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# SPECIAL REPORT FOR GROUP 15
# (Insulating Materials)

by

A.H. COOKSON*

(Special Reporter)

## 1. INTRODUCTION

There has been increasing emphasis in recent years on developing more sensitive techniques for evaluating the life and performance of electrical insulation to improve the reliability and quality of electrical equipment. The nine papers under discussion cover many of the key areas under development for new diagnostic techniques, and the impact of new materials and systems.

1) New techniques of partial discharge detection are being introduced which use powerful computerized techniques to locate and analyze these discharges, and, in some cases, to determine their causes and whether corrective action is necessary. The questions cover the sensitivity of the partial discharge measurements and the ability to be able to measure aging effects and predict insulation life.

2) Compressed $SF_6$ gas insulation used in Gas Insulated Substations (GIS) can be susceptible to failure by electrical breakdown initiated by particle contamination moving freely in the gas or being deposited on support insulators. Diagnostic techniques are being used to determine these initiatory events and if they are critical. The questions cover conditioning with particles and the performance of the insulators.

3) The recent application of power electronics for improved and more efficient motor control has resulted in a side effect of applying new types of highly repetitive, high electrical stresses to the motor insulation, which can affect the life of the motor windings. New material developments are also in progress to improve the thermal characteristics of the mica tape insulation. The questions are concerned with the reduction in insulation life and the effects of overvoltages.

4) Polymeric materials, such as silicone and ethylene propylene rubbers, are being introduced for outdoor insulators, cable termination and surge-arrester housings, to replace porcelain or glass. New laboratory tests are being developed to evaluate their life, and the electrical and mechanical performance of competing materials and designs. The questions cover criteria for recommending the preferred laboratory test and the ultimate life of the polymer insulators.

5) Electrical breakdowns that have occurred in some recent designs of compact large high-voltage power transformers have been attributed to high internal stresses initiated by static electrification of the oil. This has prompted studies of the charging mechanisms and the reduction of this effect by including additives in the oil. The questions deal with the effectiveness and life of the special additives.

## 2. PARTIAL DISCHARGE DETECTION AND ANALYSIS

Partial discharge (PD) detection techniques are frequently used for testing equipment on the production

* NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY - GAITHERSBURG, MD 20899 - United States

shop floor, and, on an experimental basis, as part of a field-acceptance test. These techniques must preferably be able to detect and determine the site and probable cause of the partial discharges, evaluate the potential impact on the life of the insulation, and determine whether any corrective action is necessary and possible.

Kreuger et al. [1] made an extensive analysis of partial discharges in artificial voids, comparing the characteristic shape of fast transient pulses (at a bandwidth of 1 GHz) with the pulse analysis from the more classical, lower frequency techniques (400 kHz) where they measure various statistical distributions of key PD parameters, including magnitude, energy, phase relationship, and polarity. They were able to show a strong correlation between the characteristic fast transient current wave shapes, key statistical operators, the type of discharge occurring in the void (e.g. streamer-like, Townsend-like, and pitting discharge), and the observed damage in the void. This appears to offer the potential of diagnosing different types of discharges at various stages of degradation before breakdown. The papers by Wang et al. [2] and the CIGRÉ Working Group 15.03 [3] discuss various types of discharge-detection techniques for discharges due to free and fixed particles, and at insulators in GIS. Very high frequency (30-300 MHz) and ultra high frequency (300-3000 MHz) measurements made with internal probes offer advantages of enabling accurate location and are insensitive to any external interference. Acoustic techniques (5-1000 kHz) have been used quite extensively on GIS with some success. Blackburn et al. [4] used acoustic emission PD techniques for oil-impregnated bushings and showed, among other effects, that the acoustic signature can give an indication of the presence of any gas bubbles and therefore, indirectly, of the effectiveness of the impregnation process.

In order to interpret PD measurements and be able to determine the state of health of the equipment under test, we must be able to understand the mechanisms. This would then enable one to predict the effect of the partial discharges on the insulation and thus predict the insulation life by extrapolation.

Question 1). Has the powerful computing and sophistication of these new high-frequency and computer-aided PD systems resulted in more confidence in measuring partial discharges in equipment in the factory and in the field such that we are able to predict the short and long term reliability? Can these systems discriminate between different types of PD occurring simultaneously and concentrate on the most critical case? Which are the areas that need further study?

Question 2). In the past few years there have been many claims that the cataloging of PD techniques and their characteristics for different insulation systems would lend PD analysis to expert systems or neural network systems. Are there examples of these systems being in operation and used on a regular basis?

Question 3). Being able to monitor long term aging of materials and systems and predict the life is the ultimate goal for partial discharge measurements. For which insulation systems do we think this is a reasonable goal to achieve?

## 3. GAS-INSULATED SYSTEMS

The presence of conducting-particle contaminants in gas-insulated systems can create conditions for electrical breakdown in the gas or flashover at the insulators. The studies summarized by Working Group (WG) 15.03 [3] have shown the ability of particles to move in the applied field. This movement is a function of the type of applied field, the shape and conductivity of the particle and the condition of the conductor surface on which the particles are located (e.g. bare or coated). The particles usually have to move close to the high field inner conductor or onto a high field area of the insulator to initiate breakdown. Frequently low field electrostatic traps are used to deactivate the particles.

In GIS, flashover marks are sometimes observed on insulators when no obvious high-voltage breakdown has occurred. These marks have often been attributed to the effects of low-energy flashovers during site testing or switching-induced fast transients. A different model is proposed in the paper by Wang et al. [2]. They propose that low-energy surface flashovers and discharges can occur in de-energized sections of GIS when stressed with relatively low levels of dc, and dc plus ac coupled by the circuit breaker grading capacitors.

Question 4). What has been the field experience in following the particle movement into traps or controlled areas? Is it better to have uncoated electrodes where the liftoff voltage is low, or take advantage of coated electrodes which may increase the liftoff voltage by a factor of three or more?

Question 5). The WG paper shows that significant dc voltages and subsequent charges may be present on GIS insulators, and that this may be a problem, especially if there are particles present. Will this have an effect on the design criteria for the insulators, and how might this change the optimum shape of the insulator?

Question 6). Are there other data to support the new mechanism proposed by Wang and his colleagues for the occurrence of flashover marks on the insulators? Are there any effective tests to determine if these marks are deleterious to the long-term performance of the insulators?

Question 7). Various tests have been proposed to determine or measure gaseous impurities in $SF_6$, due either to moisture, air, or gas decomposition products from discharges in the gas or at an insulator. Blackburn et al. [4] proposed using the characteristic change in the high-frequency (> 100 MHz) components of the current pulse in a corona discharge as a simple measurement technique, while others have proposed measuring the changes in breakdown voltage in special test cells. What is the evidence that these systems are of sufficient sensitivity? Very sensitive techniques such as gas chromatography (GC) have been studied, particularly to detect $S_2F_{10}$ compounds. Is there widespread acceptance of these GC techniques and how have they been used to verify the occurrence of partial discharges before a catastrophic failure has occurred?

## 4. INSULATION FOR ROTATING MACHINES

The application of power electronics for motor control is of growing importance, resulting in more flexible control and higher efficiencies. However, the downside is that the fast switching can cause highly repetitive current or voltage impulses which travel through the cables to the motor windings. The magnitude and frequency will depend on the type of control (i.e. pulse amplitude modulation or pulse width modulation). These pulses can be sharp-fronted ($< 1\ \mu s$) with a damped oscillatory waveform superimposed on the pulse. This can result in non-uniform voltage distributions through the windings, the first few turns being highly stressed, and can also cause high-frequency ($\sim 10$ kHz) overvoltages. Shibuya et al. [5] show that, for the oscillatory waveform, the voltage endurance of the insulation is best represented by voltage-pulse number life data. For high-voltage machines, they find that the fast component is suppressed because of the operating conditions, but the effect of the oscillations can reduce the ground wall insulation life by up to 33% compared with the 50 Hz data, so that the insulation should be strengthened. For low-voltage machines, the effect on the insulation of the randomly wound windings can be significant, and can reduce the insulation life unless precautions are taken to reduce the overvoltages and to design for no partial discharges to be present during these impulse voltages.

Another aspect of mica machine insulation is to improve the thermal conductivity of the resin-impregnated tapes (Brammer et al., [6]) with additives to the resin (e.g., alumina) and so be able to either lower the operating temperature of the insulation or reduce the cooling requirements, which may result in significant savings for generators.

Question 8). Is the conclusion widely accepted that when power electronics are used to control high-voltage machines, the insulation to ground needs to be strengthened? Is there any risk to the turn insulation? What precautions or procedures are necessary when retrofitting power electronics for motor drives? Do the high-frequency pulses have a deleterious thermal effect on the insulation?

Question 9). For the low-voltage machines, how effective is using a filter at the cable input to control overvoltages, and is it necessary to use other voltage control systems? Is it acceptable to design and manufacture low-voltage windings to be discharge-free during the overvoltages? What other precautions or corrective measures are recommended?

Question 10). Have the improved thermal conductivity tapes been tested on full-size generators and motors, and do these have the same performance and expected life as previous systems? Are any changes necessary in other parts of the insulation system to accommodate them? Would one expect a similar improvement in thermal properties for vacuum-pressure-impregnated systems which do not use as high a resin content in the tapes compared with the resin-rich tapes? Are there any efforts in progress to improve the thermal conductivity of impregnating resins for the windings?

## 5. POLYMERIC MATERIALS AND HIGH VOLTAGE INSULATORS

Polymeric materials are gradually becoming accepted for high-voltage insulators, terminations, and bushings because of their potential advantages over porcelain and glass of lower weight, non-brittleness, simplified applications, and, in some cases, superior performance under contaminated conditions. The earlier material and interface problems have been overcome with improved designs and materials (now usually silicone rubbers and ethylene propylene rubbers). A major obstacle has been to develop an accepted laboratory test for accelerated aging and flashover to simulate conditions that occur in service. For the aging test, a key topic is how to accelerate the aging to include the effects of dry band formation and ultraviolet irradiation. Gorur and his colleagues (7) reported a lack of consensus among the various laboratories involved in this testing.

The testing and application of high-strength polymer post insulators for 230 kV transmission systems was described by Burnham and Grisham [8], who claimed significant savings compared with porcelain posts. Further, they showed that, with novel post and double circuit designs, they could reduce the right-of-way requirements and reduce the magnetic field levels at the edge of the right of way. Special mechanical cantilever testing techniques were necessary to accommodate the flexibility of the insulators. No insulator failures have been reported.

Question 11). With the large number of alternative aging and flashover test methods under evaluation, what criteria will be used for making the final recommendations? How do the material analyses and observations from these laboratory tests compare with those from insulators in the field?

Question 12). The effectiveness of silicone polymers for outdoor insulation is due to the property of surface hydrophobicity, which recovers by diffusion of the mobile low molecular weight polymer chains to the surface. Is there any indication of a limited life?

Question 13). Are there any tests on the horizon that will establish, preferably *in situ*, a "threshold" property which will indicate the presence and condition of material degradation produced by tracking or erosion?

Question 14). What are the key criteria for the selection of polymer insulators in preference to glass or porcelain?

## 6. STATIC ELECTRIFICATION OF TRANSFORMER OIL

The failure of several large power transformers has been attributed to static electrification of the circulating oil causing high internal stresses in the oil and resulting in flashover. These problems first occurred with large power transformers which had a higher oil circulation rate for increased cooling. There have been extensive studies of the dependence of the charge generation, leakage, and relaxation on the various oil parameters (conductivity, molecular structure, moisture content), as well as flow rate, temperature, type of paper, and moisture content of the paper. Poovamma and Jagadish (9) studied the oil charging conditions and the effect of additives such as 1,2,3, Benzotriazole (BTA) to reduce the charging rate, and the effect of other non-cellulose materials used in the pumps and piping systems.

Question 15). Is the cure for the electrostatic charging problem simply effected with the additives such as BTA, or is other treatment necessary, for example to the paper or the drying process?

Question 16). What is the comparative performance of additives, and the effect of these additives on other properties such as loss tangent and long term aging? Do these additives age and lose their effectiveness? What has been the field experience of transformers with these additives? Have these additives been such that the original, high cooling flow rates are used or have these rates been reduced?

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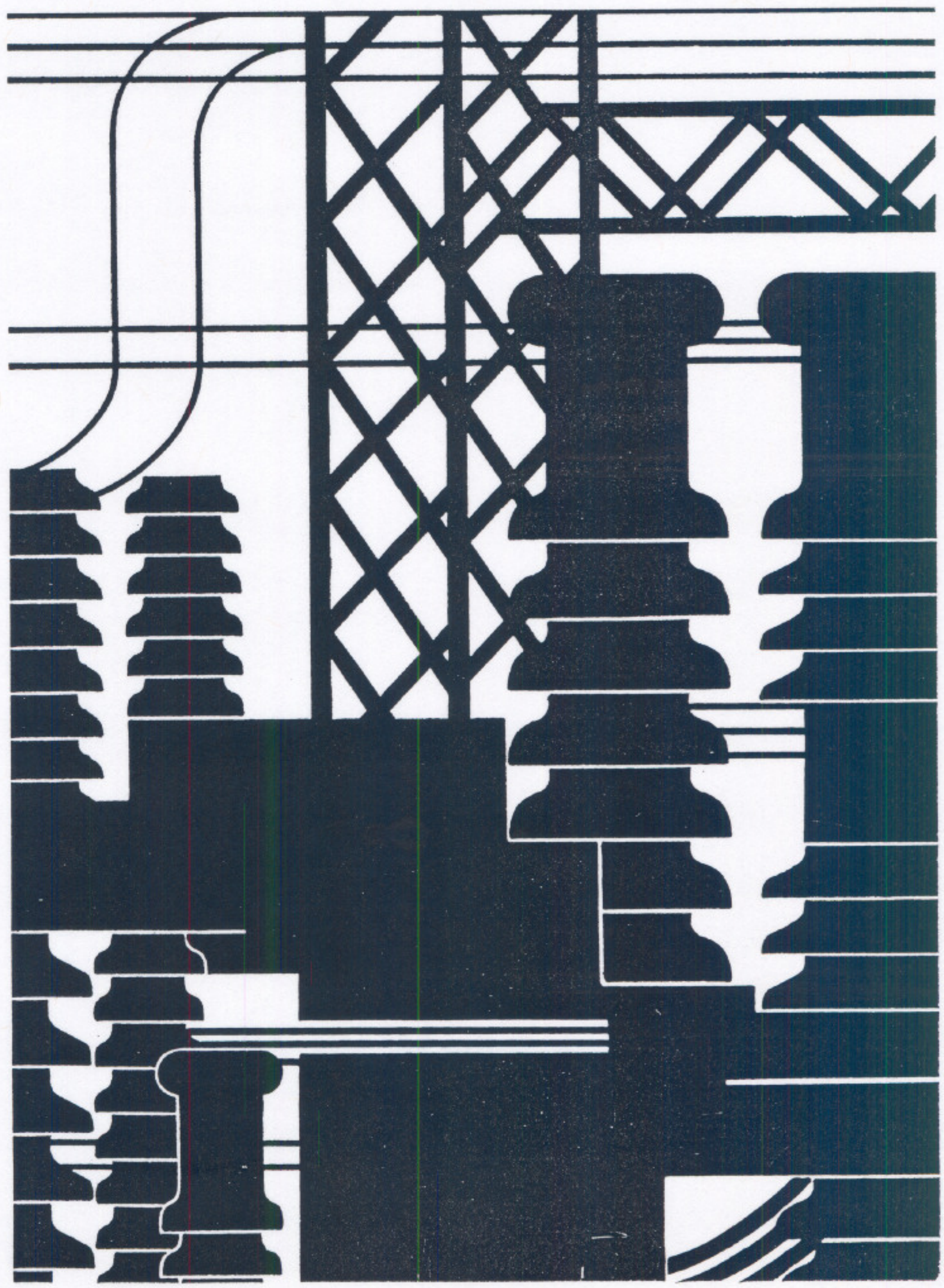

LOUIS-JEAN - 05003 GAP

Conférence Internationale des Grands Réseaux Electriques
International Conference on Large High Voltage Electric Systems

3 - 5, rue de Metz,
F 75010 Paris
Tél : +33 (1) 42.46.50.85
Fax : +33 (1) 42.46.58.27