University of Exeter
Centre for Smart Grid

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UHVnet 2024

9th and 10th May, 2024

Centre for Smart Grid, Department of Engineering

University of Exeter

Contents

UHVnet 2024

The UHVnet 2024 local committee welcomes attendees to Exeter.

About UHVnet

The Universities High Voltage Network - UHVNet - is an annual colloquium, which brings together key players from industry and academia in the field of High Voltage engineering. It also serves as a welcoming platform for PhD students and researchers to present their research to the community.

First Annual Show case meeting	National Grid Transco Headquarters Warwick	2004
First UHVnet Colloquium	Cardiff University	2005
Second UHVnet Colloquium	Glasgow Caledonian University	2009
Third UHVnet Colloquium	University of Manchester	2010
Fourth UHVnet Colloquium	University of Southampton	2011
Fifth UHVnet Colloquium	University of Leicester	2012
Sixth UHVnet Colloquium	University of Strathclyde	2013
Seventh UHVnet Colloquium	University of Surrey	2014
Eighth UHVnet Colloquium	Staffordshire University and ALSTOM Grid	2015
Ninth UHVnet Colloquium	Cardiff University	2016
Tenth UHVnet Colloquium	Glasgow Caledonian University	2017
Eleventh UHVnet Colloquium	University of Southampton	2018
Twelfth UHVnet Colloquium	University of Manchester	2019
Thirteenth UHVnet Colloquium	University of Strathclyde	2020
Fourteenth UHVnet Colloquium	Cardiff University	2022
Fifteenth UHVnet Colloquium	Glasgow Caledonian University	2023
Sixteenth UHVnet Colloquium	University of Exeter	2024

Venue

UHVNet 2024 is hosted by Centre for Smart Grid, Department of Engineering, University of Exeter. The colloquium poster session, lunch, coffee will take place at the South West Institute of Technology, University of Exeter.

Organising committee

Shuhang Shen

Xin Wang

Christian Pößniker

Rui Yu

Sponsors

IEEE Dielectrics and Electrical Insulation Society and National Grid kindly sponsor the UHVNet 2024 colloquium. We extend our greatest gratitude for their supports in making this event possible.

Agenda

Thursday 9th May 2024

Time	Activity	Location
13:00 - 13:30	Registration / Tea & coffee	SWIOT/ Room 1
13:30 - 13:35	Introduction to the day **Shuhang Shen**	SWIOT/ AI Arena
13:35 - 13:45	Opening Speech **Voicu Ion Sucala, Head of Engineering, University of Exeter**	
13:45 - 14:10	Keynote 1 **Davide Fabiani, President of IEEE DEIS** - Advancements in HVDC Cable Insulation: Research Frontiers at IEEE DEIS	
14:10 - 14:35	Keynote 2 **Simon Orr, Head of Strategy and Innovation, NGET** - Net Zero: An Innovation Imperative	
14:35 – 15:00	Keynote 3 **Matthew Barnett, Electrical Plant Subject Matter Expert, SSEN Transmission** - Alternatives to SF6 – the challenges of a growing network	
15:00 - 15:10	Group Photo	SWIOT/ Room 1
15:10 – 16:10	Poster + Refreshment Break	
16:10 - 16:30	ECR Presentation 1 **Anderson R. Justo de Araujo, Cardiff University** - Analysis of the induced effects on the newly designed transmission line with T-pylons in the steady state	SWIOT/ AI Arena
16:30 - 16:40	University Research Introduction **Stephen Robson, Cardiff University**	
16:40 - 16:50	University Research Introduction **Shuhang Shen, University of Exeter**	
16:50 - 17:00	University Research Introduction **Qiang Liu, University of Manchester**	

Steering Committee Members to meet in St John Meeting Room in Kay Building at 15:30 pm.

Friday 10th May 2024

Time	Activity	Location
09:00 - 09:30	Registration / Tea & coffee	SWIOT/ Room 1
09:30 - 09:55	Keynote 4 **Hayley Tripp, Senior Environmental Engineer, NGET** - HVDC projects at National Grid and offshore electric and magnetic field considerations	SWIOT/ AI Arena
09:55 - 10:20	Keynote 5 **Shengji Tee, Lead Engineer, Network Planning and Regulation, SPEN** - Enabling Net Zero – SPEN RIIO-ED2 Plan	
10:20 - 10:45	Keynote 6 **George Callender, Lecturer, University of Southampton** - IEEE DEIS UK&I Chapter Introduction and High Voltage Research at University of Southampton	
10:45 - 11:15	Poster + Refreshment Break	SWIOT/ Room 1
11:15 – 11:35	ECR Presentation 2 **Cheng Chi, University of Exeter** - Finite Element Modelling of Core Saturation Phenomena in Phase Shifting Transformers: Reduced Circuit Equivalence	SWIOT/ AI Arena
11:35 - 11:45	University Research Introduction **Joseph Yan, University of Liverpool**	
11:45 –11:55	University Research Introduction **TBD, University of Strathclyde**	
11:55 - 12:15	PhD Student Presentation 1 **Mohammed Alhazmi, Cardiff University** - Transient Overvoltages in GIS: Component Roles and Their System Impacts	
12:15 - 12:35	PhD Student Presentation 2 **Rui Yu, University of Exeter** - Effect of Electric Field on Long-Term Conductivity of Synthetic Ester	
12:35 - 13:30	Network Lunch	SWIOT/ Room 1
13:30 - 13:50	PhD Student Presentation 3 **Yannan Zhou, University of Liverpool** - Research on Electrical Life and Arc Erosion Tests of High-Voltage Gas Circuit Breaker	SWIOT/ AI Arena
13:50 - 14:10	PhD Student Presentation 4 **Zhengbo Xu, University of Manchester** - Evaluation of the Effects on Electrical Losses and Thermal Ageing of Transformer Heat Recovery	
14:10 - 14:30	PhD Student Presentation 5 **Joanna Rzempołuch, University of Southampton** - Synthetic Cable for Assessment of Marine Power Impacts (SCAMPI)	
14:30 - 14:50	PhD Student Presentation 6 **Shahtaj Shahtaj, University of Strathclyde** - Analysis of Partial Discharge for Defect Identification Under DC Superimposed Harmonics	
14:50 - 15:00	Closing Remarks & Student Awards **Shuhang Shen**	

Keynote Speakers

Name: Davide Fabiani
Job Title: Associate Professor
Organisations: University of Bologna
Expertise: Nanostructured material, HV apparatus diagnosis

Davide Fabiani (S'98-M'02-SM'16) was born in Forlì, Italy, in 1972. He received the M.Sc. and Ph.D. in Electrical Engineering with honors in 1997 and 2002, respectively. Since 2014, he is Associate Professor at the Department of Electrical Electronics and Information Engineering of University of Bologna where he teaches the courses of "Innovative Electrical Technologies" and "Insulation Systems Design and Diagnosis". Formerly, from 2005 to 2014 he was Assistant Professor at University of Bologna. His fields of research are mainly related to:

- Development and characterization of nanostructured materials for applications in electrical and electronic apparatus.
- Investigation of HV apparatus diagnosis mainly through partial discharge measurements
- Evaluation of the effect of non-sinusoidal waveforms on reliability of components and insulation systems (in particular, induction motors fed by power electronic converters)
- Study of electrical conduction mechanisms and aging processed in high voltage insulation systems.

He was involved in several projects financed by public and private companies. He is author or co-author of about 280 papers, most of them published on the major international journals and conference proceedings. He is Associate Editor of IET High Voltage Journal as well as reviewer for several International Journals. He is a founder of the Research Group on Electrospinning (RGE) of University of Bologna. Currently he is President of IEEE Dielectric and Electrical Insulation Society (DEIS) from January 2024. He has been member-at-large of DEIS AdCom and Chair of the Meetings Committee from 2016 to 2019, DEIS VP Technical for 2020-2021 and VP Admin for 2022-2023. He is member of the TC on Nanodielectrics of IEEE DEIS and of two CIGRE working groups on multifunctional material and insulating material diagnostics.

Name: Simon Orr
Job Title: Head of Strategy and Innovation
Organisations: National Grid
Expertise: Electricity Transmission, renewable energy storage and connection

Simon is Head of Strategy and Innovation for National Grid Electricity Transmission. He completed a PhD in Physics at Warwick University before joining National Grid 13 years ago.

Since then he has worked as a Power System Engineer designing the transmission system, as well as in Strategy and Innovation. This has included devising new ways for renewables and storage to connect to the transmission system and developing a new long term analysis and design capabilities for modelling the transmission system to 2050.

Keynote Speakers

Name: Matthew Barnett
Job Title: Technical lead
Organisations: Scottish & Southern Electricity Networks
Expertise: Switchgear, SF6 alternatives

Matthew Barnett is electrical plant subject matter expert at SSEN Transmission; he has overall technical responsibility for switchgear used for the north of Scotland electricity transmission network. He is the technical lead on the adoption of alternatives to SF6: authoring the required technical specifications and carrying our technical assessment of SF6-free switchgear up to 420 kV, as well as addressing the associated innovation, operational, asset management and policy aspects.

He is involved in various national (ENA) and international groups concerning switchgear, and presents at various events on SF6-alterantives. Currently he is a member of CIGRE JWG B3/A3.60 User guide for non-SF6 gases and gas mixtures in substations.

Matthew has varied experience across electricity transmission and distribution, with background at a major manufacturer and contractor. He has an MEng degree in Electrical and Electronic Engineering from UMIST (Manchester, UK) and is a chartered engineer.

Name: Hayley Tripp
Job Title: Lead Environmental Engineer
Organisations: National Grid
Expertise: Electric and magnetic fields

Dr Hayley Tripp is a Lead Environmental Engineer for National Grid specialising in electric and magnetic fields (EMFs) with over 20 years of experience. She is a technical specialist on all aspects of EMFs including health, calculations, policy and compliance.

Hayley sits on numerous European and International technical committees, with specialisms including microshocks and EMF interference with active implanted medical devices (AIMDs). She has extensive experience providing EMF technical advice, assurance, and assessments for planning applications, examples of which include:

- the Development Consent Order (DCO) application for the Hinkley Connection Project;
- the Richborough overhead line scheme;
- planning applicationfor the Western Link HVDC connection at Flintshire Bridge in Deeside;
- the NEMO Interconnector between the UK and Belgium; and
- the Hutton Series Compensation near Kendal in the Lake District.

Hayley holds a Ph.D. specialising in the effects of EMFs on the circadian system and a BSc (Hons) in Biological Sciences.

Keynote Speakers

Name: ShengJi Tee
Job Title: Lead Engineer
Organisations: SP Energy Networks
Expertise: System design, planning and asset management of electricity networks

Tee specialises in system design, planning and asset management of electricity networks, primarily up to 132kV in GB, with involvement in national and international working groups and standards.

Some highlights from Tee's work are the modelling and optimising of asset risk and asset management of ~261,000 substation assets, ~606,000 overhead structures and ~106,000km of linear assets; ultimately feeding into the Common Network Asset Indices Methodology (CNAIM) used by all DNOs. Tee is also the author of the GB statistical model for polychlorinated biphenyls (PCBs) risk categorisation, with >£500 million saving currently realised to the GB networks. Tee is also leading the network planning and system design of distribution networks within SPEN, with work feeding into Long Term Development Statement (LTDS), Network Development Plan (NDP) and Distribution Future Energy Scenarios (DFES), ultimately preparing the transition to a Net Zero future.

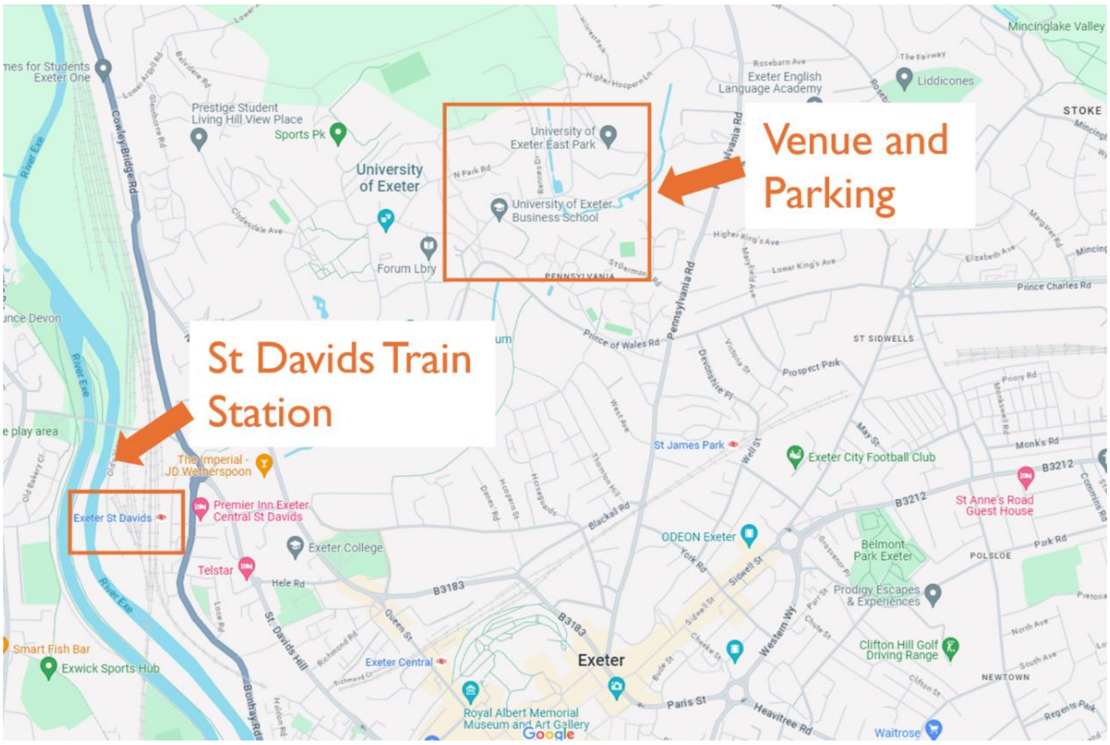
Tee holds a PhD specialising in data mining for asset management of power transformers.

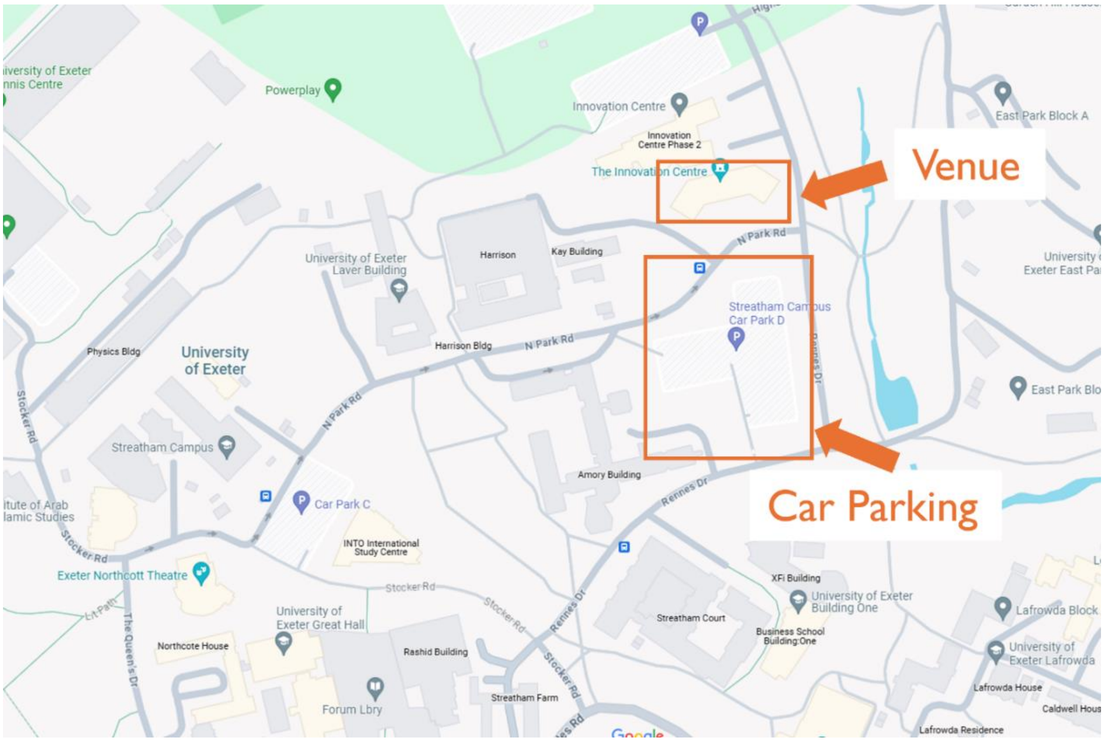
Name: George Callender
Job Title: Lecturer
Organisations: University of Southampton
Expertise: High voltage engineering

George Callender is currently a Lecturer in the Electric Power Engineering group at the University of Southampton. George's research expertise is in the numerical simulation of physical phenomena in high voltage systems, with the fundamental aim of contributing to the safe management and operation of electrical networks.

His research interests include partial discharge phenomena and the electromagnetic and thermal modelling of high voltage plant. In recent times he has focused particularly on cable systems, and much of his work in this space has been in a commercial setting, where he has constructed models of cables for a range of clients including: National Grid, Ørsted, Balfour Beatty, AP Sensing and the Carbon Trust. He regularly reviews for IEEE journals and conferences.

Directions





Travel information: To arrive at the university,

- By air: From Exeter airport, take the bus 4 or 44, to The Pyramids. Take the UNI bus from the Pennsylvania to the North Park Road, then walk to the Innovation Centre. The whole trip takes around 1 hour and 20 mins. Alternatively, take a taxi directly to the uni.
- By train: From Exeter St Davids station, take the UNI bus from the Pennsylvania to North Park Road, then walk to the Innovation Centre. The whole trip takes around 20 mins
- By road: you can drive to and park at Streatham Campus Car Park D. The car park is opposite to the venue. If you drive, please come to the reception regarding the parking ticket.
- By taxi: you need to book taxi from Apple Taxis Exeter (01392 666666)

List of Abstracts

Abstracts are listed in the following pages in the alphabet order of university.

Transient Overvoltages in GIS: Component Roles and Their System Impacts

Mohammed Alhazmi*, Maurizio Albano [2], Jonathan James [3], Anderson Justo De Araujo[4] and Manu Haddad [1]
Advanced High Voltage Engineering Research Centre, School of Engineering, The Parade, Cardiff University Cardiff CF24 3AA
[1]haddad@cardiff.ac.uk
[2]albanom@cardiff.ac.uk
[3]jamesj33@cardiff.ac.uk
[4]justodearaujoa@cardiff.ac.uk
*E-mail: Alhazmimm@cardiff.ac.uk

Abstract-- **This investigation explores the phenomena of Very Fast Transient Overvoltages (VFTOs) within a 400 kV Gas Insulated Substation (GIS), emphasizing the relationship between disconnector operations, trapped charges, and GIS component configurations. Using ATP-EMTP for simulations, this study assesses VFTO phenomena in a 400 kV GIS system through simulations of five scenarios: the baseline with a 1.1 pu trapped charge, a 10% increase in spacer values plus a trapped charge, a 10% increase in elbow values with a trapped charge, a 10% increase in bushing values alongside a trapped charge, and a control scenario without trapped charges, to understand the impact of component configurations and trapped charges on VFTO magnitudes. This analysis aims to show the mechanisms behind VFTO generation and propagation, providing insights into how component-specific modifications impact these transient overvoltages.**

BACKGROUND & MAIN RESULTS

Very Fast Transient Overvoltages in Gas Insulated Substations primarily arise from disconnector operations, leading to significant electric field fluctuations and risks such as electromagnetic interference, flashovers, and insulation degradation [1]. The complex interaction between these factors underscores the need for targeted research and mitigation strategies [2]. The value of VFTO can reach roughly 3 pu in the GIS under operating conditions [3]. The trapped charges can affect the propagation and magnitude of very fast transient overvoltages in GIS systems [4]. The trapped charges can act as a voltage source and raise the voltage in the system, which could damage equipment or cause the system to stop working. Additionally, the trapped charges can affect the insulation resistance and dielectric strength of the system, reducing the overall performance of the GIS.

Our findings reveal a marked increase in VFTO magnitudes in scenarios involving trapped charges, with the most notable raise observed in case 3, where an elbow increase combined with a trapped charge leads to a 2.16 pu voltage, approximately 32.06% higher than the baseline scenario without trapped charges which is case 5. This indicates that trapped charges significantly increase VFTO levels, highlighting the crucial role of GIS component design and configuration in managing VFTO phenomena. Such insights underscore the necessity for advanced mitigation strategies adapted to address the unique challenges caused by trapped charges and specific GIS component alterations, aiming to enhance the overall reliability and safety of GIS operations.

CONCLUSIONS

The findings from our simulations highlight the significant impact of both trapped charges and the specific adjustments in GIS component values on VFTO magnitudes. The significant increase in VFTO levels, especially with elbow value modifications, indicates the need for advanced mitigation strategies modified to component specifics. This study not only finds configurations that make worse VFTO impacts but also lays the groundwork for optimizing GIS design and operational practices to mitigate the adverse effects of VFTOs.

REFERENCES

[1] H. Seo, W. Jang, Chul-Hwan Kim, Y. Chung, Dong-Su Lee and S. Rhee. "Analysis of Magnitude and Rate-of-rise of VFTO in 550 kV GIS using EMTP- RV." *Journal of Electrical Engineering & Technology*, 8 (2013): 11-19.

[2] Haseeb, Muhammad and M. Joy Thomas. “Disconnector switching induced transient voltage and radiated fields in a 1100 kV gas insulated substation.” *Electric Power Systems Research*, 2018.

[3] M. Alhazmi, M. Albano, and A. M. Haddad. Modelling and Analysing Very Fast Transient Overvoltage under Trapped Charges Impact in Gas Insulated Substations, UHVnet2023. Glascow, 2023.

[4] M. Alhazmi, M. Albano, J. James and A. M. Haddad, "Analysis of Trapped Charge Effects on Very Fast Transient Overvoltages in 400 kV Gas Insulated Substations: Modelling, Simulation, and Implications for Design and Operation," 2023 58th International Universities Power Engineering Conference (UPEC), Dublin, Ireland, 2023, pp. 1-4, doi: 10.1109/UPEC57427.2023.10294391.

Analysis of the induced effects on the newly designed transmission line with T-pylons in the steady state

Anderson R. Justo de Araujo*[1], Mehrdad Mokhatari[1], Maurizio Albano[1], David Clark[1], Stephen Robson[1] and Manu Haddad[1]
[1]Cardiff University, School of Engineering, Queen's Buildings, 14-17 The Parade, Cardiff
*E-mail: justodearaujoa@cardiff.ac.uk

***Abstract*-- Induced voltages and currents on the de-energized circuit of a transmission line occur due to inductive and capacitive couplings related to the electromagnetic field generated by the energized side of a double-circuit transmission line. This phenomenon can produce considerably high currents and voltages that might affect the safety of workers during the maintenance operation. This paper investigates the currents and voltages on the earth wires and tower base of a 400-kV transmission line with a length of 20 km using the T-pylon configuration, in a condition that one circuit is fully energized and the other is de-energized, using the software ATP-EMTP. Results indicated that the voltages and currents at the earth wires and tower base vary significantly depend on the span selection along the route.**

BACKGROUND & MAIN RESULTS

A new transmission tower topology, called T-pylon, has been employed for the National Grid in the United Kingdom as part of a project that aims to reduce the impact on the local environment and surroundings and enable progress toward net zero. In this context, a detailed study concerning the maximum values obtained for the induced voltages and currents at the T-pylon transmission line must be elaborated by engineers to assess the potential risk associated under possible maintenance scenarios. These voltages and currents can cause damage to electrical equipment and pose a harmful threat to personnel working on maintenance operation [1]. To investigate the induced effects generated along the 400-kV transmission line using the T-pylon topology, a line of 20 km with bundled redwood wires is represented by 60 blocs of pi-circuit model, with earthing resistance of 1 Ω and load resistance of 120 Ω at the receiving end. The software ATP-EMTP was utilised to simulate this case study with a time step of 0.1 us. The substation earthmat is represented by a 0.20 Ω resistance. Figure 1 depicts the induced voltage (a) and current (b) values along the transmission line.

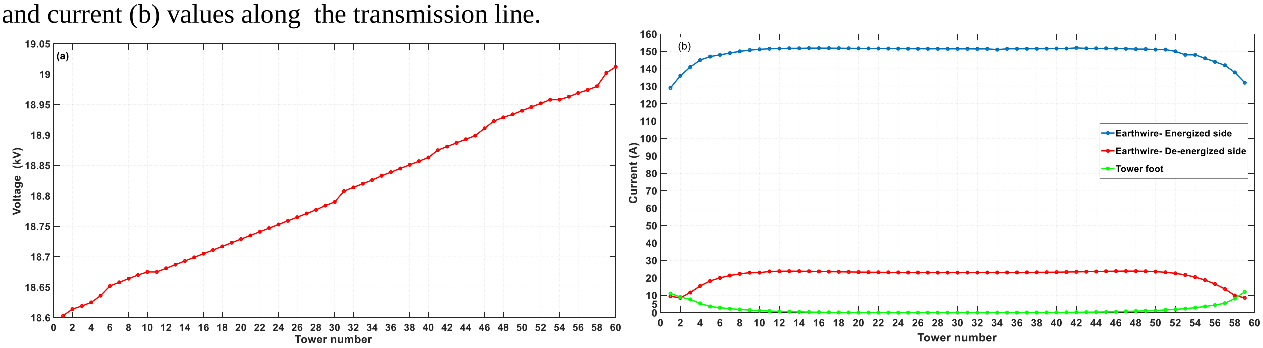


Figure 1: Induced effects on T-pylon transmission line: (a) Voltages on the de-energized circuit; (b) Currents at the earth wires and tower base.

Figure 1-(a) shows the induced voltages on the phase conductor of de-energized circuit along the towers considering both ends open. The maximum voltage observed is 19 kV (peak value) at the receiving end. Concerning the induced currents, one observes that the induced current at the earthwire on the energized side of the is 151 A. However, a induced current of 24 A is obtained in the de-energized side, both values obtained at the middle of the transmission line, as depicted in Figure 1(b). The maximum currents at the tower footing occurs closer to the substations, reaching values of 11 and 12 A at the sending and receiving ends, respectively. It is also important to emphasize that these results are dependent on the value of the tower-footing grounding resistance and load conditions that must be investigated in future scenarios.

CONCLUSIONS

Results have shown that induced effects, voltages on the phase conductors of the de-energized side and currents on the earth wires and tower base significantly varies along the tower position. The maximum values of the induced voltages and tower base currents are observed at the ends of the transmission line under this scenario. However, the maximum values for the earthwires currents occur at the central tower. These results demonstrated the importance to assess the induced currents and voltages along the transmission lines with the newly designed T-pylon towers under all possible maintenance scenarios. Such knowledge will help to ensure safety conditions for working personnel. Additionally, further scenarios considering different tower-footing grounding impedances, loading and fault conditions must be studied.

REFERENCES

[1]-R. Horton and K. Wallace, "Induced Voltage and Current in Parallel Transmission Lines: Causes and Concerns," in IEEE Transactions on Power Delivery, vol. 23, no. 4, pp. 2339-2346, Oct. 2008, doi: 10.1109/TPWRD.2008.2002658.

T-Pylon Earthing System Modelling to Investigate Safety Aspects

M. Mokhtari*[1], A. R. Justo de Araujo[1], D. Clark[1] , M. Albano[1], S. Robson[1], and M. Haddad[1]
[1]Cardiff University, School of Engineering, Queen's Buildings, 14-17 The Parade, Cardiff
*E-mail: MokhtariM@cardiff.ac.uk

***Abstract*— In this paper, a typical earthing system of a T-Pylon as a new constructed transmission tower in the National Grid Transmission Electricity Project in Mendip Hills Area is modelled using CDEGS program. In this regard, the numerical method is used to calculate the touch and step voltages as two key safety factors. The purpose of the research is paying attention on the safety aspects during the maintenance and normal operation conditions. The preliminary results show the significant increase in touch and step voltages in the corners and sides of the T-Pylon's earthing system.**

BACKGROUND & MAIN RESULTS

The Hinkley Connection Project is a national project in the UK under management of the National Grid Electricity Transmission, which will connect low carbon energy to homes and businesses and increase capacity on the network for more green energy from the south-west. The new connection will be 57 km long made up of 48.5 km of overhead line including about 20 km T-Pylon towers and 8.5 km of underground cable through the Mendip Hills Area of Outstanding Natural Beauty [1]. The Foundation earthing system is the concept of the T-Pylon's earthing system to connect every individual pole to the earth. Whereas, the foundation has large dimensions, its performance for the power application depends on tests and detailed study results. In this study, a typical earthing system with 4 m by 4 m (sides) by 1 m (height) dimensions formed by rebars and filled with 100 Ω.m concrete attached with 16 driven piles with 10-m-long in uniform soil with 100 Ω.m resistivity was taken into account. The resistance to earth of the earthing system is calculated as 3.04 Ω. The touch and step profiles under 1 A applied current is presented in Figure 1. As seen in this figure, touch and step voltage values at the corners and the sides of the earthing system are higher than the other areas. It is clear that under higher applied currents, the condition becomes more critical. In a such condition, higher key voltage values can be mitigated by considering additional parts such as buried rings connected to the earthing system. These additional parts should be designed such that the key safety voltage values kept as low as possible in order to meet the safety standard recommended values.

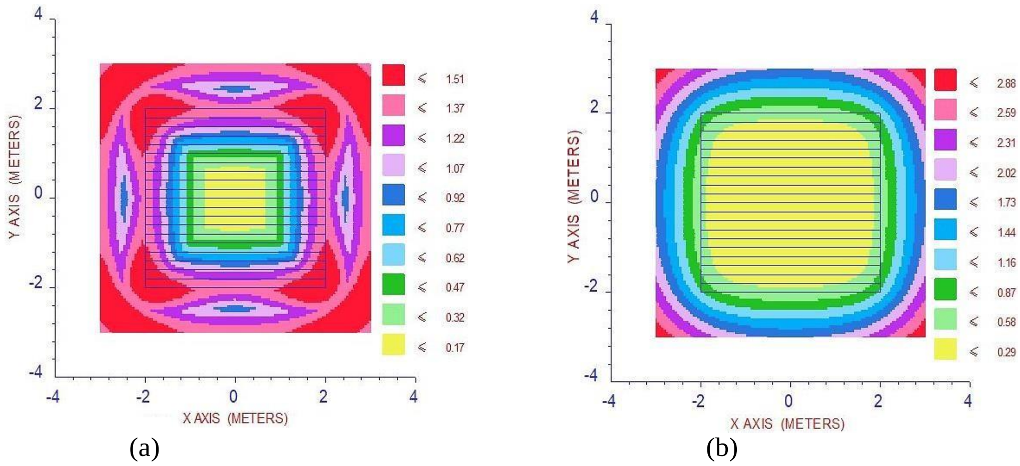


Figure 1: Voltage profiles on the earth surface: (a) step voltage in volts and (b) touch voltage in volts.

CONCLUSIONS

The calculation result showed that the earthing system foundation has an acceptable resistance to earth value which is in accordance with the standard recommendations for the application of the power system. It has been found that the touch and step voltage values are significant in the corners and sides of the T-Pylon earthing system. The safety of the mentioned areas during the normal operation with a low current values meet standard safety recommendations. However, The higher touch and step voltage values under higher applied currents can be mitigated by considering additional components such as buried loops around the T-Pylon.

REFERENCES

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Reduced Circuit Equivalence Model to Estimate Core Saturation of Quadrature Boosters

Cheng Chi[1], Shuhang Shen*[1], Zhongdong Wang[2], Peter Crossley[1] and Xiaolin Ding[3]
[1]Department of Engineering, University of Exeter, Exeter, UK
[2]Department of Electrical and Electronic Engineering, University of Manchester, Manchester, UK
[3]Strategy & Innovation, National Grid, Warwick, UK
*E-mail: s.shen@exeter.ac.uk

***Abstract*— Quadrature Boosters (QBs) are effective power flow controllers in power systems. QBs operate in bucking or boosting modes and have complex magnetic flux density distribution due to varying tap position and stronger leakage flux. Different from conventional transformers, the yoke of QB iron core sustains higher flux density than the leg in some operating conditions. To effectively analyse the core saturation, a reduced equivalent circuit model has been developed to separately examine the core leg and core yoke of QBs, where search coil method is used to measure the local magnetic flux density. In addition, Finite Element Modeling (FEM) has been conducted to simulate the magnetic field distribution of QB, and compared with the results of reduced equivalent circuit model.**

METHODS AND RESULTS

QBs encounter more complex saturation scenarios than conventional transformers, which can lead to overheating, excessive harmonics, and voltage fluctuations. These issues are caused by the unique structure and varying operational conditions of QBs compared to conventional transformers. For a dual-core QB [1], each unit is powered by two sources: one winding of shunt unit by a voltage source and the other winding of series unit by a current source. By adjusting the tap position, QBs can modulate the injected quadrature voltage, which in turn significantly alters the magnetic field across a wide range [2].

A model of a a single-phase 10.5 MVA 76kV / 19 kV transformer is constructed in COMSOL Multiphysics® to demonstrate the reduced equivalent circuit approach. To simulate the QB operational conditions, two excitation sources are applied to the transformer windings. Three search coils are placed in the model as shown in Fig.1. They are used to measure the flux densities at different locations and assess the impact of leakage flux on the maximum flux density in core leg and yoke, respectively.

Simulated three-winding short-circuit tests are used to derive three equivalent reactances of LV winding, $X_{LV,sc1}$, $X_{LV,sc2}$ and $X_{LV,sc3}$, corresponding to each system formed by the transformer windings and the three search coils. The reduced equivalence circuit model uses different equivalent reactances of LV winding to estimate different maximum flux densities in core leg and yoke. Through a numerical example studied by FEM simulation, it is demonstrated that the reduced circuit equivalence model provides an efficient and accurate solution for estimating the maximum core flux densities in core leg and yoke.

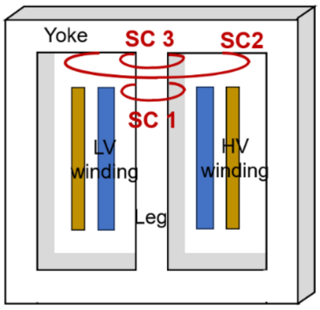

Figure 1: Locations of Search Coils.

CONCLUSIONS

A reduced circuit equivalence approach is developed to estimate the flux densities in core leg and yoke in QBs. To account for the effect of leakage flux on the core yoke, search coils are introduced to study local leakage flux via the equivalent reactance. By comparing with FEM simulation results of QB series unit, the reduced circuit equivalence provides an efficient and accurate solution for estimating the maximum core flux densities in core leg and yoke. From an operational perspective, the use of reduced circuit equivalence approach simplifies the evaluation of core saturation of QB.

REFERENCES

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[2] P. Jarman, P. Hynes, T. Bickley, A. Darwin, et al., "The specification and application of large quadrature boosters to restrict post-fault power flows," 41st International Conference on Large High Voltage Electric Systems, Paris, France, 2006.

Bubble Formation in High Temperature Transformer Insulation Systems

C. Pößniker[1], S. Matharage[2] and *Z.D. Wang[2]
[1]University of Exeter, Exeter, EX4 4PY, UK
[2]The University of Manchester, Manchester M13 9PL, UK
*E-mail: zhongdong.wang@manchester.ac.uk

***Abstract*-- Bubble formation from transformer winding insulation is a failure mechanism which may occur from a rapid temperature rise during an overload scenario. With the integration of carbon neutral renewable energy sources and the electrification of transport and heating, transformers may face unpredictable load patterns with high fluctuations where overloading could become necessary due to economic reasons or simply to ensure continuous energy supply. To cope with these changes or specific local conditions, high temperature transformer insulation materials are introduced, which are gaining popularity to prolong their lifetime and optimise their operation. However, studies on bubble formation with these materials are limited and further investigations are necessary to determine their potential risk compared to the traditional mineral oil and non-thermally upgraded Kraft paper. This study performed a coherent experimental study with a small-scale test tube setup to obtain comparable results to conclude on their impact.**

Background & Main Results

Transformers are an essential part of the electricity network and the system's reliability is strongly connected to their dependable operation. Failures could be catastrophic and severely affect the network reliability resulting in huge financial losses. Bubble formation from winding insulation is one of the transformer failure mechanisms, which is related to a rapid temperature-rise due to severe short-term loading conditions. These bubbles, if moved into an area of a high electric field, can cause transformer failure through flashover.

Understanding the fundamentals behind bubble formation mechanisms for different insulating material combinations will help to optimise the performance depending on individual environmental and loading conditions. The focus is hereby on high temperature transformer insulating materials which have an improved capability to cope with elevated temperatures to prolong the lifetime of an asset.

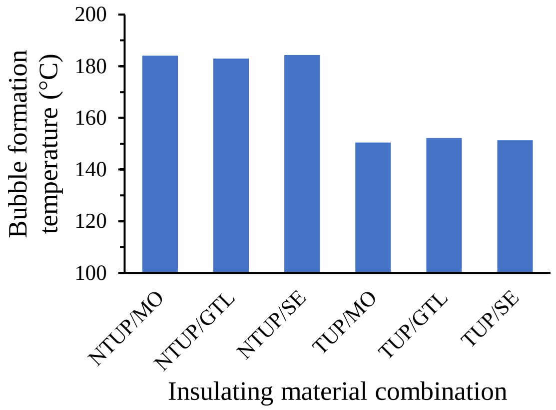

Fig. 1: Results for bubble formation temperature at 1 % water content in paper for different insulating material combinations (NTUP: non-thermally upgraded Kraft paper, TUP: thermally upgraded Kraft paper, MO: mineral oil, GTL: gas-to-liquid, SE: synthetic ester).

The developed small-scale test tube system [1, 2] uses a unique evaluation technique to evaluate the results according to the water content shortly after the bubble formation to take eventually occurring moisture migration into account. The tested materials were non-thermally upgraded Kraft paper and thermally upgraded paper in combination with mineral oil, gas-to-liquid based oil and synthetic ester. For these material combinations the bubble formation temperature according to the water content in paper at bubble inception has been determined. Tests with mineral oil and non-thermally upgraded Kraft paper have been performed as the base case scenario for comparison. The results with the different liquid types have shown that their impact is negligible and that the results are similar to the base case scenario, despite having different material properties. For the different paper types, however, a significant temperature difference could be observed, where the one from the non-thermally upgraded Kraft paper was significantly higher. This indicates that the paper type seems to play a dominant role. Additionally, moisture migration until bubble formation occurred could be observed.

Conclusions

Studies to the bubble formation phenomenon from high temperature transformer insulation systems are limited and show wide variations. This experimental work had the aim to perform a coherent study with different high temperature transformer insulating materials to obtain comparable results to their impact on the bubble formation phenomenon. Different liquid and paper types have been investigated and the results have shown that the type of liquid seems to have a negligible impact. However, the type of paper has shown a significant impact on the bubble formation phenomenon.

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Effect of Ion Types on Arc Erosion of Circuit Breaker Contact: Molecular Dynamics Simulation Study

X Wang[1], S Y Matharage[2], Z D Wang[2 *]
[1]Centre for Smart Grid, Department of Engineering, University of Exeter EX4 4PY, UK
[2]University of Manchester, M13 9PL, UK
* zhongdong.wang@manchester.ac.uk

Abstract**-- SF_6 circuit breakers are commonly used as switchgear devices in high-voltage power systems. During arcing process, the particles in arc plasma are mostly positive ions (metal ions, S ions, and F ions) and electrons at temperatures beyond 15000 K. Arc erosion on the cathode surface is dominantly determined by positive ion bombardment. Thus, studying the effect of ion type and energy on arc erosion of different contacts helps understand the failure mechanisms. The current research investigates the impacts of Cu, S, and F ions, all with a constant energy of 50 eV, on both Cu and graphene-covered Cu substrates. Utilising molecular dynamics (MD) simulation, results reveal that S ions induce more substantial damage to the Cu substrate than Cu and F ions. Cu ions have a high sticking probability to the Cu surface, and the larger size and heavier weight of S ions mean more damage than F ions with the same incident ion energy. Moreover, graphene on the surface significantly mitigates the damage caused by all three ion types, as graphene aids in energy dissipation by oscillating waves, thereby reducing the energy acting on the underlying Cu. This research provides insights into the interaction between different plasma ions and contact materials, contributing to the improvement of contact materials.**

BACKGROUND & MAIN RESULTS

Circuit breakers are critical components in electrical systems designed to interrupt current flow in case of an overload or short circuit. SF_6 circuit breakers are uniquely used in high-voltage applications due to their excellent insulating properties. An electric arc generates within the gap between contacts once they separate. The interaction between arc and contacts leads to the gradual decomposition of solid contact materials, termed arc erosion. Positive ion bombardment stands out as the dominant energy contributor to arc erosion [1]. The specific impacts of distinct ion types on arc erosion remain unclear. Consequently, investigating the effects of ion types on cathode materials assumes significance in comprehending the underlying mechanisms of arc erosion.

In this work, MD simulation is used to study the effects of ion types on arc erosion at the micro-level. SF_6 and Cu, commonly used insulating gas and contact material, are chosen as the research objectives. Additionally, a graphene-covered Cu model was also used as a substrate considering the emerging trend of employing graphene as a reinforcement to improve the arc resistance of contact materials.

MD simulation results indicate that S ions induced a larger pit on the Cu substrate surface than Cu ions and F ions. Besides, the number of lost atoms in the Cu system bombarded by S ions is much higher than others. Incident Cu ions possessing an incident energy of 50 eV have a high probability of sticking on the Cu substrate surface because a strong metal bond will be formed between incident Cu ions and substrate Cu atoms. As a result, Cu ions can become trapped in the attractive mean field of the surface long enough to dissipate their energy and stick. Moreover, the larger atomic size and greater weight of S ions relative to F ions contribute to their heightened capacity for inflicting damage upon the Cu surface during their collision with the Cu surface. G-Cu models keep almost the original surface structure. Firstly, graphene, with its exceptional mechanical properties and high melting point, serves as a strong barrier that intercepts and diverts the trajectory of the incident ions away from the Cu surface. On the other hand, graphene can dissipate part of incident energy in the form of waves. Therefore, graphene on the surface protects the substrate against direct bombardment by incident ions.

CONCLUSIONS

In conclusion, this work studied the effects of ion types on arc erosion of circuit breaker contact. The results derived from MD simulations indicated that S ions induce more substantial damage in the Cu substrate compared to Cu and F ions. In the case of Cu ions bombardment, low sputtering yield was triggered by Cu ions with 50 eV due to their high sticking probability to the Cu surface. Moreover, the larger size and weight of the S ions than F ions are attributed to the increased physical impact during their collision with the Cu surface. In addition, graphene on the surface significantly reduced the damage caused by all three ion types, as graphene can dissipate energy in the form of waves, thereby reducing the energy acting on the underlying Cu. This work provides insights into the interaction between different plasma ions and contact materials.

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Effect of Electric Field on Conductivity of Synthetic Ester Induced by Space Charge Accumulation

R Yu[1], S. M. Matharage[2], S. H. Shen[1], and and Z. D. Wang[2*]
[1]University of Exeter, Exeter EX4 4PY
[2]The University of Manchester, Manchester M13 9PL
* zhongdong.wang@manchester.ac.uk

Abstract-- **Synthetic ester has emerged as an alternative in applications where mineral oil has traditionally been used. Furthermore, their new applications in areas such as converter transformers and battery energy storage systems are currently being investigated. Conductivity of insulating materials is a crucial parameter for such new applications. This paper investigates the impact of electric field on the long-term conductivity of synthetic ester through a combination of experimental and simulation studies. The experimental results indicated that conductivity exhibited a non-linear trend with applied electric field. The computational model, which incorporates space charge accumulation and charge injection, is used to explain electric field dependent conductivity phenomena.**

BACKGROUND & MAIN RESULTS

There has been a notable global surge in the engineering applications of ester-based insulating liquids, primarily due to their environmentally friendly characteristics and fire safety features [1]. Esters have found widespread utilization in distribution transformers and a noticeable increase of use in transmission transformers with voltage ratings up to 450 kV, ongoing research is exploring their application in converter transformers [2]. Conductivity is an important parameter for the electric field design and heat loss calculation, a nonlinear conductivity with the electric field has been observed for mineral oil, it will eventually change the electric field profile in converter transformers [3].

Fig. 1 illustrates the effect of electric field on the time development of conductivity. With the increase of the electric field, the short-term conductivity (0.1 s) gradually increases whilst the long-term conductivity (3600 s) present nonlinear trend. Apart from the differences in the low electric field mainly caused by the two-terminal test cell, the simulated results were nearly the same as the measured values. Computational results indicated that the space charge accumulation and field distortion is the mechanism for electric field effect on conductivity. An increase in the electric field intensity results in more space charge accumulation on the electrode surfaces, indicating an increased migration of space charge from the bulk liquid to the electrode surface region. The electric field in the bulk region gradually decreases with the increase in the electric field, as a result, a decreasing trend in long-term conductivity is expected when the electric field ranges from 10^{-4} to 0.1 kV/mm, then increasing from 1 to 10 kV/mm due to enhanced charge injection.

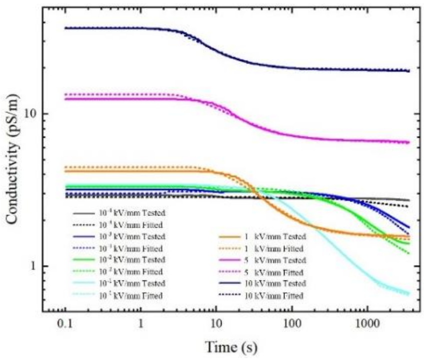

Figure 1: Measured and simulated conductivity of new ester under 30 ℃ and 30 ppm moisture content

CONCLUSIONS

This paper studied the impact of electric field on the conductivity of synthetic ester liquid. Test results indicated an exponentially increasing short-term conductivity and nonlinear long-term conductivity of ester against the applied electric field. Through a computational model, it was revealed the electric field affects the conductivity through space charge accumulation and charge injection. The results of this study provide physical insights into the conductivity of synthetic ester from the perspective of space charge phenomena.

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Arc Voltage as an Indicator of Nozzle Ablation Degradation in High-voltage CO_2 Gas Circuit Breakers

Y N Zhou[1], J E Humphries[1], J W Spencer*[1], J D Yan[1], and G R Jones[1]
[1]Department of Electrical Engineering and Electronics,
University of Liverpool, Liverpool, L69 3GJ, U. K.
*E-mail: joe@liverpool.ac.uk

Abstract-- **Energy released by electric arc during short-circuit current interruption is mostly absorbed by the surrounding cold gas and partly transferred to the arcing contacts and nozzle. The radiation is the main mode of thermal energy transfer between the electric arc and nozzle surface. Experimental research on the nozzle ablation has been carried out at a model circuit breaker, in which CO_2 is filled in the chamber and poly-tetrafluoro-ethylene (PTFE) is used as the nozzle material. It is found that the arc voltage can be as an indicator of nozzle ablation degradation by comparing the voltage at current peak and arc voltage extinction peak. Under 20 kA and 35 kA peak current interrupting conditions, the voltage at current peak decreases with the number of operations. There are two factors that affect the arc voltage at current peak. One is the size of the arc cross section, and the other is the content of PTFE entering the arc zone, which affects its conductivity.**

Background & Main Results

High voltage circuit breaker (HVCB) is a key switching element to protect the power system against various faults, and its current carrying capacity and interrupting capacity are of prime importance. Arc-extinction chamber plays an important role in the abnormal or fault current interruption. Nozzles, mainly made of poly-tetrafluoro-ethylene (PTFE), are exposed to switching arc radiation directly during current interrupting operation. Nozzle ablation has dual positive and negative effects on current interrupting capability in HVCBs [1]. On the one hand, pressure built-up is generated when the ablated PTFE vapour heats up and compresses the gas in the expansion chamber [2]. One the other hand, the throat diameter and the cross-section area of gas channel will increase after each current interruption, which reduces the current interrupting capacity of HVCBs [3]. Therefore, it is essential to monitor the interruption chamber effectively and assess the nozzle condition to prevent probable failures and predict the lifetime of HVCBs [4].

The electrical degradation of contacts and nozzles inside the interruption chamber has been extensively investigated in term of mass loss, physical change and the pressure build-up process in the experimental aspect. In order to estimate the remaining lifetime and the allowable number of interruptions of HVCBs, there are some engineering methods based on the availability of the peak current amplitude, transferred electric charge, arc energy and the gas pressure.

Experimental research on the nozzle ablation has been carried out in a high-voltage CO_2 gas circuit breaker (GCB). By comparing the voltage at current peak and arc voltage extinction peak, it is found that the voltage at current peak can be as an indicator of nozzle ablation degradation under fault current (amplitude of 20/35 kA) conditions in high-voltage CO_2 GCB.

Conclusions

In this contribution, arc ablation experimental study of high-voltage CO_2 GCB has been done at three different peak current levels (5/20/35 kA). At each current level, five consecutive arcing tests were carried out to oberve the degradation behavior of nozzle ablation. Voltage at current peak and arc voltage extinction peak were selected to present the high-current and current-zero periods respectively. It is found that the voltage at current peak decreases with the number of operations under 20/35 kA current interrupting conditions. There are two factors that affect the arc voltage at current peak, which are first the size of the arc cross section and secondary the content of PTFE entering the arc zone during the process of melting and vaporization of nozzle material. More quantitative experimental measurements and theoretical calculations of mass loss of nozzle will be carried out in the future.

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Research on Electrical Life and Arc Erosion Tests of High-voltage Gas Circuit Breaker

Y N Zhou[1], J E Humphries[1], J W Spencer*[1], J D Yan[1], and G R Jones[1]
[1]Department of Electrical Engineering and Electronics,
University of Liverpool, Liverpool, L69 3GJ, U. K.
*E-mail: joe@liverpool.ac.uk

Abstract-- **Erosion of the arcing contacts in the high-voltage circuit breaker is closely related to the arc phenomenon. The experimental research on the graphene-reinforced copper-tungsten material has been carried out at the arcing test platform. Contact erosion is the result of an extremely high energy flow injected from the arc to the contact material. This transfer of energy heats up the electrode surface which becomes molten and some of this molten material is ejected from the electrode. A high-speed camera is used to capture the arc root and arc column during operation of a model circuit breaker. For the operating conditions in the model circuit breaker and for currents less than 5 kA, the arc ignition position of the plug contacts is localised. As the number of arcing tests increases, a new arc root attachment area will be generated near the eroded surface, and the total erosion area on the contact surface will increase. The erosion mass loss rate of the plug contact will increase substantially for arc currents greater than the 20 kA. This paper will present the experimental observations and present a reasoned argument for the performance of the copper/tungsten/graphene electrodes tested.**

Background & Main Results

The arcing contacts in high voltage gas blast circuit breakers (HVCBs) have vital functions: mechanical endurance, dielectric stress withstand, current interruption, and arc roots containment [1]. Contact erosion is a process affecting the lifetime of HVCBs [2]. Contact erosion strongly depends on the design and the tip material. There are two erosion modes, namely evaporation-dominated mode and splash-dominated mode, during the current interrupting process [3].

It is important to understand the mechanisms of the erosion mode transformation for the Cu-W anode [4]. The copper phase first melts and evaporates due to the large difference in melting and evaporation points of copper and tungsten. Subsequently, the arc root is attached to the tungsten skeleton, at least in part, when the shallow copper layer is exhausted. Further injection of heat into the contact surface renders the temperature of the exposed contact surface exceed the melting point of tungsten. When the temperature is much higher than the boiling point of copper, the copper rich layer boils. Finally, the eruption of copper vapor beneath the tungsten rich layer can lead to the removal of the molten tungsten via droplet ejections.

Under the harsh arcing conditions in HVCBs, Cu-W contacts suffer from a limited operating lifetime, in which arc erosion damages the contact surface and degrades the electrical performance. Adding reinforcements is an approach to altering the properties of metal matrix composites (MMCs). There has been an interest in using graphene as an additive to improve the electrical lifetime of arcing contact. Graphene, a two-dimensional nano-material composed of a monoatomic layer of hexagonally arranged carbon atomics, is best known for its excellent mechanical, thermal and electrical properties. There are only a few reports on the application of G-Cu-W contacts in HVCBs, and the physical mechanism related to arc erosion phenomena and the role of graphene in MMCs have not yet been clearly understood. The aim of this work is to gain more understanding of the operating performance of arc contacts made from G-Cu-W and its failure mechanism.

Conclusions

The experimental research of arc erosion of Cu-W and G-Cu-W contact material has been carried out under the free-burning arc conditions in a real high-voltage CO_2 gas circuit breaker. The mass loss is used as the basic index to characterize the degree of arc erosion. The present work leads to two findings regarding contact erosion by unconfined CO_2 arcs (nozzle free) in a model circuit breaker. The mass loss rate of the plug contact rises abruptly when the current is higher than 20 kA over the range of 5 kA to 40 kA. This is believed to be caused by the elevation of current density when the arc root covers the full tip area of the contact. A comparation on the arc-endurance performance of contacts made from conventional Cu-W material and graphene reinforced Cu-W material has also been presented to help evaluate the possible role of graphene in arc contact erosion. The preliminary results point to the lower erosion rate of G-Cu-W contacts compared with the same dimension of Cu-W contacts.

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Investigating Partial Discharge Sustaining Electrical Trees in Void-contained Solid Dielectric

N F Adan*[1], S Qi Li[1] and S M Rowland[1]
[1]The University of Manchester, Manchester M13 9PL, UK
*E-mail: norfaezahbinti.adan@postgrad.manchester.ac.uk

***Abstract*—An ageing mechanism known as electrical treeing can cause dielectric failure in HV cables. The presence of defects such as voids and contaminants contribute to this phenomena. Defects such as gas-filled voids will be a weak-point within the insulation due to its reduced breakdown properties. Thus, under sufficient electrical stress, partial discharge can be sustained and may lead to initiation of electrical treeing. To understand this phenomena and model this situation, a needle-free set-up with an air-filled half-ellipsoid void is presented. An initial investigation using FEA simulation was conducted to identify the electric field strength and point of high stress within the void subjected to 15 kVrms, 50 Hz AC stress. Average values of higher than 10 kV/mm are predicted within the void which theoretically suffice to sustain partial discharges.**

Background & Main Results

Electrical treeing is a degradation mechanism in solid dielectric due to prolonged exposure to high electrical stress. This process is not reversible and will cause permanent damage to the material. The dissection of 54 (out of 161) in-service cables conducted in [1] confirmed the presence of electrical trees originated from contaminants, voids, conductor shield or insulation shield. Therefore much research has been done to understand electrical treeing in solid dielectric using the well-established needle-plane method. This method, while proven as capable of generating electrical trees under various stress conditions, may not fully represent the actual arrangement within an HV cable that has no needle-like component at all. A needle-free experimental method established in [2] could potentially bridge the gap between laboratory and service experience.

A notable finding in [1] captured half-ellipsoidal voids of smaller sizes with electrical trees and larger voids with no electrical tree growing directly from them. Evidently, electrical trees may also grow indirectly from a void [2]. These phenomena are yet to be fully understood as partial discharge could be sustained in voids leading to morphological and chemical degradation but not necessarily develop into an electrical tree [3]. Hence, this research area must be extended to further understand the nature of partial discharge within a void geometry and other factors that are involved in generating electrical trees from it. The outcome may possibly help to prevent trees growth from similar defects in the future. Figure 1 illustrates the 2D-axisymmetric FEA simulation in COMSOL of a half-ellipsoid void using needle-free arrangement to identify the electric field strength and point of high stress within the air-filled void. The simulation assumed both ideal (zero gap) and non-ideal interface (20 µm gap) between the top dielectric and the dielectric under test. The ideal interface resulted in an average electrical field strength of 11.4 kV/mm within the void while the latter 10.9 kV/mm. However, highest value of 34.8 kV/mm was recorded within the 20 µm gap in the non-ideal interface as circled in Figure 1. The predicted peak values of 13.7 kV/mm calculated using a three-capacitor equivalent circuit is also close to the average values obtained from the simulation.

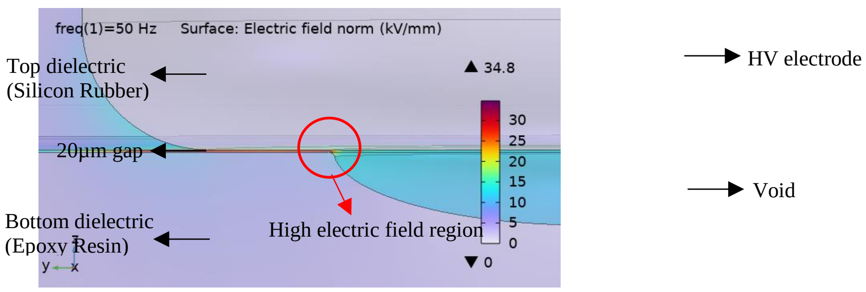

Figure 1: Electrical field strength in sample with half-ellipsoid void (4mm x 0.6mm) with non-ideal interface subjected to 15 kVrms, 50Hz AC

Conclusions

The average electrical field strength simulated is higher than air breakdown strength of 3 kV/mm in both conditions. Thus theoretically, partial discharge can be sustained within the air-filled void and the gap interface and possibly develop into electrical tree under repetitive discharges. Deeper analysis reveals in the importance of the interface between the solid dielectric and the electrode adjacent to the void.

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Electrical Characterisation of Silicone Rubber - Ester Liquid Composite Insulation System used in Subsea Cable Connectors

D. Guaña[1], Q. Liu[1], M. Jeschke[2] and D.Walton[2]
[1] Department of Electrical and Electronic Engineering, The University of Manchester
[2]Siemens Energy Limited
Email: Qiang.liu@manchester.ac.uk

***Abstract*-- Subsea cable connectors are widely considered as one of the most critical components in offshore power delivery systems. Their insulation is commonly designed as a solid-liquid composite system where polymers are typically interfaced with a conventional dielectric liquid. While extensive research has been carried out on the compatibility of liquid and solid insulation materials for connectors, there is lack of literature discussing the electrical characterisation of such composite insulations systems, especially when the dielectric liquid is replaced by an environmentally friendly synthetic ester liquid, or the temperature is increased above 20 °C. Therefore, it is essential to investigate the breakdown phenomena of the silicone rubber insulation system under AC stress at different temperatures, which could lead to a better reference for the design and production of underwater connectors.**

Background & Main Results

Subsea cable connectors are widely recognized as one of the most critical components in offshore power delivery systems. In contrast to traditional cable connectors, these components face harsh and challenging conditions present in their underwater environment. These conditions include corrosive and conductive seawater, high pressures of up to 300 bar at depths of up to 3000 meters, and temperature variations [1]. In this context, elastomers are a suitable choice due to their elasticity, high compressive strength, and low water absorption.

Typically, connector designs combine a solid insulator with conventional mineral oil due to their relative low cost and excellent dielectric properties. However, its poor biodegradability and the imminent shortages, motivates researchers to seek alternative sources of insulating liquids. Consequently, the deployment of synthetic ester liquids sounds promising as they introduce not only a good thermal stability and excellent biodegradability but are particularly appreciated in projects demanding fire resistance and where spillage concerns are critical for the environment. Unfortunately, current literature on subsea composite insulation systems lacks comprehensive coverage of their electrical characterisation. Moreover, studies on crucial factors like ester liquid immersion and temperature variations are notably scarce. This work focuses on the electrical characterisation of silicone rubber immersed in a synthetic ester liquid as a possible option in subsea cable connectors. A temperature control system is developed and used to study the AC breakdown voltage (BDV) of silicone rubber at temperatures ranging from 20 to 80°C [2]. The results are statistically analysed using a two-parameter Weibull distribution. Furthermore, the location of each breakdown event is also studied.

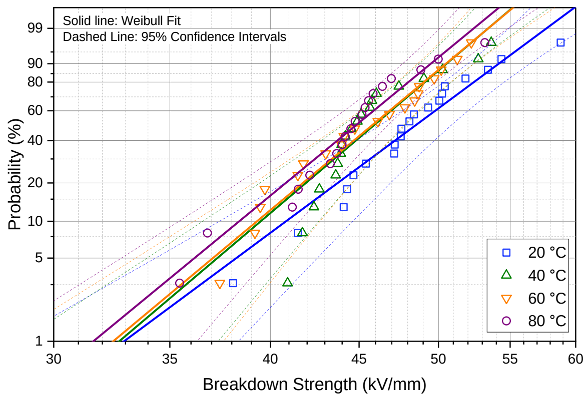

Figure 1: Influence of Temperature on SiR breakdown strength

Conclusions

The effects of temperature on BDV and breakdown strength (BDS) are analysed and discussed. The findings demonstrate that both BDV and BDS decrease slightly as the temperature increases. The investigation also recorded the location of breakdown showing that 95% of the events occurred in the vicinity of the triple point.

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Effects of Temperature on the Partial Discharge Characteristics of Silicone Oil

A.A.Mohd Nor and Q. Liu*
Department of Electrical and Electronic Engineering
The University of Manchester
Email: Qiang.liu@manchester.ac.uk

***Abstract*— For power utilities to achieve net zero target and sustainable future, it relies on the integration of a large amount of renewable energy, and this necessitates a significant increase in cable joints and terminations especially in the offshore connections. The application of the liquid filled joints and terminations are still widely used in the industry and one of the insulating liquids used in cable sealing end (CSE) is silicone oil. The construction of CSE consists of different materials such as liquid insulation, solid insulation, and semiconductor materials which discloses the implementation of liquid and solid combined insulation. The weak point of an insulation system is located at the interface existing between the liquid and solid insulations. Therefore, it is important to understand the electrical performance of the liquid-solid interface in insulation designs. Prior to understanding the interface phenomena, it is required to fully understand the dielectric performance of the liquid insulation by investigating the partial discharge (PD) characteristics of the silicone oil.**

BACKGROUND & MAIN RESULTS

Dielectric performance of the insulating liquid is crucial for the integrated insulation performance of the liquid-filled cable terminations such as the CSE and silicone oil is a prominent insulating liquid used in CSE [1]. Majority of the published studies on the partial discharge (PD) phenomena of silicone oil involved with the low-viscosity silicone oil at room temperature [2]. Therefore, the aim of this study is to investigate the PD characteristics of a high-viscosity oil at different temperatures. The sample used in this study was a high-viscosity silicone oil, DC568, where the viscosity of the oil is 13,000 cP at 20℃. Figure 1(a) shows the experimental setup for the PD measurements which complies to IEC60270 [3]. The temperature of the silicone oil was varied from 20 ℃ to 80 ℃ with steps of 20 ℃ by employing a heating oil circulating bath system. A needle-plane electrode configuration with a gap distance of 50 mm was used. At every temperature level, the PD inception voltage (PDIV), PD patterns, PD magnitude and PD repetition rate were obtained. Figure 1(b) represents the total PD repetition rate of the silicone oil at different temperatures. Moving forward the future work will consider the impact of temperature on the creepage discharge characteristics of silicone rubber interface with silicone oil. The electrical and optical observations of the creepage discharge process from initiation, propagation and breakdown will be conducted.

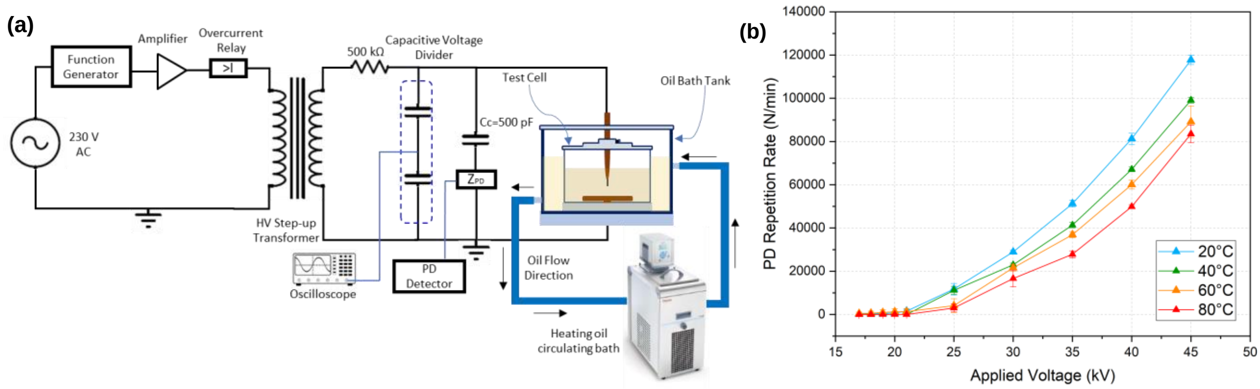

Figure 1: (a) Experimental setup and (b) PD repetition rate of DC568 at different temperatures.

CONCLUSIONS

The results obtained in this paper show that PD repetition rate of the high-viscosity silicone oil reduces with the increase of temperature. PDIV on the other hand decreased with the increase of temperature. Different temperature conditions have also demonstrated an influence on the PD magnitude and PD patterns. This study would make contribution to understanding the failure mechanism of liquid-solid interface in high voltage cable accessories, and result in a more reliable operation of CSE in power network with optimised insulation design and better asset management.

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Failure analysis of HTV silicone rubber under AC voltage in corrosive environment

Guohui Pang* and Steven Qi Li
Department of Electrical and Electronic Engineering, The University of Manchester, Manchester, UK
*E-mail: guohui.pang@manchester.ac.uk

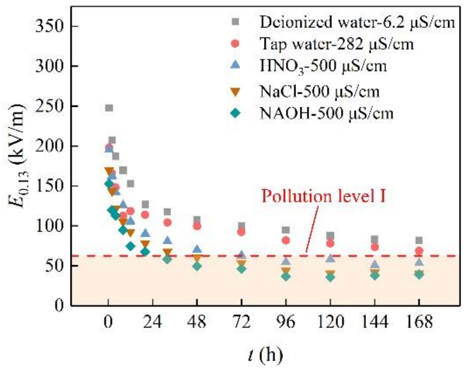
***Abstract*—The performance of high-temperature vulcanized (HTV) silicone rubber used in composite insulators will be worse in harsh environments. Acid and alkali pollutants in the atmospheric environment will affect the performance of silicone rubber. Based on the existing studies, this study investigates the failure characteristics of silicone rubber used in composite insulators within artificially simulated energized corrosion environments. The results indicated that the AC flashover voltage decreased with increasing applied voltage and fog conductivity during the aging experiments. The flashover gradient of silicone rubber exhibited a negative power function relationship with the aging duration. The characteristic index *b* of $E_{0.13}$ was affected by aging time and is the highest in alkaline mist corrosion environments with the same conductivity. According to the 99.87% withstand gradient, the reliable running time of silicone rubber materials under different conditions can be determined. Moreover, the reliable running time will shorten with the increased fog conductivity in the corrosion environment and applied voltages.**

Background & Main Results

Composite insulators have been broadly utilized in power systems. Silicone rubber (SIR) housings are subjected to harsh weather conditions during long-term operation. Additionally, SIR housings are harmed by industrial pollution of chemical acid, alkali, salt, and conductive dust emitted by industrial and mining companies and by acidic or alkaline chemical contamination in coastal and salty environments [1]. These substances deposit on the insulators and are corrosive and conductive when dissolved in water, which causes damage to the insulators under high voltage [2].
This study investigates the changes in flashover characteristics of silicone rubber during long-term energized operation in a corrosive environment through artificial simulation of heavy fog corrosion.

1 AC Failure Conditions

Taking the withstand gradient of 62.50 kV/m at the designed pollution level I of the power station as the critical condition, the withstand voltage gradient with a flashover probability of 0.13% ($E_{0.13}$) of the SIR samples is higher than 62.50 kV/m, which is reliable. Otherwise, a flashover is considered to occur. The trend of the AC flashover gradient is shown in Figure 1.



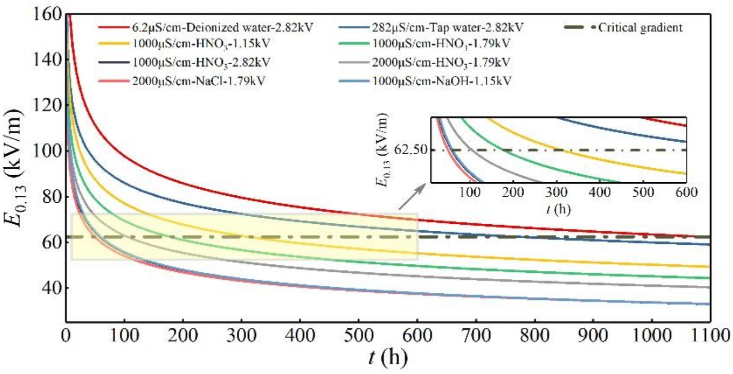


Figure 1. Relationship between AC flashover gradient and energizing duration (AC 2.82kV)

Figure 2. Prediction of reliable running time of silicone rubber in corrosion fog

It can be seen from Figure 1 that the withstand gradient of silicone rubber decreases in a negative power function law with the increase of energizing duration.

2 Prediction of Composite Insulation Failure

As shown in Figure 2, in the actual lines, the reliability of the composite insulator is much higher than the data in the laboratory. The results are derived based on the extremely harsh environmental conditions simulated in the laboratory. While in the actual transmission lines, there are no continuous corrosive fog conditions for such a long time.

Conclusions

The flashover gradient of silicone rubber decreased with the increase of fog conductivity, applied AC voltage, and energizing duration. The relationship between the reliable running time and energizing duration was a negative power exponent.

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Evaluation of the Effects on Electrical Losses and Thermal Ageing of Transformer Heat Recovery

Zhengbo Xu[1], Qiang Liu[1], Paul Jarman[1] and Gordon Wilson[2]
[1]The University of Manchester, UK
[2]National Grid Electricity Transmission, UK
Email: Qiang.liu@manchester.ac.uk

Abstract-- **To achieve the net-zero carbon target, alternatives to fossil fuels for space and water heating are required. Direct heat recovery from grid transformers becomes an option when the heat demand is close to the transformers and the transformer can be run hot enough to provide heat at an acceptable temperature. However, increasing the operational temperature of a transformer tends to result in an increased aging rate and reduced lifetime. Three transformer thermal models have been developed to evaluate transformer oil and winding temperatures and hence to derive losses and insulation thermal aging rate. First, a standard WTI (winding temperature indicator) model was developed based on IEC thermal model [1] and used as the reference. Then a quasi-static WTI model, ignoring the time constants, was developed and compared with the reference model. At last, a heat recovery model using a constant oil flow and constant top oil temperature was developed. By comparing the losses and expected lifetime between the quasi-static WTI model and the heat recovery model, it is found that the lifetime reduction for heat recovery is negligible in comparison to the expected lifetime of the transformer. There is a modest increase in winding losses at a top oil temperature of 70 °C, but this increase is approximately halved if the top oil temperature setting is reduced to 60 °C and becomes negligible when the setting is 50 °C.**

BACKGROUND & MAIN RESULTS

To achieve net-zero targets, decarbonization of space and hot water heating is essential. When heat demand is close to grid transformers, direct recovery and use of the heat from the transformer which would otherwise be dispersed to the atmosphere becomes an option. The usefulness of the heat depends on the temperature at which it is supplied, but increasing the operating temperature of a transformer has potential implications for increased electrical losses and reduced lifetime, which need to be considered. The aim of this paper is to understand the impact of heat recovery on the electrical losses and insulation thermal ageing of a 400 kV supergrid transformer.

The transformer heat recovery cooling system consists of an oil cooling loop and a water cooling loop. The oil cooling loop consists of the transformer windings, a fixed speed oil pimp and an oil-to-water heat exchanger. The water loop consists of a fixed speed water pump, an oil to water heat exchanger, a heat recovery water to water heat exchanger, and a dry water to air cooler. The dry air cooler is equipped with variable speed fans and a bypass controlled by a three-way valve. An outline diagram of the heat recovery cooling scheme is shown in Figure 1.

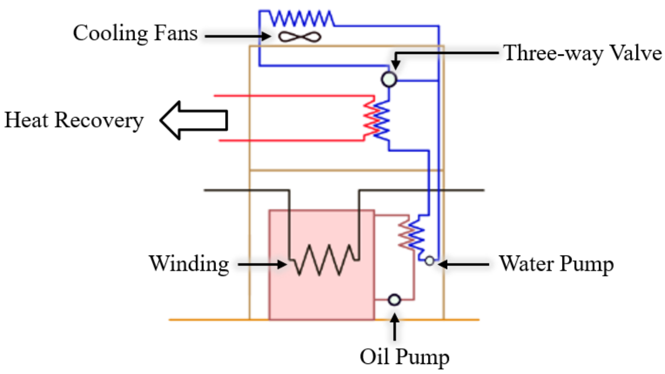

Figure 1: Diagram of heat recovery control scheme.

CONCLUSIONS

In this study, transformer thermal models have been developed that can evaluate hotspot, top-oil and average winding temperatures and hence derive winding electrical losses and insulation thermal ageing rate, given a loading and ambient temperature profile. It was founded that the lifetime reduction due to heat recovery is negligible for the investigated case study and hence heat recovery from supergrid transformers is feasible.

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Ageing Assessment of Transformer Insulation Systems using Dual-temperature Method

Cenkai Xu, Qiang Liu, and Zhongdong Wang
Department of Electrical and Electronic Engineering
The University of Manchester
*E-mail: qiang.liu@manchester.ac.uk

Abstract—Ageing assessment of transformer insulation systems has continuously been a technical challenge faced by the transformer industry. In response to the higher and more dynamic load demands in future, various combinations of solid and liquid insulation materials have been investigated for transformer application. There are mainly three types of ageing setup available for assessing the thermal performance of different insulation systems. They are single-temperature ageing cell, dual-temperature test system and functional life test model. Most of the ageing studies published in the literature were done using a single-temperature ageing cell. Dual-temperature test system is less complicated and less costly than the functional life test model, but is able to simulate non-uniform temperature profile, which cannot be achieved by the single-temperature ageing cell. Nevertheless, there are only a few ageing studies using dual-temperature test system published in the literature. This work aims to investigate the ageing performance of thermally upgraded paper insulation in combination with various transformer liquids using the dual-temperature ageing system. Long term ageing experiments will be conducted to assess the mechanical and dielectric properties of the solid and liquid insulation materials. FEM simulation will be conducted to understand the thermal profile and ageing marker migration within the ageing cell.

BACKGROUND & MAIN RESULTS

Power transformer is one of the core component of electrical power networks. Achieving carbon net-zero ambitions requires electrification of heating and transport. It is expected to see wider integration of low carbon technologies into the electrical power networks. Both existing and new transformers will inevitably experience higher and more dynamic loads in the future. Meanwhile, various combinations of solid and liquid insualitons sytems are gaining acceptance within transformer industry. Therefore, more research is imperative to gain a better understanding of the ageing performance of transformer solid insulation impregnated with various alternative insulating liquids. The ageing experiment can be categorized into three types, including single-temperature ageing cell, dual-temperature test system and functional life test model. This PhD work will utilise the dual-temperature ageing test cell [1] for assessing ageing performance of thermally upgraded paper insulation in various types of transformer liquid.

The dual-temperature test system used in this work is based on technical specifications outlined in IEC 62332-1 [2]. As illustrated in Figure 1 [3], the test system is comprised of an ageing test cell, a power supply, a control system, a monitoring and data collection system, and a safety system.

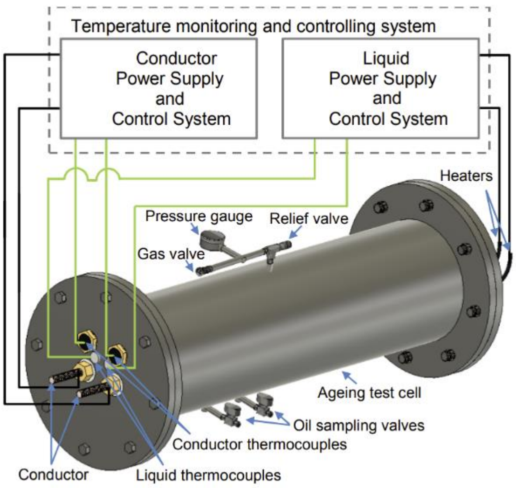

Figure 1: Dual-temperature ageing experimental set-up [3]

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Molecular Dynamics Simulation of Erosion Behaviours of an Individual Cathode Spot

Haonan Yang[1], Shuhang Shen[2] and Zhongdong Wang[*1]
[1]University of Manchester, M13 9PL
[2]University of Exeter, EX5 2FN
*E-mail: zhongdong.wang@manchester.ac.uk

Abstract-- **Plasma-surface interaction plays a pivotal role in numerous applications as either an exploitable advantage or a detriment to be mitigated. For vacuum circuit breakers, the contact erosion induced by the plasma-surface interaction emerges as a significant constraint, impacting their long-term dielectric strength and electrical lifetime. To investigate the intrinsic mechanism governing contact erosion by vacuum arcs, this study employs the Molecular Dynamics method to model the cathode spot. By establishing the simulation site representing the central position of an individual cathode spot, the surface atom emission as the primary source of mass loss from the contact is analysed. As a result, the simulated erosion behaviours including evaporation and sputtering are observed. As the dominant emission pattern, atom sputtering is observed prominent after the establishment of a high-temperature surface region. Throughout the development of the cathode spot, the erosion behaviours at the spot centre manifest a three-stage pattern: an initial growth stage, a subsequent transition stage, and a final stable stage. The simulation results are consistent with the experimental findings of the contact erosion in vacuum circuit breakers, that the erosion rate is always a material-dependent constant.**

Background & Main Results

The breakdown strength of the vacuum circuit breakers is limited by the influence of the contact surface condition, especially after contact erosion. Contact erosion on the cathode of vacuum circuit breakers was observed taking place on numerous small cathode spots with a radius ranging from 100 nm to 10 μm, and with a lifetime in the order of tens of nanoseconds [1]. Each cathode spot, serving as the path for current conduction, undergoes intense kinetic and thermal processes, leading to surface deformation and local mass loss. Throughout the arcing process, numerous cathode spots are formed and distinguished successively, contributing to the overall contact erosion. Therefore, the investigation into the erosion behaviours of cathode spots is essential to understanding the mechanisms of contact erosion. This understanding, in turn, lays the foundation for further material design aimed at mitigating contact erosion and enhancing the dielectric strength of vacuum circuit breakers.
In this study, a comprehensive model of the cathode spot is built using the Molecular Dynamics method, involving multiple effects such as electron emission, surface atom emission, and back ions. With leftover plasma ions provided as the input, the formation process of the cathode spot is simulated, represented by its local central position with the highest temperature and the most intense erosion. Compared to the assumption in the previous simulation works that the surface atom emission is solely the saturated surface evaporation, the surface-emitted atoms recorded in this work exhibit a much bigger number. By further analysis of the relationship between the surface temperature and the surface atom emission, it is found that the intense surface atom emission is dominated by the atom sputtering, which is the result of ions bombarding the surface with a high temperature above 4000K. During the cathode spot formation, the high-temperature surface region expands, thus leading to intense atom sputtering.

Further, by quantitatively calculating the surface atom emission, the erosion behaviours demonstrate a three-stage pattern, characterised by an initial growth stage, a subsequent transition stage, and a final stable stage. At the stable stage, the real-time number of lost atoms and the real-time crater depth both develop at an almost stable rate. This result is attributed to the stable atom sputtering determined by the fixed ion energy and surface temperature, which is balanced at the maximum value by the cooling effects. The back ions produced by the surface-emitted atoms work as the new input, which is much greater than the leftover plasma ions serving as the initial input. The negative feedback between the surface atom emission and back ions bombarding the cathode surface results in a stable pattern of local erosion.

Conclusions

In this work, a comprehensive model of an individual cathode spot is established by the Molecular Dynamics method, with the contact erosion represented by the erosion behaviours at the central position of the cathode spot during the spot formation. The surface atom emission is concluded to be dominant by atom sputtering, which is prominent after a high-temperature region established across the local surface by the thermal effect of ion bombardment. Moreover, the simulated erosion behaviours always evolve into a stable stage due to the negative feedback of surface atom emission and back ions bombardment. The stable erosion pattern and the simulated emission rate are consistent with the experimental findings.

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Audible Noise on OHL Conductors

Xiaochen Yuan and Steven Qi Li*
Department of Electrical & Electronic Engineering,The University of Manchester
Manchester, United Kingdom
*E-mail: qi.li@manchester.ac.uk

***Abstract*-- This study studied the acoustic noise (AN) emissions from overhead lines (OHL) using cylindrical corona cage experiments conducted within a semi-anechoic chamber. Focusing on All Aluminum Alloy Conductor (AAAC) samples, tests were conducted under both dry and continuous spray conditions, with surface electric fields varied from 8 kV/cm to 30 kV/cm. Notably, the experimental results reveals distinct AN patterns between positive and negative corona discharges, with positive corona demonstrating significantly higher amplitudes compared to negative corona. Moreover, variations in AN characteristics were observed concerning voltage polarity and surface electric field levels. However, challenges persist regarding the interference of background rainfall noise in continuous spray tests, suggesting the need for further validation methods such as active noise cancellation to isolate and confirm AN features accurately.**

BACKGROUND & MAIN RESULTS

As power systems advance, overhead line (OHL) lines operate at higher voltages to meet increasing demand, raising environmental concerns about overhead line impact. Acoustic noise (AN) generated by vibrations and electrical discharge during operation of OHL poses a significant issue. This noise affects nearby residents' quality of life and disrupts wildlife and ecosystems.

This article aims to investigate the behavior and typical patterns of AN through cylindrical corona cage experiments conducted within a semi-anechoic chamber. The experiments involve recording AN emission data from OHL, particularly focusing on the chosen AAAC sample. Both dry and continuously spray tests (simulated rain condition) have been conducted, the surface electric field of the sample has been controlled and gradually increasing from 8kV/cm to 30kV/cm for dry test and from 8kV/cm to 23kV/cm for continuously spray tests by changing the applied voltage level.

The experiment set up contains spray system, corona cage, anechoic chamber, insulation supports, bushing and microphone used to record acoustic waves (time signal). The anechoic chamber was used to isolate the background noise from both inside and outside the laboratory and reduce the reflection of the AN [1], and the corona cage was used to achieve higher electric field with a lower voltage level[2].

The time signals captured from the AAAC samples, under both dry and continuous spray conditions and with both positive DC and negative DC as applied voltage, are processed through Fast Fourier Transform (FFT) processing to convert them into frequency domain signals. Subsequently, based on the processed data, the corresponding frequency spectrum is generated, which enabled detailed analysis of the AN characteristics across various frequencies. A-weighted decibels (dB(A)) was then calculated to represent the perceived loudness of sounds by the human ear. Finally, by integrating the data according to the frequency spectrum, the typical pattern curve for each scenario is derived to illustrate the AN characteristics under corresponding conditions.

By comparing the typical patterns of AAAC and A-weighted decibels in each case, it was found that under dry conditions, negative corona onset occurs at 13 kV/cm and positive corona onset occurs at 17 kV/cm, however, positive corona discharge produces AN (>60dB) has a larger amplitude than negative values (50dB). Moreover, the AN characteristics around 100Hz for the forward DC test are significantly different from those for the negative DC test. When the surface electric field is less than 24kV/cm, positive DC will produce more A-weighted decibels, while when the surface electric field is greater than 24kV/cm, negative DC will produce more A-weighted decibels.

For continuous spray conditions, both typical positive and negative DCs show similar trends. However, since the recorded time signal contains both AN from OHL and background rainfall noise, the rainfall noise may cover some features of AN in the spectrum.

CONCLUSIONS

AAAC samples' time signals underwent FFT processing to analyze AN characteristics. A-weighted decibels were calculated to represent perceived loudness. Typical pattern curves were derived to illustrate AN characteristics. The main features are summarized below:

1. Positive corona onset was later with higher AN amplitude compared to negative corona under dry conditions.
2. Positive DC produced more A-weighted decibels below 24kV/cm, while negative DC above.
3. Continuous spray conditions showed similar trends, but rainfall noise might obscure AN features.

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A Flexible Electronic Approach to Monitoring HV Cable Stresses

Ondine Watson*[1], Orestis Vryonis[1], Abiodun Komolafe[1], and Istebreq Saeedi[1]

[1]University of Southampton, SO17 1BJ

*E-mail: ow2g20@soton.ac.uk

***Abstract*—This study investigates the possibility of using flexible sensor circuit modules to monitor high voltage (HV) cable condition and partial discharge (PD) events. Using low power electronics with processing capabilities can provide high resolution, retrofittable solutions to monitoring the condition of HV cables over long distances. This approach could be utilised to monitor high risk areas such as cable joints with high accuracy and spatial resolution. The ability to pre-process data at the site of collection will also minimise the volume of data sent back to the control centre. Linking physical events such as mechanical stresses, temperature anomalies, and PD events to the condition of the cable is key to early and effective diagnosis of cable degradation.**

BACKGROUND

Monitoring the condition of HV cables is critical to ensuring reliable operation and minimising repair costs. Early detection ofphenomena such as partial discharge (PD) can allow minor faults or defects in the cable to be identified and resolved before afull breakdown occurs or the fault causes disruption to the network. An alternative approach to cable condition monitoring is proposed here, using a flexible electronic circuit to digitally record specific events. The sensors in question will monitor thermal, mechanical, and electromagnetic characteristics of the cable. This approach is advantageous as it proposes a modular, readily replaceable monitoring system with the ability to pre-process data at the site of collection.

Current approaches to cable monitoring are mainly centred around the use of distributed optical fibre sensors (DOFS) detecting temperature and stress variations through light scattering [1] over the length of a cable (typically up to 70km, due to signal attenuation [2]). However, the spatial resolution of the DOFS readings is low in comparison to that provided by discrete spot recordings, meaning that it can be challenging to pinpoint the exact location of a PD or temperature anomaly. A network of digital sensors employed in areas of high risk such as cable joints could improve the ability of a DOFS system to locate the exact location of failure.

DESIGN AND TESTING

An embedded temperature sensor circuit has been designed for the purposes of testing the accuracy of a digital sensor on a variety of flexible substrates. The data collected from the circuit will be compared to that collected via a thermocouple to determine accuracy. This temperature data will eventually be combined with a strain and a PD detector, which will allow conclusions to be drawn about the overall condition of the cable.

In order to ensure good contact between the sensor circuit and the cable, the components are placed on flexible substrates. Common applications of flexible circuit technology are e-textiles, wearable electronics and healthcare monitoring, due to their ability to conform to the human body or be woven into a fabric without constraining movement [3]. This quality also holds benefits for monitoring cables, as the flexible nature allows for sensor modules to be retrofitted to any cable, no matter the curvature. It also allows for movement in the cable due to snaking caused by thermal expansion.

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Synthetic Cable for Assessment of Marine Power Impacts (SCAMPI)

Joanna Rzempołuch*[1], George Callender[1], Paul Lewin[1], Kevin Goddard[1] and Justin Dix[2]
[1]Tony Davies High Voltage Laboratory, University of Southampton, Southampton, United Kingdom
[2]Ocean and Earth Sciences, University of Southampton, Southampton, United Kingdom
*jr9g20@soton.ac.uk

***Abstract*— A recent rise in investments in OWFs (offshore wind farms) and interconnectors brings a demand for the assessment of the environmental impacts of submarine cables. For the environmental impacts to be assessed, the exact value of electromagnetic fields produced by submarine cables must be known and an experimental setup reproducing these values needs to be constructed. Existing literature does not address this problem accurately as the magnetic field magnitudes used in experiments are often unrepresentative of real-life conditions. Additionally, there is a disproportionate emphasis on DC electromagnetic fields despite the prevalence of HVAC submarine cables used in OWFs. In this work, a device producing electromagnetic fields comparable to that of an HVAC submarine cable is constructed and tested considering its electromagnetic, thermal and acoustic aspects, and its intended utilization within a marine biology experimental context.**

Background & Main Results

According to [1], currently installed offshore renewable sources are only 7% of what is foreseen to be installed by 2050. Hence, the assessment of environmental impacts associated with renewable investments will be more increasingly in demand due to licensing needs. Given that electroception of marine organisms is a documented phenomenon [2], there exists a plausible basis for the consideration of negative impacts of electromagnetic fields on marine animals. Testing on-site or recreating the environmental conditions using an actual HVAC cable is often not feasible due to the nature of testing or capacity to produce high enough currents. Thus, an experimental setup capable of recreating the environmental conditions accurately is needed in order to perform relevant biological tests under controlled conditions.

In order to achieve this, Finite Element Analysis (FEA) models were created in COMSOL Multiphysics 6.1 software to establish the realistic values of magnetic fields produced outside the HVAC cable (approximately 2mT at the cable's surface). The prototype model was then designed with the intent to produce the magnetic fields of the same strength. 2D and 3D FEA models of the prototype were constructed until the simulations yielded in satisfactory magnetic field magnitudes. Subsequently, the final design was manufactured and assembled. The constructed device is presented in Figure 1. It consist of a 62 turn coil within a polyoxymethylene frame. The experimental setup that has been utilised so far consists of a CT (Current Transformer), a variac (variable transformer), and SCAMPI (Synthetic Cable for Assessment of Marine Power Impacts). A current of 130A is supplied to SCAMPI via the CT. Tests have been performed to assess the magnetic fields, thermal characteristics, and noise produced by the device.

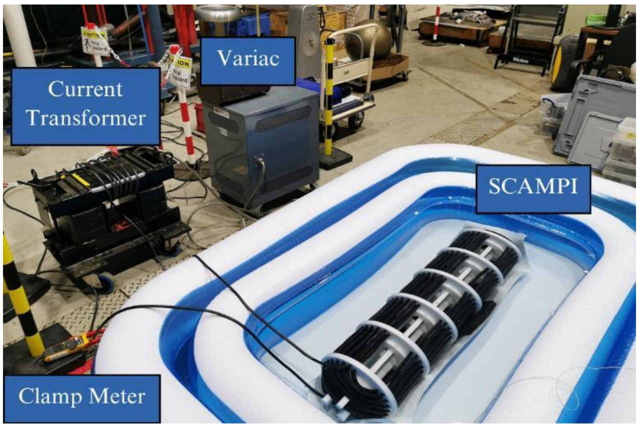

Figure 1: Experimental setup involving SCAMPI during temperature tests.

Conclusions

It has been shown that SCAMPI is capable of producing magnetic fields comparable to ones of an HVAC submarine cable. A control system used for cooling of the device in order to ensure fixed current magnitude and magnetic field will be added and methods of reproducing the device's electric field within insulated cores commonly used in experiments will be investigated.

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Influence of Sample Thickness Variation with Embedded Space Charge Layer in PEA: A Simulation Study

Ayesha Saeed*[1] and Brian Stewart[2]
[1]University of Strathclyde, ayesha.saeed@strath.ac.uk
[2]University of Strathclyde, brian.stewart.100@strath.ac.uk
*E-mail: ayesha.saeed@strath.ac.uk

Abstract-- **Rising demand of renewable energy integration in power grids and improvements in technology has driven to the use of HVDC cables in modern power systems. Moreover, development of new polymeric materials over the past few decades has led to replacement of conventional oil-based insulating materials in these cables by alternatives such as polyethylene, cross linked polyethylene (XLPE) and polypropylene etc. However, these polymeric materials are prone to accumulation of space charges in the insulating materials, affecting operational electric field and potentially causing insulation performance degradation and breakdown. Several space charge measurement techniques have been researched upon, the most widely used being pulsed electroacoustic method. Both experimental and simulation-based work has been carried into understanding the impact of various design parameters on the sensor output. This study focuses on developing a simulation tool that enhances understanding of the effect of increasing thickness of the sample with an embedded space charge layer in the middle of the sample. The research employs COMSOL Multiphysics for simulation of the PEA method. The findings indicate that considering other factors such as pulse width, pulse magnitude, electrode and piezoelectric sensor thicknesses to be constant, increasing the sample thickness affects output signal.**

Analysis of Partial Discharge for defect Identification Under DC Superimposed Harmonics

S Shahtaj*[1] and B. G. Stewart[1]
[1]University of Strathclyde, Glasgow,UK
*E-mail: Shahtaj@strath.ac.uk

Abstract-- **The durability and reliability of high voltage direct current (DC) cables are heavily influenced by the performance of their insulation materials, which can degrade due to electrical overstress factors such as the accumulation of space charges, the initiation of electrical trees, and partial discharges caused by localized defects. While partial discharge phenomena is reduced in DC cables compared to those operating at AC voltage, the presence of ripples or transients in DC voltage can increase the risk and severity of partial discharges.**

This work explores partial discharge characteristics under DC voltage and the influence of ripple components through measurements conducted on XLPE cable sample with defect. Specifically, it examines partial discharges at the inception voltage (PDIV) for DC, followed by the application of AC ripples up to 1200 Hz with an amplitude equal to 10 percent of the DC PDIV. These experiments adhere to the IEC60270 measurement standard, offering insights into the behavior of partial discharges when exposed to both DC voltage and ripples.

The phase-resolved partial discharge patterns observed at the DC inception voltage (PDIV) and various ripple levels suggest that the presence of voltage ripples can change the distribution of partial discharges, shifting from a relatively uniform spread to a concentration during the positive half-cycles of the ripples. The partial discharge measurements detailed in this study serve as a foundation for further exploring partial discharge phenomena in various defective cable samples subjected to DC voltage with realistic ripple conditions.