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Editorial

Outdoor Insulation and Gas-Insulated Switchgears

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1. Introduction

With the growth of the world's population and faster-developing industries, larger amounts of electric energy are needed [1–6]. To reduce Joule losses at longer distances, voltages delivered by generators are increased with step-up power transformers, and electric energy is transported at large voltages [7,8]. Consequently, many ultra/extra AC/DC high-voltage transmission projects have been commissioned or are under construction in many countries: Canada (735 kV), Venezuela (800 kV), China (1100 kV), Japan (1100 kV), and India (1200 kV) [9–18]. For the power to be delivered to end-users, transmission grids, including towers, conductors, insulators, as well as substations, are essential [19–22]. The main equipment in substations includes, but is not limited to: power transformers, circuit breakers, surge arrestors, relays, insulators, disconnector switches, busbars, capacitor banks, batteries, wave trapper, switchyard, as well as protection, control, and metering instruments, etc. When the equipment is installed outside, it is refereed as an "outdoor substation" and an "indoor substation" when set inside a building. One of the main advantages of an indoor substation over an outdoor substation is the independence from meteorological impacts [23–25]. Nowadays, indoor substations are commonly gas-insulated substations (GIS), as they require a much smaller footprint [23].

These transmission lines that carry power to end-users cross various regions, exposing all outdoor equipment to various atmospheric conditions [26–33]. Actually, the more or less complex profiles of insulators are essentially determined to meet a certain number of criteria in relation to the shape of the voltage waves and the conditions of pollution, fog, and rain. Understanding the fundamental aspects of outdoor insulation is, therefore, important for properly designing and monitoring practical HV transmission lines and hardware [26–33].

Listed hereafter are the topics of interest considered in the call for papers:

- Lightning phenomena and related applications;
- Long air gap discharges;
- Switching surges;
- Insulation coordination;
- Breakdown and pre-breakdown phenomena in gases;
- Insulating material efficiency improvement by chemical admixtures;
- Gas-insulated switchgear (GIS);
- Measurement, monitoring and diagnostic techniques.

With fast changes occurring in both current and future grids, developing reliable insulators for outdoor insulation applications, studying the influence of atmospheric conditions on the grid performance, investigating the very fast transient overvoltage behavior of gas-insulated substations, and protecting power equipment against lightning have become essential tasks in maintaining a reliable link for the future power grids [34–39].

This Special Issue, in its final form, focuses on theoretical and practical developments with special emphasis on pollution/icing of the power grid hardware problems and the improvement in silicone rubber performances for applications in the composite insulators. The performance of gas-insulated switchgears (GIS) and lighting protection are also concerned.

2. An Outlook of the Special Issue

"Outdoor Insulation and Gas Insulated Switchgears", a Special Issue of *Energies* has been successfully organized with the support extended from the editorial staff of the journal and the MDPI publishing team. This Special Issue was quite remarkable and successful, with a good geographical distribution of authors and coauthors: Canada (12), Chile (1), China (10), Malaysia (1), Saudi Arabia (5), the UK (10), Romania (3), Italy (1), Finland (2), Germany (3), Algeria (4), and Côte d'Ivoire (2).

A brief status of the Special Issue is as follows:

- Published papers: (13);
- Rejected papers: (3);
- Median Article Processing Time: 42 days;
- Article Type: Article (12); Review (1).

The guest editors would like to thank all the reviewers for their prompt responses during the reviewing and revising of the manuscripts.

The articles published in this issue are discussed in the subsequent sections of this editorial.

3. A Review of the Special Issue

The articles [40–45] address the flashover performance of polluted insulators. In [40], an attempt has been made by Amrani et al. to propose a mathematical model allowing the prediction of the AC surface arc propagation on polluted insulators under divergent electric fields. Several electro-geometric parameters such as the distance between electrodes, pollution conductivity, radius of high-voltage electrodes, and length of the plane electrode were taken into account. The results indicate good agreement between computed and experimental results for various test configurations.

In [41], Chen et al. proposed a dynamic pollution prediction model of insulators based on atmospheric environmental parameters (meteorological data and wind speed). Two insulators' coefficients, c1 and c2 (c1: pollution ratio of U210BP/170 to XP-160; c2: calculated pollution ratio of U210BP/170T to XP-160), were computed as monitoring parameters. It is shown that the NSDD (non-soluble deposit density) of insulators with different structures can be predicted using the insulators' structure coefficient and the reference XP-160 insulator's NSDD. The results were verified against experimental data under natural pollution.

In [42], Nan et al. investigated the pollution flashover characteristics of four types of AC composite crossarm insulators with diameters ranging from 100 mm to 450 mm under different voltage grades (from 66 to 1000 kV). The pollution grade was varied between 0.2 and 1.0 mg/cm^2. The results involving the effects of the surface hydrophobicity state of silicone rubber, core diameter, umbrella structure, arrangement, and insulation distance on the pollution flashover voltage of the composite crossarm insulators can be helpful for the structural design and optimization of the composite crossarm insulators.

In [43], Slama et al. reported a preliminary study of an in situ monitoring of 400 kV SiR textured insulators in a polluted environment. The artificially polluted HTV-textured silicone rubber insulators were electrically and thermally monitored. It was found that the level of pollution, which acted as a parameter, and the voltage affect the discharge activity and its nature. In addition, the magnitude and pulses of the rms leakage current, along with the average dissipated power, depend on the pollution levels and the dry-bands formation. Finally, emphasis is laid on the differentiation and quantification between dry-band discharge onset and dry-band arc inception.

Fofana et al. [44] has shared field experience from post-installation pollution levels assessment. It is shown that the pollution level should not be considered static due to the dynamics of environmental parameters. Tests were performed on some distribution insulators removed from service. To assess the pollution levels of the insulators, various parameters such as equivalent salt deposit density (ESDD) and non-soluble deposit density (NSDD), surface resistance, and leakage current characteristics (density, third harmonic amplitude, and phase) were monitored. It was confirmed that the dynamics of the local environmental parameters should be considered for grid reliability. The authors recommended post-installation investigations be conducted whenever the surrounding insulator's area undergoes changes (construction, habitation, changes in factory processes, etc.).

In addition to pollution concerns, the power grid may be endangered by atmospheric icing in cold regions of the world. This may cause structural damages or insulator flashovers. Over the years, various techniques have been proposed to guarantee the reliability of the grid. This includes active (heating, chemicals, and mechanical methods) and passive (nanotechnology) solutions. A snapshot of some significant developments on this topic over the last four decades is presented by the guest editors [45]. The problems in using these techniques, their applications, and perspectives are discussed.

Liu et al. [46] proposed a method to monitor of the icing degree of an insulator during icing accretion. Two algorithms (direct equalization and median filter methods) have been used to reduce the noise and enhance the contrast of the images obtained in simulated laboratory conditions. From the image, the maximum entropy threshold segmentation algorithm is used to discriminate between the insulator and ice surface. The boundaries of the non-iced insulator and the ice thickness are determined using an improved Canny operator edge detection algorithm. The location of the icicles is accurately determined using a regional growing method. This allows locating the air gap in the image of the iced insulator, the icicle length. The operator may then evaluate the likelihood of ice bridging the insulator strings. The proposed approach allows predicting icing induced flashover.

The next three articles [47–49] focus on aspects of synthetic insulation materials, either specifically silicone rubber insulation housing composites' modification by suitable fillers or more generally with a review on polymeric insulation applications.

Ghunem et al. [47] pinpoint some perceptions and design paradigms about the admixture of inorganic fillers to silicone rubber housing composites for outdoor insulation with the aim of improving resistance to erosion against dry band arcing. From their critical review, the authors recommended two aspects considered in the design: (1) the volume effect of the fillers and (2) the shield effect. They also recommended supplementary characterization tests and measurements, useful in understanding the protective filler actions in enhancing the erosion resistance of silicone rubber such as TGA, SEM, leakage current measurements, and thermal conductivity measurements.

Alqudsi et al. [48] experimentally investigated the effect of ground and fumed silica fillers (incorporated at different loading levels) on suppressing DC+ erosion in silicone rubber. To evaluate the erosion performance of the composites, the inclined plan test (IPT) under DC+ voltage was used. The analytical analyses included the leakage currents, simultaneous thermogravimetric–differential thermal analysis (TGA–DTA) under nitrogen and air atmospheres to understand the thermal decomposition characteristics of the composites, surface morphology by scanning electron microscopy (SEM) and surface roughness analysis by an optical microscope. From the investigations, it is reported that fumed silica and its interaction with silicone rubber were effective in promoting the formation of a coherent shielding residue, which resulted in suppressing the DC+ erosion.

Haque et al. [49] proposed a comprehensive survey including 144 citations, focusing on the application and suitability of polymeric materials as insulators in power equipment such as cables, transformers, insulators, etc. In this survey, the authors emphasized and highlighted the basic physicochemical properties of polymer materials, thermoplastics, and thermosets. Recent studies on their performances are reviewed. The main assessment techniques for HV applications are also discussed. Finally, future research hotspots and notable research topics are discussed for the benefit of researchers.

Two papers pertaining to gas-insulated switchgears were published in this Special Issue. In [50], Alexandru et al. proposed an electromagnetic field theory approach to study the effect of several model configurations of gas-insulated substations under very fast transient overvoltage (VFTO) using suitable computer-aided design models. The partial equivalent element circuit (PEEC) approach embedded into an XGSLab software package was adopted. The results can be seen as benchmark hints for grounding grid designers, particularly for the proper development and implementation of transient ground potential rise (TGPR) mitigation techniques across a gas-insulated substation.

Götz et al. [51] investigated the partial discharge behaviour of a distorted weakly inhomogeneous electrode arrangement in sulphur hexafluoride (SF_6) and synthetic air under high DC voltage stress. The insulation gas pressure, the gas type, the electric field strength, and the voltage polarity were chosen as parameters. Depending on the experimental parameters (discharge impulses, discharge impulses with superimposed pulseless discharges, subsequent smaller discharges and pulseless discharges), the authors identified four different discharge types. The paper ended with some suggestions for reliable partial discharge measurements under DC voltage stresses.

The last contribution in this Special Issue focuses on lightning protection. Pourakbari-Kasmaei et al. [52] proposes an inductor-based filter for the protective performance of surge arresters against indirect lightning strikes. Different surge arresters with different ratings and two different classes of energy were tested under different indirect lighting impulses. The obtained results indicate that equipping an MV transformer with surge arresters with a proper filter size enhances the performance of the surge arrester significantly.

4. Closing Remarks

High-voltage transmission networks requiring outdoor insulation or GIS play a very important role in our modern societies, and they are becoming even more essential as efforts are underway to decarbonize our energy usage through increasing electrification (for example, in the personal transportation sector) [53]. The articles published testify that research in this field is very active and that the stakes of electrical insulation are multiple.

- The insulation performance under pollution conditions will continue to be an actual topic, as urbanization and industrialization will continue to increase around the globe. In addition, recent events in various regions of the world show a tendency that extreme weather conditions will become more frequent (such as severe ice storms or wild fires during heating periods). Furthermore, more transmission lines need to be constructed through environmentally harsh areas to interconnect new renewable energy resources to the existing networks. For example, there exists large solar power potential in desert areas, important wind power potential along coast lines and offshore, and potential for new hydroelectric power stations in remote mountainous areas.
- The durability and long-term performance aspects of synthetic insulation materials also remain an ongoing issue. Among others, the hydrophobic and glaciophobic properties of the insulation surfaces are of interest to increase the performance of exterior insulation systems with respect to the environmental challenges of transmission systems. However, the conservation of their beneficial properties in the long term remains a challenge.
- The role of compact GIS insulation will increase, and the number of such installations will rise due to the urbanization and densification of residential areas. Therefore, the continuation of research efforts and improvements in this field are of interest.

The papers published in this Special Issue report on the progress made in various application areas. The combination of experimental work, modelling efforts, and analysis of utility installations help to confirm and explain the results obtained. The outcomes will contribute to design more reliable and more durable insulation systems in the future.

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