12th Universities High Voltage Network Colloquium

15th - 16th January 2019 Manchester, UK

UHVnet 2019
"High Voltage Equipment for Future Power Networks"

national grid

ea technology

M&I MATERIALS

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Contents

Welcome

On behalf of the UHVnet2019 organising committee and everyone here at The University of Manchester, it is my pleasure to welcome you to the 12th Universities High Voltage Network Colloquium, 15th–16th January 2019.

UHVnet is an informal grouping of universities founded in 2005 to further interests in HV research within the United Kingdom. The university members include Cardiff University, Glasgow Caledonian University, Staffordshire University, University of Liverpool, University of Leicester, University of Manchester, University of Southampton, University of Strathclyde and University of Surrey. These institutions are supported by a steering group which includes industrial representation from HFDE, GE Grid Solutions, National Grid, Narec and Ricardo.

The theme of this colloquium at the University of Manchester is 'High Voltage Equipment for Future Power Networks', supported by the following four topics: New Material Development, Application of New Materials, Challenges for New HV Equipment and Managing HV Assets in Future Power Networks.

Manchester is known as a city with history, passion, and character. I hope that this colloquium will be a chance for all attendees to further their knowledge in this field and to get to meet likeminded people, giving way to new friendships and potential collaborations. Please enjoy your stay in Manchester.

Thank you for your attendance and for helping to make UHVnet2019 a successful event!

Dr Qiang Liu

Chairman of UHVnet2019 Local Organising Committee
Senior Lecturer & Director of the High Voltage Laboratories
The University of Manchester
http://www.uhvnet.org.uk

Programme

12th Universities High Voltage Network Colloquium

UHVnet 2019 - Colloquium Programme

"High Voltage Equipment for Future Power Networks"

Programme Outline

Day 1 (15 January)

Venue: Harwood Room in Barnes Wallis Building

13:00 – 14:00 **Registration/Tea and Coffee**

14:00 – 14:10 **Welcome**
Q. Liu, Chairman of UHVnet 2019 Local Organising Committee (LOC)

14:10 – 14:30 **Young Research Forum: Challenges of High Voltage Equipment for Future Power Network**
I. Cotton, The University of Manchester

14:30 – 15:00 **Research and Standards**
P. Jarman, The University of Manchester

15:00 – 16:30 **Posters Session/Networking/Tea, Coffee and Refreshments**

16:30 – 17:30 **HV Lab Tour, Ferranti Building**

Day 2 (16 January)

Venue: Harwood Room in Barnes Wallis Building

08:00 – 09:00 **Registration/Tea and Coffee**

09:00 – 09:15 **Welcome**

09:15 – 10:30 **Session 1: New Material Development**

1.1. **Keynote 1 - Graphene and 2D Materials**
I. Kinloch, The University of Manchester

1.2. **The Effect of Water on the Dielectric Properties of Polypropylene/Aluminium Nitride Nanocomposites**
X. Wang, T. Andritsch and G. Chen, University of Southampton

1.3. **Understanding the Growth Mechanisms of Electrical Trees through High Resolution Chemical Analysis**
H. McDonald, S. Rowland and S. Morsch, The University of Manchester

10:30 – 11:00 **Tea and Coffee/Networking**

11:00 – 12:15 **Session 2: Application of New Materials**

2.1. **Keynote 2 – The Role of Alternative Liquids in Future Energy Supply**
P. Jarman, M&I Materials

2.2. **Development of Surface Discharge Over PTFE Insulator Surfaces in Nitrogen and Air**
M. Michelarakis[1], P. Widger[1], A. Beroual[2], A. Haddad[1], [1]Cardiff University and [2]University of Lyon

2.3. **A Geometry and Mesh Used in a High Voltage Capacitor Model**
C. Mackinnon, B. G. Stewart, University of Strathclyde

12:15 – 13:15 **Lunch/Networking**

13:15 – 14:30 **Session 3: Challenges for New HV Equipment**

3.1. **Keynote 3 - Electricity in the Future Energy System**
R. Wood, Tyndall Manchester

3.2. **Current Interruption in a Rotary Arc based Load Switch**
J. Qiang and J. D. Yan, University of Liverpool

3.3. **High Current Generator System based on Power Electronics**
M. Cheah-Mane[1], M. Pages-Gimenez[2], C. Chillon-Anton[1], D. Montesinos-Miracle[1,2], [1]CITCEA-UPC and [2]TeknoCEA

14:30 – 15:00 **Tea and Coffee/Networking**

15:00 – 16:15 **Session 4: Managing HV Assets in Future Power Networks**

4.1. **Keynote 4 - Does Asset Management Matter?**
P. Barnfather, EA Technology

4.2. **Cable Condition Diagnosis Based on Local Increase of Cable Surface Temperature**
H. Yi and C. Zhou, Glasgow Caledonian University

4.3. **Advances in Signal Analysis and Diagnostics for On-Line PD Monitoring of HV Rotating Machines**
A Kokkotis, M S Grant, A Polley and E Barnwell, High Voltage Partial Discharge

16:20 **Closing Ceremony**
Student Awards (Oral + Poster)

16:30 **End**

List of Abstracts

Oral Presentations

1. **The Effect of Water on the Dielectric Properties of Polypropylene/Aluminium Nitride Nanocomposites**
   X. Wang, T. Andritsch and G. Chen, University of Southampton

2. **Understanding the Growth Mechanisms of Electrical Trees through High Resolution Chemical Analysis**
   H. McDonald, S. Rowland and S. Morsch, The University of Manchester

3. **Development of Surface Discharge Over PTFE Insulator Surfaces in Nitrogen and Air**
   M. Michelarakis[1], P. Widger[1], A. Beroual[2], A. Haddad[1], [1]Cardiff University and [2]University of Lyon

4. **A Geometry and Mesh Used in a High Voltage Capacitor Model**
   C. Mackinnon, B. G. Stewart, University of Strathclyde

5. **Current Interruption in a Rotary Arc based Load Switch**
   J. Qiang and J. D. Yan, University of Liverpool

6. **High Current Generator System based on Power Electronics**
   M. Cheah-Mane[1], M. Pages-Gimenez[2], C. Chillon-Anton[1], D. Montesinos-Miracle[1,2], [1]CITCEA-UPC and [2]TeknoCEA

7. **Cable Condition Diagnosis Based on the Increase of Cable Surface Temperature**
   H. Yi and C. Zhou, Glasgow Caledonian University

8. **Advances in Signal Analysis and Diagnostics for On-Line PD Monitoring of HV Rotating Machines**
   A Kokkotis, *M S Grant, A Polley and E Barnwell*, High Voltage Partial Discharge

Poster Presentations

9. **Enhanced Circuit Models for Very Fast Transients in Gas Insulated Substations**
   J James, M. Albano and A. Haddad, Cardiff University

10. **Outdoor Insulation for HVDC Overhead Lines: a Research Project**
    D. Pinzan, M. El Amine Slama, M. Albano, R.T. Waters, A. M. Haddad, Cardiff University

11. **Current sensor to investigate the tree mortality rate caused by lightning strikes in tropical forests**
    S. Stivanello[1], T. Hill[2], D. Clark[1], D. Mitchard[1], C Stone[1] and A. Haddad[1], [1]Cardiff University and [2]University of Exeter

12. **Different Heating Phenomenon between Faulted Insulator and Intact Insulator in infared pictures**
    K. Y. Zhang and J. D. Yan, University of Liverpool

13. **Effect of Air Humidity on the Flashover Strength of Solid Insulation**
    R. Macpherson, M. P. Wilson, I. V. Timoshkin, S. J. MacGregor and M. J. Given, University of Strathclyde

14. **Investigating the role of particle interphase on the electrical behaviour in nanodielectric materials**
    S. Chaudhary, T. Andritsch and A. S. Vaughan, University of Southampton

15. **Effect of Charge Transport on Surface Flashover**
    S. Pan[1,2], G. Chen[2], X. Wang[1] and S. Li[1], [1]Xi'an Jiaotong University and [2]University of Southampton

16. **Identification of faults of pumps and fans in transformer cooling system using winding temperature indicator and load data**

A. Doolgindachbaporn[1], N.H. Nik Ali[1], G. Callender[1], J. Pilgrim[1], P. Lewin[1] and G. Wilson[2], [1]University of Southampton and [2]National Grid

17. **DILO-Alternative Gases**
    A. Hunter, DILO

18. **Prebreakdown and Breakdown Phenomena in Transformer Liquids under Lightning Impulse Voltages**
    S. Shen, Q. Liu and Z.D. Wang, The University of Manchester

19. **Study of the Thermal Behaviour of Transmission Transformers in a Complete Cooling loop**
    S. Zhao, X. Zhang, Q. Liu and Z.D. Wang, The University of Manchester

20. **Development of a Dual Temperature Test Cell for Laboratory Ageing Experiment of Transformer Insulation System**
    B. Mebrahtom, *Q. Liu and Z.D. Wang*, The University of Manchester

21. **Data Analytics for Transformer Asset Management**
    G. T. Herath, Z.D. Wang and Q. Liu, The University of Manchester

22. **Effects of Electrical Conductivity of Contamination on Tracking Formation in High Voltage Aerospace System**
    W. Li and I. Cotton, The University of Manchester

23. **Effect of Micro Air Gap at the Needle Tip on Electrical Trees in LDPE**
    F. Liu[1], H. Zheng[1], S. Rowland[1] and J. Carr[2], The University of Manchester

24. **Thermal modelling of disc-type transformer windings in steady states**
    X. Zhang, M. Daghrah, Z.D. Wang, Q. Liu, The University of Manchester

25. **Interpretation of Frequency Response Analysis through Transformer Modelling**
    B. Cheng, P. Crossley, Z.D. Wang, The University of Manchester

26. **Ageing and Failure Mechanisms of Electrical Materials for High Voltage Systems in Aerospace Applications**
    H. Haghighi and I. Cotton, The University of Manchester

27. **Ageing Tests for Superhydrophobic Coatings on Overhead Line Conductors**
    C. Lian and I. Cotton, The University of Manchester

28. **Acoustic noise emitted from overhead line conductors with superhydrophobic coatings**
    X. Zhang, I. Cotton and C. Lian, The University of Manchester

29. **Breakdown Characterisation of C3F7CN as an Environmentally Friendly Alternative to SF6 for High Voltage Applications**
    H. Xu, L. Chen and I. Cotton, The University of Manchester

30. **Review of Area and Volume Effects on Breakdown Voltage of Transformer Liquids**
    H.C. Yu, Q. Liu, Z.D. Wang, The University of Manchester

31. **Dielectric behaviour of Ester liquid-solid composite insulating systems under lightning impulse stress**
    C. Williamson, I. Timoshkin, S. MacGregor, M. P. Wilson, M. Given, M. Sinclair, A. Jones, The University of Strathclyde

32. **The Search for an Economically Viable and Climate-friendly Alternative for Replacing SF6 in HV Accelerator Applications**
    I. Iddrissu, L. Chen, C. Nagel, The University of Manchester

Oral Abstracts

O1. The effect of water on the dielectric properties of polypropylene/aluminium nitride nanocomposites

Xinyu Wang[*1], Thomas Andritsch[1] and George Chen[1]
[1]School of Electronics and Computer Science
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A series of aluminium nitride/polypropylene nanocomposites were prepared. Nano aluminium nitride was surface functionalised by silane coupling agents with different hydrolysable groups and the effect of the surface chemistry and preconditioning (i.e., under different relative humidity) on their AC breakdown strength and the DC conductivity was investigated. The effect of water on the nanosilica-based nanocomposites have been studied by many researchers and the dramatically decreased AC breakdown strength and DC resistivity for wet samples were reported[1, 2]. By contrast, aluminium nitride filler with less hydrophilic sites, hydroxyl groups, was applied in this study. Furthermore, octyl silanes were adopted and the displacement of hydroxyl groups to short carbon chain on the particle surface is expected.

The preconditioning results show that the silane functionalisation can effectively reduce the amount of water absorbed during 15 days of immersion in deionized water. The dielectric properties show a high dependency on the sample preconditioning and water content. The DC conductivity of the non-treated aluminium nitride/polypropylene nanocomposites is 2 orders of magnitude higher than the octyl functionalised silane. Similar behaviour was observed on the AC breakdown data. However, the difference between systems treated with silane coupling agent with different hydrolysable groups cannot be seen from the weight monitoring and dielectric properties mentioned above. Although the dielectric results in [3] show the different hydrolysable groups might bring different bonding structure between nanoparticle and silane coupling agents, the interaction with water seems to have less dependency on it.

In this study, It can be concluded that the nanoparticle surface chemistry is very important in determining the macroscopic properties, especially in a humid environment. The surface functionalisation by silane coupling agent can effectively minimise the hydrophobicity of nanocomposites.

[1] D Qiang, Y Wang, G Chen, and T. Andritsch, "Influence of Water Absorption on Space Charge Behavior of Epoxy Nanocomposites," 2016.

[2] I. Hosier, M. Praeger, A. Holt, A. Vaughan, and S. Swingler, "On the effect of functionalizer chain length and water content in polyethylene/silica nanocomposites: Part I—Dielectric properties and breakdown strength," *IEEE Transactions on Dielectrics and Electrical Insulation,* vol. 24, no. 3, pp. 1698-1707, 2017.

[3] X. Wang, T. Andritsch, and G. Chen, "Effect of Surface Functionalization on the Dielectric Properties of Polypropylene Aluminium Nitride Nanocomposites," in *2018 IEEE 2nd International Conference on Dielectrics (ICD)*, 2018, pp. 1-4: IEEE.

O2. Understanding the Growth Mechanisms of Electrical Trees through High Resolution Chemical Analysis

H McDonald, S Rowland and S Morsch
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The large-scale transmission of electricity is essential in the modern world, and the consistency and cost of this supply has impacts of societal, financial and political significance. Undergrounded cables are widely used and polymeric insulation has become increasingly popular in recent decades for cable insulation, joints and terminations due to their low weight and cost combined with strong dielectric performance. A variety of polymers including epoxy resins, polyethylene and ethylene propylene rubber are deployed at a range of voltages from LV to 500 kV. This necessitates the study of degradation mechanisms affecting polymers. Considered here is a major process of degradation known as electrical treeing, in which microscopic gaseous channels form and grow within the insulation eventually leading to catastrophic failure. Understanding this process is essential for the development of resistant materials and improved asset management methods.

Previous work utilised a recently developed and powerful chemical analysis technique, Atomic Force Microscopy with Infrared Spectroscopy (AFM-IR), to study electrically aged epoxy samples and map the chemical degradation around a field enhancement point [1]. This technique provides topographical and chemical information on the scale of tens of nanometres (Figure 1), far exceeding those available using other techniques such as Fourier Transform Infrared Spectroscopy (FT-IR). The significance of such resolution is that electrical treeing occurs on sub-micron levels; therefore, accurate modelling of their growth requires an understanding on sub-micron levels.

Here the AFM-IR technique is applied to electrical tree channels grown in epoxy resin, studying the chemical products within and beyond the channels and compared with more thoroughly studied and understood ageing mechanisms, such as surface corona discharge and thermal ageing. It is observed that damage to the epoxy during channel growth is limited to carbonisation on the surface of the channel walls, not extending further into the surrounding material. Bearing similarities with coronal discharge ageing in this respect. Also notable is the formation of volatile chemical products within the channels, which are easily dislodged. The localisation of chemical degradation enabled by the AFM-IR technique allows such features to be identified and factored when studying the underlying mechanics of electrical tree growth.

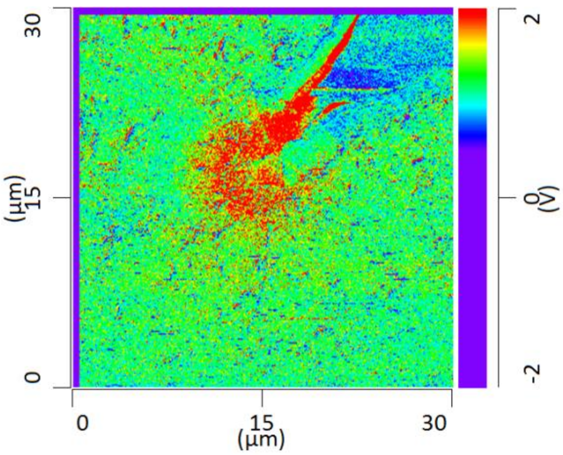

Figure 1: AFM-IR imaging showing the density of alkene bonds generated around a metallic needle tip at voltage. It can be seen that the density is highest within an approximately 10µm region of where the tip had been.
(The density is charted on the bar at the right. Red meaning greater density, blue meaning less.)

H McDonald, P D Bastidas, S Rowland and S Morsch. "Chemical Analysis of Solid Insulation Degradation using the AFM-IR Technique.", *IEEE 2nd International Conference on Dielectrics (ICD)*, pp. 1-4. IEEE, 2018.

O3. Development of Surface Discharge Over PTFE Insulator Surfaces in Nitrogen and Air

M. Michelarakis*[1], P. Widger[1], A. Beroual[2], A. Haddad[1]

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In high voltage equipment, solid/gaseous interfaces are frequently encountered in components and insulation applications. Under a variety of circumstances, triple junctions are source of additional concern for the design and dimensioning of efficient insulating systems. So far, many studies [1],[2], both experimental and simulated, are dedicated to the characterisation and understanding of the related phenomena with a variety of different parameters such as insulator geometry and material, applied voltage waveform, electrode configuration, gaseous insulating medium, etc.

For the purposes of the current work, first, the process of designing and simulating the electrodes configuration using a Finite Element Solver (FEM) is described. The aims of the simulation are to optimise the electrodes configuration design and to calculate the maximum electric field stress within the electrode geometry. The distribution of the generated electric field on the surface of the insulator samples is of high interest, constituting a major role on the surface discharge propagation. Following the simulation process, a series of practical tests are performed using insulator disc samples of polytetrafluoroethylene (PTFE). The full electrode test configuration is enclosed in a pressure vessel filled with an insulating gaseous medium of Nitrogen (N_2). Different voltage waveforms were applied according to the relevant standards [3]. The case of air at atmospheric conditions is also considered for comparison purposes. Typical records of the obtained measurement results are shown in Fig. 1. For the measurement of the current associated with the surface discharge activity, a wide-bandwidth, high-frequency and high-sensitivity current transformer was employed ensuring electrical isolation between the test and recording configurations and also improved reliability of the obtained measurements. The presented results constitute a preliminary part of a future extensive research programme.

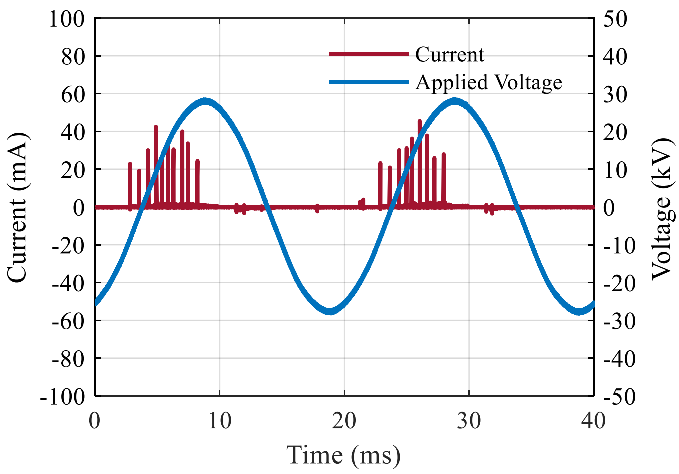

Figure 1: PTFE of 4mm thickness in N_2 at 1 bar gauge pressure, under 20 kV/50 Hz (rms) AC voltage application.

[1] F. Sadaoui and A. Beroual, “AC creeping discharges propagating over solid-gas interfaces,” *IET Science, Measurement & Technology*, Vol. 8, Issue 6, pp. 595– 600, November 2014.

[2] F. Sadaoui and A. Beroual, "DC creeping discharges over insulating surfaces in different gases and mixtures," *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 21, Issue 5, pp. 2088-2094, October 2014.

[3] “High-voltage test techniques - Part 1: General definitions and test requirements,” BS EN 60060-1:2010, 2011-03-31.

O4. A Geometry and Mesh Used in a High Voltage Capacitor Model

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HVDC systems require high voltage capacitors for reactive power support and harmonic filtering, in addition to those deployed for power factor correction and as part of other systems throughout an electrical network. Permittivity of the dielectric used in these assets is central to their operation, and, in lieu of sufficient reliability data from a limited asset base, it is desirable to develop a boundary element model [1] as a means of efficiently simulating voltage stresses, temperatures, and dielectric integrity within a capacitor module [2]. This contribution presents a high voltage capacitor model to that end, with an initial simulation geometry illustrated by Figure 1. The geometry is parameterised, such that a user can specify a module's size, number of capacitive elements, dielectric conditions, and so on, to which the geometry and mesh will adapt. In turn, this allows this model to be supported by Comsol's application builder, meaning it can be executed independently for different module designs. The mesh, too, is parameterised to allow the user to control a level of granularity on aluminium foils central to the module's function, and the means by which mesh elements grow between inner and outer boundaries as a result. Selections are defined to specify the distribution of voltage and allow the physical representation to be coupled with an electrical circuit boundary condition, to provide a simulated electrical context and to emulate component behaviour in response to a variety of signal characteristics. Module longevity is highly dependent on temperature over an operational lifetime, and an ability to detect and respond to failures early can prevent cascading dielectric breakdown [3]. By providing a geometry and mesh used in a high voltage capacitor model, the authors hope to efficiently model the physical basis for these assets from first-principles, to better understand how component operating environments can affect their electrical behaviour, and ultimately to ascertain the influence of environmental conditions on reactive power support and harmonic attenuation in practical power system applications.

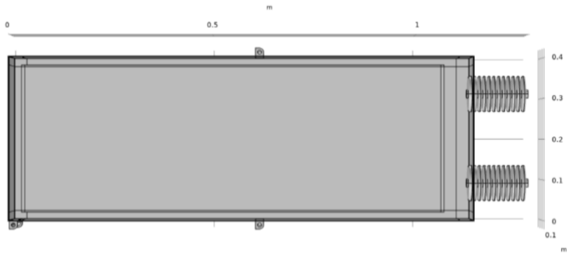

Figure 1. An example capacitor model geometry.

[1] B. Sjodin, "How to Create Electrostatics Models with Wires, Surfaces, and Solids", [Online.], August 2017, *Accessed: 2018-11-09*.

[2] H. Jouybari-Moghaddam, T. S. Sidhu, M. R. Dadash Zadeh, P. P. Parikh, "Shunt Capacitor Banks Online Monitoring Using a Superimposed Reactance Method", *IEEE Transactions on Smart Grid*, 2017.

[3] M. Ellis, D. J. Meisner, and M. Thakur, "Innovative Protection Schemes for H Configuration Fuseless Grounded Shunt Capacitor Banks", *Proc. 65th Annual Conference for Protective Relay Engineers*, pp. 449-458, 2012.

O5. Current Interruption in a Rotary Arc based Load Switch

Jing Qiang[*1], J D Yan[2]
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The electrical power network is becoming more intelligent and eco-friendly to protect the environment. Load switch, which is used in almost all heavy industries, perform switching duties to start or stop a machine process. In order to reach the demand of developing power system, design of such devices is pushed towards low carbon, compact in size and high reliability. An ecomonic technique applied in load switch is to use magnetic field induced Lorentz force to rotate and quench the arc. This kind of employment can reduce contact erosion to prolong its life time. Meanwhile, the produced relevant movement between arc and surrounding gas can enhance the interruption performance.

Currently the theoretical knowledge of switching arc process is still insufficient so the present work is aimed at a better understanding. The arcing phenemomon is studied in a 40 kV load switch experimentally first to obtain important information about the arc behaviour or features. The current and voltage of arc are measured. And a high speed color camera captures the photographs of the arcing process. The typical results show that the radius of the upper part of the arc column is around 5mm at 500 A, and 9 mm at 1200 A. The maximum current density of the arc column is between $5 \times 10^6\ \mathrm{A/m^2}$ and $10^7\ \mathrm{A/m^2}$. The arc at high current has a clearly defined conducting column but turns into a cloud-like hot gas when the current approaches its zero point. Based on the experimental evidence, a 3D model is to be established which will be used to simulate the arcing process. The challenge for simulation is the high computational cost. The ultimate objective is to provide a link between the design parameters and its interruption capability so the model can benefit the design.

In the presentation some of the important outcomes and understanding based on our recent work will be reported e.g typical experimental results, arc rooting and radiation calculation.

O6. High Current Generator System based on Power Electronics

M. Cheah-Mane*[1], M. Pages-Gimenez[2], C. Chillon-Anton[1] ,D. Montesinos-Miracle[1,2]
[1]CITCEA-UPC [2]TeknoCEA
*E-mail: marc.cheah@upc.edu

High current testing is essential to validated the capability of electrical components, such as circuit breakers, cable connectors or fuses, and to ensure compliance with IEC standards. In particular, short-circuit tests of compression and mechanical connectors for power cables are based on a test rig with a high current transformer following the IEC 61238 [1]. This traditional solution requires a high input power and the current output is difficult to control, which might lead to significant inaccuracies to follow the standard specifications. An alternative solution are short-circuit generators, which are widely used for high current testing [2]. Such generators are based on a motor-generator set that stores kinetic energy and provides a large current for a short period of time. However, this solution might be expensive due to the high maintenance of rotation components. Similar options can be developed based on power electronic converters.

The present work shows a high current generator system based on Voltage Source Converters (VSCs), which stores electrostatic energy in supercapacitors. A converter is responsible for charging the supercapacitors before the short-circuit test. Then, another converter releases the stored electrostatic energy as a controlled output current through the tested connectors. Since the released energy is controlled by a VSC, the applied current can have different frequencies and profiles, which could be convenient to test other electrical components for high and low voltage applications.

Figure 1 shows the experimental results of a 26 kA short-circuit test of a 400 mm^2 connector. According to the IEC 61238 the connector temperature during the test should raise at most between 250ºC and 270ºC. It is observed that the temperature (purple curve) raises below 270ºC for a 3 seconds test.

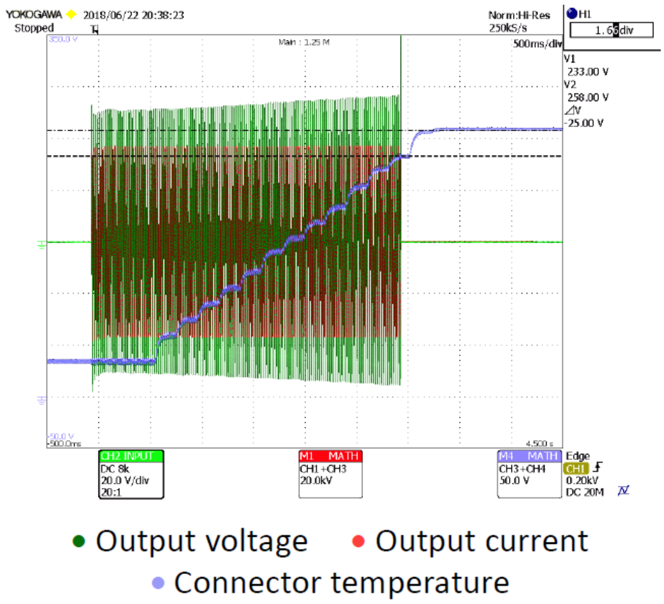

Figure 1: 26 kA short-circuit test of 400 mm^2 connector.

[1] M. Runde, H. Jensvold, and M. Jochim, “Compression Connectors for Stranded Aluminum Power Conductors,” *IEEE Trans. Power Deliv.*, vol. 19, no. 3, pp. 933–942, Jul. 2004.
[2] H. Yoda, M. Fujita, E. Nakamura, T. Ikuzawa, T. Otaka, and S. Nagano, “The world’s largest class 8,880MVA short circuit generator,” in *IEEE Power Engineering Society Summer Meeting*, vol. 2, pp. 688–693.

O7. Cable Condition Diagnosis Based on Local Increase of Cable Surface Temperature

Huajie Yi[*1], Chengke Zhou[1]
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*E-mail: Huajie.Yi@gcu.ac.uk

Cable condition monitoring techniques play a key role to inform operators of the state of cables. A number of researches have been carried out in measurement of cable partial discharge (PD), dielectric loss (DL/tanδ) and cable insulation resistance (IR). However, the diagnosis based on cable PD, DL or IR are sensitive to noise level, accuracy of current sensors and resolution of test devices, respectively. The degradation of cable insulation can lead to the phenomenon of heating which can be reflected by increasing the cable surface temperature [1].

This paper presents a case study on a 275 kV oil-filled cable. The condition assessment and diagnosis are based on analysis of cable surface temperature in relation to its current load and insulation dielectric loss. The work was initiated by a local abnormal temperature rise of 5.2 °C in cable surface temperature, which was observed during a routine inspection. The temperature rise occurred at bend area with a length of approximately one metre in the Blue Phase. No PD activity was identified using on-line PD measurement. The relation between cable surface temperature, cable core temperature and cable insulation condition was then simulated based on the thermal model of power cables. According to simulation analysis, poor condition of cable insulation or oil from an oil duct penetrating a region under the cable surface were identified as possible reasons for the problem observed. An in service X-ray scanning technique was employed for further investigation and to aid diagnosis. The X-ray images revealed a slight distortion of the PVC sheath and the presence of multiple voids between cable insulation paper and the lead sheath. It was concluded that an oil leakage from the oil duct to the voids under the cable lead sheath was responsible for the local cable surface temperature rise. The result removed the concern of incipient cable breakdown, and a potential unplanned outage.

[1] Lubkov, A.N., Privalov, I.N. & Mezgin, V.A, "Diagnostics of the insulation of high-pressure oil-filled 220 and 500KV cable lines when operating in hydroelectric power plant", *Power Technology and Engineering*, vol. 45, no 1, pp 69- 75, May 2011.

O8. Advances in Signal Analysis and Diagnostics for On-Line PD Monitoring of HV Rotating Machines

A Kokkotis*, M S Grant, A Polley and E Barnwell
High Voltage Partial Discharge Ltd
*E-mail: andreas.kokkotis@hvpd.co.uk

Nowadays, the running operation of rotating machines has become more intermittent than ever. In power generation, the penetration of renewables combined with energy demand fluctuations has led to a more sporadic usage of generators associated with conventional and green power generation. In heavy industry and oil & gas sector, motors that drive machines such as pumps and blowers are traditionally used intermittently. Despite the decreased running time of these assets, certain defects can be caused by frequent starts and stops and fast-changing loads.

In the stator winding of rotating machines, the main defects that are related to such operations are slot discharges and delamination. On-line Partial Discharge (OLPD) monitoring can detect flaws in the insulation at an early stage and trend their development over time.

In rotating machinery, PD pulses, high-frequency machine triggering pulses and on-site noise can superimpose resulting in a complicated Phase Resolved PR (PRPD) pattern. Irrelevant pulses can distort correct diagnosis and prevent accurate trending of PD values. Signal de-noising and classification can be performed by novel advanced analysis tools.

High-resolution visualisation of all captured pulses based on common and novel features allows different PD types to be distinguished from each other as clusters. Similarly, PD clusters can be differentiated from irrelevant pulses. The data system registers the time for each event which allows the clusters to be trended individually.

Expert analysts can then evaluate the overall condition of the stator winding and locate the defected area(s) by interrogating the PRPD patterns of the PD clusters.

Maximum utilisation of the OLPD monitoring can be achieved by the capability to transfer and analyse the data regularly. Network topology and cloud computing methods have been developed to automatically and securely transfer data from the substation to an analysis centre anywhere in the world.

In this paper, a variety of rotating machine PRPD patterns that were captured with on-line monitoring are presented via high-resolution visualisation and advanced plotting tools. The monitoring technique for the acquisition of the PRPDs is remote monitoring. Remote monitoring pertains to emplacement of the OLPD sensors at the switchgear end of the assets.

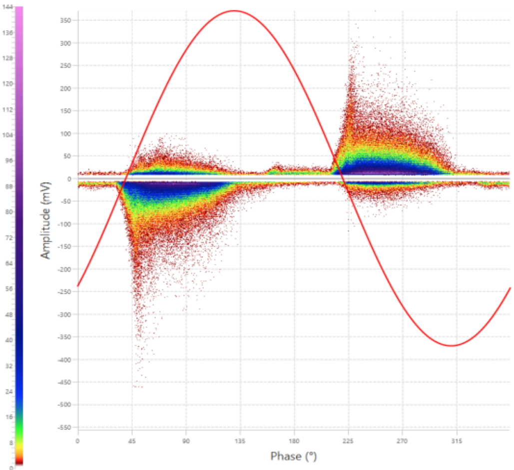

Figure 1: PRPD of internal delamination between the copper conductor and the main insulation captured remotely via OLPD monitoring

Poster Abstracts

P9. Enhanced Circuit Models for Very Fast Transients in Gas Insulated Substations

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Abstract:

When modelling components at low frequencies, in which the associated wavelength is much greater than the physical size, a lumped element approach will often suffice. However, modelling at very high frequencies requires consideration of the travelling waves phenomenon. Very Fast Transients (VFTs) are high magnitude transients that are commonly associated with disconnector switching in Gas Insulated Substations (GIS). VFTs are responsible for insulation ageing, flashovers and Electromagnetic Interference (EMI) issues [1]. VFTs have frequency content extending up to 100MHz [2], Thus, circuit models for VFTs should consist of distributed parameter lines which account for a number of travelling wave effects. For the components within the system that have a small length, such as an insulating spacer, a distributed parameter line representation in a transient circuit simulator would require a very small timestep. This would result in long computation times and significant storage requirements. Therefore, these components are often represented as simplified lumped circuit equivalents.

Lumped element representation is generally based on modelling guidelines or analytical calculations. Misrepresentation of important system components could lead to modelling errors which could ultimately result in insulation failure. Where component geometries and dimensions are available, a better representation can be realised using Finite Element Modelling (FEM) to find a solution for a wave equation, subject to the component geometry and material characteristics. For this work, the radio frequency (RF) module of COMSOL Multiphysics® [3] is used to solve a time harmonic wave equation for a range of frequencies that cover the VFT spectrum, so allowing the frequency response of the device as a discrete component to be calculated in the form of S parameters. S parameters characterise a device in terms of its transmission and reflection coefficients. These S parameters are subsequently converted to R, L, C and G circuit parameters for use within a distributed line model. A comparison of standard and enhanced circuit models is then carried out to compare Very Fast Transient Overvoltage (VFTO) magnitudes throughout the system.

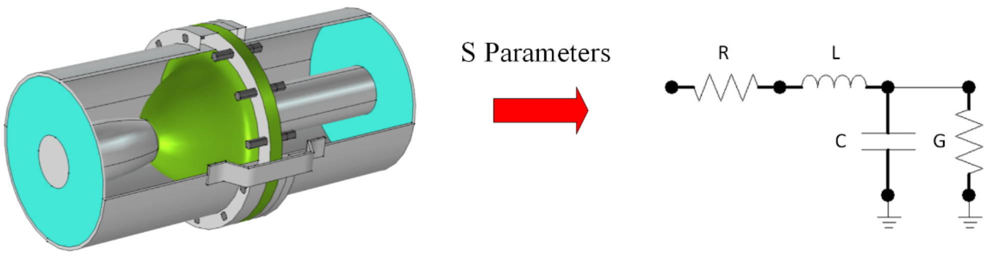

Figure 1: Finite Element Model conversion to RLCG parameters for a distributed line

[1] H. Koch, *Gas Insulated Substations*. Wiley Blackwell, 2014.
[2] British Standards Institution., "BS EN 60071-4:2004 - Insulation co-ordination - Part 4:Computational guide to insulation co-ordination and modelling of electrical networks," 2004.
[3] "COMSOL Multiphysics® v. 5.3a." COMSOL inc, Stockholm, Sweden.

P10. Outdoor Insulation for HVDC Overhead Lines: a Research Project

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In a world of growing power demand, it is critical to increase the power transfer capability of the power system. This can be ensured through a grid physical expansion, voltage uprating of existing AC lines, or their conversion from AC to DC operation. The latter option is the focus of this project investigating the Performance of Outdoor Insulation under HVDC Stress.

An overview of current knowledge on outdoor insulation for both AC and DC [1] was undertaken, including the inert and active pollution effects on HVDC energised polymeric insulators, innovative laboratory polluting methods, dimensioning of HVDC energised insulators [2] and conversion of existing lines from HVAC to HVDC.

Given the nature of the DC electric field is monopolar, a continuous force is exerted on the pollution particles in the vicinity of the insulator, which may lead to an increase of the amount of electrolyte deposited on its surface in case of light rain or fog. Such an undesirable accelerated pollution on the insulator surface can result in more frequent discharge activity and lead to flashover. Hydrophobicity transfer from the bulk of the silicone rubber material to the polluted surface will reduce the effect of pollution on surface conduction and discharge activity, and such property is highly useful for HVDC applications. Such phenomena are studied in this work

The research is now developing solutions for the conversion of transmission overhead lines from AC to DC operation [3], which allows to increase of power transfer capability by a factor of 3. In this regard, climate and environment as well as specific tower configurations were considered. This is a growing engineering challenge, as conversion cases are starting to become more needed around the world to address growing bulk electrical energy transfer. A systematic approach for assessing the best engineering choice for the most suitable HVDC scheme must be considered to optimise energy delivery under fault conditions.

This paper gives an overview of the above research activities.

[1] CIGRE Task Force 33.04.01, "Polluted insulators: a review of current knowledge." CIGRE, Jun-2000.

[2] CIGRE Working Group C4.303, "Outdoor insulation in polluted conditions: Guidelines for selection and dimensioning - PART 2: THE DC CASE." CIGRE, Dec-2012.

[3] CIGRE Working Group B2.41, "GUIDE TO THE CONVERSION OF EXISTING AC LINES TO DC OPERATION." CIGRE, May-2014.

P11. Current sensor to investigate the tree mortality rate caused by lightning strikes in tropical forests

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Abstract:

Tropical forests harbor a big amount of the living carbon and much of the world's biodiversity. The mortality of trees in the tropical forests has increased over the last years and there is a poor understanding of what is driving this trend. This increase in mortality has reduced the rate of carbon stored in tropical forests, causing a globally significant decline in the reserve of terrestrial CO_2.

The hypothesis that lightning could be a key driver of tree mortality in tropical forests, where the frequency of lightning strikes is the highest, has to be considered. Trees struck by lightning may show little or no visible signs of damages and so the research to develop a particular sensor able to detect if a lightning has stricken a tree is necessary. The Morgan-Botti Lightning Laboratory at Cardiff University, with Exeter and Edinburgh Universities, are now undertaking a NERC-funded project to investigate the interaction between lightning and tree mortality.

The developed sensor design uses a ducting hose reinforced with a spiral of steel-coppered wire. The design takes into account the cost of raw materials and ease of on-site installation and monitoring work. The materials need to be durable to degradation due to harsh environmental conditions in tropical forests. The sensors have fuses that allow determination of the lightning current magnitude after the strike to the tree. Rogowski coils with carefully designed fused terminations have been built, tested and installed at selected locations in a tropical forest in Nigeria. Further installations are planned in Ghana.

Laboratory tests have allowed to determine the best configuration of the physical dimensions of the coil (wire and core materials and turn and coil radii). To evaluate the performance of the sensors, their measured induced voltages were compared with the calculated values, by performing various high current lightning tests in the laboratory. The responses of six sensors with different lengths, corresponding to different trees diameter classes, were experimentally determined by applying increasing current magnitudes of lightning impulses. A number of terminating fuses were tested to determine their failure thresholds. Good correlation was found between the predicted and measured values.

P12. Different Heating Phenomenon between Faulted Insulator and Intact Insulator in Infared Pictures

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Insulators play an important role in energy system as they electrically insulate the power and mechanically sustain transmission lines. Infrared detection is an effective way to find faulted discs by spotting the abnormal bright points. The potential distribution along insulator strings is not linear due to influence of stray capacitance, causing a saddle-like distribution curve. Two sides of the curve are high, and the bottom is low, which means the insulators at either side of the string would stand a higher voltage. Intact insulators might also become bright in infrared pictures because of the uneven distribution. This paper analyses the results of field experiments under different voltage levels and utilizes finite element method simulations as supplements. The different heating phenomena between faulted insulators and intact insulators have been concluded. Temperature distribution of faulted insulator's steel-cap was well-distributed, while the lower part of intact insulator's steel-cap is brighter than its upper part. Additionally, porcelain temperature of faulted insulator remains nearly unchanged, whereas that of the intact disc rises by almost 1.2℃. These conclusions would help to discern faulted insulators in case of mis-detection.

P13. Effect of Air Humidity on the Flashover Strength of Solid Insulation

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Surface flashover across solid dielectric/gas interfaces is a problem that can occur during operation of gas (air) insulated high voltage (HV) equipment. The present work is aimed at investigation of the surface flashover characteristics of different solid dielectrics, stressed with sub-μs HV impulses in atmospheric air with low and elevated humidity. An experimental system has been developed to control the relative humidity (RH) of air, to determine the effect on the flashover strength of different solid materials at atmospheric pressure. The 3 materials, tested between parallel-plane electrodes, are Delrin, HDPE and Ultem. Breakdown tests with no solid dielectric between the electrodes are also reported, to provide baseline data on the breakdown of air with different levels of humidity. The samples of solid dielectrics are cylindrical, with their surfaces machined to a smooth finish. Positive polarity impulse voltages will be applied across the electrodes using a 10-stage Marx generator, configured to produce a 100/700 ns ouput voltage waveform, with a peak voltage up to 200 kV.

Each solid sample is characterised in terms of average flashover voltage and time to breakdown, over 20 individual breakdown events. The voltage will be increased in steps of 3 kV from a 'no breakdown' level until a flashover occurs, then the process will be repeated until 20 flashover data points have been gathered per test condition. Two withstand levels will be observed before a valid breakdown voltage is recorded, in accordance with the ASTM D3426-97 standard. Solid samples will be tested in air with low (<10%) RH, and in air pre-treated with an ultrasonic humidifier to achieve high (>90%) RH. The results will inform on the most suitable solid material to maximise the flashover voltage, under different relative humidities.

P14. Investigating the role of particle interphase on the electrical behaviour in nanodielectric materials

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Many research studies have been performed in order to understand the role of polymer interphase, i.e. the interaction zone for the polymer matrix and the nanofillers, in nanocomposites. A commonly accepted idea is that bonding between the polymer matrix and nanofillers increases, as the size of the nanoparticles decreases, as a result of the increased surface area [1]. This leads to the properties being dominated by the characteristics of the interaction zone, thereby changing the electrical properties which have been measured to explain the role and structure of the interface. However, the aim of this study is to explore the idea proposed by Fuad Alhabill [2], investigating the role and effect of the particle interphase within the boundaries of the nanoparticle, on the properties of the overall nanocomposite.

The initial approach is experimenting with different combinations of core-shell structure nanofillers, such as Al_2O_3/AlOOH, AlN/AlOOH or Al_2O_3/SiO_2 in same polymer matrix i.e. epoxy. The working hypothesis is that by keeping the shell the same, we would observe no significant changes to the polymer interphase. Whereas altering the core changes the particle interphase, by changing the bond structure leading to a different concentration of localized electronic states [2]. Meseaurments for permittivity, DC conductivity, glass transition temperature, AC and DC breakdown are performed. Analysis of the measurements would demonstrate the effect of the particle interphase on the dielectric properties of the bulk material.

This study would help determine the importance and relevance of the particle interphase. The results could potentially be of importance for designing nanocomposites with improved or desired dielectric properties. Future work will examine altered charge transport mechanisms as a result of the different particle interphases, by means of space charge analysis.

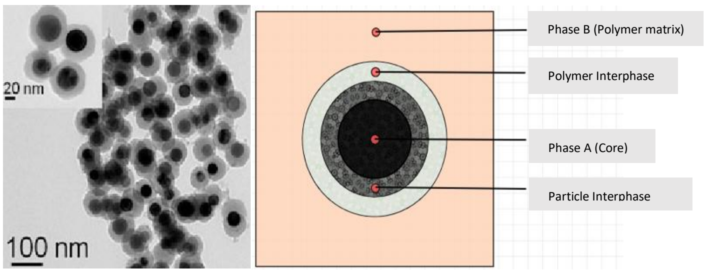

Figure 1. a) Ag@SiO_2 core–shell nanoparticles in epoxy resin [3] b) Core – Shell structure along with polymer and particle interphase.

[1] F. Aldawsari, C. J. Angammana and S. H. Jayaram, "Influence of interface on the electrical properties of silicone nanocomposites," 2017 IEEE Conference on Electrical Insulation and Dielectric Phenomenon (CEIDP), Fort Worth, TX, 2017, pp. 513-516.doi: 10.1109/CEIDP.2017.8257645

[2]Fuad N. Alhabill, Raed Ayoob, Thomas Andritsch, Alun S. Vaughan,Introducing particle interphase model for describing the electrical behaviour of nanodielectrics,Materials & Design,Volume 158,2018,Pages 62-73,ISSN 0264-1275, https://doi.org/10.1016/j.matdes.2018.08.018.

[3]Niu, Yujuan & Bai, Yuanyuan & Yu, Ke & he, li & Xiang, Feng & Wang, Hong. (2013). Fabrication, structure, and property of epoxy-based composites with metal–insulator core–shell structure fillers. Journal of Materials Research. 28. 10.1557/jmr.2013.248.

P15. Effect of Charge Transport on Surface Flashover

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The main stream theory of surface flashover is the theory of secondary electron emission avalanche (SEEA). It is generally acknowledged that surface flashover is initiated by field-emission (FE) electrons emitted from the cathode-dielectric-vacuum triple junction(CTJ). Some of these field-emission electrons will return to the dielectric surface and strike it to yield secondary electrons (SE), some of which will also return and strike the dielectric surface to yield additional secondary electrons. Repetition of these processes develops into an SEEA (Figure 1). Meanwhile, electron bombardment leads to the release of adsorbed gas. It is through this gas that the flashover plasma is finally formed. In this model, electrons emerging from the CTJ and the insulator surface have an initial velocity directed away from the insulator. To deflect these electrons toward the insulator, the assumption of positive charging of the insulator surface is usually employed. However, in our previous experiments, the dielectric surface suffers sustaining electron irradiation, and electrons will deposit on the surface. So the assumption of pre-existing positive surface charges needs to be reconsidered. We established a two dimension model to simulate the charge transport before and during the surface flashover process. The results show that charge transport in the dielectric layer will influence the electric field in the vicinity of cathode and anode (Figure 2), as well as the development of the discharge plasma.

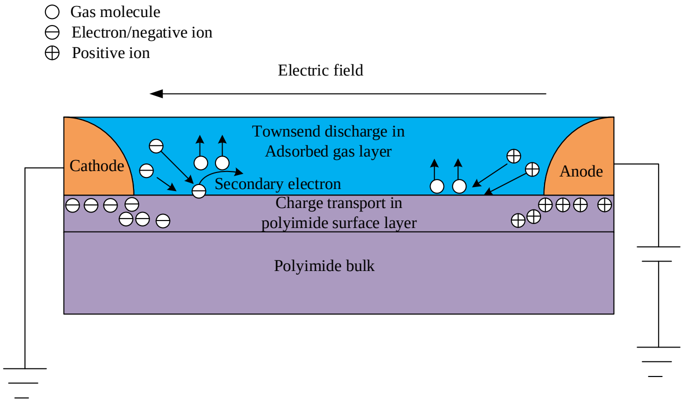

Figure 1. Schematic of charge transport in surface flashover process

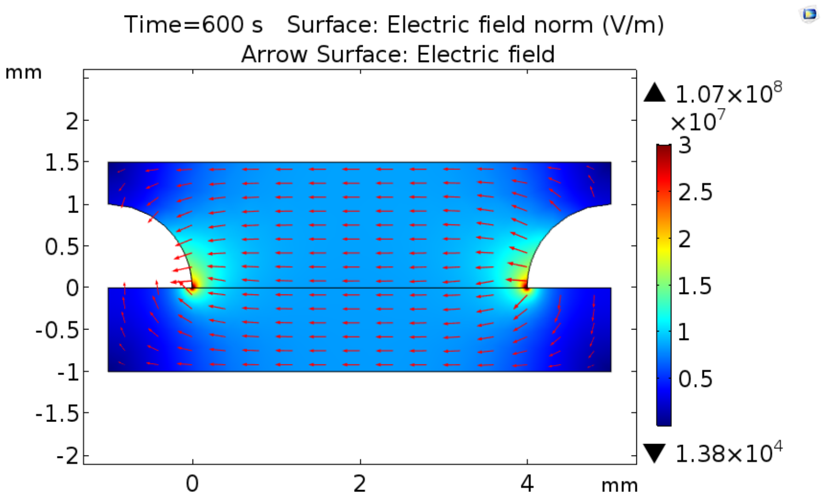

Figure 2. Electric field distribution considering space charge effect before surface flashover

[1] A. S. Pillai and R. Hackam, "Surface flashover of solid dielectric in vacuum," J. Appl. Phys., vol. 53, no. 4, pp. 2983–2987, 1982.
[2] H. C. Miller, "Flashover of Insulators in Vacuum Review of the Phenomena and Techniques to Improve Holdoff Voltage," IEEE Trans. Electr. Insul., vol. 28, no. 4, pp. 512–527, 1993.
[3] S. Li, S. Pan, G. Li, D. Min, W. Wang, and S. Li, "Influence of electron beam irradiation on DC surface flashover of polyimide in vacuum," IEEE Trans. Dielectr. Electr. Insul., vol. 24, no. 2, pp. 1288–1294, 2017.

P16. Identification of faults of pumps and fans in transformer cooling system using winding temperature indicator and load data

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Rating power transformers is a crucial part of operating and managing power systems. At present transformers will typically be de-rated only if significant faults with cooling systems are detected. Detecting these faults at an early stage would prevent thermal damage to transformers and avoid an over rating situation. Identifying faults of pumps and fans or a reduction in cooling performance is presented in this work by analysing winding temperature indicator (WTI) temperature and load data.

Firstly, a method is needed to remote determine whether the WTI sensor reads the temperature correctly. An unresponsive WTI sensor, broken current transformer (CT) or heating element could be detected using time series decomposition techniques. The WTI temperature and load data are decomposed into trend, weekly and daily seasonal components and an irregular component according to an additive model. A low correlation between load and WTI temperature of each component would indicate an inactive sensor. Unlike an inactive sensor, a WTI sensor with broken CT or heating element (i.e. reading top oil temperature only) still yields high correlation between load and WTI temperature. The issue could be identified by calculating the average expected WTI temperature from the average load over a given period according to IEC 60076-7 [1] and then compared to the measurement data. If the measurement is significantly lower than the expected value, it would indicate a broken heating element.

The same idea is also applied to detect forced cooling faults in transformers. The WTI measurement while the cooling system is active was compared with the calculated WTI temperature based on IEC 60076-7 and the Susa model [2]. The results have shown that the calculated WTI temperature based on Susa model is relatively similar to the measurement whereas the calculated WTI temperature based on IEC 60076-7 is an underestimated compared to the measured data. This is because the WTI temperature in the IEC thermal model does not consider a variation in oil viscosity which leads to higher thermal resistance at a lower temperatures. If the measurement tends to be significantly higher than the calculated values or no longer follows the calculated values, it would indicate faults in the cooling system. Future work will aim to develop an alternative thermal response of transformers using learning algorithms.

[1] Power transformers – Part 7: Loading guide for oil-immersed power transformers, IEC Publication 60076-7, 2018.
[2] D. Susa, M. Lehtonen, and H. Nordman, "Dynamic thermal modelling of power transformers," IEEE Transactions on Power Delivery, vol. 20, no. 1, pp. 197-204, 2005.

P17. DILO-ALTERNATIVE GASES

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Focus on the environment

SF_6 is an excellent insulating and arc quenching gas that has been in use in the energy industry worldwide for more than 50 years. The energy development in medium, high and ultra-high voltage would have been impossible without the use of SF_6 with its excellent dielectric strength and good arc quenching properties. Due to its high global warming potential with a GWP index of approx. 22,800 CO_2e, SF_6 is the most potent known greenhouse gas remaining in the atmosphere for approx. 3,200 years. For this reason, politicians have been calling for alternative solutions. Agreements and regulations such as the Kyoto protocol, the EU F-gas regulation and the Paris climate change agreement of 2015 have a common global goal:

THE REDUCTION OF GREENHOUSE GAS EMISSIONS.

As a pioneer in SF_6 gas handling with over 50 years of experience, we are also one of the pioneers in the development of equipment for handling alternative gases. During CIGRE 2018, DILO launched its green line products covering service and measuring devices for alternative gases. The first serial products developed by DILO are already in use by switchgear manufacturers and end users. The range of alternative gas mixtures is wide and the requirements for the device design must be specially adapted to each type of mixture. As SF_6 gas handling expert, however, we have the necessary knowhow and development potential to offer the necessary products for the complete spectrum of gas handling for the new eco-efficient gases as well.

The green line can be differentiated between the product groups

C4 for $(CF_3)_2CFCN$ = 3M™ Novec™ 4710
C5 for $CF_3C(O)CF(CF_3)_2$ = 3M™ Novec™ 5110

An overview of our Alternative Gas handling products that are available

The product ranges shown currently relate to gas mixing, analysing, leak detection and handling of gas mixtures based on 3M™ Novec™ 4710 or 3M™ Novec™ 5110.

As a specialist for gas handling, DILO also works with manufacturers and institutes that do not focus on the basic gases mentioned above.

Thanks to our in-house expertise in all fields of gas and gas mixture handling, we can offer you individual product solutions. DILO can supply a suitable product for your special application, starting with concept development through detailed technical development and complete control development, the production of individual and special systems right up to commissioning.

P18. Prebreakdown and Breakdown Phenomena in Transformer Liquids under Lightning Impulse Voltages

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Understanding the pre-breakdown mechanism, commonly termed as ‘streamer’, of transformer oil is critical to transformer insulation design. This paper presents a study on the streamer characteristics in a mineral oil and a synthetic ester liquid under positive lightning impulse. The study of streamer is greatly facilitated by high speed imaging techniques [1]. In this paper, a Schlieren optical system is set up, and streamer propagation is captured by both laser and flash light sources. Non-uniform field could experimentally facilitate the discharge in liquid. However, the non-uniform field extremity cannot fully represent the real scenario in transformer insulation [2]. To circumvent this problem, a semi-uniform field is applied in this paper. Streamers are visualised in a plane-needle-plane semi-uniform electrode configuration, and the results are compared with the needle-plane non-uniform electrode configuration. During streamer propagation, Mach-cone shaped shockwaves are registered ahead of the streamer channel heads, while circular shockwaves are registered in further regions away from streamer channels. It is also found that, under same gap distance, streamers under semi-uniform field has less branched structure. The propagation is more restrained in the axial direction. Compared to mineral oil, the streamers in synthetic ester have more offshoots along the main channels. Besides, streamers under semi-uniform field exhibit larger scattering in streamer initiation and propagation probability. Nevertheless, it has been verified that the streamer in uniform field is a more initiation-dominated process, while in non-uniform field it is a more propagation-dominated process [3]. In this paper, field inhomogeneity factor (maximum field to average field) is used to describe the degree of the non-uniformity of field geometry. It is found that as field inhomogeneity factor decreases, the field tends to be more uniform, and the streamer propagation is greatly facilitated. As a consequence, a transition from propagation-dominated process to initiation-dominated process of streamer development as field inhomogeneity factor decreases is well observed and evidenced.

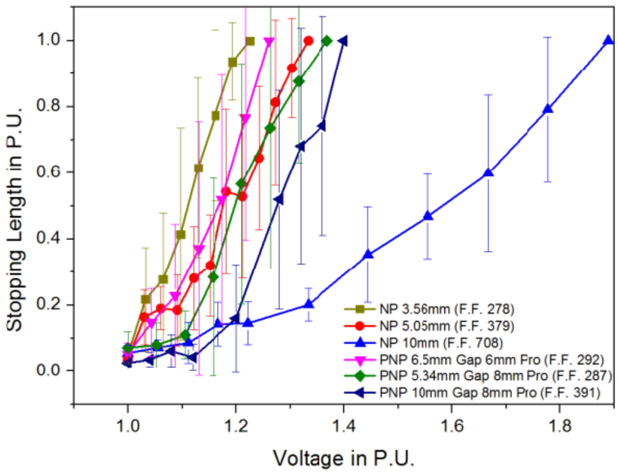

Figure 1. Normalized stopping length versus normalized applied voltage in synthetic ester under lightning impulse. Stopping length normalized to gap distance; applied voltage normalized to 50% initiation voltage.

[1] A Beroual, M Zahn, A Badent, K Kist, A J Schwabe, H Yamashita, et al., "Propagation and structure of streamers in liquid dielectrics," *IEEE Electrical Insulation Magazine*, vol. 14, pp. 6-17, 1998

[2] T V Top and O Lesaint, "Streamer initiation and propagation in mineral oil in a semi-uniform electrode geometry," *Proceedings of the 1999 IEEE 13th International Conference on Dielectric Liquids, 1999(ICDL '99)*, pp. 122-125

[3] O Lesaint and R Tobazeon, "Streamer Generation and Propagation in Transformer Oil under AC Divergent Field Conditions," *IEEE Transactions on Electrical Insulation*, vol. 23, pp. 941-954, Dec 1988

P19. Study of the Thermal Behaviour of Transmission Transformers in a Complete Cooling loop

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Transformer thermal modelling is important for both transformer design and operation. Most thermal modelling work has been focused on modelling individual components of a transformer, e.g. windings or radiators. However, the reliability of an individual component model is highly dependent on its boundary conditions prescribed. To achive reliable modelling of a transformer, study of the complete cooling loop is needed.

This paper presents the framework of the study of the temperature and flow distributions in a transmission transformer complete cooling loop, including both the winding and the radiator as shown in Figure 1. Based on the study of the fluid flow and heat transfer processes in the transformer complete cooling loop, its thermal performance will be predicted, taking into account all geometric characteristics (horizontal and vertical cooling ducts in the winding and oil channels in the radiator, etc.), material properties (paper insulation, copper disc, transformer liquid and radiator metal plate, etc.), power losses, ambient temperature and other accessories assembled like the pump or fan. This complete loop modelling work makes possible the study of the thermal performances of different transformer liquids. Moreover, the complete cooling loop results can also be used to optimize the transformer thermal design to control its hot-spot temperature.

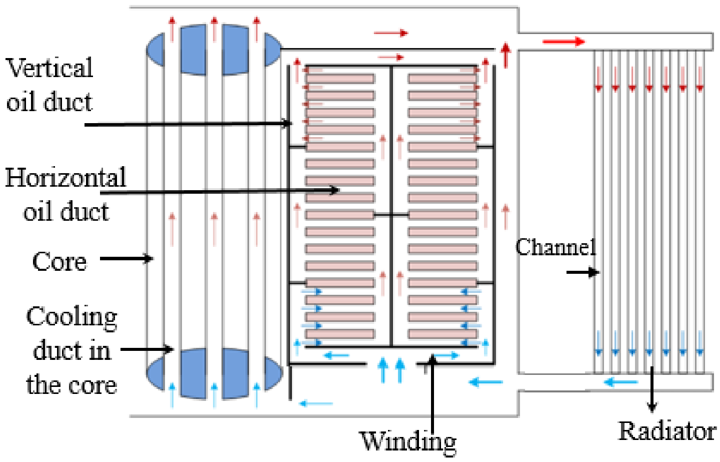

Figure 1 Configuration of complete coolilng loop

[1] F. Torriano, H. Campelo, M. Quintela, P. Labbé, and P. Picher, "Numerical and experimental thermofluid investigation of different disc-type power transformer winding arrangements," *International Journal of Heat and Fluid Flow*, vol. 69, pp. 62-72, 2018.

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[3] S. B. Paramane, W. Van der Veken, and A. Sharma, "A coupled internal–external flow and conjugate heat transfer simulations and experiments on radiators of a transformer," *Applied Thermal Engineering*, vol. 103, pp. 961-970, 2016.

P20. Development of a Dual Temperature Test Cell for Laboratory Ageing Experiment of Transformer Insulation System

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Abstract

As accelerated ageing test is impractical in real transformers, laboratory ageing experiment is used to determine the condition of transformer insulation system. Three main types of ageing experiment set-ups can be identified in literature: a functional life test model, dual temperature test cell and sealed tube single temperature test cell. A functional life test model transformer is a better representation of transformer operation, but it is very expensive. Sealed tube single temperature test cell is the simplest and widely used laboratry test set-up but cannot reflect nonuniform temperature profile inside a transformer. The dual temperature test cell is less complicated and less costly than the transformer model. It has the ability to simulate the different temperatures experienced by transformer insulation by independently controlling the solid and liquid insulation temperatures, which is an advantage over the sealed tube test method.

Dual temperature ageing method was first introduced by McNutt in 1996 and several successful tests have been carried out since [1-3]. The dual temperature ageing test system includes test cell, power supply, toroidal current transformer, control and monitoring system, and safety system. As shown in Figure 1, the dual temperature ageing test cell has many parts such as stainless steel test tube, current carrying copper conductor, pressboard, thermocouples,sampling valves and oil heaters. To make the test cell reasonably realistic, the material and volume ratios are selected based on the IEC 62332-1 standard.

Test carried out using dual temperature ageing test cell shows that conductor temperature of 160 °C and liquid insulation temperature of 115 °C can be achieved and temperature gradient maintained. For this project, dual temperature ageing experiments are carried out using mineral oil and alternative insulating liquids (natural ester, synthetic ester and gas-to-liquid oil) with standard kraft paper and thermally upgraded paper. Different ageing periods (500h – 2000h) and sampling intervals are selected to assess the ageing condition of transformer insulation system. Finally, several diagnostic ageing parameters such as water content, acidity, furan content and breakdown voltage are analysed to assess the ageing condition of transformer insulation system.

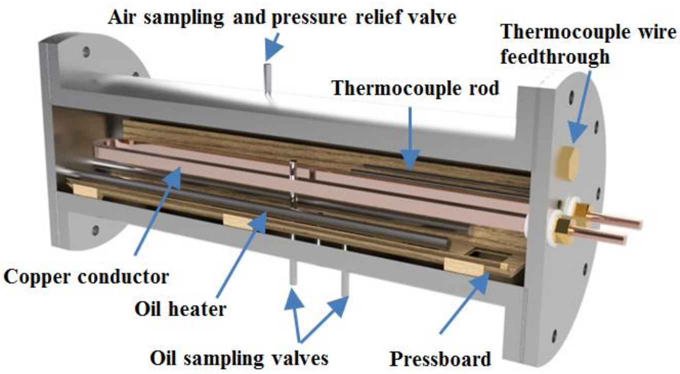

Figure 1: Dual temperature ageing test cell (cross sectional view)

[1] W J McNutt, R L Provost and R J Whearty, "Thermal Life Evaluation of High Temperature Insulation Systems and Hybrid Insulation Systems in Mineral Oil", *IEEE Transactions on Power Delivery,* vol. 11, no. 3, pp. 1391 - 1398, 1996

[2] T A Prevost , H P Gasser, R Wicks, B Glenn, R Marek , "Estimation of Insulation Life Based on a Dual Temperature Ageing Model", *Fifth Annual Technical Conference,* pp. 1 - 12, 2006

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P21. Data Analytics for Transformer Asset Management

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Insulation condition monitoring of high voltage electrical equipment is a vital step to ensure a reliable operation of the asset. In this respect, massive amount of transformer condition data has been gathered through on-line monitoring and conventional oil samplings over the years. Hence, maximise the utilisation of these databases and develop productive analysis methodologies to support transformer asset management are the primary objectives of this research.

Currently, IEEE and IEC standards are widely used to assess the condition of the insulation system of transformers through the particular test parameters. However, parallel to these standards, various types of asset management models are proposed by the literature. Commonly, these models are based on either composite indicators or machine leaning models [1], [2]. With respect to composite indicators, one of the popular indicators is "Health Index (HI)" [2]. In order to calculate HI, a suitable weight for each test parameter followed by a scoring system should be introduced using a proper database analytical process. On the other hand, supervised and unsupervised machine learning models have been put forth to build automatic and intelligent asset management models [3]. For instance, literature reports transformer remnant life prediction models based on artificial neural networks and fuzzy logic rules [1].

In order to achieve the primary objectives of this research, a strategic research plan has been developed to analyse oil test and DGA data of several utilities. At the first stage, ageing indicators from oil and DGA databases will be analysed to identify the correlation among them. Secondly, scrapped transformers will be analysed. Data analysis of these scrapped units provides a unique opportunity to inform and verify the practice of condition assessment for in-service transformers. With the gained knowledge from above two key stages and transformer design information along with loading and operating history, improved weighting factors will be proposed for transformer insulation HI formula. Finally, the research will focus to develop an automatic and intelligent asset management model.

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P22. Effects of Electrical Conductivity of Contamination on Tracking Formation in High Voltage Aerospace System

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More Electric Aircraft (MEA) use increased amounts of electrical energy as they seek to replace hydraulic / pneumatic systems with electrical alternatives. The amount of electrical power used on board and hence the operating voltage is forecast to increase further as all-electric aircraft are developed. When systems are operated in the aerospace environment, the ambient temperature, relative humidity and air pressure all varying with altitude. On insulating surfaces, there is a need to ensure creepage distances are sufficient to withstand the applied electric field.

There is little risk of tracking activity when an aircraft is at high altitude, and surfaces are dry albeit cold. However, when the aircraft begins the descent cycle, the surface temperature will lag behind that of the ambient temperature. In addition, the relative humidity is usually increased with decreasing altitude. As a result, there is a high probability of condensation on the surface of the insulation material during the descent phase. When the surfaces are contaminated by pollution, the possibility of electrical tracking across creepage distances is high.

This paper examines the impact the contaminant conductivity has on the behaviour of relatively small gaps as used in aerospace systems operating at a voltage level of around 1-2kV. Experimental testing has been carried out with single water droplets that are placed in a groove on the surface of an insulating material that is placed in a partial vacuum. The single droplets have a range of conductivity from 0.1 S/m to 0.25 S/m. The liquid temperature is measured by an IR-camera under various conductivities and voltages, and the leakage current is recorded by LabVIEW. The value of this approach is that it allows the likelihood of evaporation and resulting tracking damage to be understood. The results of this investigation should support the development of guidelines for creepage distance design in high voltage aerospace systems. This template is supplied with the correct style set.

Keywords: Electrical tracking, high voltage aerospace system, the creepage distance

P23. Effect of Micro Air Gap at the Needle Tip on Electrical Trees in LDPE

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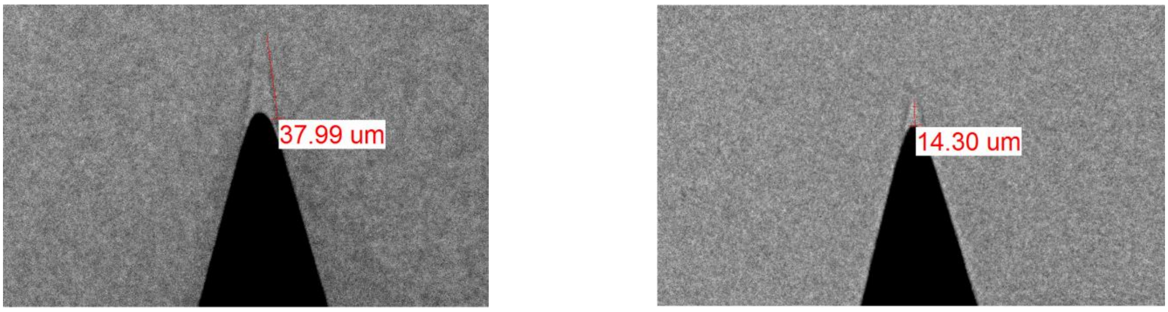
Electrical treeing is one type of long-term electrical degradation of polymeric cable insulation. Tree-like channels can form when there is a high and divergent electric field. In laboratory tests, a metallic needle tip is commonly employed to form the geometry, which generates a divergent electrical field when high voltage is applied to the needle.

While the effect of the air gap with large size, such as 2 mm, at the needle tip on tree initiation and growth has been extensively studied before [1, 2], much less is known when the air gap is of much smaller size, which can be the case in needle-plane electrode system. Through 2D radiographs, or projections, from X-ray Computed Tomography (XCT) technique, air gap of tens of micrometres is identified, as is shown in Fig 1.



(a) Micro-XCT image of PE13 (b) Micro-XCT image of 1910

Fig. 1 Typical images of the samples with micro air gap

Here tree initiation and growth under AC stresses is observed in samples with and without micro air gaps. Real-time images of tree initiation and growth and PD signals are recorded, after which tree initiation time, tree growth characteristics and PD activity signatures are analysed. For now we concluded: 1) Within the same time period, tree length in samples with air gap is longer than without air gap; 2) PD magnitude in samples with air gap is larger than without air gap; 3) Tree initiation time in samples with air gap is shorter than without air gap.

Further analysis and experiments are ongoing.

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P24. Thermal modelling of disc-type transformer windings in steady states

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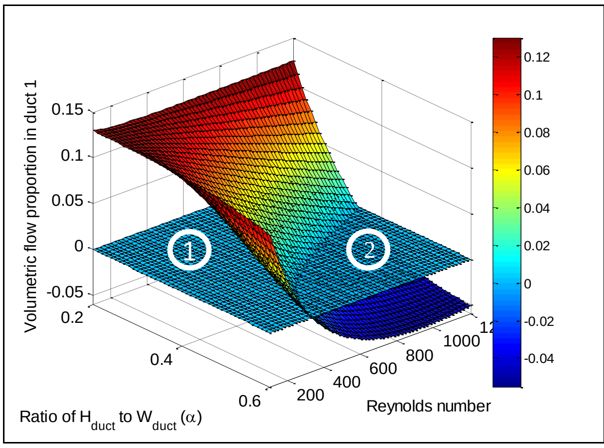
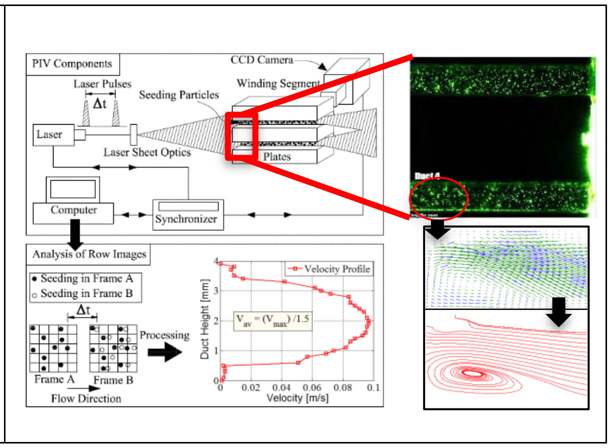
Determination and optimisation of the winding hot-spot temperature is essential for managing the loading capability and thermal ageing of transformers. The liquid flow in the various winding cooling ducts directly impacts the position and magnitude of the hot-spot temperature. In addition, the static pressure drops over the winding determines liquid split among windings connected hydraulically in parallel, e.g. HV winding and LV winding in the same phase.

This paper studies the liquid flow distributions, pressure drops and temperature distributions in disc-type transformer windings in steady states. Experimental measurements of liquid flow in a winding test rig using particle image velocimetry (PIV), pressure drop measurements using a differential pressure measurement instrument and temperature measurements using thermocouples are implemented. Computational fluid dynamics (CFD) models are established to get detailed fluid flow, pressure drop and temperature information. In addition, dimensional analyses are adopted to guide CFD simulations and experimental tests to obtain simplicity, insight and universally applicable results.

Both liquid forced and directed (OD) cooling modes and liquid natural (ON) cooling modes are investigated. For a fixed winding geometry in OD cooling modes, dimensionless flow and temperature distributions and pressure drop coefficients are found to be controlled by the Reynolds number (*Re*) at the pass inlet. At high *Re*, reverse flows and overheating occur at the bottom part of the pass. For a fixed winding geometry in ON cooling modes, both dimensionless flow and temperature distributions are mainly controlled by the Richardson number (*Ri*). At high *Ri*, reverse flows and overheating occur at the top part of the winding.



Volumetric flow proportion at the bottom duct of a pass, negative refers to flow reversal



Particle Image Velocimetry (PIV) measuring system to measure flow rates in horizontal ducts

Reference

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P25. Interpretation of Frequency Response Analysis through Transformer Modelling

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Power transformers are crucial devices in a power network, and faults can result in health and safety problems and economic loss to the utility. A major fault a power transformer can suffer is mechanical winding deformation, this can be detected using Frequency Response Analysis (FRA) which is regarded as one of the most sensitive and effective techniques to detect winding deformation and displacement; nevertheless, there is no widely accepted standard for FRA signature interpretation.

In this work, a three phase 400/275/13 kV 1000MVA auto-transformer was modelled and used to investigate the influence of winding equivalent electrical parameters on the FRA responses. Firstly, to validate the accuracy of the model, the FRA simulation results were compared with the measurement results , demonstrated in Figure 1. Next, the impacts on the FRA results of winding electrical parameters were identified through sensitivity studies. Finally, the conclusions present the influence of the electrical parameters on the corresponding FRA response.

The work presented has studied the influence of transformer winding electrical parameters on the corresponding FRA responses, consequently it helps to understand the dominace of each electrical parameters in different frequency ranges and constributes to the interpretation of the FRA plots.

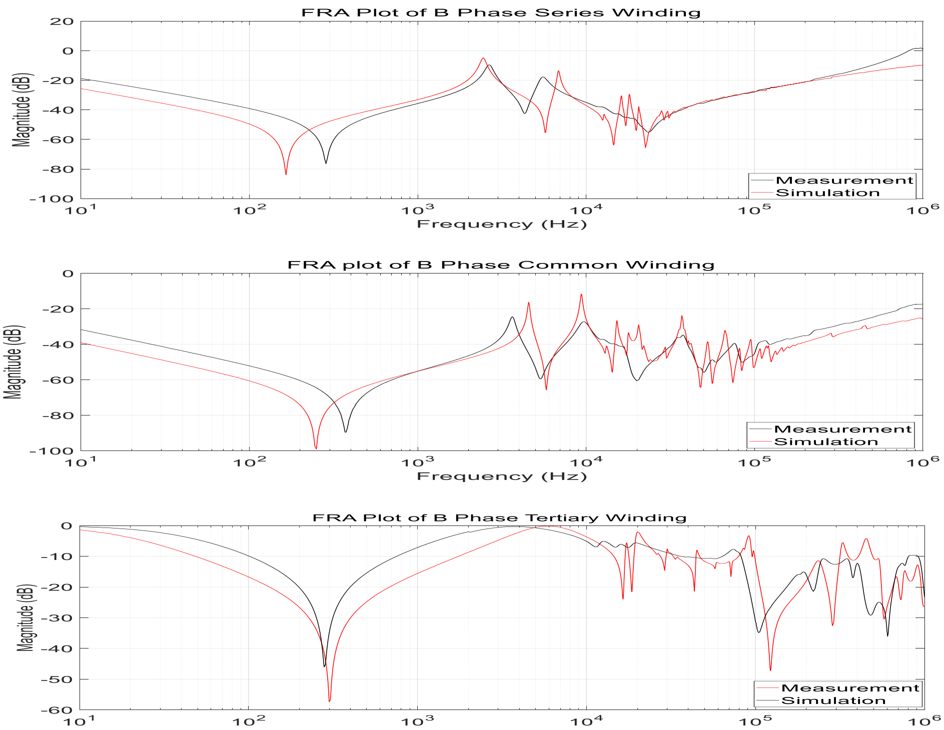

Figure 1 Comparison between simulation and measurement results

P26. Ageing and Failure Mechanisms of Electrical Materials for High Voltage Systems in Aerospace Applications

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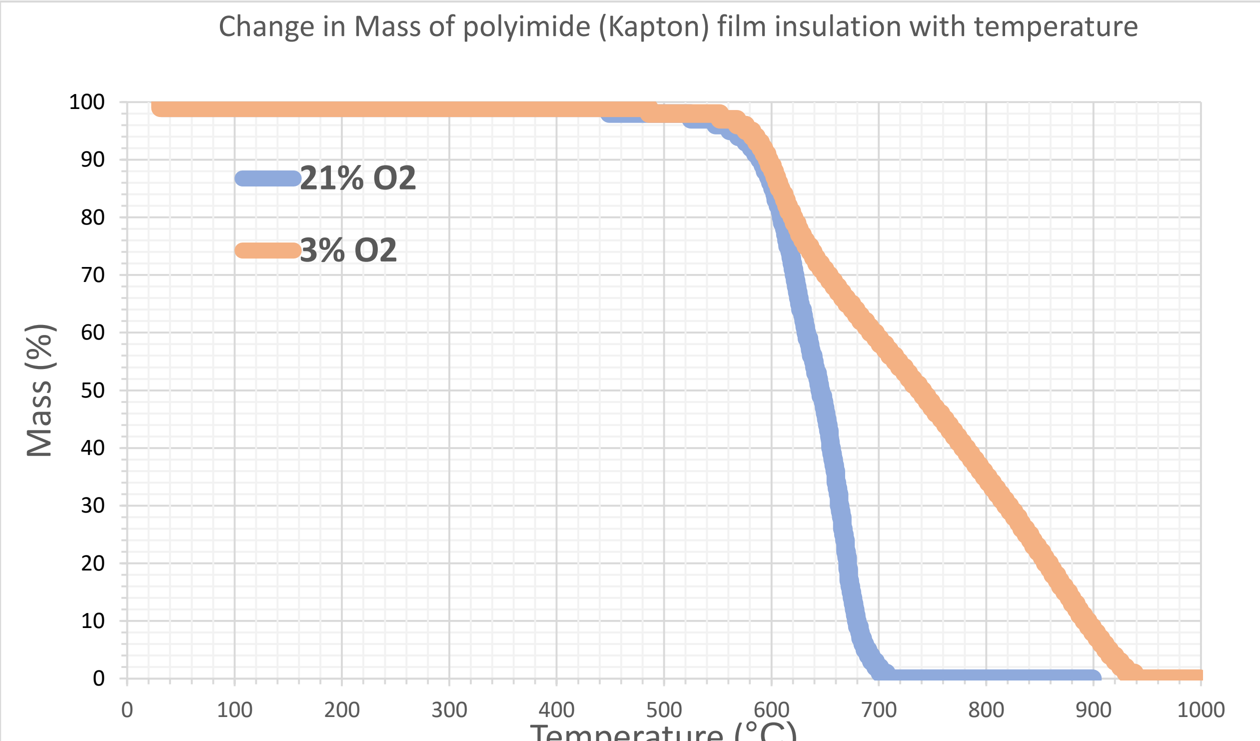
Ageing of materials in aerospace conditions is much less commonly known and dissimilar to ageing occurring at ground-level. This becomes highly important for next generation aircraft, where electrical systems be required to increase their voltage levels to meet the power demands required on-board, increasing the rate of electrical ageing especially in low pressure environments typically observed with increasing altitudes. For this reason, it becomes essential to explore the behaviour of the insulation system in the aerospace environment, especially in variable operating environments that can reach as high as 250 °C with low ambient temperature below - 65°C, as well as varying air pressure, humidity and ozone. Understanding the impact of environment on the degradation rates of high voltage insulation systems is crucial in predicting lifetime over the service of an aircraft. This paper describes the results derived from thermogravimetric analysis (TGA) work on poly (4,4'-oxydiphenylene-pyromellitimide) or more commonly known as Kapton film under two distinct atmospheres, 21% and 3% oxygen concentrations, using heating rates of 5, 10 , 20, and 50 K/min. The atmospheres chosen are that to mimic the oxygen concentrations at ground-level and at cruising attitude of 15 km. From the rate of conversion at various temperatures, kinetic parameters such as the activation energy (Ea) and pre-exponential factor (A) are found. This is then used to determine the relationship between low oxygen concentrations and the ageing and degradation rates of polyimide insulation. This is done by using the Arrhenius equation to find ageing mechanisms and relative lifetimes of insulation systems in an aerospace application compared to similar ground-based systems.



Thermogravimetric Analysis (TGA) of polyimide under two different oxidising environments

P.27 Ageing Tests for Superhydrophobic Coatings on Overhead Line Conductors

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The accretion of ice and pollution can lead to serious damage and failure of overhead line systems due to the additional mechanical loads applied during icing events. In severe cases, complete overhead line towers can fail. CIGRE TB361 has detailed a family of advanced coatings in terms of their water and ice repellent abilities. These coatings expect to improve the reliability and performance of the system under extreme icing weather and during pollution events. If these coatings could be applied to overhead lines in a way that eliminates ice accretion, they may enable a significant overhead line performance improvement. Additionally, new overhead lines could have mechanical design requirements reduced allowing lower cost systems to be built. However, the CIGRE brochure describes the need for further experiments to ensure that long-term durability tests of coatings are proven before being deployed.

This paper details the replication and optimisation of the manufacturing procedure to coat overhead line samples with a stearic acid based coating. This was loaded with SiO_2 nanoparticles and achieved a sliding angle of 3˚ and a contact angle of 169˚ on aluminium substrates. The paper also describes our experience in establishing a system of comprehensive ageing tests, including thermal ageing/cycling, corona exposure tests, ultraviolet tests, freezing/thaw tests and outdoor environmental tests. All of these tests are intended to examine whether the coating has reached a sufficient stage of maturity to be deployed onto power networks. The stearic acid with SiO_2 nanoparticles coating is applied to both flat aluminium and round conductor samples to better simulate the practical ageing conditions. The performance of this coating system is compared against another commercially available superhydrophobic coating. Samples are characterised using different techniques such as static and dynamic contact angle measurements and microscopy tests before and after each ageing test.

When you submit your paper , please write your paper information in the email subject in the form of ‘Name of the first author + Paper title ’.

P.28 Acoustic noise emitted from overhead line conductors with superhydrophobic coatings

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Overhead lines can generate significant levels of audible noise containing low frequency hum and/or high frequency crackling. The frequency of hum is twice the supply frequency while the crackling noise is in the frequency range of 1 kHz to 20 kHz. While conductor choice and the use of bundles can reduce electric fields and minimize noise, some surface defects including damage, insects, raindrops and pollution will always enhance electric fields and lead to noise generation. This results in the need to use specific conductor types/geometries to avoid the creation of a significant nuisance. According to the World Health Organization (WHO) noise is the second largest environmental cause of health problems, just after the air quality. This paper will present work that has examined whether the noise level generated by an overhead line can be reduced by coating overhead line conductors with superhydrophobic coatings.

To test audible noise, an enclosed chamber with a low noise level is utilized. The system under test includes a meshed cylinder with a radius of 7 cm placed around a length of conductor. The conductor has a length of 50 cm and is either bare or coated with a superhydrophobic coating of which contact angle is above 160o. Within the experiment, a voltage is applied to the conductor gradually to a level of 40 kV while water droplets are sprayed on the coated conductor. The noise level is measured by microphones and the movement of water droplets is recorded by a high speed camera under the various voltages. The value of this approach is that it allows the noise level to be understood alongside the physical mechanisms that are causing it. Through this study it is hoped that further insights will result that demonstrate the potential value of superhydrophobic coatings in overhead line applications.

Key words: Acoustic noise, superhydrophobic coatings, overhead lines, water droplets

P.29 Breakdown Characterisation of C_3F_7CN as an Environmentally Friendly Alternative to SF_6 for High Voltage Applications

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Abstract – Sulphur hexafluoride (SF_6) is widely used as an insulation and arc quenching medium for high voltage gas-insulated equipment. However, SF_6 is a greenhouse gas with a global warming potential (GWP) that is 23,500 times higher than CO_2 [1]. At present, around 10,000 tons of SF_6 are installed annually, 80% of which are used in the power transmission industry [2]. Although the compress gas-insulated equipment is a closed-loop system, gas leakage cannot be totally avoided. Therefore, it is necessary to replace SF_6 with an environmentally friendly alternative for high voltage applications. So far, a gas with the chemical formula C_3F_7CN is considered to be a promising candidate [2]. This gas was developed by 3M and is also commercially known as Novec™ 4710 [1]. The dielectric strength of C_3F_7CN is nearly double than that of SF_6 under atmospheric pressure and uniform field with a considerably lower GWP that is 2,100 times higher than CO_2. Although it has a relatively high boiling point of -4.7 °C, it can be mixed with a buffer gas such as CO_2 to reduce the overall liquefaction temperature [2].

This work summarises the physical, chemical and thermal properties of C_3F_7CN in comparison to SF_6. There are research gaps surrounding the suitability of C_3F_7CN which will be experimentally investigated in this project. The aim is to characterise the breakdown characteristics of C_3F_7CN gas mixtures under various test conditions (e.g. electrode configurations, gap spacing, pressures, mixture contents and impulse polarities), which can be used to examine the insulation performance of C_3F_7CN gas mixtures in comparison to SF_6. Figure 1 shows the AC breakdown characteristic as a function of increasing pressure for several gases and gas mixtures using parallel disk electrodes. It can be seen that a 20/80% C_3F_7CN/CO_2 gas mixture has a comparable breakdown voltage to SF_6. CO_2 was chosen as the buffer gas because it has a better arc quenching performance than N_2 and air. In conclusion, C_3F_7CN can be a promising alternative to SF_6 for high voltage gas-insulated applications.

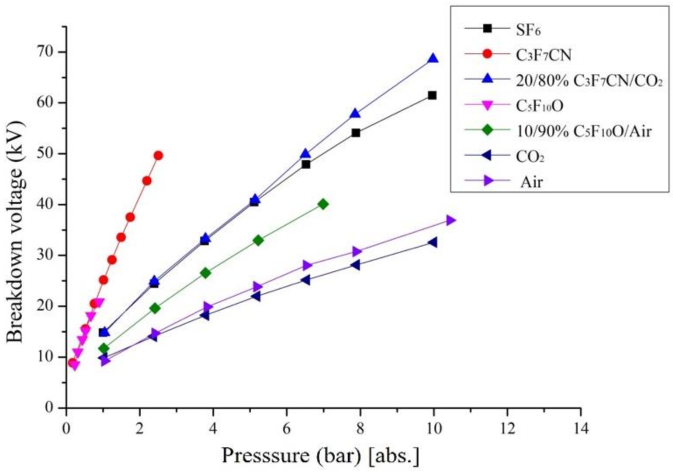

Figure 1: AC breakdown voltage as a function of pressure tested for pure gases (SF_6, C_3F_7CN, $C_5F_{10}O$, Air and CO_2) and gas mixtures (20/80% C_3F_7CN/CO_2, 10/90% $C_5F_{10}O$/Air) using parallel disk electrodes with a 2.54 mm gap distance [1,3].

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P.30 Review of Area and Volume Effects on Breakdown Voltage of Transformer Liquids

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Oil paper insulation system plays an important role in power transformers. Dielectric strength of insulating liquids is one of the most important properties to be considered during the transformer insulation design process. But it is hard to do the breakdown test when the test gap is long or the electrode area is big. For example, when measuring the dielectric strength of mineral oil and natural ester with test gaps from 50 mm to 150 mm, the 12500 liter steel tank and 1800 kV BIL rating bushing were used [1]. In addition, It is not straightforward to compare breakdown results obtained from different electrode configurations.

The breakdown of insulating liquid can be triggered by contamination in the liquid, e.g. particles and bubbles. At the same time, the electrode surface state/defects can also influence the initiation of breakdown. The area and volume should be the stressed electrode area and the stressed liquid volume which locate at high enough field region. According to the weakest link theory, the dielectric strength of insulating liquid decreases when the stressed liquid volume or the stressed electrode area increases [2-3] and which one is the main factor depends on the liquid quality and the surface state of the electrodes.

This paper introduces the development of research about area and volume effect and analyses the dielectric strength data of different insulating liquids with different electrodes from reference papers. It could help to predict the dielectric strength under different electrodes according to the present data for insulating liquids, especially for the liquids rather than mineral oil which has little experience.

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P.31 Dielectric behaviour of Ester liquid-solid composite insulating systems under lightning impulse stress

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The benefits of both natural and synthetic ester liquids are well known, such as their improved biodegradability, low toxicity, high flash point and ability to absorb moisture. Due to these advantageous properties natural and synthetic ester liquids are being adopted in the power and pulsed power industries as a long term replacement for mineral oils within liquid insulating systems. Significant research efforts have been focused on the electric and dielectric characteristics of natural and synthetic ester liquids within bulk liquid insulating systems [1-3], however review of publications in this field indicate a lack of information on dielectric performance of solid polymer-ester liquid composite insulating systems.

The purpose of this study is to, firstly, evaluate how the chosen ester liquid performs within a bulk liquid insulating system under lightning impulse stress of both positive and negative polarity. This will be achieved using the internationally recognised IEC 60897 testing method, with key parameters such as breakdown voltage and time to breakdown evaluated. Following this the same ester liquid will be tested under lightning impulse stress when acting as the liquid medium of a composite polymer solid-ester liquid insulating system. Testing of the composite system will, as in the case of the bulk system, be performed to the IEC 60897 standard with both positive and negative polarity tests being conducted. This allows the evaluation of how the inclusion of solid dielectric material can affect dielectric characteristics of the composite insulating system. Furthermore, it will allow the identification of operational dissimilarities in the composite system when exposed to impulses of differing polarity. Identification of these variations in dielectric performance will have large implications for how these systems are designed and ultimately how they are applied for use, primarily, within the power and pulsed power industries.

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P.32 The Search for an Economically Viable and Climate-friendly Alternative for Replacing SF_6 in HV Accelerator Applications

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Abstract: A particle accelerator is a machine that uses strong electromagnetic fields to accelerate charged particles to very high speeds and operate at extremely high electronvolt (eV). Many direct voltage industrial accelerators use SF_6 as an insulating medium to withstand the required high voltage thanks to its excellent dielectric strength. However, SF_6 is a potent greenhouse gas (GHG) with a global warming potential (GWP) 23,500 times higher than CO_2 and a long atmospheric lifetime of 3,200 years [1]. Although majority of SF_6 is used in transmission equipment, accelerators can contain large quantity of SF_6.

Dynamitron® accelerators are one type of medium energy, direct voltage accelerators used primarily in crosslinking applications and producing electron beam with an energy up to 5 MeV and 160 mA. SF_6 losses from Dynamitron® are generated in normal operating conditions due to vessel and equipment permeability and during maintenance operations. Technical (over-pressure) or mishandling incidents can also lead to significant SF_6 leaks. Although these incidents are rare they can have serious environmental consequences given the large SF_6 volumes at stake in the Dynamitron® as shown in Figure 1. Thus, there is an urgent need to find a climate-friendly alternative with similar or better insulating strength than SF_6 for use in high voltage accelerator applications.

The LIFE_SF6-Free project has received funding from the LIFE programme of the European Union to identify a shortlist of alternatives for investigation, demonstration, validation and roll-out for replacing SF_6. A high pressure test rig will be designed and developed to determine the breakdown characteristics of alternative gases and their mixtures in comparison to SF_6 using small-scale prototypes. The test data will be used to inform the design of a large-scale industrial demonstrator. Knowledge generated during this project will be disseminated and communicated to the wider audience, local communities, policy makers on climate change, public organisations and relevant industries.

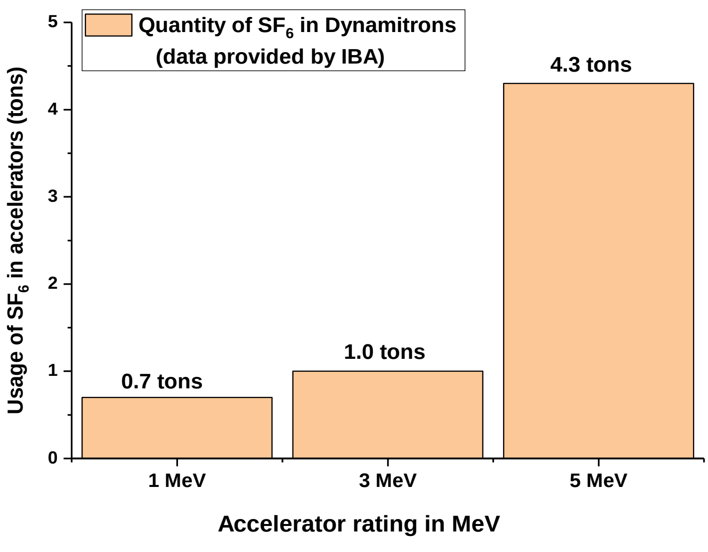

Figure 1. Quantity of SF_6 in typical Dynamitron® accelerators (data provided by IBA)

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