Thursday 17\textsuperscript{th} January

Oral session 1  10:00 – 12:00

10:00  Keynote Lecture by Mr Jack Blackett:

"High Voltage Testing Techniques – IEC Publication 60060”

10:40  Riccardo Giussani, University of Manchester, Abstract No. 27:

"RF detection of Electrical Tracking”

11:00  David J Smith, Glasgow Caledonian University, Abstract No. 8:

"A Comparison between 50Hz and Variable Frequency Measurement of Moisture Content within an OIP Bushing”

11:20  Miao Hao, University of Southampton, Abstract No. 16:

"Influence of Thermal Aged Paper on Space Charge Dynamics in Oil-paper Insulation System”

11:40  Qiang Liu, University of Manchester, Abstract No. 35:

"Oxidation Assessment of Thin Films of Environmentally Friendly Natural Ester Transformer Liquid”

Oral session 2  14:00 – 16:10

14:00  Keynote Lecture by Dr Norman MacLeod:

"Challenges Facing HVDC in the Early 21\textsuperscript{st} Century”

14:40  Short presentation by Prof. John Walker:

"Impressions of some Overseas HV Networks”

14:50  Hualong Zheng, University of Leicester, Abstract No. 13:

"Investigation of HVDC Polymeric Power Cable Reliability Using Space Charge Measurements and Computer Simulation”

15:10  Matt Praeger, University of Southampton, Abstract No. 18:

"Nano-Silica Filled Polystyrene: Correlating DC Breakdown Strength and Particle Agglomeration”

15:30  Faisal Peer-Mohamed, University of Strathclyde, Abstract No. 10:

"Generic data acquisition system with high-speed sampling and synchronized triggering for measurements in any electromagnetic environment”

15:50  Maurizio Albano, Cardiff University, Abstract No. 19:

"Artificial pollution layer application on conventional and textured silicone-rubber insulators”
A. Abubakar Mas’ud, B.G. Stewart, S.G. McMeekin and A. Nesbitt, Glasgow Caledonian University, Abstract No. 1:
“Classification of PD patterns from single void and two void arrangements in poly-ethylene-terephthalate”

A.S. Ayub, W H Siew, S.J. MacGregor, University of Strathclyde, Abstract No. 2:
“Lightning Protection System for Wind Turbine Blades – A New Approach”

A. Mohamad and G. Chen, University of Southampton, Abstract No. 3:
“Polymeric Insulation for High Voltage DC Application”

B. Sheng, C. Zhou, W. Zhou, D.M Hepburn and B. Alkali, Glasgow Caledonian University and Wuhan University, Abstract No. 4:
“A novel technique for on-line PD localisation based on PD signal propagation characteristics in HV power cable”

C. McGarvey, I.V. Timoshkin, S. MacGregor, M.P. Wilson, M.J. Given, T. Wang, University of Strathclyde, Abstract No. 5:
“Plasma closing switches filled with environmentally friendly gases: applications in pulsed power systems”

C. Chen and Z.D. Wang, The University of Manchester, Abstract No. 6:
“Application of Fluorescence Spectroscopy to Assess the Ageing of Transformer Oils”

“Modelling PD in Cavities and PD-based Degradation Mechanisms”

D. Adhikari, D.M. Hepburn and B.G. Stewart, Glasgow Caledonian University, Abstract No. 9:
“Analysis of Partial Discharge Resistances of Four Different Polymeric Insulators”

F. Hanaffi, W.H. Siew and I.V. Timoshkin, University of Strathclyde, Abstract No. 11:
“Transient analysis of grounding using Finite Element Method (FEM)”

F. Xie, A.M. Haddad, and H. Griffiths, Cardiff University, Abstract No. 12:
“Single Ended Fault location method based on Wavelet for Two Terminals Double-Circuit Transmission Lines”

J. Paterson, A.J. Shields, D.M. Hepburn, Glasgow Caledonian University, Abstract No. 14:
“Temporal Behaviour of Occluded Void Gas Pressure in Partial Discharge Degradation of Mica”

J.C. Nwobu, I.B. Efika and L. Zhang, University of Leeds, Abstract No. 15:
“Cascaded Modular Multi-level Converter using Wavelet-Energy Operator Synchronisation for High Power Applications with Unbalanced Voltages”

M. Hao, Y. Zhou, and G. Chen, University of Southampton, Abstract No. 17:
“Impedance of Space Charge Dynamics at the Interface between Oil and Impregnated Paper/Pressboard”

M.G. Hogg, I.V. Timoshkin, S. MacGregor, M. Wilson, M. Given, T. Wang, University of Strathclyde, Abstract No. 20:
“Optimisation of gas-filled plasma closing switch by investigating dielectric medium and electrode topology with corona pre-ionisation”

N.H. Aziz, M.D. Judd and V.M. Catterson, University of Strathclyde, Abstract No. 21:
“Generating PD Data from Electrical Treeing in Silicone Rubber for Insulation Lifetime Modelling”

O. El Mountassir, B.G. Stewart, S. McMeekin and A. Ahmadinia, Glasgow Caledonian University, Abstract No. 22:
“Effect of sampling rate on the location accuracy of partial discharges using RF location techniques”

M. Pattouras and S.M. Rowland, University of Manchester, Abstract No. 23:
“The effect of material interfaces on electrical tree growth and breakdown time of epoxy resin”

P. Widger, A. Haddad and H. Griffiths, Cardiff University, Abstract No. 24:
“CF3I as an alternative to SF6 in Distribution Equipment”

Q. Tang, Z.D. Wang, P. I. Anderson, A. J. Moses and P. Jarman, University of Manchester, Cardiff University and National Grid, Abstract No. 25:
“Improvements of Single Sheet Tester for Measurement of Electrical Steels Magnetic Properties at High Flux Densities”
Z. Liu, Q. Liu and Z.D. Wang, University of Manchester, Abstract No. 26:
"Streaming Electrification of Environmentally Friendly Transformer Liquids"

S.J. Tee, Q. Liu and Z.D. Wang, University of Manchester, Abstract No. 28:
"Transformer Ageing Assessment through Furanic Compound Analysis"

S. Qin, I. V. Timoshkin, M. P. Wilson, S. J. MacGregor, M. J. Given, M. Maclean, J. Anderson and T. Wang, University of Strathclyde, Abstract No. 29:
"Pulsed Electric Field Assisted Treatment of Algae for Bio-Fuel production: Modelling and Analytical Evaluation of PEF Treatment"

S.P. Phuan, J.A. Pilgrim and P.L. Lewin, University of Southampton, Abstract No. 30:
"Predictive Rating Models for Wind Farm Export Cables"

S. Christou, P.L. Lewin, J.A. Pilgrim and S.G. Swingler, University of Southampton, Abstract No. 31:
"Prognostic Indication of Power Cable Degradation"

S. Robson, A. Haddad, and H. Griffiths, Cardiff University, Abstract No. 32:
"Fault Location on Branched Distribution Networks"

L. Chen, M.S. Kamarudin, K.H. Elnaddab, A. Haddad, and H. Griffiths, Cardiff University, Abstract No. 33:
"Gas Insulated Transmission Lines Using CF3I"

W. Zhao, W.H. Siew and M.J. Given, University of Strathclyde, Abstract No. 34:
"The Electrical Performance of Thermoplastic Polymers When Used As Insulation in Cables"

X. Dong, C. Zhou, B. Sheng, P. Wallace, and B. Alkali, Glasgow Caledonian University, Abstract No. 36:
"Diagnostic Rules for Sheath Circulating Current Monitoring in Cross-bonded Three-phase HV Cables"

X. Hu and I. Cotton, University of Manchester, Abstract No. 37:
"Impact of Climate Change on Overhead Transmission Line Ratings"

Y. Jiang, A. Reid, A. Nekahi, A. Wilson and S.G. McMeekin, Glasgow Caledonian University, Abstract No. 38:
"The investigation and development of pollution monitoring for high voltage insulators"

Y. Jing, I.V. Timoshkin, M.J. Given, M.P. Wilson, S.J. MacGregor and T. Wang, University of Strathclyde, Abstract No. 39:
"Dielectric characterisation of insulating fluids for power and pulsed power applications"

Y. Liu, I.V. Timoshkin, S.J. MacGregor, M.P. Wilson, M.J. Given and T. Wang, University of Strathclyde, Abstract No. 40:
"Charging of particles in non-thermal plasmas: improvement of precipitation efficiency of fine and ultra-fine particles"

Y. Gao and Z.D. Wang, University of Manchester, Abstract No. 41:
"Assessment of IEC 60076-7 Thermal Model Exponent and Constant Parameters"

Y. Tao, W.H.Siew and J.J. Soraghan, University of Strathclyde, Abstract No. 42:
"Transient Fault Location in Low Voltage Distribution Networks"

R. Tang, J. Liggat and W. H. Siew, University of Strathclyde, Abstract No. 43:
"Partial discharge detection and recognition in PET films"
Partial discharge (PD) measurements are commonly applied in monitoring the degradation of dielectric insulation subjected to high voltage (HV) stress. One important PD defect of HV insulation system is the void. This is because of its unpredictable behaviour [1]. The number of discharges and the PD amplitude in a void can sometimes increase or decrease and in some cases even disappear. Over the years, a number of researchers have analysed PD activity within voids [2] but few have analysed voids in poly-ethylene-terephthalate (PET) [3].

HV insulation may contain more than one void at any localised position. Thus it is important to study the discharge patterns emanating from single and two void arrangements in PET and compare them to observe whether there exist variations in the PD patterns and statistics over longer degradation periods. To this end the aim of the work presented in this paper is as follows:

1. To evaluate and compare the statistical parameters of the $\phi$-$q$-$n$ (phase-amplitude-number) patterns for different single and two void arrangements within PET insulations. To achieve this, experiments were carried out and $\phi$-$q$-$n$ patterns established for the different voids (see example Figure 1) enabling statistical parameters to be captured over long test periods i.e. when the degradation of the insulation initiates. The voids considered have 0.6mm diameters.

2. To apply an ensemble neural network (ENN) to classify and capture any statistical distinctions existing among the void arrangements. The results of the ENN are compared with the widely applied single neural network (SNN).

The results demonstrate that both the ENN and SNN are capable of distinguishing between the three different void arrangements, with the ENN always providing an improved performance over the SNN.

Figure 1: Sample $\phi$-$q$-$n$ plots for a) 0.6mm single voids and b) 2 parallel voids 0.6mm dia. each.


Lightning protection systems for wind turbine blades have been adapted from the successful practice in other industries (i.e. building, aircraft) [1]. Most blade manufacturers prefer to have an internal lightning down conductor so as to preserve its aerodynamic properties. However, the blades are vulnerable to damage and burn from lightning strikes [1, and 2]. Owing to that, the authors believed that having an external lightning protection system for the blades (i.e. receptor and down conductor) is likely to reduce the risk of damage [3]. One could envisage an external lightning protection system would look similar to the one installed on a building or an aircraft. Hence, when considering an external lightning protection system (i.e. receptors and down conductor) on a wind turbine blade, some potential aspects shall be considered. These are:

A. Mechanical

- Wind flow around the turbine blade and aerodynamics properties
  A wind turbine blade is designed to produce optimum performance. Hence, preserving its aerodynamic properties is important. Therefore, having an external lightning protection system would result in protrusions on the wind turbine blade’s surface, thus potentially compromising the aerodynamic properties. The crucial question is therefore, “To what extent can this compromise be accepted?”

- System installation
  In any external system, the potential for excessive wear and tear is increased. Maintenance of external systems on aircraft and buildings is convenient but would not be an easy exercise on wind turbine blades. Hence, what would be the best method of fixing?

B. Electrical

- Extra attachment points
  As the lightning receptor is discreet in size that normally sits flushed with the surface of the blade, the presence of down conductors on the surface of the blades would provide ‘extra’ attachment points for lightning leaders to attach. Thus, a logical conclusion might be that an external system is more effective. An added question is, “Is one return (ground) conductor sufficient?”

- CFC material for the blade
  Most blades are currently manufactured using glass-fibre-reinforced-polymer (GFRP). However, with increasing size of the turbine blades, the use of carbon-fibre-composites (CFC) may increase due to its better mechanical strength. Since the CFC is partly conductive, the installation of external down conductor would reduce the risk of lightning current flowing into the blades (with CFC), and so reduce the risk of blade disintegration provided no significant current leakage is maintained. How could this be achieved?

- Radar transparency
  The presence of CFC material in the blade may interfere with radar systems. It has been reported that the image (i.e. radar signature) of offshore wind farm appears to be shadowed due to poor signal reflection [4, and 5]. Since an external protection system is considered, it is highly likely to change the radar signature. Would it provide a better signature?

Polymeric Insulation for High Voltage DC Application

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With growing interests in renewable energy, high voltage DC transmission has become a hot topic worldwide. Charge accumulation under high voltage DC is a major issue as its presence distorts the electric field, leading to premature failure. Significant reduction in DC flashover voltage has been observed by various studies and its maximum decrease may reach ~40-50% compared to AC or short-term strength [1]. We aim to chemically treat polymeric insulation and change charge transport characteristics of the material via fluorination process. In doing so, exceptional surface properties similar to fluoropolymers can be achieved without compromising the bulk characteristics of the original polymeric insulation [2]. The modifications in chemical components at the surface of polymeric insulation should in turn lead to corresponding modifications in electrical properties of the surface and suppress the charge accumulation.

Various fluorinating conditions will be experimentally investigated and the fluorinated samples will be electrically characterised and tested, so an optimal processing condition can be achieved to meet practical requirements as DC insulating material. Modelling and simulation of electric field distribution with new developed insulating material have been planned to help design an insulation spacer in high voltage DC GIS systems.

In this present paper, fluorinations of epoxy resins were carried out to suppress charge accumulation and consequently enhance flashover voltage. A surface flashover model with finger-like electrodes has been developed using COMSOL Multiphysics 3.5. Figure 1 shows the sample with electrodes arrangement geometry and the analysis region. The distance between the two electrodes is 8mm. The maximum electric field relaxation on the surface as well as inside the bulk of epoxy samples were performed for each fluorinating conditions. Identifying the influence of each fluorinating conditions on the electric field will help to determine the influence of fluorination modification on the electrical properties at the surface of polymeric insulation.

![Figure 1: Analysis model for surface flashover of fluorinated epoxy using finger electrodes and finite element meshes](image)


A novel technique for on-line PD localisation based on PD signal propagation characteristics in HV power cable

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High voltage (HV) Power cables are subject to electrical, thermal, mechanical, and environmental stresses on a constant basis when in service. These stresses, and occasionally problems resulting from inadequate installation and maintenance practices, lead to insulation degradation or defects. In many instances the deterioration leads to partial discharge (PD) which exacerbates the degradation of the insulation and shortens the cable life. PD measurement is widely recognised as a useful tool of assessing the quality of the insulation system of HV power cable. It should, however, be noted that, although on-line PD detection can reveal insulation defects, a technical breakthrough is still required to locate the site of origin of serious insulation problems before a breakdown, so that timely actions can be taken on the insulation, cables joints or terminations with defect.

A major challenge in accurately locating the source of PD activities in power cables is that PD pulses suffer from significant attenuation as they travel from their site of origin to the cable terminal where a PD monitoring system is connected. This attenuation results in detected PD signals possessing different waveforms from the original PD pulse. Identifying PD pulses, establishing the correlation between the pulse at the site of origin and that at the detection point(s), and correctly identifying the time-of-arrival for calculating location of the signal source becomes crucial. This study presents an effective PD localisation method for use in on-line cable PD monitoring system, which is based on the transfer function of characteristic parameters of PD signal propagation in power cables.

Experiments were carried out to study the relationship between the characteristic parameters of the original and detected PD pulses in cables with different lengths and with cables of various voltage ratings and physical sizes. In addition investigation was also carried out to analyse signal propagation in a cross-bonded three phase cable system. An algorithm for PD localisation, with consideration of earthing methods, cable size and lengths is then generalised. Results show that this method can give a good accuracy of PD localization.


Plasma closing switches filled with environmentally friendly gases: applications in pulsed power systems

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Sulphur hexafluoride (SF₆) has advanced dielectric properties and this gas is typically employed as a dielectric media in gas-filled plasma closing switches (PCS). However, environmental and economical reasons stimulate pulsed power research community to minimise the use of SF₆ as it is a “greenhouse” gas and the cost of SF₆ is significantly higher than the cost of dry air or nitrogen. The main aim of the proposed research programme is a search for environmentally friendly alternatives for sulphur hexafluoride used in the plasma closing switches in impulse generators. It is expected that performance of the plasma closing switch filled with alternative gases will be similar to the conventional SF₆-filled switches. The main parameters which define the switch performance include DC and triggered breakdown voltage, jitter, switch inductance and energy losses. The proposed project is focused on the study of these parameters using existing industrial plasma switch topologies including triggered PCS’s filled with environmentally friendly gases (gas mixtures). It is planned to study the performance of plasma switches filled with dry air, nitrogen or their mixtures. These experimental results will be used in the development of advanced lump-circuit model of the switch and industrial pulsed power systems. As a result of this research programme, the performance of the plasma closing switches filled with nitrogen, dry air and their mixtures will be characterised and optimised. Based on the experimental results, the model of the PCS will be developed and will be used for characterisation of the performance of different pulsed power systems.
Application of Fluorescence Spectroscopy to Assess the Ageing of Transformer Oils

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With large population of transformers in service, ageing assessment of transformer oils has become a subject of increased concern and speculation. During the ageing process of transformer oils, problems such as increased acidity and local overheating will occur. In order to avoid of final failure of the transformer, conditions of transformer must be monitored. One example of condition monitoring measures is the combination of fluorescence spectroscopy and fingerprinting which has been recently used in oil industry to assess oil conditions. This work is mainly aimed to prove whether fluorescence spectroscopy and fingerprinting method can be efficiently and reliably implemented to assess the ageing of transformer oils.

In the paper, two main methods are used to assess the ageing conditions of transformer oils. They are traditional method and optical method. Mineral oil 10 GBN is chosen to conduct ageing experiment. Optical measurements have been proved to be non-destructive, portable and cheap. In order to move from traditional indicator to the implementation of optical parameters, their reliability and efficiency need to be identified. Therefore, fluorescence spectrums of oil samples with different ageing status are measured. Then Principal Component Analysis (PCA) method is applied to find the correlation between the spectrum responses and ageing status of transformer oils.

IEC 60422 standard specifies acidity is a good ageing indicator of transformer oil. This parameter has been used for a long time and this acidity quantity is an important indicator in asset management. So, acidity of transformer oil is selected as a traditional indicator. Then acidities of transformer oils undergoing different ageing status are measured and the correlation between acidity and ageing status of transformer oils is used as a benchmark for optical measurements. The correlation between acidity and optical parameters is subsequently determined.

![Figure 1. PCA mapping for 10 GBN oils.](image)


Modelling PD in Cavities and PD-based Degradation Mechanisms

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Micro cavities are considered to be unavoidable during manufacturing processes of polymeric insulation materials. Partial discharge initiated by micro cavities can induce various levels of damage and degradation, sometimes leading to global breakdown. Thus, developing an understanding of PD activities in such cavities and damage caused is essential. This project commenced in May 2012 and contains experimental validation and development of simulation models. The focus is on PD activities in micro cavities, damage and degradation resulted, and final breakdown mechanisms. Experimental work aims to observe degradation process by stressing five identical samples simultaneously until one fails, so that the different levels of degradation of the other samples that have yet to suffer catastrophic breakdown can be studied. Different insulation materials will be involved, such as epoxy resin, LDPE, and XLPE. Moreover, three types of methods are used to create cavities inside the samples, including the traditional sandwich structure, syringe injection, and use of a foaming agent.

Predicted experimental results are the initiation and growth conditions of degradation and final breakdown mechanisms. Among all mechanisms, thermal ageing and breakdown, pitting, and treeing are the major interests of this work. The experimental results will be simulated, based on some existing models and theories, the major ones are Niemeyer’s PD model, and its Matlab version by Illias that uses COMSOL for field simulation [1]; Sanche’s hot electron theory [2], and its Matlab version by Testa to analyse energy and speed spectrums of PD avalanches and the resultant damage caused [3]. Please note that throughout the experiments, PD data will be recorded to study possible relationships between PD pattern and degradation status, as well as to prove that the experimental method is valid against multiple sample data superposition and interaction. A typical superposition of five samples as below:

![PD pattern superposition of five identical samples](image)

To conclude, this project aims to provide more complete knowledge for PD and related degradation process, by distinguishing the major damage type, identifying the conditions for it to initiate and grow in different insulating materials, and providing simulation models as a conclusion of experimental results and theories.


A Comparison between 50Hz and Variable Frequency Measurement of Moisture Content within an OIP Bushing

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The ingress of moisture within a power transformer oil impregnated paper (OIP) bushing condenser can significantly reduce its life expectancy and is the most common cause of failure. Moisture can enter the component through the deterioration of seals and fittings, and typically settles and ingresses the lower condenser region [1] [2], as shown in Figure 1(a). Due to the orientation of the condenser grading foils, moisture diffuses axially into the bushing insulation. It is typical for 10% to 15% of the condenser bulk volume to be affected by wet regions [2], as shown in Figure 1(b).

Moisture content is normally evaluated by comparing the changes in measured dissipation factor and capacitance at 50Hz to limits specified by the manufacturer. However, the distinction between moisture contents at 50Hz can be difficult, particularly at ambient temperature. Dielectric frequency response (DFR) measurements of dissipation factor and capacitance can provide an improved distinction between moisture contents at lower frequencies, where only a single temperature measurement is needed. Currently, DFR models are focused on power transformers but these models are not suitable for bushings, due to the differences in geometry.

This work presents the modelled DFR dissipation factor results of a bushing with varying uniform and localised moisture contents. It is shown that there is little distinction in dissipation factor up to 1.0% moisture content at 50Hz, and only a clear distinction becomes apparent for moisture contents greater than 2.0%. However, an improved distinction in dissipation factor between moisture contents occurs at lower frequencies using the DFR technique. Overall, a localised wet region DFR response has a much steeper gradient than the uniform distribution at lower frequencies, and this characteristic may be used to identify such regions.

Figure 1: OIP Bushing. (a) Lower region where arrows indicate moisture ingress, (b) Condenser system.


Analysis of Partial Discharge Resistances of Four Different Polymeric Insulators

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Polymeric insulating materials with excellent electrical properties are widely used in electrical power equipments. These materials are degraded however when they are subjected to partial discharge (PD) with different polymeric materials possessing different levels of PD resistance. PD occurs within the gases trapped inside the microscopic voids in polymeric insulation when the electric field exceeds a threshold value and leads to degradation of the void surfaces. In this paper the PD characteristics and degradation caused by PD are analysed and compared for four different polymers – poly(ether sulphone) (PES), poly(ethylene terephthalate) (PET), poly(propylene) (PP) and low density poly(ethylene) (LDPE). An artificial void is created in each of the polymer samples and the samples are electrically stressed 10% above PD inception voltage (PDIV) for four hours.

Little work has correlated void PD characteristics with material degradation induced by PD across a range of different polymers and subsequently categorized them according to their PD resistances. This paper therefore presents a comparative study of the n-q patterns of PD pulses (a plot of the number of discharges against the measure of apparent charge), PD repetition rate, the total charge injection inside the void and the chemical and morphological changes occurring on the void surfaces for each type of polymer. The results show that the PD resistance of these four polymers can be categorized in a decreasing order according to the following sequence: LDPE, PP, PET and PES with LDPE being most resistant to PD and PES the least resistant.

Figure 1. Typical n-q plot of PD in +ve cycle for PES, PET, PP and LDPE after 2 hours

Generic data acquisition system with high-speed sampling and synchronized triggering for measurements in any electromagnetic environment

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Condition monitoring provides the early warning of potential failures thus enabling the development of preventive maintenance strategies to minimize the risk of failure. In general any monitoring systems needs to capture the necessary signals associated with the application. One of the reasons for capturing such signals is to analyze and hence achieve a better understanding of the underlying physical phenomena. In most cases, these signals originate as physical or sensory data from the real world and include signals such as biological signals, vibration signals, speech signals, seismic signals, signals from electrical systems, and others. The parameters used to characterize those signals are normally signal frequency and signal power. Hence there would be a requirement to identify the relevant equipment to capture the signals of interest based on the signal characteristics. This needs technical skills and also this approach may not provide a cost effective solution. Hence there is a clear requirement to have a data acquisition system which is capable of acquiring data irrespective of the area of application. In this paper, generic data acquisition system with 80 MHz bandwidth is proposed. Time synchronization functionality in this system, using zigbee or GPS, can be used for accurate distributed measurements[1]. Photograph of the prototype is shown in figure 1.

1. GPS Antennae  
2. GPS Receiver  
3. USB interface  
4. Power supply board  
5. Mother board  
6. Analogue input

Figure 1. System prototype

The implementation of variable frequency and gain/attenuation control makes this system self adaptable for various applications. Based on the results from laboratory and field trials for transient and PD source location in cables, the system can also work in harsh electromagnetic environment including indoor and outdoor applications and also higher measurement accuracy is achieved. Further advantages include portability and low cost.

Transient analysis of grounding using Finite Element Method (FEM)

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Grounding systems play important role in order to protect life or facilities from any fault and transients in power system. The main purpose of a grounding system is to provide the lowest impedance path for transient current (especially lightning current) that exhibits high current magnitude and high frequency spectrum. Previous research shows that grounding systems behave differently when a transient current flows through the grounding conductor. Modelling of a grounding system when subjected to a transient current is important as accurate modelling will allow better protection for human beings and electronic equipment. Various approaches have been undertaken by other researchers to model a grounding system and to simulate its transient response. These include as the transmission line approach, electromagnetic analyses, and hybrids. In [1], solution of the exact Maxwell equations is demonstrated and compared with quasi static approximation. The comparisons show that it is important to consider displacement current in high frequency simulations to get more accurate modelling. Accurate modelling is important in order to optimize grounding grid designs which have limited guide and references incorporating transient excitation. The main objective of this project is to improve grounding grid design for better protection of human and equipment in various conditions, including in particular the consideration of transient excitations. In this paper, Ampere’s law with displacement current as shown in equation (1) is proposed as the governing equation for solving the grounding behaviour of a substation grid under an impulse current. In order to implement the governing equation, Comsol Multiphysic which is based on Finite Element Method (FEM) is used in this modelling. Comsol Multiphysic is choose because the simulations can be done in time domain with full 3D model for the soil and grounding conductor. First step is to validate the use of the governing equation by comparing with published results. Comparable results are obtained using validation data from [2] which is based on a single horizontal wire. Work is continuing and it is hoped that more results would be available during the event when we increase the complexity of the grounding grid.

\[
\nabla \times \frac{1}{\mu_r} (\nabla \times A) + \sigma \mu_0 \frac{\partial A}{\partial t} + \mu_0 \frac{\partial}{\partial t} (\varepsilon_r \varepsilon_{r_e} \frac{\partial A}{\partial t}) = 0
\]


Single Ended Fault location method based on Wavelet for Two Terminals Double-Circuit Transmission Lines

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Fault detection and location in long distance transmission systems requires high accuracy and fast reaction. The presently used fault detection methods include: impedance based measurements [1,2] and the travelling wave based method [3,4]. Within the Wavelet Transform (WT), time and frequency information can be measured simultaneously. This eases the detection of high-frequency transients generated by faults on transmission lines.

Therefore, this paper presents a new single-ended fault location method using wavelet transform to capture the fault generated transients and locating the fault point. The proposed method uses the difference of travelling wave arrival time at one terminal to accurately locate the fault point. The adoption of discrete wavelet transform (DWT) on reverse travelling waves reflected from another terminal can easily be distinguished from the transients reflected from the fault point. The algorithm proposed in this paper to locate the fault with signals sampled from terminal SEND is:

\[
L_{\text{fault}} = L - \frac{(t_2 - t_1) \times C_0}{2}
\]

Where \(L_{\text{fault}}\) is the distance between terminal SEND and fault point, \(L\) is the total length from terminal SEND to terminal RECEIVE, \((t_2 - t_1)\) is the time difference between the arrival of voltage/current waves directly from fault point and \(C_0\) is the speed of light.

In order to develop the method based on wavelet theory, a single line to ground fault is simulated on a 400 kV transmission line model, which was built based on the National Grid datasheet [5], using ATP/EMTP. The so computed terminal signals are further analysed in Matlab. The Detail Coefficients of terminal signals in a third level wavelet decomposition, as shown in Figure 1(b), are used to measure the fault location. Impacts of transformers and substations on the accuracy of this algorithm are also discussed in this paper. The proposed fault location method permits high accuracy to determine the fault position.

![Figure 1](image-url)

Figure 1. (a) The ATP/EMTP computed current signals measured from terminal S; (b) The Matlab measured Detail Coefficients in a third level wavelet decomposition.

Investigation of HVDC Polymeric Power Cable Reliability Using Space Charge Measurements and Computer Simulation

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The reliability of HVDC polymeric cables is widely believed to be related to the presence of space charge\(^{(1)}\). To investigate the space charge behaviour of polymeric materials (PE, XLPE) used for HVDC cable insulation, a space charge measurement system based on PEA (Pulsed electro-acoustic) method has been developed for measuring small-size model cable (or mini-cable) samples. This system allows high temperature measurements up to 80°C by using a piezoelectric sensor made from poly[(vinylidene fluoride-co-trifluoroethylene)] [P(VDF-TrFE)], which exhibits enhanced stability of the piezoelectric constant at high temperature. Clamping force applied onto mini-cable samples is reproducibly controlled up to 2000N during the temperature range. A purpose designed pulse generator is able to produce pulses with a width of 20ns and magnitude up to 2kV. Using this system, space charge behaviour of several cable systems (different combination of insulation and semiconducting layers) will be studied over a temperature range of 20-80°C and electric stress up to 50kV/mm. PEA signals are analysed to correct for instrument response and acoustic attenuation and dispersion. Software has also being developed to determine electric field distribution inside the mini-cable. The design specifications and preliminary observations of space charge in mini-cables will be described.

Computer simulation models have been developed in parallel based on bipolar charge transport models in literature \(^{(2)}\). By fitting with experimental results, simulation models are aimed at addressing the key parameters influencing the space charge behaviour.

\[1\] YEWEN, Z., LEWINER, J., ALQUIE, C. & HAMPTON, N. "Evidence of strong correlation between space-charge buildup and breakdown in cable insulation. Dielectrics and Electrical Insulation", IEEE Transactions on Dielectrics and Electrical Insulation, 3, 778-783


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Aging tests aimed at the development of defect based life models were performed on mica layered specimens with artificial voids. Aging models of this type require an understanding of gas and cavity interaction dynamics in order to reproduce as closely as possible the degradation processes occurring in service insulation. The majority of work carried out in this area has investigated discharges in voids in polymeric insulation [1-3]. It is known that partial discharge (PD) changes void gas composition and alters the cavity surface environment, i.e. changes in surface chemistry, conductivity and roughness are observable. The gas in a void (usually assumed to be air) participates in chemical combination with void interface materials in short time scales. Reactive species such as ozone, oxygen ions and oxygen atoms are produced by the following process:

\[
e + O_2 \rightarrow O_2 + hv
\]
\[
e + O_2 \rightarrow O^- + O^+ + e
\]
\[
e + O_2 \rightarrow O^- + O
\]
\[
O^- + O_2 \rightarrow O_3 + e
\]

In this work, the behaviour of void gas enclosed by mica was recorded by means of a small glass capillary tube with a silicone oil plug, see figure 1. The aging test was stopped briefly at regular intervals and the displacement of the oil plug measured. Previous work, using Atomic Force Microscopy (AFM) and Energy Dispersive X-ray analysis (EDAX) imaging of occluded voids in mica which had been PD stressed for one hour, showed no observable surface features or change in chemical composition when compared to unstressed mica.

Oxygen present in PD stressed voids is believed to be steadily converted to gaseous by products such as CO$_2$ and CO, from reactions in air or at the cavity surface. Experimental results in this work, where void pressure remains constant, show a 16.51% reduction in occluded void gas volume after 15 minutes of HV AC application. The time behaviour of the void gas volume reported in percentage of the value prior to voltage application is given in figure 2. As it is expected that variation in void gas parameters, such as pressure and composition, will influence discharge repetition rate, amplitude and discharge pattern this information and future work can provide input into degradation studies. Consideration of this will be presented.

References
Abstract

Conventional two-level converters synthesize an output by connecting two switches to the $V_{DC}$ rail at a high switching frequency in order to produce an acceptable output. The associated voltage stress and switching loss per device, makes them unsuitable for medium to high voltage applications (FACTs and interfacing renewable sources).

This paper presents a cascaded modular multilevel (CMMC) converter structure, specifically the cascaded floating capacitor modular multilevel converter (CFC-MMC) which has the ability to operate at a lower device switching frequency and is easily extended to higher voltage levels. The basic unit in this structure is a module, which consists of a 5-level full bridge FC [1]. Depending on power rating (or number of voltage levels) required, modules are cascaded (series-connected) to form a single phase or three single phases are connected to form a three-phase structure. Fig. 1(a), shows the output from a simulated 6-module (i.e 2 modules-per-phase) configuration with nine voltage levels. Also, the structure of the CFC-MMC module presents other redundant topology configurations as it can be reconfigured to the hybrid FC of conventional h-bridge and this increases the reliability of the converter. A wavelet-energy operator synchronisation technique is also introduced with the ability to handle each phase of the converter as a single phase which is important when dealing with amplitude based grid unbalances.

Wavelet transforms are shown to have good phase tracking property [2] in power signal processing. An online lifting wavelet transform is used to extract unwanted voltage harmonics in the system and energy operator [3] to extract the positive sequence and estimate the amplitude and the phase angle used for synchronisation to the CFC-MMC structure. The energy operator overcomes the issue (ability to on-line measure the changes in amplitude) seen by both basic and conventional synchronisation methods under abnormal grid conditions. One unique characteristic is that the synchronisation signals of each phase of the grid voltage can be generated through this scheme. The wavelet transform enhances this scheme allowing synchronisation with unbalanced voltages and harmonics (Fig. 1b).

Fig. 1. Schematic showing control blocks of the CFC-MMC structure and wavelet synchronisation scheme


Influence of Thermal Aged Paper on Space Charge Dynamics in Oil-paper Insulation System

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As the main insulation used in HVDC convertor transformers, oil-paper insulation system should withstand not only AC voltage, lightning impulse and switching surge, but also DC stress and polarity reversal [1]. One of the major issues associated with HVDC is the easy accumulation of space charge. Therefore, it is important to investigate and understand the factors that affect the formation of space charge in the oil-paper insulation system [2]. In this study, the Kraft papers are dried and thermally aged at 150 °C for 0 day, 5 days and 15 days. Then, they are separately impregnated with fresh oil, and aged oil for comparison. The effects of thermally aged papers on space charge dynamics in the oil-paper insulation system are investigated by the pulsed electroacoustic (PEA) technique under different DC electric fields at room temperature. The properties of the fresh and aged oil are also characterised by the ultraviolet/visible (UV/Vis) spectrum. The results of space charge behaviour in the oil-paper insulation system indicate that the more deterioration of paper and the higher applied stress, the more homo-charges inject from the electrodes, and the more space charge accumulated in the dielectric bulk. However, compared with different oil properties, the impact of aged paper is generally not significant on charge accumulation. Remarkable negative charges are injected and accumulated in the sample with aged oil. And the results of decay tests indicate these negative charges are mainly fast charges due to the large conductivity of the aged oil.

Figure 1 Total charge amount in 1kV (left) and 2kV (right) volts-off

Dielectric properties of oil-paper/pressboard insulation systems play an important role in the reliability of HVDC converter transformers [1]. It has been demonstrated that the interface between dielectrics as well as electrode/dielectric behaves as a barrier to accumulate space charge significantly [2,3]. It is, therefore, necessary to investigate space charge dynamics at the interface between oil and impregnated paper/pressboard, especially under combined AC and DC voltages and polarity reversal. In the present study, a purposed-built PEA system is established to measure space charge not only within the impregnated paper/pressboard bulk, but also at the interface between impregnated paper/pressboard and oil. A 15mm thick aluminium plate is used as ground electrode, and acts as oil container with 5mm in depth. Brass films with different thicknesses are applied to provide oil gaps between the upper electrode and the impregnated paper/pressboard sample. The output signal is enhanced by using a 40µm PVDF sensor and a high voltage pulse generator. The dried papers with 500µm in thickness are separately impregnated in fresh oil and aged oil as comparison. And the thickness of the oil gap is about 300µm. The results show that space charge is injected and accumulated at the interface between oil and impregnated paper under the DC voltage application of 20kV. The peak of the interfacial charges is increasing with the duration of stressing time. Moreover, more charges are injected and accumulated at the interface between aged oil and impregnated pressboard than fresh oil and impregnated pressboard in 30 minutes.

Figure 1 Oscilloscope output of space charge in fresh oil sample (left) and aged oil sample (right) under 20kV

Nano-Silica Filled Polystyrene: Correlating DC Breakdown Strength and Particle Agglomeration.

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In the field of polymer dielectrics nano-fillers have attracted a great deal of academic interest since they potentially allow significant modifications of material properties to be made. Despite the high levels of interest, no clear picture has yet emerged because results in the literature show considerable variability. Difficulties in achieving highly uniform nano-filler dispersal are perhaps the main driving force for this variability and have also hampered the adoption of nano-fillers for industrial scale applications. In this work we correlate the results from two analysis techniques in order to deepen our understanding of the action of nano-fillers in polymer dielectrics.

Nano-composites were produced with filler fractions ranging from 0 – 10 %. The filler is composed of fused silica particles with a typical size of 20 nm and the matrix material is polystyrene. Polystyrene was chosen because its amorphous matrix provides a relatively simple and uniform background on which to study the action of the nano-particles. Alternative polymers which may crystallise or exhibit lamella type structures add additional layers of complexity to the study which could obscure the effect of the nano-particles.

Firstly, we show the DC breakdown strength of the composites as a function of filler fraction. Secondly, samples undergo permanganic etching and are then imaged by a Scanning Electron Microscope. The SEM images of the etched surfaces reveal, as a function of filler fraction, the degree of agglomeration that has occurred. Combining these two data sets brings new insight to the action of the nano-filler within our model system as it allows the DC breakdown strength results to be interpreted in light of the agglomeration data.
Artificial pollution tests in clean-fog chamber for ceramic insulators are described in IEC 60507 [1]. In these tests a pollution layer is applied to the test sample using a contaminating suspension. For sites in polluted environments, IEC 60815 [2] describes a technique for measurement of salt deposit density (SDD) and non-soluble deposit density (NSDD) deposition on the insulator surfaces. Adopting modified Standards’ procedure, several tests were carried out in order to apply and measure the SDD ad NSDD layer for artificial pollution tests on silicone-rubber insulators. Rectangular silicone rubber samples and full insulators with plane surface and with textured patterns [3] were polluted according to a modified version of IEC 60507 solid layer method. The contaminating suspension consisted of kaolin, tap water, wetting agent Triton X-100 and a suitable amount of sodium chloride to achieve a volume conductivity range from 2.9 to 20.0 S/m. The SDD and the NSDD were evaluated for each sample. A first correspondence between suspension pollution conductivity and salt deposit density has been determined for the rectangular samples. The salt deposit density versus pollution suspension conductivity for all rectangular samples for the pollution range 4 to 20 S/m is shown in Figure 1. Despite of the presence of the dimples on textured surface could suggest increased deposition, the SDD is higher on sample with plain surface. Conventional and textured full insulators were evaluated in a second series of tests. In particular, the SDD values measured on the selected areas of the insulator: trunk, top shed, under shed, top and lower trunks. These measurements permitted to verify the uniformity of the pollution layer over the entire insulator surface and a detailed comparison between the different designs. A second correspondence between suspension pollution conductivity and salt deposit density has been finally obtained for the full insulators.

Figure 1 Salt deposit density versus pollution suspension conductivity for silicone-rubber rectangular samples; values for conventional and textured surface samples in red and in green respectively.

[1] IEC 60507: 1991: “Artificial pollution tests on high-voltage insulators to be used on a.c. systems” (currently under revision).
Optimisation of gas-filled plasma closing switch by investigating dielectric medium and electrode topology with corona pre-ionisation

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Gas-filled spark gaps are used in the pulsed power systems for generation of high voltage impulses (plasma closing switches) and the power industry for protection of equipment from transient over voltage (surge protectors). Traditional insulating gases for switching sulphur hexafluoride (SF$_6$) is a greenhouse gas posing significant threat to the environment. Therefore, there is a requirement for switches which operate with environmentally friendly gases such as dry air, nitrogen and nitrogen/oxygen mixtures.

This research is aimed at developing a compact gas-filled plasma closing switch with environmentally friendly gases (dry air, nitrogen and nitrogen/oxygen mixture) and low pressure (0, 0.5 and 1 bar gauge). The DC self-breakdown voltage spread was investigated with respect to 3 different topologies (sphere-sphere, plane-plane and cone-plane) with and without corona pre-ionisation.

Corona pre-ionisation has been shown to work in SF$_6$ [1] and in dry air [2]. This work shows that the use of corona pre-ionisation can be used to reduce the self-breakdown voltage spread in plasma switches and investigates the effectiveness in different gases. Figure 1 shows normalised histograms for a sphere-sphere topology in atmospheric pressure dry air (1.5%rh) without (a) and with (b) corona pre-ionisation.

Figure 1: Normalised histograms for atmospheric pressure dry air with negatively energized sphere-sphere topology. (a) without corona pre-ionisation (b) with corona pre-ionisation.

Abstract No. 21

Generating PD Data from Electrical Treeing in Silicone Rubber for Insulation Lifetime Modelling

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Electrical treeing is a degradation phenomenon in solid dielectric material resulting from high and non-uniform electrical field or partial discharges (PD). The presence of electrical treeing, therefore, can be examined through PD monitoring by looking for characteristic features within the phase-resolved plot of PD data. As electrical trees evolve in time, time-resolved analysis of PD data may be more descriptive of the correspondence between discharges and tree propagation [1]. Continuing partial discharges in electrical treeing may lead to catastrophic failure, but there is still a lack of understanding of the evolution of PD characteristics prior to breakdown. This paper focuses on a method of simplifying the production and growth of electrical trees in silicone rubber (SiR), an advanced insulating material that is widely used in high voltage cable accessories due to its excellent insulation and mechanical performance. Commercially available pre-formed samples of SiR are used to ensure consistency and eliminate the need for the mixing, degassing and heating process in sample preparation [2][3]. The experimental methodology is described, in terms of sample preparation, applied voltage regime, and data capture. A constant 50 Hz AC voltage is applied to the samples (with a needle-plane test arrangement using hypodermic needles) at a level sufficient to induce PD, leading to breakdown within hours. Both IEC60270 electrical method and radio frequency (RF) sensors are used to capture PD data, while a digital microscope is used for visual observation. The paper describes the features found within the PD phase-resolved plot, and evaluates the similarities and differences between the two measurement techniques. Future work aims to automatically detect those features corresponding to electrical tree growth, and give a lifetime prediction for the insulation samples being studied.


Effect of sampling rate on the location accuracy of partial discharges using RF location techniques

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To date many experimental studies have succeeded in determining the location of partial discharges (PD) in 3 dimensions using the time-difference-of-arrival (TDOA) technique and triangulation algorithms [1-2]. Key problems encountered when investigating RF location methods relate mainly to signal noise and the ability of processing algorithms to determine the TDOA accurately and therefore the PD location. Some studies [3] have highlighted the importance of increasing the sampling rate of the oscilloscope used to acquire RF signals from an electrical PD source and how this by default will improve the location accuracy performance. But few studies have investigated and quantified the influence of sampling rate on the RF detected PD position for different types of PD energy level and frequency content signals, particularly in relation to how increased sampling will affect the actual location accuracy.

This paper presents an evaluation of the effect of three different sampling rates (1GS/s, 5GS/s and 10GS/s) on the location accuracy for two different PD, (i) a low energy, low frequency content, point-to-plane air corona discharge, and (ii) a higher energy, high frequency content, artificially created discharge produced through an avalanche generator (AG). The study was carried out using both cross correlation and thresholding algorithms to determine the arrival times for both PD sources for the different sampling rates e.g. (Fig. 1). The location process was carried out using a custom “Y shaped” arrangement of 4 receiving antennas and the standard least squares (SLS) iterative algorithm.

In the case of corona discharges, results show that increasing the sampling rate improved the located PD position when using the cross correlation algorithm to determine the time-of-arrival whereas when using the thresholding algorithm the located PD position was found to be improved at a lower sampling rate. In the case of the AG source, where the SNR is of good quality, at all three sampling rates the detected PDs were within a close range of the source when using thresholding and better accuracy was only found at higher sampling rates when using cross correlation. In summary it has been shown that the SNR, the frequency content and the TDOA estimation algorithm itself should all be considered when selecting a sampling rate for a given PD location.

The effect of material interfaces on electrical tree growth and breakdown time of epoxy resin

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Dielectric reliability has been a very popular discussion/research topic amongst the dielectric and insulation community. As such, the means to minimize the failures and extend the lifetime of dielectric materials used with HV equipment are continuously being investigated. Even though failure can occur anywhere in the dielectric due to manufacturing imperfections such as voids and contaminants or even cracks, most of the faults occur at the joints or interfaces. For this reason, an investigation of how interfaces affect the electrical tree growth and breakdown time/strength of model epoxy resin systems is being carried out. More specifically, this will test whether interface positioning, thickness and/or composition has any effect towards the polymer’s lifetime. Long term electrical breakdown testing is reported. Details of new sample fabrication techniques are described, and data on tree length growth characteristics are discussed.

This project is funded by EPSRC and is a part of the HubNet Consortium with its focus being the research on how new materials be used to design power equipments that are more efficient and more compact.
Abstract No. 24

CF₃I as an alternative to SF₆ in Distribution Equipment

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SF₆, commonly known as sulphur hexafluoride, is an insulating medium that is employed throughout the UK distribution network in applications such as Gas Insulated Switchgear (GIS), circuit breakers, switch disconnectors and ring main units (RMU’s) at high and medium voltages. This is due to the high dielectric strength and interruption performance of SF₆.

SF₆ is of rising environmental concern and has been placed on the Kyoto list of substances of which the use and emission of said substances should be minimized. SF₆ gas has a very high global warming potential (GWP) of around 23,900 times that of CO₂ [1] and is also an efficient infrared (IR) absorber. Due to the chemical inertness of SF₆ it is not readily removed from the earth’s atmosphere and is also regarded to have an atmospheric lifetime of around 3,200 years (estimated) making SF₆ a significant contributor towards global warming [2].

SF₆ is currently banned in all applications where alternatives are available, however, a viable alternative is not available for high voltage (HV) and medium voltage (MV) switchgear in the electrical industry.

New research suggests that the gas CF₃I (Trifluoro-iodo-methane) may form a suitable viable alternative to SF₆, for applications in gas insulated switchgear. This is because it has a higher dielectric strength than SF₆ under a uniform electric field, a low GWP of less than 1.2 compared with the aforementioned 23,900 of SF₆ and has an extremely low environmental impact. Initial characterization of CF₃I when used as an alternative insulation medium has revealed weaknesses such as its limited current handling capabilities, lower dielectric strength under a non-uniform electric field than that of SF₆ and a high boiling point. It is hoped that mixtures of CF₃I with CO₂ will help overcome these inherent issues.

Research is focused upon initial evaluation of CF₃I and pressure-pressure mixtures of CF₃I-CO₂ in MV switch disconnectors, testing the equipment up to and above its rated lightning impulse withstand voltage to give an assessment of its usefulness and viability as an alternative insulating medium.

Improvements of Single Sheet Tester for Measurement of Electrical Steels Magnetic Properties at High Flux Densities

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In a power transformer, the electrical steel core serves as a low reluctance path for the main magnetic flux linking primary and secondary windings, which is made from the stacked laminations stamped out of electrical steel sheets. The knowledge of electrical steels magnetic properties is therefore essential to design an efficient and reliable transformer.

Normally, power transformers are predominantly operated within the linear portion of the core steel magnetization curve. However, more challenges do exist for very high flux densities scenarios in the transformer cores, resulting from geomagnetically induced currents (GIC) and the overvoltage in quadrature boosters (QB) \cite{1}, \cite{2}. For instance, substantial core power losses are produced at high flux densities. The consequent core overheating will then lead to thermal degradation of the surrounding insulation, and even transformer failure. We thus inevitably need the magnetic properties of electrical steels at high flux densities to study the transformer deep saturation scenarios.

The characteristics of electrical steels in deep saturation obtained from measurements are not readily available now, and the current IEC standards for electrical steels measurements are not applicable above 1.8 T either \cite{3}. Under such a background, an improved single sheet tester (SST) with modern flux waveform control technique is proposed here, which eliminates the errors caused by the air flux and the magnetic field strength calculation. The magnetic properties measurement results up to theoretical saturation limit (around 2 T) of cold-grain-oriented (CGO) steel and high-permeability-grain-oriented (HGO) steel are also reported.

![Fig. 1. Improved SST for electrical steels magnetic properties measurements up to high flux densities.](image)


Abstract No. 26

Streaming Electrification of Environmentally Friendly Transformer Liquids

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In oil-filled power transformers the insulating liquid is forced to circulate between the transformer tank and the external cooler to enable heat dissipation. The flow of the insulating liquid could lead to the occurrence of streaming electrification phenomenon at the liquid-solid interface. This phenomenon has been extensively investigated over the past decades, since it is identified as one of the causes of transformer failures [1].

Ester liquids are becoming increasingly popular in recent years due to their superior biodegradability and better guarantee of fire safety. Their physical, chemical, electrical and thermal properties have been widely investigated by worldwide researchers; however, very little research effort has focused on the streaming electrification phenomena in ester liquids. To provide more information on the application of esters, this research investigates the dependence of the streaming currents caused by the electrification at ester-pressboard interfaces on rotational speed and temperature using the rotating disc method.

A synthetic ester liquid and a natural ester liquid were used to constitute the transformer liquid-pressboard interfaces. The rotating disc system built up in the laboratory enables precise control of rotational speed and oil temperature. This paper presents the measurements of the streaming currents generated at rotational speeds ranging from 100 rpm to 600 rpm and at temperatures ranging from 20°C to 80°C. The results indicate that increased rotational speed and oil temperature can lead to enhanced streaming electrification.

![Figure 1. Streaming currents generated at the synthetic ester-pressboard interface at different temperatures](image)

RF detection of Electrical Tracking

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The drive to miniaturize electric systems while coping with the increasing demand for power and the increase of the voltages at which they operate to supply this need, puts a new level of stress onto the insulation systems they employ. Consequently all these systems are more and more affected by all sorts of electrical discharges as partial discharges (PD) and electrical tracking discharges (ET).

Electrical tracking is a degenerative phenomenon described by the IEC as: “progressive degradation of the surface of a solid insulating material by local discharges to form conducting or partially conducting paths” a path that allows the flow of a fault current which reduces drastically the lifetime of any insulator at any voltages either in wet or dry conditions. Consequently the reliability of the electric system is compromised.

Partial discharge is a well know phenomena and lots of techniques have been developed and employed to monitor its presence in a wide variety of systems. One of these techniques is the detection and monitoring of PD through radiofrequencies detection (RF). This experimental work shows how with the same technology (methodology and hardware) it is possible to monitor and detect also the presence of ET in electric systems.

A test rig to evaluate the capability of RF techniques for detecting ET has been developed in-house in an electromagnetic noise free environment. The system is composed of two main parts; a tracking rig built according to IEC60587 and a measurement system equipped with two sensors: a current transformer to detect the leakage current, a monopole antenna (bandwidth 25-2000MHz).

Samples of hygroscopic and hydroscopic materials have been tested and the results show that the detection system is able to monitor both PD and ET. Furthermore the RF signals detected during the evolution of the ET phenomena have been analysed and evidence of how the emissions change reported.

![Figure Evolution of the electrical tracking phenomena.](image)

References

The state of solid insulating paper is crucial as its failure ultimately means the end of transformer life. As paper ages, furanic compounds or furans are generated. Owing to the intrusive nature of obtaining paper samples for monitoring their mechanical strength, presence of furans that are soluble in oil has enabled the use of non-invasive furanic compound analysis in evaluating solid insulation ageing and hence the estimation of residual transformer life. Notwithstanding its prevalent use, the accuracy of furanic compound analysis is still a subject of constant debate and research. Apart from the difficulty of associating furans to degree of polymerisation (DP) of paper, the trend of furans with age is affected by a number of factors, such as temperature, moisture, oxygen, oil maintenance and transformer designs. The presence of these elements complicates interpretation of furans detected in oil.

As a way to minimize the influence that each factor has on furanic concentration, population or database analysis can be done to acquire general or normal ageing furanic trends. In this paper, population analysis was performed on 132/33 kV distribution transformers furanic database. The resulting general furanic trend has a decreasing portion after mid-ageing period. This furanic drop appears to be counter-intuitive as paper ages, more furans will be generated and hence more furans should be detected in oil. Nonetheless, the drop in furanic concentration could be attributed to the evaporation of furans, migration of furans back into paper or degradation of furans due to high oil acidity.

After identifying the furanic trend and elucidating the drop in furanic concentration in oil after mid-ageing period, furanic trend was mathematically modelled. Peak furanic value can be selected as a reference point that separates the trend into two halves. The resulting mathematical expression following this piece-wise analysis provides a proper representation of the furanic trend. However, a discontinuity will exist since this piece-wise model is essentially a concatenation of an equation corresponding to the increasing half and another equation associated with the decreasing half. To overcome this issue, Gaussian model was implemented to attain a smooth representation of the overall trend.

![Figure 1: Gaussian model representation of normal ageing furanic trend](image-url)


Pulsed Electric Field Assisted Treatment of Algae for Bio-Fuel production: Modelling and Analytical Evaluation of PEF Treatment


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The present project is focused on the optimization of pulsed electric fields (PEF) and non-thermal plasma treatment in order to facilitate efficient extraction of oil from algae. The high voltage impulses and plasma impulses with duration in the range from a few tens of nanoseconds to a few hundreds of microseconds will be used to generate electromechanical stresses in biological membranes in order to facilitate the lysis process. The present stage of the project focuses on modelling and analytical evaluation of the electric field strength induced in the bio-membranes by high voltage impulses. Modelling of the transient electrical processes in the cell located in liquid between parallel-plane electrodes has been conducted based on the theory developed in [1]. The transient electric field across the bio-membrane has been calculated for different parameters of the cell and external medium. Figure 1 shows the maximum field generated in the model cell membrane as a function of the conductivity of the external medium. The static electric field has been analysed using Quickfield electrostatic software. Future work in the framework of this project includes experimental PEF and non-thermal plasma treatment of algae, optimization of the electrode topologies and current and voltage wave-forms, evaluation of energy consumption of the PEF/plasma assisted bio-fuel production.

Figure 1. Maximum electric field in the membrane as a function of the conductivity of the external medium.

Predictive Rating Models for Wind Farm Export Cables

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With plans for future offshore wind farms having larger power ratings and being situated much further offshore, there will be a growing trend towards the usage of High-Voltage Direct Current (HVDC) transmission technology for submarine cables [1]. HVDC submarine cables provide lower investment cost for long-haul transmission, higher operating voltages and have no reactive power consumption, thus they have less losses than AC lines. DC transmission schemes may consist of a single polarity cable (monopole) carrying full circuit power with sea return, but there is a preference for having two cables of positive and negative polarity (bipole) each carrying half circuit power.

The power output generated by these wind farms is not constant, fluctuating with wind speed [2]. They generate a lot of electricity when they are working at their maximum, but most of the time they generate at a much lower rate. The conventional rules for calculating cable ratings use thermal models based on steady state conditions with maximum load. This approach often leads to cables being oversized compared to real requirement. Incorrectly rated subsea cables can lead to poor asset utilisation. Therefore, new modelling techniques are essential to drive down the cost of connecting offshore renewable energy projects to the grid. Using predictive rating modelling to assess cable requirements more accurately, should result in a smaller and (therefore cheaper) cable; thus reducing the cost of connecting wind farms to the electricity grid.

This research project uses Finite Element Analysis (FEA) to create a 2D predictive model a pair of extruded XLPE HVDC submarine cables, laid side by side in a trench on the seabed. Historical wind farm output data will be used to compare the performance of cables using conventional assumptions with those using the predictive model. Adoption of such approaches by the industry could lead to substantial savings on wind farm export cable systems, improving the viability of offshore wind and delivering long term cost savings to the consumers.

Figure 1: Wind Forecast Out-turn Plot [2]


Prognostic Indication of Power Cable Degradation

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Abstract - The reliability and the health performance of network assets are of a great interest due to power network operators. This project investigates methods of developing a prognostic capability for evaluating the health and long term performance of ageing distribution cable circuits. From the instant of installation and operation, the insulating materials of a cable will begin to age as a result of a combination of mechanical, thermal and electrical factors. Development of simulation models can significantly improve the accuracy of prognostics, allowing the targeting of maintenance and reduction of in service failures [1]. Real-time measurements taken close to underground cables can update the simulation models giving a more accurate prognostic model.

Currently the project investigates a thermal prognostic simulation model which will predict the likely temperature impact on a cable at burial depth according to weather conditions and known loading. Anomalies of temperature measurements along the cable compared to predicted temperatures will indicate a possible degradation activity in a cable. An experimental surface trough has been set up where operation of power cables is simulated with a control system which is able to model any cable loading. The surface temperature of the cable is continuously monitored as well as the weather conditions such as solar radiation, soil moisture content, wind speed, humidity, rainfall and air-temperature.

![Figure 1: Cable duct test bed for prognostic indicator assessment](image)

Fault Location on Branched Distribution Networks

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Fault location is particularly problematic on radial networks with many branches. Existing single-ended and two-ended techniques, though offering good accuracy on point to point and simple networks, perform poorly on networks with many branches [1]. Unfortunately, networks found in rural areas tend to be of the radial, many-branch type, meaning a fault is both difficult and time consuming to locate and remedy. In this work, a multi-ended fault location is proposed. The approach relies on the detection and time-stamping of the high frequency transient initiating by the fault. The algorithm is shown to provide a fault location estimate that surpasses the accuracy of existing techniques.

The downside of the discussed approach is the requirement for fault recorders at every branch termination in a monitored network. However, it is shown that it is possible to use fewer fault recorders at the expense of a reduction in fault accuracy in certain branches. It is further shown that a cost-effective device including GPS, an FPGA based communication MODEM and transducers is possible by exploiting a repeater-free communication scheme and advances in the capability digital electronics.

Gas Insulated Transmission Lines Using CF$_3$I

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Increasing power demand in large metropolitan areas, combined with the fact that new exploitable energy sources are often situated far away from load centres, leads to the need of new high capacity transmission systems. The construction of new Overhead Lines (OHL), introduces challenges in terms of routing and public acceptance. There is interest in developing alternative transmission technology that has less visual impact, and ecofriendly with affordable cost [1]. The length over which power may be transferred using traditional AC cables is limited, as there is a need to supply large capacitive charging currents. In comparison, Gas-Insulated Transmission Lines (GIL) have much lower capacitance, and, have capacity to transfer large amount of power over longer distances than AC cables. If the cost of GIL were to reduce significantly as the technology matures, it could perhaps be considered as a competitive alternative to HVDC cable.

The first generation GIL systems used 100% SF$_6$ gas as insulation medium. Although SF$_6$ is a potent greenhouse gas, it is not banned in high-voltage applications only because there is no suitable replacement gas. However, there is a growing interest in developing systems which use less SF$_6$ or none at all. Consequently, the second generation GIL used a gas mixture ratio of 80% N$_2$ with 20% SF$_6$. CF$_3$I has a Global Warming Potential (GWP) of 1.2, and the gas decomposes by solar light shortly after it is released to the atmosphere [2], and hence could be a suitable alternative gas to replace SF$_6$ in GIL. This paper summarises on-going work at Cardiff University: high-voltage tests on CF$_3$I–CO$_2$ gas mixture with ratio of 70%:30%, a point-to-plane electrode is used to provide non-uniform field. Preliminary results shown in Figure 1, reveal good dielectric properties of the gas mixture. The breakdown voltages were obtained for rod-plane gap of 1 to 5cm. The rods have a 45° point end.

In addition, a computer model has been developed using EMTP–ATP to evaluate the suitability of GIL and quantify the voltage, current and power transfer characteristic of the GIL [3]. It was found that, up to 300km, acceptable power transfer is feasible with no requirement for reactive compensations.

![Figure 1: Positive and Negative impulse under 50% breakdown voltage (U$_{50}$).](image)


The Electrical Performance of Thermoplastic Polymers When Used As Insulation in Cables

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With the technological development of the chemical synthesis industry, polymeric insulation and insulation based on rubber composites are mainly used in low-voltage power cables. Where possible, the technology is further developed for use in high-voltage power cables [1]. Although polymer degradation is fairly well understood, there are still research interests in the accelerated growth of water trees in polymer under various stress conditions [2].

XLPE is a popular polymeric material for cable insulation in view of its many superior properties. However, the material does not lend itself to ease of recycling [3]. Recently, there is interest shown in using material that is easily recycled. Thermoplastic material seems an automatic contender but research is required to understand the electrical performance of such material. Historically, preference has been given to using non-thermoplastic material as cable insulation and consequently, not many (if not none) published literatures exist regarding the electrical properties of thermoplastic material. Although it is clear that the behaviour of polymeric material changes with different stresses, there is also not many publications on the behaviour of polymers with changes in frequencies or indeed with changes in multi-frequency stresses. The latter is clearly an aspect of potential concern with the rapid expansion of HVDC systems.

Therefore, assuming the thermoplastic material is suitable for use as electrical insulation. The aim of this project is devided into parts. Firstly, the electrical properties of popularly used material would be investigated and used as a bench-mark. The investigation would then be repeated on thermoplastic material to assess its performance relative to the standard insulation material. If possible, new thermoplastic material would be created by addressing the weaker properties and the new material re-assessed. Finally, the properties of XLPE and other material would be investigated for their performance under multi-frequency stresses.


Oxidation Assessment of Thin Films of Environmentally Friendly Natural Ester Transformer Liquid

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Natural esters are increasingly considered as alternatives to conventional mineral oils, due to their good biodegradability and high fire-point [1]. To date, natural esters have been successfully applied in sealed distribution, traction transformers and even a few cases in power transformers. But the low resistance to gelling/oxidation of natural esters presents a technical challenge to the extension of their application in free-breathing transformers.

Different from mineral oils, natural esters do not create sludge precipitates during oxidation, but instead tend to gradually polymerize and increase of viscosity. Thin films of natural esters left on the surface of cooling ducts during manufacturing might oxidize to gelled forms during the long-term transportation of newly built up transformers [2]. In addition, whether the natural ester can be gelled on the top oil surface of free-breathing transformer is in question [3]. Therefore the comprehensive study on oxidation behaviour of natural esters is necessary for their applications in free-breathing transformers.

In this paper, a series of accelerated thermal ageing tests of thin films of natural ester were taken at 120 °C with air supply. The thickness of the films ranges from 1 mm to 20 mm. Changes in dynamic viscosity and total acid number of samples were measured to evaluate the oxidation trend of natural ester. In addition, AC breakdown voltage of natural ester during gelling process was also measured using special designed test cells. Results show that both dynamic viscosity and total acid number increase gradually when the natural ester is changing from initial liquid phase to eventually gelled form. Meanwhile the dielectric strength of natural ester remains unchanged during the whole gelling process.

![Figure 1. Relationship between dynamic viscosity and total acid number of natural ester under different film thickness conditions at test temperature of 90 °C (Thermal aging temperature: 120°C).](image)


Abstract No. 36

Diagnostic Rules for Sheath Circulating Current Monitoring in Cross-bonded Three-phase HV Cables

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There has been huge growth in adoption of high voltage (HV) underground power cable in recent years, mainly due to its reliability and aesthetics concerns. Take the city of Wuhan as an example, the length of HV cables at 110kV and over has increased from none to over 400km over the 15 years. In HV cables, cross-bonding of the three phase cable sheath is widely used in grounding arrangement in order to reduce induced voltage. However, due to problems such as third party damage, inadequate installation and maintenance practices more failures related to sheath problems have been experienced than reasons from the main insulation. As many sheath faults, repairable in their early stages, manifest in high level of sheath circulating current, on-line monitoring of sheath circulating current is therefore important as it allows timely maintenance to be carried in order to reduce unplanned outage.

This paper aims to correlate load current and sheath circulating current and establish a set of rules or criteria which can be used in monitoring of sheath circulating current. Through computer simulation, the relationship between load current and circulating current under normal working conditions will be firstly established. During the mathematical modelling, mutual induction due to sheath circulating current will be included. This is often ignored in previous publications. Then simulation of scenarios with selected problems such as sheath-earth fault, incorrect connection during installation, and short-circuit (due to flooding), in cable link-box will also be presented. Through a tabular analysis and comparison of the results under normal and abnormal conditions diagnostic rules for monitoring of sheath circulating current will be derived. In addition indication of the fault localisation will also be provided.

A 4.5km length of 220kVHV cable system will be taken as an example in the case study where numerical simulated results will be validated against measurements.
Impact of Climate Change on Overhead Transmission Line Ratings

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The rating of the overhead transmission line conductor is largely dependent on the ambient weather condition. As indicated in the IPCC (Intergovernmental Panel on Climate Change) Forth Assessment Report, global warming is predicted to occur during 21st century with an earth surface temperature rise of 1.1 °C to 6.4 °C. Facing the challenge of climate change, it is necessary to investigate the capacity of power transmission system. This poster provides a probabilistic based approach to investigate the impacts of climate change on static ratings of the overhead line. Thermal model is utilized as the tool to convert the weather data to overhead line’s ratings. Based on the simulation future weather data provided by the UKCP09 projections, the ratings of two example overhead line conductors (ACSR Zebra and AAAC Araucaria) are studied in the timeframes of 2020s, 2050s and 2080s. The results from the study show that the overhead line will face a de-rating up to 15.12% for the static rating in 2080s.

The investigation and development of pollution monitoring for high voltage insulators

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HV insulators are employed extensively in overhead transmission lines and substations and form an essential component in power systems and networks. The build-up of pollution and surface contamination on the insulators can lead to an increase in leakage current and partial discharge (PD) activity and may eventually result in flashover. Flashover is one of the most common causes of failure of HV insulators resulting in the loss of power supply and an increase in the associated engineering and maintenance costs. This problem is particularly severe in the remote hill and coastal areas favoured for wind farms and marine renewables where moisture, snow, fog and high salt concentrations will all lead to increased levels of contamination [1].

There has been a significant amount of research investigating the relationship between the leakage current and the levels of pollution on insulators for a wide range of industrial and environmental contaminants. Recent work has reported a strong correlation between leakage current the level of PD activity [2]. The work presented outlines a proposed programme of research to characterise this correlation for defined levels of pollution. The proposed investigation will include several approaches, including simultaneous measurement of leakage current and RF activity, finite element modelling of the electric field concentration under polluted conditions and novel optical techniques for measuring pollution under dry conditions. This initial paper will present an overview of the proposed study and an initial Finite Element Method (FEM) model that studies the relationship between the leakage current and the changes in the electric field distribution along the surface of the insulator as a result of dry banding. The model will enable the PD inception voltage to be predicted for various levels of pollution and a correlation to the leakage current to be established [3].

Figure: Comsol modelling of a HV insulator shelled with pollution on lower surface

Dielectric characterisation of insulating fluids for power and pulsed power applications

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Insulating liquids are widely used in industrial high voltage systems which include the power stations, high voltage transformers and impulse power generators. Typical insulating liquids used in the industrial applications are mineral oils. The stringent environmental protection regulations direct the industry towards the use of bio degradable liquid dielectrics with low toxicity. Also modern high voltages system require the insulating liquids which are able to withstand high electric fields, thus new insulating liquids are needed.

In recent years, a large number of research papers which focus on search for suitable liquid dielectrics to replace mineral oils and to achieve better dielectric performance have been published. The dielectric performance of insulating liquids is a key factor which has to be considered in industrial design of high voltage systems. Natural, organic oils and synthetic esters can be considered as a new choice, these liquids potentially can be used instead of traditional naphthenic mineral oils. The aim of this research project is to identify new bio degradable insulating liquids with low toxicity, which will provide advanced dielectric performance properties compared with traditional mineral oils. As a part of this programme a study of dielectric properties of different insulating liquids including synthetic and natural esters will be conducted and these properties will be compared with the dielectric properties, of transformer oil.

The dielectric properties which are being investigated in the framework of this programme include AC, DC and impulsive strength of insulating liquids, their pre-breakdown conductivity and dielectric permittivity which are important characteristics of dielectric properties. Dielectric properties of synthetic ester (Midel 7131), mineral oil (Shell Diala) and basic vegetable oil have been investigated.

The power industry recognises several standards of measurements for the breakdown strength of liquid dielectrics. These standard methods have been used to detected and analyse the liquids dielectrics characteristics.

The results of this study can help engineers to choose suitable insulating liquid for different industrial applications including design and development of power and pulse high voltage systems.
Charging of particles in non-thermal plasmas: improvement of precipitation efficiency of fine and ultra-fine particles

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Electrostatic precipitation of fine and ultra-fine particulate matter can offer an efficient method for air cleaning in industrial and domestic environment. The efficiency of precipitation depends on the charge accumulated by particles in non-thermal plasma discharges. The project will be focused on analysis of mechanisms of particle charging (diffusion and field charging), charging processes for particles with different conductivities and permittivities will be investigated. Experimental part will be focused on investigation of precipitation of particles as small as 25 nm. These particles will include solid particles suspended in atmospheric air, and analysis of the influence of electric charge on airborne microorganisms will be conducted. It is expected that electrostatic charge accumulated in corona discharge will help not only to remove aerosol particles with microorganisms but also to kill pathogenic microbes.

Different approaches to efficient particle charging and charging mechanisms are being reviewed. Ideal dielectric mechanisms in which only relative permittivities for both particles and media are taken into account are compared with the complex approaches in which the impact of electrical conductivities and relative permittivities of particles and media are taken into consideration. Analysis of the dynamics of charging and total charge for particles with different conductivities and relative permittivities will be conducted.

The influence of electric charge which can be accumulated by microorganisms in the external electric field is being reviewed. It is expected that the mechanisms of electrostatic disruption of microorganisms will be found. It will allow the development of new methods of electrostatic inactivation of microorganisms which will be implemented in the framework of this project.

The project started with the design and development of Faraday cup sensor in order to measure charge density of ions in plasma and gas. It is expected to use this sensor for evaluation of total charge accumulated by airborne particles charged by non-thermal plasma discharges.
Assessment of IEC 60076-7 Thermal Model Exponent and Constant Parameters

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Hot-spot temperature is one of the most critical parameters to understand the transformers thermal performance and overloading capability beyond nameplate rating. Hot-spot temperature can be measured by optical fibres, however due to cost restrictions it is not possible to fit all transformers with optical fibres. Thermal modelling is an alternative method that can be used to predict hot-spot temperature. One of the most commonly used thermal models is IEC 60076-7 [1].

The IEC 60076-7 thermal model utilizes a set of exponent parameters (x and y) and constant parameters (k_{11}, k_{21} and k_{22}) for predicting the hot-spot temperature. Under steady state conditions, oil exponent (x) and winding exponent (y) are used to define the non-linearity of the heat flow in oil and the winding. Constants (k_{11}, k_{21} and k_{22}) are utilized under dynamic state conditions to indicate the variation of the oil and winding time constants with oil viscosity. The recommended values of the exponent and constant parameters for specific types of transformers are given in IEC 60076-7. However, the suitability of the values for transformers with different designs could be an issue since the values were obtained based on a few transformers. Moreover, according to previous literature, it was found that the values for the exponent and constant parameters obtained from calculation could be different from the recommended values. There is a need for refining the values of the constant and exponent parameters in order to improve the prediction of hot-spot temperature.

In this paper, the IEC 60076-7 thermal model is assessed by analyzing the parameters separately under steady state and dynamic state. Under steady state conditions, refined values of oil and winding exponents are proposed based on information obtained from previous literatures. Under dynamic state conditions, reasonable ranges of k_{11}, k_{21} and k_{22} are proposed which could be used as an alternative to the recommended values. The case studies show that the refined values of the exponent and constant parameters give better accuracy than the recommended values for predicting hot-spot temperature.

![Figure 1. The function $f_2(t)$ for different types of cooling [1]](attachment:image)

Transient Fault Location in Low Voltage Distribution Networks

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Underground cables are widely used in UK to distribute electricity to users. However many of the cables were approaching their designed life. To achieve maximum cable value in use, Distribution Network Operators (DNOs) normally will keep these aged cables in service for some time. However, the aged cables are prone to develop fault and result in loss of power supply. This leads to customer minutes lost -- a parameter that is monitored by the Electricity Regulator (ER). Hence, it becomes desirable to know where in their power network, a fault might be developing. The early stages of a fault could be classified as transient faults. Time domain reflectometry (TDR) is mainly used to pre-locate faults in low voltage underground cable network. However the success of this technique to address transient faults relies both on the simplicity of the cable circuit being diagnosed and the diagnostic point. This is because T-joints in a cable network and parallel circuits at the diagnostic point could result in a complicated waveform acquired and therefore induce inaccuracy in pre-locating. Hence current technologies for identifying and locating transient fault either require access to residential homes or use of a heavy blocking inductor to ensure that only a particular circuit is being investigated. Furthermore, the network operator may have nothing acquired from the ‘suspended’ power cable due to transient faults are irregular in occurrence and may not appear during investigation. Transient faults that occur in underground cable networks are electric arcing caused by failure insulation. Electric arcing in low voltage cables is often self-extinguishing \cite{1} and does not present an immediate hazard. This is the reason for transient faults to be unpredictable and irregular in occurrence. This paper is therefore to review some existing technologies and to present a strategy that overcomes the restrictions or limitations posed by the existing strategies for locating transient faults.

![Figure 1: A transient fault was found at 285 meters away from the bus bar.](image)

Partial discharge detection and recognition in PET films

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A photovoltaic cell (PV cell) is a very common and basic unit in a photovoltaic system, which can convert the sunlight energy into electricity directly. Due to their excellent dielectric properties and low cost, polymeric films have been used in the backsheets of PV cells from the early days of the industry.

However, these polymeric films may undergo partial discharge (PD) that usually occurs in defects such as microvoids, PD can deteriorate the insulating materials slowly and cause some chemical degradation. Hence, it is important to understand how the physical and chemical properties (thickness, different fillers, crystallinity level, humidity level, different extents of UV ageing) of the polymeric films influence the PD phenomenon in terms of the inception and extinction voltage, measurable charges, repetition rate and distribution of the PD events.

![A typical PD measurement display panel](image)

Figure 1 A typical PD measurement display panel