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IEEE Electrical Insulation Magazine

A Publication of the Dielectrics & Electrical Insulation Society

In this issue

- Look into laboratory to real-life tests of a polymeric insulator instrumented with sensors for monitoring high voltage transmission lines
- Read about insulation research regarding short-pulse conditions at Northwest Institute of Nuclear Technology in China
- Learn about visualization of corrosion hidden under opaque anticorrosion coatings using radio waves
- Find out about Hulya Kirkici's career journey, life experiences, and involvement with DEIS

DEIS

IEEE

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:
Feipeng Wang, Editor in Chief
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FEATURED ARTICLES

Cover: DEIS Summer School class of 2022, Monmouth, Wales, UK.

DEPARTMENTS

IEEE Electrical Insulation Magazine

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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

Antonios Tzimas

Editor Emeritus

Serving as the editor in chief of this magazine the past year has indeed been a rewarding experience. I received over 30 manuscripts from over 100 authors across the globe discussing electrical insulation challenges. It has been a pleasure working with the editorial board to enhance the magazine with the introduction of a new column "Stories from China"; a new article series on "A day in the life of a ______ laboratory"; and a feature concerning "Transportation Electrification," where articles continue to be invited! Furthermore, this year a new article series has started that introduces our members and focuses on their careers and the role of DEIS. Our readers can also benefit from being able to read the magazine in a flipbook digital format in addition to the hardcopy.

During the last year the magazine's team has grown: two new members joined the editorial board and there is a new contributing editor. This year there will be further changes, with another two new members joining: Mark Winkeler from Elantas, USA, and Tony Lujia Chen from the University of Manchester, UK. A new contributing editor is joining the magazine to take over from John J. Shea of Schneider Electric, our longest serving Book Reviews column editor, with over 1,000 book reviews since 1998. Our new Book Reviews column editor is Professor Nihal Kularatna of Waikato University, who shares his farewell thoughts of John, which, I believe, reflect many of our thoughts too:

"John's contributions to the DEIS magazine as the books editor for a quarter century has undoubtedly benefited many of us. His patience in reading books and communicating with publishers is quite a magical talent on his part. I have read many of his reviews and made my selection decisions on books, and his ability to filter the pros and cons of a book has helped the readership enormously. We all are very grateful for his dedicated time and the commitment to be the books editor for such a long period, despite his busy job in industry.

We wish him all the best."

Ivanka Atanasova-Hoehlein, from Siemens, who served the magazine with her expertise on transformer dielectric liquids, was a member of the editorial board for four years before deciding to step down. Ivanka has brought a spark to the board meetings that generated new ideas for invited article topics and editorials and facilitated many article reviews. Naturally, now it is also time for me to pass the torch to Dr. Feipeng Wang of Chongqing University, who will be the 2023 editor in chief of the magazine, and I wish him all success and many rewarding experiences. In the following, you can find the farewell notes from John J. Shea and Ivanka Atanasova-Hoehlein.

John J. Shea

Book Reviews Column Experience

It is hard for me to believe that I started as a contributing editor for the *IEEE Electrical Insulation Magazine* book reviews column 25 years ago! After these many great years being associated with the magazine, I have decided it is time to step down and let someone else take over the column. Professor Nihal Kularatna from the University at Waikato, located in New Zealand, will be taking over the book reviews column. Even though writing the column for each magazine issue has taken considerable time, it has been quite rewarding to be able to acquire and review so many technical books. Just being able to read through such a broad variety of books has given me wide exposure to so many different topics, always with a focus on current topics in electrical engineering, electrical materials, and dielectrics. Hopefully you have found a few books of interest over these many years! I highly recommend, especially to those just starting their engineering careers and having to learn about a new subject and even seasoned readers, to get a copy of the relevant books or articles of interest and just constantly read whatever you can get your hands on, magazines, papers, newspapers, and so on. It is the easiest way to quickly learn about the details of a new topic and stay current with evolving technologies. Reading is the way!

I am grateful for having worked with so many dedicated magazine editors and coordinators over these years. They have really put a lot of time and effort into making a high-quality magazine available to our DEIS members. Also, thanks are extended to the book publishers who provided so many books. Without their contributions, the book reviews column would not exist. I wish all the best to Prof. Kularatna for continued success of the book column and the *IEEE Electrical Insulation Magazine*.

Ivanka Atanasova-Hoehlein

Editorial Board Experience

My voluntary time for IEEE as an editorial board member was from September 2019 to 2022. I am very thankful to the great Stanislaw Gubanski, who contacted me and asked whether I would do it. Without knowing too much what it meant, I said yes. Joke aside, I never regretted it, because in this time I had the opportunity to get to know new colleagues like Peter Morshuis, Brian Stewart, Greg Stone, Alun Vaughan, Feipeng Wang, Antonios Tzimas, Simon Sutton, and, later, Hua Li and Gordon Wilson. It was very helpful for me to have a broader insight, being involved in the daily work in the industry of electrical equipment—how do academia, universities, and research institutes deal with the same topics as industry? I would have been happy to have some more time to help, because a big part of the burden is taken over by the editor in chief, who takes regular care that everything works well and by nonforgiving time deadlines. I would encourage future applicants to take over this voluntary work, which will enrich your experience not only professionally but also personally. My great thanks are extended to all editorial board members!

From the Editor

Feipeng Wang

Editor in Chief
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It was the days that China intended to be reopened to the world after the surge of COVID-19 infections all over the country by the policy shift on zero-COVID, which started the last month of 2022, which was believed to speed up the step to leave the disruptive health management in the past three years. It was also the moment when I took over the torch as the editor in chief of our magazine from Antonios Tzimas. The three-years-long chapter displays further evidence that there is no winner in the war between human being and virus, because of the virus's high diversity to generate many variants to escape the immune system. The fight against the virus has united forces from everybody. This was achieved by supporting scientists and engineers and all other fields via knowledge transfer. The same spirit supports our editorial board and DEIS community: we transfer know how from last to next and strengthen members. Therefore, I must highlight the great efforts of Antonios and Peter and previous editors of our magazine, which of course excite me to work as the editor in chief with soul. I hope it will be possible to achieve the level of *meraki*!

This issue is launched with an editorial contributed by Antonios that addresses the innovations during his time as editor in chief, which manifests the color of *meraki* exactly. In the coming 2023, our magazine will continue with new characters. The first Young Professionals (YP) Highlights is born with the story of a YP team in that SuperGrid Institute that was matured through designing and manufacturing a medium-voltage, medium-frequency transformer from specifications to a prototype. A photo details how team working is the way to success.

The News from Japan from Professor Ohki shares insight on "Development of Ultralow-Loss and Low-Crosstalk Four-Core Communication Fiber." There is also a Story from China from LV Zepeng with the title "3D Printing for Advanced Electrical Insulation: Recent Progress in China." Within the bulletin board are highlights from the Summer School in last August and two reports of our conferences, including ICHVE and CATCON.

This issue of the magazine starts with a featured article presenting an instrumented polymeric insulator with sensors to monitor high voltage transmission lines. The second article talks about the development of insulation research under short-pulse conditions in the Northwest Institute of Nuclear Technology in China. The third article visualizes the corrosion hidden under opaque anticorrosion coatings using terahertz and millimeter radio waves. The fourth article is a personal profile article on Professor Hulya Kirkici from the University of South Alabama.

The first article in this issue, titled "Technological Development of a Composite Insulator for High Voltage Transmission Line Monitoring," is authored by Tarso V. Ferreira, Gabriel S. Bolacell, Mauro A. da Rosa, Edson G. da Costa, George R. S. Lira, Jose F. Pissolato, Filipe L. M. Andrade, Regelii S. A. Ferreira, Estácio T. Wanderley Neto, and Roberto P. Francisco, a Brazilian team from various locations: Federal University of Sergipe (UFS), Federal University of Santa Catarina (UFSC), Federal University of Campina Grande (UFCG), Federal Institute of Paraíba (IFPB), University of Quebec at Chicoutimi (UQAC), Federal University of Itajubá, Federal University of Goiás (UFG), INESC P&D, and Unicamp. In this article, the authors developed a polymeric insulator embedded with optical sensors based on the Faraday effect. The electric current monitoring results on a 220-kV transmission line could be supportive for future application at the higher voltage level, e.g., 525-kV lines.

The second article, authored by Liang Zhao, Jian Cang Su, Rui Li, Bo Zeng, and Jie Cheng from the the Northwest Institution of Nuclear Technology in China is titled "Review on Recent Development in Insulation Research Under Short-Pulse Conditions." The authors describe in the article the developments in insulation research under short-pulse conditions in the institute. Readers may find the solid insulation under nanosecond pulses and the vacuum insulation under microsecond pulses besides the insulation structure design for prolonged lifetime.

The third article is titled "Nondestructive Terahertz and Millimeter Wave Imaging for Underfilm Corrosion" authored by a Japanese team of N. Fuse, Y. Hori, and T. Takahashi from the Central Research Institute of Electric Power Industry and M. Mizuno from the National Institute of Information and Communications Technology in Japan. The article displays a nondestructive imaging method using radio-frequency waves to see the corrosion under opaque anticorrosion coatings, based on the concept of impedance mismatch from the interfaces in corrosion, a method feasible for electrical engineers to master.

The fourth article is authored by Elizabeth Aragao and is part of a series that focuses on the profiles of our DEIS members. This fourth interview article is titled "Looking at the Bigger Picture with Hulya Kirkici." The author goes through Hulya Kirkici's early career journey and how it was colored by both physicists and electrical engineers. She was always motivated by the vision of advancing technology for humanity. She recognizes IEEE as a kind of drug that guided her into deep involvement with our society as the president of IEEE DEIS in 2009–2010. The author highlights Hulya Kirkici's fruit of dielectric breakdown and electrical insulation for space and aerospace power systems and her spirit of planting seeds with a bigger picture for the next generation.

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

Technological Development of a Composite Insulator for High Voltage Transmission Line Monitoring

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This work was developed in Project TECCON II with *Transmissoras Brasileiras de Energia* (TBE), under the framework of the Research and Development (R&D) Program regulated by *Agência Nacional de Energia Elétrica* (ANEEL), code PD-2651-0011/2015. This work was supported in part by the Brazilian National Council for Scientific and Technological Development (CNPq), partly by the Coordination for the Improvement of Higher Level Personnel (CAPES)–Finance Code 001 and partly by the Institute of Systems and Computer Engineering, Research and Development of Brazil (INESC P&D Brasil).

Key words: electric current measurement, instrumented insulator, transmission lines monitoring, transients

This article presents an instrumented polymeric insulator with sensors applied to monitor high voltage transmission lines. Practical developments are presented from the laboratory stage until the real transmission line tests.

Introduction

Reliable energy facilities are necessary for continuity of power delivery, requiring several complex systems working in compatible ways, and among those, insulation systems are indispensable. Electrical insulators are present in all electric power systems, whether in generation, transmission, or distribution, and have numerous shapes and connection mechanisms, depending on their application. There are 3 main classes of dielectrics that have been used for high voltage (HV) insulator construction: porcelain, glass, and polymer [1]. An insulator itself is a relatively low-priced equipment; however, in an insulator failure event, the consequences can be very severe, causing the line to be disconnected or even the conductor to fall, eventually interrupting the power supply for several hours.

When considering power line monitoring, insulators, which have massive presence in electrical systems, present themselves as a quite advantageous equipment to add sensing functions, such as current or temperature in the conductor, for instance. The concept of an instrumented insulator with sensors is also welcome in the actual and emerging context of smart grids and the digitization of power systems.

Taking as an example the transmission line operation, in most cases the available information is obtained from measured quantities at the substations. However, decisions made during the operation of such systems could have better results if professionals had access to information obtained along the line and in real time [2]–[7]. The determination of a conductor's ampacity depends on several of its physical properties and meteorological conditions. Normally, it is assumed that the conductor is always in thermal equilibrium (steady state), and the ampacity is determined considering the worst meteorological scenario. However, if real-time information about the conductor and line surrounding condition in critical spans is available, dynamic line rating (DLR) is possible [8], [9].

Considering all the opportune advantages that come together with the idea of an insulator capable of monitoring, this work presents the results of the project "Technology in Optical Fiber Sensors for Supervision, Protection, and Control of Electrical Energy Systems II (TECCON II)," which establishes itself as an effective and feasible alternative.

The TECCON II Project

The TECCON II project has been proposed with the challenge of improving the technology readiness level (TRL) of

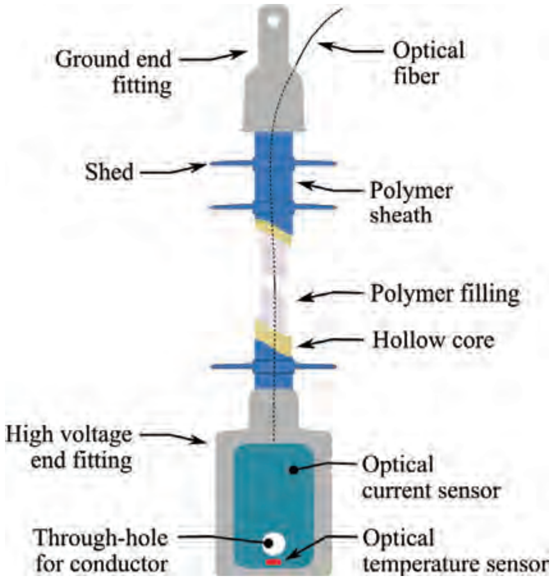


Figure 1. Structure and main components of the instrumented polymeric insulator.

monitoring subsystems from rating 4 to 7 [10]. The TRL can be interpreted as an approach of qualitative assessment that can be used to make clear technological progress of a specific prototype. To accomplish that, a real-time monitoring system, robust enough, has been developed to be installed in a HV transmission line of the South Subsystem of the Brazilian Interconnected System, demonstrating the system prototype operation in a real environment (TRL 7).

During the five years of development (2015–2020), several challenges have needed to be overcome to build a real-time transmission line monitoring system, such as processing optical/analogic signals from sensor arrangements, ensuring a continuous and reliable energy supply, and establishing a robust communication system to send the local information to the substation where the line operator has the front-end information. These subsystems should be installed remotely on a specific span of the transmission line, usually, critical spans, and the location of the components on the tower must be chosen precisely to avoid electromagnetic interference and vandalism.

The monitoring system, named TECCON MS, is based on a polymeric insulator that serves as an interface between optical fiber sensors and the transmission line. TECCON MS provides information about the electrical current, mechanical tension, conductor temperature, and weather variables (wind direction and speed, pressure, humidity, precipitation, dew point, and ambient temperature). Using the data obtained, it is possible to implement the DLR concept, to enhance the capacity of existing transmission lines, and a fault locator method based on three points of measurement. Figure 1 presents the structure of the instrumented polymeric insulator, showing how the optical sensors are embedded in the insulator.

The measuring principle of the electrical current is based on the Faraday effect, where a piece of crystal is used as a transductor, and it is positioned close of the electrical conductor. The electrical current is measured by considering the rotation of the light polarization plane, which is proportional to magnetic field intensity [11]. The measurements of mechanical tension and conductor temperature are based on the Fiber Bragg Grating technology [12].

There is an opto-electronic signals processing unit (OESPU) that integrates, in a printed circuit board, all the parts necessary to receive, process, and send the information. The digital module packs all the information into ethernet frames and sends to an ethernet-to-fiber media converter, which sends the data to the substation with real-time condition monitoring (RTCM) via an optical ground wire (OPGW) link. The OESPU, developed specifically for TECCON II project, acquires the information from the optical sensors and provides power supply for the optical source in adequate voltage level.

The energy supplying system is composed of solar panels and a battery sized to supply all the load on the transmission line tower. The system has been dimensioned for an autonomy of 4 days, appearing as a reliable energy supply for the TECCON MS operation. It is supplied the load of the OESPU, optical sensors, optical source, media converter, and weather station.

The TECCON MS entire solution can be split into 5 subsystems: (1) HV insulator; (2) sensors unit; (3) OESPU; (4) energy supplying; and (5) RTCM unit. This article is focused on showing principal results related to the HV instrumented insulator unit, presenting the main developments required to elevate the TECCON MS from TRL 4 to TRL 7. In fact, the tests in a laboratory and relevant environment must be performed to ensure that the instrumented insulator design has been adequate and the prototype operates following the specific requirements. After those stages, the system has conditions to operate in the real outdoor environment (HV transmission line).

The remainder of this article is organized as follows. Electrical, Mechanical, and Material Tests presents the main electrical, mechanical, and material tests with the polymeric insulator (TRL 4, component validation in a laboratory environment). Results in a Relevant Environment outlines the main achievements in relevant environment (TRL 5, component validation in a relevant environment; and TRL 6, system prototype demonstration in a relevant environment). Results in a HV Transmission Line presents the main outcomes in a HV transmission line of the Brazilian Interconnected System (TRL 7, system prototype demonstration in an operational environment). Finally, Conclusions and Future Applications highlights final remarks and future applications.

Electrical, Mechanical, and Material Tests

During the step characterized as TRL 4, the polymeric insulator, a constituent part of TECCON MS, underwent several laboratory tests.

In the following sections, procedures adopted and results obtained during some of the mechanical, material, and electrical tests are briefly presented [13].

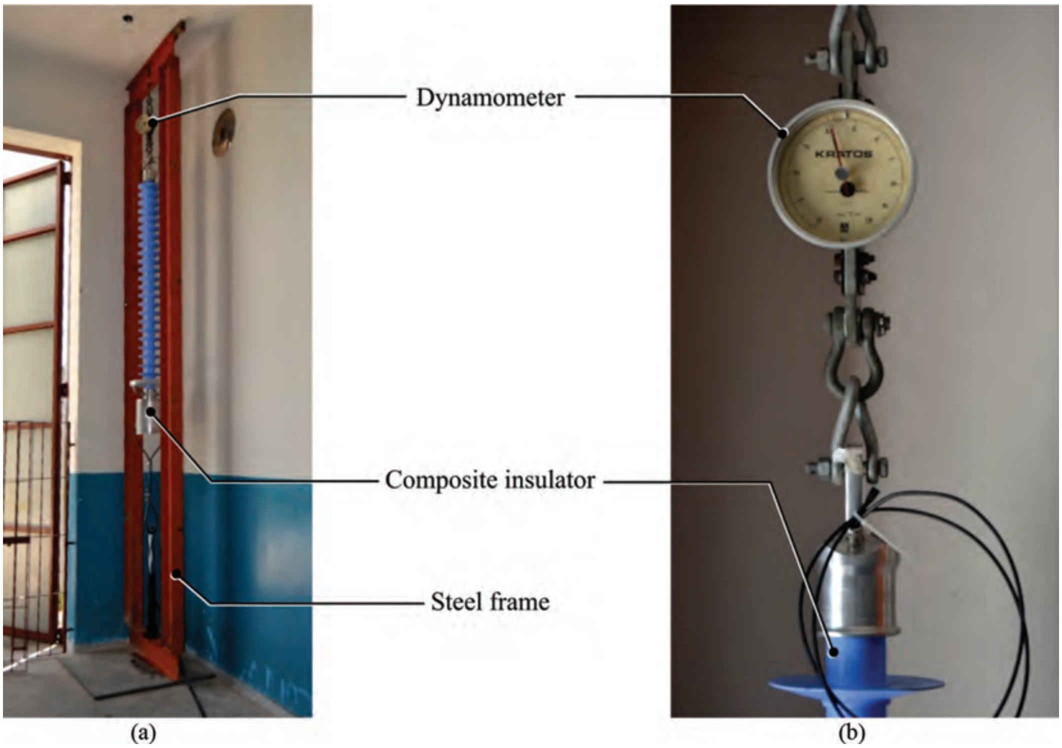


Figure 2. Mechanical tests: (a) main setup; (b) dynamometer marking during first part of load-time test.

Mechanical Load-Time Test and Interface Verification Between Hardware and Coating

The mechanical tests performed on the TECCON MS insulator followed the recommendations in [14]. The load-time test and interface verification between hardware and coating are intended to verify the mechanical supportability of the core to long periods of high tensile strength, as well as the adhesion of the coating to the core. It is a test divided into two stages. In the first stage, the insulator was subjected to an applied tensile load of 70% of its specified mechanical load (SML = 5 kN). This traction was maintained for 96 h. In Figure 2(a) the test arrangement with the insulator tensioned with a mechanical load of 3.5 kN is presented. In Figure 2(b) the dynamometer showing the mechanical load during the test is shown in detail. The dynamometer indicates 4.1 kN due to the initial force (weight) of the array, 0.6 kN. Next, an inspection is carried out to search for cracks in the polymeric coating using dye. No cracks were found.

In the second stage, the insulator was submitted to 100% of the SML for 90 s, and the core must not be broken for approval. The insulator passed in the test.

Adhesion Tests

The adhesion verification test analyzes the quality of adhesion between an insulator's core and polymer housing, i.e., que bonding layer quality.

According to [14], with appropriate equipment, a longitudinal cut must be made in the interface between the insulator's housing and core. The housing must be manually tensioned, aiming to dislodge it from the core and hardware, performing a visual check to observe the existence of coating adhesion at the interfaces (hardware–housing and core–housing).

It was not possible to move the housing of the core or hardware manually without causing its destruction, as shown in Figure 3. Thus, the insulator passed the adhesion test.

Flammability Test

The flammability test was carried out in accordance with the requirements of [14]–[17]. Five samples were taken from the insulator sheds. The set of five test samples was conditioned for 48 h at 23°C and 50% relative humidity [17]. Once removed from the conditioning chamber, the samples were tested in a period of less than 30 minutes. During the test, the specimens are positioned vertically in relation to the flame, as shown in

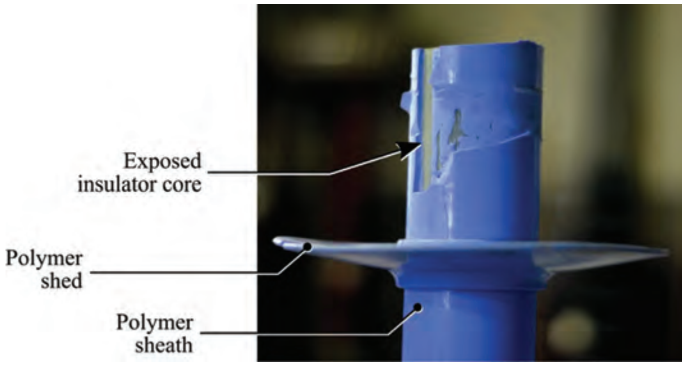


Figure 3. Photograph taken after the adhesion test.

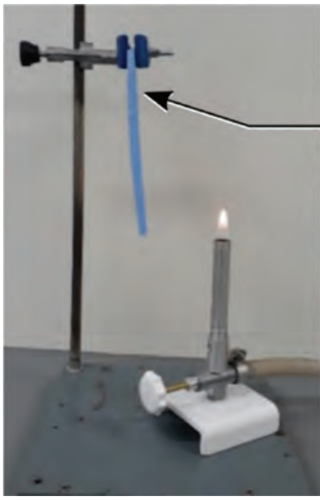


Figure 4. Photograph of the flammability test.

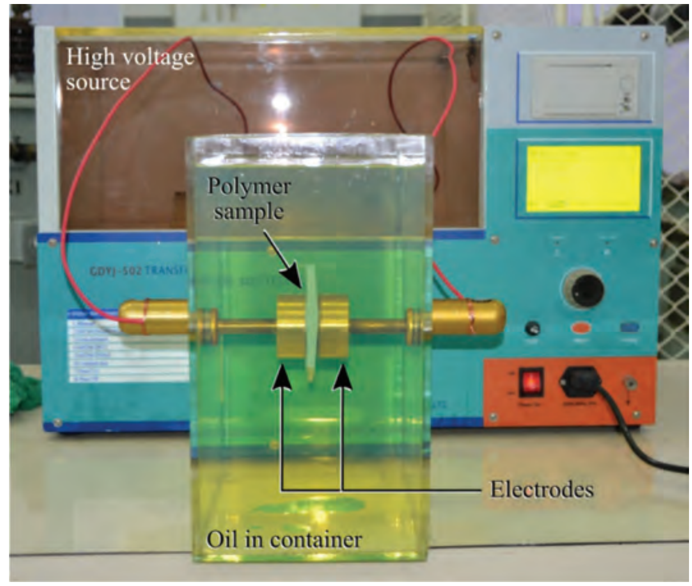


Figure 5. Photograph of the dielectric strength test.

Figure 4. At the bottom, a piece of cotton is placed, to assess its inflammation in case of dripping of melted plastic material.

Following the criteria determined by the standard, the tested material was classified as belonging to the "V0" category according to [16] and having been approved according to [15]. Flame propagation or dripping of melted material capable of causing combustion in the cotton was not observed.

Dielectric Strength Test

The dielectric strength test was performed according to [14], [15], and [18]. Six samples of silicone rubber extracted from the insulator sheds, with dimensions 60 × 60 mm and thicknesses varying between 4.9 mm and 4.6 mm, were used in the test.

The samples were conditioned for 24 hours in an environment with a temperature of 24°C and a relative humidity of 50%. After 24 hours, the samples were placed in a closed container, until the test was performed.

During the test, the samples were immersed in insulating oil in an acrylic vat, between electrodes, to which the voltage was applied, as shown in Figure 5. The voltage was increased at a rate of 3 kV/second, as per [18], so that the break occurs within 10 to 20 seconds. Sample thicknesses are measured exactly where the electrical breakdown has occurred, with the aid of a micrometer. According to [14], the samples must present values above 10 kV/mm. The samples showed dielectric strength between 10.5 and 12.1 kV/mm.

Tracking and Erosion Test

A set of five samples were taken from the insulator and then measured, abraded, and weighed as in [14] and [19]. For the test, a constant alternating voltage of 3.5 kV was applied to the samples, with a 22 kΩ resistor used to limit the current on the surface of the material in the event of an electrical breakdown. The samples were placed on a 45° inclined acrylic support and fixed using electrodes with the design specified in [14]. A conductive solution (ρ = 3.95 Ωm) was dropped onto filter paper filters located between the top electrode and the sample at a rate of 0.6 mL/minute. During the test, the current in each sample was measured.

Figure 6 shows photos of the tracking machine and the execution of the test.

During the test, the leakage current was monitored in each of the samples, to prevent the current from exceeding 60 mA for more than 2 seconds. All samples were approved at the end of the test, with no erosion or mass loss greater than that defined in [14], nor perforation.

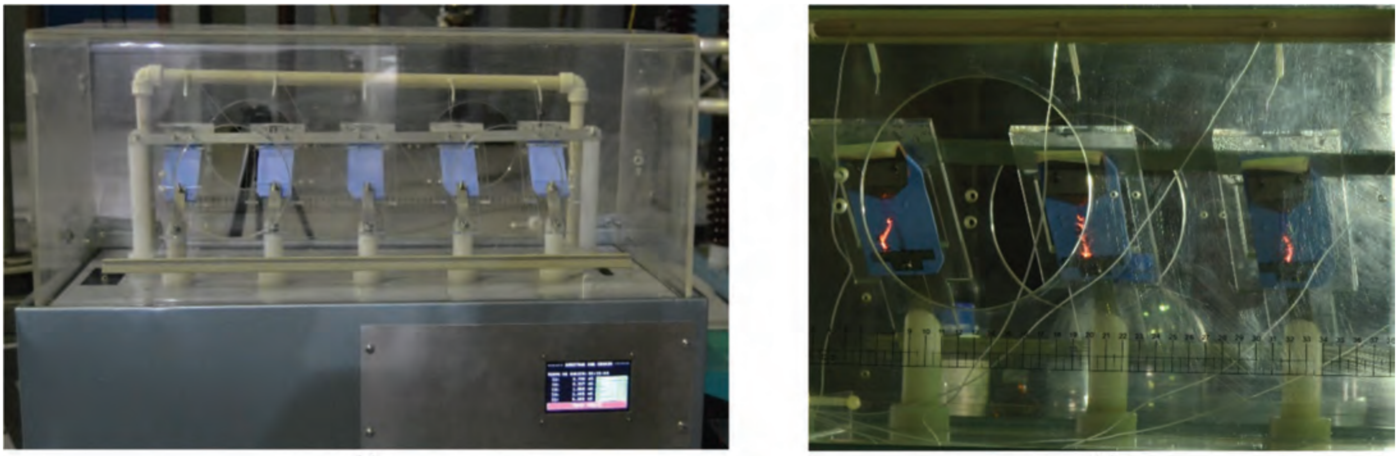
Results in a Relevant Environment

After the mechanical, material, and electrical tests in the laboratory environment and before the final implementation of the TECCON MS on the transmission line, there is a stage in which some tests with all components (units) need to be carried out in a HV laboratory (HVL), such as fast current transients and impulse voltage tests, ensuring the TRL 5 and 6 of the maturity scale.

To make those electric tests using the polymeric insulator feasible, some tasks have been realized in the HVL. The process has been composed of (a) passing the optical fiber cable through the core of the insulator, (b) insulators filling, and (c) continuity tests in the optical cables. In this section, the outcomes of the continuity test in the optical fiber cables inside the insulator, the leakage current measurement in the applied voltage tests, and the fast current transient tests will be addressed, respectively.

Optical Fibers Continuity Test

After the passing of the optical fiber cable through the insulator and the filling with silicone gel, selected fibers have been fused to test the continuity of the cable in terms of signal integrity. To verify whether the filling of the insulator has imposed



(a) (b)

Figure 6. Execution of tracking and erosion test: (a) main setup with five samples being tested in parallel; (b) occurrence of superficial discharges on the samples.

some difficulties to the light path, it has been applied an optical power equal to 17.1 dBm (originated by an amplified spontaneous emission light source) at one end, and in the other side of the fiber, the optical power has been measured with the aid of an optical power meter, configured at a wavelength of 1,550 nm.

The results obtained are shown in Table 1. The differences in the values are because not all fusions have been aligned with absolute accuracy. However, it is important to notice that the attenuations are inside the expected values, which comply with the required results to proceed with the electric current measurements using the optical sensors embedded in the insulator.

Insulator Leakage Current

The insulator has been submitted to the electrical supportability tests with the leakage current measurement. The tests have been realized according to the standard NBR 15643. The procedures are (a) nominal voltage application, 230 kV, during 15 minutes with leakage current measurement and (b) 1.1 pu voltage application during 1 minute. Table 2 shows the results of the tests.

Analyzing Table 2, one can note that the insulating capacity of the insulator with the optical fiber cable and silicone gel filling is elevated and has been not compromised the traditional role of the insulator.

Impulse Current Fast-Front Transients Test

The impulse current fast-front transients test guarantees the TRL 5 and 6 for TECCON MS technology, i.e., the component and prototype demonstration on a relevant environment, respectively. The goal is to ensure the normal (adequate) operation of the system in a HV relevant ambient and verify the accuracy of the optical measurement and its accessories (A/D conversion, signals filtering process, and so on) and eventual saturation occurrences. To measure electric current impulses (fast current transients), the following methodology has been proposed:

1) The insulator prototype, together with the optical sensors and the OESPU (a subsystem of TECCON MS), is suspended in the HVL at an adequate height for current impulses application (duration of roughly 500 microseconds) with distinct crest values.
2) The optical and electronic modules should be activated to operate, recording the existing signals.
3) The OESPU needs to be positioned at a safe distance from the electric conductor.
4) The electric current impulse should be applied, which must be registered by the TECCON MS.

To make feasible the tests and the migration in the technological maturity scale level, a methodology to measure the fast current transients (transitory event) has been proposed. In addition, the positioning and encapsulating of all parts of the TECCON MS have been assessed, bearing in mind the final configuration of the monitoring system in the tower of the real transmission line. The TECCON MS has been tested in a HVL, located at Unicamp, Campinas, Brazil, to reproduce the test proposed, as shown in Figure 7.

In the impulse electric current tests, the magnitudes of impulse current applied and the sensor signal amplitude results are presented. The aim is to simulate fast current transients that can occur in an operating environment and analyze whether the electric current optical sensor is able to measure and interpret

Table 1. Measured optical power in the fused fibers

Fiber	9	10	11	12	13	14	15
Power (dBm)	17.0	15.0	16.9	16.9	16.4	16.6	16.9

Table 2. Applied voltage tests

Nominal voltage (15 minutes)	Voltage: line to ground (kV)	Leakage current (μA)
	132.9	54.39
Overvoltage supportability (1 minute at 147 kV)	Attended	

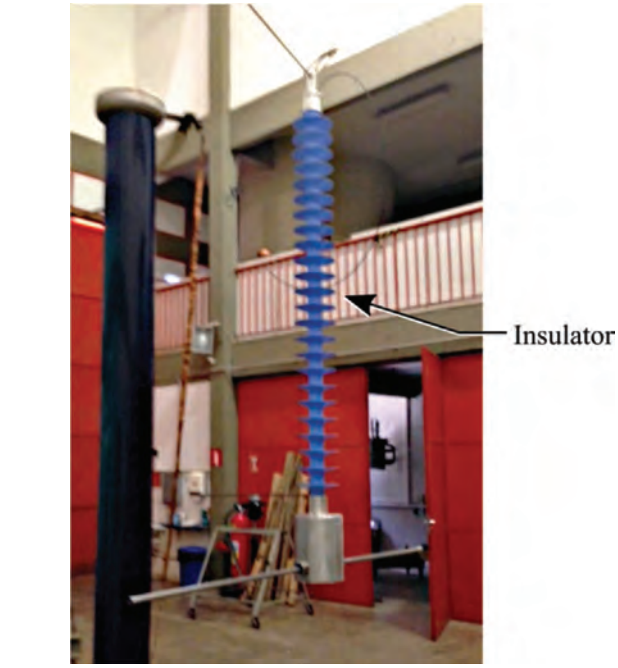


Figure 7. Instrumented insulator in a high voltage laboratory.

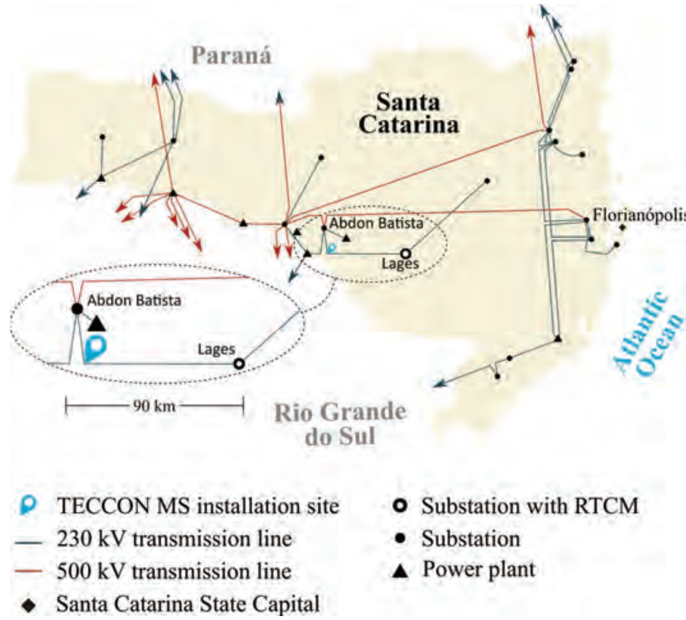


Figure 8. Lages–Abdon Batista transmission line region. RTCM = real-time condition monitoring.

such transitory conditions. Distinct voltage levels are used to charge the capacitor bank devoted to producing the electric current impulse. Table 3 presents the crest value of the impulse electric current, in kiloamperes (kA), for the eight tests performed. The results have shown that the sensor was able to identify and measure fast current transients (high current impulse measurements) in all tests, presenting signals of saturation next to 18.6 kA. The results related to the tests developed in the HVL with the TECCON MS technology elevate the system's TRL to rating 6.

Results in a HV Transmission Line

The instrumented polymeric insulator has been installed in one phase of the electrical circuit 2 (C2) of Lages–Abdon Batista 230 kV transmission line, which is part of the Brazilian Interconnected System (South Subsystem). Figure 8 shows the electro-geographic map of Santa Catarina state, Brazil, highlighting the installation local of the TECCON MS and the right of way of the transmission line itself.

The insulator has been placed first on the auxiliary insulator string (jumper insulator) at an anchorage tower, as shown in Figure 9, where some elements of the TECCON MS in the tower have been highlighted, such as (1) weather station; (2) insulator optical splicing box; (3) instrumented central rod of an anchorage hardware piece: mechanical deformation monitoring; (4) ground end fitting; (5) insulator body composed of a core embedding the optical fiber cable; and (6) barrel-shaped end fitting where the electric current sensor is mounted.

Table 3. High voltage laboratory tests with the electric current sensor

	Test number							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Electric current impulse (kA)	6.2	8.7	10.9	12.2	13.9	16.3	18.6	21.0

Subsystems placement in the tower has guaranteed the electromagnetic compatibility of the enclosures and no electromagnetic interference on the photovoltaic panels. The tests with the TECCON MS have ensured proper operation in the HV ambient, achieving the TRL 7. The TECCON MS has been measuring electric, physical, and mechanical variables related to the transmission line since July 2020. Those measurements allow the discussion about some practical results of the TECCON MS real operation. The monitoring system provides information about the following variables:

- Physical variables: wind relative speed, wind corrected speed, wind relative direction, wind corrected direction, atmospheric pressure, ambient temperature, line conductor temperature, relative humidity, dewpoint, precipitation, total precipitation intensity;
- Geographical and general information: latitude, longitude, and altitude; date and hour; voltage supply and status;
- Electric variable: electric current on circuit 2 of the line; and
- Mechanical variables: tensile stress, mechanical force, and deformation of the line conductor.

Outcomes about the electric current measurements and the relation between those and climatic variables are addressed in next subsections.

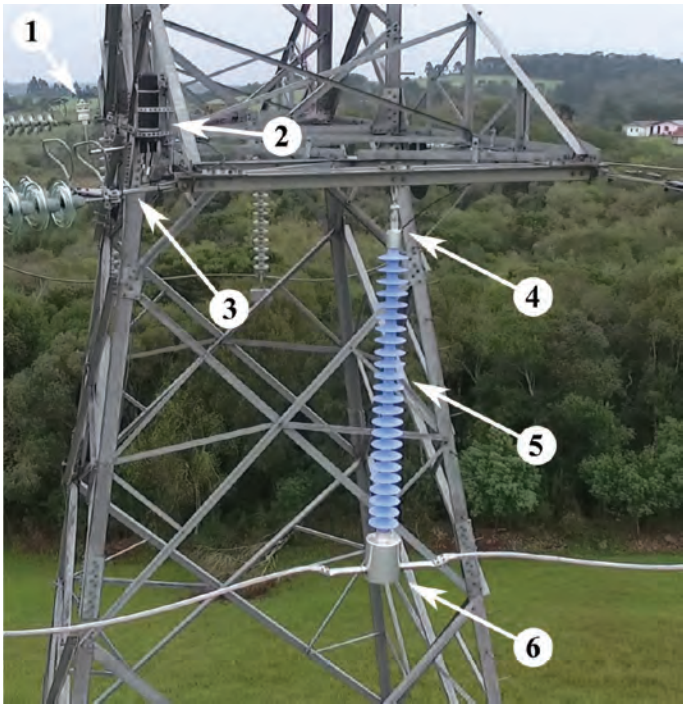


Figure 9. Instrumented polymeric insulator installed in the transmission line tower.

Steady State Electric Current Measurement

To validate the accuracy of the electric current measurement, the load curve acquired by the utility supervisory system has been compared with the measurement obtained with the TECCON MS, during the day of December 13, 2020. The graph in Figure 10 presents the data gathered using the electric current optical sensor and the data provided by the transmission utility, permitting the measurement validation. One can notice that the transmission line was out of operation during the Sunday afternoon, being reconnected to the system around 5:00 p.m.

Therefore, the amplitude curves show that the TECCON MS electric current measurement is following the transmission utility supervisory system data with fidelity, indicating that this sensor can be used as a real-time monitoring system because it has a high-resolution rate. Another example of electric current real-time monitoring is shown in Figure 11. The transmission line has a design static rating of 940 A, and the Bluejay conductor limit is equal to 1,060 A. Therefore, Figure 11 shows that the conductor is, on average, operating under transmission line and conductor static limits, indicating possible situations in which line could be more exploited.

In addition, the electric current optical sensor provides results that can be observed in terms of harmonics and waveform.

Slow-Front Transients Measurement

The TECCON MS installation in the operating environment has yielded conditions to monitor and interpret transients that may occur in the transmission lines operation. The results have shown that the optical electric current sensor embedded in the insulator is able to detect switching transients in the real transmission line operation, as shown in Figure 12. It presents the waveform of the photodetector's output signal, which is processed by the OESPU and dictates the electrical current waveform. Those events can be classified as slow-front transients, having distinct characteristics from the impulse current event measured in the HVL (relevant environment), which may be classified as a fast-front transients event [20].

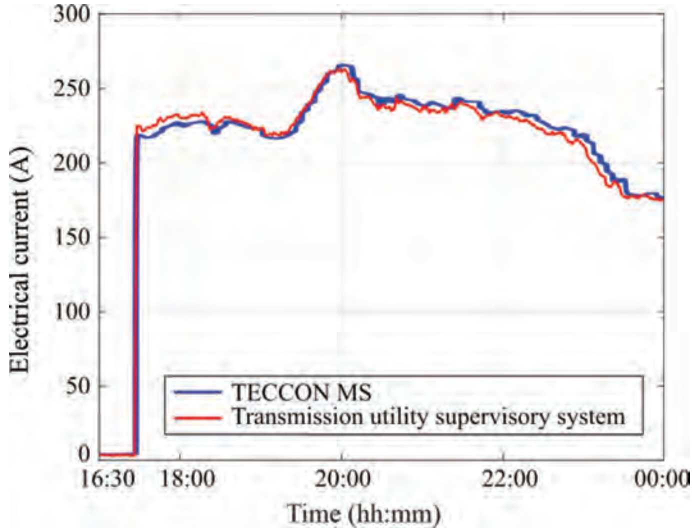


Figure 10. Electrical current measurement.

Climatic and Electric Variables Relationship

TECCON MS provides measurements at each second using OPGW, transmitting data from the transmission line intermediate tower to the substation with a RTCM unit (roughly 72 km). The interdependency between climatic variables and transmission line electric current is shown in Figure 13, presenting the relation between electric current and ambient temperature for February 2, 2021. It shows that the line is more loaded during

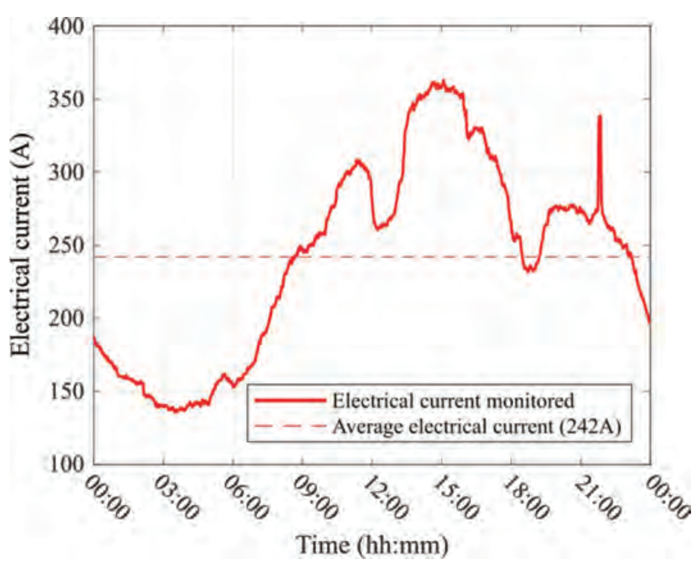


Figure 11. Conductor electric current variation on February 2, 2021.

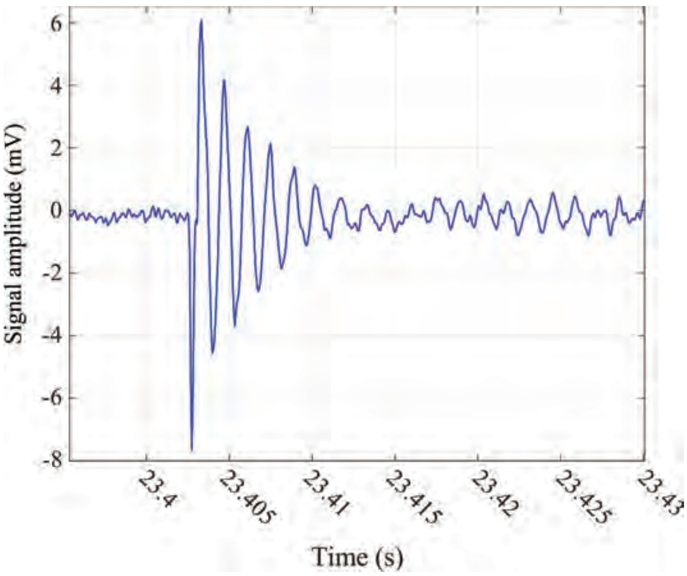


Figure 12. Waveform of a switching transient measurement using the optical electric current sensor.

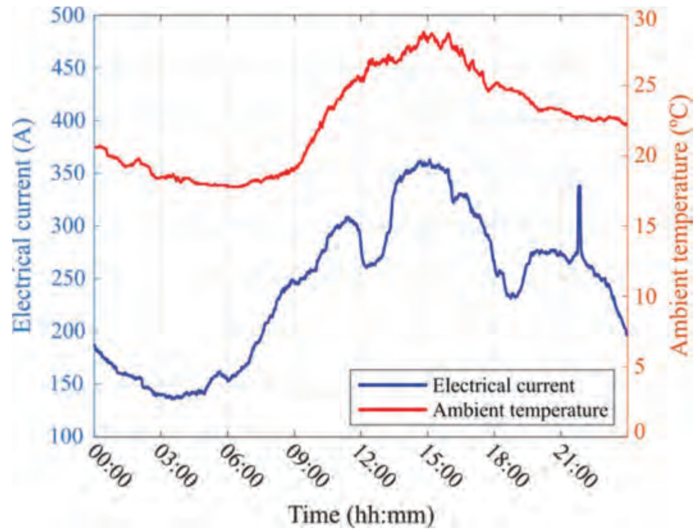


Figure 13. Electric current and ambient temperature variation on February 2, 2021.

the afternoon, having its lowest value at roughly 3:00 a.m. The ambient temperature increases at 9:00 a.m. and reaches its peak at 3:00 p.m. The graph displays a traditional summer weekday.

Conclusions and Future Applications

The TECCON MS is suitably operating in a HV transmission line of the Brazilian Interconnected System, since its installation in 2020. The results have shown main challenges and tests performed to make feasible the TECCON MS field installation, highlighting the main aspects required to migrate the technology from TRL 4 to TRL 7. The focus has been on the HV unit of TECCON project, showing the developments of instrumented composite insulator.

The TECCON MS copes with improving observability, provides correlation between measured variables, enables dynamic line rating and a fault locator implementation with an enhanced accuracy considering three points of measurement. The laboratory and field tests presented have guaranteed the proper operation of the TECCON MS in an operating environment. Also, real-time results at transmission line, e.g., electric current, have been validated with the transmission utility supervisory system.

Therefore, this article summarizes the path as a passive insulator become an active element at the grid, positioning main outcomes during the project development in the innovation chain conducted by the TRL concept. In future works, the project team aims to extend the voltage level and system configuration enabling 525 kV transmission lines application, monitoring bundled conductors and implementing improvements related to maintenance applications.

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Review on Recent Development in Insulation Research Under Short-Pulse Conditions

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Key words: pulsed power systems, solid dielectric insulation, vacuum insulation, insulation design

This article summarizes the recent developments in insulation research under short-pulse conditions in the Northwest Institute of Nuclear Technology in China, which include four aspects: (1) solid insulation under nanosecond pulses, (2) vacuum insulation under microsecond pulses, (3) insulation design methods, and (4) long-lifetime insulation structures.

Introduction

Pulsed power technology, from 1960s, intends to compress power into mega- or gigawatts and output to the loads [1]–[3]. This technology is not an alternative to traditional AC or DC power engineering. Pulsed power systems are designed to produce and transfer short pulses that have a width ranging from sub-nanoseconds to hundreds of nanoseconds. After more than 60 years of developments, pulsed power technology has achieved conspicuous developments. Several pulsed power systems, which can produce high-voltage or large-current pulses, have been constructed all over the world, such as Z/ZR, Saturn, Magpie, Angara-5-1, PST, Yang, the Flash-II, and the Qiangguang-I.

In recent decades, pulsed power systems that were used as high-power microwave generators were also established, such as the Sinus-series, the Radan-series, and the SOS-series generators in Russia; the TPG-series, the CKP-series, and the CHP-series generators in China; and the PFN-Marx-series generators and the compact Marx generator in America. Among these generators, the TPG series, which was constructed in the Northwest Institute of Nuclear Technology (NINT), has different features. For example, the TPG2000 can output a pulse with a power as great as 40 GW [2]; the TPG700L can output a pulse with a width as long as 200 ns [3]; and the TPG400 can be used for research of vacuum breakdown under both nanosecond and microsecond pulses [4]. Figure 1 shows a photo of the TPG700L and its output waveform.

The short times inherent in the operation of active components of pulsed power systems are attained by taking advantage of a variety of physical phenomena and technologies, such as high voltage (HV) electrical insulation technology, switch technology, pulse forming technology, plasma production technology, and so on. Among these technologies, HV electrical insulation technology is the foundation and has drawn great attention. The rapid development of pulsed power technology has put forward an urgent requirement for insulation research. So, researchers have conducted plenty of research in this field. For example, the researchers in NINT paid attention to radio-frequency surface flashover [5]–[16], nanosecond solid dielectric breakdown [17], microsecond vacuum gap breakdown [18]–[20], and insulation design methods. A conspicuous feature of this research is that it was conducted under short-pulse conditions. Here, the phrase of "short pulses" denotes pulses with a length shorter than tens of microseconds. Under such conditions, the heat accumulation effect is weak and the discharges' electronic nature is more obvious.

A lot of useful conclusions and formulae were suggested from NINT. The review on research of the radio-frequency surface flashover can be found in [11]; the one on solid dielectric breakdown under nanosecond pulses can be found in [17]. In this article, the recent developments in research on insulation under short-pulse conditions were reviewed, which includes four aspects: (1) solid insulation under nanosecond pulses, (2) vacuum insulation under microsecond pulses, (3) insulation design methods, and (4) long-lifetime insulation structures. These four aspects are reviewed in the following four main sections of this article, respectively. The last section is for the conclusions of this article.

Solid Dielectric Breakdown and Insulation

This section mainly reviews the recent developments in research of solid insulation under short pulses, which include three subsections: (1) the thickness effect of solid dielectrics, (2) the electrical-tree-growth model, and (3) the correlation be-

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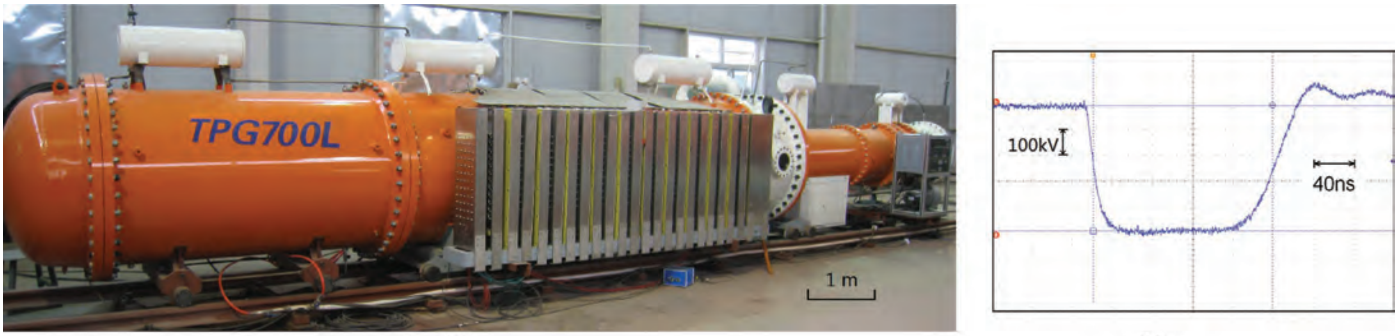


(a) (b)

Figure 1. (a) A photo of the TPG700L pulsed power generator in the Northwest Institute of Nuclear Technology. (b) Output waveform of TPG700L.

tween the size effect (thickness effect) and the lifetime (electrical tree).

Thickness Effect of Solid Dielectrics

The thickness effect of solid dielectrics means the relation between the electrical breakdown strength (E_{BD}) and the dielectric thickness (d). This effect is highly related to the scale transition of insulation structures and thus attracts great attention from researchers all over the world. Different relations were suggested to depict this effect, such as the constant relation [21], [22], the reciprocal-single-logarithmic relation [23], [24], the minus-single-logarithmic relation [25], and the minus power relation [26], [27]. All of them were summarized in [28]. The thickness effect of polymers under nanosecond pulses has also been investigated in the perspective of the Weibull statistical distribution in [29], which gives a minus power relation as follows:

$$E_{BD}(d) = E_1 d^{-a}, \tag{1}$$

where a and E_1 are constants. Eq. (1) was not only supported by the experimental results from [29], but also supported by plenty of experimental results [28]. However, the physical mechanism of Eq. (1) was not clear.

In 2020, Eq. (1) was deduced out theoretically from the perspective of electron multipactor. The basic physical process was as follows. The j_i electrons are emitted from the electron sea of the cathode into a dielectric by overcoming the potential barrier. These primary electrons expand to $j_i \exp(\alpha d)$ due to multipactor with a factor of $\exp(\alpha d)$ after moving a distance of d in the dielectric. The final electron number in the avalanche head may reduce to $j_i \exp(\alpha d)P$ due to the avalanche formation probability P, which is smaller than 1. There are basically two steps for this process: Step 1, electron injection; Step 2, electron multiplication and avalanche. Step 2 can further be divided into two substeps for clarity, namely, multiplication and avalanche formation, as shown in Figure 2. This mechanism is as follows:

$$j(d) = j_i P \exp(\alpha d), \tag{2}$$

where $j(d)$ represents the final current density when the seed electrons march a distance of d; j_i represents the initial current density near the cathode; P represents the avalanche formation probability; $\exp(\alpha d)$ represents the expansion factor for one seed electron moving a distance of d; α is the ionization coefficient, which means that α times of impact ionization to the atoms can take place when an electron moves a distance of 1 cm along the inverse field direction in dielectrics. When $j(d)$ increases to a certain value of j_{BD}, the breakdown is defined to occur, i.e.:

$$E_{BD} = E\,|_{j(d)=j_{BD}}\;. \tag{3}$$

By using the electron emission formula based on the Tunnel effect and the Schottky effect, E_{BD} can be solved as a function of d, as follows:

$$E_{BD}(d) = \begin{cases} E_{ST} d^{-1} \\ E_{TN} d^{-\frac{1}{2}}, \\ E_i d^{-\frac{1}{m}} \end{cases} \tag{4}$$

where E_{ST} is a constant related to the Schottky effect; E_{TN} is a constant related to the tunnel effect; E_i is also a constant; m is a constant that is larger than 4. By comparing Eq. (1) with Eq. (4), it can be seen that the two equations have the same form, i.e., the minus power relation, and that $a = 1/m$. In a word, the thickness effect of solid dielectrics is deduced out theoretically.

Electrical-Tree-Growth Model

The thickness effect depicts the solid dielectric insulation under a single pulse; the electrical tree phenomenon is for the

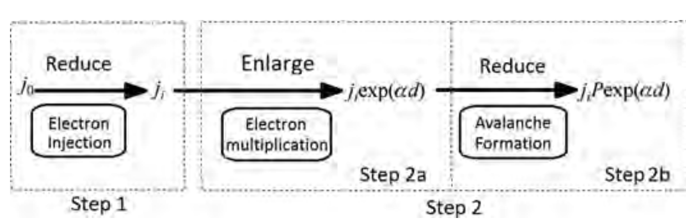


Figure 2. Physical mechanism for the thickness effect of solid dielectrics under short pulses.

Table 1. Three tree growth cases predicted by the mathematical model

Case	Development case	Stagnation case	Transition case
Solutions to $dl/dt = al^2 - bl + c$	$\Delta < 0$ "tan(*t*)" form $l_\gamma \tan(At - B) + l_0$	$\Delta > 0$ Horizontal asymptote $l_1 - \{C/[D \exp(\delta t - E) - 1]\}$	$\Delta = 0$ Horizontal asymptote $l_0\{1 - [1/(\sigma t + F)]\}$
Comments on growth characteristics	Tree continues to grow until final breakdown occurs.	Tree stops at l_1 and never resumes growth.	Tree growth stagnates midway but may resume due to perturbations.
Tree pattern	Branch	Bush	Branch-bush
Physical nature	$E_{loc} > E_c$ $dl/dt > 0$	$E_{loc} \geq E_c$ together with $E_{loc} < E_c$ $dl/dt \geq 0$ together with $dl/dt < 0$	$E_{loc} \geq E_c$ $dl/dt \geq 0$

insulation of solid dielectrics under repetitive pulses, which seriously threatens the safety of HV devices. Due to its importance, research on this topic is a hot spot. L. A. Dissado *et al.* [30] and S. T. Li *et al.* [31] published two books to describe this phenomenon, respectively. Theories such as DBM (dielectric breakdown model), DAM (discharge avalanche model), DCM (deterministic chaotic model), and FDTG (field-driven tree growth) model were suggested to characterize the electrical tree growth characteristics. These models give a clear physical picture of electrical tree growth. But, a quantitative description about the electrical tree growth characteristics was not reported.

In 2022 a mathematical model for conductive electrical tree growth in dielectrics was put forward in NINT [32], [33]. In this model, it was postulated that the electrical-tree growth rate (dl/dt) was proportional to the rate of destruction due to partial discharges. By referring to the DAM and the FDTG model, the following differential equation was presented to describe the electrical tree length:

$$\begin{cases} \dfrac{dl}{dt} = al^2 - bl + c \quad (a, b, c > 0), \\ l\,|_{t=t_0} = 0, \end{cases} \tag{5}$$

where $l|_{t=t_0} = 0$ means that the first electrical tree initiates at t_0.

Solving Eq. (5) gives three types of solutions, which predict three cases of electrical tree growth in dielectrics, namely, the development case, the stagnation case, and the transition case, as listed in Table 1. In this table, Δ is the discriminant ($\Delta = b^2 - 4ac$).

The physical nature of the three cases lies in the comparison of the local field (E_{loc}) and the critical field (E_c) caused by the space charges due to a partial discharge. When $E_{loc} > E_c$, $dl/dt > 0$ and the electrical tree develops. When $E_{loc} < E_c$, $dl/dt < 0$ and the electrical tree stagnates. When $E_{loc} = E_c$, $dl/dt = 0$ and the electrical tree stays at a transition state. The physical meanings of coefficients a, b, c were also explored.

(1) c is determined by the applied voltage, V. The larger V is, the larger c is. As V increases from low to high, the solution changes from the stagnation case to the transition case and then to the development case. The electrical tree changes from a bush type to a bush-branch type and then to a branch type.

(2) b is used to describe the initial stage of tree growth characteristics. The larger b is, the faster the tree grows in the initial stage.

(3) a is used to describe the final stage of the tree growth characteristics in the development case. The larger is a, the faster the tree grows in the final stage.

Experiments were designed and conducted to verify the mathematical electrical-tree-growth model using a nanosecond-pulse generator, a cone-plane electrode, an on-line microscope, and a lot of PMMA (polymethyl methacrylate) samples. The experimental method was designed as follows:

Step 1: launch a nanosecond pulse on an intact sample;
Step 2: record the image of the sample via the on-line microscope;
Step 3: repeat Step 1 and Step 2 until breakdown occurs;
Step 4: measure the electrical tree length of l at the Nth pulse;
Step 5: change the voltage level and the test sample; then, repeat Steps 1 through 4.

The typical electrical tree images were classified into the development case, the stagnation case, and the transition case, as shown in Figure 3. Figure 4 plotted the l versus N data, and the data were fitted using the three types of solutions in Table 1. From Figure 4, it can be clearly seen that the fitting curves from the solutions agree with the tree growth characteristics.

Correlation Between Size Effect and Lifetime Formula

The theoretical lifetime formula of solid dielectrics was $N_L = (E_{BD}/E_{op})^m$; the unified formula for the size effect on E_{BD} was

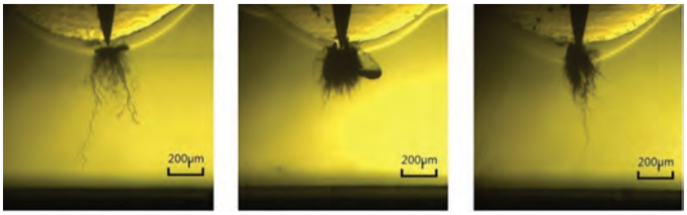


Figure 3. Typical electrical tree under pulsed voltages observed in experiments: (a) development case; (b) stagnation case; (c) transition case.

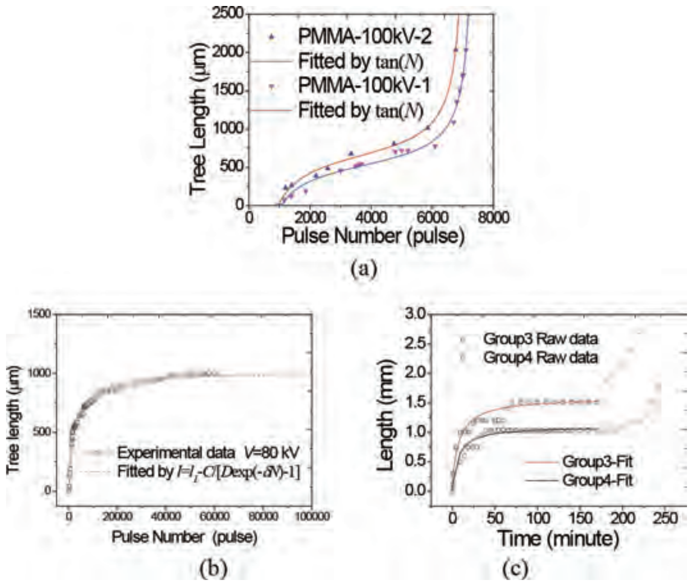


Figure 4. Experimental verification of three types of solutions: (a) development case; (b) stagnation case; (c) transition case.

$E_{BD} = k\zeta^{-1/m}$, where ζ can represent the characteristic size of the dielectrics. It can be seen that the two formulae correlate with each other via the parameter of m. But, the physical meaning of m was not fully understood.

In 2021 it was theoretically proven that $1/m$ has the same meaning of the relative variance (δ) of E_{BD} [34]. It is known that any form of discharge can be described by the Weibull distribution, that is, $F(E) = 1-\exp[-(E/E_{BD})^m]$. So, the standard error, E_σ, of E_{BD} is as follows:

$$E_\sigma = \eta^{1/m}\delta(m), \quad \text{where} \quad \delta(m) = \left[\Gamma\left(1+\frac{2}{m}\right) - \Gamma^2\left(1+\frac{1}{m}\right)\right] \tag{6}$$

Figure 5 shows the relative variance, $\delta(m)$, dependent on m in a log-log coordinate system, which shows that:

$$\delta(m) \approx 1/m^{0.95} \approx 1/m. \tag{7}$$

So, it has been proven that $1/m$ has the physical meaning of the relative variance, δ. With this conclusion, the relation between the size effect and the lifetime of solid dielectrics is more clear, as is described in Figure 6.

Long-Gap Vacuum Breakdown and Insulation

This section mainly reviews the recent developments in long-gap vacuum insulation under short pulses in NINT, which also include three subsections: (1) the vacuum insulation characteristics using coaxial-line electrodes, (2) the vacuum insulation characteristics using parallel-plate electrodes, and (3) the long-gap vacuum breakdown mechanism. It is worth mentioning that when $g > 2$ mm, this range is defined as long vacuum gap; when $g < 0.5$ mm, this range is defined as small vacuum gap; and the range for 0.5 mm $< g <$ 2 mm is the transition according to Latham [35].

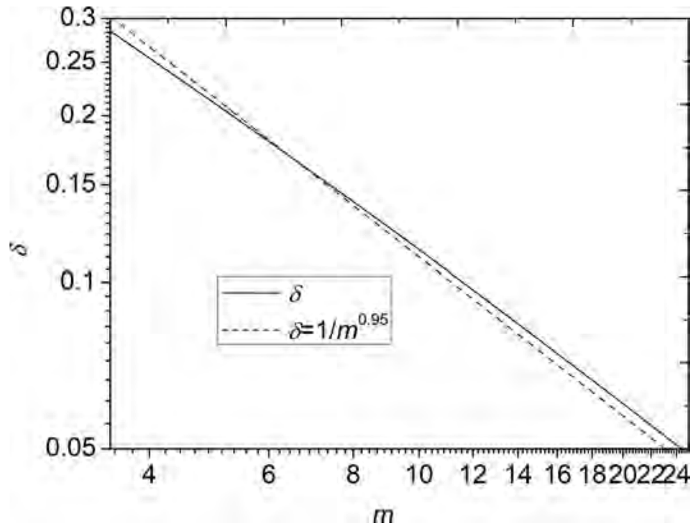


Figure 5. Fitting of $\delta(m)$ on m in a practical range of 0.05 to 0.3.

Vacuum Insulation with Coaxial-Line Electrodes

Based on the multifunctional experimental setup, TPG400 [4], the vacuum insulation characteristics using coaxial-line electrodes under microsecond pulses were investigated. The microsecond pulse had a full wave at half maximum of 30 microseconds. The coaxial vacuum gaps were set as 5.75, 7.67, and 10.2 cm [18], respectively. The vacuum level was 5×10^{-3} Pa.

The experimental results show that the electric breakdown field (E_b) dependent on both the gap distance (g) and the electrode area (A) conforms to the following formula:

$$E_b(g,A) = k_{co}/(g^{1/3}A^{1/6}), \tag{8}$$

where k_{co} is a constant. By combining the reported coaxial vacuum breakdown data in the literature, it is concluded that g is as large as 10 cm and A is from 2×10^3 cm^2 to 2×10^5 cm^2, as shown in Figure 7.

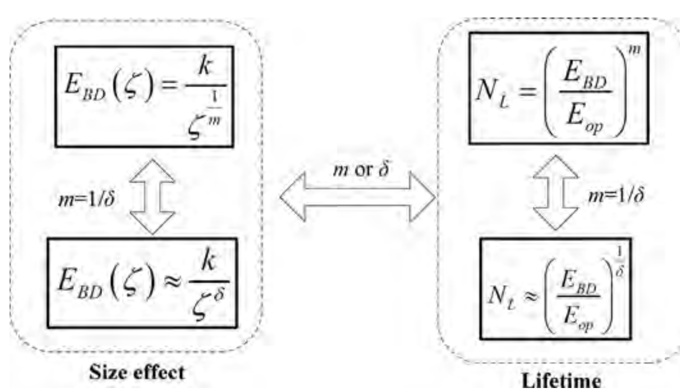


Figure 6. Relation of lifetime formula and size effect via δ.

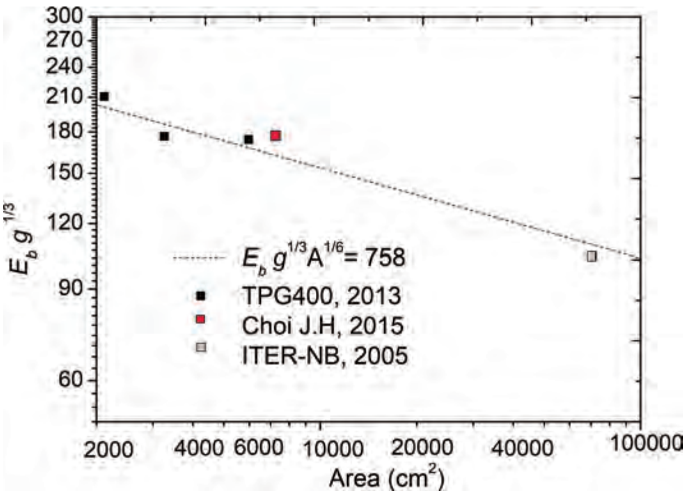


Figure 7. E_b dependent on g and A for the vacuum-insulated coaxial lines in a wide range [18]. The pressure from TPG400 is 5 × 10^{-4} Pa. The pressure from Choi is 8.7 × 10^{-4} Pa. The pressure from ITER-NB cannot be found.

Vacuum Insulation with Parallel-Plate Electrodes

Also based on the TPG400, the vacuum insulation characteristics under 30-microsecond pulses were explored with many parallel-plate electrodes for g ranging from 2.5 to 5.5 cm. These electrodes all have a Bruce profile, which can overcome the edge effect. Similarly, by combining the reported long-gap vacuum breakdown data, it is found that E_b and g meet a linear relation in a log-log coordinate system. If expressed as a formula, the relation between E_b and g is as follows:

$$E_b(g) = k_{pa}/g^{1/3}, \tag{9}$$

where k_{pa} is a constant. Eq. (9) is applicable for a gap separation from 0.4 to 400 cm, as shown in Figure 8(a).

Aside from the gap effect and the area effect on E_b, the pulse width (τ) on E_b was also summarized using the data in NINT. It is showed that E_b and τ meet a linear relation in a log-log coordinate system from 1 ns to 1 ms, as shown in Figure 8(b) [20]. If expressed as a formula, E_b and τ conform to the following:

$$E_b(\tau) = k_\tau/\tau^{1/6}, \tag{10}$$

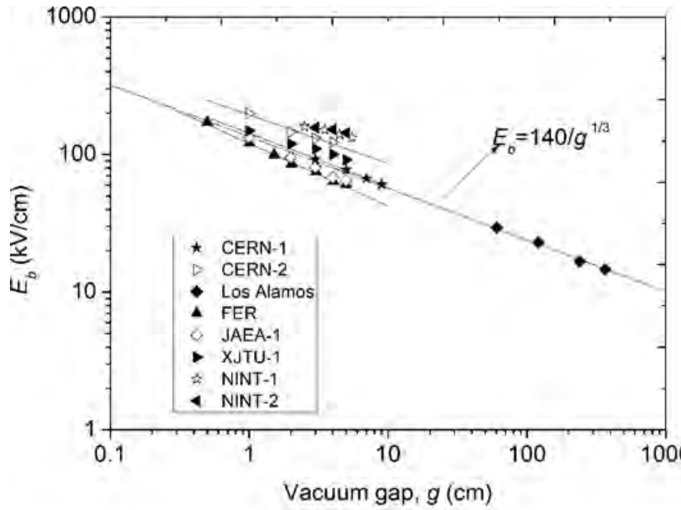
where k_τ is a constant. Eq. (10) is applicable for a pulse width ranging from 0.001 to 1,000 microseconds.

Because τ and g are independent of each other, the two effects on E_b can be written as one by combining Eqs. (10) and (9), i.e.:

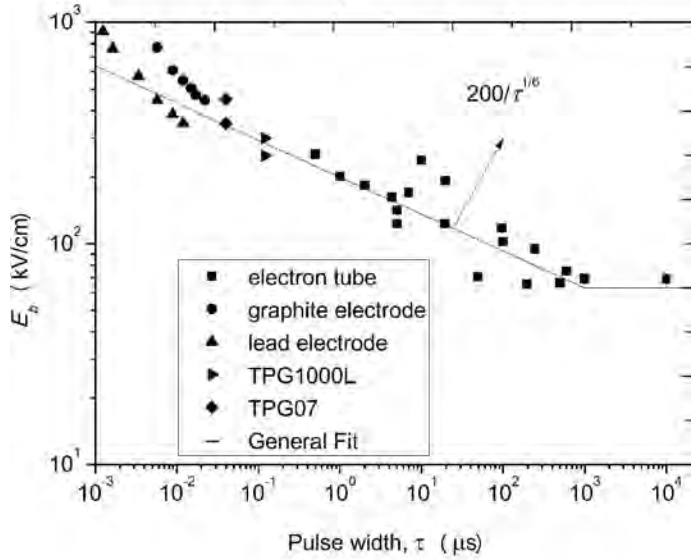
$$E_b g^{1/3}\tau^{1/6} = k_{vb,pa}. \tag{11}$$

In addition, because τ, g, and A are independent of each other, the effects of τ, g, and A can also be written together by combining Eqs. (10) and (8), i.e.:

$$E_b g^{1/3}A^{1/6}\tau^{1/6} = k_{vb,co}. \tag{12}$$



(a)



(b)

Figure 8. (a) E_b dependent on g in a wide vacuum gap [36]. (b) E_b dependent on τ in a wide time scale [20].

In Eqs. (11) and (12), $k_{vb,pa}$ and $k_{vb,co}$ are both constant. Eq. (12) can be used to predict the E_b under different conditions.

Long-Gap Vacuum Breakdown Mechanism

There are several mechanisms responsible for the vacuum breakdown phenomenon, such as the field-induced electron emission (FEE) theory [37], the explosive electron emission (EEE) theory [38], the ABCD theory [39], and the clump theory [40], [41]. The features of these theories are summarized as follows:

In the FEE theory, the vacuum breakdown is initiated by the seed electrons emitted from the cathode in a strong field higher than 1 MV/cm.

In the EEE theory, the seed electrons are supplied by the explosion of whiskers, which are small protrusions on the cathode surface.

In the ABCD theory, it is assumed that one seed electron from the cathode bombards the anode, producing A positive ions and C photons. Each ion in turn bombards the cathode,

Table 2. Three conditions for five forms of discharge

Discharge form	Primary electron sources	Low-density regions	Feedback dynamics
Gas breakdown	Cathode electrical contacts	Gas itself	Continuous carrier injection from the cathode
Liquid breakdown	Cathode electrical contacts	Bubbles in front of cathode	Continuous carrier injection from the cathode
Solid breakdown	Cathode electrical contacts	Low density domains	Continuous carrier injection from the cathode
Vacuum breakdown	Cathode	Metallic vapor	Continuous bombardment to electrodes
Vacuum surface flashover	Cathode triple junction	Desorbed gas	Continuous bombardment to insulator surfaces and electrode

producing B electrons. Each photon also bombards the cathode, producing D electrons. When AB + CD >1, the vacuum breakdown can take place.

In the clump theory, the breakdown was assumed to be due to detachment of a clump of material loosely adhering to one electrode. This clump moves toward and impacts the opposite electrode, leading to evaporation of the electrode or the clump itself. The vapor is then ionized and forms the plasma.

All of these theories can be used to explain the short-gap breakdown phenomenon. However, only the clump theory was suggested by Cranberg [40] and Slivkov [41] to interpret the long-gap breakdown phenomenon. In the experiments in NINT, more experimental proofs that supported the clump theory for the long-gap vacuum breakdown mechanism were found, which are as follows:

(1) γ for the relation of E_b versus $g^{-\gamma}$ is 1/3. So, $1-\gamma$ is equal to 2/3 for the power exponent in total voltage effect of $U_b = C_a g^{1-\gamma}$. This value is close to that suggested by Slivkov, which was 0.625.
(2) Vacuum experiments with a pair of TC4 (a brand of titanium) and stainless steel electrodes were conducted in [36], where evaporated spots of stainless steel appeared on the surface of TC4. This agrees with the fact that the evaporated material moves from one electrode to another in the breakdown process.
(3) The TC4 electrodes were covered with the polyimade (PI) power on the surface to increase the insulation ability. However, the insulation of the PI-powder-covered TC4 electrodes collapsed earlier, and the aging could not be constructed at all. The PI powder in this breakdown process played the role of clumps, and the micro discharge was due to the impact and ionization of the powder [20].

Insulation Design Method

This section reviews the results related to insulation design for pulsed power generators, which include (1) unified field formulae for five basic discharge forms, (2) a multi-physic-field lifetime-evaluation formula, and (3) a design method for composite insulation structures.

Unified Field Formulae for Five Basic Discharge Forms

Different insulation design formulae was suggested for gas, liquid, solid, and vacuum breakdown and vacuum surface flashover by J. C. Martin at the Aldermaston Weapon Research Establishment for pulsed power design [1], [42]. In addition, other formulae were also suggested from different organizations, such as Tomsk Polytechnic University [43], the North Star Research Corporation [44], Sandia National Laboratories [45], and the Institute of Electrical Engineering [46]–[49]. All these formulae provide precious guidelines for practical insulation design in pulsed power fields. However, these formulae were not systematic, and the application ranges of each formula were not clear.

In 2021 the basic physical processes of different discharge forms were analyzed, and the similarities were summarized [50]. It was concluded that all the five forms of discharges meet three conditions: (1) a stable primary electron source; (2) a low-density region for electron multipactor to occur; and (3) feedback dynamics to support the continuity of the discharge process. Table 2 lists the three conditions for the five discharge forms.

Based on these similarities, a unified formula for the five discharge forms, i.e., gas breakdown, liquid breakdown, solid breakdown, vacuum breakdown, and vacuum surface flashover, under pulsed electric field was proposed [50]. This formula considered the effects of the number of dimensions and pulse width on the electric field together, which is as follows:

$$Et^{1/\alpha}\Omega^{1/\beta} = k, \tag{13}$$

where t represents the effective duration of the electric field that corresponds to the field exceeding $0.63E_{\max}$; Ω represents the dimension of insulation structures; and α and β are positive constants. For different discharge forms, Ω has different meanings; α and β also have different values, which were summarized in Table 3.

Eq. (13) can be used to transform experimental data with a small size under a known pulse width into those with a large size under the application pulse width and is thus important for insulation design.

Multi-Physic-Field Lifetime Evaluation Formula

There are several formulae to evaluate the lifetime (N_L) of insulation structures exposed to pulsed electrical fields, such as the famous Martin's formula [1], [51] and those summarized in [34]. There are also some qualitative analyses on the mechanical stress effect on lifetime of N_L. However, in practice, the insulation structures usually suffer both the electrical field and the mechanical field. A formula to describe the effect of both of the two fields together on N_L is not reported.

Table 3. Summary of electric field formulae for different discharge forms under short pulses

Insulation failure forms	Insulation formulae	Definitions and units	α	β	Application condition	Researchers
Gas breakdown	$E_g t_e^{1/6} g^{1/6} = k_{g,p}$	E_g = gas breakdown field in kV/cm; t_e = the time for a field to exceed $0.63E_g$, in μs; g = in cm; $k_{g,p}$ = constant related to pressure	6	6	In non-unified field, 0.1 ns < t_e < 1 μs; g is as large as 10 cm.	J. C. Martin
Liquid breakdown	$E_l t_e^{1/3} A_l^{1/10} = k_l$	E_l = liquid breakdown field in MV/cm; t_e = in μs; A_l = the electrode area sustaining a field exceeding 0.9 E_l in cm^2; k_l = constant	3	10	In unified field, 0.1 μs < t_e < 1 μs; for transformer oil, 0.1 cm^3 < A_l < 10^5 cm^3.	J. C. Martin
Solid breakdown	$E_s t_e^{1/5} \zeta^{1/8} = k_s$	E_s = solid dielectric breakdown field in MV/cm; t_e = in ns; ζ = thickness of solid dielectric, in cm; area, in cm^2; or volume, in cm^3; k_s = constant	5	8	In unified field, t_e < 100 ns; for effect of volume, $V < 10^4$ cm^3; for effect of area, $A < 10^3$ cm^2; for effect of thickness, d ranges from μm class to cm class.	L. Zhao
Vacuum surface flashover	$E_{vf} t_e^{1/6} A_{vf}^{1/10} = k_{vf}$	E_{vf} = vacuum surface flashover field in kV/cm; t_e = in μs; A_{vf} = the insulator surface sustaining a field exceeding 0.9 E_{vf} in cm^2; k_{vf} = constant	6	10	For surface flashover switch, 10 ns < t_e < 10 μs; A_{vf} as large as 40 cm^2 was reported in [1]; for insulator stack, 30 ns < t_e < 1 μs, A_{vf} is as large as 4 × 10^4 cm^2.	J. C. Martin
Vacuum breakdown	$E_v t_e^{1/6} g_v^{1/3} = k_{vg}$ $E_v t_e^{1/6} A_v^{1/6} = k_{vA}$	E_v = vacuum breakdown field in kV/cm; t_e = in μs; g = vacuum separation in cm; A_v = electrode area sustaining a field exceeding 0.9 E_v in cm^2; k_{vg} = constant related to the electrode area; k_{vA} = constant related to electrode separation	6 6	3 6	10 ns < t_e < 10 μs; for parallel electrode, 0.4 cm < g < 400 cm; for coaxial electrode, g is as large as 10 cm, 2 × 10^3 cm^2 < A_v < 7 × 10^5 cm^2.	L. Zhao L. Zhao

In 2021 a combined lifetime formula to evaluate N_L of insulators exposed to multiple physical fields consisting of pulsed electrical field and mechanical stress was put forward [52], which is as follows:

$$N_L(S, E_{av}) = \frac{K(S_0 - S)}{E_{av}^m}, \tag{14}$$

where E_{av} is the average pulsed electric field; S is the mechanical stress; S_0 is the critical mechanical stress at which an insulator cannot endure any electrical field; m is a constant ranging from 7 to 10; and K is a constant.

This formula can be used to evaluate the lifetime of insulators suffering the two fields together or just one of the fields. For example, in the experiments conducted by Arbab [53], a series of test samples were exposed under a 7-kV, 50-Hz electric field and different mechanical stresses simultaneously. The experimentally tested lifetimes are listed in Table 4. With Eq. (14) as well as the given conditions of $m = 8$, $E_{av} = 28$ kV/cm, and $S_0 = 47$ MPa, the theoretical lifetimes of each tested sample were calculated and listed in Table 4. The two sets of lifetimes are compared in Figure 9. From this figure, it can be seen that the theoretical lifetimes agree with the experimental ones, which proves the effectiveness of Eq. (14).

Design Method for Composite Insulation Structures

In HV devices, the composite insulation structures include solid-liquid types, solid-gas types, and solid-vacuum types, as shown in Figure 10. Each insulation structure contains more than one potential insulation failure form. Taking the solid-liquid insulation structures as an example, the insulation may fail due to solid breakdown, liquid breakdown, or solid-liquid surface flashover. All these failure forms should be taken into account together in the insulation design process, rather than only one form. As aforementioned, different insulation formulae were suggested from different organizations. But, these formulae only focused on one form of discharge. There is no report on methods to consider all the potential insulation failure forms as a whole.

In 2022 a composite insulation design method was proposed. The basic idea was to consider the solid insulation, the surface insulation, and the fluid insulation as a whole. The quantitative

Table 4. Comparison between the tested lifetime and the predicted lifetime and of polyester resin samples under different mechanical stress

Mechanical stress, S (IMPa)	Tested lifetime, N_L (hours)	Predicted lifetime, N_L (hours)
0	245[1]	257
6.9	203	212
11.5	167	188
23	121.7	127
34.5	69.2	66

[1]These data are fitted with the formula of $N_L = l_\gamma \tan(At - B) + l_0$.

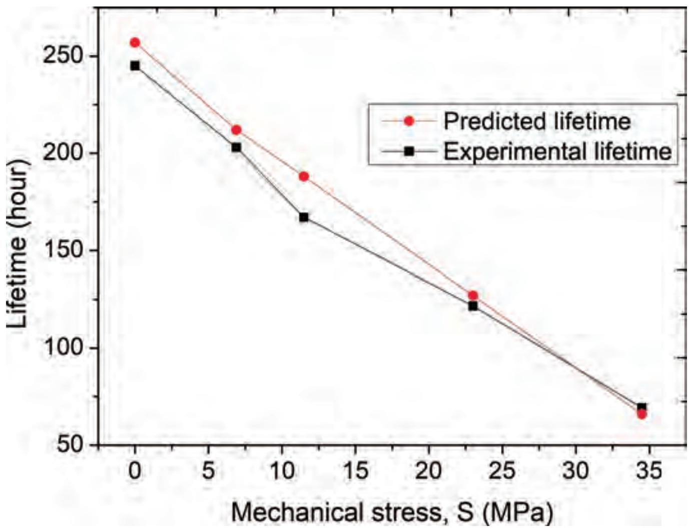


Figure 9. Comparison of practical lifetime and predicted lifetime.

design begins with the reliability of R. Namely, R of the insulator, R of the interface, and R of the fluid should all be no smaller than the required reliability of R_c within the given lifetime of N_L, i.e.:

$$\min\{R_{\text{solid}}, R_{\text{fluid}}, R_{\text{surface}}\}\,|_{N<N_L} \geq R_c. \tag{15}$$

There are two key points for this composite insulation design method. The first is the unified electric field formula for different discharge forms, which is used to calculate the E_{BD} (= $E_{50\%}$) under a given pulse width with a given structure. The specific formula can be found in Table 3. The second is the reliability formulae for different insulation forms. As to fluid or surface where the cumulative effect of partial discharge trace is weak, the upper design field, E_{Rc}, at the given condition of (R_c,N_L) is follows:

$$E_{Rc} = E_{50\%}[\ln(1/R_c)/\ln 2]^{1/m}, \tag{16}$$

where $E_{50\%}$ can be calculated out with the unified formula (13); m is just equal to β in Table 3. As to the solid where the cumulative effect of partial discharge trace is obvious, the design field at the given condition of (R_c,N_L) is follows:

$$E_{Rc} = E_{50\%}[\ln(1/R)/N_L]^{1/m}. \tag{17}$$

With Eqs. (16) and (17), as well as the unified formula (13), the design for composite insulation structures can be conducted. Specifically, there are five steps to finish such a method:

Step 1: recognize the potential insulation failure forms in an insulation structure;
Step 2: calculate the field $E_{50\%}$, which corresponds to R of 50% with Eq. (13) for each insulation form;
Step 3: calculate the theoretical field of E_{Rc} at the given condition of (R_c, N_L) with Eqs. (16) and (17);

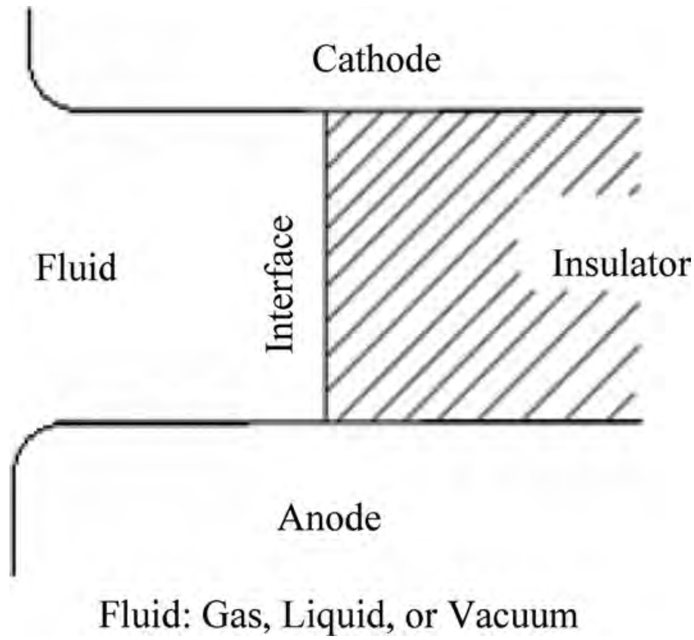


Figure 10. Typical composite insulation structure.

Step 4: find the maximum applied field $E_{\max}$ in different positions in the insulation structure via software simulation; and
Step 5: compare E_{Rc} with $E_{\max}$ for each insulation form to determine whether the design is okay. If $E_{\max} < E_{Rc}$, the design is acceptable; else, further optimization is needed.

A specific example for the design of a multifunctional coaxial vacuum insulator was presented in [54].

Design of Long-Lifetime Insulation Structures

All the conclusions, formulae, and methods mentioned previously serve insulation design in HV devices. Different long-lifetime insulation structures were designed and tested in NINT, which show a lifetime in a million-pulse level. In this section, a compact multi-wire-layer secondary winding and a multifunctional coaxial HV vacuum insulator of such kind were introduced.

A Compact Multi-Wire-Layered Secondary Winding

The secondary winding is one of the key components for the TPG-series generators. The performance of the secondary winding highly affects the reliability and lifetime of the generators. The traditional secondary winding is single layered, using electrical paper board as the base tube. Each turn of wire is fixed with glue. So, they have drawbacks of low electrical strength, low mechanical strength, large length, and week fixation to the coaxial line. Turn-to-turn breakdown tends to take place on this kind of winding, which limits the lifetime of the winding and the reliability of the generators.

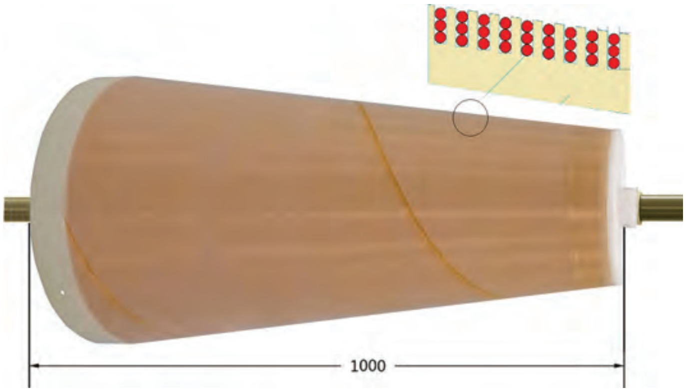


Figure 11. Photo of a multiwire-layer secondary winding.

In 2017 a compact multi-wire-layered (MWL) secondary winding for Tesla transformer was put forward. The basic idea was to wind the metal wire on a grooved polymeric base tube in a multi-layer manner.

Figure 11 shows a photo of this type of winding as well as the winding method, which is realized via concentric-circle grooves perpendicular to the axis of the tube and carved on the surface of tube.

The MWL winding has the following advantages: high electrical strength because voids were precluded from the surface of the winding; high mechanical strength because polymer was fabricated as the base tube; reliable fixation to the Tesla transformer as special mechanical connections were designed; and compact size due to the multi-layer-winding way. A 2,000-turn winding, which has a total length of 1.0 m, can boost the voltage to 1 MV at a repetition rate of 50 Hz reliably and can work for a lifetime longer than 1 million pulses without any insulation failure trace [55].

A Multifunctional Coaxial HV Vacuum Insulator

The vacuum insulator is used to separate the gas or oil in a transmission line (TL) from the vacuum in the load for the TPG-series generators. The conventional vacuum insulator only has the functions of separation and support. In addition, the lifetime is limited.

In 2020 a compact multifunctional, long-lifetime coaxial HV vacuum insulator for the TPG-series generators was proposed for high-power microwave generation [56]. This vacuum insulator had two features. First, it was multifunctional because it had a "λ" sectional view, as seen in Figure 12(a). This type of design could not only support the two conductors of the coaxial TL and supply a vacuum environment for the load, but also eliminate the pre-pulse from the main pulse, which was realized via the grounded inductor wound in the surface of switch side. Second, it had a long lifetime. This was realized by the grooves in the vacuum side, as shown in Figure 12(b).

A 50-cm, 700-kV insulator of such kind was designed for a 1-MV Tesla-type generator to drive the relativistic backward-wave oscillator for high-power microwave generation, as shown in Figure 12(c). It decreased the axial length of the generator by 2 m. By far, it has operated for a lifetime longer than 0.9 million pulses at a rate of repetition of 50 Hz without any insulation failure trace.

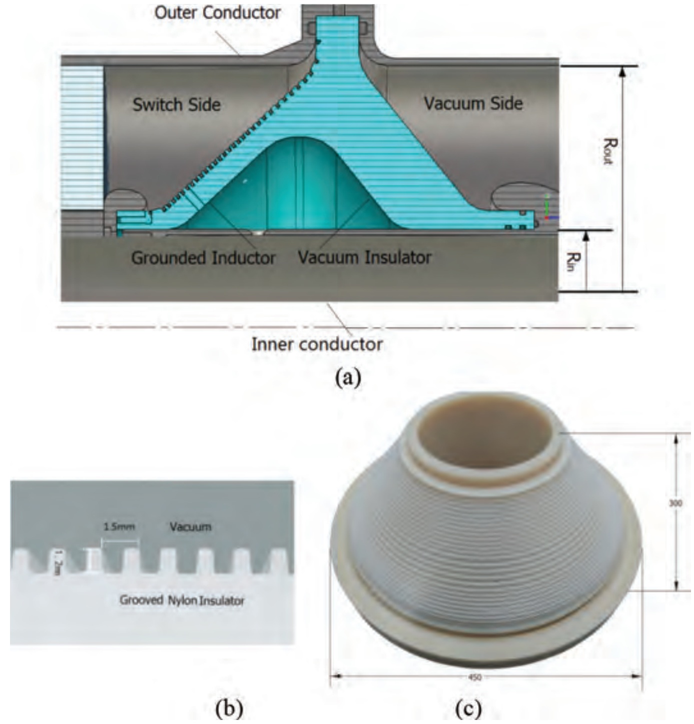


Figure 12. Multifunctional vacuum insulator. (a) Schematics, (b) photo, and (c) grooves on the surface.

Conclusions

The recent developments on short-pulse insulation in NINT were summarized, which include four aspects: (1) short-pulse solid insulation, (2) microsecond long-gap vacuum insulation, (3) insulation design methods, and (4) long-lifetime insulation structures.

(1) As to the short-pulse solid insulation, the mechanism for the thickness effect of solid dielectrics was proposed; a mathematical model for electrical tree growth was put forward; and the correlation between the lifetime and the size effect was presented.
(2) As to the microsecond long-gap vacuum insulation, the empirical vacuum breakdown formulae for both coaxial and parallel electrodes were put forward, and the proofs supporting the clump theory for the long-gap vacuum breakdown mechanism were summarized.
(3) As to the insulation design method, a unified formula for five basic forms of discharge under short pulses was proposed; a multi-physical-field lifetime-evaluation formula was presented; and a composite insulation design method for solid structures was put forward.
(4) As to the long-lifetime insulation structures, a compact multi-wire-layered secondary winding and a multifunctional long-lifetime HV vacuum insulator were designed

and applied, which both show lifetimes in a million-pulse level.

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Nondestructive Terahertz and Millimeter Wave Imaging for Underfilm Corrosion

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Key words: aging management, nondestructive testing, terahertz waves, millimeter waves, underfilm corrosion, transmission towers, repair paints

Corrosion hidden under opaque anticorrosion coatings is hazardous for outdoor installation. This type of corrosion can be visualized using radio waves, which are familiar to electrical engineers with field case experience.

Introduction

Addressing the problem of corrosion in the electric industry is related to the management of obsolete equipment in generating and outdoor electrical systems. Aging of transmission line towers [1], [2] is a worldwide concern, with maintenance costs that have already amounted to almost 3.8 billion yen (31 million dollars) as of 1997 [3]. The International Council on Large Electric Systems (CIGRE) has issued a guideline for corrosion control. The fundamental corrosion types and mechanisms were comprehensively reviewed in TB-765 [4], but industrial cases and requirements needed clarification. Anticorrosion coating (i.e., paint) is often applied to steels used in electric transmission lines. Steel equipment is hot-dip galvanized to inhibit atmospheric corrosion when installed. The anticorrosion coating is applied when the galvanizing is worn out after a long-term operation. However, the applied coating also suffers from degradation. Therefore, maintenance is essential not only for the steel but also for the coating.

Table 1. Standardized procedures applicable for walk-around checks and simple examinations that evaluate the coating degradation on steel [5]–[20]

Target	Method candidates	ISO Std.	ASTM Std.
Gloss value		2813 [5]	D523 [6]
Film thickness	Electromagnetic method	2808 [7]	
	Galvanic method	2808 [7]	
	Cross-sectioning method	2808 [7]	D4138 [8]
Pinholes (holidays)			D5162 [9]
Adhesion	Pull-off testing	16276-1 [10] 4624 [12]	D4541 [11]
	Cross-cut testing	16276-2 [13] 2409 [14]	
Blistering		4628-2 [15]	D714 [16]
Cracking		4628-4 [17]	D660 [18]
Flaking		4628-5 [19]	D772 [20]

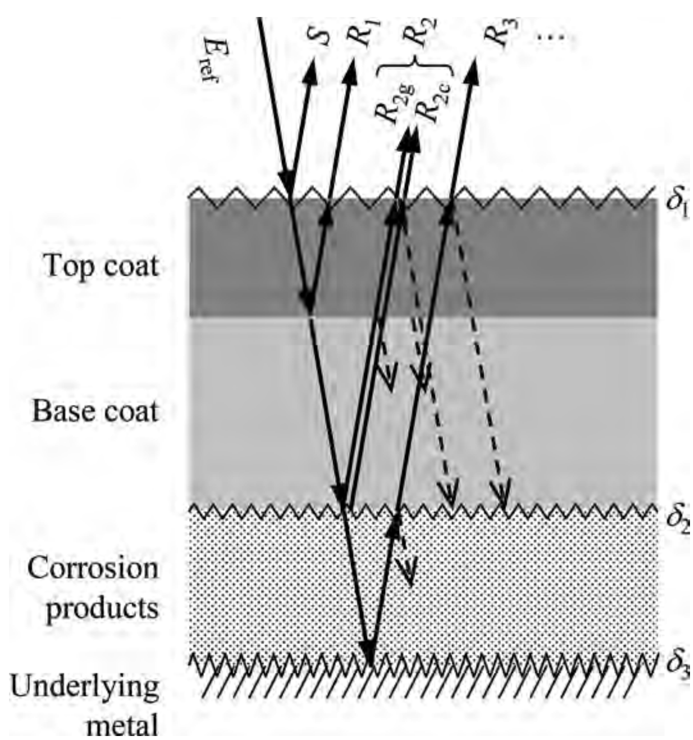

Figure 1. Radio frequency wave reflection from the coated steel with an underfilm corrosion layer. The interface roughness is represented by δ.

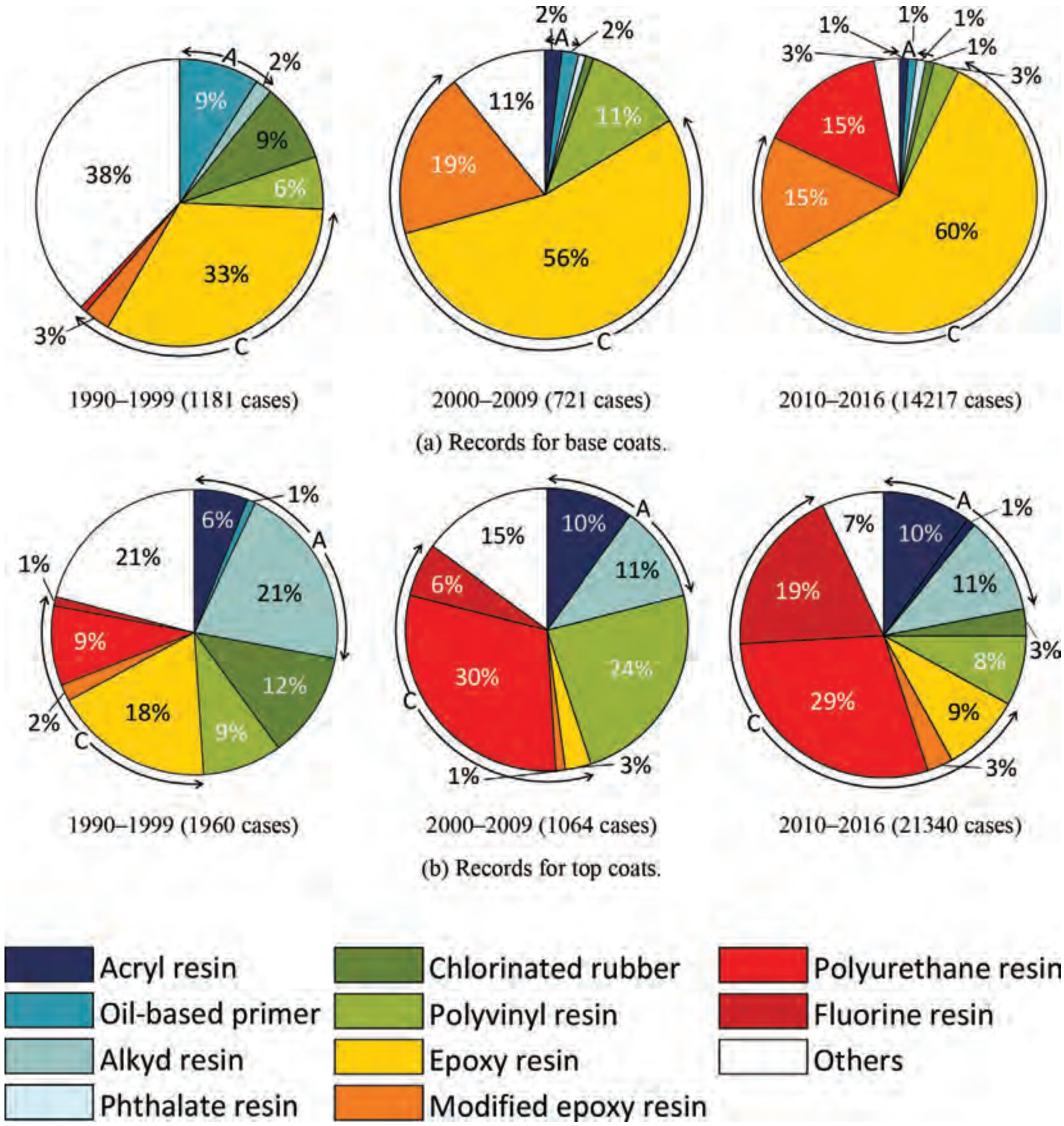

Figure 2. Repair paint materials used in Japanese power transmission towers [26]: records for the (a) base and (b) top coats. Notations for terms "A" and "C" are described in the main text.

Several methods can be used for walk-around checks and simple examinations to evaluate the coated steel integrity. Table 1 summarizes these methods [5]–[20]. Many focus on blistering and loss of adhesiveness in the coatings because these degradations directly affect the corrosion extent. ISO 16276 specifies adhesiveness test procedures [10], [11], whereas ISO 4628 defines the blistering level classification procedure performed by comparing digital camera snapshots with boundary samples [21]. The electrochemical impedance method is a promising field technique that requires only a handy LCR meter [22]. However, attention has been limited to electrochemical corrosion mechanisms and integrity evaluation against coatings.

Repair costs and substrate damage could be reduced if corrosion can be visualized. Fundamental studies frequently use the scanning vibrating electrode technique [23]. The corrosion current detection can be reconstructed to visualize the corrosion state under a coating. A wide-range observation in a short duration through scanning probe microscopy is often difficult. Deep learning techniques have recently been employed for the aerial imaging of transmission towers, which are needed to rank their degradation levels [24]. However, this is only applicable to uncoated steels because underfilm corrosion occurs underneath opaque films. On the other hand, radio frequency (RF) waves can effectively detect degraded regions. For example, corroded steel reinforcement bars under a concrete cover can be observed via a radar using megahertz RF waves because they can penetrate several meters into the concrete or soil [25]. Meanwhile, for anticorrosion films with a thickness in the order of several 100 µm, high-frequency waves like terahertz (THz) and millimeter waves (MMWs) are better suited for diagnosis at high space resolution. This study reviews the authors' contributions to the visualization of underfilm corrosion using emerging technologies [26]–[31]. The readers may find that both detection techniques and material treatments are

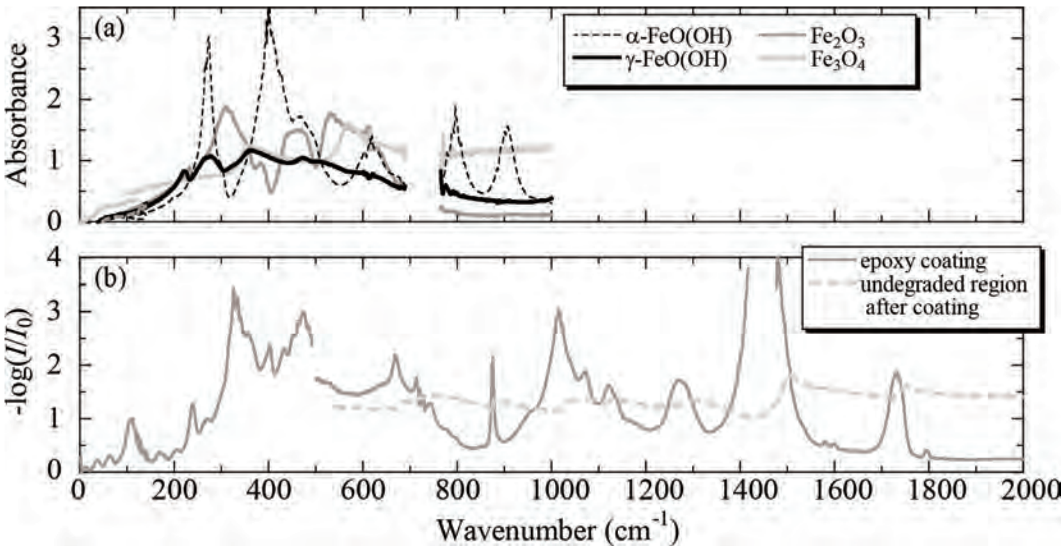

Figure 3. Far-infrared absorbance spectra observed (a) for several iron molds in high-purity powder form and (b) for epoxy coating [19]. The reflection spectrum of the coating adhered to a steel plate is also shown in (b). I_0 and I represent the intensities of the irradiated and reflected radio frequency waves, respectively.

familiar topics to engineers who are working in the electrical insulation field and tackling aged facilities. Corrosion control now requires material engineers who are familiar with electrical engineering.

Polymeric materials are widely used as insulators in cables and transformers. Because these materials are expected to show sufficient transmissivity in the THz region, it may be possible to use nondestructive THz spectroscopy to obtain electrical equipment images and detect internal defects, even when the equipment is covered with opaque polymers. Fundamental research results can be found elsewhere [32]–[35]. In this study, the coating is dielectric; the example is imaging rust, a major problem for network owners worldwide.

Figure 1 illustrates the reflection of RF waves from a coated steel plate with corrosion products on the adhering interface. Only a fraction of the waves is reflected because of the modest mismatch of the refractive indices, n, at the interface. The remainder is transmitted through the sample. The reflections from the top coating surface S, top/base coating interface R_1, base coating/corrosion product interface R_2, and metal substrate R_3 are presented in the figure. The reflection (R_2) splits into two reflections (i.e., R_{2c} and R_{2g}) if an air gap exists between the back surface of the base coating and the corrosion products. The multiple reflections that travel back and forth in these cross-sections have been omitted for simplicity. The reflections provide tomographic information in a nondestructive manner if RF pulses are used. Actual observations will be provided in the THz imaging section. The interference waves emerging from the interaction between the reference wave and its reflection from the target are observed if continuous RF waves are used. The interference intensity change by the phase shift caused by the presence of a rust layer is used for corrosion detection. Examples will be given in the MMW imaging section.

Paints and Their Optical Transparencies

Repair paints used in public facilities are customized according to specific requirements and different for each industry. This work conducted a survey of 41,869 paint cases in Japanese power transmission towers recorded since 1976 [26]. A summary of the results is provided in Figure 2. A two-layer coating is typically used to realize excellent antiweather ability and adhesion to steel. The coating technology has gradually shifted from alkyd resin systems to epoxy systems. These two systems comply with general combinations of paints, which can be found in ISO 12944-5 [36]. The figure calls the two systems "A" and "C," which are frequently used in Japan. Although it is already superseded, a British standard uses a different nomenclature for coating systems [37].

Figure 3 displays the absorption spectra observed using a far-infrared spectrometer and a THz time-domain spectroscopic system [27]. Far-infrared spectral characteristics specific to steel rust depend on its chemical structure. Absorption bands that originate from lattice vibrations are investigated in the literature [38]–[40]. The absorption of an epoxy coating becomes low at frequencies lower than approximately 300 cm^{-1}. The anticorrosion epoxy coating used here was a general-purpose product rather than a special material for transmission tower repair. However, the observed spectra indicated that the THz and MMWs exhibited good transparency for anticorrosion coatings for the effective detection of hidden rust.

Terahertz Imaging

The time-of-flight measurements of the THz pulse waves are typically realized using photoconductive antennas, whereas lock-in technologies with delay lines are used for signal ob-

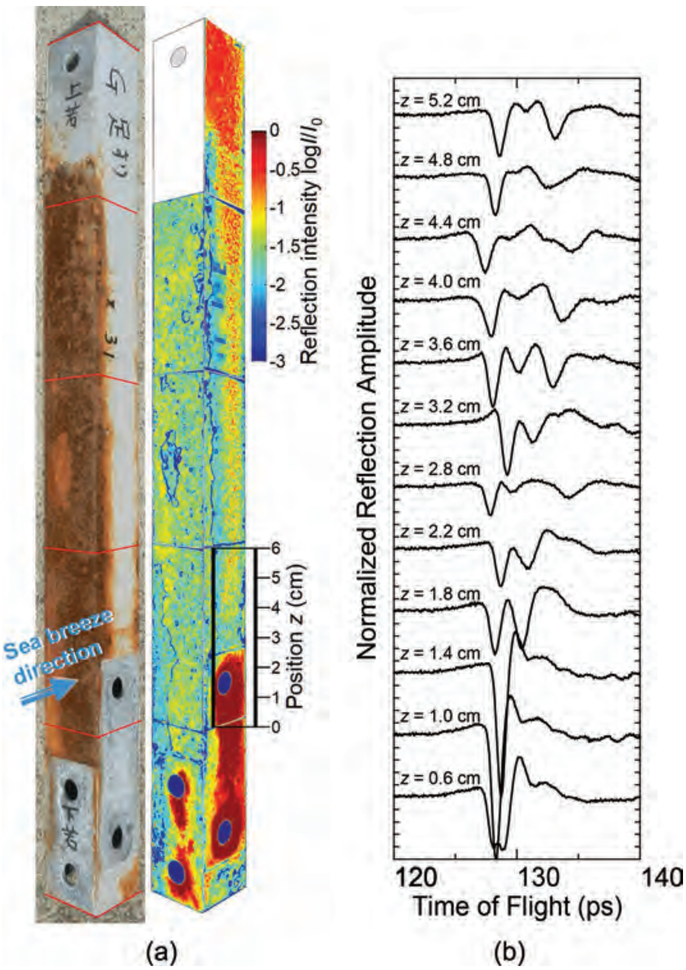

Figure 4. Mapping of the steel corrosion distribution under a paint layer by terahertz (THz) reflectance imaging: (a) appearance of a sample and its THz imaging and (b) time-of-flight reflection waveforms collected along the z-axis.

servation. A time-domain spectroscopic imaging scanner under a catoptric system can detect locations, where the THz wave reflections are attenuated by deformations under the coating. For inspection, a bar sample was removed from a power transmission tower located in a coastal area (Figure 4) [28]. The external appearance indicated that corrosion was most intense on the surface facing the sea breeze because most of the epoxy coating was lost. Indicating the presence of underfilm corrosion, the reflection intensity of the THz waves was weak on this surface because the corroded materials strongly absorbed the THz waves.

Figure 4 also depicts the reflected THz waveforms. The layered structure of the metal, rust, and coating induced a series of echoes at their interfaces when irradiated with the THz pulse waves. Among the three reflection peaks observed for the areas where the coating remained intact, the second and third peaks corresponded to the reflection at the coating–rust and rust–steel layer interfaces, respectively. From their time delay, the rust thickness was determined as 110 µm, a value that agreed with the direct measurement. Spectral analysis of the reflection echo also enabled material identification. Although not described in detail in this study, the deconvolution technique can resolve the echo waveform distortion and enable waveform separation. This computation was similar to that conducted for space charge profiles that are important for HVDC engineering [41]. The spectral analysis of the separated reflection echoes provided a tomographic visualization of steel rust and related matters by mapping the refractive index distribution [29].

If a THz camera and quantum cascade laser are used together, the measurements can be performed more than 11 times faster [30]. Terahertz imaging is utilized in many industrial and cultural fields, such as artwork conservation [42], [43]. The recent advancement in the THz semiconducting device has enabled a real-time walk-through body scanner for the security gate [44]. The measurement system is now expected to enable inspections at high altitudes and in narrow spaces that are not easily accessible to humans.

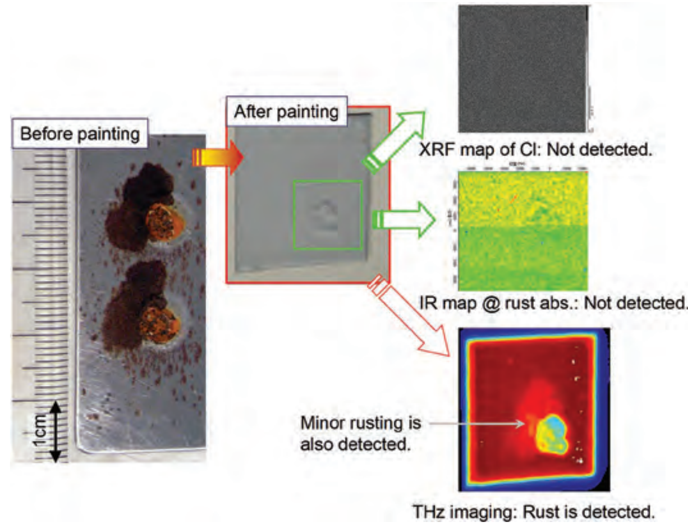

Figure 5. Imaging comparison of the underfilm corrosion fabricated by dropping a NaCl solution and a coating surface using an epoxy spray. The infrared mapping wavenumber was 1,500 cm^{-1}, where bare rust showed a strong absorption.

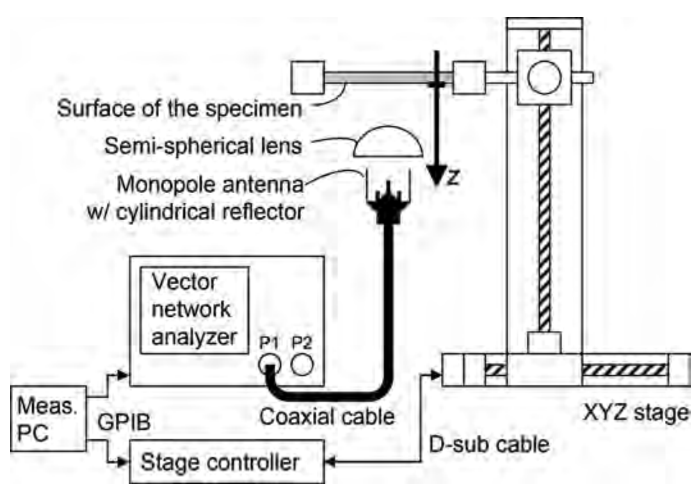

Figure 6. Schematic setup for the evaluation of the lens effect on millimeter wave imaging.

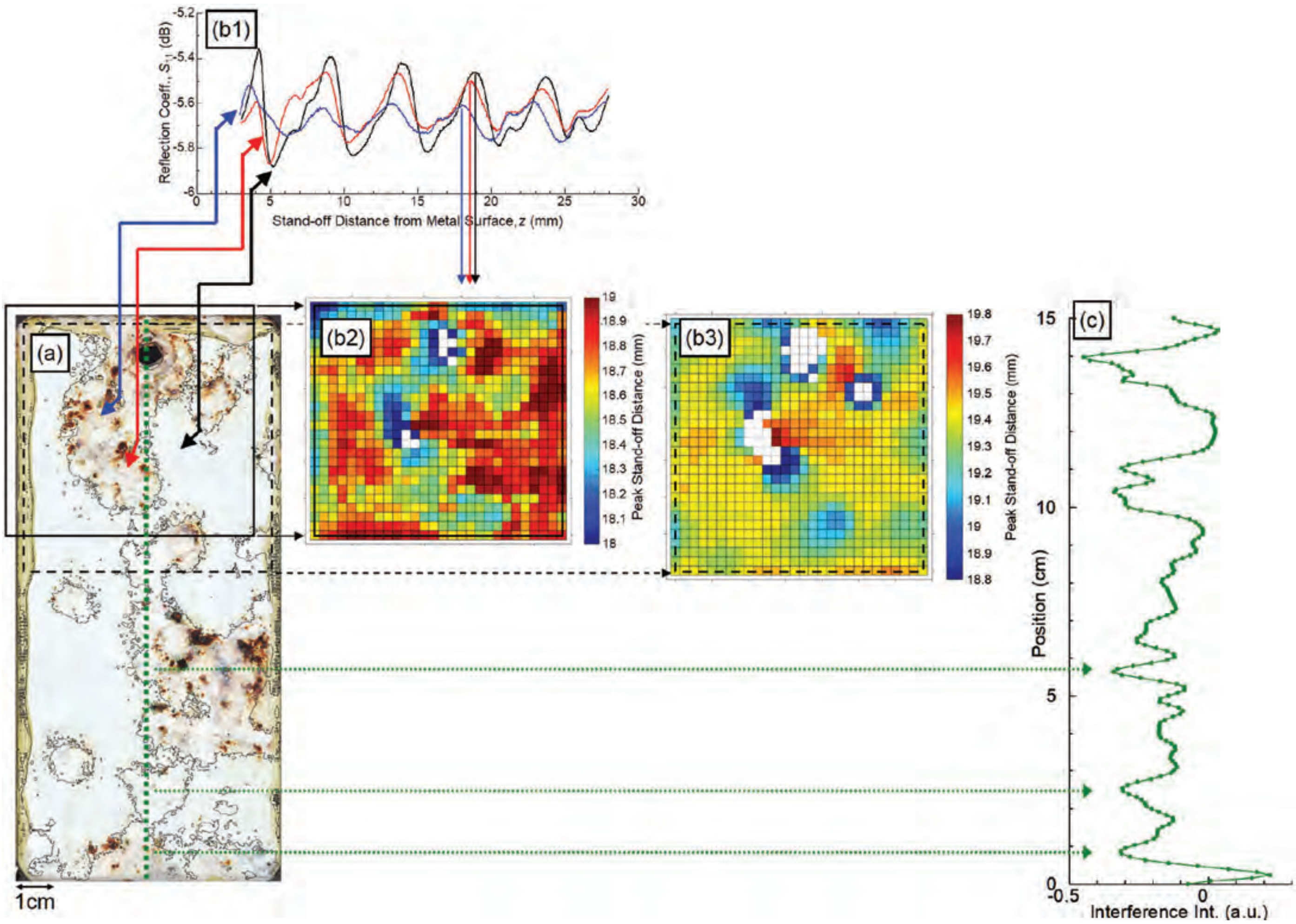

Figure 7. Summary of the millimeter wave (MMW) imaging results: (a) appearance of the sample after the cyclic corrosion test, (b1) typical S_{11} waveforms and MMW imaging results using (b2) the lens-antenna system and (b3) the rectangular waveguide all obtained using the XYZ stage, and (c) another amplitude variance obtained along the sample surface using the portable module.

A 1-mm-thick uncoated carbon steel plate was artificially corroded by placing a few drops of NaCl solution on its surface. The NaCl solution was wiped off, and the plate surface was coated with the epoxy resin analyzed in Figure 3. Subsequently, to detect the corroded region hidden under the coating, several nondestructive testing methods were tried [27]. Figure 5 summarizes the obtained results. The intensity distribution of the reflected THz waves accurately reproduced the rusted region. In contrast, X-ray fluorescence mapping of chloride atoms was unable to find it. The detected characteristic X-ray spectra only showed material signals from the inorganic fillers mixed in the coating. The X-rays emitted from the instrument were weak; therefore, a stronger source was required. Fourier-transform infrared (FTIR) mapping via catoptric measurement could not detect the hidden corrosion either. Figure 3(b) depicts an example of the observed FTIR spectrum. The infrared spectra observed in the intact and corroded regions were identical. Their spectral shapes followed the Kramers–Kronig relation with the absorption spectrum of the coating. In other words, only information regarding the coating surface was reflected in the FTIR spectra.

Millimeter Wave Imaging

The THz waves cannot always reveal severe corrosion partly because of the scattering on uneven surfaces and the strong attenuation in the thick rust layer. Therefore, the focus is shifted to MMWs, which have negligible scattering and demonstrate good transmissivity. The MMW technology has remarkably advanced in recent years. For example, MMW antennas are already being mounted on drones for collision avoidance [45]. Accordingly, fast imaging is expected to be realized by arraying such small devices.

The MMW corrosion imaging was tested in the outdoor field but was found to be cumbersome [46]. The MMW imaging for corrosion inspections can be realized by overcoming diffusion over the stand-off distance defined as the distance from the radiation tip to the target surface. The reported stand-off distances are in the order of several millimeters if an open-ended waveguide is used [47], [48]. The authors developed a diffusion control lens-antenna that enables measurements to be performed with a centimeter-level stand-off distance necessary for field inspections. Figure 6 presents a schematic of the optical reflection measurement system that consists of a vector network analyzer as the MMW source and the lens-antenna probe attached to the coaxial cable tip. For fabrication of the probe, a monopole antenna with a cylindrical reflector and a semispherical silicone lens with a 30-mm diameter [49], [50] were used.

A hot-rolled steel sample was galvanized and coated with siliconized epoxy resin. A cyclic corrosion test using a sprayed 3% NaCl solution was performed according to the standards of the Japanese Automobile Standards Organization [51] for 1,000 cycles. This corresponded to 8.3 years of exposure in Okinawa, Japan. Figure 7 summarizes the inspection results. The blistered areas on the sample surface observed under a three-dimensional microscope were overwritten to the sample appearance. The changes in the reflection coefficient S_{11} with the stand-off distance z were evaluated at a selected frequency of 33.1 GHz. The S_{11} waveform interference intensities varied with the stand-off distance (hereinafter referred to as the delay) when the measurement was conducted on a blistered point, where steel rust was present under the coating. Although not shown, clearer delays were also observed for the tablet-shaped samples manufactured by compressing the high-purity rust powders investigated in Figure 3. The delay width was related to the phase shifts of the reflection waves produced by the presence of a rust layer. It was calculated for the waveforms obtained for the whole raster-scanned area. As shown in Figure 7(b2), the reconstructed image successfully reproduced a C-shaped area where blistering occurred. The image became imprecise and blurred when the probe was replaced with an open-ended waveguide. This result suggests that the lens-antenna system suppressed the signal distortion caused by the MMW diffusion.

The authors developed the portable and affordable prototype module illustrated in Figure 8. The 8.3-GHz MMWs emitted from the dielectric resonator oscillator were multiplied to generate 33.1-GHz MMWs. The adopted measurement principle was phase shift modulation for detecting the maximum interference intensity, regardless of the abovementioned phase change. As demonstrated by the line scan example in Figure 7(c), the interference intensity became weak in the presence of underfilm corrosion. Figure 8(b) shows an example of the raster scanning attempted for the previously scanned area. This approach successfully reproduced a C-shaped underfilm corrosion area. If two-dimensional scanning could be performed by arraying the probe and using a high-speed coaxial switch, the entire 7 × 15 cm steel plate could be measured in 20 to 30 seconds.

Conclusions

Nondestructive testing using RF waves has significant merits of visibility and remote sensing ability; therefore, its application to inspect various public infrastructures is advantageous. The fundamental mechanism of detecting hidden corrosion is based on the fact that RF waves are transparent against anticorrosion coating and that part of them reflects at the interfaces that exhibit an impedance mismatch. These reflections exhibit a train of reflection echoes when pulse RF waves are used. Electrical engineers are familiar with data interpretation, and

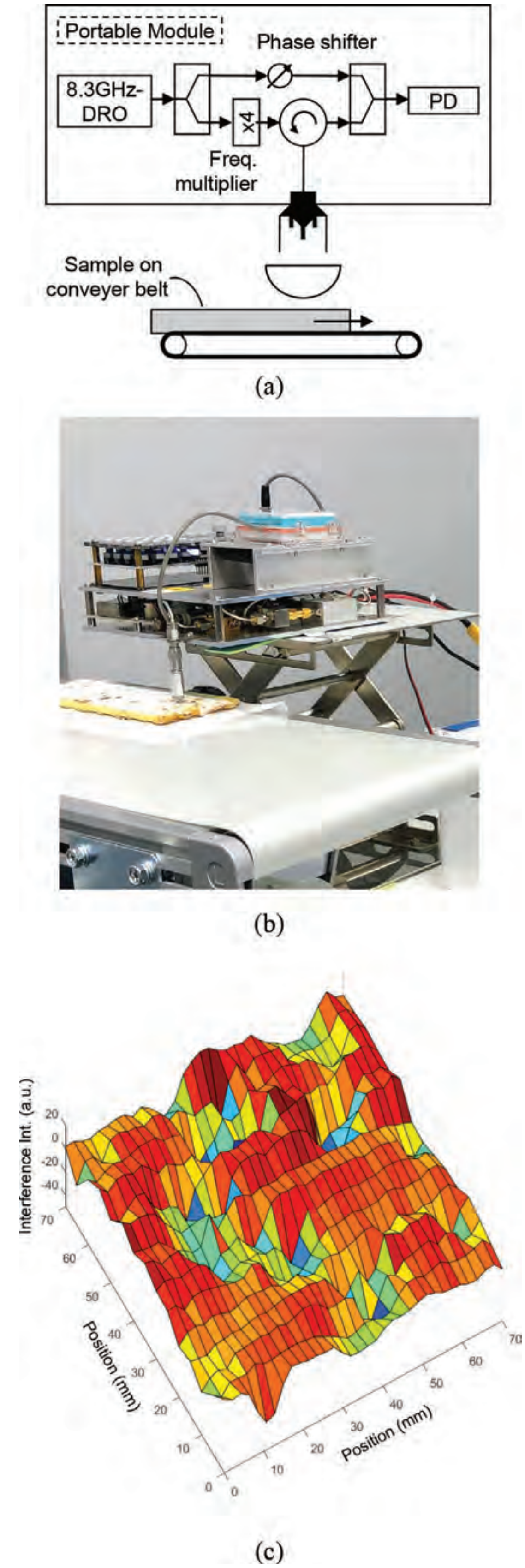

Figure 8. (a) Schematic setup (DRO = dielectric resonator oscillator, PD = photodetector), (b) photograph, and (c) experimental millimeter wave image using the portable module. A 7-mm-diameter lens was used.

corrosion control now requires electrical engineers with knowledge of industrial cases and requirements. The following points summarize the current status of visualizing underfilm corrosion:

- Several THz devices are now available on the market, allowing potential users to attempt see-through imaging. Rust fluids spread over the steel–coating interface and expand the corrosion-affected areas. Corrosion evaluation is often insufficient if attention is paid only to the coating integrity. This study demonstrated the superiority of corrosion visualization compared with X-ray and infrared analysis in a steel bar removed from a power transmission tower.
- The MMW technologies used in collision-avoidance radars and 5G communication are promising in terms of corrosion inspection. The MMW diffusion must be controlled for inspections; thus, to assess their effect, a semispherical lens was adopted in this study. Additionally, the authors developed a portable and affordable module that can detect the amplitude reductions caused by the presence of a rust layer.

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Maya Mizuno received her PhD degree in engineering from Tohoku University in 2006 while she was working at RIKEN. She was a limited-term researcher at the National Institute of Information and Communications Technology (NICT) from 2006 to 2010 and is presently a senior researcher in the Radio Research Institute at NICT.

Looking at the Bigger Picture with Hulya Kirkici

Elizabeth Aragao

At the heart of all Hulya Kirkici's work is a commitment to solving humanity's problems. This was instilled in her by her family at a very young age and has grounded her throughout a career of pioneering research in electrical insulation of aerospace and space power systems, lasers, plasma physics, and beyond. Long before becoming a PhD, IEEE Fellow, Eric O. Forster Distinguished Service Award recipient (and many more accolades), she was a little girl fascinated by numbers.

As a young student in Turkey, Hulya Kirkici loved math. When her seventh grade teacher began "talking about planets, gravity, how the bodies in space move, their attractions and their forces," she was hooked.

"I said, 'yes, I am going to be a physicist.' I didn't even know what it meant to be a physicist at that point, but that was how it all started."

She was also inspired by her father's ingenuity.

"He didn't have a college education, but he was an innovator. I remember him building cars, changing engines. He even designed his own natural gas burning engine for his car. My dad always said you need to look at the bigger picture. It's not always black and white. You need to consider everything."

Kirkici's parents were supportive of her educational pursuits: her father encouraged her to continue her education instead of leaving for a job in industry; her mother traveled with her to Istanbul to take exams for the scholarships she would eventually win.

With a laugh, she also remembers her mother saying, "What kind of job can you get as a physicist? Well, you can be a school teacher in physics, so that will be good."

A Physicist and an Engineer

The Turkish government awarded her with a Ministry of Education Graduate Scholarship, which allowed Kirkici to continue her research on lasers in the United States at Texas Tech University. However, her advisor soon let her know that he and their research project were relocating to Polytechnic University (now New York University's Tandon School of Engineering). He invited her to join; yet, there was a catch: the physicist would need to switch to the electrical engineering department.

"To me, engineering was more applied work, and I expressed that concern to him." She remembers him laughing and saying, "Oh Hulya, I am a physicist in Germany (where he was from), but here I'm an electrical engineering professor. In this country engineers make more money!"

Kirkici made the move, leading to her PhD in electrical engineering, with a dissertation on electronic energy transfer lasers,

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including pioneering work in gas laser technology now in use today.

A Whole World of Research

The next step in Kirkici's original plan was to return to Turkey to become a professor. However, Auburn University in Alabama had an offer: apply her knowledge of lasers at their Space Power Institute, which was doing research for the US government's "Star Wars Project"—putting lasers in space as part of a national defense system.

"There was a whole world of research there. It was the marriage of plasma physics, lasers, and high power systems."

Kirkici was intrigued by the complexity surrounding power systems in space: how rapidly insulation would deteriorate, how a discharge could propagate through the system and destroy an aircraft, and what could be done to mitigate the breakdown phenomena. She wondered: do I take this research opportunity or return to Turkey?

"One of my professors in Turkey said, 'If you're going to come back, come back and be happy. If you're going to stay, stay and be happy. If you're in between, you will never be happy. Make a decision based on that.' That was really good advice. So, I decided to stay and said, 'Ok, this is home.'"

Auburn University became Kirkici's first academic home. Her three-year post doc commitment turned into 25 years of research and teaching at Auburn, including work on a number of cutting edge research projects.

For example, as a visiting scientist at NASA, she was part of a team looking for an alternative to hydrazine as a fuel source for the space shuttle's auxiliary power system. The team researched batteries as a fuel source at a time when battery technology was not mature, doing pioneering work experimenting with and designing a new type of power system for the shuttle program.

For this work Kirkici was named an IEEE Fellow for her contributions to high frequency, high field dielectric breakdown and electrical insulation for space and aerospace power systems. The recognition was an honor, but she sees the most impactful part of her work as planting seeds for others to nurture and build upon.

"Ten years ago there were not many publications in that area. Now that area is flooded, and looking at that, one can say, wow, I was part of that moment."

Later, Kirkici returned to her roots of plasma physics as a visiting scientist in the US Air Force Research Lab at Wright Patterson Air Force Base. There she researched scramjet propulsion, specifically investigating nanoscale plasma ignition of combustion as an alternative to chemical combustion. She notes that this research is still in its infancy but sees it becoming a major milestone in efficiently operating fighter jets in higher altitudes.

Asking Kirkici to pick a favorite project, she compared it to asking to choose your most precious child. She values all the work because each project is trying to answer the challenges that we face as humans.

"Working in a technical field and being creative and developing new technologies are exciting. But I think, at the end of the day, if it's not for humanity, it has no value. Everything we do is to make our lives more enjoyable, comfortable, safer, and in peace. A lot of the time many of us lose that; we just get so focused on the very short-term outcomes of whatever we are doing."

IEEE: A Good Kind of Drug

In many ways, Hulya Kirkici is one of a kind. She was often the only woman in the room and the first woman to achieve major milestones throughout her studies, career, society activities, and beyond. But she doesn't want it that way. She notes that women are not staying in the field and it's up to everyone to fix that.

In a 2017 editorial for this publication she wrote, "Women know they have a challenging career ahead of them, but I think it is the duty of both men and women to be mutually supportive, facing challenges together and finding solutions together." She challenged readers to take the time to mentor a female engineer today.

In our interview she reiterated that message, saying that "As a society, we can do better. It is not women's problem, it's everybody's problem to be diverse and accepting of all the talents."

While equity is still a major concern, IEEE's vision of "technology for humanity" resonates with Kirkici, who has volunteered with the organization in various capacities since 1998. She presented a paper at the CEIDP conference in Austin, Texas, and was asked to host the next event. Soon she was chairing the Local Arrangements Committee for that upcoming conference. After that came secretary and vice presidential positions, editorial roles with this publication, and eventually, president of IEEE DEIS.

That role was one that made her mother especially proud. As a very young child Kirkici once said she was going to be president. Her mother kept the issue of this publication with Kirkici's photo on the cover, saying, "You said you were going to be President, now you are a President!"

Kirkici calls IEEE "a good kind of drug" saying once you get hooked on volunteering for IEEE, it's very hard to let go, because it is so rewarding. It's a place where you can make mistakes, get positive feedback, and meet amazing people.

"It's incredible how much talent is in the group. You look at them and think, 'I thought I was good. But I'm not nearly as good as this person!' And you appreciate how that puts everything in perspective."

Now as a professor and chair of the Electrical and Computer Engineering Department at the University of South Alabama, Kirkici is continuing to plant the seeds for the next generation of engineers and physicists, clearing the path for them to be successful in their own careers, jobs, and studies. And like her father taught her, she teaches her students to look at the bigger picture.

"It's not just putting numbers into the equation and getting the correct answer. I always tell them, giving me a numeric answer has no meaning, unless I understand the way that you thought about solving this problem."

She looks at this as their time to explore, have fun, and consider the problems they'd like to solve.

"We need to continuously stress that whatever the students do today has a really big impact on future generations. That culture is so important. We have to keep pressing every single time, every single place, every single conversation. We always teach our students to do things that are good for themselves, but in doing so, they also impact the future generations."

It's the same message she received from her parents, teachers, and advisors.

"They didn't ask anything of me; they just said 'Sure. I'll support you.' And that's what we need to do."

With that kind of support, Kirkici has accomplished so much. Imagine what the next generation will do when we provide them with that same level of encouragement.

Elizabeth Aragao is a writer and marketing consultant based in Boston, Massachusetts. She started her career writing, producing, and reporting the news. Her favorite pieces were always profiles of interesting people and unique places. She later spent nearly a decade working in the power industry, which uniquely prepared her for this assignment: interviewing members of IEEE DEIS for a series of feature articles. When she is not writing, Aragao works with a variety of businesses, from retail stores to independent movie theaters, on their marketing.

News From Japan

Yoshimichi Ohki

Development of Ultralow-Loss and Low-Crosstalk Four-Core Communication Fiber

In today's international society, a vast amount of information that no one could have imagined a while ago is circulating in the world. This trend is expected to be further accelerated in the "new normal" life with COVID-19, where online social activities have become commonplace. Although organic polymers are also used for short-distance in-equipment information-transmission optical fibers, only amorphous silica (SiO_2) is used for long distances. In other words, what supports the information society is the insulating material familiar to readers of this *IEEE Electrical Insulation Magazine*.

As Google announced in 2018, a private 250 Tbit/s 6,600-km transatlantic communication cable Dunant, named for Henry Dunant, connecting the United States (Virginia Beach) and France (Saint-Hilaire-de-Riez), began operating in 2020 [1]. In recent years, the amount of intercontinental information transmission has continued to increase at a tremendous pace. In this regard, the importance of an optical submarine cable system as an international data communication infrastructure, which realizes large-capacity communication, is increasing.

As mentioned earlier, it is necessary to increase the amount of international information transmission. The improvement of the transmission capacity of optical communication systems using conventional single-mode fiber is approaching a theoretical limit. In order to respond to such a situation, it is necessary to increase the number of optical fibers accommodated in an optical submarine cable. Space division multiplexing (SDM) technology is drawing attention as such a technology. One example of SDM technologies is a technology that arranges a large number of optical fibers, such as 6,912 cores, in an optical cable with the same outer diameter as existing ones, such as 29 mm, as introduced in the News from Japan column in the May/June 2021 issue of this magazine [2]. The mode-division multiplexing is another example of such a method.

However, with conventional SDM technology, there is a limit to the number of optical fibers that can be accommodated without changing the outer diameter of the optical fiber cable, which makes further increases in communication capacity difficult. Therefore, as another SDM technology, a multicore fiber (MCF), of which cladding has multiple cores that can work as independent lines, is considered. This short article introduces the first successful development of MCF conducted by a Japanese team consisting of KDDI Research, Tohoku University, Sumitomo Electric Industries, Furukawa Electric, NEC, and Optoquest by the research funded by the Ministry of Internal Affairs and Communications.

As shown in Figure 1, optical fiber has a cylindrical coaxial structure consisting of a central core, through which light propagates, and a surrounding cladding. The principle of light transmission is the well-known total internal reflection of light. At the interface of two media with different refractive indices, light partly reflects and travels through the original medium. The rest refracts and travels through the new medium according to Snell's law, as shown in Figure 2. However, when light travels from a medium with a high refractive index to a medium with a low refractive index, if the angle between the direction of light and the interface is smaller than the critical angle, the light cannot travel to the low-refractive-index medium. As a result, all the light reflects at the interface and travels through the original high-refractive-index medium. This is total internal reflection. In an optical fiber, as shown in Figure 1, a medium with a slightly higher refractive index, called a core, is placed in the center of a concentric structure through which light travels, and a medium with a slightly lower refractive index, called a cladding, surrounds it. This is the principle of the transmission of light by total reflection.

The MCF with a cladding diameter of 125 µm, the standard diameter of single-mode fiber, has attracted much attention from the viewpoint of practical applications because its use has a major advantage in that existing techniques can be used for cutting, connecting, and splicing fibers [3], [4]. Because a typical core is about 10 µm in diameter, it is geometrically possible to place four cores in a typical cladding with a diameter of about

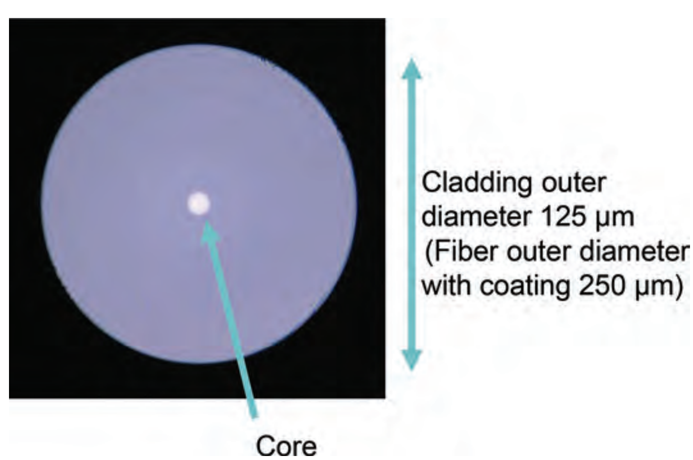

Figure 1. Cross section of a typical single-mode optical fiber.

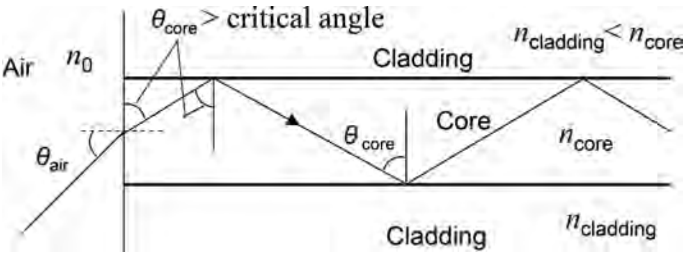

Figure 2. Principle of light propagation through a core in an optical fiber. n = refractive index, θ = injection angle of light.

125 μm. However, even if four cores with a higher refractive index than the cladding are simply placed in the cladding, crosstalk of information occurs between the cores. Crosstalk occurs because 100% of the light does not perfectly reflect, and some light leaks into the cladding despite the claim of total internal reflection. With this situation, the Japanese team has succeeded in preventing crosstalk by creating a region with an even lower refractive index in the cladding as shown in Figure 3.

In Japan, optical fibers are made by the vapor phase axial deposition method. In this method, soot-like SiO_2 is deposited by oxidizing $SiCl_4$ in an oxyhydrogen flame. Its chemical reaction formula is

$$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl.$$

Thin optical fiber can be obtained by heating and melting the base material with accumulated soot to vitrify it and then by drawing it.

The refractive index of SiO_2 is about 1.46. The addition of Ge to SiO_2 increases the refractive index, whereas the addition of F decreases the refractive index. Therefore, for example, it has already been confirmed that crosstalk in MCF was successfully prevented by arranging Ge-doped SiO_2 as a core at the center, non-doped SiO_2 as a cladding around it, and F-doped SiO_2 concentrically as the second cladding a little farther away. Crosstalk was also confirmed to be prevented by arranging undoped SiO_2 as a core, F-doped SiO_2 as a clad, and F-doped SiO_2 with an increased doping amount a little farther away as the second cladding. As a result, an uncoupled four-core optical fiber with a cross section shown in Figure 4 was developed by Furukawa Electric, one of the members of the Japanese team.

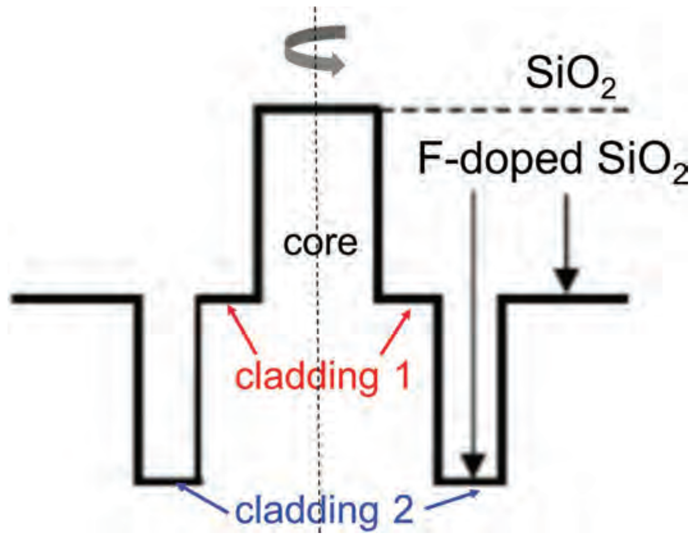

Figure 3. Example of refractive index distribution in a multi-core fiber (MCF).

The typical specifications and features of the MCF developed by Furukawa Electric are listed in Table 1 [5]. In addition,

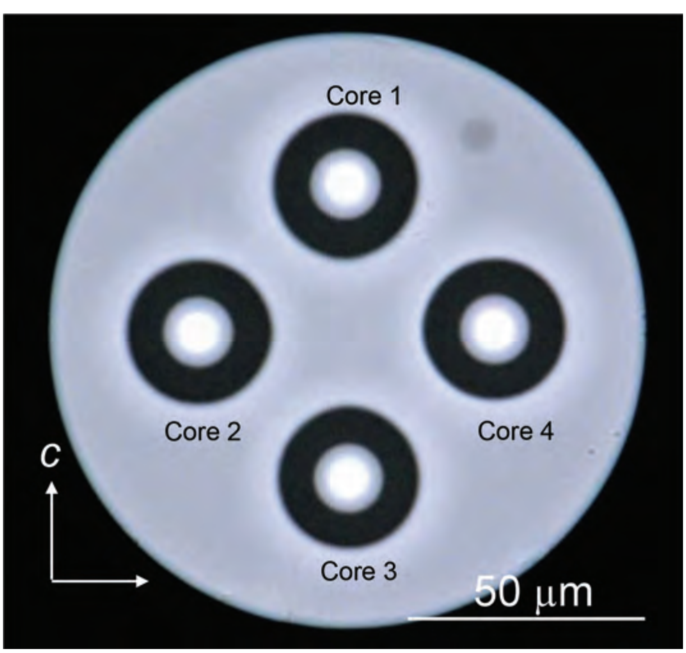

Figure 4. Cross section of the uncoupled four-core optical fiber developed by Furukawa Electric.

Table 1. Specifications and features of the uncoupled four-core optical fiber at 1550 nm developed by Furukawa Electric

Characteristic	Unit	Value
Cladding diameter	μm	125
Coating diameter	μm	245
Core pitch	μm	43.0
Effective area	μm2	87.1
Cut-off wavelength (22 m)	nm	1,539
Dispersion	ps/nm per km	22.6
Dispersion slope	ps/nm2 per km	0.06
Attenuation loss		
Core 1	dB/km	0.155
Core 2	dB/km	0.156
Core 3	dB/km	0.157
Core 4	dB/km	0.155
Intercore crosstalk		
Core 1–Core 2	dB/100 km	–63.8
Core 2–Core 3	dB/100 km	–60.7
Core 3–Core 4	dB/100 km	–62.7
Core 4–Core 1	dB/100 km	–61.8

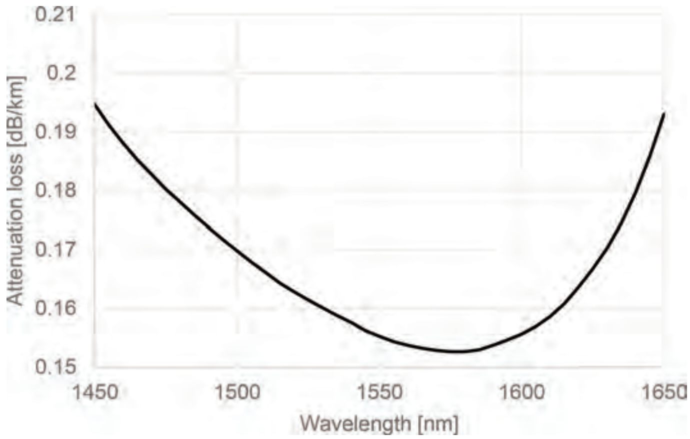

Figure 5. Attenuation loss spectrum of core 1 of the uncoupled four-core optical fiber developed by Furukawa Electric.

Figure 5 shows the attenuation loss spectrum of core 1 of the developed uncoupled four-core optical fiber.

The main features of the newly developed MCF are as follows: (1) It uses uncoupled four-core fiber, which has four times as many cores as the conventional single-core fiber cable. Therefore, it is possible to increase the transmission capacity significantly while maintaining the same fiber size. (2) Crosstalk between cores, which is a problem in MCF transmission, is suppressed to a low crosstalk of −60 dB/100 km or less while achieving the world's lowest transmission loss of 0.155 dB/km for MCF. (3) By applying the developed optical fiber, the team has demonstrated that it is possible to transmit optical signals of 56 terabits per second over 12,000 km in addition to being able to transmit ultra-high-capacity optical signals of 109 terabits per second over 3,120 km [6].

The submarine cable developed by the Japanese team can accommodate a maximum of 32 uncoupled four-core fibers, which makes possible optical transmission using 128 cores. As a whole, the Japanese team will construct a 3,000-km-class optical submarine cable system covering the Asian region, etc., consisting of optical submarine cables accommodating 32 cores (16 pairs) of four-core fibers, multi-function devices, and optical amplifiers. The team has confirmed the possibility of increasing the capacity of the cable to about 1.74 petabits per second using the developed submarine optical communication system [7].

This article was completed in cooperation with Akira Fujisaki, Ryuichi Sugizaki, and Masanori Takahashi of the Furukawa Electric Co. Ltd.

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Stories From China

Lv Zepeng

3D Printing for Advanced Electrical Insulation: Recent Progress in China

3D printing is a manufacturing process to create three-dimensional objects directly from a computer designed model. The 3D-printed objects are fabricated by the gradual addition of point-wise, line-wise, or layer-wise material elements, making it also known as “additive manufacturing” [1]. Additive manufacturing technology was developed decades ago with Chuck Hull’s invention of stereolithography in the 1980s. Due to its availability to improved performance, complex geometries, and simplified fabrication, additive manufacturing is now actively embraced by a variety of industrial sectors, e.g., automotive, aerospace, medical and dental care, education, art, culture, and so on. China has given great attention to the 3D printing technology. The Ministry of Industry and Information Technology and the National Development and Reform Commission have successively issued policy documents (in 2015, 2017, and 2020) to support the research and development of 3D printing. Moreover, 3D printing is also highlighted in the “Made in China 2025” program.

The application of 3D printing in the electrical power industry is also an emerging topic worldwide. Currently, various power system components have been 3D-printed for better product performance and higher fabrication efficiency, including electrical power fittings, substation buildings, battery electrodes, and downsized device models for engineering education [2]. Attention is also paid to the 3D printing of electrical insulation objects. However, most of the initial studies are based on generic, commercially available configurations, which cannot fully use the advantages of 3D printing. Fortunately, innovative progress in the 3D printing of advanced electric insulation was achieved by Chinese researchers and engineers, which can be categorized in the aspects of material, technique, and application.

Innovative 3D Printing Materials

The first progress is about the 3D printing materials. Generic printing materials usually have high dielectric loss, inadequate mechanical strength, and unsatisfactory thermal properties,

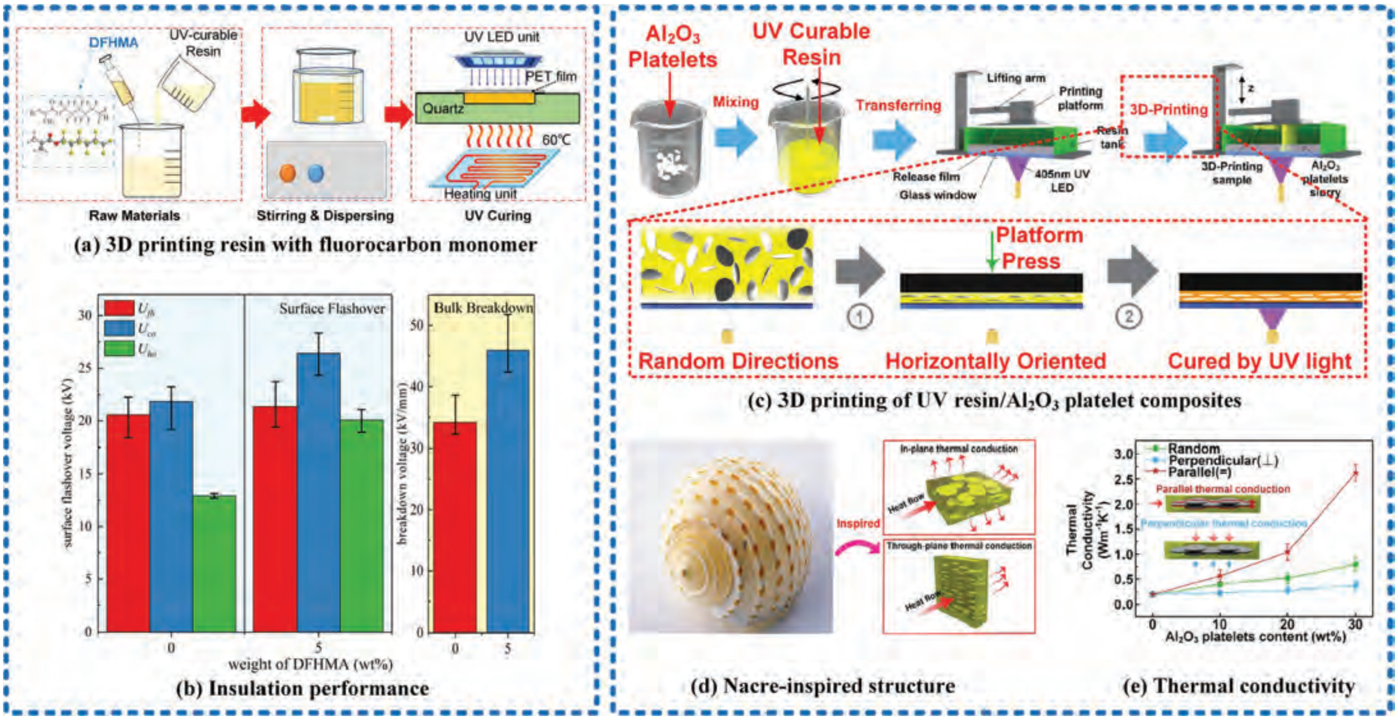

Figure 1. 3D printing materials with elevated properties. (a) and (b) are the fluorocarbon-modified 3D printing material (UV resin) [3]. (c) through (e) are the 3D printing composites with bioinspired structure and high thermal conductivity [5].

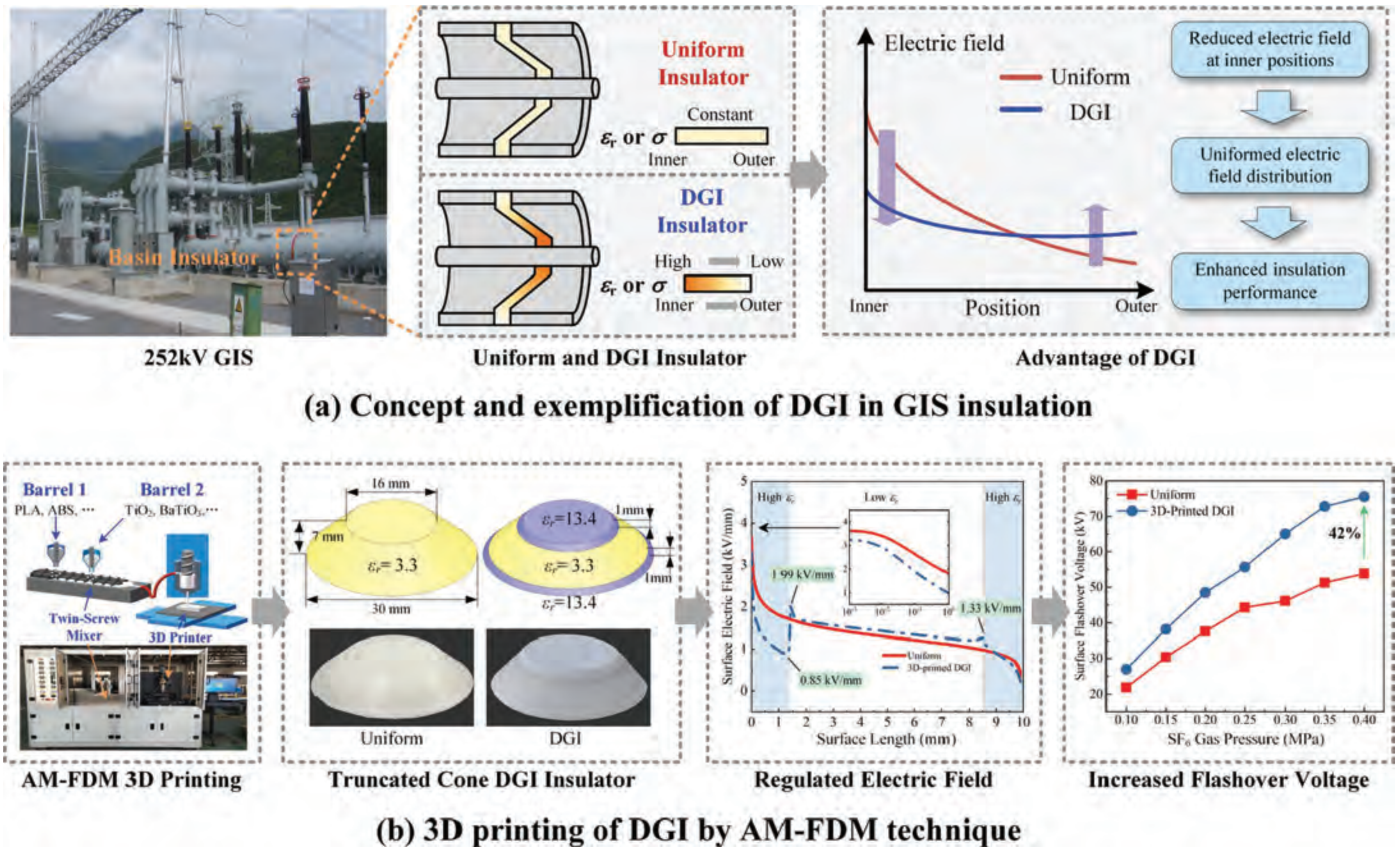

Figure 2. 3D printing of dielectrically graded insulation (DGI). The active-mixing fused deposition modeling (AM-FDM) description is from [12]. The photo of 252-kV gas-insulated switchgear (GIS) is provided by Shandong Taikai High Voltage Switchgear Co. Ltd.

restricting their use in electrical insulation. Recently, Zhang's group from Xi'an Jiaotong University [3] doped 5 wt% of fluorocarbon acrylate modifier (dodecafluoroheptyl methacrylate) into the photocurable, 3D printing material, which significantly increase the bulk breakdown strength (34.7%) and surface flashover voltage (21.1%) due to the introduction of electron trap sites, i.e., F atoms. Huang's group in Chongqing University [4] developed a dual-curing 3D printing material, in which reduced dielectric loss and increased impact strength is found. Another interesting research topic [5] is the 3D printing of bioinspired nacre-like insulation materials. The layer-by-layer formation process makes 2D Al_2O_3 platelets well-oriented in the UV resin and increases the thermal conductivity of 3D printing material 14 times. These studies confirm that when a proper modification strategy is used on the 3D printing material, the applicability of 3D printing in electrical insulation can be largely improved, and some novel insulation material (i.e., thermally conductive by electrically insulative) can be achieved (Figure 1).

Innovative 3D Printing Techniques

The progress in novel 3D printing techniques also facilitates the implementation of advanced insulation components. A promising example is the 3D printing of dielectrically graded insulation (DGI), which is also known as the electric insulation using functionally graded material. The distinctive feature of DGI is the nonuniform spatial distribution of electrical permittivity or conductivity (i.e., dielectric gradient), which offers the ability of electric field regulation inside or along the surface of solid insulators. Previous studies [6] have verified the effectiveness of DGI in enhancing the insulation performance, elevating the reliability and life-span of insulation devices [Figure 2(a)]. However, fabrication of DGI is challenging due to the complexity and difficulty in precisely building the dielectric gradient.

In 2015 Li et al. from Xi'an Jiaotong University [7] proposed that 3D printing can be used to build DGI and pointed out that the key issue in developing DGI-applicable 3D printing methods is the ability to change the dielectric parameters of each geometrical element (e.g., layers or voxels). Thereafter, two novel 3D printing techniques, including the active-mixing fused deposition modeling [8] and multi-material 3D printing with constraint sacrifice layer [9], were developed to build DGI using thermoplastic and UV curable materials, respectively. Based on the corresponding 3D printing device and customized control program, truncated cone DGI spacers were fabricated, which has significantly increased (42% maximum) surface flashover voltage [Figure 2(b)]. The above research progress indicates that 3D printing can become an effective approach for the realization of next-generation, high-performance insulation components, especially when complex outline geometry or internal structure is involved.

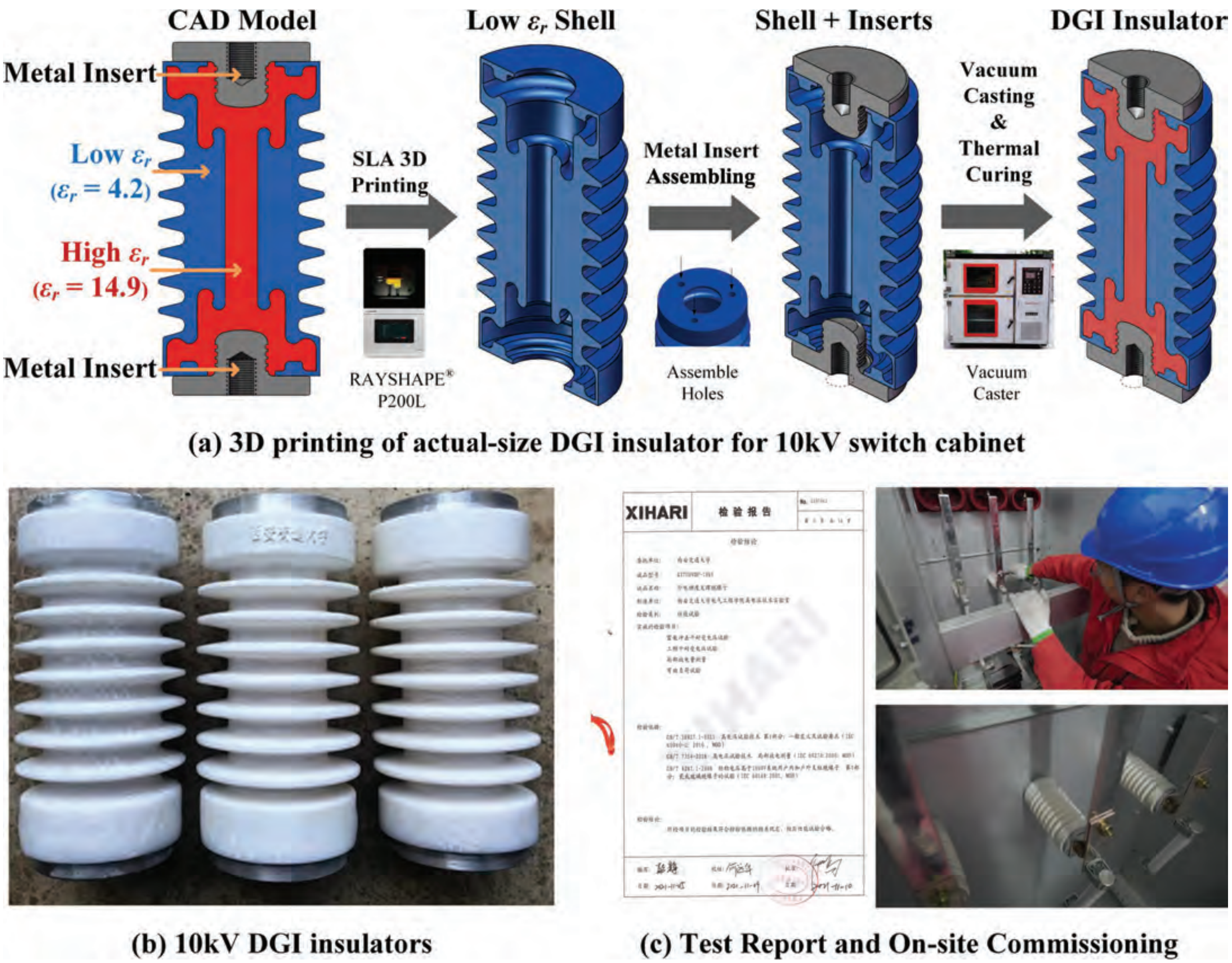

Figure 3. Fabrication and on-site commission of 10-kV dielectrically graded insulation (DGI) insulator.

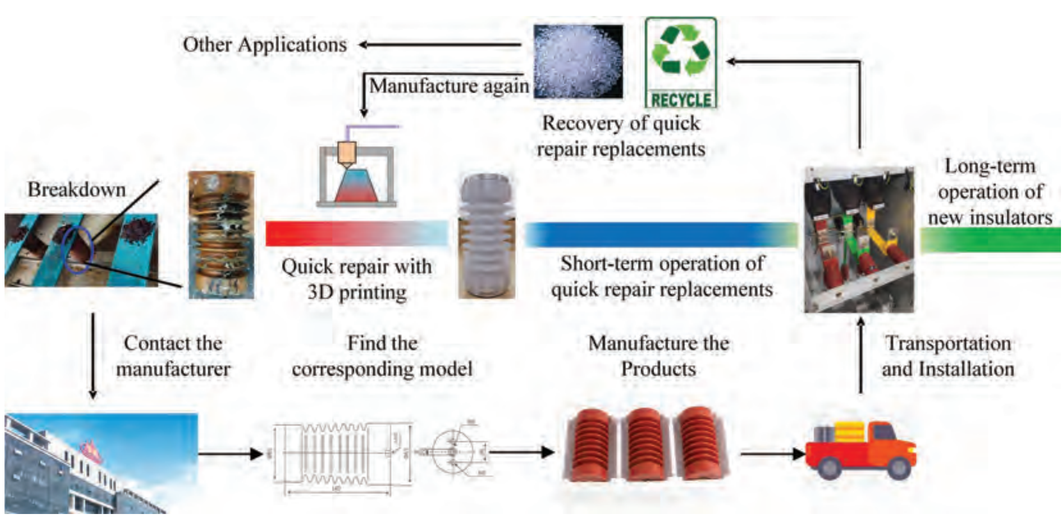

Figure 4. Quick repair of solid insulators assisted by 3D printing technology.

Innovative 3D Printing Applications

With the development of both materials and techniques, the application of 3D printed insulators is also realized in some most current studies. One is the application of a DGI support insulator developed for the switch cabinets in distribution networks (Figure 3). This insulator is made by a combination process of photocuring-based 3D printing and vacuum casting and has a three-region dielectric gradient as shown in Figure 3(a). The uniformity of electric field is improved by this permittivity gradient. Standardized test results according to DL/T 404 indicate that the 3D printed DGI insulator satisfies the requirements of industrial-grade 10-kV electric equipment. Moreover, the partial discharge inception voltage is increased by 17.5%. In November 2021, the on-site commissioning of the DGI insulator was conducted in a 10-kV switch cabinet in Anji, Zhejiang province, which has been in stable operation ever since.

Another application of a 3D printed insulator is as a 10-kV support insulator used for quick repair. The economic losses caused by insulation accidents are strongly dependent to the repair time, but the speed of repair is often limited by manufacturing and transportation in the absence of field replacements. In a report from Xi'an Jiaotong University [10], a 10-kV support insulator was built using a desktop 3D printing device and polycarbonate (PC) material. Experimental results show that the flashover voltage and partial discharge inception voltage of the 3D printed PC insulator were close to the epoxy control, and the total manufacturing period took only 1 to 2 days for the 3D printed PC insulator, which is much less than epoxy insulators because the time-consuming fabrication of casting molds is no longer necessary. This study is meaningful for reducing power black-out and economic loss caused by insulation accidents (Figure 4).

In summary, by continuous R&D from Chinese researchers and engineers, the material restrictions in the electrical insulation use of 3D printing can be overcome, and the advances in 3D printing techniques enable the implementation of conventionally unavailable insulation components (e.g., dielectrically graded insulation). All this progress leads to successful deployment of 3D printed support insulators in 10-kV on-site equipment, expanding the applicability of 3D printing technology and improving the comprehensive performance and fabrication efficiency of electrical insulation components.

Acknowledgment

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Young Professionals

Designing a Medium-Voltage, Solid-State, Medium-Frequency Transformer: From Specifications to Prototype, and All the Steps In Between

Life for a young researcher is often limited to one area of expertise. Therefore, being a part of a team with many different specialties and a clear goal is highly motivating. This is the story of a project that forced a team of young researchers from SuperGrid Institute into the reality of developing an operational system from beginning to end. For almost three years, we designed and manufactured a medium-voltage, medium-frequency transformer, from the specifications to a prototype, through testing to validation.

SuperGrid Institute, located in Villeurbanne, France, is an independent innovation and research company dedicated to the development of technologies for the future power transmission system and the massive integration of renewable energy. The purpose of SuperGrid Institute is to build the knowledge and skills that industries need to develop reliable HVDC grids.

A total of 155 people of 21 different nationalities share the same ambition, to play a key role in the progress of electrical power systems. We identify and address the technological challenges faced by our partners and customers, we co-develop solutions and products with European industrial and academic partners, and we offer high-value-added testing, expertise, and research services.

With an average age of 33, young researchers are at the heart of our research and development teams. This project was no exception, being led by a group of highly motivated young people, each with their own acute expertise.

The Project

SuperGrid Institute was solicited by a customer to design and prototype an innovative medium-frequency transformer. As project leader, and with almost 15 years of experience under his belt, Martin Guillet was able to understand the specification and put together a team to overcome the challenges of this multidisciplinary project. Each member brought their distinct but crucial skillset to the table, making it possible to successfully accomplish the client's objective.

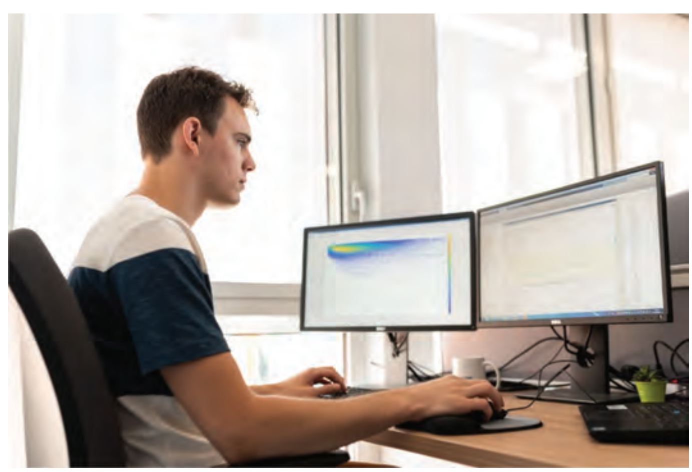
In the first stage of the project, the software was used to identify the theoretical feasibility of the transformer according to the specifications given by the client. "After several executions of this software, it was made clear that due to the geometrical constraints, the only possible route to take to end up with a fully functioning transformer was to select a solid insulation for the high voltage coil," explained Alexis Fouineau.

The Choice of Materials and the First Prototypes in the Midst of a Pandemic

When it came to selecting the insulating material, Sophie Iglesias was appointed to take on the responsibility. After receiving her PhD in material science in 2018, she took up the position of material scientist at SuperGrid Institute. An epoxy composite was chosen based on the most critical parameters extracted from Alexis' software.

With the geometry and key materials selected, a major milestone in the development process was achieved. Then came the

Alexis Fouineau finished his PhD on the design methodology of medium-frequency transformers for medium- to high-voltage applications in 2019. As part of his PhD, he developed a software to optimize transformers' designs: a valuable tool for the conception of these components.



The question of a transformer withstanding 11 kV in a compact geometry was tackled by Hugo Reynes. In 2018 he completed his PhD at SuperGrid Institute with INSA, University Lyon 1, focusing on the dielectric design of power electronics, making him the perfect person to be involved at this stage.

Long evenings in the laboratory preparing the samples and adapting to the new normal of working with face masks and social distancing—(from left to right) Priscillia Daniel, Sophie Iglesias, and Hugo Reynes.

question of the termination connecting the transformer, and how to make its design match the requirement for an overall compact system.

Unexpected global events disturbed the progress of the project. “During the COVID-19 pandemic, the lockdown forced us all to work from home,” remembered Hugo Reynes, “and that is how the first termination design was, in fact, created remotely! For this phase of the project, many experts were consulted, remotely, working from their living rooms.”

Then the situation got better and the team found its way back to the laboratory where the first prototypes were prepared to test the termination designs. Testing the samples in the dielectric platform proved to us that the simplest model was not robust enough. To achieve the low partial discharge target and pass a dielectric withstand up to three times the nominal value, a more complex termination design was proposed.

To test this new model, there was no choice other than to make a new mold that would be used to cast epoxy resin around the HV coil. Nicolas Deveaux started his career as a draftsman at SuperGrid Institute in 2017. He already had some prior experience in designing molds for epoxy samples, though nothing as intricate as what we needed at the time: “To succeed with this level of complexity, the collaboration of the whole team and the support of renowned experts was once again necessary. After each molding phase or test, several tweaks to the casting process were necessary to eradicate defects in the termination samples,” explained Nicolas.

(From left to right) Martin Guillet, Alexis Fouineau, Hugo Reynes, Nicolas Deveaux, Pierre Bertrand, and Servane Haller presenting the operational prototype of a medium-frequency transformer.

Once the termination design was validated, it was time to manufacture the prototypes. “Designing a mold for the full-size prototype was very challenging, but we had learned a lot from all the previous steps,” continued Nicolas. Once again, everyone teamed up with Nicolas to make sure the mold would give us the best chance of making prototypes that would pass the required dielectric tests.

Christian Lao, a laboratory technician with a wealth of experience in polymers, was in charge of optimizing the process so that the right injection parameters were adjusted to match all the requirements of the design. This task was completed by Pierre Bertrand, who took over Christian’s position within the Institute, to manufacture the final prototypes to be delivered to the customer.

Ultimately, the transformers were assembled by Alexis and then tested by Hugo. The whole team gathered in the dielectric platform to test the final electrical performance. With the last lightning impulse test over, and all the other tests confirming the target performance, we turned the page on a three-year-long chapter.

Servane Haller
SuperGrid Institute

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

John J. Shea

The Physics of Organic Electronics—From Molecules to Crystals and Polymers

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ISBN 978-0-7503-3347-4
119 pp., $159 (eBook), 2022

This book provides the fundamental theory for organic electronics including organic metals, superconductors, and semiconductors for organic electronics. It is intended for students, researchers, or engineers interested in learning about organic electronic theory and devices, who have some background in condensed matter physics and either basic quantum mechanics, chemical physics, or materials science.

The book can be divided into two parts. The first part presents the theory involving short reviews on intermolecular interactions, structure, and scattering theory followed by the main theories describing the interaction of electronics in quasi one-dimensional systems, including a model and case studies. The case studies illustrate the most relevant transport properties and mechanisms, phase transitions, and magnetic effects of interest. The remainder of the book covers the physics of organic light emitting diodes, organic solar cells, organic transistors, and molecular-scale electronic devices.

The future of organic electronics brings with it the promise of many new applications. This book is for our readers interested in learning about this theory who already have the background necessary to understand the material being presented.

DC Microgrids—Advances, Challenges, and Applications

N. Gupta, M.S. Bhaskar, S. Padmanaban, and D. Almakhles, Editors
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480 pp., $225 (Hardcover), 2022

A microgrid is generally defined as a self-sufficient power source that provides power to a local geographic point such as a university campus, building, hospital, or neighborhood for example. They typically have distributed energy resources (DERs) such as solar power photovoltaic (PV) arrays, wind generators, and battery energy storage. But, they can also employ other power sources such as hydro, fuel cells, geothermal, and others. They are typically defined as being local to a specific area, can be run independent of the AC power grid, and are intelligent, meaning that they can control bidirectional power flow and control loads based on load demand and available power. Microgrids can be either AC or DC based or a combination of both. The interest in DC microgrids is growing because of the emergence of inherent DC renewable power sources (PV and batteries) along with the improvement of solid-state power conversion equipment in combination with some of the inherent advantages of DC over AC, including no reactive currents, no harmonics, and no phase matching required when transitioning between power sources.

This book provides a view into many aspects of DC microgrids. There is a multitude of factors that need to be considered when using a DC power system, especially when connecting a DC microgrid to an existing AC power. The topics described include protection challenges, control schemes, fault detection methods, energy management methods including power sharing, matrix, multilevel, and Z-source converter technology reviews, a voltage source converter DC microgrid case study, and various passive and active islanding methods.

The editors of the book have done an excellent job at taking many various topics on DC microgrids and making a book that covers many of the important topics when designing DC microgrids but with a bias towards DC implementation. The book covers many of the important topics to be considered in a DC microgrid but does not always present a viable or practical solution to some of the issues. For some readers, some areas to be aware of in this book are the lack of reference to North American standards and regulations and some grammatical errors that may confuse the reader. However, if you are looking to understand the technology of DC microgrids and some of the issues and challenges about DC microgrids, then this book is an excellent way to quickly learn about DC microgrids.

Innovative Processes and Material in Additive Manufacturing

S. Singh, C. Prakash, and S. Ramakrishna, Editors
Woodhead Publishing Series
Elsevier
50 Hampshire Street, 5th Floor
Cambridge, MA 02139

http://www.elsevier.com/books-and-journals
ISBN 978-0-323-86011-6
325 pp., $320 (Softcover), 2023

Additive manufacturing is a relatively new method for creating parts by using computer aided designs (CAD) software models to control machines that lay down layer upon layer of a material to create the CAD part. "Additive manufacturing" is the more general term, but "3D printing" is also frequently used to describe this process.

Additive manufacturing allows designers to quickly create parts without the need of molds or other tooling generally required for traditional molding of plastic parts. Also, traditional machining of parts from blocks of material wastes material, whereas additive manufacturing adds material during the process rather than removing the material, eliminating waste. Also, additive manufacturing can be used to create intricate parts that cannot be made by traditional machining methods.

This book provides a glimpse into the world of additive manufacturing. It is a collection of background and application examples using the latest additive manufacturing techniques and materials. The editors of the book assume that the reader is already familiar with the basics of additive manufacturing because they jump right into discussing the quality characteristics of additively manufactured polypropylene and the effects of post-heat treatment of parts, primarily used to reduce residual stress. Other chapters provide a comprehensive overview of the wire arc additive manufacturing method and the steps needed to ensure high quality parts from this method along with a description of an extrusion-based process.

The remainder of the book describes various application-specific products, with the majority in the medical and biomedical fields. Other applications include hydrogels for scaffolding and concrete 3D printing for housing. 4D manufacturing, involving time as the fourth dimension, is briefly detailed.

This book is not for someone looking to learn about the basics of additive manufacturing but rather for someone who wants to learn about a few of the issues and solutions being used to solve issues that can arise in the additive manufacturing process. It is also useful for those interested in certain medical and biomedical applications becauase these are the primary focus of the applications presented.

Advances in Energy Storage—Latest Developments from R&D to the Market

A. Hauer, Editor
John Wiley & Sons Ltd.
111 River Street
Hoboken, NJ 07030
http://www.wiley.com
ISBN 978-1-119-23935-2
927 pp., $165 (Hardcover), 2022

Energy storage is a critical component in power systems of the future. Although battery energy storage has been the most prevalent storage media in the news today, there are a wide variety of other types of energy storage devices either commercially available or still in the research stages. This book provides a comprehensive summary of the technical details of many different types of energy storage methods.

After a brief introduction on the background of energy storage for future energy systems, the book covers six different energy storage technologies. The first part describes electrochemical, electrical, and superconducting technologies. Battery chemistry is detailed along with descriptions of the operation of various battery types including lead acid, Li-ion, flow, and sodium-sulfur batteries. Supercapacitors are the electrical energy storage media. They are used as an alternative to battery energy storage and compared to batteries. Superconducting magnetic energy storage (SMES) is covered in great detail with information on operation, key technologies, testing, wires and tapes, cryogenic technology, and control strategies.

The next part covers mechanical and pumped hydro energy storage technologies. After an overview of pumped hydro, the authors discuss pumped storage machines, hydro-mechanical equipment, and hydraulic short-circuit operation. Part three covers another mechanical energy storage system using compressed air energy storage (CAES) and flywheels. This section describes the present status of the technology, various methods, and market acceptance for CAES.

The fourth part describes chemical energy storage with a focus on hydrogen gas or syngas, illustrating the conversion of CO_2 and renewable H_2 to methanol and hydrogen fuel cells.

Part five deals with thermal energy storage. Background on this technology, new phase change materials, sorption material advancements, vacuum insulated thermal storage systems for buildings and industrial applications, heat transfer enhancement methods, and industrial applications (combined heat and power) for thermal energy storage are covered.

Part six makes the case for using energy storage to reduce global warming and also discusses regulatory barriers and markets. This section deals with the business side of these technologies including energy storage in electricity markets, public acceptance of various technologies, a business case for energy storage in Japan and Germany, and the integration of renewables using a distributed energy approach.

This book would be of interest to practicing engineers and material scientists and students studying and developing future power grid technologies. It provides the latest technical details into many of the energy storage systems being developed today that would help the reader quickly understand these technologies and learn about the performance and limitations for each technology.

Wireless Communication Network Technology and Evolution

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27 Warren Street
Suite 401-402

Hackensack, NJ 07601
http://www.worldscientificpress.com
ISBN 978-981-124-505-3
645 pp., $168 (Hardcover), 2022

Wireless communication has become ubiquitous throughout the world and continues to grow in speed, size, and complexity. This book explores three wireless communication network technologies and the evolution of cellular mobile networks covering 5G, Wireless Local Area Network (WLAN), and Narrow Band Internet of Things (NB-IoT).

The authors jump right into the technical details by introducing the fundamentals of communication networks, leading into an explanation of evolution and technical details of 1G to 4G technologies with detailed explanations of 4G and Wi-Fi networks. Application examples and the future outlook for Wi-Fi are also covered. The history and evolution of the internet of things (IoT) with a focus on the Narrow Band Internet of Things (NB-IoT) is reviewed along with several other protocols. The majority of the book focuses on explaining 5G technology, including applications, performance, and the technology of the physical layer of the 5G access network. Comparisons are made between 5G technology in China and the United States with some insights in the prospects of 6G.

Our readers in enterprise engineering and communications professionals or students will find this book to be an invaluable resource for learning about the latest technologies in cellular communications. It is very well written and provides clear and concise explanations of each topic without delving into too much mathematical deviations but rather using detailed narratives to explain the material. It is well worth acquiring a copy of this book if you want to learn more about the latest communication protocols.

Signals, Instrumentation, Control, and Machine Learning

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5 Toh Tuck Link
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http://www.worldscientific.com
ISBN 978-981-125-186-3
842 pp., $198 (Hardcover), 2022

This book uses an example of a continuous steel casting application as a way to teach students about process and control systems including all the technical details that could be used in such an application. The book begins by describing the continuous casting process of steel and the issues that occurred in the system. The remainder of the book details various aspects of control systems for this application as well as generalities.

This involves an introduction to signal analysis, signal processing, filtering, and associated instrumentation. Example topics cover AC and DC signal coupling methods, motion sensing circuits, and strain gauge instrumentation. Digital sampling methods are described using A/D and D/A converters, and extensive analog and digital filtering methods are presented. Spectral analysis and control system basics are also introduced along with basic controller designs. Basic elements machine vision and machine learning are also covered.

The appendices provide many fundamental methods for reference. These include useful mathematical formulas, system classifications, the basics of random signal, Fourier transform, Laplace transform, basic types of sensors and actuators, mechanical beam models, and select MATLAB testbed models.

This book provides a comprehensive example for solving a real-world problem to illustrate how real processes are controlled. Students studying mechanical engineering, electrical engineering, or control process engineering would find this book very useful for gaining vital knowledge of a control system.

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 15–19, 2023
Centennial Edition
Hilton Meadowlands, East Rutherford, NJ
Conference Chair: Kai Wu, Xi'an Jiaotong University, China
Email: wukai@xjtu.edu.cn
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 18–21, 2023
Quebec City, Quebec, Canada
Conference Chair: Joe Williams, Electrolock Inc.
Email: joe.williams@electrolock.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 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

2023 Fully Sponsored Conferences

Conference	Date	Location	Website and contact
ICEMPE	May 7–10, 2023	Shanghai, China	jdwu@sjtu.edu.cn www.icempe.org
EIC	Jun. 18–21, 2023	Quebec City, Canada	joe.williams@electrolock.com https://ieee-eic.org/
ICDL	Jun. 25–28, 2023	Worcester, MA, USA	jyagoobi@wpi.edu https://www.icdl2023.org
ISE	Sep. 18–23, 2023	Linz, Austria	ise19@jku.at http://ise19.somap.jku.at
CEIDP	Oct. 15–19, 2023	East Rutherford, NJ, USA	wukai@xjtu.edu.cn https://ceidp.org/

their application; microelectronics and photonics; eco-friendly dielectrics and recycling; biodielectrics; and electrohydrodynamics.

July 3–7, 2022
Palermo, Italy
To be held in a hybrid mode (in person and virtual)
Conference Chair: Pietro Romano, University of Palermo
Email: pietro.romano@unipa.it
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).

June 25–28, 2023
Worcester Polytechnic Institute, Worcester, MA, USA
Conference Chair: Jamal Yagoobi
Email: jyagoobi@wpi.edu
Website: https://www.icdl2023.org

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: yiny@sjtu.edu.cn
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.

September 25–29, 2022
Chongqing, China
Conference Chair: Feipeng Wang, Chongqing University, China
Email: f.wang.2015@ieee.org
Website: http://www.ichve2022.org/

ISE (International Symposium on Electrets)

This is a research-oriented conference on electret materials held anywhere in the world every three years. Some topics of interest include charge injection, transport, and trapping; thermally stimulated current and dielectric relaxation; nanoscale measurements of electrostatic phenomena; ferroelectric, piezoelectric, and pyroelectric phenomena; ferroelectret and photoelectret; electrostatic and dielectric phenomena in life science: bioelectret; nonlinear electrical and optical effects; application of thin-film ferroelectric; electrets in organic electronics; and soft actuators and sensors.

September 18–23, 2023
Linz, Austria
Conference Chair: Martin Kaltenbrunner, Johannes Kepler University Linz
Email: martin.kaltenbrunner@jku.at
Website: http://ise19.somap.jku.at

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.

July 11–15, 2021
It was held as a virtual conference.
Conference Chair: Abdul-Malek Zulkurnain, Universiti Teknologi Malaysia
Email: zulkurnain@utm.my
Website: attend.ieee.org/icpadm-2021/

ICEMPE (International Conference on Electrical Materials and Power Equipment)

This is a conference on applications of electrical insulation and dielectric materials to be held every two years in China. Some topics of interest include dielectric physics related to conduction, polarization, and breakdown (trees); space charge; molecular simulation and calculation; insulating materials related to performance, composition, and structure;

nanocomposites; eco-friendly dielectrics; biodielectrics; power equipment related to fabrication, detection, operation, and assessment; cable, motor, transformer, GIS, HVDC insulating materials and phenomena related to superconductivity, arcing, gas discharge, and surface discharge; structural optimization of electrical insulation; electrical insulation techniques under extreme conditions and high temperature; and electrical insulation in space.

May 7–10, 2023
Shanghai, China
Conference Chair: Yi Yin
Email: yiny@sjtu.edu.cn
Conference Secretary: Jiandong Wu
Email: jdwu@sjtu.edu.cn
Website: www.icempe.org

IWIPP (International Workshop on Integrated Power Packaging)

IWIPP is a biennial IEEE event dedicated to advancing the state of the art in power semiconductor packaging, which is widely recognized as one of the critical factors influencing the performance and reliability of today's power electronics. The conference is financially sponsored by the IEEE Power Electronics Society, IEEE Dielectrics and Electrical Insulation Society, Power Sources Manufacturers Association, and the IEEE Electronics Packaging Society.

August 24–26, 2022
Grenoble, France
Conference Chair: Prof. Francesco Lannuzzo
Email: fia@et.aau.dk
Website: http://iwipp.org

Technically Sponsored Conferences

These are conferences in which the IEEE DEIS participates. The papers meeting IEEE standards may be available via IEEE Xplore.

INSUCON (International Electrical Insulation Conference)

INSUCON is being held in Europe at intervals of three or four years. The first conference in this series was held in 1970 and was called the BEAMA International Conference. Since 1998 INSUCON has been organized by the Electrical Insulation Association, a trade association in the UK, and the conference attracts engineers, consultants, and university researchers from all over the world. INSUCON covers a wide range of materials, processes, and products used in engineering applications. Although generally directed at medium and high voltage equipment, there is a broad scope to the technical papers that are accepted for publication.

April 18–20, 2023
Birmingham, UK
Conference Chair: Andrew Keefe
Email: andrew.keefe@altana.com
Technical Chair: Fabrice Perrot
Email: fabrice.perrot@ge.com
Website: https://insucon.org/

ISDEIV 2023 (30th International Symposium on Discharge and Electrical Insulation in Vacuum)

The International Symposium on Discharge and Electrical Insulation in Vacuum (ISDEIV) is a nonprofit, international organization whose purpose is to encourage the advancement of the science and application of electrical insulation and discharges in vacuum, primarily by conducting symposia for the exchange of scientific information. The symposia are usually held biennially. The symposia are interdisciplinary meetings for the exchange of results, presentation of progress, and discussion of ideas and challenges for the future in the field of electrical discharges and insulation in vacuum. Both fundamental and applied aspects are covered.

June 25–30, 2023
Okinawa, Japan
Website: http://isdeiv2023.w3.kanazawa-u.ac.jp/index.html

Bulletin Board

Report on the 2022 IEEE DEIS Summer School in Monmouth, Wales

Introduction

From August 21 to 25, 2022, the sixth annual IEEE DEIS-sponsored Summer School on Extra-High Voltage DC (EHVDC) Transmission took place in Monmouth, located on the border between England and Wales, UK. Unfortunately, the summer school was not spared from the COVID-19 pandemic, which, as many of us know, has become a constant companion in our everyday lives. As a result of some cases of illness among the moderators and speakers, the summer school was quickly adapted into an all-too-familiar hybrid event. However, this made it possible for all participants to attend all presentations, network, and exchange ideas in the best way possible, while also staying safe.

The objective of this year's summer school was to organize brainstorming sessions among young researchers that revolved around challenging topics in the field of EHVDC transmission and in the field of dielectrics and electrical insulation. This included the discussion of research methodologies and support for the creation of research networks and aimed to stimulate subsequent activities, possibly including joint research work, presentations, and special sessions at future IEEE DEIS conferences. The summer school was accessible for PhD students, early-career postdoctoral researchers, and early-career engineers working in the industry. Overall, there was a total of 28 participants and 5 moderators, forming an international gathering from Austria, France, Greece, Italy, India, Sweden, Switzerland, the UK, and others. The summer school was led by Thomas Andritsch, John Fothergill, Peter Morshuis, Istebreq Saeedi, and Alun Vaughan. This report was written by this year's participants for the wider IEEE DEIS community and provides a summary of this year's summer school.

Figure 1. Highlights of Monmouth: Shire Hall, the Kings Head Pub, and the River Wye.

To meet the global net-zero targets, the current quest to simultaneously increase electrification and decarbonize has stimulated a plethora of technological initiatives, both in academia and in industry. HVDC transmission, which facilitates the remote connection of load centers to renewable energy sources, such as hydroelectric, wind, and solar, has received significant attention and is becoming increasingly widespread. The benefits of HVDC over traditional HVAC include aspects such as controllability, high efficiency, ability to be transmitted over greater distances, flexibility to transmit between systems operating at different frequencies, absence of the skin effect in conductors, and lower environmental impacts [1].

HVDC transmission primarily employs two technologies: overhead conductor-based lines, and cables [1]. Typically, transformers are used for long-distance terrestrial power transfer. Comparatively, cables need fewer transmission line corridors and offer a wider variety of uses, including subterranean and underwater power transmission. Furthermore, it allows the

Figure 2. First session with Peter Morshuis (left) and John Fothergill (right).

Figure 3. Participants (and organizers) with their thinking hats.

integration of offshore renewable energy sources [2]. Current HVDC insulated cables may be separated into mass-impregnated (MI) and extruded DC cables [3]. MI cables have several issues, including expensive installation and maintenance costs, complex production and maintenance procedures, and low working temperatures, and are potentially environmentally polluting [2]–[4]. Therefore, HVDC extruded cables have further been identified to be the predominant alternative for HVDC transmission, owing to their advantages associated with maintenance, lower cost, and the ease of installing accessories.

However, a number of issues currently impede the mass adoption of HVDC transmission technology, which could be largely ignored in the HVAC case. These issues revolve around the role of field- and temperature-dependent conductivity, insulation temperature, space charge accumulation, and aging. These pressing issues therefore formed the basis of discussion for this session of the IEEE DEIS summer school.

Over the course of the summer school, participants were led by the instructors with the goal of developing research proposals relevant to EHVDC transmission. To achieve this, participants were split into groups and, over the days which the summer school took place, were progressively provided with three different strategies to work with. The first was the six thinking hats decision method, in which each member of the group was provided with a colored paper hat that defined their role. For example, red "emotion" hats would express their raw feelings toward the research question under consideration, green "ideas" hats would recommend new ideas and concepts to improve the proposal, and brown "negative" hats would take a pessimistic stance and consider the hurdles that may appear when implementing the research in question. This strategy helped participants to consider the problem from every perspective, brainstorm, and bring fresh ideas to the table.

The next concept that was introduced was SMART thinking, based on the requirement that a research question should be Specific (are the objectives clear in scope, with no ambiguity?), Measurable (can the researcher measure the output?), Attainable (is it plausible, given constraints and limitations?), Relevant (is the research important and desirable?), and Timely (can it be achieved in the time available, has it been done before?). Altogether, applying the SMART criteria to a proposed research question can help to ensure that the question is well-posed, which may ultimately save both time and effort in the long run. Participants were first given example questions to collectively evaluate against the SMART criteria. This led to insightful discussions about what makes a research question SMART. This same thinking was then applied to the groups' own research questions, with valuable peer feedback given to each team. There was a marked difference when comparing the original research questions to their refined counterparts, before and after SMART was applied.

Last, the groups were introduced to the idea of known knowns, known unknowns, unknown knowns, and unknown unknowns and subsequently to the concept of effective research hypotheses. From this perspective, a research question is a known unknown, and a hypothesis is a research question that also includes the predicted result. Participants learned that hypotheses should be specific and quantifiable, for example: "Increasing the system voltage by 10 kV, will increase the ampacity by 20%." Therefore, they are useful as a guide, to ensure that the proposed research is testable and that the research objectives are achievable.

The combination of these three tools provided by the instructors led to the successful development and refinement of research proposals for each team. These have been summarized by each team below.

Group Proposals

Group A—Juliana Beça, Fabian Bill, Sofia Mavidou, Rohith Sangineni, Adeep Santosh, and Kai Zhang

The research topic chosen by this group within the HVDC domain was concerned with XLPE cables. This was a topic that interested all group members, as it overlapped with everyone's individual research work. After engaging in discussion regarding the research focus, aging was the topic we ultimately decided upon. The reason to choose aging was informed by the fact that high voltage XLPE cable technology is still quite young, and thus the aging process remains largely unexplored. Only in the coming years will the first HVDC cables begin to reach the end of their designed lifetime. Moreover, the understanding of insulation aging processes and associated behavior is an important part of ensuring the long-term stability of future cable installations.

The main concept that the research question was formulated around was to compare the performance of new and aged XLPE samples and to possibly develop a lifetime model through laboratory-aged samples. In the initial draft of the research question, the goal was to compare the insulating performance of three different artificial aging states: new-, medium-, and long-aged XLPE, from which a research question was then deduced. Thanks to the input of the other participants, some concerns regarding the specificity of the question were raised, prompting the group to improve upon this question. Since the summer school, several meetings have taken place, where future steps and final goals were discussed. At the moment, the main focus is on the literature review. Once complete, it will be possible to finally form a SMART research question. Unfortunately, this has not happened yet, as the research idea is still being fine-tuned. Most recently, there is a potential change of plan to not include artificially aged samples but use actual cable samples. In the process of finding a SMART research question, one attribute has proved to be the most challenging: attainability. Already, in the first rounds of discussion, there was the realization that the availability of instrumentation and other equipment would be the most limiting factor for this group. Thus, significant time is spent during the discussion, assessing the attainability of the proposal with the available equipment. Nevertheless, the willpower to finish this project is undeniably present, and the measurements are hoped to commence soon.

Group B—Yifei He, Naveen Janjanam, Philip Mathew, Maria-Irina Oancea, Yinka Leo Ogundiran, Timothy Wong, and Luming Zhou

Considering the HVDC theme of the summer school, this group decided to focus their efforts on novel strategies for increasing the ampacity of extruded XLPE HVDC land cables. Currently, a limiting factor to the power transmission capacity of cables is the thermal limit of the insulation. Resistive losses in the conductor core gradually cause the cable to heat up and, at elevated currents, could easily tend toward thermal failure, if left unchecked. Yet, increasing the ampacity of a cable could lead to economic benefits due to increased power density. Therefore, the idea was that any active (or passive) methods of improved thermal management should be able to increase the ampacity of a cable for the same conductor cross-section, see [5] for instance. We eventually settled on the research question “Can the addition of an intra-conductor embedded cooling channel in XLPE land cables increase the ampacity of the cable, and what are the effects of the fluid characteristics?” Although some studies have previously demonstrated the possibility of external fluid cooling [6], we would like to explore the effectiveness and feasibility of placing an active cooling channel inside the conductor core, as to not affect the properties of the existing insulating layers. This would further expand to investigate the effects of the fluid characteristics, such as flow velocity, inlet/outlet temperature, or viscosity.

Figure 4. Participants working in groups to form different research proposals.

As multiple members of this group have prior experience with computational simulation, the novel concept would initially be tested in a series of multiphysics simulation studies. This would primarily focus on a performance comparison of the novel design to a traditional cable, while a secondary focus will be on the necessary considerations to terminate the cooling channel at the cable joints. The cable parameters could then be exported and integrated into a system-level model to evaluate its impact. If successful, future work may include the construction of an experimental prototype to test the concept in practice.

Group C—Faisal Aldaswari, Konstantinos Gektidis, Raj Hirani, Frances Hu, Fang Liu, Daniele Mariani, and Xiwen Wu

Group C included seven researchers with expertise in high voltage engineering, specifically partial discharge, space charge, material analysis, and other HV test techniques.

After understanding the need for HVDC applications and the sensitivity of HVDC insulating materials to temperature due to changes in conductivity, it was obvious that the thermal aging effects of materials such as EPDM and PP should be investigated, to predict the future aging characteristics of components. Hence, the group proposed “An Investigation into the Thermal Aging Effects on Electrical Properties of PP/EPDM for HVDC Cable Joint Applications.”

Based on background information from previous literature, the group hypothesized the following.

1. Thermal aging increases mechanical weaknesses in EPDM, causing a decrease in PDIV according to IEC 60270.
2. After thermal aging, the level of accumulated space charges increases at the PP/EPDM interface.
3. DC breakdown strength increases after short-term thermal aging and decreases with longer aging periods.

The aim of the research proposal was to build a relationship model to predict electrical performance for HVDC cable joints. To do so, the group first proposed a literature review, to understand previous knowledge on aging, cable joints, sample preparation, and testing procedure. The thermal aging technique for the intended materials can then be optimized before testing is completed.

Samples will undergo chemical analysis, permittivity measurements, and partial discharge analysis, before and after aging. Also, DC conductivity and space charge measurements can be done. To investigate the performance properties, DC breakdown and lightning impulse testing will be implemented. The final goal—to build a relationship model between the electrical properties of PP and EPDM after thermal aging—can be completed after thorough data analysis.

The group has planned to expand and improve this research proposal after the summer school and work as a multinational team to develop an accurate and trustworthy model that is hoped to be used in future lifetime prediction models for cable accessories.

Group D—Giacomo Ciotti, Christian Mier Escurra, Jiachen Gao, Phichet Ketsamee, Patrik Ratheiser, Shahtaj, and Haonan Yang

The use of renewable energy has increased in recent years due to the energy transition. However, most of these renewable energy sources are located in rural, often remote, areas. This makes an efficient and climate-friendly energy transportation scheme an urgent necessity. HVDC transmission was proven to be a better solution for long distances than HVAC. Yet, some of the phenomena related to DC are not well known and are of great concern for utility companies.

One of the most important phenomena in this context is space charge accumulation. The presence of space charges may enhance the local electric field within the insulation material, and they are quantifiable with, e.g., the Field Enhancement Factor (FEF). However, a correlation between the FEF and the insulation breakdown voltage would be of major interest. This led group D to the following SMART research question: "What is a critical value for the FEF, related to the accumulation of space charges on XLPE, which leads to a breakdown in used insulation materials?" Hypotheses, such as "the DC breakdown voltage during a step test of the insulation material XLPE is inversely proportional to the field enhancement factor," were formulated. The common opinion regarding this topic is that space charge accumulation in XLPE leads to a breakdown in cable systems. Therefore, a lot of research has been conducted for XLPE with additives, which aim to reduce the space charge accumulation in the used insulation material. However, what amount of space charges would be considered critical in the insulation of DC cables? This further raises the question of whether this is necessary for every nominal DC voltage level. Additionally, the relation of FEF on the breakdown voltage should be investigated for DC XLPE cables (MVDC, HVDC, EHVDC). These points underline the relevance of the aforementioned matter.

Figure 5. Group discussions.

During the considerations made by group D, the following specific objectives were defined. It is necessary to investigate the relation between space charges and breakdown voltage on plaque and cable samples at different temperatures. Furthermore, there is a need to characterize the investigated XLPE breakdown voltage related to the FEF, and a "critical" value for space charge accumulation for the investigated XLPE needs to be established.

Because the participants in this group have different skills and knowledge, we planned to divide the project into small work packages. The implementation should be done step by step, with each participant informing the others about their findings after finishing their work to achieve a smooth implementation. Because the project is very extensive and therefore requires many resources, approximately a year should be planned for it. As such, the best way to realize this project would be to either work as a group, internationally, with the support of the universities, or start a new PhD project. To implement this project in this form, financial and material resources need to be organized and obtained first.

Future Work

One thing that everyone has undoubtedly taken home is the newfound network of friends and colleagues. As most of us are in the early stage of our careers, we are very happy that the networking was kickstarted in the format of the IEEE DEIS Summer School. We not only extended our network, but also formed some crucial research collaborations. This is a perfect example of what happens when you put a number of young professionals in a room and give them something to discuss. In this sense, the summer school could be considered a kickoff meeting for multiple, international, research projects. We were all quite astonished that this was as successful as it was. We are all keen to see how these projects evolve over time and what publications might be spawned as a result of this year's summer school.

Figure 6. IEEE DEIS Summer School group photo.

Figure 7. Participants enjoying the final night together before the end of the summer school.

The format of the summer school was perfect for young professionals. The group was not too big or too small. The circle of attendees provided the perfect environment to meet likeminded people. Also, the talks given were perfect to stimulate discussions, and there was enough room for ideas to be heard. We all sincerely hope that this will not be the last time the IEEE DEIS Summer School would be held—there is almost no better way for young professionals in this area to build up a network and start international research collaborations!

Fun Nights!

Apart from the scheduled presentations and discussions, an equally important (perhaps more important!) aspect of this summer school was the fun nights that we were able to spend together after daily sessions. Getting to know each other and developing a network with other participants in the same research field (and more importantly, at a similar career stage!) was incredibly beneficial to us. In the evenings, we stayed together, searching Monmouth for some good places to chat and drink. By spending several nights together, bonds were established between each and every participant, as well as to this summer school itself, by sharing our personal views and experiences beyond just research. Moreover, we are hugely grateful to the organizers for putting together the treasure hunt activity! This was held at the end of the summer school and aimed to encourage us to explore some famous sites around Monmouth and to familiarize ourselves with its history and culture, in the form of a competitive hunt for local landmarks.

Acknowledgments

The authors would like to thank the organizers—Thomas Andritsch, John Fothergill, Peter Morshuis, Istebreq Saeedi, and Alun Vaughan—for their support as well as the IEEE DEIS for sponsoring such a wonderful event. The authors would also like to extend their thanks to the Monmouth School for Boys for hosting the participants.

Fabian Bill, Frances Hu, Patrik Ratheiser, and Timothy Wong
Representatives of the IEEE DEIS Summer School class of 2022

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Would you be interested in …
a 5-Day Summer School on Extra-High Voltage DC Transmission?

Monmouth, Wales, UK, August 21–26, 2023
Organizers: IEEE Dielectrics and Electrical Insulation Society

Over the last few years, we have organized summer schools for research students and those just starting their careers. If you think you might be interested in this year's school, then let us know—without committing yourself—so that we can keep you informed of the plans.

These IEEE DEIS Summer Schools bring together young researchers to help them to be more successful in their research and careers. If you join the summer school,

- You will take part in inspiring creative discussions on challenging topics in the field of dielectrics and electrical insulation;
- You will develop techniques and methodologies for successful research;
- You will meet like-minded people from around the world and make plans for joint research work, and you will present your work and write the framework for a journal paper;
- You will have the opportunity to organize a special session in an IEEE DEIS–sponsored conference; and
- You will leave with friends and research networks that survive beyond the summer school.

The summer school takes place this year in the historic county town of Monmouth in Wales, UK. Free transport is provided from London Heathrow airport and back. In this relaxed setting, you will be part of a group of about 30 PhD students and junior researchers and take part in creative sessions exploring timely topics in dielectrics research. As mentors who are experienced in the field of dielectrics and electrical insulation, we will stimulate and guide these sessions to give you the maximum opportunity to develop your skills.

It is not all work and no play! So that you get to work well together, we will organize some social events as well. The local area includes options to canoe along the beautify river Wye, visit historic Chepstow castle, tour the world-famous Rockfield Recording Studio, experience the World's fasted seated zip line, among many others.

In this year's summer school, we are planning to consider the challenges to be faced with the development of high-voltage DC power cables and accessories.

Who We Are

- Dr. Thomas Andritsch is program leader of Electrical Engineering and Mechatronic Engineering, at the University of Southampton, UK.
- Prof. John Fothergill is a consultant and an emeritus of City, University of London, UK.
- Dr. Istebreq Saeedi is a lecturer at the University of Southampton, UK.

- Prof. Alun Vaughan is an emeritus of the University of Southampton, UK.
- Dr. Peter Morshuis is an independent consultant at Solid Dielectric Solutions, the Netherlands.

How to Show Your Interest

To qualify for participation, you must either be a PhD student, an MSc student with some research experience, or in the first three years of your career. You should have a reasonable command of English.

If you think you might be interested in this year's Summer School, please let to Dr. Peter Morshuis know by emailing peter.morshuis@dielectrics.nl by May 30, 2023.

It would help if you could describe in a few lines your main field of study and the reason why you would like to participate in the Summer School. Please be aware that numbers are limited, so it is first come, first served!

Does It Cost Much?

The Summer School is sponsored by IEEE DEIS. Therefore, your fee is significantly reduced if you are an IEEE (student) member. The cost of becoming an IEEE student member is very low if you consider the benefits you will get. Becoming an IEEE student member is easy: https://students.ieee.org/become-a-member/.

- Fee for IEEE (student) members: £162 (20% VAT included, £135.00 ex VAT)
- Fee for nonmembers/nonstudents: £300 (20% VAT included, £250.00 ex VAT)

The cost of participation includes transportation from London Heathrow Airport (LHR) to the venue on the August 21, a single en suite room for five nights, food and beverages, social activities, and transportation back from the venue to LHR on August 26.

Contact

If you need more information, please contact Dr. Peter Morshuis: peter.morshuis@dielectrics.nl.

ICHVE 2022

The 8th IEEE International Conference on High Voltage Engineering and Application (ICHVE 2022) was held from September 25 to 29, 2022. It was fully sponsored by the IEEE Dielectric and Electrical Insulation Society (DEIS); co-organized by Chongqing University, Xi'an Jiao Tong University, and the University of Connecticut; and supported by the Chongqing Electric Power Research Institute of State Grid Corporation and the CSEE High Voltage Professional Committee. The general chair of ICHVE 2022, Feipeng Wang, from Chongqing University, opened the conference in the morning of September 26. Impacted by the COVID-19 crisis, ICHVE 2022 was organized as a hybrid mode, i.e., in person for attendees from China and virtual for friends from outside of China. The conference was held successfully in the Radisson Blu Hotel Chongqing, bringing together more than 400 domestic and international scholars, students, and engineers online and on site. Brian Stewart, president of IEEE DEIS, delivered a warm speech at the opening ceremony. Besides the two awardee speeches from 2022 IEEE Caixin Sun and Stan Grzybowski Award recipients, the conference invited 12 internationally reputable high voltage engineering scholars to give keynote speeches and carried out 32 oral and 7 poster sessions, with rich contents and various forms. All presentations were streamed on the Zoom platform.

ICHVE 2022 covers research topics such as electromagnetic field calculation and measurement, online monitoring and fault diagnosis, external insulation, new insulation materials, grounding systems, transformer, and motor insulation, aging, and space charge, electrical insulation for special environments, industrial applications, and high-voltage engineering education. ICHVE 2022 accepted 621 abstracts, and 578 papers from 18 countries were allowed for presentation.

Feipeng Wang from Chongqing University opening ICHVE 2022.


Warm words from Brian Stewart, president of IEEE DEIS.


Awardee speech from William Chisholm.


On-site attendees listening to a presentation.

Keynote speech from Shengtao Li.

The Chinese arts show and personal communication.

Shengtao Li (left) and Guangning Wu (right) receiving a thank you certificate.

The speeches in the first day, September 26, were initiated by announcing the 2022 IEEE Caixin Sun and Stan Grzybowski Award recipients: William A. Chisholm from the University of Toronto, Canada, as the Lifetime Achievement Award recipient and Yang Yang from Northwestern University, USA, as the Young-Professional Achievement Award recipient. Both re-

Group photo of on-site participants.

cipients released their informative awardee lectures in the first quarter of the day.

The technical programs started each day with a general plenary session followed by five parallel oral and poster sessions in the morning and afternoon. On Wednesday afternoon, technical tours to ABB Transformer Chongqing Ltd. and to the ultra-high-voltage branch of the State Grid Chongqing Electric Power Company were scheduled.

ICHVE 2022 held a banquet Wednesday evening for on-site participants. The evening was filled with more than a banquet because there were also a Chinese arts show and intensive personal communication among participants.

Summary

ICHVE 2022 attracted more than 400 participants who came in person or connected online. As the general chair of ICHVE 2022, I sincerely thank all committee members and volunteers for their tremendous effort to make this conference semi-physically possible in the times of uncertainty. Furthermore, ICHVE 2022 invites colleagues and students in high voltage research field to attend ICHVE 2024 in Berlin, Germany, tentatively in September of 2024.

Feipeng Wang
Chair of ICHVE 2022
Chongqing University, China

Conference Report—2022 IEEE 6th International Conference on Condition Assessment Techniques in Electrical Systems (IEEE CATCON 2022)

The IEEE CATCON started its journey in 2013 from Kolkata, in which I was associated as the founder chair of the IEEE DEIS Kolkata Chapter. The first edition of CATCON was held at Jadavpur University, Kolkata. Four more IEEE CATCONs were successfully completing at Central Power Research Institute Bangalore (2015), Indian Institute of Technology Ropar (2017), Indian Institute of Technology Madras (2019), and National Institute of Technology Calicut (2021). This year, the sixth edition of IEEE CATCON was held at the National Institute of Technology (NIT) Durgapur December 17 through 19, 2022, in a hybrid mode. This is the flagship conference organized by the Dielectrics and Electrical Insulation Society (DEIS) of IEEE Kolkata Section, which is the only one of its kind in India.

The conference started with keynote lectures delivered by Sivaji Chakravorti of Jadavpur University on "Measurement of Partial Discharge" and C. C. Reddy of IIT Ropar on "Locating Short Circuit Fault in a Cable Using Sweep Frequency Response Analysis—Future Prospects." These were followed by a talk by the India representative of the DEIS YP Committee, Ashok Narayan Tripathi. The second day of the conference started with a keynote lecture by Rabi Choudhury from Calcutta Electric Supply Corporation (CESC) Limited on "Condition Monitoring of Transformers Using Dielectric Response Analysis." The afternoon session of the second day began with an online keynote lecture by L. Satish of the Indian Institute of Science (IISc) Bangaluru on "Detecting and Interpreting Loss of Clamping Pressure in Transformers." The third day of the conference also started with a keynote lecture, by Marco Tozi of Camlin Energy, Italy, in online mode. Tozi delivered his lecture on "Data to Decisions: Real Cases Studies on Power Transformers." Every keynote lecture was followed by paper presentations in technical sessions. Overall, CATCON 2022 hosted ten offline technical sessions and eight hybrid sessions in the span of three days with a specialized theme of each session. The evening of the second day of the conference was filled with a cultural program followed by gala dinner.

Sivaji Chakravorti with Robi Choudhary.


Delegates from the IEEE Kolkata Section attending the conference.

Ashok Tripathi, IEEE DEIS YP India representative, delivering a lecture at IEEE CATCON 2022.


Lunch break between the sessions.

Audience in a technical session.

An Indian classical dance performance in the cultural program.

In the 6th edition of CATCON, we had an all-time high number of submitted papers—173, and the number of accepted papers was 91, with an acceptance rate of 52%. Many quality papers could not be included in the conference due to the strict decision of review panel members regarding the scope of the conference.

The DEIS chapter of the IEEE Kolkata Section firmly believes that quality and not quantity should be the hallmark of

Student participants in IEEE CATCON 2022 asking questions.

Delegates enjoying the cultural program.

Participants enjoying the gala dinner after the cultural program.

Valedictory session of IEEE CATCON 2022.

Ashok Tripathi with Chiranjib Koley, Conference Chair IEEE CATCON 2022.

this conference. For this purpose, the best minds in the topics of the conference have been roped in for reviewing the papers.

The tone of any conference is set by the keynote speeches. I am happy that we had excellent speakers, who shared their vast experiences at our conference. Because the topic of this conference was practically very significant, it was indeed essential to have strong industrial participation in the conference. With this in view, experts from industries and utilities were invited to share their thoughts on different aspects of condition monitoring and the importance of asset management.

The success of any conference depends largely on its finances. We are extremely thankful to our sponsors and advertisers, who have supported our conference most generously. It is to be mentioned here that our sponsors are top organizations involved in promoting excellence in research and development.

Finally, I would be failing in my duties if I did not mention the untiring efforts of the members of the organizing committee and the volunteers to make the conference what it is today. I am also thankful to NIT Durgapur and the IEEE Kolkata Section for their unstinted support.

For the first time, the DEIS Young Professionals Committee participated in CATCON, and it was represented by Ashok Narayan Tripathi. He delivered a talk introducing the newly formed IEEE DEIS YP Committee to all the attendees. The talk also included information about the YP program and the benefits of being a DEIS YP member. To encourage young professionals, advertising items (caps, bottles, bookmarks, and stickers) with IEEE and DEIS logos were distributed to all the YP attendees at the conference by the DEIS YP Committee.

The next edition of the conference is to be held in 2024 in Kolkata, India. In the seventh edition of CATCON, we will take it up to a whole new level. We encourage international participation in the upcoming editions of CATCON. If you are working in the area of condition monitoring and asset management of electrical systems, we will be glad to have your gracious presence at CATCON 2024.

Chiranjib Koley
Conference Chair IEEE CATCON 2022
NIT Durgapur, India

IEEE to Form a Technical Council on Transportation Electrification

Recognizing the momentous technical and societal trends occurring in transportation electrification, the IEEE recently approved the formation of a Technical Council focused on the subject, to be called the Transportation Electrification Council (TEC). It will come to official existence next year on January 1, 2024. Technical Councils are very much like IEEE Societies, except that their field of interest overlaps with the technical focus of a number of IEEE Societies, and accordingly, Councils are formed by member Societies. This is particularly appropriate in this situation where the new Council will work on and for an industry and application that involve many different electrical engineering specialties.

It is the case with your particular Society elected to become a member of the Council. As a member of this Society, you will be eligible to be a member of the Council for free. Be sure to be on the lookout for that option when renewing your IEEE membership in late 2023 for 2024. In the meantime, you can become a participant of the Transportation Electrification Community, a predecessor organization to the Council. If you have not done so yet, you can join the Transportation Electrification Community by logging on to your IEEE member profile (https://www.ieee.org/membership-catalog/productdetail/showProductDetailPage.html?product=CMYEV740). You can add this membership to your portfolio by using the following comp code: TECCOMP2022.

As a Technical Council, TEC will have its own independent budget and, more importantly, will be able to develop new programs for members, such as local chapters, conferences and symposia, publications, standards, and so on. Eventually, this will give transportation its rightful place within IEEE, reflecting the major technical and societal transition we are experiencing with a shift with more electric, if not full electric, modes of transportation. The Council will cover all modes of transportation (road, off road, air, rail, water) as well as component and system issues, from propulsion technology to autonomous vehicles and the network they are or will rely on.

IEEE TRANSPORTATION ELECTRIFICATION COUNCIL

So, if you work in the transportation industry, or simply have an interest in the field, please participate in current or future Transportation Electrification Community activities (check the Transportation Electrification Community website at tec.ieee.org). Better yet, volunteer, suggest new initiatives, or take the lead in developing programs for transportation engineers, managers, and researchers.

Bruno Lequesne
Chair, Transportation Electrification Community (2019–2022)

A PUBLICATION OF THE IEEE DIELECTRICS AND ELECTRICAL INSULATION SOCIETY

IEEE TRANSACTIONS ON DIELECTRICS AND ELECTRICAL INSULATION

DECEMBER 2022 VOLUME 29 NUMBER 6 ITDEIS (ISSN 1070-9878)

PART B: APPLICATIONS

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

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