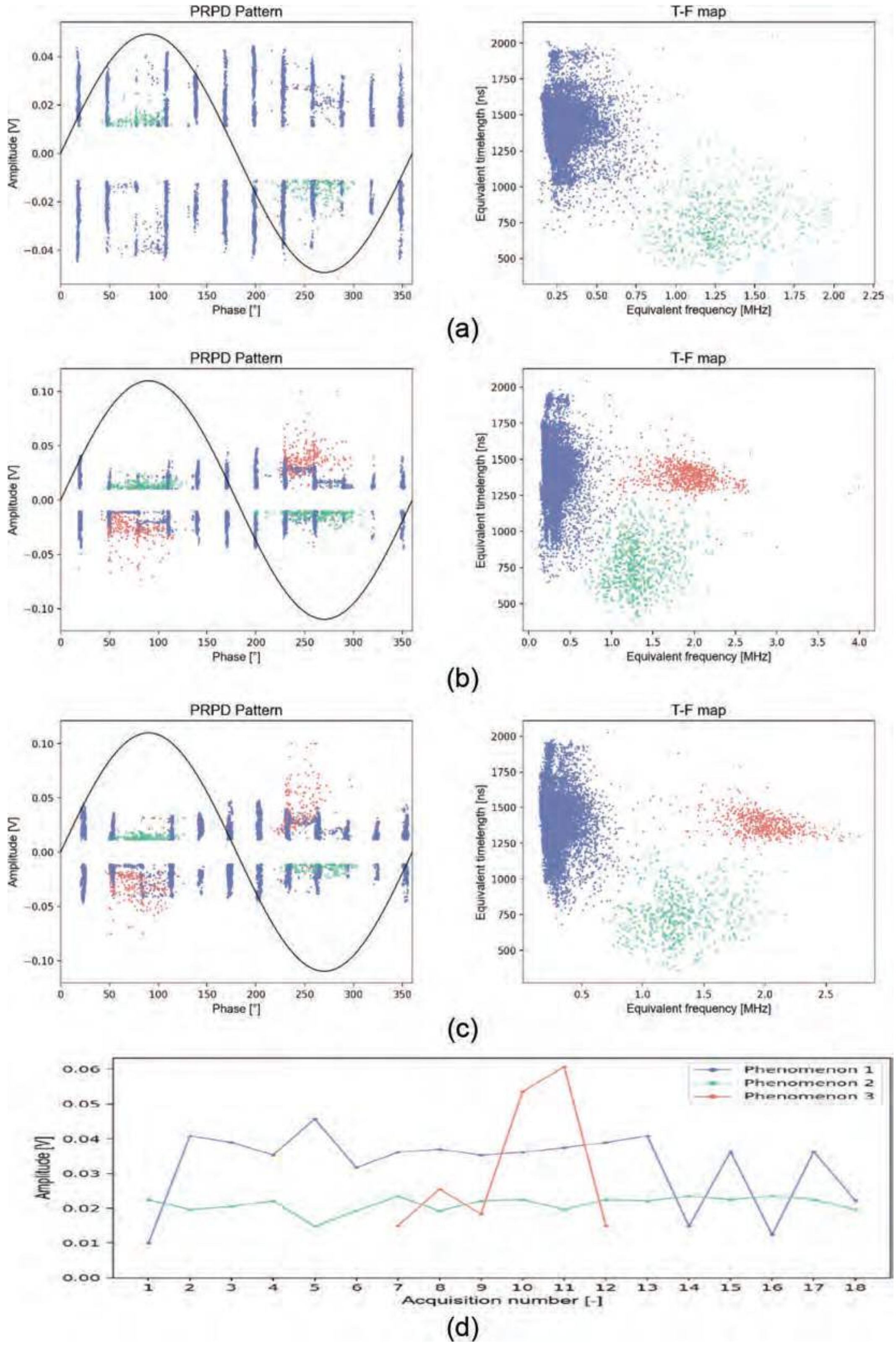

Figure 5. Historical clusters correlation example. (a), (b) and (c) Acquisitions performed on the same electrical asset in different periods. (d) Distinct amplitude trends of multiple phenomena.

T-F Map and T-F Map Clusterization: Once the shape parameters [21], [22] are extracted from the acquired signals, they are plotted in a graph, the T-F map. Signals from similar sources have similar waveshapes; thus, they are represented by similar shape parameters, allowing the waveshapes belonging to the same sources to be grouped into clusters in the T-F map.

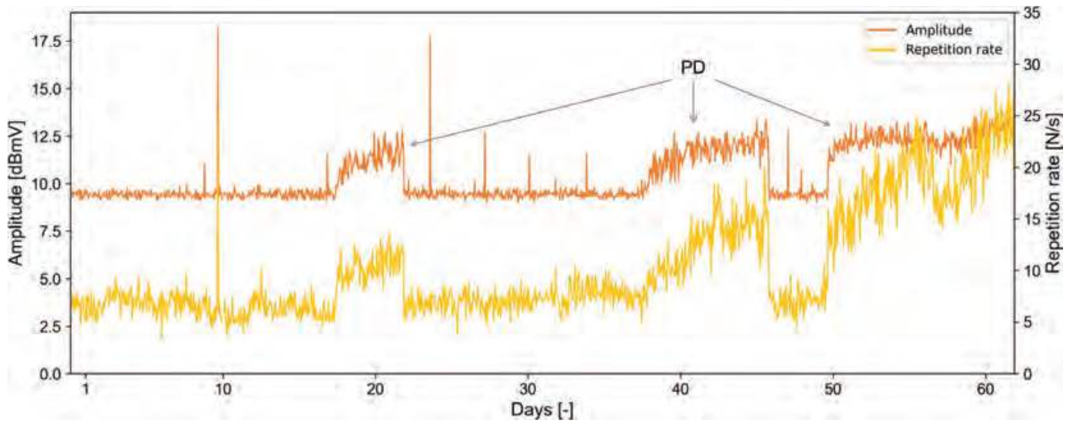

Figure 6. In-depth analysis of the phenomena.

Clusters can be separated and analyzed singularly both manually or automatically. In the current CM, clusters are separated automatically.

Signal Source Identification: The identification of each separate cluster from the previous step is based on an ES having as input the statistical markers of the phase-resolved PD pattern of each cluster. In particular, the ES exploits statistical markers derived from the Weibull distributions for each phenomenon and therefore the characteristics of different PD typologies or noise [21]. On the other hand, the time of occurrence of the pulses is utilized to identify the sources characterized by periodicity (e.g., disturbances). The goal of using the statistical parameters in the ES is the discrimination between PD and disturbances.

Historical Clusters Correlation: This algorithm aims at correlating each phenomenon spotted in the last acquisition with the historical data to create distinct time trending for those activities repeatedly observed in the monitored asset. Because the signals generated from the same source are grouped in the same T-F map area, it is feasible to link the same signal source, detected in different acquisitions, through the analysis of the shape and position of its clusters.

The example reported in Figure 5 shows three PRPD patterns and T-F maps acquired 30 minutes apart on the same detection point. The clusters that lay in the same area on the T-F map are related to the same phenomenon on the PRPD pattern. In (a), (b), and (c), the output of the cluster correlation algorithm is represented through colors: the clusters plotted with the same color have been matched and linked. Finally, Figure 5(d) distinctly reports the signal amplitude trends for the three phenomena along a nine-hour timeframe.

Matching the same clusters on acquisitions subsequent in time allows the highlighting of the persistent phenomena and the discarding of those triggered sporadically, with the verified assumption that they are characterized by a lower risk of fault, and before the failure they commonly become persistent. The output of the cluster correlation algorithm is the trending of one or more data sets. Each trend is related to a phenomenon, and the trending is composed of the values related to acquisitions performed at different times.

PD Alarms Evaluation: The last step is the PD alarm evaluation and management. The design choice for the alarm output has been the common traffic light convention: green color for no alarm, amber for light alarm, and red for serious alarm. The data sets in output from the cluster correlation algorithm are subjected to the following steps:

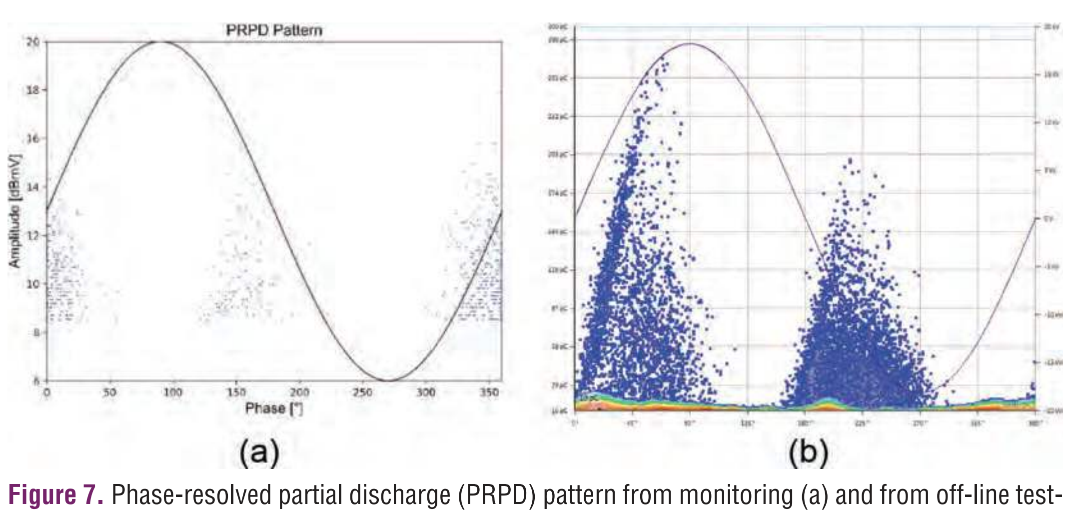

Figure 7. Phase-resolved partial discharge (PRPD) pattern from monitoring (a) and from off-line testing of the current transformer (b).

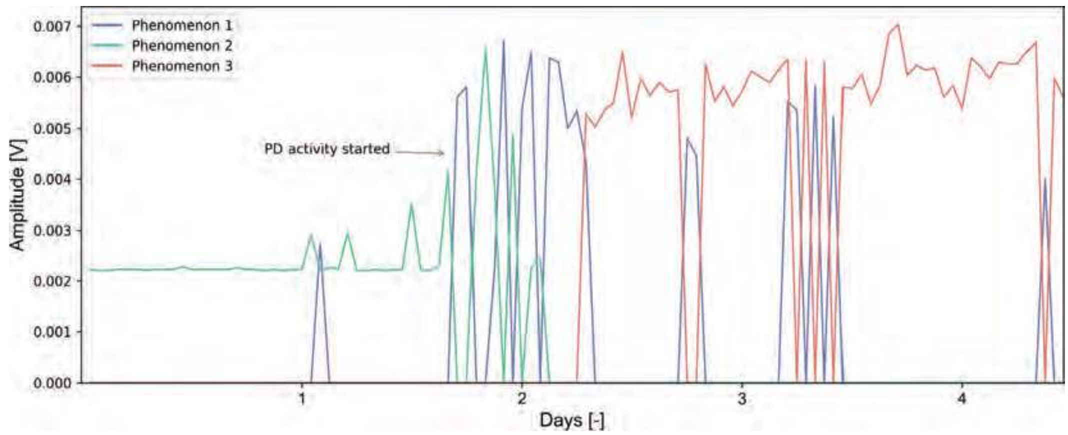

Figure 8. Activity of the monitored panel by high-frequency-current-transformer sensor.

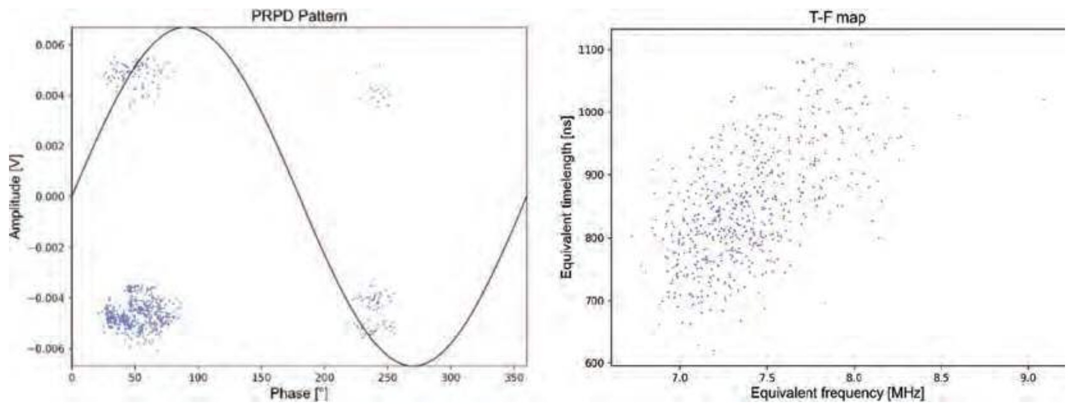

Figure 9. Phase-resolved partial discharge (PRPD) pattern and T-F map at the condition monitoring side.

- Discarding all the intermittent phenomena while focusing only on the persistent discharge activities stressing the monitored asset;
- Rejecting the activities not identified as PD phenomena, by considering the historical data of each phenomenon and defining its *average identification* over a fixed number of acquisitions;
- Comparing the average amplitude of the remaining data (i.e., PD phenomena that are not intermittent) with a threshold to define the alarm level to be notified. The thresholds for magnitude are set to default values that allow warning about the inception of new phenomena and the increase of existing ones.

The algorithm described previously allows the analysis of the different sources separately. In this way, the characteristic parameters used for the evaluation are not dirtied by overlapping phenomena, and they are more accurate. Furthermore, the evaluation of the historical data belonging to the same cluster prevents the effect of outliers that would affect the response of a system based on the thresholds alone.

The outcome to the end user is the sum of the alarms related to the number of persistent clusters acquired.

Case Studies from the CM System

Detection of PD Phenomenon from Aged Current Transformer of AIS

An amber alarm was picked up by the on-line CM system while monitoring AIS panels in a substation. In that AIS, a TEV

Figure 10. Distance of partial discharge source from the on-line condition monitoring system.

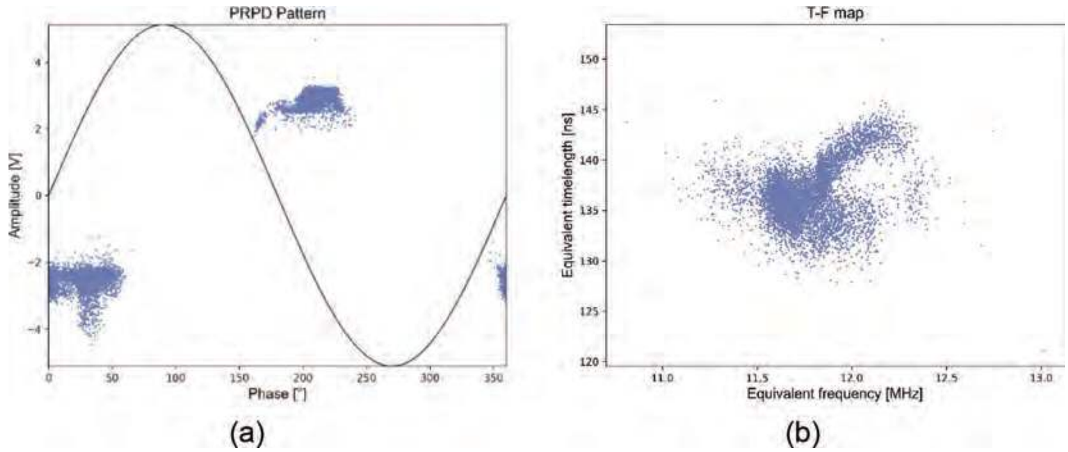

Figure 11. Phase-resolved partial discharge (PRPD) pattern and T-F map of partial discharge at the origin side.

sensor was installed on the cable. Figure 6 shows an extract of the time behavior of the activity in terms of magnitude and repetition rate. It is noticeable that there are intervals without PD activity.

Each time the PD activity reappears, there is a slight increase in PD magnitude and repetition rate. Based on the way the alarm algorithm is designed, the increment in repetition rate highlights the increasing harmfulness of the PD phenomenon.

Having stored the historical data in a central database, it was possible to further investigate the single acquisition. Figure 7(a) is related to a single acquisition, and it shows an indication of PD activity from the PRPD display. The pulse waveform was also confirmed as local PD activity.

Further investigation was carried out by performing a switching operation and lastly with off-line testing. Off-line high voltage AC test with PD measurement according to IEC 60270 [23] confirmed that the PD originated from the current transformer. Figure 7(b) shows the PRPD test result from the off-line HVAC test.

This verified the defect detected by the on-line system was from the current transformer. The shape of the phenomenon in the PRPD patterns of Figure 7, detected from two different commercial PD acquisition units, is similar, leading to relate both acquisitions to the same PD source.

PD Phenomenon from Downstream Substation with GIS

The on-line CM system installed in a substation composed of GIS raised an alarm relevant to PD activity having increasing magnitude. The measurement chain in use in this installation was an HFCT on the earth lead of the incoming MV cables of the switchgear. Figure 8 displays the time behaviors of the magnitude of each of the PD activities separated in the acquisitions from the detection point, where it is noteworthy the increasing trend of some and the sporadicity of others.

Figure 9 shows the acquisition detail of the activity highlighted in the trend. By reviewing the detailed data plotted in the PRPD pattern, T-F map, and pulse waveform as shown in Figure 9, it was confirmed by an expert operator to be a PD phenomenon.

In the T-F map of Figure 9, the cluster related to the PD phenomenon is centered at an equivalent frequency of about 7.5 MHz. A further investigation was conducted to localize the PD source [24]. It was found to be originating from a downstream substation switchgear defect. As illustrated in Figure 10, the on-line CM system detected the PD about 1 km away, with one substation in between.

Figure 11 shows the measurement at the local substation where the PD defect originated. By comparing Figure 9 and Figure 11, the magnitude of the PD phenomenon was attenuated about 150 times due to the propagation from the local substation to the substation having the on-line CM system installed. From the T-F map of Figure 11, it is noticeable that the center of the equivalent frequency is at about 11.5 to 12 MHz, higher than the 7.5 MHz identified in Figure 9 due to the dispersion due to the propagation. Therefore, it is possible to have a rough idea of the closeness of the detection point from the origin of

Figure 12. Discharge marks at the terminations.

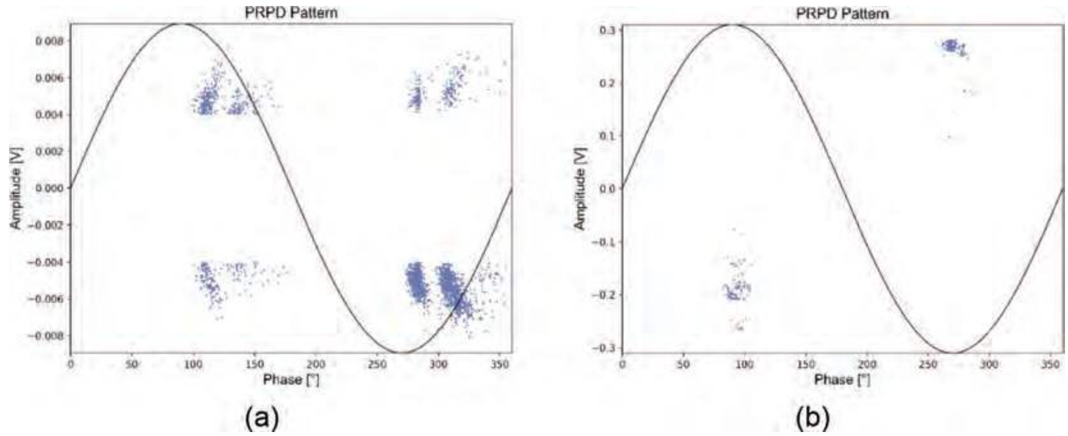

Figure 13. Phase-resolved partial discharge (PRPD) pattern (a) at the detection point and (b) close to the origin.

the defect: the higher the equivalent frequency, the closer to the defect origin. Additional investigations from the SP Group identified the PD source and determined it to originate from a defect in the termination of GIS as shown in Figure 12. Clear burnt marks were observed at the lug of the termination. Thus, the component was removed and replaced with a new outer cone. After the replacement, no alarm nor PD defect was any longer detectable from the detection point that previously acquired it.

PD from Downstream Customer Electrical Plant

An amber alarm was picked up by one CMD displaying an increasing magnitude. By reviewing the activity in the PRPD pattern, the presence of a PD phenomenon triggering the alarm was confirmed. Further investigation was conducted to trace the PD source. It was found to have originated from a downstream customer substation. The on-line CM system detected the PD source located at about a 150-meter distance, with one station in between. Figure 13(a) shows the measurement at the detection point and Figure 13(b) at the local station: it was traced that PD originated from a customer station very close. By comparing Figure 13(a) and 13(b), the measurements show an attenuation due to propagation of more than 40 times from the on-line CM system detection point. Thus, SP Group informed the customer of the existence of PD, and the customer took the necessary steps to investigate and replace the defect.

Conclusions

The adoption of CM on distribution networks is an important step to ensure the reliability of the assets in it and, as a consequence, the reduction in interruptions and perturbations on the network, positively affecting the power quality. The preliminary results discussed here, relevant to the installation of the first tens of pieces of equipment of the CM system in a countrywide network, showed the effectiveness of such an approach, where, having as a peculiarity most of the power distributed through underground cables, knowing the status of the assets is vital.

Case studies from the preliminary evaluation of the system have been gathered and discussed to highlight the performances of the detection, sensitivity, and analysis approach designed for the system. The results showed the CM system covering not only the distribution network but also, sometimes, the assets connected to it.

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News From Japan

Yoshimichi Ohki

Development of Innovative Solar Cells for Achieving Carbon Neutrality: Part 1

The world's annual average temperature in 2023 is expected to be the highest on record [1]. Although its principal cause is unknown, many people believe the increase in global warming gases such as carbon dioxide is mainly responsible. Therefore, governments, various institutions, and major companies around the world are embarking on countermeasures. For example, efforts are being made to replace conventional power generation using fossil fuels with nuclear power plants and various renewable energy sources that can reduce global warming gases.

In Japan, solar power generation is exhibiting the highest rate of adoption among various renewable energy sources. Regarding this, many companies in Japan are focusing on the development of new solar cells. The solar cells mainly used today for power generation use silicon (Si). However, Si solar cells are hard, unbendable, thick, and heavy. For this reason, there is a shortage of new places to install Si solar cells, especially in urban areas where buildings are densely packed. If we can create thin, light, and flexible solar cells, it will be possible to generate electricity in a variety of places, such as curved parts of buildings and the roofs of electric vehicles (EV). This will help alleviate the previously mentioned problem. Another disadvantage of Si solar cells is that they generate electricity using only a long-wavelength part of solar light. Therefore, it would be desirable if there were solar cells that could use both long-wavelength and short-wavelength sunlight.

The efforts toward the realization of the above two targets being conducted by Toshiba Group will be introduced in this News from Japan column. This issue describes tandem solar cells that can generate electricity using nearly all wavelengths of sunlight, and the next issue will discuss solar cells that are thin, light, and flexible.

The absorption of light by a solid is most fundamentally determined by its bandgap energy or the width of its forbidden band. Photons with energies greater than the bandgap energy are absorbed. In other words, light with wavelengths shorter than the wavelength corresponding to the bandgap energy is absorbed. Therefore, if we can make a double-layer or four-terminal tandem solar cell, like the one shown in Figure 1, consisting of an upper-layer cell made of a material with a wider bandgap than Si and a Si solar cell as the lower layer, it can make full use of sunlight and increase the power generation efficiency.

The bandgap of Si is 1.1 eV. In consideration of candidate materials for wide-bandgap solar cells suitable to the upper layer of the tandem solar cell, several Japanese companies have considered III-V semiconductors such as GaAs with a bandgap of 1.42 eV and perovskite compounds. However, the production of III-V semiconductors such as GaAs requires expensive epitaxial growth equipment. In this regard, the price is tremendously high for the GaAs/Si tandem solar cells already used for spaceships. Another critical point for tandem solar cells is that the lifespan should be similar between the upper and lower cells. The perovskite solar cells available at present have a much shorter lifespan than Si cells.

Taking this into account, Toshiba set copper (I) oxide (Cu_2O) with a bandgap energy of 2.15 eV as a candidate material for the upper material of the tandem solar cell. The upper cell must transmit a part of solar light to the lower cell. This means the development of Cu_2O solar cells with as high transparency as possible is an urgent issue in addition to the increase in size.

A research group in Toshiba developed a reliable method for the deposition of Cu_2O using reactive sputtering of Cu and O in 2019 [2]. Because the reactive sputtering, whose principle is schematically shown in Figure 2, does not need special equipment, this contributes to lowering the manufacturing cost of Cu_2O.

Displayed in Figure 3 are X-ray diffraction patterns measured for Cu_2O thin films deposited by reactive sputtering of Cu and O with three different O_2 flow rates. When the O_2 flow rate is 8.0 sccm (standard cubic centimeters per minute), we see Cu as an impurity, whereas another impurity, CuO, is seen when the flow rate is 10.0 sccm. Figure 4 shows the average transmit-

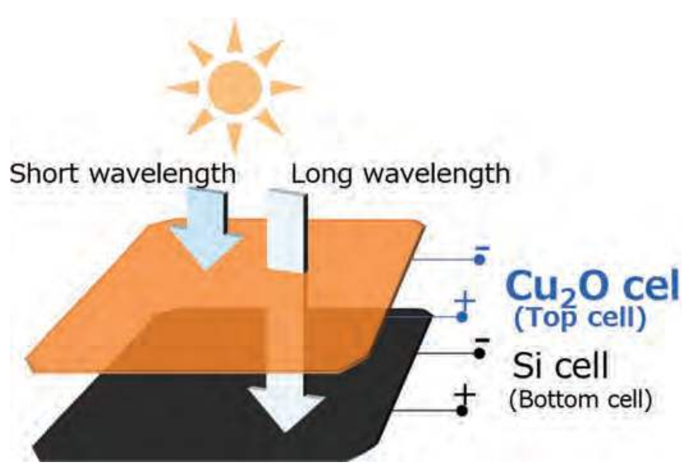

Figure 1. Conceptual diagram of a four-terminal tandem solar cell.

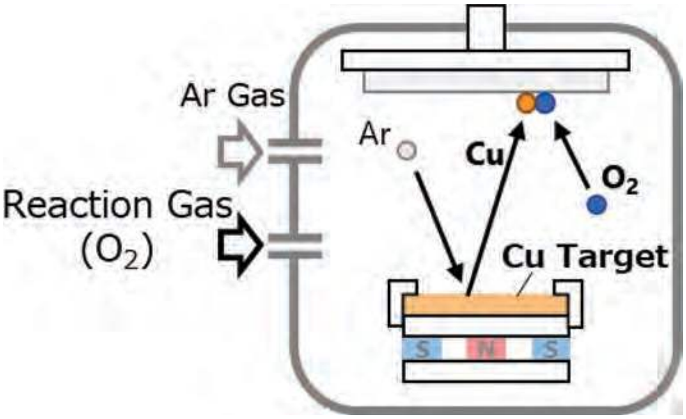

Figure 2. Schematic drawing of reactive sputtering of Cu and O to deposit Cu_2O.

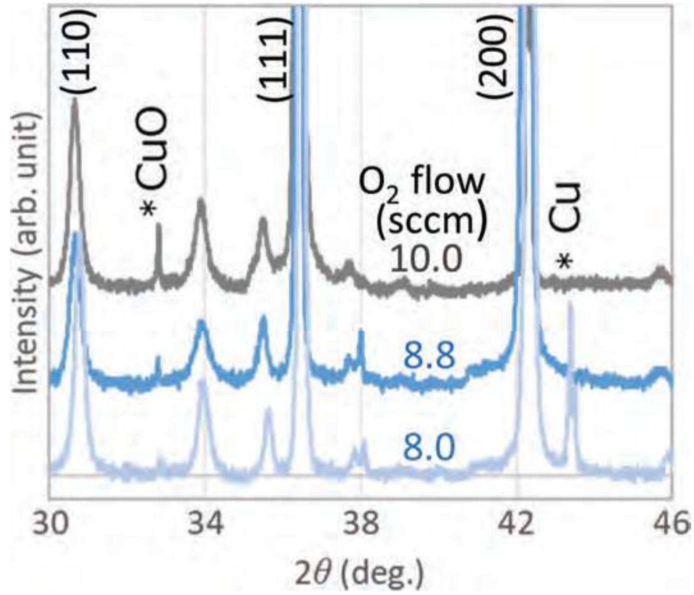

Figure 3. X-ray diffraction patterns measured for Cu_2O thin films deposited by reactive sputtering of Cu and O with three different O_2 flows of 10.0, 8.8, and 8.0 sccm (standard cubic centimeters per minute).

tance of Cu_2O thin film as a function of the flow rate of O_2 during the reactive sputtering. The part colored ocher indicates the range of O_2 flow rate where almost no impurities appear in the deposited Cu_2O thin films. It has become evident that the most suitable O_2 flow rate is 8.8 sccm.

Figure 5 demonstrates semi-transparency of the deposited Cu_2O thin film with a thickness of several micrometers. Because it generates electricity by light from ultraviolet to yellow or orange and transmits light from red to infrared, the letters underneath can be seen.

Figure 6 shows the structure of the Cu_2O solar cell. In this structure, the p-layer consisting of Cu_2O and the n-layer consisting of Ga_2O_3 and zinc tin oxide (ZTO) form a p-n junction, which generates electricity by absorbing sunlight from ultraviolet to orange with wavelengths shorter than around 580 nm (= 2.15 eV), as indicated in Figure 7. The top layer, aluminum-doped zinc oxide (AZO), is transparent conducting oxide (TCO) that extracts power to an external electric circuit. In addition, antimony tin oxide (ATO) and indium tin oxide (ITO) are also TCO. All the constituent layers are transparent to long-wavelength light from red to infrared. Therefore, the light with such wavelengths, at which Si solar cells have high efficiency of electricity power generation, can pass through and reach the underlying cell.

Toshiba has continuously improved the efficiency of the Cu_2O solar cell since its development in 2019 [2]. The efficiency reached 8.4% in December 2021 [3] and 9.5% in September 2022 [4]. It is 10.3% as of October 2023 [5]. Toshiba also succeeded in making a Cu2O solar cell with a size of 40 mm2 in September 2022, which has an effective power generation area 180 times that reported in 2021 [2].

Regarding the above, when we make a tandem solar cell using the 10.3% Cu_2O cell as the upper layer and a Si solar cell with an efficiency of 25.9% as the lower layer, the efficiency

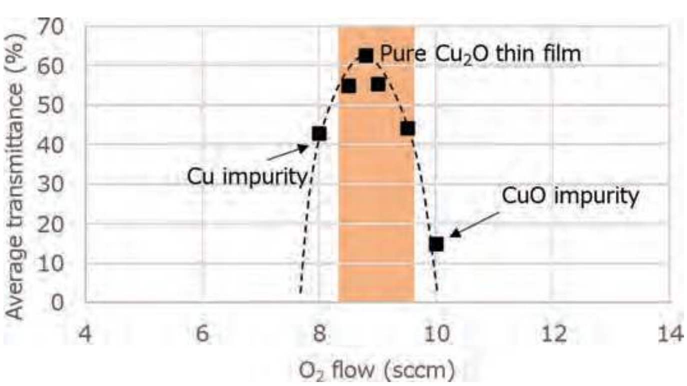

Figure 4. Average transmittance of Cu_2O thin film as a function of the flow rate of O_2 during the reactive sputtering of Cu and O. The ocher column shows the range of O_2 flow rate where almost no impurities appear.

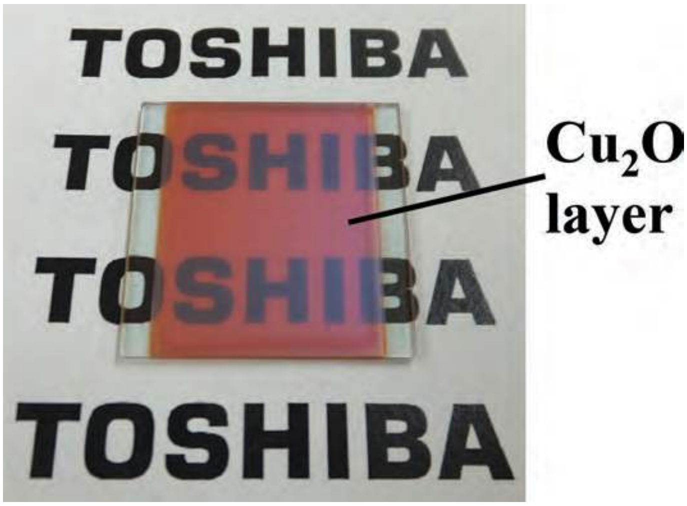

Figure 5. Semi-transparent Cu_2O. Because it generates electricity from light from ultraviolet to orange and transmits light from red to infrared, the letters underneath can be seen.

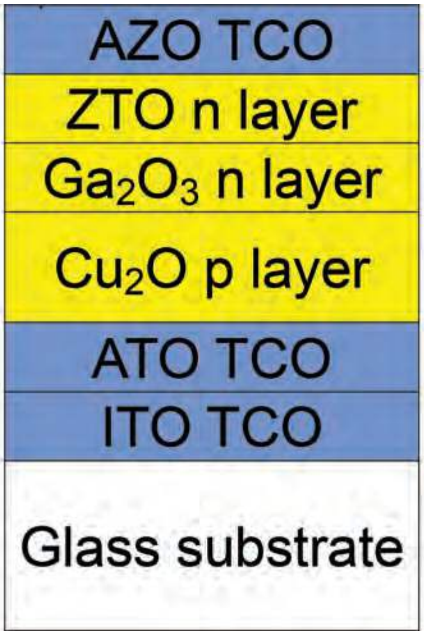

Figure 6. Schematic diagram of Cu_2O cell cross section (configuration example). AZO = aluminum-doped zinc oxide, TCO = transparent conducting oxide, ZTO = zinc tin oxide, ATO = antimony tin oxide, ITO = indium tin oxide, yellow = power-generating p-n junction, blue = electrodes (TCO).

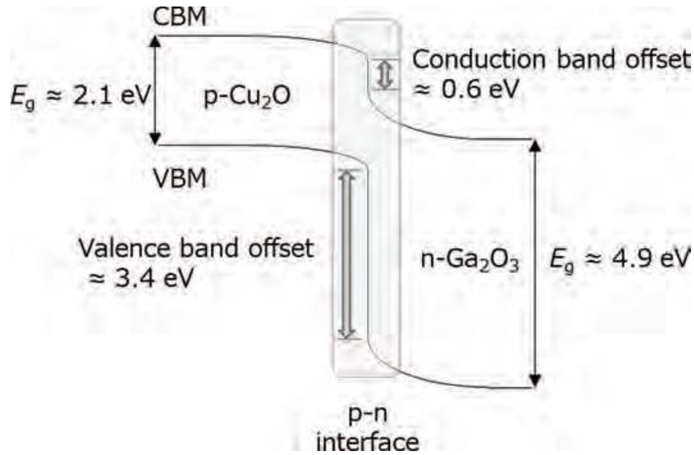

Figure 7. Principle diagram of power generation at the p-n junction of Cu_2O and Ga_2O_3. CBM = conduction band minimum, VBM = valence band maximum.

of the tandem cell is estimated to be 30%. For example, if the tandem solar cell is installed on the roof with an effective area of 3.3 m2 of an EV, Toshiba estimates that the EV can run using only solar energy for up to 39 km a day with clear skies, with no charging. This distance is half the average short-distance driving in Japan. Furthermore, charging equipment becomes virtually unnecessary for mobile or smartphone users. These situations are expected to make a significant contribution toward achieving carbon neutrality.

Part of the previously mentioned research and development was conducted in a project in cooperation with the New Energy and Industrial Technology Development Organization (NEDO). This article was completed in cooperation with Mr. Kazushige Yamamoto, Dr. Soichiro Shibasaki, Mr. Mutsuki Yamazaki, and Dr. Naoyuki Nakagawa of Toshiba Corporation, and Mr. Tomohiro Tobari and Mr. Masayuki Kosakada of Toshiba Energy Systems & Solutions Corporation.

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Stories From China

Zepeng Lv

China's First ±550-kV DC GIS Has Passed 180-Day Outdoor Long-Term Electrification Test

On February 26, 2024, China's first ±550-kV direct current (DC) gas-insulated switchgear (GIS) passed the 180-day outdoor long-term electrification test, which belongs to the first pass of the electrification test for the ±550-kV DC GIS in China. The project was codeveloped by Xi'an Jiaotong University, Xi'an XD Switchgear Electric Co. Ltd., and China Southern Power Grid Scientific Research Institute Co. Ltd. Because no product standard nor operational performance of similar products exists, the project team designed a scientific verification scheme by referring to relevant domestic and foreign literature. During the test, the operating voltage reached 1.2 times the rated voltage for more than half of the time while applying a DC current of 5,000 A, so as to simulate the real-working conditions. The test was conducted in open air (Figure 1), during which the product was exposed to the sun, rainstorms, sand dust, high temperatures, heavy snow, and other severe weather, undergoing the most rigorous assessment.

The DC GIS equipment can significantly reduce the manufacturing cost on the DC side of the flexible DC transmission system and improve operating reliability. It is a key equipment for new energy development and large-scale energy transmission. Compared with traditional DC air-insulated switchgear, the application of the DC GIS at the same voltage can save the space by 70~95% and reduce the volume of offshore converter platforms by about 10%, thus significantly reducing the cost of offshore wind power development. Moreover, because the high-voltage components are not affected by external influences such as dust, salty air, rain, snow, and other environmental factors, the DC GIS can operate with high reliability in a complex environment.

Aiming at the fact that interface charge accumulation and induced surface discharge restrict the insulation reliability in the development of DC GIS, the project team established a full-scale ±550-kV DC GIS basin-insulator surface charge measurement device, as shown in Figure 2. The team proposed a life cycle process of interface charge accumulation and dissipation, which provides references for the development of DC insulation materials and structures under the conditions of a high temperature gradient and high electric field distortion.

On the basis aforementioned, the team also studied the correlation mechanism between charge trap characteristics and microstructure. A heatproof and high-resistance curable aniline epoxy resin formulation and a new DC GIS basin insulator were developed by matching design of structure and materials, as shown in Figure 3. The newly designed insulator suppresses surface charge accumulation and increases DC flashover voltage by 18%.

Figure 1. Schematic diagram of the long-term electrification test for the ±550-kV DC gas-insulated switchgear.

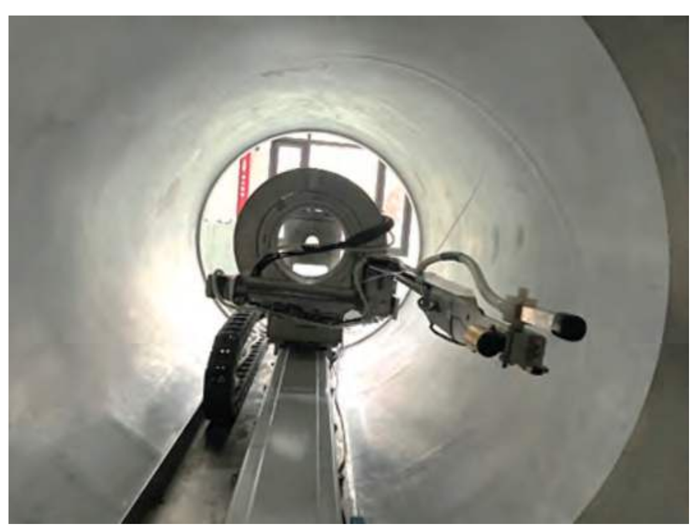

Figure 2. A full-scale ±550-kV DC gas-insulated switchgear insulator surface charge measurement device.

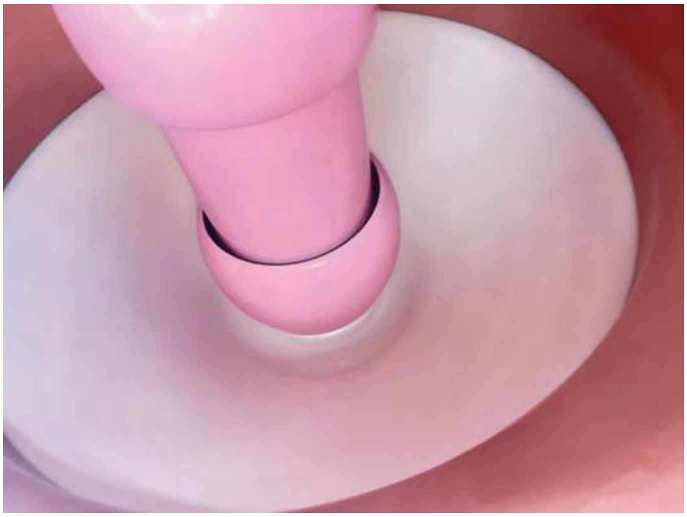

Figure 3. Schematic diagram of the inner metal guide rod–basin insulator.

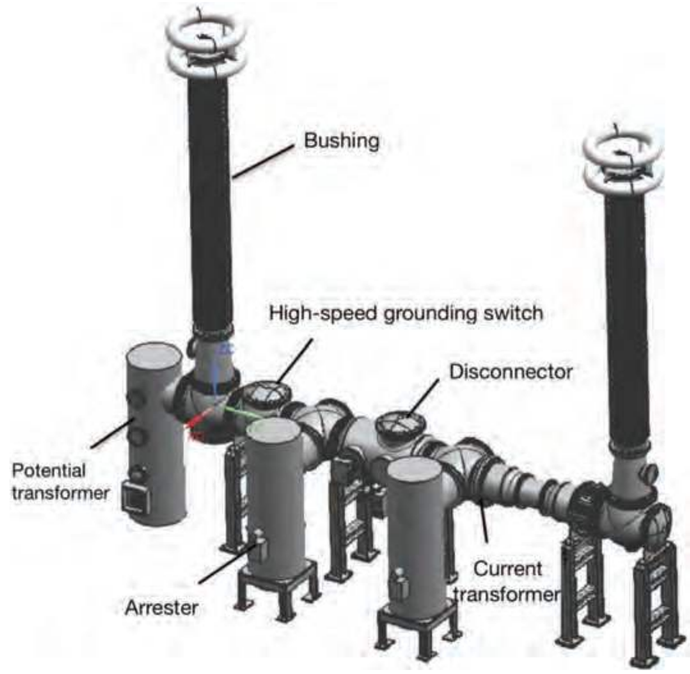

Figure 4. The modular design of the ±550-kV DC gas-insulated switchgear.

The team proposed a codesigned method of multidimensions and multifields for the ±550-kV DC GIS, which achieved a compact and modular design of the functional units including the disconnectors, earthing switches, current measurement devices, voltage measurement devices, arresters, and bushings (Figure 4). A differentiated long-term electrification test program for the DC GIS was also built to support the establishment of the standard system for DC GIS testing and high-voltage DC GIS development.

With the increasing global demand for clean energy and the urgent call to tackle climate change, the new energy development is attracting more and more attention. In this background, the DC GIS is a key equipment in large-scale grid integration of new energy with its low development cost and high reliability. The ±550-kV DC GIS equipment is expected to be widely used in large-scale new energy development.

Young Professionals

The Beaten Path Less Traveled By

Like many of us, I have attended numerous panels, seminars, and workshops geared toward helping young professionals and students. The more senior professionals are gathered for us to question and tap them for wisdom and anecdotes. One such question that inevitably comes up in one form or another is, "How did you get to where you are?" A thinly veiled question intending to ask how can one get to the same or similar position. The response often begins with a soft chuckle and a "well…" Their answers are caveated by "my path was not the typical path."

However, I have heard about this "atypical" path so often that perhaps this "atypical" path is in fact a typical path. That is, most folks seem to meander a bit, changing directions, going on whims with various folks in their network, and perhaps "getting lucky" or being in the "right place at the right time." A similar journey has certainly been my own experience.

My Path

When I decided I wanted to attend college, I had no clue what I wanted to study. I was most interested in psychology at the time, but I was under the impression that a graduate degree was necessary for the degree to hold utility. I did not envision a future with graduate school in it. I instead chose to study physics on a whim, as I was good at math and considered science generally interesting. This led me to conduct various research projects during my undergraduate time, primarily focusing on surface brightness fluctuation analysis to determine distances to galaxies, with an example of such a measurement shown in Figure 1 for galaxy IC1919. I enjoyed the research and the relaxed environment of education that I experienced. Because of this, I seemingly played a joke on my past self and decided to apply for graduate school.

When considering graduate schools and programs, I bounced between many programs from astronomy to plasma physics, waiting until the very last moment before accepting a fellowship at Utah State University to investigate the pulsed electroacoustic (PEA) method and apply it to spacecraft charging issues. A representative schematic of the PEA system is given in

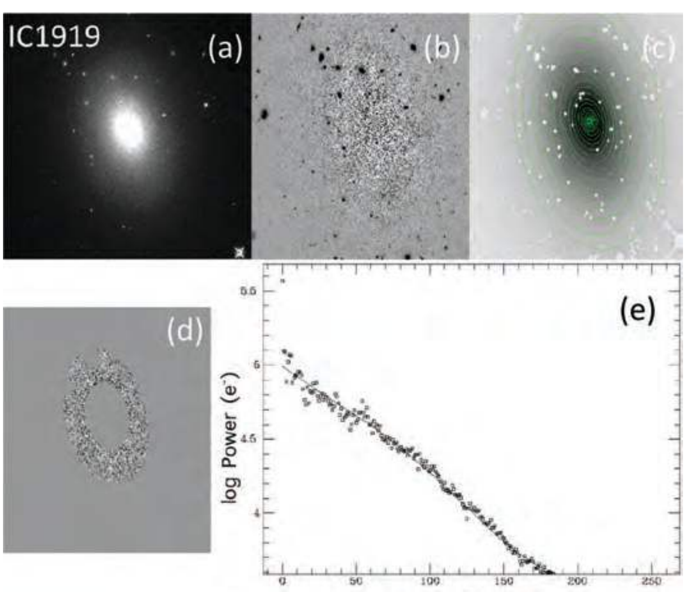

Figure 1. Surface brightness fluctuation analysis example. (a) Image of galaxy IC1919, (b) residual image, (c) masked and elliptical isophotes, (d) annular mask, and (e) SBF fit to power spectrum of masked annulus [1]. (Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the data archive at the Space Telescope Science Institute (STScI). STScI is operated by the Association of Universities for Research in Astronomy Inc. under NASA contract NAS 5-26555.)

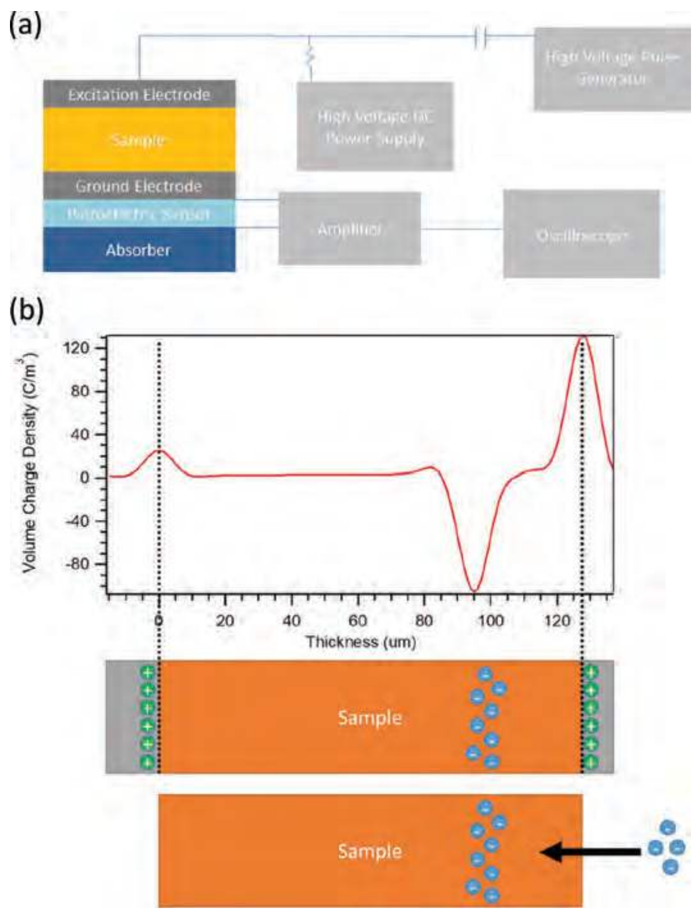

Figure 2. Pulsed electroacoustic method: (a) representative schematic and (b) representative result of electron irradiated polymer [3].

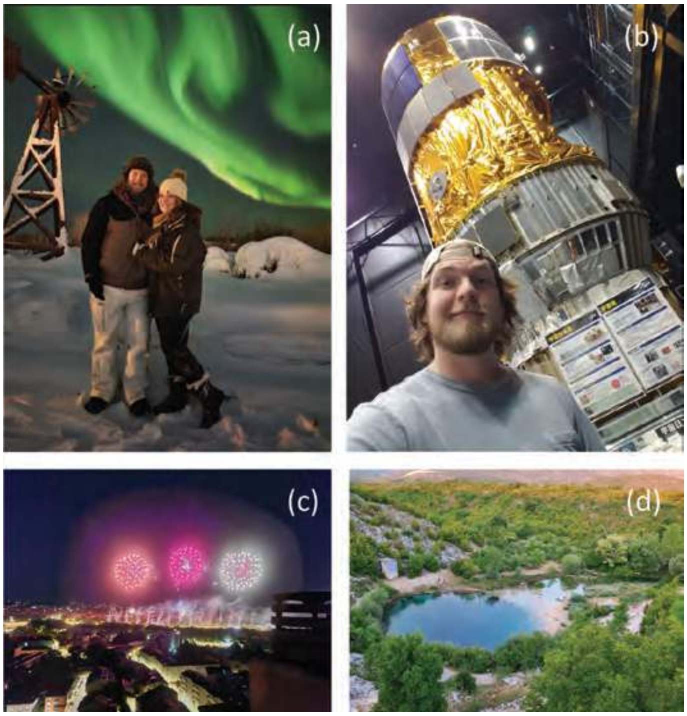

Figure 3. Photos from my travels: (a) my partner and me under the northern lights in Fairbanks, Alaska; (b) me at JAXA in Tsukuba, Japan; (c) Bastille Day fireworks in Toulouse, France; and (d) the source of the Cetina River, “eye of the Earth,” in Croatia.

Figure 2, along with an example result from a polymer irradiated with an electron beam. At the time, I had no idea what I was getting into. I only knew that I wanted to do more “hands on” physics and the research would be tangentially related to my prior muse of astronomy.

During graduate school, I had experiences I never imagined were possible. I traveled the world presenting at conferences and expanding my network, contributing to a field of knowledge. I was fortunate enough to have the experience of spending a month studying in Japan and several months conducting research in France. I delved deep into the science of charge dynamics in highly disordered insulating materials, a topic which I had not previously considered of interest but now consider incredibly fascinating. I even managed to propose and validate something completely new, a simple method of measuring shallow charge distributions via the PEA method [2], earning a PhD in physics at last.

Looking Back

Reflecting on my experiences throughout my education, I have come to realize many things. An overarching theme occurs to me that you can never quite be prepared for what is to come, but I believe this to be essential to the learning experience. Although, I do have a few words of advice for others to aid in their journeys.

First and foremost, be sure to enjoy what you are doing. Take time to achieve personal goals as well, as graduate school can feel all encompassing. One of the best simple pieces of advice I have received and follow myself is to keep weekends sacred, no work. Of course, the odd working weekend may slip in every so often. Make a conscious effort to do things outside of school. For me, this was traveling. I managed to take advantage of conference travel, fellowships, and any free time I had to travel the world. I have shared some of my travels in Figure 3.

Professionally, the best advice I can give is to talk to people. Know people in your field. Reach out, ask questions, and start collaborations. Solicit your research to folks to give presentations at laboratories and universities that may be interested. Ride the fine line between taking advantage of any opportunities that come up and knowing when to say no. Take advantage of opportunities that may seem unrelated as well, such as serving on committees, teaching, joining clubs, and so on. It does not hurt to have more breadth and to know more people. Do not be afraid to take advantage of opportunities now, reach out to other folks, and make connections.

Zachary Gibson
zachary.gibson.15@spaceforce.mil

References

[1] Z. J. Gibson, J. B. Jensen, H.-c. Lee, and J. Blakeslee, “Probing Stellar Populations in the Virgo and Fornax Clusters with Infrared Surface Brightness Fluctuations,” Poster. Salt Lake City, UT: NASA Space Grant Consortium, 2015.

[2] Z. Gibson and J. Dennison, “A simple method for determining shallow charge distributions in dielectrics via pulsed electro-acoustic measurements,” in *IOP Conf. Series: Materials Science and Engineering*, 2023, p. 012017.

[3] Z. Gibson, “Precise determination of charge distributions in electron irradiated polymers via pulsed electroacoustic measurements with applications to spacecraft charging,” PhD Dissertation, Utah State Univ., Logan, UT, 2023.

The Young Professionals column features young researchers, engineers, and entrepreneurs in our community to share their experiences and discuss matters related to their professional development. If you would like to contribute or have any suggestions, please contact the DEIS-YP Secretary Allen Andresen at allen.j.andersen@jpl.nasa.gov. Follow us on LinkedIn at https://www.linkedin.com/company/ieee-deis-young-professionals/ for the latest updates and events that are of interest to DEIS-YPs.

Book Reviews

Nihal Kularatna

Energy Smart Appliances: Applications, Methodologies, and Challenges

A. Moreno-Munoz and N. Giacomini, editors
Wiley-IEEE Press
John Wiley & Sons Inc.
Hoboken, NJ
https://www.wiley.com/en-us
ISBN: 978-1-119-89944-0 (e-book)
ISBN: 978-1-119-89942-6 (print)
368 pp., $108 (e-book), $135 (hardback), 2023

Over the past 20 years appliances used in our households have become very advanced, with networking capabilities and user friendliness. With the environmental concerns about the power grid, energy efficiency and renewable energy resources are central discussions in all countries on the future of power grids. Energy smart appliances, where optimization of energy consumption is to be combined with smart power grid capabilities, are becoming a hot topic of research, within the industry and academia. This book on energy smart appliances is a timely effort by its editors to investigate the present and future direction of whiteware we use at our residences.

Chapter 1, written by the editors, starts with an excellent overview of the present-day power grid and its demand-side flexibility. This chapter provides an overview of the worldwide power grids with a summary of power and energy consumption patterns, and the discussion progresses into a summary of smart grid with renewable energy sources, distributed generation, advanced metering infrastructure, and demand-side management (DSM). Power grid flexibility expected from the gradually advancing power grid with smart features is in the middle of the chapter. Then, it provides a very good overview of power quality, reliability, and the resilience expected in the future smart grid, with a fairly detailed discussion on power quality disturbances leading into a discussion of economic implications and issues of poor power quality. Finally, the chapter provides an overview of the internet of things (IoT) and submetering (measuring energy usage of individual appliances as opposed to bulk metering), leading into a summary discussion on energy smart appliances. The list of symbols and abbreviations at the end of the chapter is very useful to a reader, given the new concepts used in smart grids with renewable energy resources.

Chapter 2, titled Deep Dive into the Smart Energy Home, authored by co-editor Neomar Giacomini, is a very informative and useful discussion on the smart home, its penetration forecasts, and a discussion on connected devices as at 2022. The chapter also discusses the limitations and concerns from an industrial perspective. Chapter 3 provides a very useful overview on household energy demand management and the technologies available, together with a summary of what some European countries are developing with respect to demand response.

Chapter 4 is a very practically oriented discussion on DSM, demand response, and the advanced metering infrastructure, where DSM strategies, demand-response programs, and home are networks (HAN)/building area networks (BAN) are discussed in the context of efficient management of central supply of AC electrical energy coupled with onsite-generated renewable energy. There is a very good summary of components and technologies associated with HAN systems. Chapter 5 provides an excellent discussion on the standardizing aspects of DSM, describing the open automated demand response (OpenADR) standard and the related communication protocols, with a lot of device examples in the present-day market for consumers to make use of these automated energy management systems applied at the individual appliance level.

With a technical overview of the internal design of many appliances used in a household, Chapter 6 presents a discussion on how these whiteware and other household consumer electronics systems could become energy smart appliances on a progressive basis. It also details the use of a smart energy controller sometimes known as a home energy management system. The co-editor's own experience at Whirlpool corporation is well embedded in the chapter content.

Chapter 7 on the subject of Smart Applications Reference Ontology developed by the European Telecommunications Standards Institute (ETSI) is a good discussion on developing smart applications in the IoT field. This chapter is a good read for a team of practicing engineers or researchers developing energy smart appliances for smart home environments. Chapter 8 is on the software and algorithmic development aspects of scheduling of residential smart appliances. Chapter 8 starts with a summary discussion on six major objectives of DSM and then moves on to a discussion on time-shiftable and smart appliances in residences based on nature-inspired smart metaheuristic algorithms.

Chapter 9 is on the distributed operation of an electric vehicle (EV) fleet in a residential area, with an overview of vehicle-to-vehicle, vehicle-to-grid, vehicle-to-home, and vehicle-to-load interactions, which are commonly known as V2X interactions. This chapter also provides an overview of EV charging station categorization according to SAE Std J1772v (2012). It also provides a discussion on an EV aggregator usable in a residential area with lot of EV and associated algorithms for decentralization of a heavy EV load. Chapter 10 is on the use of EV as smart appliances for residential energy management. Both Chapters 9 and 10 provide a discussion on the use of the EV charging standard IEC 61851. Chapter 10 has additional discussions on other standards such as SAE J1772 (for US) and GB/T 20234 (in China). Chapter 10 provides details on V2X operation details with a futuristic approach. Chapter 11 is on induction heating as a smart home appliance, with a lot of hardware design details on an induction cooktop.

All chapter supply a comprehensive list of references for further details, and the two editors, Antonio Moreno-Munoz and Neomar Giacomini, have done excellent work collecting the right type of contributions with a balance of theory, practice, and standards from a set of experts, and most chapters come with a useful list of abbreviations. The index at the end of the book is very useful for readers.

Electrical and Mechanical Fault Diagnosis in Wind Energy Conversion Systems

M. Ben Khader Bouzid and Gérard Champenois, editors
Wiley-ISTE
John Wiley & Sons Inc.
111 River Street
Hoboken, NJ
www.wiley.com
ISTE Ltd
27-37 St. George's Road
London, SW19 4EU, UK
www.iste.co.uk
ISBN: 978-1-394-23643-5 (e-book)
ISBN: 978-1-786-30931-0 (print)
224 pp., $132 (e-book), $165 (hardback), 2023

Wind energy is an important renewable energy resource that is easily converted into electrical energy and its use is rapidly growing. A wind energy conversion system is an important technology for generating clean renewable electrical energy. Fault detection in these systems is an important item to ensure their reliability and safety. Whereas carrying out regular hardware maintenance and inspections is important to achieve reliability, condition monitoring in wind systems is important for zero down time or minimal unexpected downtime. Present-day advanced control systems could incorporate system condition monitoring as an integral part of the wind energy conversion electronics and the associated firmware.

This book is an opportunity for readers to appreciate potential theoretical concepts and mathematical approaches to electrical and mechanical fault diagnosis.

Chapter 1 is an analytically oriented theoretical discussion on how to apply symmetrical-component-based techniques, to locate potential faults on windings and rectifier units. Use of a theoretical approach based on negative sequence voltage expressions is discussed. Chapter 2 is on control and diagnosis of faults in multiphase permanent magnet synchronous generators used for high power wind turbines on a theoretical basis, with an emphasis on model predictive control.

Chapter 3 is on gearbox fault monitoring using electrical signals in induction machines, with a discussion on motor current signature analysis based on an extended Park vector approach. Chapter 4 is on control of a wind turbine distributed generator for auxiliary services under grid faults. The contents in Chapter 4 discuss energy storage systems based on batteries and supercapacitors, with theoretical control strategies based on fuzzy logic control. Chapter 5 is on fault tolerant control of sensors and actuators in wind turbine systems, based on a fuzzy logic mainly.

All chapters present significant lists of research publications for interested researchers to get more detail. This book would be a good resource for researchers working on the theoretical aspects of diagnostics and control of wind turbine systems.

The value of this work could have been much improved by the addition of one or two chapters on hardware design aspects of wind turbine electronics, paying specific attention to electronic subsystems and their components, with a maintenance engineers' approach to practical hardware fault tracing and fixing.

Protection of Modern Power Systems

J. Ekanayake, V. Terzija, A. Tennekoon, and A. Rajapakse
John Wiley & Sons Inc.
Hoboken, NJ
https://www.wiley.com/en-us
ISBN: 978-1-118-81722-3 (e-book)
ISBN: 978-1-118-81723-0 (print)
228 pp., $88 (e-book), $110 (hardback), 2023

With our power networks growing rapidly with renewable energy sources and energy storage systems, protection of power systems has continued to become a very important subject among the electrical power engineering community. This book published in 2023 is authored by a team of academics and a practicing engineer with protection experience.

Chapter 1 of the book starts with a review of principles of protection and has a discussion on philosophy of protection relaying. Chapter 2 has a very detailed discussion on instrument transformers, linking relevant international standards. A comprehensive discussion on current transformers and voltage transformers with relevant calculations of instrument specifications are provided here, with specific attention to both steady state and transient conditions.

Chapter 3 is a very practically oriented review of principles of protection. It provides a protection engineer's view on protection subsets such as excess current protection, differential protection, distance protection, overload protection, and over-flux protection.

Chapter 4 is on protecting distributed generation systems such as small hydropower plants, biomass, geothermal, and so on. Fault current contribution for synchronous generators and induction generators (directly connected or power converter connected) is discussed in the first part, and the second part has a discussion on protection of distributed generators. The effect of distributed generation on the distribution network is discussed in the latter part of the chapter. A good overview on protection of wind farms is provided in Chapter 5, with special attention to lightning surge protection and so on.

Chapter 6 is on the protection of PV plants, with a review of solar array fundamentals. Chapter 7 is on theoretical concepts related to signal acquisition and digital processing as applied to protection systems. Chapter 8 is on the subject of numerical relays where microprocessor techniques are used to convert the voltage and current transformer information into digital data useful in protection systems.

Chapter 9 is on substation automation and the relevant European standard IEC-61850. This chapter is quite self-contained and comprehensive in its content as applied to practical circumstances. Chapter 10 is on wide-area monitoring, protection, and control fundamentals with a good discussion on synchronized measurement technology. This final chapter comes with some case study summaries from UK and elsewhere.

As a general comment, this book offers a comprehensive exploration of both classical and modern protection techniques, catering to a diverse audience with varying levels of expertise. For undergraduate students particularly, it comes with worked examples to facilitate comprehension of key concepts and with a companion website, providing access to chapter-end problem solutions, aiding instructors in their teaching. For postgraduate students this work provides dedicated chapters that delve into advanced topics within specific areas such as advanced protection, digital protection, modern power systems, and a discussion on renewable energy system protection.

From a practitioner's view, it provides a solid foundation for newcomers entering the field of protection. It is well suited for practitioners who are involved in designing renewable energy projects, implementing digital protection systems, and using phasor measurement units.

Meetings Calendar

Frank Hegeler

Please submit calendar information to Frank Hegeler, Naval Research Laboratory, Code 6752, 4555 Overlook Ave., SW, Washington, DC 20375. Tel: (202) 404-4440, Fax: (202) 767-3553, Cell: (703) 994-0825, email: frank.hegeler@nrl.navy.mil or frankhegeler@yahoo.com

DEIS Meetings Committee

Frank Hegeler, Jerome Castellon, Nancy Frost, George Laity, Pietro Romano, and Feipeng Wang

DEIS Fully Sponsored Conferences

DEIS sponsors a series of international conferences to provide a forum for members and nonmembers to participate and share research results, new developments, and practical experience in the dielectrics and electrical insulation fields. Some conferences are held annually, whereas others are every other year or even every three years. The following is a listing of these events with a description, frequency, and next venue. Be sure to mark your calendars for the events of interest to you and look for announcements from the organizing committees. **Please be careful when searching the internet for DEIS conferences.** There are fraudulent websites advertising predatory conferences with very similar names. The sole purpose of these predatory conferences is to collect paper or registration fees. The correct web address for each DEIS conference will be shown on our DEIS website: https://www.ieeedeis.org as soon as it becomes available.

CEIDP (Conference on Electrical Insulation and Dielectric Phenomena)

This is an annual research-oriented conference usually based in the Americas, providing an international forum for the discussion of current research on electrical insulation, dielectric phenomena, and related topics. Some of the topics of interest include biodielectrics, aging, high frequency dielectric phenomena, surface flashover and treeing, outdoor insulation, and polarization phenomena. In 2020 CEIDP was 100 years old. Due to the COVID pandemic, one full day of celebrations, including a special Centennial Session and a visit in New York City where the conference began in 1920, will be organized in October 2023.

October 6–9, 2024
Auburn, AL, USA
Conference Chair: Thomas Andritsch, University of Southampton, Southampton, UK
Email: T.Andritsch@soton.ac.uk
Website: https://ceidp.org/

September 14–17, 2025
Manchester, UK
Conference Chair: Thomas Andritsch, University of Southampton, Southampton, UK
Email: T.Andritsch@soton.ac.uk
Website: https://ceidp.org/

EIC (Electrical Insulation Conference)

This is an annual applied conference and exhibition on liquid, solid, and gaseous materials based in the Americas. The papers present practical applications of electrical insulating systems and materials and diagnostics, for all types of electrical and electronic equipment. Some topics of interest have included rotating machines, variable-speed drives, transformers, cables, outdoor insulation (including live line work), aerospace, switchgear (including arresters), and capacitors.

June 2–6, 2024
Minneapolis, MN, USA
Conference Chair: Alan Sbravati, Hitachi Energy
Email: alan.sbravati@hitachienergy.com
Websites: https://ieee-eic.org/

ICD (International Conference on Dielectrics)

This is mainly a research-oriented conference with a broader scope in recognition of the fact that many breakthroughs in science occur at the interface among different areas and that the solid, liquid, and gaseous dielectrics communities will benefit from more interaction. ICD is

2024 Conferences

Conference	Date	Location	Website and contact
IPMHVC	May 28–June 1, 2024	Indianapolis, IN, USA	algarner@purdue.edu http://www.ipmhvc.com/
EIC	June 2–6, 2024	Minneapolis, MN, USA	alan.sbravati@hitachienergy.com https://ieee-eic.org/
ICD	June 30–July 4, 2024	Toulouse, France	gilbert.teyssedre@laplace.univ-tlse.fr https://ieee-icd.org/
ICPADM	August 4–7, 2024	Phuket, Thailand	norasage.pa@kmitl.ac.th https://icpadm2024.kmitl.ac.th/
ICHVE	August 18–23, 2024	Berlin, Germany	plath@ht.tu-berlin.de https://ichve2024.org/
CEIDP	October 6–9, 2024	Auburn, AL, USA	T.Andritsch@soton.ac.uk https://ceidp.org/

based in Europe every two years. Topics of interest include conduction, polarization, and breakdown; space charge and related effects; aging, degradation, and failure; materials and insulation systems; multi-functional materials; diagnostics and experiments; treeing; new materials for active and passive components; nanodielectrics; electro-active polymers and their application; microelectronics and photonics; eco-friendly dielectrics and recycling; biodielectrics; and electrohydrodynamics.

June 30–July 4, 2024
Toulouse, France
Conference Chair: Gilbert Teyssedre, LAPLACE, Paul Sabatier University Toulouse
Email: gilbert.teyssedre@laplace.univ-tlse.fr
Website: https://ieee-icd.org/

ICDL (International Conference on Dielectric Liquids)

This is a research-oriented conference on dielectric liquids, based in Europe, every two years. Examples of relevant topics are basic properties (ionization, conductivity, interfacial effects, space charge); modeling and theory; prebreakdown and breakdown phenomena; biophysics and related phenomena (aqueous liquids); radiation-induced processes, detectors, and application; measuring techniques (material characterization, diagnostics); materials (insulation, molten polymers, water, liquid crystals, new liquids, emulsions, etc.); electro-hydrodynamics (charge-induced flow, electrocoalescence, electrorheology); and applications (electrical insulation, static electrification, EHD pumps).

May 18–22, 2025
Lodz, Poland
Conference Chair: Pawel Rozga
Email: pawel.rozga@p.lodz.pl

IPMHVC (International Power Modulator and High Voltage Conference)

Based in the Americas every two years, this is an applied and research-oriented conference on repetitive pulsed power; power modulation; and high voltage theory, components, diagnostics, and subsystems. Some specific topics include power conditioning and pulse shaping, high energy systems, energy storage devices and components, rotating machines and energy converters, high voltage testing and diagnostics, high-rep-rate systems and thermal management, high voltage design and analysis, high power microwaves, radiating structures, electromagnetic propagation, prime power, and power systems.

May 28–June 1, 2024
JW Marriott Indianapolis, IN, USA
Conference Chair: Allen Garner, Purdue University
Email: algarner@purdue.edu
Website: http://www.ipmhvc.com

ICHVE (International Conference on High Voltage Engineering and Applications)

This event is held every two years, alternating between China and elsewhere in the world. The current demands for a large amount of electrical energy are resulting in new strategies for developing high voltage power systems, transmission lines, substations, and appropriate equipment. In many countries, the new energy strategies require the planning and construction of UHV AC and DC transmission systems. ICHVE provides an excellent opportunity for high voltage engineering scientists, researchers, faculty, industrial representatives, and students to share their state-of-the-art research on topics such as electromagnetic fields; grounding systems; high voltage insulation systems; aging, space charge, and industrial applications; and high voltage measurement techniques and instrumentation.

August 18–23, 2024
Berlin, Germany
Conference Chair: Ronald Plath, TU Berlin, Germany
Email: plath@ht.tu-berlin.de
Website: https://ichve2024.org/

ICPADM (International Conference on the Properties and Applications of Dielectric Materials)

ICPADM is a conference combining research and application practice in dielectrics covering the general areas of electrical insulation in power equipment and cables, outdoor insulators and bushings, monitoring and diagnosis of insulation degradation, insulation for HVDC systems, aging and life expectancy of insulation, dielectric phenomena and applications, partial discharges, electrical and water treeing and surface tracking, electrical conduction and breakdown in dielectrics, surface and interfacial phenomena, nano-technology and nanodielectrics, space charge and its effects, new and functional dielectrics, dielectric materials for electronics and photonics, eco-friendly dielectrics, bio-dielectrics, dielectrics for superconducting applications, and new diagnostic applications.

August 4–7, 2024
Duangjitt Resort and Spa, Phuket, Thailand
Conference Chair: Norasage Pattanadech, King Mongkut's Institute of Technology Ladkrabang, Thailand
Email: norasage.pa@kmitl.ac.th
Website: https://icpadm2024.kmitl.ac.th/

DEIS Technical Co-Sponsored Conferences

IYCE 2024 (9th International Youth Conference on Energy)

July 2–6, 2024
Colmar, France
Conference Chair: László Székely
Email: szekely@iyce-conf.org
Website: https://www.iyce-conf.org/

CMD (10th International Conference on Condition Monitoring and Diagnosis)

October 20–25, 2024
Gangneung, Gangwon-do, South Korea
Conference Chair: June-Ho Lee
Website: https://www.cmd2024.org

ISH (24th International Symposium on High Voltage Engineering)

August 24–29, 2025
Karuizawa, Japan
Conference Chair: Akiko Kumada
Email: kumada@hvg.t.u-tokyo.ac.jp.

ISDEIV (2025 International Symposium on Discharges and Electrical Insulation in Vacuum)

September 21–26, 2025
Sichuan University, Chengdu, China

Bulletin Board

Registration for the conference is open via the website www.ieee-eic.org.

The 42nd Electrical Insulation Conference (EIC) will take place from June 2 to 5, 2024, in the beautiful city of Minneapolis, Minnesota. Famous for the severe winters, the region offers gorgeous springs and summers. Expect pleasant temperatures, beautiful landscapes, and lots of things to do in the Mall of America, as our venue hotel is attached to it.

The conference will feature three outstanding short courses taught be industry experts. They will be held Sunday afternoon, June 2.

1. *Generator Winding Failure, Case Studies, and Repair Methods*
   Instructor: Joël Pedneault-Desroches
2. *Machine Learning Algorithms in the Power Industry*
   Instructor: Luiz Cheim
3. *The Integration of Liquid Insulation Diagnostics and Field Condition Assessment of Power Transformers*
   Instructors: Dr. Diego Robalino, Nick Perjanik

EIC is the world's premier applied electrical insulation conference. Over 25 different countries gather in this venue to validate the truly international nature of the conference and its participants. Thanks to the outstanding number of abstracts received, we expect over 300 attendees.

The conference program features relevant keynote speakers, technical and poster sessions, and more. NEMA will lead a discussion panel on the electrification of transportation. The conference program is combined with an In-dustry Expo, where selected manufacturers will have a dedicated space to actively interact with the attendees. For this and additional sponsorship opportunities, please contact Exhibitors Chair Dr. Diego Robalino (diego_robalino@ieee.org).

For more information, visit our website at www.ieee-eic.org or our LinkedIn Group page: https://www.linkedin.com/groups/12289607/.

The schedule of activities follows.

IEEE EIC 2024

Electrical Insulation Conference

Minneapolis, MN, United States
Radisson Blu Hotel / Mall of America
June 2 – 6, 2024

	Sunday June 2	Monday June 3	Tuesday June 4	Wednesday June 5	Thursday June 6
8:00 AM to 9:00 AM		Keynote Speaker	Keynote Speaker	NEMA Panel Session: Impacts of Transportation Electrification on the Electrical Grid	Materials Subcommittee Technical Meeting (Invitation Only)
9:00 AM to 9:30 AM	Open Workshop: Electrification of Transportation	Sponsored Technical Speak / Case Studies	Sponsored Technical Speak / Case Studies		
9:30 AM to 10:00 AM		Coffee Break Industry Expo	Coffee Break Industry Expo	Coffee Break	
10:00 AM to 12:00 PM		Technical Sessions Oral Presentations	Industry Expo + Poster Session	Technical Sessions Oral Presentations	
12:00 PM to 1:30 PM	Lunch Break	Lunch Break	Closing of Industry Expo Lunch Break	Best Articles Awards & Conference Closing (30 min)	
1:30 PM to 3:30 PM	Short courses: (parallel sessions) 1 – Generator Winding Failures 2 – Machine Learning Applications 3 – Condition Assessment	Technical Sessions Oral Presentations	Technical Sessions & Outdoor Insulation Workshop	Admin Session (BoG) Board of Governors IEEE DEIS (Invitation Only)	
3:30 PM to 4:00 PM		Coffee Break Industry Expo	Coffee Break		
4:00 PM to 5:30 PM		Technical Sessions Oral Presentations	Technical Sessions Oral Presentations		
6:00 PM to 7:00 PM	Conference Opening Keynote Speaker (TBD)		Open Bar		
7:00 PM to 10:00 PM	Reception + Industry Expo Posters Technical Session		Banquet		

IEEE International Conference on Dielectrics
University Toulouse III – Paul Sabatier
June 30th - July 4th 2024, Toulouse, France

5th IEEE-ICD in Toulouse: Call for Participation

Conference Dates: June 30 – July 04, 2024

Location: Paul Sabatier University, 118 route de Narbonne, 31062 Toulouse, France

Update information at: https://ieee-icd.org/

E-mail: icd2024@laplace.univ-tlse.fr

The 5th edition of ICD, fully sponsored by IEEE Dielectrics and Electrical Insulation Society, will take place in Toulouse, France, from Sunday 30th June 2024 until Thursday 4th July 2024, just 20 years after the 2004 ICSD Edition. Nicknamed 'The Pink City', due to the colour of the predominant bricks, Toulouse has a marked southern European feel and charm. Toulouse is a major European City in the field of Aeronautics and Space, with Airbus headquarters. It can be easily reached with 26 airline companies and 69 international destinations in 2023.

We warmly welcome you in Toulouse to participate to the 5th ICD.

Program highlight

Sunday 30/06/24	Monday 1/07/24	Tuesday 02/07/24	Wednesday 03/07/24	Thursday 04/07/24	Friday 05/07/24
	Opening **E Foster ML**	Special session	Oral session	Oral session	**Tutorial PEA**
	Break	Break	Break	Break	
	Oral session	Oral session	Poster session **YR Contest**	Poster sessions	
	Buffet	Buffet	Lunch Box	Buffet	
Workshops *DEIS Adcom*	Oral session	Oral session	Excursion	Oral session	
	Break	Break		Closing sess.	
Welcome Cocktail	Poster sessions	Poster sessions		*ICD Board*	
		Gala dinner			

The Eric O. Forster Memorial Lecture

Eric Forster was one of the founding fathers for this conference series. The Eric O. Forster Memorial Lecture is a prestigious lecture given at the opening of the conference. For the 2024 Edition, Dr Christian Franck from ETH Zürich, Switzerland will be awarded.

Special session on Insulations in Aeronautic Environment

An invited lecture with Dr Jean Rivenc from Airbus will be given. The plenary lecture will be followed by Oral presentations relevant to this topic.

Young Researchers Awards

A Young Researchers Contest is organized to encourage the participation of students and young researchers in the conference. Proven full-time engineering and science researchers and PhD students from academia as well as industry are encouraged to participate.

Workshops

Two workshops will be organized on Sunday 30 June, ahead of the Conference. The proposed topics are:

-AFM characterization of nanodielectrics

-Eco-friendly materials in electrical insulation

A Tutorial on Assembly of space charge equipment for Cable is proposed as side event to the conference (Friday 05/07).

Registration to ICD

Registration to ICD should be done using Conftool at: https://www.conftool.pro/icd2024/ Every registration opens to the participation to all the conference activities and includes lunches from Monday 1st to Thursday 4th, welcome cocktail, conference diner and excursion scheduled on Wednesday afternoon. The early bird registration fares are accessible up to June, 1st, 2024.

Profile	Early bird registration (€)	Late registration (€)
IEEE DEIS Member	480	530
IEEE Member	500	550
Non-Members	580	630
Student - IEEE Member	380	430
Student - Non-Member	430	480
IEEE Life Member	380	430
Workshop registration	80	80
Companion persons	150	150
Extra-paper fees	150	150
Extra-page	100	100

Get Your Work Published in *IEEE Electrical Insulation Magazine*

The *IEEE Electrical Insulation Magazine* is always looking for new and exciting articles. The magazine's subscribers have a wide range of interests and experience. If you have a topic for an article that you think has a broad appeal, please send us an abstract.

To reiterate the information found on the inside cover,

- Articles are oriented to engineers and technologists;
- The content should have to do with the use and application of electrical insulating materials and systems;
- Articles should be appealing and understandable to a wide audience, not just specialists on the article topic; and
- Articles should be tutorial or review in nature and not a conference-paper style.

Please share your knowledge to help the whole industry.

If you have any questions, please feel free to contact Mark Winkeler (mark.winkeler@altana.com).

A PUBLICATION OF THE IEEE DIELECTRICS AND ELECTRICAL INSULATION SOCIETY

IEEE TRANSACTIONS ON DIELECTRICS AND ELECTRICAL INSULATION

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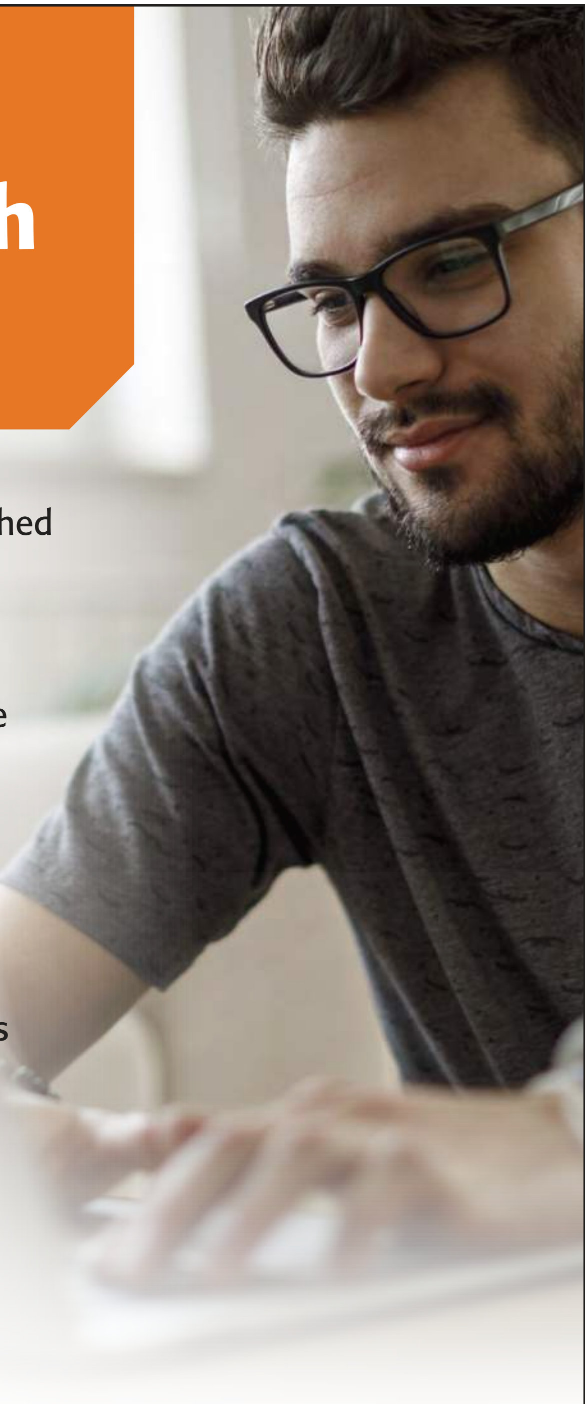
PART A: FUNDAMENTALS

PART B: APPLICATIONS

CALLS FOR PAPERS



Author's Guide for *IEEE Electrical Insulation Magazine* Technical Articles

Authors are required to submit an abstract to the Editor-in-Chief to ensure relevance of a paper topic before submission of a full paper. Together with the abstract, the authors shall include a cover letter that describes why their proposed paper is of interest to the general DEIS membership (200 words), why their proposed paper is timely and important (100 words) and how they would characterize their paper, i.e. as a review or tutorial.

All technical articles received by the Editor-in-Chief are reviewed for content. Peer review is vital to the quality of published content. Per IEEE policy, your submitted article will first be evaluated by the EIM Editorial Board and then by at least two independent reviewers who are experts in your article's subject matter. Peer review ensures the integrity of science by excluding invalid or low-quality research. Reviewer feedback will contribute to the editor's decision on whether to accept or reject your article for publication.

During the peer-review process, editors and reviewers are looking for the following:

Scope: Is the article appropriate for this publication?

Novelty: Is this original material distinct from previous publications?

Validity: Is the study well designed and executed?

Data: Are the data reported, analyzed, and interpreted correctly?

Clarity: Are the ideas expressed clearly, concisely, and logically?

Compliance: Are all ethical and journal requirements met?

Advancement: Is this a significant contribution to the field?

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Text

- If English is not your native language, consider using an English language editing service before submitting your article for review.
- The use of an editing service is paid for by the author and does not guarantee acceptance in an IEEE publication.
- An article should be a maximum of 8 pages including illustrations.
- The text should be one column with minimal formatting
- (titles, subtitles, captions).
- Microsoft Word is recommended.
- Electronic submission is preferred. Send a separate email to the editor in advance.
- Include a 30- to 35-word summary.
- Include a biography (maximum of 75 words) and picture for each author.

Figures

- Include figures in the text and as separate files (preferably in original format).
- Graphic files should be self-contained, without links to other files.
- Name graphic files with the author's last name and the figure number.
- Digital photos should
  - have a minimum of 300 dpi at final use size,
  - be a minimum of 1,000 pixels in width, and
  - be submitted as PDF, TIFF, JPEG, EPS, or PNG files.
- If your article contains screenshots, send the original digital image.
- Do not send figures with logos or other elements you do not have permission to have published.

References

Use the IEEE style to cite references. References should be listed in order of citation in the text. Examples are given below.

Article in a periodical

[1] I. Thompson, "Women and feminism in technical communication," J. Bus. Tech. Commun., vol. 13, no. 2, pp. 154–178, 1999. doi: 10.1177/1050651999013002002.

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