Conference Agenda

2019 IEEE 37th Electrical Insulation Conference (EIC)

Date: Sunday, 16/Jun/2019

9:00am - 12:30pm **Neilson 1**	**SC1: Insulation Testing of Turbo Generators** Session Chair: **Douglas Conley** Turbo Generators are designed for operation over a long period of time. High quality stator winding insulation is an important factor to achieve the expected reliability and forced outage rates. This course will provide basic description of stator insulation components and systems. It will include an overview of technical principles, applications and testing requirements outlined in IEEE 56, IEEE Guide for Insulation Maintenance of Electric Machines, along with some points from IEEE 4, 43, 95, and 286.
9:00am - 12:30pm **Neilson 2**	**SC2: Generators: Engineering Approach to Modernization and Rehabilitation of Hydropower** Session Chair: **Inna Kremza** Voith experts, present project case studies to demonstrate the engineering approach and proven solutions for modernization and rehabilitation of hydro generators. A recommended framework for rehabilitation schedules and modernization solutions will be reviewed in relation to the lifecycle of various hydro systems and equipment. The course goal is to present solutions, based on real projects, which can be used to inform and optimize the project outcomes for power plant operators including engineering, maintenance and operations.
9:15am - 9:30am **SC Coffee Break**	**SC-CB-M1: SC Coffee Break - M1**
12:30pm - 1:30pm **Short Course - Lunch**	**LSC: Lunch - SC - Lunch is on your own** Lunch is on your own
1:30pm - 5:00pm **Neilson 1**	**SC3: Transformer Insulation Diagnostics – Field perspective** Session Chair: **Diego Robalino** This course describes the most important methodologies used for transformer insulation diagnostics in the field. The topics include time and frequency domain methodologies described in the international literature including insulation resistance, Power Factor, newly developed features for improved Power Factor diagnostics and advanced diagnostics with Dielectric Frequency Response.
1:30pm - 5:00pm **Neilson 2**	**SC4: Why should the DEIS care about the Smart Grid?** An afternoon workshop exploring the world of the Smart Grid from a DEIS perspective, in conjunction with the IEEE DEIS Technical Committee on the Smart Grid.
2:15pm - 2:30pm **SC Coffee Break**	**SC-CB-A1: SC Coffee Break - A1**
6:00pm - 8:30pm **Stephen Room A&B**	**P1: ROTATING MACHINES** Session Chair: **Hugh Zhu**

Analysis of the Degradation Kinetics of Kapton Film in an Aerospace Environment

H. Haghighi, I. Cotton
University of Manchester, United Kingdom

This paper describes the results derived from thermogravimetric analysis (TGA) work on poly (4,4'-oxydiphenylene-pyromellitimide), or more commonly known as Kapton film. The test are completed under heating rates of 5, 10 , 20, and 50 K/min and two distinct atmospheres, concentrations of 21% and 3% oxygen. The atmospheres chosen mimic the oxygen concentrations at ground-level and at a cruising altitude of 15 km, which are the two extremes of the environments the insulation is expected to operate in when being applied in commercial aircraft electrical systems. From the rate of TGA conversion data at various temperatures, kinetic parameters such as the activation energy (Ea) and pre-exponential factor (A) are found. This is then used to illustrate the relationship that can exist between oxygen concentrations and the ageing and degradation rates of polyimide insulation as expressed using the Arrhenius equation. From this, differences between the ageing mechanisms and relative lifetimes of insulation systems in an aerospace application compared to those operating in ground-based systems can be found.

Improving dielectric properties and suppression of partial discharges in fiber/thermoset-matrix composites by polymeric nanofibers

R. Polansky[1], P. Prosr[1], J. Pihera[1], J. Chvojka[2], T. Kyselak[3]

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The polymeric nanofibrous layers as a new material for possible improving dielectric properties and suppression of partial discharges in fiber/thermoset-matrix composites are introduced in this paper. Electrospun nanofibers made from polybenzimidazole (PBI) and polyimide (PI) were incorporated into the structure of the commonly used fiber/thermoset-matrix composites to enhance their dielectric behavior. PBI and PI were electrospun using a Nanospider laboratory scale machine. The spinning process was set to produce nanofibrous layers with two different areal weights (1 and 3 g·m-2 for composites with PBI and 3 and 5 g·m-2 for composites with PI). Control composites without nanofibers as well as composites containing electrospun PBI and PI nanofibrous layers were manufactured by compression molding in a laboratory press without any previous vacuum debulking. To verify the positive or negative influence of the incorporated nanofibrous layers on the overall dielectric behavior of the composites, the volume resistivity □ (Ω·m) and dielectric strength Ed (kV·mm-1) were comprehensively measured. Initial results revealed that the volume resistivity of modified composites increased (of about 126 % for PBI and 217 % for PI) as well as the dielectric strength (of about 11 % for PBI and 53 % for PI). Obtained results were subsequently supported by partial discharge analysis which confirmed that the nanofibrous layers are capable to significantly suppress the partial discharge activity inside the composite structure.

A Novel Nonlinearly Equivalent Circuit Model for Calculating Electric Fields Along the Stator End-winding of HV Rotating Machine

P. Liu[1], X. Liu[1], Y. Zhang[2], Z. Liang[2], B. Hu[2]

[1]xi'an jiaotong university, People's Republic of China; [2]Dongfang Electric Machinery Company

In order to study the performances of electric potential or electric field distribution along the stator bar end-winding, a novel equivalent circuit model was proposed to calculate the electric field distribution along the surface of stress grading system in this paper. Compared with the conventional equivalent circuit which just described the stress grading tape (SGT) and groundwall insulation, this model was more complex and also took the air gap into account. Based on the proposed equivalent circuit, the transient potential and electric field distributions along the three-segment SGTs, usually named as medium, medium-high and high resistance coating respectively, of a rated 24 kV class hydro-generator stator bar end-winding were simulated. The simulation results show that the transient potential or electric field at each point along the three-segment SGTs has a significant phase or time difference (or delay) with any other location at a moment. This novel proposed equivalent circuit model should be adequate to optimize SG system of stator end-winding for the high voltage rotating machines.

Characteristic Research on the Sensor for Inter-turn Partial Discharge Measurement of Inverter-fed Motor Winding

P. Yuan, X. Liu, T. Zhang, P. Liu

xi'an jiaotong university, China, People's Republic of

In this paper, the characteristics of a novel type of non-contact electromagnetic induction sensor suitable for inter-turn partial discharge (PD) detection under an induced impulse voltage were studied. Taking the flexible advantage of ferrum-based nanocrystalline alloy thin strip applied in the open magnetic core, the sensor was desigined to be sensitive for the detection of high frequency but low amplitude PD current signal, and had a flexible and thin framework based on consideration of the convenient arrangement at the limted air gapness between the adjacent end-windings of motor. Through the sensor equivalent circuit model established, the curve patterns of the sensor's amplitude gain in the frequency domain were obtained. The transfer characteristics of the sensor were studied by means of theoretical and simulated analysis. The sensor's amplitude performes a bell-shaped characteristic, and its maximum gain can reach 10kV/A at a frequency of about 55 MHz. The finally experimental results, obtained from a typical case of the inverter-fed traction motor windings with the inter-turn void defects, have indicated that the this sensor has a excellent performance in detecting response signal of possible inter-turn PD of motor.

Temperature Dependence of RPDIV of Motorette Sample with Varnish Treatment

Y. Nishigaki[1], T. Kubo[1], T. Matsuzoe[1], N. Kita[1], Y. Nakano[1], M. Kozako[1], M. Hikita[1], T. Nakamura[2], J. Sun[2], A. Izumi[2], T. Sakurai[2], K. Karasawa[2], K. Nojima[2], T. Hirose[3], S. Hiroshima[4]

[1]Kyushu Institute of Technology, Japan; [2]Toshiba Mitsubishi-Electric Industrial Systems Corporation, Yokohama, Japan; [3]Toshiba Infrastructure Systems & Solutions Corporation, Fuchu, Japan; [4]Toshiba Energy Systems & Solutions Corporation, Yokohama, Japan

Recently, driving of inverters has been advanced to improve the characteristics of motors. Along with that, concerns are raised that inverter surge deteriorates the insulation system of the motor. The problem of insulation deterioration is particularly serious in high-voltage motors where insulation structure is important, and analysis of phenomena of deterioration is strongly desired. We have measured repetitive partial discharge inception voltage (RPDIV) of an enamel twisted pair sample using a repetitive impulse voltage generator which can arbitrarily change the voltage value, pulse rise time and width, etc. This paper deals with RPDIV of a motorette that can simulate all connections in the motor (phase to phase, turn to

turn, phase to ground) and investigates the influence of temperature on RPDIV characteristics. Measurements of RPDIV of the motorette with varnish treatment were also made in the temperature range between room temperature 25 °C and 155 °C. Experimental results revealed that the RPDIV for the phase to phase and turn to turn connection tends to decrease with increase in temperature. An attempt is made to interpret the temperature dependence of the RPDIV in terms of the temperature dependent pressure change in void defect which may exist in the vanish of the motorette.

A New Approach to Make the Electric Field Uniform Along the Stress Grading System of A Form-Wound Coil under Square Waves

A. Naeini, E. Cherney, S. Jayaram
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Surface partial discharges on the stress grading system of a medium voltage form-wound coil fed by an inverter can lead to insulation failure. Reducing the maximum surface electric field is therefore essential for prolonging insulation life. Under square waves in simulations using COMSOL Multiphysics, this work studies how floating metal foils added to the stress grading tape (SGT) affect electric field and temperature distributions. The results show that the metal foils make the electric field uniform but increase the temperature, due to increased current density in the stress grading tape. However, the temperature rise is below that considered to be detrimental to the insulation.

The Effects of Steep Voltage Slopes on Insulation Systems of Coil Windings caused by Next Generation Power Semiconductor Devices

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Next generation silicon carbide (SiC) and gallium nitride (GaN) semiconductors offer much faster switching char- acteristics in power electronic devices. The faster switching speed allows higher switching frequencies in combination with lower losses, which leads to smaller components and thus, a higher power density. However, the high voltage slopes associated with fast switching cause exceeding stress on the insulation systems, especially of coil windings. This increased stress results in accel- erated aging and thus, premature failure of the insulation system. This paper focuses on the design and execution of experiments to quantify the detrimental effects of fast switching on the insulation system of coil windings. To investigate these effects, a dv/dt- generator is developed to excite various specimens with steep voltage slopes. Commercial products are not suitable for this purpose as they are either not available on the market or do not fully exploit the potential of the next generation semiconductors. A SiC-based inverter with an H-bridge topology is selected. The dielectric strength of twisted pair enameled wires are tested using a standardized insulation tester and the proposed dv/dt-generator. While the specimen withstands the standardized insulation test, partial discharges occur during excitation with high dv/dt, which leads to a premature breakdown after short time, even though the dv/dt test voltage is less than a sixth of the standardized test. It is experimentally observed that the steepness of the voltage slope has a major impact on the insulation system.

6:00pm - 8:30pm
Stephen Room A&B

P2: PARTIAL DISCHARGE

Session Chair: **Mona Ghassemi**

Investigation of Partial Discharge in Aircraft Conformally-Coated Printed Circuit Boards

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Printed circuit boards (PCB) are key components of any electronic system. The reliability of PCBs under operating conditions is an important factor to ensure the performance of the system. In recent years, the electrical power demand in more-electric aircraft has significantly increased. To provide more power, the operating voltage is increased which imposes a higher level of electrical stress on the insulation system of PCBs and, therefore, a higher risk of failure. Partial discharges in PCBs are more likely to happen within the air gap. To improve the insulation of PCBs, they are coated with an insulation material. In this study, test boards with two parallel traces were fabricated and coated based on aerospace industry approved standards. The boards were energized using a 60-Hz adjustable high voltage source. Partial discharges were measured for silicone-coated test boards under pollution and conductive particles conditions. The impact of pollution location on partial discharge was investigated. Besides, the breakdown voltage of test boards was measured under different coating conditions and low air pressure. An increased withstand voltage for coated boards was confirmed.

Finite Element Modeling of Partial Discharge Activity within a Spherical Cavity in a Solid Dielectric Material under Fast, Repetitive Voltage Pulses

S. M. Razavi Borghei, M. Ghassemi

Virginia Polytechnic Institute and State University, United States of America

Accelerated aging of insulation systems used in different apparatus under fast, repetitive voltage pulses is the most significant barrier to benefit from wide bandgap (WBG) power electronics. Frequency and slew rate which are higher for WGB devices than Si-based ones are two of the most critical factors of a voltage pulse, influencing the level of degradation of the insulation systems that are exposed to such voltage pulses. Finite element analysis (FEA) has been widely used to study partial discharge (PD) behavior under a power frequency (50/60 Hz) sinusoidal waveform within cavities in a solid dielectric. However, the new technologies urge the need to utilize it under square waveforms. In this paper, a FEA model of PD activity is developed. The model is used to investigate the change in the electric field distribution before and after PD occurrence and the impact of different involved parameters when repetitive voltage pulses are applied to the dielectric.

Influence of Metal Particles on Discharge Characteristics of Insulating Oil under Lightning Impulse

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In this paper, a research work on the influence of metal particles on lightning impulse discharge characteristics of transformer insulating oil is carried out. The main research contents are as follows: The lightning impulse discharge test platform for insulating oil was established. The influence of the development characteristics and breakdown characteristics of the streamer in the insulating oil with different metal particle concentration under pre-breakdown voltage was studied. The discharge characteristics of pure insulating oil and particle-containing granular insulating oil were compared and analyzed. The breakdown characteristics of insulating oil with different metal particle concentration under different oil gaps were measured, and the influence of metal particles on the lightning breakdown characteristics of insulating oil was obtained. The results show that the metal particles promote the initiation and development of the streamer in the oil. The stop length and development speed of the streamer are positively correlated with the particle concentration, while the initial voltage of the insulating oil is negatively correlated with the breakdown voltage and the particle concentration.

The Implications on the PD Characteristics of Unipolar versus Bipolar PWM waveforms

T. J. Hammarstroem

Chalmers university of Technology, Sweden

Speed drives fed by pulse width modulated (PWM) inverters allows a more efficient use of electric energy. The drawback is however that the stress imposed on motor winding insulation increases due to a higher frequency harmonic content compared to the classical 50 Hz sinusoidal voltages. High frequency contributions have been observed in high voltage DC (HVDC) applications as well. In particular, partial discharges (PDs) considered the major contributor to the reduction in the insulation life time. It has been shown that the usage of electrical filters decreases electrical stress imposed on the insulation. Another option is to use multi level inverters, which have been shown to reduce magnitude of the PDs. It however remains to explain how the size of these voltage steps as well as polarity influences the level of PDs. Here twisted pair test objects are exposed to PWM inverter waveform at various rise times. Both bipolar and unipolar waveforms as well as different step sizes and rise times of each voltage flank are employed to present a gradual change between bipolar PWM to a more constant DC voltage magnitude with superimposed voltage ripple. To compare the performances, measurements of both PD inception and extinction voltages were conducted for the different cases. Additionally, the total number of PDs, their average maximum amplitude per cycle and pulse repetitive PD pattern (PRPD) are presented. The decreased step size to resemble more HVDC waveform and the resulting change in PD characteristics is discussed. Important factors are the time until PDs are observed (time lag) together with observed polarity dependences.

Computation of the Corona Onset Voltage for DC at Two Different Altitudes

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In this paper, a methodology based on the finite element method is used to analyze the corona onset voltage on different structures of HVDC lines, the methodology includes atmospheric conditions such as pressure and temperature. The results obtained in simulations were verified through two experimental set-ups (rod-to-plane and corona cage) at sea level and 2200 m above the sea level. According to the results, the predicted values are in good agreement with the measured values in most of the tested configurations. Once the accuracy of the methodology was verified, it was used to modify the conductor bundle geometry of an HVDC line to maximize the corona onset voltage. The importance of this work is due to the prediction

of the corona onset voltage since corona discharge in elements of a high voltage transmission line is an undesirable phenomenon because it causes power losses and electromagnetic interference.

Effect of Vibration on Surface Discharge of Epoxy Resin

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As mechanical vibration usually exists in reactors, its influence on partial discharge (PD) needs to be studied so as to provide new clues for further understanding of the abnormal aging process of the insulation material as well as improve the reliability of on-line PD monitoring method. In this paper, PD characteristics of epoxy resin under different vibration conditions are investigated. Research shows that vibration could promote or suppress the occurrence and development of discharge by changing the state of field emission, the dissipation of charges and the conduction current, obvious variation was observed with the changing vibration amplitude. Moreover there are differences between the variation trend of the PD magnitude at different vibration frequency, which is due to the relative displacement of the electric field distribution and space charge, and the promotion or suppression of surface charge dissipation.

IoT-based On-line Monitoring System for Partial Discharge Diagnosis Of Cable

X. Gao, T. Zhuang, M. Ren, B. Song, W. Huang, M. Dong

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Partial discharge monitoring of power cables is an important technical means to ensure the safe operation of cables. However, the traditional cable monitoring method is difficult to apply to the distribution network system with complex feeder structure, wide distribution area and more cost-sensitive. To solve this problem, a cable insulation state sensing technology based on Internet of Things (IOT) technology is proposed in this paper. Firstly, considering scalability and accessibility, the overall framework of wireless sensor network for cable partial discharge monitoring is designed; secondly, the technical requirements of sensor nodes, low power management, data communication and other basic units of Internet of Things sensor network are analyzed; finally, based on the above research, it is realized. Distributed IoT monitoring for high frequency current of partial discharge in power cables. The system has broad application prospects in the on-line monitoring of partial discharge in cables.

Enhancing the Accuracy of Partial Discharge Localization in Power Transformers Using the UHF Measurement Technique

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Reliable operation of power systems depends highly on the condition of power transformers, hence making their condition monitoring top priority. Partial discharge (PD) is among the most common and deteriorative faults in a power transformer. PDs cause progressive degradation of the insulation system of transformers, and may lead to catastrophic failures, if no countermeasure is taken.

The ultrahigh frequency (UHF) measurement technique is capable of detecting and localizing PDs inside a power transformer. In this method, electromagnetic waves emitted from the PD fault are captured by UHF probes. From the difference in arrival times of the signals, captured by the probes, the location of the PD fault can be obtained. To date, several researches have attempted to introduce a method for arrival time detection. However, these methods are not capable of providing an acceptable location for the PD inside the transformer tank for each set of the received signals. This reduction in the provided PD locations by the signal sets is exacerbated when the electromagnetic waves encounter more barriers in their path to the UHF probes.

This contribution is aimed at optimizing the number of selected signal sets that yield an acceptable location for the PD, in order to improve the localization accuracy. The PD signals are denoised using wavelet filtering, and the arrival time detection method is then applied to the denoised signals. The obtained PD locations are subsequently assessed to estimate the PD fault position with the highest possible accuracy. This research is accompanied by experimental measurements to acquire the location of a PD source inside a specially designed transformer tank and evaluate the proposed algorithm. A novel approach regarding the optimal selection of the captured signal sets is presented and the results are compared.

Nonlinear Field Dependent Conductivity Materials for Electric Field Control within Next-Generation Wide Bandgap Power Electronics Modules

M. Mesgarpour Tousi, M. Ghassemi

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We are witnessing an excitement in the research community to develop next-generation wide bandgap (WBG) power electronics. The superior characteristics of WBG materials regarding their operational

capability at higher voltages, temperatures (200°C) and switching frequencies in comparison with commercial Silicon devices, has made them auspicious materials for the future power electronics. Increased voltage blocking capability and at the same time, an interest in high-power density designs can enhance the local electric field, in particular, at the edges of the metalized substrate. The increased electric field can become large enough to lead to severe partial discharges (PDs) within the module and thus the failure and reduction of the reliability of the insulation system. This paper shows that applying nonlinear field dependent conductivity (FDC) materials as a coating applied to highly stressed regions combined with a protruding substrate design can well address high field issue within high-voltage high-power-density modules.

Searching for Optimal Connection Schemes for Partial Discharge Testing of Inverter-Fed Rotating Machines

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Partial discharge testing of complete, low voltage induction machines using the configurations proposed in the IEC 60034-27-5CD, is discussed. Based on tests performed on a machine with accessible coil terminals, the most promising configurations for type tests and quality control, is proposed and the limits of the IEC 60034-18-41 highlighted.

Estimation of the Partial Discharge Inception Voltage of Low Voltage Cables

R. Cselko, I. Kiss
Budapest University of Technology and Economics, Hungary

There is an increasing interest in the diagnostics of low voltage cables that serve safety systems of nuclear power plants. Besides the assessment of the lifetime of the cable material in bulk, the detection of local defects is also important, as these can result in function loss of the cables in case of critical events. Partial discharge measurement is widely used for the condition monitoring of medium and high voltage cables, but its application on low voltage cables is a difficult task, as these cables are not designed to be partial discharge free at their test voltage. In the present paper estimation of the inception voltage is given mainly for intact cables based on electric field calculation. Cables of different design are studied. The effect of the number of cores and their cross section are investigated through electric field calculations. Finally, the calculation results are compared with measurements.

Partial Discharge Detection Strategies under Fast Rise Time Voltages Generated by Wide-bandgap Semiconductor Devices

Z. Wei, H. You, B. Hu, R. Na, J. Wang
The Ohio State University, United States of America

Wide-bandgap (WBG) semiconductor device is one of the leading contenders for the next generation semiconductor device. Its advantages include but not limited to: higher voltage rating, switching speed and frequency. However, when electrical applications are driven by WBG devices, the voltage stress is inevitably changed. To be more precise, the voltage stress is more likely to be enhanced based on the premature failures observed for various applications driven by WBG devices. As has been well accepted, partial discharge (PD) is considered as the main cause for insulation failure in high frequency equipment. Thus, it is necessary to study PD behaviors under the new stress introduced by WBG device. However, the issue is inherently challenging due to the nature of the equipment under test and the extremely high dv/dt (fast rise time) square-wave voltage introduced. Huge charging/discharging current would be seen at the rising/falling edges of the square-wave pulse train. The magnitude of the charging/discharging current can be hundreds of or even thousands of times larger than that of PD pulse current. In some cases, even in frequency domain, the PD pulse current would be masked by the charging/discharging current. In this paper, a summary is made on past research related to PD detection strategies under fast rise time square-wave voltage or impulse voltage. Their advantages and disadvantages would be introduced to provide a full picture about this issue for future researchers when the need of PD detection under fast rise time excitations arises.

Can Low Voltage Inverter-Fed Induction Motors Be Designed Allowing Partial Discharge Activity?

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[1]University of Bologna, Italy; [2]Sichuan University; [3]Tianjin University

Most users of low voltage electrical drives know that inverter surges can reduce the reliability of the stator insulation if partial discharges (PD) are incepted [1,2]. If interphase insulating films are placed correctly, the turn/turn insulation is the most critical one. To improve the PD inception voltage, two alternatives can be pursued. The first one is increasing the insulation thickness. Filling all the voids within the slot with a varnish or a resin is the alternative [3]. In the first case, the thicker insulation reduces the slot filling factor, thus lowering the specific power of the actuator. The alternative can be critical if the filling procedure is

not perfect and if, under thermal stress, the filler depolymerizes and is removed by mechanical stress. Also, a correct filling requires a number of steps that complicate the manufacturing procedure leading to higher production costs.

An intermediate solution would be to design the insulation thickness in a way that, even without the filler (i.e., the worst case), PDs inception probability is low. That would involve losing a small fraction of the lifetime, without affecting the insulation reliability appreciably. In this paper, we want to propose a roadmap to arrive at the design of insulation systems that can tolerate PDs for a prescribed fraction of time based on the drive operating point statistics. The approach will be speculative, with the final goal of defining which data should be collected regarding the drive operation statistics and the insulation lifetime curves.

6:00pm - 8:30pm
Stephen Room A&B

P3: NEW MATERIALS

Session Chair: **FERNANDO PEREIRA**

Dielectric and Insulation Properties of Polyimide-based Boehmite Nanocomposite Material

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In recent years, small and medium size generators are used as engine generators. The authors aim to develop enamelled wire that exceeds conventional resin insulation lifetime. Among nanocomposite materials, boehmite-based materials are reported to have a longer lifetime than silica-based materials, and they are expected as new insulating materials for enamel wire insulation layer. In this paper, we report on the effect of boehmite filler on dielectric properties and AC conductivity by acquiring complex permittivity and AC conductivity of a film sample with nano-boehmite alumina added to polyimide resin compared with those of samples with silica nano-fillers and without nano-fillers. As a result, it is suggested that the ionic carrier is more likely to move in the polyimide sample with AlOOH filler than in the neat sample in the high temperature region of 180 °C. From the above results, it is considered that the conductivity and the relative permittivity increase in the high temperature and low frequency region are due to the influence of crystal water of boehmite. In addition, measurements of life time of enamel twisted pair samples coated with polyimide filled with boehmite alumina nano-filliers were also made with comparison to that of samples without the boehmite alumina fillers.

Acoustic noise emitted from overhead line conductors with superhydrophobic coating

X. Zhang, C. Lian, C. Emersic, I. Cotton

The University of Manchester, United Kingdom

Overhead lines can generate significant levels of audible noise containing low frequency hum and/or high frequency crackling. The frequency of hum is twice the supply frequency while the crackling noise is in the frequency range of 1 kHz to 20 kHz. While conductor choice and the use of bundles can reduce electric fields and minimize noise, some surface defects including damage, insects, raindrops and pollution will always enhance electric fields and lead to noise generation. This results in the need to use specific conductor types/geometries to avoid the creation of a significant nuisance. This paper presents work that has examined whether the noise level generated by an overhead line can be reduced by coating overhead line conductors with superhydrophobic coating. To test audible noise, an enclosed chamber with a low noise level is utilized. The conductor is either bare or coated with a superhydrophobic coating of which contact angle is 168 o. With water manually placed on the conductor, the noise levels at 100 Hz are higher than background noise at different voltages, showing that the noise at 100 Hz is generated by water droplets on the conductor. Furthermore, compared with a bare conductor, testing of the conductor with a superhydrophobic coating shows lower noise levels at 100 Hz under different voltages. The superhydrophobic coating can be used to reduce noise levels at low frequency because water droplets, the reason for the hum, cannot stay on the conductor.

Design of the Polymer Insulator between HVDC Converter Valve Modules

J.-H. Koo[1], H.-Y. Lee[2], R. Hwang[2], J.-M. Joo[3], J.-W. Park[3], B.-W. Lee[2]

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The polymer insulator between HVDC converter valve modules is one of the key elements of ultra-high voltage dc transmission. In prior to designing dimension of shed, end fitting, and sealant of polymer insulator, the dc electric field analysis should be conducted. Therefore, the electrical conductivity of the polymer specimens was measured for various temperature since the electrical conductivity depends on the temperature. Based on measured electrical conductivity of specimens, the dc electric field analysis for 4 types of polymer insulators were carried out. From the simulation results, the specimen with the lowest dc electric field was selected. Besides, the dielectric strength of polymer should also be determined in designing the polymer insulator. Therefore, the experiment on determining the dielectric strength of the

polymer was conducted. The test jig for breakdown tests was fabricated corresponding to the IEC 60243-1 standard. The dc breakdown tests were corresponded to the IEC 60243-2. In addition to breakdown test, the surface flashover test was also conducted. The test jig was designed using the uniformity of electric field based on the dc electric field analysis and the surface flashover test on the polymer specimens was performed.

Development of High Thermal Conductivity Epoxy Composite for Large Current Switchgear

G. Komiya, T. Imai, Y. Miyauchi
Toshiba Infrastructure Systems & Solutions Corporation

Since SF6 gas used as an insulating medium for switchgear is a greenhouse gas, its use needs to be reduced. Toshiba Corporation has developed solid insulated switchgear (SIS) in which the main circuit is molded with an epoxy composite. Since developing the 24 kV class SIS in 2002, a 72/84 kV class SIS has been launched. The high dielectric strength of the epoxy composites enables these solid insulation systems to provide compact equipment. However, it is necessary to consider the problem of heat radiation in SIS, as epoxy composite has low thermal conductivity. Therefore, development of high thermal conductivity epoxy composites has been desired for large current class SIS. In this study, we focus on magnesium oxide (MgO), which has a thermal conductivity having low-cost. The developed epoxy composite was filled with MgO having high thermal conductivity and SiO2 having a low coefficient of thermal expansion. By using the estimation equations of thermal conductivity and coefficient of thermal expansion, we could efficiently determine the formulation of the high thermal conductivity epoxy composite. The thermal conductivity of the developed material was 1.39 W/(m•K), which is equivalent to 2.5 times that of conventional material. In addition, other characteristics also showed excellent values, such as 23×10-6/K of the coefficient of thermal expansion and 2,513 mPa•s of viscosity. These values satisfied the required ones for large current SIS. Thermal analysis revealed that applying the high thermal conductivity epoxy composite to 2500 A SIS can reduce the temperature rise by about 10 K. By applying the high thermal conductivity epoxy composite, we are convinced that a large current of SIS with merits such as low maintenance and compactness will be realized.

Insulation Characteristics of C5F10O Gas Mixtures under Quasi-Uniform Electric Field

Y. ZHANG, X. Zhang
wuhan university, China, People's Republic of

Sulfur hexafluoride has been widely used in the power industry because of its excellent insulation properties and arc-extinguishing properties, but its strong greenhouse effect has prompted researchers to accelerate the search for alternatives to SF6. In recent years, C5F10O has attracted attention due to its stable chemical properties, good insulation properties, and extremely low greenhouse effect values etc. The current research on the insulation properties of C5F10O gas mixtures is not sufficient. In this paper, the power-frequency breakdown characteristics of C5F10O gas mixtures with nitrogen or dry air as buffer gas under quasi-uniform electric field are studied. The insulation strengths of nitrogen, dry air, SF6 and C5F10O gas mixtures was compared, it is found that the insulation strength of C5F10O gas mixtures is always lower than SF6 but higher than buffer gas under the same total filling pressure. The insulation strength of the C5F10O gas mixtures increases with the total filling pressure or the C5F10O partial pressure. C5F10O gas mixtures has the potential to replace SF6 as a gas insulating medium.

Examination of clearances during high voltage live-line working

D. Szabó, G. Göcsei, B. Németh, R. Cselkó, L. Rácz
Budapest University of Technology and Economics, Hungary

High voltage live-line maintenance (LLM) became a decisive working method in Hungary in the 1960s. Most of the LLM techniques and equipment – which are still in operation nowadays – were developed by Dr. Béla Csikós, who was one of the pioneers of high voltage live-line work. In those days the live maintainability of the power lines was a significant aspect during the design of towers and insulator strings. Contrarily, structures change year-by-year, especially regarding the insulators. Therefore, live working methods also shall be developed. Nowadays, new types of tower structures and insulator strings are used with reduced distances, which also means reduced clearance between the different potentials in the arrangement. During bare-hand live working method, the lineman has to keep the adequate distances from different potentials of power lines. Moreover, there is no uniform standard and international practice for the regulation of safety clearances. New type of mounting chair made of non-conductive material is suitable for approaching the insulator strings and their fittings safely, as the air gap between the conductive parts does not shorten. The aim of this paper is to investigate the usability of non-conductive mounting chair and the regulation of phase-to-ground clearances during insulator replacement technology, in case of several tower types and insulator types used in the Hungarian transmission grid. Another purpose of this article is to examine the possibility of reducing minimal approach distances, such as by the application of portable protective air gap (PPAG).

The production of cellulose fibers

Y. Bekzhanov[1], A. Useinov[1], K. Kamalbay[2], R Aidarkhanov[3]

[1]Eurasian National University; [2]AO "KTZ"; [3]KPK

The production of cellulose fibers is carried out in suspension with water at a consistency of up to 60%. Consistency is the percentage by weight of the cellulosic material in the mixture of cellulosic material and water. One serious disadvantage of using cellulosic fibers is the difficulty of obtaining dry cellulosic fibers without reducing their dispersibility in an aqueous medium and / or their hardenability. This difficulty is similar to the difficulty of drying other cellulosic microfibrils or nanofibrils or even wood fibers in the traditional way and due to so-called keratinization. Hornification is caused by many factors, which include: the formation of irreversible hydrogen bonds (H-bonds) and / or the formation of lactone bridges. Keratinization leads to dried cellulosic fiber that cannot be re-dispersed in water, aqueous solution, or aqueous suspension, such as wood and paper suspension, when dry cellulose fibers are mixed with wood pulps in a shredder or in a checkerboard blend to be used as reinforcing paper additives. Each of these approaches has its drawbacks. In the case of the first approach, to reduce keratinization, MFC is dried with additives that block the formation of H-bonds and help prevent the formation of H-bonds and the lactone bridge. These supplements include sucrose, glycerol, ethylene glycol, dextrin or carboxymethyl cellulose. Here the main disadvantage is the large number of required additives, in some cases more than 15% wt. Are used. The second approach to reducing keratinization in the MFC and NFC during the drying process involves the derivatization of microfibrillated or nanofibrillated cellulose by introducing various groups, including carboxyl groups. However, derivatization requires the use of large amounts of reagent, for example, 5.81 g of monochloroacetic acid (MHC) (7.26 g of 80% MHC) per 36 g of MFC in isopropanol and aqueous solution under nitrogen atmosphere. It has not been established that MFC, derived from MHC or other molecules, can be re-dispersed in water after drying.

Date: Monday, 17/Jun/2019

7:00am - 8:00am **Neilson 1**	**ABM: Author Breakfast** Session Chair: **David McKinnon**
7:00am - 8:00am **Imperial Ballrooms 1, 2, 3**	**GBM: General Breakfast**
8:00am - 9:00am **Imperial Ballrooms 4, 6, 8**	**PL: Plenary**
9:00am - 9:30am **Imperial Ballrooms 5, 7, 9**	**EXM1: Exhibition**
9:00am - 9:30am **Grand Foyer 3 & 4**	**CBPL: Coffee Break - PL**
9:30am - 10:45am **Imperial Ballroom 4**	**TR1: TR - Fault Analysis** Session Chair: **Diego Robalino**

9:30am - 9:55am

Detection of Forced Cooling Faults in Power Transformers based on Winding Temperature Indicator and Load Data

A. Doolgindachbaporn[1], N. H. Nik Ali[1], G. Callender[1], J. Pilgrim[1], P. Lewin[1], G. Wilson[2]
[1]The Tony Davies High Voltage Laboratory, University of Southampton, United Kingdom; [2]National Grid, United Kingdom

In this paper, time series decomposition and thermal models are used to identify WTI issues; specifically an absence of sensor load dependency and detecting when the WTI is tracking top oil. Following this, two different transformer thermal models are used to calculate WTI temperatures which are then compared to WTI measurements under forced-cooling conditions to identify cooling issues, especially a reduction in cooling performance. A discussion of the differences between two different transformer thermal models, IEC 60076-7 and one purposed by Susa, is provided.

9:55am - 10:20am

Evaluation of Natural Ester Retrofilled Transformers After One Year of Continuous Overload

R. Breazeal[1], A. Sbravati[2], D. Robalino[3]
[1]Southern California Edison, United States of America; [2]Cargill, United States of America; [3]Megger, United States of America

Despite the efforts of the utilities to designate properly sized transformers for the distribution network, transformers are routinely subjected to significant overloads during peak hours. This is especially common during hot summer days where the hot spot temperature value may exceed the design limits. With the utilization of natural ester liquid in distribution transformers, the rate of paper degradation is expected to be reduced in comparison to a traditional mineral oil unit at same conditions. The acceptable top oil temperature for natural ester is significantly higher than that for mineral oil. The improvements for both solid and liquid insulation enhance the ability to subject the distribution transformer to overload conditions. An experimental protocol was performed in 2017 to further investigate these properties of natural ester oil.

In this document, the research work performed by Southern California Edison (SCE) is summarized and described in detail. For a period of one year, 11 transformers were subjected to thermal overload and thus, to an accelerated aging process. Transformers were loaded for cycles of 4 weeks, up to 145% of nameplate rating. After each loading cycle the transformers were cooled down to ambient temperature and tested using dielectric frequency response to document and trend the changes in the dielectric conditions of the complex insulation system.

Challenges, lessons learned and recommendations are discussed herein.

10:20am - 10:45am

Laboratory Model for Evaluation of Incipient Transformer Thermal Fault Involving Insulating

H. M. WILHELM[1], P. FERNANDES[1], G. C. SANTOS[1], T. K. P. PEREIRA[1], D. A. FILHO[2], M. RIBEIRO[2], A. MAR[2]
[1]VEGOOR, Brazil; [2]Geradora de Energia do Maranhão, Brazil

In order to age thermally upgraded kraft paper immersed in insulating oil without aging the oil, an “aging device” was built in which a copper electric resistance was covered with insulating paper and the setup was immersed in insulating oil contained in a vessel. The oil was water cooled to keep its temperature below 60 0C, while paper’s temperature was raised up to 500 0C. The experiment allowed the determination of the CO2/CO rate variation against aging time and temperature. The generation of other decomposition products, namely furan compounds, methanol and ethanol was also determined against aging time and temperature. Paper aging status was also determined through degree of polymerization (DP). The aging of oil was also monitored.

9:30am - 10:45am
Imperial Ballroom 6

RM1: RM - Diagnosis, Dissection, and Repair

Session Chair: **Reza Soltani**

9:30am - 9:55am

Corona in High Voltage Rotating Machines Stator. Causes, Repair and Prognosis.

A. Gegenava, A. Khazanov, F. Dawson
National Electric Coil, United States of America

Corona in high voltage rotating machines (HVRM) is a very common and might be considered an inevitable phenomenon. Corona has various different signatures, causes, severity, and potential hazard for reliable machine operation. The necessity, frequency, and procedure for effective repair are contingent upon proper evaluation of all the issues discussed in this article.

9:55am - 10:20am

Calculation of the Electric Field Inside Cavities Found Through Stator Bar Dissection

E. Cloutier-Rioux[1], H. Provencher[2], A. Turgeon[2], C. Hudon[2]
[1]Hydro-Québec, Canada; [2]Institut de Recherche d'Hydro-Québec, Canada

Quality control tests, including partial discharge (PD) measurements and dissections, were performed on a new production lot of epoxy-mica stator bars for a 13.8-kV hydroelectric generator. The location and the characteristic patterns of PD were identified by scanning the straight portion of the bar with an electromagnetic antenna. A sample from those locations was selected for dissection and another sample without PD was selected as a reference. Microscopic analysis of specimens from the sample with localized PD activity showed cavities in the groundwall insulation close to adjacent copper strands.

Numerical simulations of the electric field inside different cavities were conducted to determine if PD activity can be initiated in cavities of different shapes. Results of the average and maximum field were compared with the Paschen curve for air. The analysis showed that with the maximum calculated field, all simulated cavities would result in PD activity regardless of the inner temperature.

10:20am - 10:45am

Observations from the Dissection of Several Aged Stator Coils from Different Hydrogenerators

G. Stone[1], H. Sedding[1], R. Wheeler[1], A. Wilson[2]
[1]Iris Power, Canada; [2]CEATI

Stator coils and bars from 10 different hydrogenerators with a wide variety of ratings and operating hours were dissected to determine the degree of aging of the stator groundwall insulation. The bars and coils came from machines that were being rewound due to failure, old age or uprating. In cases where the coils/bars were not damaged during extraction from the generator, off-line electrical tests were performed and compared to the condition of the groundwall insulation, as determined by dissections. Only one of the windings had essentially unaged insulation. All the rest showed various degrees of thermal or thermo-mechanical aging. Only one of the 10 windings also showed severe aging due to surface partial discharge. The coin tap test was a good predictor of the degree of thermal and thermo-mechanical (load cycling) aging. The PD test was a good predictor of the coils/bars that had any of the three types of aging.

10:00am - 11:00am
Bannerman/Walker

GSOC: Guest Social

10:45am - 11:10am
Imperial Ballrooms 5, 7, 9

EXM2: Exhibition

10:45am - 11:10am
Grand Foyer 3 & 4

CBM1: Coffee Break - M1

11:10am - 12:25pm
Imperial Ballroom 4

TR2: TR - Insulation

Session Chair: **Alan Sbravati**

11:10am - 11:35am

Estimating the Thermal Stability of Cellulose Insulation using MSD and Tg parameters by Molecular Dynamics Simulation

W. HOU, L. YANG
Chongqing University, China, People's Republic of

Oil-impregnated cellulose paper is the main insulation material used in power transformers. The thermal stability of cellulose insulation is important for the steady and safe operation of a transformer. The reinforcement of the thermal stability of cellulose via physical and chemical modification has attracted much research attention. Considering that traditional experiments are costly and time-consuming, molecular dynamics simulation is introduced to predict or estimate the performance of modified cellulose by calculating several key parameters. However, linking the model performance parameters with macroscopic properties of materials at the molecular simulation scale is difficult. In this study, two parameters, namely, mean square displacement (MSD) and glass transition temperature (Tg), are proposed to evaluate the thermal stability of cellulose. The validity of these two parameters to characterize the thermal stability of cellulose is verified by the simulation results from natural cellulose and acetylation-grafted cellulose models. In engineering application, acetylation-grafted cellulose performs better than natural cellulose in terms of thermal stability. According to the simulation results, the Tg of acetylation-grafted cellulose is approximately 111 K higher than that of natural cellulose. Compared with the natural cellulose, the MSD of acetylation-grafted cellulose considerably decreased, indicating that the intensity of movement for the acetylation-grafted cellulose chain is prominently smaller than the natural cellulose chain at every time step. These results also show that acetylation-grafted cellulose can improve the thermal stability of cellulose, which is consistent with previous studies.

11:35am - 12:00pm

Modeling Transformer Core With Appropriate Boundary Conditions for Partial Discharge Studies

S. Janaki Raman[1,2], P. Mukherjee[1,2], S. K. Panda[1,2]
[1]National University of Singapore, Singapore; [2]Sembcorp-NUS Corporate Laboratory

Study of Partial discharge (PD) in a transformer is crucial as it leads to enhanced thermal stress in the insulation and local resonances in windings, and thus instigates an accelerated aging of winding insulation. A typical PD pulse occurs with a rise-time less than 2 ns. Its frequency analysis, as reported in literature, reveals components from tens of MHz to GHz. The transformer is generally modelled with air-cored winding for analyzing PD pulse propagation. Although this consideration drastically simplifies computation, an accurate estimation of winding's response to PD requires considering core behavior as a grounded perfectly electric conductor (PEC) and a perfectly magnetic insulator (PMI) in the frequency regime of interest. This paper models the winding as a multi-conductor transmission line (MTL) while the core is modelled using charge and current simulation methods. The effect of core is emulated by defining boundary conditions in terms of: (i) zero tangential electric field for PEC in charge simulation method and (ii) zero magnetic vector potential for PMI in current simulation method. Simulated charges and currents thus evaluated are used to estimate the capacitance and inductance matrices which are used to solve the MTL model in time-domain. A typical single layer winding is considered for the simulation study. The PD induced voltage is emulated as a fast rising Gaussian voltage in the middle of the winding and currents induced at different locations in the winding are estimated. Efficacy of the core model is scrutinized by evaluating the electric potential of the core at different locations (test points) from the currents obtained from the MTL model. The simulated charges and currents were carefully considered to ensure minimal error in the boundary conditions at an arbitrarily chosen time during the propagation of the PD induced current. The response of the winding with and without considering the effect of core will be compared in the full paper showing large deviations in estimated current distribution in the winding.

12:00pm - 12:25pm

Transformer Insulation Degree of Polymerization Estimation through Adaptive Neuro Fuzzy Inference System Approach

E. T. Mharakurwa[1], G. N Nyakoe[2], A. O. Akumu[3]
[1]Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI), Kenya; [2]Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya; [3]Tshwane University of Technology (TUT), South Africa

The useful life of a power transformer is linked to the integrity of its solid (cellulosic) insulation. The insulation deterioration is time dependent and is influenced by varying temperatures, moisture, oxygen, oil conditions and loading profiles. Accordingly, once the solid insulation state is compromised, its dielectric and mechanical properties are not recoverable. Thus, longevity in service of a power transformer can only be achieved by incessant monitoring and assessing the credibility of its insulation system. The tensile strength of the solid insulation can be indicated by determining the degree of polymerization of the paper. Consequently, the degree of polymerization is a key indicator of the insulation status that correlates well with the transformer remnant life. Since degree of polymerization measurement is an intrusive test

involving transformer disassembling, utilities have opted to the use of furans concentration in the oil as a way of determining the degree of polymerization of transformer solid insulation. However, these furans and degree of polymerization correlations are based on mathematical models. This paper introduces an adaptive neuro fuzzy model to estimate the degree of polymerization of a mineral oil-immersed power transformer based on furan content and CO2/CO gas concentration ratio in the insulation system. Practical data from numerous power transformers of different lifespans subjected to different operating regimes have been used to validate the accuracy and credibility of the established adaptive neuro fuzzy model. Compared to the conventional models, the results show that the proposed model is effective in estimating the degree of polymerization of transformer solid insulation.

11:10am - 12:25pm
Imperial Ballroom 6

RM2: RM – PD and Aging Studies

Session Chair: **Claude Hudon**

11:10am - 11:35am

Unidirectional accelerated lifetime investigations of mechanically dominated aged electrical insulation system used in generator winding bars

A. Cimino[1], F. Jenau[1], A. Mashkin[2]
[1]TU Dortmund University, Germany; [2]Siemens AG, Muelheim, Germany

This paper investigates the influence of electrical, thermal and in particular mechanical stress on the electrical insulation system of generator stator bars. For this purpose, accelerated ageing tests are performed in order to analyze the ageing behavior with experimental results. As the focus is on mechanically dominated ageing, there is a defined variation of the mechanical load. Previously, studies have been performed on alternating stress, which is fully reserved. In this work the unidirectional stress is investigated.

11:35am - 12:00pm

Partial Discharge Characterisation of Stator Windings Taken From a 50-year-old Norwegian Hydrogenerator

G. Berg, E. Eberg, S. Hvidsten
SINTEF Energy Research, Norway

This paper presents results from laboratory measurements of partial discharge (PD) activity in stator bars taken from a 95 MVA hydrogenerator after 52 years in service. The generator has previously been subjected to off-line condition monitoring including partial discharge (PD) testing at both 0.1 and 50 Hz, and on-line PD monitoring at 50 Hz. Stator bars were selected from representative positions along the winding, including both the neutral point and high voltage side. Initial PD testing has been performed at a fixed voltage level (9 kV/1.2 U0) to assess the current state of the stator bars. Based on the PD measurements a comprehensive set of characteristic discharge data has been found for 161 stator bars retrieved from the decommissioned hydro generator. The selection of measured data for presentation in this paper is based on the phase and position of the bars in the generator providing an extensive PD activity mapping of the generator. The test results show a large variation in discharge activity among the stator bars. However, using statistical analysis it is not possible to distinguish between service-aged bars taken from high and low electric stress regions.

12:00pm - 12:25pm

Investigation of Partial Discharge Activity and Insulation Life of a Large Hydro Generator

R. Soltani[1], I. Chichkin[2], P. Gaillardetz[2], B. Ledger[3]
[1]Powertech Labs, Canada; [2]BC Hydro; [3]Wref's Consulting Inc.

Partial discharge (PD) is a well-known indicator of an aging insulation system, so trending the PD activity is suggested as a tool to prevent insulation failures by targeted interventions. This paper presents a case study in which on-line PD measurements showed a significant increase over several years and triggered an investigation and repair plan. Off-line site tests confirmed the concerns and helped in locating and replacing the most vulnerable bars. Laboratory tests on the service-aged bars also provided valuable information about the root cause and insulation condition of the winding.

11:10am - 12:25pm
Imperial Ballroom 8

TT1: Partial Discharge

Session Chair: **Greg Stone**

11:10am - 11:35am

Partial Discharge Inception Voltage in DC insulation systems: a comparison with AC voltage supply

G. C. Montanari[1,2], P. Seri[2], L. Cirioni[2], H. Naderiallaf[2], R. Hebner[1], A. Gattozzi[1], X. Feng[1]

[1]CEM, Texas University at Austin, USA; [2]DEI, University of Bologna, Italy

In this paper the AC and DC partial discharge inception voltages, PDIV, are modeled and validated through measurements performed on multi-layer flat specimens with artificial defects. The results highlight that, depending on temperature and material conductivity, there can be a large difference between PDIV under DC and AC, which depends on insulation temperature, thus, e.g., cable loading. Indeed PDIV-DC can be much larger than PDIV-AC at room temperature, but the two values can be very close (with PDIV-DC being even smaller than PDIV-AC) at maximum operating temperature, i.e. full load.

11:35am - 12:00pm

The RPDIV and the limits of its definition according to IEC 60034-18-41: the effect of voltage conditioning

A. Caprara[1], A. Cavallini[2], G. Ciotti[1], A. Rumi[2]

[1]Techimp - Altanova group Srl, Italy; [2]University of Bologna, Italy

This paper investigates the behavior of the Repetitive Partial Discharge Inception Voltage (RPDIV), which is defined as the voltage level at which at least one PD occurs in two voltage impulses (or at least five in ten – according to the Standard in use). It has been noted that, increasing by steps the voltage value above the PDIV level, sporadic bursts of PD occur. During the bursts, the conditions for RPDIV are met, but the PD activity is unstable and may well extinguish. Since the definition of RPDIV in the International Standards does not consider PD bursts, the results of RPDIV using different measurement systems might vary depending on how the RPDIV is calculated, affecting the overall comparability of the results. In the test reported here, it came out that conditioning the system above PDIV might be a suitable way to reduce the probability of observing PD bursts. By combining the behavior of PD activity and the impact of conditioning, suggestions to perform more accurate measurements are eventually derived.

12:00pm - 12:25pm

Opto Electronic Technique for Detection of Corona Discharges in Air and Oil

N. R. BURJUPATI

CENTRAL POWER RESEARCH INSTITUTE, India

A study was undertaken in the laboratory of CPRI to understand the detection capability of corona/partial discharges in air and oil medium using opto electronic technique. The experimental investigations were carried out in a high pressure test chamber fitted with high voltage bushing, electrode arrangement with a moving seal, view ports, gas inlets and outlets. PD measuring system consisted of ac high voltage test setup, fluorescent optical fiber, normal optical fiber, fiber adaptor, photomultiplier tube and picoscope for detection of discharges by optical method. Simultaneously the discharges were also detected by electrical method using the conventional system consisting of a high voltage ac source, coupling capacitor cum standard capacitive voltage divider, PD detection unit and test cell. The studies were conducted both in air & oil under uniform and non-uniform electric fields using point plane electrode geometry. The electrode gap distance is varied from 5 mm to 30 mm. The response of different colored fluorescent optical fiber was studied. The results are presented and discussed.

12:25pm - 2:00pm
Imperial Ballrooms 5, 7, 9

EXM3: Exhibition

12:25pm - 2:00pm
Grand Foyer 4

LM: Lunch - Monday

Session Chair: **Kevin Alewine**

2:00pm - 3:15pm
Imperial Ballroom 4

NM1: New Materials

Session Chair: **Santosh Janaki Raman**

2:00pm - 2:25pm

A New Representation of Paschen's Law Suitable for Variable Temperature Power Applications

A. Al-Taie[1,2,3], C. Park[4], P. Cheetham[1,2], C. Kim[2], L. Graber[4], S. Pamidi[1,2]

[1]FAMU-FSU College of Engineering, Department of Electrical & Computer Engineering, Tallahassee, FL, 32310, USA; [2]Center for Advanced Power Systems, Florida State University, Tallahassee, FL, 32310, USA; [3]University of Technology, Electrical Engineering Department, Baghdad, 10066, Iraq; [4]Georgia Institute of Technology College of Engineering, Department of Electrical & Computer Engineering, Atlanta, GA, 30332, USA

High temperature superconducting (HTS) power devices are being developed for high power density electrical devices for power grid, aviation, shipboard, data centers, and high energy physics applications. The appeal of HTS technology is the ability to achieve high power densities at low and medium voltages. HTS operate at cryogenic temperatures achieved by cryogenic liquid or gas medium. Liquid cryogens such as nitrogen, helium and hydrogen have all been explored for superconducting power applications.

Limitations of liquid cryogens are safety hazards and limited operating temperature range. The use of gaseous cryogens allows larger operating temperature windows and thus greater design flexibility. Both the cryogenic thermal management and dielectric insulation characteristics of gas-cooled HTS devices depend significantly on the operating temperature and pressure. Hence, the power ratings in terms of voltage and current depend on the operating conditions, and it is essential to establish the relationship between the power ratings and operating conditions of gas-cooled HTS devices. The insulation rating of an HTS power device is a function of the dielectric strength of a selected gaseous cryogen. In our previous work, we have demonstrated that the dielectric strength of gaseous helium is a function of its density. We continued to investigate the dielectric design aspects of HTS devices and develop guiding relationships among the various design variables. This paper discusses the development of practical relationships for binary and ternary gas mixtures that are being developed as cryogenic cooling media for HTS power devices. Operational conditions where the Paschen's curve remain valid are identified, and useful alternative methods of representing the relationships among the dielectric strength, operating temperature and pressure are discussed.

2:25pm - 2:50pm

Polymer-Impregnated Concrete Insulators/Insulating Structures

M. Gunasekaran
Sekar Enterprises, United States of America

As we embark into the 21st century, the electrical industry will need to show greater attention to the choice of materials in the context of environmental requirements and aspirations. It has become abundantly clear that highly energy-intensive materials such as electrical porcelain are now forced to give way to other materials. Interestingly, lower cost, easily processable and far less energy intensive materials, such as polymer concrete, are now readily accepted and even preferred than porcelain in many parts of the world. Such was not the case about 30 years ago when work at Westinghouse/EPRI sponsored the R&D of such materials and brought them to the industry's attention after exhaustive laboratory and field testing. This paper deals with PIC, a hydraulic cement based material, which, when dried and then impregnated with a low-viscosity monomer which is then thermally/radiatively polymerized, becomes a super dielectric and insulating structural material. An over-view of work done in this field of materials is presented,together with technical data, and feasible and practical ideas for realizing PIC's full potential for insulators and insulating structures of the future are presented. The enormous life-cycle cost benefits of using PIC are also discussed.

2:50pm - 3:15pm

Investigation of Persea Americana Oil as an Alternative Transformer Insulation Oil

B. M. Makaa, G. K. Irungu, D. K. Murage
Jomo Kenyatta University of Agriculture and Technology, Kenya

Mineral insulating fluids have conventionally been used as insulating liquids in electrical equipment for over a century. These fluids serve as dielectrics and coolants. They are however known to be environmentally toxic and are highly flammable. Hence, they require costly fire protection schemes and deluge systems. Increasing awareness of environmental protection and fire safety is leading to accelerating trend of looking for plant based oil alternatives that are environmentally friendly. Increase in power rating of electrical equipment also calls for high temperature performance insulating oils. Plant based dielectric fluids have been found to defeat mineral oils in many of these aspects. They are non-toxic, possess better thermal properties and have excellent biodegradability. In order to reduce the adverse environmental impact and to improve the fire safety of transformers, there is an increasing demand for plant based insulating liquids as transformer insulating oils. This paper presents results of series of experiments that were performed to investigate the electrical, thermal, physical and chemical properties of food grade Persea americana oil (PAO) for possible use as insulation oil. For comparison, the corresponding properties of mineral insulation oil (MIO) in the same experimental conditions were also measured and compared with those of PAO. In this investigation, two different types of Persea americana oil samples consisting of extra virgin and refined PAO were tested. The obtained results show that the average electrical, thermal, physical and chemical properties of PAO meet the IEC and IEEE specifications for new natural liquid insulation oils. This may suggest that Persea americana oil can be tried as an alternative transformer liquid insulation.

2:00pm - 3:15pm
Imperial Ballroom 6

RM3: RM – Temperature and Humidity Effects on PD

Session Chair: **Ahmed Gad**

2:00pm - 2:25pm

Influence of Ambient Humidity on PDIV and Endurance of Inverter-fed Motor Insulation

P. Wang[1], P. Li[1], Y. Li[1], A. Cavallini[2], Q. Zhang[3], J. Zhang[4]

[1]Sichuan University, China; [2]University of Bologna, Italy; [3]St. John's University, USA; [4]Northeast Electric Power University

This work aims to report the influence of ambient humidity on partial discharge inception voltage (PDIV) and lifetime (endurance) of the insulation for inverter-fed motors. The PDIV on polyimide film and rotor bar insulated by NOMEX at sinusoidal voltages with 50 Hz frequency and the endurance tests of inverter-fed motor turn insulation under repetitive unipolar impulsive voltages with 10 ns rise time and 200 ns voltage on-time were performed at four relative humidity (RH), i.e. 40%, 60%, 80%, 95%, controlling the ambient temperature at 50 ℃. Experimental results show that both the PDIV and endurance decrease significantly with increasing RH. Accordingly, the influence of ambient humidity on the test results should be carefully considered when performing PDIV and endurance tests on the insulation of low-voltage and high-voltage inverter-fed motors according to IEC standards.

2:25pm - 2:50pm

Material Temperature Dependence on Behavior of Partial Discharge in Epoxy Resin

T. Sakoda[1], M. Kawakone[1], N. Hayashi[1], M. Setoguchi[2]

[1]University of Miyazaki, Japan; [2]Research Laboratory, Kyushu Electric Power Co., Inc.

For epoxy resin equipment, voids may exist owing to imperfection of insulation manufacturing. The electric field becomes high in the voids, and partial discharges (PDs) occur in such defects. Incidentally, the insulation material temperature varies with the status of load and the environmental condition. It is crucial to investigate PD activity at different void temperature and electric field. In this study, we carried out measurements of PDs in an artificial void of epoxy resin at various temperatures in the range of 30 – 50 degrees Celsius. The maximum electric fields in the void 1.5 mm in diameter were set at 4.6 kV/mm and 8.0 kV/mm. For a 4.6 kV/mm-void, the number of PDs was large at lower temperature at around 30 degrees Celsius. The number of PDs decreased with the increase of the number of temperature-time cycles. The PD magnitude slightly increased with the increase of temperature because the dielectric constant of epoxy resin might become high and the electric field in a void might become high. In contrast, the variation tendency of the number of PDs for an 8 kV/mm-void was much different from that for a 4.6 kV/mm-void. The number of PDs was large at around 50 degrees Celsius and in the middle of temperature rising from 40 to 50 degrees Celsius. Thus, we investigated that PD behavior during temperature-time cycles differs in electric field.

2:50pm - 3:15pm

Temperature and electric field profiles along the stress grading system of a form-wound coil as a function of conductive nonlinearity under pulse voltage

A. Naeini, E. A. Cherney, S. H. Jayaram

University of Waterloo, Canada

The effectiveness of the conductive nonlinearity of stress grading tape (SGT) on the electric field distribution, the temperature profile, and hot spots along the stress grading system is important in high voltage rotating machines fed by adjustable speed drives. Simulation studies on the effect of various SGT conductive nonlinearities on the electric field and temperature distributions along the stress grading system has been evaluated in this work under pulse voltage. The validity of the 2D axisymmetric simulations using COMSOL® 5.2a have been confirmed by measurements of the temperature profiles. The results show that increasing the conductive nonlinearity of SGT increases the effectiveness of the SGT, thereby reducing the maximum temperature rise and the peak of the electric field.

2:00pm - 3:15pm
Imperial Ballroom 8

CA1: Cables - PD

Session Chair: **Stan Gubanski**

2:00pm - 2:25pm

Influence of Cavity Geometry on Partial Discharge Measurement at Very Low Frequency

S. Morsalin[1], B. Phung[1], M. G. Danikas[2]

[1]The University of New South Wales, Australia; [2]Democritus University of Thrace, Greece

As a promising alternative to conventional high voltage AC testing at PF (power frequency 50/60 Hz), VLF (very-low-frequency, typically 0.1 Hz) testing is nowadays used in practice. The increasing application of VLF testing for condition assessment of power apparatus necessitates understanding the partial discharge (PD) behaviors at this frequency. In this paper, the influence of cavity geometry on PD activities is investigated. A comparative experimental study is carried out with PF and VLF voltage excitations for different void structures (cylindrical, block, prism). Measurement results are presented with phase-resolved discharge patterns and integrated parameters such as average void discharge, repetition rates, etc. Under the same applied overstress relative to inception voltage, measurement results show that void discharges are strongly dependent on the cavity geometry as well as excitation frequency. With increasing

cavity volume, PDs are more likely to occur and in particular, VLF excitation yields lower discharge magnitude, repetition rate and the phase range of occurrence.

2:25pm - 2:50pm

Water Tree Detection in Medium Voltage XLPE Cables

W. McDermid, T. Black, M. Partyka
Manitoba Hydro, Canada

During the period of 1993-1995 Manitoba Hydro investigated the claim by a service provider that water trees could be detected and located in service aged medium voltage XLPE cables by means of time domain reflectometry (TDR) following conditioning of the cable dielectric with direct voltage. In order to avoid subsequent short time in-service failures, it was necessary to limit the conditioning voltage to 0.5 per-unit. With this restriction, no conditioning related surge impedance anomalies were found in cable that subsequently was determined as containing substantial vented water trees. However, it was established that the measurement of leakage current at 0.5 per-unit negative polarity direct voltage did correlate with the magnitude of subsequent 0.1 Hz breakdown voltage. Beginning in 2014 Manitoba Hydro has been assessing service aged medium voltage XLPE cables using Tangent Delta measurements at 0.1 Hz voltages in accordance with IEEE Std 400.2. However, the notion that water tress can be detected and located as a result of conditioning with direct voltage is still of interest as is indicated by publications that have appeared in the literature in recent years, but the related conditioning utilizes direct voltages in excess of 0.5 per-unit.

2:50pm - 3:15pm

Partial Discharges in XLPE Insulated Cable under Superimposed Transient Voltages

J. Wu
Delft University of Technology, Netherlands, The

This paper investigates the partial discharges (PD) at artificial defects in a cross-linked polyethylene (XLPE) insulated cable joint under superimposed voltage. The experiments are conducted on a 16-meter long 150 kV commercial XLPE cable, together with a cable joint and two terminations. Defects are fabricated on purpose in the cable joint. The cable system was subjected to a 50 Hz AC voltage, being in between PD extinction and inception values, superimposed with a lightning impulse voltage. Partial discharges are measured by two HFCT sensors at the two ends of the cable joint. The measurement results show that, the impulse voltage could trigger partial discharges. The partial discharge occurrence is mainly influenced by the time period during which the applied voltage is higher than PDIV.

3:15pm - 3:30pm **Imperial Ballroom 4**	**COM-M1: Omicron Lab**
3:15pm - 3:30pm **Imperial Ballroom 6**	**COM-M2: PMDT**
3:15pm - 3:30pm **Imperial Ballroom 8**	**COM-M3: Nippon Rika**
3:30pm - 3:45pm **Grand Foyer 3 & 4**	**CBM2: Coffee Break - M2**
3:30pm - 6:00pm **Imperial Ballrooms 5, 7, 9**	**EXM4: Exhibition**
3:45pm - 6:00pm **Grand Foyer 3 & 4**	**P4: CABLES** Session Chair: **Jiayang Wu**

The Effect of AC Ripple Voltage on Space Charge Accumulation in Double Layer Polymer Samples

A. A. Mulla, S. J. Dodd, N. M. Chalashkanov, L. A. Dissado
University of Leicester

High frequency AC ripple voltage due to the switching of the converter's power electronic valves is an undesirable artefact in high voltage direct current (HVDC) transmission. This paper presents an investigation of the effect of AC ripple voltage superimposed on the DC voltage on space charge accumulation and electric field profiles in double layer polymer samples. A pulsed electro acoustic method (PEA) was used to measure the space charge accumulation under pure DC voltage and under 10% AC ripple voltage superimposed on DC voltage. The experimental results demonstrate for the first time that the presence of ripple voltage enhances the accumulation of homocharge close to the electrodes as well as charge at the interface between the two layers.

Evaluation of Nano-Composite XLPE Compound on Accelerated Aging Cable Performance

S. J. Han[1], S. Wasserman[2]

[1]The Dow Chemical Company, United States of America; [2]The Dow Chemical Company, United States of America

One way to ensure longer cable life is to retain high electrical strength under longer field aging conditions. When the electrical strength of the insulation in the cable declines below a certain minimum level, it is known that the propensity of cable degradation accelerates. Further, the probability of cable failure increases as a result of electrical stress from field conditions such as lightning and power surges from switching operations. In this study, the performance of 15 kV cables comprising components made from nano-composite XLPE compounds was investigated in accelerated wet aging conditions for 120 days and tested, as well, for AC breakdown strength. The retained AC breakdown strength of the treated nanocomposite XLPE cable was comparable to that of the XLPE control cable. This study assesses on impact and importance of insulation quality on expected breakdown strength in comparison to XLPE cable.

Effects of Acetophenone on Charge Dynamics in Low Density Polyethylene

M. Chen[1], Y. Yin[1], H. Zhang[1], Z. Gao[2], Z. Ma[3], J. Wu[1]

[1]Shanghai JiaoTong University, China; [2]Zhoushan Power Supply Company, State Grid Zhejiang Electric Power Co., Ltd,China; [3]Wuxi Jiangnan Cable Co., Ltd, China

It is well-known that space charge accumulates easily in polyethylene in the presence of crosslinking byproducts. Acetophenone is one of the mainly byproducts produced after crosslinking with dicumyl peroxide (DCP). This paper intended to investigate the mechanism of space charge formation with the existence of acetophenone in polyethylene. The addictive-free low density polyethylene (LDPE) sheets and the LDPE soaked into acetophenone for 24 hours (referred as L-AP) with 300μm thickness were prepared. The space charge distribution and high field conduction characteristics were measured in both untreated LDPE (referred as L-u) and L-AP. In the space charge measurement using pulsed electroacoustic (PEA) technique, three relatively low DC electric fields, 5, 7, and 10 kV/mm were applied subsequently at 298 K and 323 K. It is generally acknowledged that no obvious space charge can be observed under these fields in LDPE. In the high field conduction measurement, samples were stressed under DC electric field at the same temperature. Gas chromatography-mass spectrometry (GC-MS) was employed before and after space charge test to investigate the variation of acetophenone. According to the space charge distribution in L-AP, negative charges started to appear under 5 kV/mm in the vicinity of the anode at 298 K and positive charges dominated the bulk of the sample at 323 K. The acetophenone content decreased during the space charge test from GC-MS result. Acetophenone changed the pattern of space charge in LDPE, which became more obvious at high temperature. According to the conduction measurement results, the dissociation of acetophenone brought about more free charges and changed the conduction mechanism in polymer.

Long-term Durability of Stearic Acid Silicon Dioxide Nanoparticle Superhydrophobic Coating on Aluminium Alloy Overhead Line Conductors

C. Lian, X. Zhang, C. Emersic, R. Lowndes, I. Cotton

The University of Manchester, the United Kingdom

The accumulation of ice can lead to serious damage and failure of overhead line systems due to the additional mechanical loads applied during icing events. CIGRE TB361 has detailed a range of advanced superhydrophobic coatings and this paper details the replication and optimisation of the manufacturing procedure to coat overhead line samples with a stearic acid-based coating. The solution was loaded with Silicon Dioxide (SiO2) nanoparticles and achieved a sliding angle of 3˚ and a contact angle of 169˚ on aluminium substrates. The paper also describes several ageing tests, including thermal ageing, corona exposure, ultraviolet radiation, and outdoor environmental exposure. Samples were characterised using different techniques such as contact angle measurements and microscopy tests before and after each ageing test. High temperature and corona discharge were shown to have a strong degrading effect on coating's superhydrophobicity. Ultraviolet exposure and outdoor tests changed the wettability performance of samples and led to 'sticky' surfaces with high contact angle hysteresis. Tests indicated that the coating has poor performance under difference ageing conditions and is unsuitable for deployment onto overhead power lines.

Investigation of the Thickness Effect on DC Breakdown Strength for HVDC Flexible Cable Insulation Associated with Space Charge

P. Su[1], Y. Yin[1], X. Zheng[2], Y. Xuan[2], J. Wu[1]

[1]Shanghai Jiao Tong University, Shanghai 200240, China; [2]Zhoushan Power Supply Company, State Grid Zhejiang Electric Power Co., Ltd, Zhoushan 316000, China

Crosslinked polyethylene (XLPE) is the main insulation material in HVDC (high-voltage direct current) flexible cable. DC breakdown characteristics of XLPE are important indicators to determine operational safety. The accumulation of space charge could change the electric field distribution within the cable insulation layer, and could lead to insulation breakdown in severe cases. In response to these problems, this paper investigated on the breakdown strength and space charge characters of XLPE with different thicknesses. DC breakdown experiments were conducted for three different sorts of XLPE at positive and negative electric fields, where the thicknesses of the samples were 100 μm, 200 μm, 300 μm and 400 μm. Besides, the space charge measurements were carried out on 200 μm and 400 μm XLPE samples at 70kV/mm and 80kV/mm. The electric field distortion within the sample was calculated. The results show that the breakdown strength of XLPE decreases as the thickness of the XLPE increases. Power function was applied to describe the relationship between the breakdown strength and thickness. The homo charges injected from anode form packet-like charges which could move towards the cathode at high electric field. For thicker samples, more space charges are accumulated and there is a larger maximum electric field distortion. Therefore, the breakdown strength of thicker samples could be relatively lower than thinner samples.

Measurement of Space Charge Distribution Characteristics in the Actual HVDC Cable

Y. Zhou, W. Wang, T. Guo, J. Qi

North China Electric Power University, China, People's Republic of

The accumulation effect of space charge in high voltage direct current (HVDC) cable may lead to the distortion of internal electric field, accelerate insulation aging and even cause insulation breakdown, which seriously affected the reliability of operation of HVDC cable. With the operation of HVDC cable, the radial distribution of temperature gradient is developed within the insulation material among the temperature presented high on internal layer and low on external layer. However, as the existence of non-linear phase distortion of the measurement system, cylindrical geometric structure for HVDC cable and temperature gradient, the measured waveforms of space charge in HVDC cable based on pulsed electro-acoustic (PEA) method induces distortion. In this paper, the temperature at cable core is set at 30°C, 60°C and 90°C respectively in order to form different temperature gradients, the negative DC electric Field of 10 kV/mm is applied to HVDC cable, space charge distribution characteristics are researched based on the space charge measurement system using PEA method for HVDC cable, the measured waveforms developed by our laboratory can be corrected by modified recovery algorithms. It is concluded that with the increase of temperature at cable core, heterocharges gradually accumulate near the lower temperature side of HVDC cable. The higher temperature at cable core can also promote the injection of homocharges in HVDC cable. The temperature gradient in HVDC cable has importance impact on space charge accumulation, the research on space charge distribution characteristics can provide basis for further study on space charge behavior mechanism under temperature gradient.

Analysis of AC 500kV XLPE Submarine Cable Insulation Laboratory Aging Condition Based on Frequency Domain Dielectric Spectroscopy

Z. Liu[1], Z. Gao[2], J. Hao[1], C. Liu[1], H. Li[2], X. Dai[1]

[1]State Key Laboratory of Power Transmission Equipment & System Security and New Technology Chongqing University Chongqing, China; [2]Zhoushan Power Supply Company of State Grid Zhejiang Electric Power Supply Company Zhoushan, China

With the rapid rise of new energy industry and its rapid development all over the world, there is a great market for submarine cable products. The world's first class AC 500kV cross-linked polyethylene (XLPE) insulated submarine cable will soon be put into operation in the “Zhoushan-Ningbo” interconnection project. Aging of insulation materials after operation will be an important factor restricting the safe operation of the 500kV XLPE cable. Taking into consideration that the frequency domain spectroscopy (FDS) is a nondestructive testing (NDT) method, in this paper, the changes of dielectric spectroscopy of the AC 500kV XLPE submarine cable material during 130℃thermal aging process were studied. The aged samples show increasing dielectric constant and dielectric loss. Besides, is defined to estimate the aging condition of XLPE samples. It can be clearly seen that the samples severely aged when the exceeds 1. The can be used to diagnostic the aging condition of the AC 500kV submarine cable insulation material. Besides, the and tanδ in the lower frequency of the seriously aged sample increase significantly, and the inflection points of tanδ curves for the seriously aged sample move to higher frequency significantly

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Capacitive Transfer Cable and Its Performance in Comparison with Conventional Solid Insulated Cable

Y. Yang[1], M. Darwish[1], M. Moghadam[2], D. Quennell[2], A. Hajiloo[2]

[1]Brunel University London, United Kingdom; [2]Enertechnos, United Kindom

With the development of offshore wind power, long-distance cable transmission is required to transmit fluctuating power. A Capacitive Transfer System (CTS) cable was proposed to decrease the line reactance to increase the transmission capability by the designed dielectric layers between strands and special connection of the strands. Because of the dielectric layers between strands, the paths of eddy currents

between strands are blocked. In addition, the dielectric layers between strands work as a long capacitor to cancel the line inductive reactance. The geometry design of CTS IV L model is demonstrated in COMSOL. Finally, a set of laboratory tests are carried out to verify the reactive power compensation.

3:45pm - 6:00pm
Grand Foyer 3 & 4

P5: TRANSFORMERS

Session Chair: **Diego Robalino**

Simulation of nanofluid as a two-phase flow in a distribution transformer

L. Raeisian[1], P. Werle[1], H. Niazmand[2]

[1]Leinbiz University of Hanover, Germany; [2]Ferdowsi University of Mashhad, Iran

In this article, the natural convection heat transfer of Fe3O4/oil and graphene/oil nanofluids and mineral oil inside a 200 kVA distribution transformer is numerically studied. The Fe3O4/oil and graphene/oil nanofluids were simulated as a mixture two-phase flow where mineral oil was modeled as a single-phase flow with the temperature dependent thermophysical properties. Based on the simulation results, the nanoparticles when dispersed in oil enhance the convective heat transfer of oil and decrease its hotspot temperature. So that, the hotspot temperature of the Fe3O4/oil and graphene/oil were respectively 1 ˚C and 4.5 ˚C lower than that of the mineral oil. In addition, the transformer filled with graphene/oil nanofluid experienced considerably lower temperature in the thermally critical region. According to the obtained results, employing the nanofluid improves the cooling performance of the transformer, which leads to a more reliable operation and longer life.

Prediction Method for Power Transformer State Based on Chaos Theory

J. Yang[1], P. Zhang[1], Z. Wen[1], Q. Wang[2], B. Qi[1], C. Li[1]

[1]North China Electric Power University, China, People's Republic of; [2]Maintenance and Test Center of Extra High Voltage Company of China Southern Grid

Power transformer is one of the most expensive and important equipment in power system. Transformer fault will directly affect the stability of power system and cause irreversible loss to itself. It is of great significance to predict the operation state of power transformer and timely repair or recover it. However, the actual prediction method for transformer fault is insufficient in analyzing the correlation between transformer operating state variables, resulting in slow diagnosis convergence speed and insufficient attention to the internal connection between various fault information. It is difficult to give the transformer operating state and potential fault development trend in the future stage. The monitoring data of transformer oil chromatography are chaotic and predictable. Therefore, this paper proposes a prediction method for transformer state based on chaos theory. Firstly, the phase space reconstruction of a typical transformer oil chromatographic monitoring data in a substation is carried out. Secondly, mutual information method and Cao method are used to calculate the delay time and embedding dimension respectively. Finally, based on the phase space parameters of chaos reconstruction obtained, the chaos prediction model of transformer fault is established by using the weighted first-order local prediction method, and the transformer state is predicted.

The Method of Identifying and Repairing Abnormal DGA Data for Transformer Fault Diagnose Based on a Semi-supervised Multi-dimensional Grey Model

Y. Wang[1], R. Zhang[1], Z. Wen[1], J. Cheng[2], B. Qi[1], P. Zhang[1], C. Li[1]

[1]North China Electric Power University, China, People's Republic of; [2]State Grid Fujian Electric Power Company, China, People's Republic of

Transformers are important equipment for power system, and accidental power outage caused by their failures can lead to huge losses to the national economy. Therefore, it is of a great significance to realize on-line monitoring and fault diagnose of transformers. DGA is a common basis for transformer state evaluation, which collected from built-in sensors and offline oil chromatography gas content measurement experiments. Affected by factors of accuracy and sensitivity of devices, the previously available fault data has large outliers. Especially for the severe electric heating conditions, the above abnormal data is obvious. The abnormal data cannot accurately reflect the actual state of devices, increasing the possibility of model divergence and affecting the ability of the fault diagnosis model to identify. In this paper, a semi-supervised multi-dimensional grey anomalous data identification and repair method for transformer fault diagnose is proposed. Firstly, this paper summarizes the existing fault diagnose models and analyzes the advantages of them. Secondly, this paper proposes an anomaly data recognition model based on semi-supervised fuzzy C-means clustering (SS-FCM), which can map different types of fault data into high-dimensional space. Finally, this paper proposes an abnormal data repair model based on multi-dimensional grey theory, through which obvious abnormal points can be repaired. This method focuses on the multi-dimensional relationship of different kinds of gases of different fault types. Based on this relationship, the abnormality of the original data is identified and repaired, which improves the quality of data and provides a reference for the fault diagnose modeling of transformers.

Method for Interpolating Monitoring Data of Dissolved Gas in Oil for Power Transformer State Assessment

R. Zhang[1], P. Zhang[1], Q. Wang[2], B. Qi[1], C. Li[1]

[1]North China Electric Power University, China, People's Republic of; [2]Maintenance and Test Center of Extra High Voltage Company of China Southern Grid

Power transformers are the key equipment of power systems. Dissolved gas analysis (DGA) in transformer oil is an important method for evaluating the state of the transformer. However, due to the influence of electromagnetic interference and harsh operating environment, the dissolved gas content data in the oil obtained by the online monitoring system has a large number of missing values. Incomplete data sets cause difficulties in transformer state assessment. The Markov process can analyze the possibility of the system shifting between all states. Therefore, this paper proposes a Markov model based method for interpolating dissolved gas monitoring data in transformer oil. The dissolved gas data in the oil that changes with time is converted into a Markov chain transferred between different states, and the complementary value is calculated by using the state transition matrix. This paper establishes a comprehensive evaluation system for the quality of dissolved gas data in oil from the perspective of data mining, the effect of data completion is evaluated from multiple angles, and D-S evidence fusion theory is applied. The accuracy of the method is verified by field data.

Influence of pressboard orientation in the electric field on lightning impulse discharge characteristics of oil-pressboard insulation

J. Li[1], C. Wei[1], Y. Wu[1], S. Wang[1], Y. Lin[1], L. Huang[2], H. Li[2], Y. Wang[2]

[1]Jiangsu Electric Power Company Research Institute, Nanjing, China; [2]Chongqing University, China, People's Republic of

In recent years, due to the high concentration of solid particles in transformer insulating oil, some large power transformers domestic and abroad have caused insulation fault. The influence of metal particles on the breakdown voltage of transformer oil is self-evident, relevant research shows that the damage of metal particles to the insulation performance of transformer oil is much higher than that of non-metallic particles such as cellulose particles. In this paper, a discharge test tank was designed and manufactured, and a lightning impulse discharge test platform for oil-paper insulation was built based on shadow imaging principle. The preparation method of insulating oil sample containing fixed metal particle concentration was put forward, a streamer development characteristic test scheme had been worked out. The effect of copper particles on the discharge characteristics of oil-impregnated insulating paper under two different field arrangement was studied. Discharge streamer imaging experiments of two insulating paper models were carried out under pre-breakdown voltage, and the streamer morphology characteristics were compared with the pure oil gap. When the insulating paper is placed along field lines, the streamer tends to develop along the surface of the insulating paper as a whole, and the insulating paper will speed up the development of streamer in oil. When the insulating paper is placed perpendicular to field lines, the paper will not affect the development of the streamer between the oil gaps, but will prevent the final formation of the main discharge channel of the streamer.

Research on Correlation Degree of Oil Chromatographic Data for Transformer Fault Prediction

Y. Wang[1], Z. Wen[1], R. Zhang[1], J. Chen[2], B. Qi[1], P. Zhang[1], C. Li[1]

[1]North China Electric Power University, China, People's Republic of; [2]State Grid Fujian Electric Power Company, China, People's Republic of

Power transformers play an important role in power system. Accurately predicting the operating state of transformers is important to monitor and control the power systems. Most of fault predictions are based on transformer oil chromatography data. Because of the insufficient consideration of the time domain, gas types and fault types, the existing fault prediction models often have large errors. In addition, there are large uncertainties in fault prediction and equipment state estimation. To fill this gap, an oil chromatography data mining method for fault prediction of power transformers was proposed. Firstly, the existing fault prediction models were summarized as the basis of model. Secondly, a correlation measurement method for transformers, which was based on the autocorrelation principle, was proposed to measure the time domain of continuous DGA time series. Thirdly, based on the fault case database, a DGA sequence correlation degree measurement method with the Maximal Information Coefficient was proposed to measure the relationship between different gases. Finally, combined with the results of data mining, the multi-dimensional relationship of oil chromatography data was summarized. In this paper, the data mining method was used to analyze the correlation of oil chromatography data between different time, different gas types and different fault types. This method is suitable for oil chromatography fault diagnose with strong fuzzy characteristics and uncertainty. It can support the accuracy of existing fault diagnose and prediction methods.

Research on Transformer Condition-based Maintenance Optimization Based on Live Detection

J. Deng[1], C. Wei[2], J. Li[2], H. Li[3], G. Wang[3], Y. Wang[3]

[1]State Grid Jiangsu Electric Power Co., Ltd.; [2]State Grid Jiangsu Electric Power Co., Ltd. Electric Power Research Institute; [3]ChongQing university, China, People's Republic of

At present, the maintenance strategy for transformers mainly focus on the optimization of maintenance mode and time, while the influence of state parameter detection mode on power grid is often ignored. Considering the popularization and application of live detection technology, an optimization method of transformer state maintenance strategy based on live detection is proposed, which considers the economy and reliability. Firstly, on the basis of defining the key detection parameters of power cut test, an alternative analysis model based on online oil chromatographic data is constructed for replacing power cut test parameters. And then the average value of absolute error is introduced as an evaluation index to determine whether to replace or extend the power cut test, which is called the formulation of optimal scheme. Finally, a quantitative model of acquisition risk of state parameters and transformer failure risk is established with the comprehensive optimization of reliability and economy as decision variables. The example of maintenance decision-making for a 220kV transformer shows that the state maintenance based on live detection can reduce the maintenance cost on the principle of ensuring safe and reliable operation of transformer.

Study on the Ageing Characteristics of Persea Americana Oil as an Alternative Transformer Insulation oil

B. M. Makaa, G. K. Irungu, D. K. Murage

Jomo Kenyatta University of Agriculture and Technology, Kenya

Mineral insulation oils have been used as a liquid insulation in electrical equipment for several decades. However, mineral oil is non-biodegradable and non-renewable. It has been predicted that they may run out in the near future. There is thus an urgent need to find their alternatives. Natural, plant based insulating oils are the solution. They are non-toxic, and possess higher fire points and excellent biodegradability characteristics. Therefore, to improve fire safety of transformers and to decrease the harmful environmental impact, there is an increasing demand for these insulating liquids as transformer insulating oils. Persea americana ester (PAE), a plant based oil has high biodegradability and is renewable. PAE has shown through experiments, a likelihood of being an alternative to mineral insulation oil (MIO) because of its good physico-chemical and electrical properties, so far investigated. Since insulating oil for transformers is used over several years, it is imperative to study the ageing characteristics of proposed new insulation oils. Accelerated ageing using open beaker method with copper catalyst was carried out to predict the reliability of Persea americana oil when in operation. The ageing test was based on accelerated thermal ageing to induce the ageing mechanisms within a short period (96 and 164 hours). Results obtained for Specific Resistivity at 27oC and 90oC, Dielectric dissipation factor, Total acidity and sludge for PAE; suggest that PAE could be a potential transformer insulating liquid. For comparison, the corresponding properties of mineral insulation oil (MIO) in the same experimental conditions were also measured. The results obtained as per the IEC and ASTM specifications gives hope for new natural liquid insulation oil.

3:45pm - 6:00pm **P6: SWITCHGEAR**

Grand Foyer 3 & 4 Session Chair: **suat ilhan**

Classification of Insulating Liquids Thermal Treatment Using Infrared Spectroscopy and Multivariate Statistical Method

P. Prosr, R. Polansky, J. Pihera, P. Hahn

University of West Bohemia, Czech Republic

Paper is focused on the investigation of the possibility of using statistical methods as discriminant analysis and principal component analysis for a classification of the aging of insulating material. The Statistical method was used in combination with Fourier Transform Infrared Spectroscopy results (FT-IR). The investigation was carried out on thermally aged mineral oil samples. The tested oil was exposed to thermal treatment at a temperature of 130°C for times ranging from 24 to 572 hours. Infrared spectra were measured at predefined times of aging using transmission technique in the middle area of the infrared electromagnetic spectrum. Program TQ Analyst was used for other evaluation of changes in measured infrared spectra and the possibility of their separation according to aging times. Based on the experiment performed, discriminability of individual levels of aging based on infrared spectra (IR) measurements was identified even in cases of minimum spectra differences. Combination of FT-IR measurement together with the application of multivariate statistical methods seems to be promising in possible application to aging level identification and automatization of the process of evaluation.

Geometrically Optimized Phase Configurations and Sub-conductors in the Bundle for Power Transmission Efficiency

S. M. Razavi Borghei, M. Ghassemi
Virginia Polytechnic Institute and State University, United States of America

This paper develops a revolutionary design for transmission lines by shifting phase configurations and sub-conductors into unconventional arrangements that are geometrically optimized, leading to very high surge impedance loading (HSIL) and very low corridor width (CW) (ultra SIL/CW).

Insulating Liquids, an Alternative to Silicone Gel for Power Electronic Devices

O. AGRI[1,2,4], J. L. AUGE[1,3,4], E. VAGNON[1,2,4], F. BURET[1,2,4]
[1]Université de Lyon; [2]Ecole Centrale de Lyon; [3]Université Claude Bernard Lyon 1; [4]Laboratoire Ampère, France

This paper studies the breakdown voltage for different insulating materials encapsulating power electronic devices. A comparison between some liquids and silicone gel is carried out. The 50 Hz AC voltage tests were performed according to the IEC 60156 specifications. The same process was applied to the DC voltage tests due to a lack of standard procedure concerning DC voltage tests on liquids. In each case, a ceramic substrate was placed in a container filled with the insulating material. A voltage was applied between two electrodes glued on the substrate. Mineral, both synthetic and natural ester oils and silicone gel were tested. The voltages of breakdown between oils were quite similar in AC and DC. The gel is more resistant to DC stress even though its self-healing is less than the liquids investigated.

A Study of Relationship Between V-t and Tanδ Characteristic on Epoxy Resin

J. YOON, J. KWON, J. RYU, C. BAE, J. CHOI, Y. KIM, K. LIM
LSIS, Korea, Republic of (South Korea)

In electric power equipment, the insulator is an important item. Long-term operation of the facility reduces the electrical and mechanical strength of the insulator. This aging of insulator causes fatal defects in the stable operation of the facility. That is, the lifetime of the electric power equipment and the degradation progress of the insulator are closely related. Therefore, the life of an insulator determines the life of equipment. In this paper, a long-term stress experiment was carried out on epoxy resin. Epoxy is mainly used as a spacer material for GIS. The aging stress was tested up to 3000 hours by applying voltage and thermal stress. In order to predict the lifetime of the epoxy resin, V-t characteristics were obtained by using the Weibull distribution. The life parameter n and A was calculated from the V-t characteristics. Also tanδ by the aging progress was measured and plotted on the graph. As a result of the experiment, a life prediction equation of the material by electric stress was presented. Finally, through the relationship between the V-t characteristic and the tan δ characteristic did estimate the aging progress of the insulator.

3:45pm - 6:00pm
Grand Foyer 3 & 4

P7: NANODIELECTRICS

Session Chair: **Pugazhendhi Sugumaran Chelladurai**

Effect of Gas-phase Fluorination on Trap Level of Nano-Alumina / Epoxy Resin Nanocomposites

F. Wang, M. Z. Khan, L. He, Z. Huang, M. Yang
Chongqing University Chongqing China, China, People's Republic of

In this work, nano-alumina / epoxy resin nanocomposites with nano-alumina fraction of 1, 3 and 5 wt.% were prepared and subsequently fluorinated at 40°C in F2/N2 gas mixture (20/80 v/v) with pressure of 0.05 MPa. The nano-alumina was treated by the saline coupling agent of γ-aminopropyltriethoxysilane (KH550) to restrict the aggregation. The chemical bonding was examined by Fourier transform infrared spectroscopy (FTIR) which has indicated the molecular-chain scission during the gas-phase fluorination. The trap density and trap level distribution in the nanocomposites before and after fluorination were investigated by thermally stimulated current (TSC). The results shown that fluorination introduces shallow traps on the surface which increases the surface conductivity. Hence depth of charge traps are considerably reduced after fluorination. The results shown that nanocomposites with 1 wt.% nano-alumina appeared with deeper traps and higher trap energy level comparing with the other samples. However with increased nano- alumina mass fraction, e.g. 3 and 5 wt.%, considerable over-lapping interaction zones appear, that results in the reduced trap energy level.

Space Charge Analysis of Epoxy-Boron Nano-Composites and the Importance of Dispersion Techniques

D. Saha[1], R. Kochetov[2], P. H. Morshuis[3]
[1]Technische Universiteit Eindhoven; [2]ABB Switzerland; [3]Solid Dielectric Solutions

The present research work analyzes the space charge (S.C.) behavior and correlated dynamics in epoxy based nano-composites (NC) with hexagonal boron nitride (hBN) nanoparticles. The importance of adopting an effective particle dispersion technique for producing such nano-composites is also experimentally validated. Three different dispersion techniques are contrasted in terms of the corresponding space charge behavior exhibited, and the interplay between increasing filler content and

dispersion techniques is investigated and reported. It is observed that an effective particle dispersion technique results in a homogeneous distribution of nano-particles in the polymeric matrix, which in turn gives rise to evenly distributed trap sites and affects the local mobility of charge carriers, effectively restraining them. More significantly, since most of the developed trap-sites are located close to/in the interfacial zone between the injecting electrode and nano-composite specimen, an initial, reasonably homogeneous distribution of nano-particles at relatively lower loading (vol. %) is just as efficient in restricting bulk space charge accumulation as higher loaded nano-composite specimens – proving the importance of adopting an effective particle dispersion technique. Achieving lower levels of bulk space charge accumulation (as demonstrated in this work) results in smaller internal electric field distortion and stress in insulation material, thus having the beneficial effect of prolonging operational life-time and increased reliability.

3:45pm - 6:00pm
Grand Foyer 3 & 4

P8: TESTING TECHNOLOGIES

Session Chair: **suat ilhan**

Diagnostic Technique for Electrical Tree by Current Integration Method

S. Iwata[1], R. Kitani[1], T. Takada[2]

[1]Osaka Research Institute of Industrial Science and Technology, Japan; [2]Tokyo City University, Japan

The degradation of insulating property of polymeric materials was evaluated by the new diagnostic technique of current integration system, hereafter referred to as the “Q(t)-meter”. The Q(t)-meter measures the change with time in integrated charge accumulated by a capacitor inserted between a DC high-voltage power supply and a sample of the insulation material under study. Q(t)-meter is suitable for the monitoring of time dependence of leakage current of the insulating sample under DC voltage. To demonstrate the performance of this new device, we evaluated the influence of generation and propagation of “electrical tree” in epoxy resin sample on DC leakage current. The electrical tree is a typical electrical degradation of polymeric materials. Hence, non-destructive diagnostic methods for electrical tree are expected. In this study, the electrical tree was generated in the epoxy resin by AC high voltage between two needle electrodes. The inter-electrode distance was 2 mm. In the Q(t) measurement, the sampling frequency, total sampling time, DC applied time, and test voltages were 2 s, 600 s, 900 s, 250-1,000 V, respectively. We conducted Q(t) measurement at three stages of electrical treeing -before tree generation, after tree generation, and after tree propagation. It was found that the leakage current increased with increase in the tree length. A remarkable trend of steep rise and fall in the Q(t) curve was also observed. Experimental results obtained by the Q(t)-meter were analyzed assuming an “RC circuit model”.

Date: Tuesday, 18/Jun/2019

7:00am - 8:00am
Neilson 1

ABT: Author Breakfast
Session Chair: **David McKinnon**

7:00am - 8:00am
Imperial Ballrooms 1, 2, 3

GBT: General Breakfast

8:00am - 9:40am
Imperial Ballroom 4

TR3: TR - Asset Health and Management
Session Chair: **Christoph Krause**

8:00am - 8:25am

Transformer Remnant Life Estimation and Asset Management model based on Insulation Stress Assessment

E. T. Mharakurwa[1], G. N Nyakoe[2], A. O. Akumu[3]
[1]Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI), Kenya; [2]Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya; [3]Tshwane University of Technology (TUT), South Africa

The performance and useful life expectancy of a power transformer generally depends on the condition of oil-impregnated paper insulation system that has a finite life span. End of technical life of a power transformer is reached when some of the insulation diagnostic characteristics drop to a level where further operation is unacceptable. Thus, recurrent evaluation of the transformer insulation system diagnostics enhances better estimation of transformer residual life. However, being a function of voluminous conflicting attributes, the design feature, changing operating conditions, and different maintenance strategies, a flawless affirmation of the criteria governing the transformer remnant life estimation is a very complex issue. Power transformer operational condition that can be mirrored by criticality of ageing and fault stress levels has substantial impact on its residual life estimation. This paper explores the possibility of developing a remnant life estimation and asset management decision model based on diagnostics of transformer insulation characteristics. The proposed model is developed upon the integration of the fuzzy logic diagnostic tool and the fuzzy logic remnant life mapping model. The diagnostic details are signified by fuzzy rules for an accurate assessment to reach a defined outcome in terms of fault stress level and energy of faulting, ageing stresses and transformer condition. A multi-criteria analysis was used in developing the model whereby the outcome of the model is achieved by including the combined effect of individual sub outcomes using fuzzification of all the employed attributes. The developed remnant life model is validated using data collected from several in-service mineral oil immersed transformers. Results show that the proposed model provides an approximate but practical means of remnant life estimation and asset management decision.

8:25am - 8:50am

Improving the Assessment of Remaining Life of Service Aged Power Transformers

A. Naderian Jahromi, P. Pattabi, L. Lamarre
METSCO Energy Solutions Inc., Canada

A significant number of power transformers worldwide are displaying an ever-increasing trend of unreliable operation and shortened lifetimes, due to poor electrical or mechanical conditions and onerous loading situations. Monitoring the condition of these transformers and accurately predicting their useful remaining life is quite significant to utilities and/or independent owners especially considering the high replacement cost and criticality associated with the smooth functioning of these assets. In this regard, the condition of the insulation system plays a pivotal role in influencing the remnant useful life associated with power transformers. This paper provides a better estimation for determining the remaining life of a power transformer based on the results of an improved dynamic model. The model is an upgrade over the basic life expectancy formulation provided by existing IEEE and IEC standards in this domain and considers parameters such as hot-spot temperature, moisture, oxygen, the ratio of carbon oxides (CO2/CO), the degree of polymerization (DP) and the concentration of furfural (2-FAL) or methanol (MeOH) as aging markers.

8:50am - 9:15am

Technical and economic analysis of copper utilization on new windings of repaired distribution transformers originally designed for aluminum

J. P. Villibor, E. T. Wanderley Neto, G. P. Lopes, G. H. Faria, M. P. Pereira, T. A. Nogueira, P. V. P. d. O. Tavares
UNIFEI Federal University of Itajuba, Brazil

This paper aims to analyze, technically and economically, the benefits of the copper utilization on new windings of repaired distribution transformers, originally designed for aluminum. Three commercial single-phase distribution transformers commonly installed on urban and countryside areas of Brazil were

submitted to routine tests and temperature rise test. All the tests were performed at LAT-EFEI - High Voltage Laboratory in accordance to Brazilian standards and the Brazilian Labeling Program (PBE) for oil-immersed distribution transformers. The technical evaluation compares the losses before and after the repair process and the temperature rise test results of the repaired transformers. The economic analysis is based on load losses and no-load losses capitalization along the equipment useful lifetime and compares the investment in a repaired level C transformer, made with copper, against level E transformer, made with aluminum, providing the net present value and the investment payback time.

8:00am - 9:40am
Imperial Ballroom 6

PD1: PD - Modeling and Simulation

Session Chair: **Eric David**

8:00am - 8:25am

Plasma Dynamic Simulations of Partial Discharges within Electrical Tree Structures

G. M. Callender, P. L. Lewin
University of Southampton, United Kingdom

This paper is a preliminary investigation into the physical mechanisms of PD within gaseous tubules in a needle plane electrode arrangement. It is intended as a simple representation of an experimental system which formed electrical trees. A drift diffusion model is used to simulate plasma dynamics, where it is assumed that the gas within the tubule is atmospheric pressure air. The findings were in reasonable agreement with the existing literature on the tubule length required to initiate a PD. The PDs were found to be positive streamers, which propagated towards the needle tip at negative applied voltage polarity, and away from the needle tip at positive voltage polarity. There a number of possible developments for future work with the ultimate aim of improving simulations of electrical treeing in high voltage plant.

8:25am - 8:50am

Multivariate Time Series Modeling for Long Term Partial Discharge Measurements in Medium Voltage XLPE Cables

Z. Ahmed, M. Rostaghi Chalaki, K. Yousefpour, J. V. Klüss
Mississippi State University, United States of America

A multivariate time series analysis was performed for a system of several PD response variables, i.e. average charge, number of discharge pulses, average charge current, and largest repetitive discharge magnitude over the data acquisition period. Experimental lifelong PD data obtained from cable samples subjected to accelerated degradation was used to study the dynamic trends and relationships among those aforementioned response variables. Stochastically formulated cointegrated variables recognized by those tests can be combined to form new stationary variables to estimate the parameters for the Vector Auto Regression (VAR) and Vector-Error Correction (VEC) models. The validity of both models was evaluated by generating Monte Carlo and Minimum Mean Squared Error (MMSE) simulated forecasts. True observed data and forecasted data mean values lie within the 95th percentile confidence interval responses which demonstrates the soundness and accuracy of both models. A life-predicting model based on the cointegrating relations between the multiple response variables, correlated with experimentally evaluated time-to-breakdown values, can be used to set an emergent alarming trigger and as a step towards establishing long-term continuous monitoring of partial discharge activity.

8:50am - 9:15am

Research on Stages of AC corona discharge Based on Visible Digital Images Gray-level Co-occurrence Matrix

Z. Guo, Q. Ye, Y. Wang
State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering,Huazhong University of Science and Technology, China, People's Republic of

In terms of optical image digital processing of gas discharge, the morphological research is mainly engaged in the image of UV, which has relatively few studies on discharge state by using grayscale texture information of visible images. Thanks to the progress of photoelectric detecting technique, the visible image contains more abundant space structure information, which makes it possible to detect the characteristic of grayscale texture information. In this paper, the 50Hz AC high voltage power source was applied to the 15mm needle-plane gap under room temperature and atmospheric pressure. The discharge images in the time scale of seconds were obtained by a high resolution digital camera. We introduce the research method of gray-level co-occurrence matrix into the corona discharge image processing. Contrast, entropy, correlation and the expected value ratio of vertical (90°) and horizontal (0°) directions are used to describe the state of corona development. The calculation results show that the contrast and entropy can effectively reflect the corona pre-breakdown state, and the correlation can effectively reflect the initial state. The expected value ratio can effectively reflect the process of growth, suppression, and gap-penetration of the discharge in the positive half cycle, which has a good correlation with the oscilloscope

electrical signals. The method allows us to take advantage of visible light images to study the stages of AC corona, which provides a new method of low temperature plasma diagnostics.

9:15am - 9:40am

Research on arc non-thermal equilibrium characteristics using chromaticity information from a visible digital image

Y. Wang, Q. Ye, Z. Guo
Huazhong University of Science & Technology, China, People's Republic of

In this study, a method was developed for diagnosing the non-thermal equilibrium physical properties of a free burning arc in air using the chromaticity information from a visible image. After extracting RGB values from the image and using digital image processing, the following two comparisons are made: (1) the red-component rate of arc for different electrode materials; (2) the chromaticity distribution at different stages of the AC arc; Analyses are also conducted based on the space radiation characteristics of the arc, differences due to the electrode material. Experiments showed that the proposed method can distinguish experimental materials and arc stages. Furthermore, since the image method is used, the method does not need to assume that the arc is in the thermal equilibrium stage.

8:00am - 9:40am
Imperial Ballroom 8

RM4: RM - Motors/Generators Testing

Session Chair: **Keith Grzegorczyk**

8:00am - 8:25am

A Novel Breakdown Protection Circuit for Endurance Tests under Repetitive Impulsive Voltages

P. Wang[1], Y. Gu[1], Q. Wu[1], A. Cavallini[2], Q. Zhang[3], J. Zhang[4]
[1]Sichuan University; [2]University of Bologna; [3]St. John's University, USA; [4]Northeast Electric Power University

Different from conventional three-phase asynchronous motor working at sinusoidal voltages, the inverter-fed motors are stressed by high frequency semi-square wave voltages generated by inverters. Due to the over-voltages at the motor terminals and the voltage uneven distribution in winding, the electrical field in insulation may reach partial discharge inception voltage (PDIV) and PD will occur with high probability. For the insulation systems of Type II motors, whose insulation is composed of corona-resistance materials, moderate PD activities are allowed. The endurance (lifetime) tests, however, under repetitive impulsive voltages should be carried out to evaluate the insulation performance. One of the problems needed to be solved for the endurance tests at impulsive voltages is how to design a reliable breakdown protection circuit used to remove the samples (in several microseconds) from the whole system when breakdown occurs and record the endurance time. Conventional over-current hardware used under AC and DC voltages cannot be used anymore because the peak magnitude of the normal charging and discharging current at rising and falling flanks of impulsive voltages and the breakdown current are similar. This paper aims to report a novel breakdown protection circuit specially designed for the endurance tests at impulsive voltages. The current at impulsive voltages will be measured by HALL sensors and processed by FPGA in real time to distinguish the possible breakdown current from the normal charging-discharging current and responds to the generator in several micro-seconds when breakdown occurs.

8:25am - 8:50am

Fault Diagnosis in Rotor Windings in DFIG using Magnetic Flux Measurement Coil Antenna

A. U. Rehman[1], Y. Chen[1], Y. Zhao[1], Y. Cheng[1], Y. Zhao[2], T. Tanaka[3], P. Wang[4]
[1]Xi'an Jiaotong University, School of Electrical Engineering, People's Republic of China; [2]Xi'an Thermal Power Research Institute Co. Ltd, Xi'an, Shaanxi, People's Republic of China; [3]Waseda University, IPS Research Center, Kitakyushu, Fukuoka, Japan; [4]Sichuan University, China

Nowadays harnessing electric power through wind is one of the most important forms of sustainable power production. A doubly fed induction generator is commonly used in wind turbines, however short circuit fault of rotor windings severely affect its performance. So for this purpose, an experimental platform has been designed to detect the inter turn short circuit fault in rotor windings in doubly fed induction generator using a magnetic flux measuring coil antenna. The experimental platform has the following nameplate data: 100 kW wound rotor induction machine, supply voltage 400V, rated speed 1800 rpm, stator/rotor connection Δ/Y and rated current 129/45 amp. The experimental setup comprises of the following subsystem: a motor to drive the generator, a condition monitoring system to acquire the date, a control system to regulate the speed and to perform the short circuit fault, a short circuit cabinet to make connection between the generator and control system. The experiment was performed at a no load, 25 kW and 50 kW load conditions. A magnetic field measuring coil antenna having a frequency range of 20 Hz - 500 kHz was placed on the axial side of the generator to acquire the output voltage. An obvious change in the amplitude of output voltage at frequencies of 250 Hz, 270 Hz and 280 Hz was observed, when the inter turn short circuit fault occurred. Which serves as a clear indication of the short circuit fault

in the windings. The amplitude at these frequencies increases as the fault level increases, which is helpful for testing the fault severity. The results show that monitoring the search coil voltage is more effective and advance way than the motor current signature analysis to detect the inter turn short fault in rotor windings in doubly fed induction generator.

8:50am - 9:15am

Evaluation of Offline Partial Discharge in Vacuum Environments

H. W Penrose[1], M. B Dreisilker[2]

[1]MotorDoc LLC, United States of America; [2]Dreisilker Electric Motors, Inc., United States of America

An evaluation of several insulation system types at various degrees of vacuum using repetitive discharge inception and extinction voltage offline testing will be presented. Insulation systems were evaluated in atmosphere and compared to values to 0.1mmHg using a commercial partial discharge surge tester. The insulation systems evaluated include unvarnished windings, dip and bake epoxy, epoxy trickle impregnation, and vacuum encapsulated. The results provide the potential impact of partial discharge with repetitive surges for applications of electric machines in low atmosphere conditions with inverters.

9:15am - 9:40am

Detection of Partial Discharges Occurring in Propulsion Coils of Superconducting Maglev Systems Using a Radio Interferometer System with a Vector-Antenna Mounted on a Test Bogie

M. Kawada[1], R. Ikeda[2], M. Aiba[2], K. Watanabe[2], M. Suzuki[3]

[1]Tokushima University, Japan; [2]Railway Technical Research Institute; [3]TESS Co., Ltd.

We have been studying radio sensing techniques to detect partial discharges (PD) occurring in propulsion coils used in superconducting magnetic levitation (Maglev) systems. In this study, preliminary experiments were carried out for setting an objective of detecting PDs occurring in the propulsion coils by using a radio interferometer system with a vector-antenna mounted on a test bogie, which can be run at the speed of 200km/h by remote control. In the experiments, the radio interferometer system with the vector-antenna was mounted on the test bogie that was kept stopped; PD sources occurring in a propulsion coil were located. The vector-antenna composed of vertical and horizontal dipole-antennas was set to the center of the antenna-array of the on-board radio interferometer system. An antenna-module contains the antenna-array composed of three dipole-antennas and the vector-antenna. Three sets of mock-ups of the propulsion coil and the levitation-guidance coil were arranged in a row on the side of the test bogie. One of the propulsion coils has eight cylinder-shaped holes penetrating through the insulating material to the inner conductor for attaching a needle-electrode; one or some of the holes can be voluntarily chosen to generate PDs. Experimental results show that a PD source generated at a voluntary position of the propulsion coil could be roughly located by using the antenna-array; the vertical and horizontal components (electric fields) of EM waves emitted from the PD source could be separately received by using the vector-antenna.

9:40am - 9:55am **Imperial Ballroom 4**	**COM-T1: Megger**
9:40am - 9:55am **Imperial Ballroom 6**	**COM-T2: Dynamic Ratings**
9:40am - 9:55am **Imperial Ballroom 8**	**COM-T3: ELANTAS PDG, Inc.**
9:55am - 10:20am **Imperial Ballrooms 5, 7, 9**	**EXT1: Exhibition**
9:55am - 10:20am **Grand Foyer 3 & 4**	**CBT1: Coffee Break - T1**
10:20am - 12:00pm **Imperial Ballroom 4**	**TR4: TR - Thermal Characteristics and Analysis - Oil Filled** Session Chair: **Paul Lewin**

10:20am - 10:45am

Effect of Nanofibrillated Cellulose Doping on Properties of Oil Immersed Insulating Paper during Thermal Aging

Y. Mo, R. Liao, L. Yang, Y. Yuan

ChongQing University, China, People's Republic of

To evaluate the performance of Nanofibrillated cellulose (NFC) modified insulating paper under long term running process, 10 wt. % NFC modified insulating paper and ordinary insulating paper were subjected to

accelerate thermal aging for 720 hours in a 130 °C thermal aging chamber. The aging characteristics and electrical performance were measured during the aging process. Results show that NFC modification can delaying the thermal aging rate of oil immersed insulating paper and enhancing the electrical strength of oil immersed insulating paper during thermal aging process. NFC makes oil-impregnated insulating paper more compact during thermal aging process, resulting in higher polymerization degree and crystallinity. NFC modification can increase the relative permittivity and dielectric loss of the oil-impregnated paper during thermal aging process slightly. The AC and DC breakdown strength of the NFC modified paper are better maintained than the conventional oil-impregnated paper.

10:45am - 11:10am

Rapid analytical method for elemental sulphur detection in power transformer insulation

S. B. Garcia[1], R. C. D. Brown[1], G. J. Langley[1], P. Birkin[1], J. Pilgrim[2], P. Lewin[2], G. Wilson[3]
[1]School of Chemistry, University of Southampton, United Kingdom; [2]Tony Davies High Voltage Laboratory, University of Southampton; [3]National Grid House, Warwick Technology Park

Over recent decades there have been reported failures of oil/paper-based transformers caused by corrosion of copper conductor surfaces and breakdown of insulation. A small number of failures were caused by silver corrosion in tap-changers, promoted by the presence of elemental sulphur at mg/kg levels. The electrical power infrastructure and the entire transformer fleet can be at risk from unexpected failures, so preventive measures are necessary. In this work a rapid analytical technique to monitor elemental sulphur levels (< 1 mg/kg) in insulating mineral oil has been developed. The method can be used as a routine test, or to confirm the presence of elemental sulphur in samples where corrosion has occurred. The potential of the method is demonstrated through its application to some real mineral oil samples from transformers.

11:10am - 11:35am

Influence of Oil Duct Variation on Thermal Characteristics of Converter Transformer Winding

C. Liu[1], J. Hao[1], R. Zou[1], Z. Li[2]
[1]State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing University, China; [2]Baoding Tianwei Baobian Electric CO.LTD, Baoding, China

Power transformers are the key equipment of power transmission and distribution system. Therefore, it is necessary to study the influence of different fault types on the temperature distribution of transformer windings. Based on the real converter winding model, a fast solution method is proposed to obtain the temperature and velocity distribution of the winding. And the typical winding faults are analyzed. Oil duct flow velocity in the maximum oil baffle plate, the flow of the oil take away heat, makes the temperature rise between regions is about 6-8 K. Hot spot temperature of the winding is located at 184 the layers (92% of the height) and is 67.3 ℃. With the decrease of oil flow velocity, the increase of the overall winding temperature and the overheating of the end area as a whole. Oil change for little effects on the overall temperature of the winding, but the wire under the narrowed oil channel generated local overheating and became a new hot spot. This paper provides a preliminary exploration for the development of transformer thermal faults.

10:20am - 12:00pm
Imperial Ballroom 6

NA1: Nanodielectrics

Session Chair: **Roman Kochetov**

10:20am - 10:45am

Estimation of Interphase Permittivity and Interphase Thickness in Epoxy based Nanocomposites using Electrostatic Force Microscopy

A. Sharma, S. Basu, N. Gupta
IIT Kanpur, India

Inclusion of a small quantity of metal oxide nano-fillers significantly improves electrical and other properties of a polymer dielectric; literature attributes this improvement to the interphase region between matrix and nano-particle. Till date, direct observation of the interfacial region has not been possible. The current work explores the possibility of detecting the interphase using Electrostatic Force Microscopy (EFM). Experiments are performed on epoxy-based nanocomposites with barium titanate nano-fillers. EFM detects the phase shift around a single nanoparticle embedded in the polymer matrix. A computational model, simulating the experimental conditions, is used to generate the EFM phase shift numerically. This is matched with the experimental EFM phase image, to obtain an estimate of the interphase permittivity and thickness. Statistical analysis of particle size in powder form and when embedded in the epoxy lends credence to the estimates obtained.

10:45am - 11:10am

Influence of Metal oxide and Metalloid Nano Particles on the Dielectric Response of HVDC Cable Nano Dielectric

N. R. BURJUPATI
CENTRAL POWER RESEARCH INSTITUTE, India

Influence of nano fillers like MgO, SiO2 and clay on the dielectric response of HVDC cable dielectric is investigated. Surface treated metal oxide MgO, metalloid SiO2 nanoparticles and nano clay of different concentrations in low density polyethylene was considered for the study. LDPE-nano dielectric was prepared by using Brabender twin screw extruder and thin samples were obtained using hot plate vulcaniser. Electrical & dielectric properties were determined. The study indicated that, inclusion of nano fillers in the LDPE matrix resulted in increase in contact angle and lower wetting energy of the composite. Surface potential decay was observed to be slow with composites indicating increased resistance to surface charge mobility. The relative permittivity and dielectric loss factor of nano dielectric increase with filler concentration and with decreased frequency. The polarization currents decrease exponentially with time and stabilizes in much lower than LDPE. The results are presented and discussed.

10:20am - 12:00pm
Imperial Ballroom 8

RM5: Rotating Machine Insulation Testing

Session Chair: **Alfredo Contin**

10:20am - 10:45am

Impulse Voltage-based Test Method for Identifying the Stator Insulation Component with PD Activity for Low Voltage AC Motors

S. B. Lee[1], A. Naeini[2], S. Jayaram[2], G. Stone[3], M. Sasic[3]
[1]Korea University, Korea, Republic of (South Korea); [2]University of Waterloo; [3]Iris Power - Qulaitrol

IEC 60034-18-41 has been developed as a standard acceptance test to ensure partial discharge (PD)-free operation for improving the reliability of low voltage (LV) variable frequency drive (VFD) motors. Although the test can verify whether PD exists in the stator for a voltage surge with predetermined magnitude and risetime, the information on where PD activity is occurring in the stator insulation is not clearly given. In this paper, a method based on variable risetime surge voltage testing is proposed for identifying the component of the stator insulation system where PD occurs in LV random wound motor stators (turn, phase, or ground insulation). This information can be used for increasing the PD inception voltage for improving the reliability of the motor through insulation system design/manufacturing. The test is implemented with a 4.5 kV variable risetime surge generator prototype. 4 LV ac motors are tested to show where PD is likely to occur in commercial LV motors.

10:45am - 11:10am

Dielectric response analysis as tool to assess the mechanical deterioration of VPI insulation

C. Staubach[1], S. Meissner[1], A. Cimino[2]
[1]University of Applied Sciene Hannover, Germany; [2]TU Dortmund, Germany

In this paper test bars are mechanically aged by means of a cyclic bending test setup. At specific time intervals the dielectric response analysis is performed on these bars. This diagnostic technique consists of a combination of polarization and depolarization current (PDC) measurement in the time-domain and frequency-domain processing of the measurement results together with a frequency-domain spectroscopy (FDS). The aim of this work is to investigate the possibility to assess the degree of mechanical deterioration by means of this diagnostic technique. Ideally, a correlation between the mechanical lifetime consumption and the change in the measurement results can be derived.

11:10am - 11:35am

Compatibility of Mica Binder Resins with Medium and High Voltage Impregnation Resins

T. T. Nguyen
ELANTAS PDG, Inc., United States of America

To process and test high voltage sample bars or full sized coils of a generator or motor stator, requires a lot of time and expense. If there is a way to break the testing down into small parts using smaller specimens, a lot of time and expense could be saved.

In this study, we will prepare samples using 80% to 90% of epoxy, unsaturated polyester and polybutadiene impregnating resins with 10% to 20% of various mica binder resins for test. Based on the combinations of both resins, a study of electrical properties including dissipation factor (DF) will be conducted. With the study of these properties, we hope to identify a potential screening procedure for the selection of resins prior to the impregnation of high voltage coils or test bars.

11:35am - 12:00pm

Synthesis of Experiences using Resistive Temperature Detectors (RTD) as PD Sensors for Detecting and Locating Electrical Defects inside Generator Stator Windings

R. Kuppuswamy[1], S. Rainey[2]
[1]Dynamic Ratings; [2]North California Power Agency (NCPA)

It is generally accepted within the industry that terminal partial discharge (PD) measurements are less sensitive to electrical discharges deep within the stator windings. Typically, on large generators, electrical defects beyond 10-15% from the line-end of the stator winding cannot be detected. This equates to first 2 to 3 coils from the line-end. Therefore, other measures are necessary to expand the zone of detection.

Large generators and motors are typically equipped with 12 or more resistive temperature detectors (RTDs) embedded into the stator winding. The RTD acts as an RF-antenna placed into a winding that is sensitive to the high frequency component of an electromagnetic pulse caused by PD. The RTD is both capacitively and magnetically coupled to the PD pulse originated by a discharge. Calibration tests show that the RTD is useful in assessing PD levels within a few adjacent slots from its location.

Using case examples, comparison between two forms of PD measurements is presented – (a) Conventional terminal PD measurements using three 80pF epoxy mica capacitors on the lineside of each stator winding-phase; (b) Deep winding PD monitoring using embedded resistive temperature detectors (RTDs) as PD sensors. For the latter case, few RTDs in each stator winding-phase were selected to cover high and low potential slots in the winding. Detecting PD at lower potential slots using RTDs allows to detect faults caused by loose bars in the slot, “vibration sparking”.

This report synthesizes the overall PD monitoring experience using collection of experiences from hydro and turbo generators. The focus is placed on demonstrating how RTDs have helped catch faults close to the winding neutral. Defect location capability of RTD PD sensors is demonstrated and results compared.

12:00pm - 2:00pm
Imperial Ballrooms 5, 7, 9

EXT2: Exhibition

12:00pm - 2:00pm
Grand Foyer 4

LT: Lunch - Tues

Session Chair: **Kevin Alewine**

2:00pm - 3:40pm
Imperial Ballroom 4

CA2: Cables - Materials

Session Chair: **Ali Naderian Jahromi**

2:00pm - 2:25pm

Additive effect on dielectric spectrum of crosslinked polyethylene used in nuclear power plant cables

S. V. Suraci, D. Fabiani, C. Li
DEI - University of Bologna, Italy

Low-voltage electrical cables are extensively used throughout nuclear power plants (NPP) for power transmission, control of equipment and instrumentation, communication of signals and data. Most of the NPP commissioned in ’70s and ’80s are now reaching end-of-life but decommission costs are pushing NPP regulator to ask for life extension of NPPs to 60 (possibly even 80) years . Since electric cables are one of the long life equipment that have not considered for replacement during the design life of a NPP, usually 40 years, evaluating degradation condition and predicting residual life are very critical issues. Finally, as new reactors are being constructed and many others are in planning for the next future, appropriate cable choice and use of effective condition monitoring (CM) techniques to assess cable condition from commissioning, can be very useful at a later time for an effective cable lifetime management.

This is the scope of a new EU Project called TEAM CABLES which aims at providing NPP operators with a novel methodology for efficient and

reliable NPP cable ageing management by developing cable ageing models and algorithms, which are based on multi-scale studies and can be tailored to cover variations in fillers, additives and degrees of crosslinking.

In this paper, in particular, the effect of different fillers and additives on the dielectric spectroscopy of the cable insulation is investigated in order to single out the main factors which could be correlated with radiation and temperature aging. It is shown that the addition of antioxidants and fire retardant fillers provide a modification of imaginary permittivity spectra with respect to the base material. With thermal and radiation aging a significant increase of permittivity at high frequency, i.e. above 100 kHz, is observed, particularly for the base material, without additives. This is a first step towards modelling of electrical properties with aging of materials used as electrical insulation in NPP low-voltage cables.

2:25pm - 2:50pm

High Resolution Chemical Analysis of Electrical Trees through AFM-IR Spectroscopy

H. McDonald, S. Morsch, S. Rowland
The University of Manchester, United Kingdom

Accurate modelling of electrical tree growth is dependent upon a physical and chemical understanding of the insulation and degradation processes on the scale of the tree branches. While imaging techniques for the physical elements of tree growth have improved in recent years, those for the chemical regime are lagging behind. In this paper AFM-IR (Atomic Force Microscopy - Infrared Spectroscopy) is applied to a non-conducting tree channel grown in epoxy resin. This provides chemical analysis with a spatial resolution of 50 nm. The distinct chemistries from within buried channels, exposed channels and the epoxy bulk are revealed for the first time.

2:50pm - 3:15pm

Off-line and Simulated On-line PD Tests on Thermally Aged MV Cable Joints

A. Contin[1], J. Borghetto[2], G. Pirovano[3], C. Tornelli[4]
[1]University of Trieste, Italy; [2]R.S.E. Milano, Italy; [3]R.S.E. Milano, Italy; [4]R.S.E. Milano, Italy

The diagnostic results provided by Partial Discharges (PD) measurements, performed by testing on-line and off-line MV cables, is discussed in this paper. Twelve cables equipped with different types of joints were connected together to form a ring in short-circuit. The ring was energized at rated voltage and current. Temperature cycles with a period of one day were applied by inducing and controlling the current by means of heating toroidal transformers. PD were monitored during the heating and cooling periods. After given umber of thermal cycles, each cable was tested separately at different voltage levels and at room temperature. Experimental evidence shown that the formation of a defect in XLPE cables was discovered earlier during on-line PD monitoring, while off-line PD were detected only after a significant number of thermal cycles. It was also observed a random behavior of PD activity during the heating/cooling periods with a progressive attenuation of the partial discharge phenomenon. After such periods, off-line PD tests allowed to discover the presence of the defects.

3:15pm - 3:40pm

A Modified Measuring Technique Based on the Isothermal Relaxation Current Measurement Used for Power Cable

X. Zhu[1], J. Wu[1], X. Zheng[2], Q. Bao[3], C. Zhang[3], Y. Yin[1]
[1]Department of Electrical Engineering, School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, China; [2]Zhoushan Power Supply Company, Zhejiang Electric Power Corporation of State Grid, China; [3]Wuxi Jiangnan Cable Co., Ltd, China

Isothermal relaxation current (IRC) method is a non-destruction evaluation method for cable based on the dielectric response theory. In this paper, a modified IRC measurement technique is put forward to eliminate the current interference produced by test line. The equivalent circuit of XLPE cable with IRC system is built to analyze the relaxation current, and a modified measurement circuit is designed based on a method of independent measurement loop. The modified circuit can exclude the interference produced by test line from the measurement loop. By the use of the Multisim software, the difference among ideal current, current with interference and current acquired by the modified circuit is discussed, which demonstrates the feasibility and the validity of modified technique in theory. Furthermore, an IRC system is established, and a XLPE cable which has been aged thermally is detected by the IRC system. The results show that there are a lot of deep traps distributed in the aged cable insulation, which verifies the effectivity of the modified technique in practice.

2:00pm - 3:40pm | OI2: OI - Transmission Lines, Insulators, and Protection

Imperial Ballroom 6

Session Chair: **Richard Cselko**

2:00pm - 2:25pm

Statistical Significance of Wavelet Extracted Features in the Condition Monitoring of Ceramic Outdoor Insulators

A. S. Haiba[1,2], A. Gad[1], S. M. Eldebeikey[1], M. Halawa[2]
[1]Ain Shams University, Cairo, Egypt; [2]National Institute of Standards, Giza, Egypt

The components of high voltage transmission lines such as towers, insulators, wires, and accessories are continuously subjected to severe environmental conditions. As a result, it is necessary to monitor their health condition to prevent any sudden interruption in the supplied load and to allocate the maintenance investments where they are highly needed. Defective discs of ceramic insulators essentially contain partial discharge (PD) activities; i.e., the presence of PD activities may characterize the insulator's poor condition. The detection of radio frequency (RF) waves emitted from the PD activities is an emerging technique to monitor the insulator's condition during its operation. In this paper, various artificial defects are introduced

to the insulator discs and the corresponding RF signatures are captured using a high frequency sensor under the normal operating voltage. Several features are extracted from the captured signals after their decomposition using the discrete wavelet transform. The analysis of variance test has been adopted to evaluate the significance of each feature and level in identifying the defect type. This step facilitates the training of an intelligent classifier that will automatically distinguish the insulator strings that has to be replaced along the line.

2:25pm - 2:50pm

Electrical Performance of HTV Silicone Rubber under Different Fillers and Filler Loadings

S. ILHAN, D. TUZUN, A. OZDEMIR
Istanbul Technical University, Turkey

This paper presents tracking and erosion performance of high temperature vulcanizing (HTV) silicone rubber (SIR) materials for different filler loadings. Different concentrations of alumina trihydrate (ATH) filler particles of 3.6 µm median size and silica (SiO2) filler particles of 4 µm median size are considered together with HTV-SIR material. Tracking and erosion performance of the compositions were evaluated by using standard inclined plane (IP) tracking and erosion tests, according to IEC 60587 standard. IP tests are performed at 3.5 kV power frequency (50 Hz) constant test voltages, for 0.3 ml/min contamination flow rate, at an ambient temperature of 23 ± 2 Degrees C, and for six hours of test periods. Time-to-failures, eroded masses, and leakage currents of HTV-SIR filled with ATH and silica particles are investigated for different filler concentrations.

2:50pm - 3:15pm

CFD Simulation of a High Voltage Circuit Breaker Coupled with a Mechanical Operating Mechanism

M. T. Dhotre, F. Agostini, S. Kotilainen
ABB Switzerland Ltd, Switzerland

In high voltage circuit breakers, the arc extinction is achieved by the pressure generated from the arc. The generated pressure is such that it acts against the mechanical operating mechanism used for the contacts separation. This process leads to slower or even reverse movement of the contacts. In the present work, such a contact travel behavior is evaluated using a fully coupled simulation of the arc physics and of the mechanical drive. Furthermore, the design measure and possible optimization of the pressure and drive energy is presented to limit the reverse travel of the contacts.

2:00pm - 3:40pm
Imperial Ballroom 8

RM6: Rotating Machine Partial Discharge Optical

Session Chair: **Stan Gubanski**

2:00pm - 2:25pm

Improvements in the Identification of Defects on the Semiconducting Slot Coating of Stator Bars Using Partial Discharges

F. PEREIRA[1], H. TATIZAWA[2], M. ZANOTTI[2]
[1]VOITH HYDRO LTDA, Brazil; [2]Instituto de Energia e Ambiente da Universidade de São Paulo

The present work describes how the detection of surface defects located in the slot portion of high-voltage bars (or coils) can be improved with the use of partial discharge (PD) tests. In spite of all care, surface defects capable of damaging the semiconducting slot coating of bars can eventually be created during their manufacturing process or later on, during their installation at site. Although the most commonly used methods to search for surface defects are based upon visual inspections, this work will explore a possible improvement in such methodologies by using electrical methods, such as the acquisition and discrimination of PD pulses. The results shown here represent a first progress report of a larger ongoing project that aims to develop a test method suitable for the quality control of bars and coils mass production. To address the topic in laboratory scale, a series of artificially created defects were produced and systematically tested with different parameters. A number of test conditions was employed to determine under which circumstances the test can be sensitive enough to permit a clear detection and discrimination of the surface damages. It was found that although the mere recording of PD amplitudes is a simpler and straightforward method of detection, it is the analysis of the complete PD patterns that provides the most useful information to identify the defects.

2:25pm - 2:50pm

Thermal Imaging for Rapid Noninvasive On-site Insulation Diagnostics

S. L. Morrison, J. Kluss, L. Cagle, J. Ball, S. Bryan
Mississippi State University, United States of America

High voltage electrical failures are dangerous and costly events in any type of power system. The troubleshooting and diagnostic time required to identify and locate these failures can be significant. Partial discharge is one of the early warning signs for electrical degradation. In insulation systems, partial discharge typically occurs in voids located within the dielectric, at material interfaces, or along energized electrode surfaces. Effective methods for finding this failure precursor enabling circumvention of future catastrophic events are highly valuable as successful detection can improve safety, reduce service interruptions, and result in significant financial savings. The presented method was successful in localizing the excess stress without direct line of sight, a clear advantage over night vision and corona cameras. The investigated methodology provides the ability for any user in varying on-site conditions to quickly and noninvasively diagnose the health of a component or device while maintaining safe clearance from energized parts.

2:50pm - 3:15pm

UHF Measurement of Partial Discharge on Stator Bars Using Patch Antennas

M. Partyka[1,2], G. E. Bridges[1], W. McDermid[2], T. Black[2], B. Kordi[1]
[1]University of Manitoba, Winnipeg, Manitoba, Canada; [2]Manitoba Hydro, Winnipeg, Manitoba, Canada

Compared with other methods, there is limited research on the measurement of partial discharges (PD) in rotating machine windings using antenna-based UHF techniques. In this work, to investigate the value of measuring winding PD at higher frequencies, we designed and fabricated three patch antennas operating at 900, 1500, and 2450 MHz. The antennas are used to perform UHF PD measurements on single rotating machine bars rated at 13.8 kV. Measurements were performed in a laboratory with the specimens placed in grounded dummy stator slots. PD was produced by over-stressing the test specimens with a PD-free high voltage test set, and also by shorting out stress control region(s) using semi-conductive tape. The UHF PRPD patterns were compared to those from measurements on the same specimen with a VHF commercial instrument. It was clearly shown that PD can be measured with UHF patch antennas, despite some disagreement between UHF and VHF PRPD patterns.

3:15pm - 3:40pm

Scanning Individual Stator Bars and Coils with an Antenna to Detect Localized Partial Discharges

C. Hudon, É. Cloutier-Rioux, H. Provencher
Hydro-Quebec IREQ, Canada

Partial discharge (PD) measurements have been carried out for years on generators, individual bars and form-wound coils. Even if the determination of quantitative criteria for what is considered normal and abnormal PD still represents a challenge in the industry, phase resolved partial discharge (PRPD) pattern recognition has been successfully used to recognize the nature of PD activity [1-3]. In the present work, conventional PD measurements using a capacitive coupler were compared with measurements made using an antenna to detect localized PD sites on individual bars and coils. The antenna was used to map localized PD sites along the entire length of the straight portion. The measurements were carried out on bars and coils of four different designs. The results revealed that the two measurement techniques give complementary information. It was found that the antenna had a limited sensitivity to PD occurring in micro-voids occluded within the groundwall insulation. For most of the bars and coils tested, the antenna did not detect any signal, even if there was always PD activity measured with the standard capacitive coupler. However, some of the specimens tested with the antenna revealed localized PD sites with distinctive PRPD patterns, suggesting that some anomalies were present at these sites. This information can thereafter be used to determine where to perform dissection of bars and coils.

3:40pm - 3:55pm **Imperial Ballroom 4**	**COM-T4: Omicron**
3:40pm - 3:55pm **Imperial Ballroom 6**	**COM-T5: Astro Chemical Company**
3:40pm - 3:55pm **Imperial Ballroom 8**	**COM-T6: Phenix Technologies, Inc.**
3:55pm - 4:15pm **Grand Foyer 3 & 4**	**CBT2: Coffee Break - T2**
4:15pm - 5:05pm **Imperial Ballroom 4**	**CP1: Capacitors - Analysis of Degradation** Session Chair: **William (Bill) McDermid**

4:15pm - 4:40pm

A High Voltage Capacitor Element Model

C. Mackinnon, B. Stewart

University of Strathclyde, Glasgow, Scotland

High voltage capacitors are becoming ever more prevalent on modern electrical power networks, as they offer simple means of power factor correction and voltage support, and are inherent to modern power electronic converter designs. Large capacitor banks comprise many modules, each of which contains an array of individual elements, across which voltage stresses and thermal conditions are shared. A module's partial degradation due to short-circuited elements can increase stresses on the insulation of those that remain, sometimes leading to cascading element failure. This paper presents a high voltage capacitor model, and then explores the distribution of voltage under healthy and short-circuit scenarios. It shows voltage distributions between elements within a capacitor module have nonlinearity due to a module's geometry, and are affected by series element failure.

4:15pm - 5:05pm
Imperial Ballroom 6

CA4: Cables - Partial Discharge Testing

Session Chair: **Gian Carlo Montanari**

4:15pm - 4:40pm

Diagnostic Testing of Power Cable Insulation For Reliable Smart Grid Operation

S. Morsalin, A. Sahoo, B. Phung

The University of New South Wales, Australia

Polymeric insulation, especially cross-linked polyethylene (XLPE) insulated power cables are widely used in practice to transport electrical energy. XLPE has excellent dielectric properties, but its degradation due to various factors while in service is unlikely to avoid. Moreover, electrical, mechanical or thermal stresses accelerate the ageing process and shorten the lifespan. In the era of smart grid, its safe and reliable operation is vital. Hence, condition monitoring of insulation through diagnostic testing has become critically important to the smart maintenance of electrical infrastructure. In this paper, the diagnostic behaviors of XLPE insulation are explained by using two popular diagnostic methods, partial discharge (PD) and dielectric response (DR) measurements. For PD diagnosis, a comparative study of surface discharge and their characteristics under conventional power frequency (50 Hz) and very low frequency (0.1 Hz) excitation are presented. Dielectric responses are investigated in the frequency domain by tanδ measurement and in the time domain by pol/depolarization current measurement. It is shown that useful information for insulation diagnosis can be extracted from the measurement results.

4:40pm - 5:05pm

Study on Location Accuracy of Partial Discharge Locator

K. Yamashita[1], T. Miyake[1], T. Sakoda[1], W. Kawano[2]

[1]University of Miyazaki, Japan; [2]Nishi Nippon Electric Wire & Cable Co., Ltd

At joint and terminal sections of the cross-linked polyethylene (XLPE) cable, partial discharges (PDs) occur in defects of insulating materials. The PD generation can occur at any points in the insulation system where electric field strength exceeds a PD inception electric field and can develop until breakdown occurs. That is, PDs which are owing to local electrical stress in the insulation or on the surface of the insulation reflect a kind of sign of insulation deterioration. Therefore, PD measurement is a useful technique of assessing the insulation deterioration of XLPE cables. For conventional systems to measure and locate PDs, the propagation velocity of PD pulse must be known. However, it likely depends on the aging deterioration of power cable and the number of joint sections. We therefore propose a partial discharge locator (PDL) system which has a time synchronization measure and a unique time generation measure based on LabVIEW. The PDL is possible to locate a PD occurrence position without power interruption. We here show how the PDL works with a time synchronization between detecting devices arranged at both sides of an XPLE cable to be measured. Additionally, it is investigated that the PD-position locating accuracy is within 10 %.

4:15pm - 5:05pm
Imperial Ballroom 8

RM7: Rotating Machine Detection and Testing

Session Chair: **Anna Gegenava**

4:15pm - 4:40pm

Characteristics of the Partial Discharge-induced Current along Epoxy resin film under Superimposed AC-DC Voltage

T. Zhuang[1], X. Gao[1], M. Ren[1], S. Wang[1], J. Huang[2]

[1]Xi'an Jiaotong University, China, People's Republic of; [2]Electric Science Research Institute of Guizhou Power Grid Co.,Ltd

Insulation of power electronic devices and converter station equipment is often under superimposed AC-DC voltage. The understanding of PD characteristics under AC-DC combined excitation plays an important role in designing the insulation of power electronic device. Previous researches focused on the stochastic features and mechanism under AC or DC voltages, while little attention was paid to the PD-induced charge movements under superimposed AC-DC field. The charge movements include the transient behavior of PD and the slow movement, which can be characterized by the transient PD current and the excess

current respectively. In this paper, a composite AC-DC voltage is applied to a pair of rod-plane electrodes sandwiching epoxy film. And a sensitive high-frequency Rogowski coil and a capacitor-resistor shunt impedance are used to simultaneously measure the transient PD current and the excess current during PD. The excess current can be measured by cancelling the capacitive current from the total current. In the measurement, first set the AC voltage at 1.5 times the AC PDIV, then gradually raise the DC voltage up. The results show that, as the DC bias increases, the phase distributions of PD events are expanded, but the average PD currents and excess currents are lower than that under the pure AC electric field. Moreover, only few PD events are observed when the DC voltage rises close to the peak of AC voltage, and the surface flashover starts once the DC voltage rises above the peak of AC voltage. It is proved that the additional DC voltage suppress the corona discharge excited by the AC voltage to a certain extent, but it may also result in surface flashover if the DC bias exceeds the AC amplitude.

4:40pm - 5:05pm

Automated identification of insulation faults using Electro Magnetic Interference methods

J. Slater[1], I. Mitiche[1], A. Nesbitt[1], G. Morison[1], P. Boreham[2]

[1]Glasgow Caledonian University, United Kingdom; [2]Doble Engineering, United Kingdom

On-line condition monitoring of substation electrical equipment depends on reliable, non-invasive surveillance techniques. Early detection of faults helps to mitigate the need for reactive maintenance and unplanned system downtime, thus ensuring continuity of supply. The Electro Magnetic Interference (EMI) method is a surveillance technique that can assist in identifying insulation degradation and conductor faults; such as Partial Discharge (PD) and Arcing. EMI frequency scans are used to identify the frequencies that are characteristic of fault conditions. Time-resolved analysis at these frequencies provides crucial data necessary for the classification of these faults. With the emergence of continuous on-line monitoring, there is an increasing need to embed more intelligence within monitoring devices to automatically recognise developing fault conditions. The main challenges faced with this method is that there is too much emphasis put on engineers in the field being able to identify these key frequencies by eye or knowledge alone, which limits the ability to automate the process. This paper presents a novel 'diagnostic assistant' that will automatically identify the spot frequencies the engineer would manually capture for further, time-resolved analysis. The resultant time-resolved scans are then analysed to perform feature extraction and dimensionality reduction to automatically classify the data to a known fault category. Validation of the proposed techniques has been performed on real world data captured and labeled by engineers in the field. The accuracy of this method is established through direct comparison between the choices made by the engineers in the field to the classification of fault conditions and the decisions of the automated 'diagnostic assistant'. The consistent accuracy of the results obtained paves the way for a fully automated expert system that can identify and classify possible emerging fault conditions utilising EMI diagnostics.

6:00pm - 7:00pm **Grand Foyer 2**	**Reception: Reception** Session Chair: **Kevin Alewine**
7:00pm - 9:00pm **Imperial Ballrooms 1, 2, 3**	**Banquet: Banquet** Session Chair: **Kevin Alewine**

Date: Wednesday, 19/Jun/2019

7:00am - 8:00am
Neilson 1

ABW: Author Breakfast
Session Chair: **David McKinnon**

7:00am - 8:00am
Imperial Ballrooms 1, 2, 3

GBW: General Breakfast

8:00am - 9:15am
Imperial Ballroom 4

CA3: Cables - Partial Discharge
Session Chair: **Sayidul Morsalin**

8:00am - 8:25am

Adding nanofillers in polymeric insulating materials: so far so good? The case of polypropylene for DC cables

G. C. Montanari[1,2], P. Seri[1], H. Naderiallaf[1], A. Blume[3], W. Dierkes[3], G. Perego[4], C. Mazel[4], M. Paajanen[5], M. Karttunen[5]
[1]DEI, University of Bologna, Italy; [2]CEM, University of Texas, Austin, Texas; [3]Department of Mechanics of Solids, Surfaces & Systems, University of Twente, The Netherlands; [4]Nexans Research Center, France; [5]VTT Technical Research Centre of Finland Ltd, Finland

This paper has the purpose to point at the weaknesses implicit in nanostructuration of insulating polymers for cable insulation, with reference to polypropylene and nanosilica. It also tries to single out which types of properties would be more or less affected by nanofiller introduction, and if in a positive or negative way, depending on nanofiller functionalization process. It is shown, for example, that nanofiller might increase, rather than decrease, space charge and conduction current, as an effect of functionalization, and that a decrease of space charge is not necessarily correlated to an increase of life.

8:25am - 8:50am

Towards a Hybrid Power Cable Health Index for Medium Voltage Power Cable Condition Monitoring

J. I. Aizpurua[1], B. G. Stewart[1], S. D. J. McArthur[1], N. Jajware[2], M. Kearns[3]
[1]University of Strathclyde, Glasgow, United Kingdom; [2]Bruce Power, Kincardine, Canada; [3]EDF Energy, Glasgow, UK

Power cables are critical assets for the safe and cost effective operation of the power grid. However, the health assessment of cables is intricate due to its various degradation mechanisms. Motivated by the generation of a consistent cable health index metric, this paper presents a novel hybrid cable health index approach which combines data-driven and physics-of-failure degradation models. Data-driven models are focused on partial discharge tests and physics-of-failure models are focused on cable lifetime estimation based on thermal and electrical stresses. The combination of these models offers an enhanced cable health indicator which supports engineers in the power cable maintenance related decision-making processes.

8:50am - 9:15am

Gas-Insulated High Temperature Superconducting Coaxial Dipole for MVDC Power Systems

P. Cheetham[1,2], C. Park[3], S. Satyanarayana[1], C. Kim[1], L. Graber[3], S. Pamidi[1,2]
[1]Florida State University's Center for Advanced Power Systems, United States of America; [2]FAMU-FSU College of Engineering, United States of America; [3]Georgia Institute of Technology, United States of America

We have been investigating novel insulation designs for high temperature superconducting (HTS) cables. One of the designs we have studied is referred to as the superconducting gas insulated transmission line (S-GIL) as it utilizes helium gas as both the coolant and dielectric medium for the superconducting cable. Dielectrically, the S-GIL is similar to conventional gas insulated transmission lines (GIL) but comes with additional challenges which include the required cryogenic operating temperatures as well as the need to circulate helium gas at high pressures. Measurements conducted on prototype S-GIL samples showed promise of significantly higher operating voltages than what is currently available for helium gas cooled HTS cables. Encouraged by these results we have started investigations on possible designs for coaxial dipole S-GIL. A coaxial dipole superconducting cable design is advantageous as it has the potential to reduce the size of the cryogenic system required as well as significantly reducing the electromagnetic interference caused by HTS power cable which operate at several kilo amperes of current. The design studies on the dipole coaxial S-GIL considered the current densities in HTS cables and the dielectric characteristics of cryogenic helium gas and helium gas mixtures. Also considered are the design challenges of cable terminations where significant heat load as well as high electrical and mechanical stresses are encountered.

This paper discusses the design challenges faced for coaxial dipole S-GIL. Results of the finite element analysis of the electrical and magnetic aspects that were used to evaluate the designs and conclusions drawn from the studies are presented.

8:00am - 9:15am
Imperial Ballroom 6

PD2: PD - Inverters

Session Chair: **Andrea Cavallini**

8:00am - 8:25am

Partial Discharge Behaviors in Power Module under Very High Dv/dt Repetitive Square Voltages

H. You, Z. Wei, M. Aldawsari, B. Hu, R. Na, J. Wang
The Ohio State University, United States of America

Partial discharge (PD) is more likely to happen in the power module due to the increasing switching speed of new generation semiconductors. However, little research has been done to study the PD behaviors under very fast dv/dt (above 50 kV/μs) repetitive square-wave voltages. To address this problem, PD behaviors of designed direct bonded copper (DBC) samples with different trench distances and chamfer radiuses under fast dv/dt (130 kV/μs) repetitive square voltages are studied. The results show that, for different trench distances, the partial discharge inception voltage (PDIV) increases linearly with increasing trench distances when the chamfer radius is larger than 0.5 mm, while PDIV shows a hump curve when the chamfer radius is less than 0.5 mm. The apparent charge becomes 23 nC with a large dispersion when the trench distance is 0.5 mm. For different chamfer radiuses, PDIV presents a U-shape shape curve with increasing radiuses from the zero (right angle) to 0.7 mm. The apparent charge is about 325 pC with a large dispersion when the chamfer radius is zero. The detailed experiment results and discussions are presented in this paper.

8:25am - 8:50am

Partial Discharge Behavior on Twisted Pair under Ultra-short Rise Time Square-wave Excitations

Z. Wei, H. You, B. Hu, J. Wang
The Ohio State University, United States of America

The use of wide-bandgap (WBG) semiconductor device is increasing due to its capability to operate at much higher voltage, frequency and temperature compared with traditional semiconductor device. WBG semiconductor device is capable to generate voltages with ultra-high dv/dt (ultra-short rise time), which would alter the voltage stress in various electrical apparatus, e.g., inverter-controlled motors, and consequently change partial discharge (PD) behavior. Combine this with the fact that PD detection in inverter-controlled motor winding, even with slow-rising voltages, is intrinsically complicated, the study of PD behavior under ultra-fast square-wave voltages is much needed. In this paper, experimental observations and results for twisted pair samples stressed by an impulse generator with the ability of generating ultra-fast square-wave voltage are presented. Statements and hypotheses on PD behaviors and mechanism under ultra-fast dv/dt square-wave excitations are also put forward based on the test results.

8:50am - 9:15am

Study of partial discharge detection in motors fed by SiC-MOSFET and Si-IGBT inverters

R. Acheen[1,2,3], C. Abadie[1], T. Lebey[2], S. Duchesne[3]
[1]IRT Saint-Exupéry, Toulouse, France; [2]LAPLACE, Université de Toulouse, CNRS, Toulouse, France; [3]Laboratoire Systèmes Électrotechniques et Environnement, Université d'Artois, Béthune, France

Voltage inverters based on the pulse width modulation are widely used for applications that require controlling rotation speed. The devices used today to create pulse width modulation are Silicon (Si) IGBTs. The use of IGBTs enables to generate rising edges of tens of kV/μs, and to reach switching frequencies around 20 kHz. These improvements have helped to reduce switching losses and motor torque ripple. On the other hand, the reliability of motors has declined dramatically. The causes of motor failures may be due to different phenomena, but one of the main ageing mechanisms is the erosion of the different insulation materials induced by Partial Discharges (PD).

For high voltage, high power and/or high frequency applications, silicon carbide (SiC) based components will in most of the case replace the current silicon-based components. If some works have already been achieved for on-line PD detection in low voltage motors fed by inverters using Si-IGBT technology, works are now needed when SiC-based components are used.

For motors fed by low voltage, PDs mainly occur during the voltage edge. It is therefore necessary to discriminate them from the noise induced by switchings. The use of high pass filters proved its effectiveness for IGBTs but the use of SiC MOSFET will result in an increase of switching speed and

consequently an increase of the noise frequency. For such conditions, it may be difficult to differentiate partial discharges from noise.

This paper presents a study on the partial discharge inception voltage, on the ability to detect partial discharges and on the voltage stresses in motors supplied by SiC-MOSFET and Si-IGBT inverters. These results are discussed and possible strategies are proposed.

9:15am - 9:40am
Grand Foyer 1

SS-MTG: Student Stipend Meeting

Session Chair: **Nancy Frost**

Students Please Note! Students who have been granted a stipend will need to meet with staff representative (Dr. Nancy Frost) personally on Wednesday morning (6/19/19) at 9:15am at the registration desk (Grand Foyer 1) in order to complete the paperwork for the stipend. Please bring your id! Students who do not show up, will not receive a stipend!

9:15am - 9:40am
Grand Foyer 3 & 4

CBW1: Coffee Break - W1

9:40am - 10:30am
Imperial Ballroom 4

TT2: TT - Partial Discharge

Session Chair: **Ashfak Shaikh**

9:40am - 10:55am
Imperial Ballroom 6

PD3: PD - Inverters

Session Chair: **Zeeshan Ahmed**

9:40am - 10:05am

About the relevance of using Paschen's criterion for partial discharges inception voltage (PDIV) estimation when designing the electrical insulation system of inverter fed motors

P. COLLIN, D. MALEC, Y. LEFEVRE
LAPLACE, France

In the literature, the Paschen's criterion is widely used to determine partial discharges (PD) inception in the electrical insulation systems (EIS) of machines. This criterion has been established for 2 metallic plane electrodes facing each other in a uniform electric field. The objective of this communication is to determine whether Paschen's criterion may still be used in a configuration of enameled round wires in non-uniform field. For that purpose, PD risk between 2 parallel enameled round wires at atmospheric pressure has been studied, from both measurements and simulation points of view. Different experiments with different samples geometry, fully measured by a digital microscope, has been compared to simulation using Paschen's criterion. This work aims to bring out a more complete criterion on PD detection, in the case of enameled round wires, in order to use it as a reference in a software under development. This software will help designers to take into account the PD phenomena in the design stage of the EIS of a low voltage rotating machine fed by an inverter.

10:05am - 10:30am

The Ohio State University Partial Discharge Detection Platform for Electric Machine Windings Driven by PWM Voltage Excitation

H. Xiong, R. Liu, B. Hu, H. You, Z. Wei, J. Zhang, J. Wang
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Unexpected premature insulation breakdown has been reported for many electric machines driven by variable speed drives (VSDs). A major cause is the reflected voltage overshoots at the machine winding caused by the pulse voltage excitation, leading to severe stress on the insulation system. At The Ohio State University (OSU), we have started a series of efforts to understand the degradation and breakdown of the insulation systems in electric machines driven by VSDs. This paper reports our activities on partial discharge (PD) detection and characterization for random-wound low voltage and form-wound medium voltage coils excited by PWM voltages. A PD detection platform has been established consisting of three main systems: the testing samples and setups, the pulsed voltage generation system, and the PD detection system. One silicon (Si) based and two silicon-carbide (SiC) based pulsed voltage generators were employed to produce voltage excitations with a magnitude up to 10 kV and a dV/dt up to 70 kV/µs. The PD detection system, moreover, installed nine sensors catering to five different physical manifestations during PD: electrical current, electromagnetic wave, optical light emission, acoustic ultrasound emission and chemical ozone emission. The detection effectiveness of each type of sensor is presented and compared using twisted pairs of magnet wire samples. The demonstrated results hope to provide a better understanding of the effect of VSDs on the behaviors of PDs in electric machine winding insulation systems, and also some insight for the selection and evaluation of PD detectors for various VSD applications.

10:30am - 10:55am

Noise Rejection and Partial Discharge Identification in PDIV Tests of Insulated Wires Under Repetitive Impulse Supply Voltage

	G. C. Montanari[1,2], P. Seri[1], R. Ghosh[1] [1]DEI, University of Bologna, Italy; [2]CEM, University of Texas, Austin, Texas Partial discharge (PD) detection is a fundamental test for the design and diagnosis of insulation systems, particularly organic materials which must operate throughout their whole life without PD. The measurement of Partial Discharge Inception Voltage (PDIV) and Repetitive Partial Discharge Inception Voltage (RPDIV), the latter defined for power electronic-type supply, is therefore a key issue for the design and qualification tests of Type I insulation system of rotating machines fed by power converters. While experience and technology for PD inception measurements under sinusoidal voltage supply is well established, the same does not hold under repetitive-pulse voltage waveforms, such as those provided by inverters. In addition, electromagnetic noise generated by electronic switch commutation can overlap with PD pulses signals and this is even more cumbersome when fast rise-time components are employed, such as GaN or SiC semiconductors. Moreover, this is also the condition which is the most stressful for stator wire insulation. This work investigates methods to detect PD pulses on enameled wires, rejecting noise efficiently, under repetitive impulsive voltages with different rise times, from 60 ns to 1000 ns. The proposed techniques can be implemented to achieve un-supervised noise rejection, which would be an important goal for both off-line and on-line PD testing.
10:55am - 12:00pm **Grand Foyer 4**	**EOC: End of Conference** **NOTE: Anyone interested in attending the IEEE Working Group Meetings after the conference can attend the meetings without paying a fee! The full schedule of Working Group Meetings is shown below.**
12:00pm - 12:45pm **Bannerman/Walker**	**WG-P97: "Diagnostic Test Methods for AC Electric Machinery using Direct Voltage"** Session Chair: **Laurent Lamarre** Laurent Lamarre, Doug Conley, Tyler Gaerke
12:30pm - 4:00pm **BOG Meetings - Stephen A&B**	**EICBOG: EIC Board of Governors Meeting**
12:45pm - 1:30pm **Bannerman/Walker**	**WG-286: "Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation"** Session Chair: **Douglas Conley** Doug Conley, Jim Lau
1:30pm - 2:30pm **Bannerman/Walker**	**WG-1434: "Measurement of Partial Discharges in AC Electric Machinery"** Session Chair: **William (Bill) McDermid** Bill McDermid
2:30pm - 3:30pm **Bannerman/Walker**	**WG-P2465: "Pulse-type Partial Discharge Measurements on Individual Stator Coils and Bars"** Session Chair: **William (Bill) McDermid** Bill McDermid
3:30pm - 3:45pm **Bannerman/Walker**	**WG-Break: WG - Coffee Break**
3:45pm - 5:45pm **Bannerman/Walker**	**WG-P522: "Testing Turn Insulation of Form-Wound Stator Coils for AC Electric Machines"** Session Chair: **Paul Gaberson** Paul Gaberson, Kevin Alewine
5:45pm - 6:30pm **Bannerman/Walker**	**WG-P1719: "Evaluating Stator Cores of AC Electric Machines Rated 1 MVA and Higher"** Glenn Mottershead, Stefano Bomben, Aleksandra Jeremic

Date: Thursday, 20/Jun/2019

8:00am - 9:00am **Bannerman/Walker**	**WG-1799: "Quality Control Testing of External Discharges on Stator Coils, Bars and Windings"** Session Chair: **Claude Hudon** Claude Hudon
9:00am - 10:00am **Bannerman/Walker**	**WG-1043: "Voltage Endurance Testing of Form-Wound Bars and Coils"** Session Chair: **Reza Soltani** Reza Soltani
10:00am - 11:00am **Bannerman/Walker**	**WG-1776: "Thermal Evaluation of Unsealed or Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Pre-Insulated Stator Coils for Machines Rated 15 kV and Below"** Session Chair: **William Chen** William Chen, Kevin Alewine
11:00am - 12:00pm **Bannerman/Walker**	**WG-P433: "Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency"** Session Chair: **Ashfak Shaikh** Ashfak Shaikh, Aleksandra Jeremic
12:00pm - 12:30pm **Bannerman/Walker**	**WG2-Lunch: WG2-Lunch**
12:30pm - 1:30pm **Bannerman/Walker**	**WG-DGTF: Dissection Guide Task Force Nancy Frost, Charles Millet, Andy Brown** Session Chair: **Nancy Frost**
1:30pm - 3:30pm **Bannerman/Walker**	**WG-P1553: "Standard for Voltage Endurance Testing of Found-Wound Coils and Bars for Hydrogenerators"** Session Chair: **Hugh Zhu** Hugh Zhu, Aleksandra Jeremic
3:30pm - 3:45pm **Bannerman/Walker**	**WG2-Break: WG2 - Coffee Break**
3:45pm - 4:45pm **Bannerman/Walker**	**WG-62.2: "Diagnostic Field Testing of Electric Power Apparatus – Electrical Machinery"** Jim Lau, Doug Conley
4:45pm - 5:30pm **Bannerman/Walker**	**WG-MSC: Material Subcommittee Meeting (MSC)** Session Chair: **Tyler Gaerke**