Paper ID: 2112

Distinguishing Between Phase to Ground, Phase to Phase and Cross-Coupled PD Signals in Stator Windings

Sasic, Mladen;Sedding, Howard;Stone, Greg

Iris Power-Qualitrol

PD detection in stator windings is widely used to assess the condition of the electrical insulation. When the winding is excited by 3-phase AC voltage, PD current pulses can occur between each phase and ground (i.e. within the stator slot and just outside of the same slot). PD can also occur in the endwinding region, driven by the phase to phase voltage. In addition, PD occurring in one phase often induces a “cross-coupled” signal into another phase, presumably due to the capacitance between phases in the endwinding region. These three “sources” of pulses can complicate the phase-resolved PD (PRPD) plots from each phase. Although some methods to separate these three types of pulses from one another have been proposed using post-data acquisition processing – they still require considerable expertise to separate them reliably. In this paper, experiments are conducted on stator winding models and complete stator windings to identify the characteristics of the phase to ground, phase to phase and cross-coupled PD signals, in order to separate the sources in real time. Such separation is important, since PD in the endwinding is often much easier to repair than PD occurring with stator slots.

Paper ID: 2117

Comparison of Magnetic Nature of Vegetable Oil based Nanofluids

Sangineni, Rohith;Baruah, Niharika;Kanumuri, Deepak;Nayak, Sisir Kumar

Indian Institute of Technology Guwahati, India

Transformer is the most important equipment in a power system network. Thermal and electrical stresses are the major cause of concerns for failures in a power transformer. These stresses are sustained by mineral oil (MO) which provides insulation as well as acts as a coolant in the transformer. Vegetable oil (VO) usage is growing in transformer applications due to environmental concern. To overcome the thermal and electrical stresses it is important to enhance the insulation properties. This can be possible by suspension of nanosized particles in the oil to form nanofluids (NFs). NFs have changed the trend in terms of breakdown, moisture saturation capabilities, etc. The generation of leakage flux in the transformer is responsible for the voltage dip on the load side; hence its reduction is important to maintain good voltage regulation and efficiency. This flux also flows through the liquid dielectric of a power transformer. Thus, it is very much important to analyze the magnetic nature of the liquid dielectric and its impact on the leakage flux. To study this phenomenon, two types of oils are considered; VO and VO based NFs (VO-NFs) with Copper oxide (CuO), Titanium oxide (TiO2) and Hexagonal Boron Nitride (Eh-BN) nanoparticles (NPs) dispersed in them. These oil samples are studied for their magnetic nature using vibrating sample magnetometer (VSM). The liquid insulation magnetization for both VO and VO-NFs is plotted with respect to magnetic field strength. The magnetic characteristics of VO based nanofluids (VO-NF) are discussed in the paper.

Paper ID: 2132

Effects of Corona Discharges on Silicone Rubber Samples under Severe Weather Conditions

Hakami, Mohammad;El-Hag, Ayman;Jayaram, Shesha

University of Waterloo, Canada

Understanding the silicone rubber resistance to corona discharges is considered of great importance since the corona discharges are one of the main aging factors influencing the silicone rubber insulators. In addition, the effects of the corona discharges can be accelerated by harsh weather conditions like severe ultraviolet (UV) radiation and high humidity. Hence, significant studies have been conducted to investigate the performance of silicone rubber material exposed to corona discharges under different environmental conditions. There is a lack in the literature to investigate the synergetic effect of corona and different environmental conditions on the aging of silicone rubber material. The results of this study will assist in understanding the behaviour of silicone rubber insulators sustaining the corona discharges in some geographical areas with significant UV radiation. Thus, the objective of this study is to perform corona experiment on the silicone rubber samples to analyze their performance under various environmental conditions including UV radiation and humidity. Experiments are conducted by applying a 10 kV AC voltage on sharp needle electrode with tip radius of 200 um in order to generate corona discharges on the surface of silicone rubber samples for 24 hours. The gap distance between the surface of the samples and the tip of the needle is kept at 6 mm. The experiment is executed in an environmental chamber where both the UV radiation and humidity concentration can be controlled. To UV is produced using UVA-340 lamps with wavelength range from 295 nm to 400 nm and 1 mW/cm2 intensity. The humidity inside the test chamber is produced using an ultrasonic humidifier. The mist is produced using deionized water and the humidifier with a capacity of 1/3 L/h. Three silicone samples are exposed to corona discharges along with both UV radiation and humidity, and another three samples are only exposed to corona discharges and humidity. The experiments are conducted under three humidity settings, i.e. high-humidity (80 to 90%), medium-humidity (65 to 75%), and low-humidity (30 to 40%) conditions. After the treatment, the silicone rubber degradation is quantified using the static contact angle measurements. The measurement was conducted over 100 hours to assess the recovery of hydrophobicity. It has been found that the contact angle dropped significantly after the aging test. Moreover, the results revealed that both the UV radiation and humidity have significant impact on the loss and recovery of hydrophobicity. To further understand the degree of surface damage, Scanning Electron Microscopy (SEM) has been conducted.

Paper ID: 2134

Deeper insight into the relationship between experimental expressions of conductivity and DC electric field in cables

Diban, Bassel (1);Mazzanti, Giovanni (1);Guerrini, Nicola (2);Troia, Ivan (3)

1: University of Bologna, Italy, Italy;2: Prysmian Cables & Systemes, France;3: Scapa Italia SpA, Italy

Purpose/Aim: unlike AC cables, the electric field in HVDC cables depends on conductivity, whose variations as load changes considerably affect the field profile within the insulation wall. This paper aims at finding an analytical relationship between the parameters of different experimental models for the electrical conductivity in HVDC cable insulation and the DC field in the same cables. This relationship has been preliminarily investigated in a previous paper focusing on one model of electrical conductivity only. In this paper the analysis is broadened to another more complex relationship used sometimes in the technical-scientific literature.Experimental/Modeling methods: the relationship between the following two models is studied:1) Model (1): an analytical model for electric field calculation introduced by Eoll - hereinafter referred to as Eoll's formula – which is very useful for a preliminary order-of-magnitude calculation of DC electric field in cable insulation. Eoll's formula in turn depends on an experimental relationship between electrical conductivity and both temperature (T) and electric field (E). This relationship is exponential, with the argument proportional to both T and E; the proportionality constants are, respectively, alpha - the temperature coefficient - and beta - the field coefficient. Due to its simpler form, it is effective, but it is phenomenological in nature and does not appear as directly related to the physical phenomenon of conductivity within cable insulation.2) Model (2): another experimental relationship found in literature, which is described as an exponential Boltzmann-like function of temperature and hyperbolic Sinusoidal function of electric field. This more complicated dependence on E and T includes physical parameters directly related to insulation micro-structure (like Ga, thermal activation energy governing the temperature dependence of the conductivity), thus it seems physically sounder, although apparently not related to an analytical expression of the electric field.The use of Eoll's formula strictly requires using Model (1). Therefore, the use of Eoll's formula with Model (2) is still not consistent so far. However, this will be possible by finding a relationship between parameters of both models. The difficulty of finding such an analytical relationship is the nonlinearity and the complexity of this relationship, as well as the different nature of the functions that describe the relationship between conductivity on the one hand and both temperature and electric field on the other hand. This complexity may imply the necessity of applying some simplifying hypotheses to obtain an analytical closed-form relationship.Results/discussion: finding a link between Model (1) and Model (2) will enable to use "physical" Model (2) in conjunction with a quasi-analytical expression of the electric field of the kind of Eoll's formula. This inter-model consistency allows more comparisons and verification between different models, which is particularly useful for first-hand estimates at design and testing stages.

Paper ID: 2137

Application of Convolution Neural Network in Hydrophobicity Classification

Fahmy, Yehia;El-Hag, Ayman

University of Waterloo, Canada

Evaluating silicone rubber outdoor insulators surface condition is crucial to ensure their health conditions. A hydrophobicity classification (HC) system first developed by Swedish Transmission Research Institute (STRI) and recently adapted by the IEC 62073 standards classifies the insulators to seven different classes. The HC system classifies the insulators to hydrophobic (HC1) to hydrophilic (HC7). The application of the HC system requires certain expertise to be able visually to distinguish between the different classes. Such expertise may not be available in many utilities and hence there is a need to automate the classification process.The objective of this paper is to apply deep learning to classify non-ceramic insulators hydrophobicity. Moreover, the efficiency of deep learning will be compared with the traditional machine learning (ML) approach. A previous dataset will be used for this paper. The samples used in this study were prepared using 10cm x 10cm ceramic tiles. The ceramic tiles were coated with a room-temperature-vulcanizing (RTV) silicone rubber coating. It has been reported that depending on the percentage of alcohol by volume (ABV) in a solution composed of distilled water and alcohol, various HC classes can be obtained from class 1 with 0% ABV to class 7 with 100% ABV. A total of 280 images were taken for the 7 classes. The downside of using deep learning is that we require a much larger set of data than the one used by classical ML algorithms. Since there were only 40 images for each class (280 images total), extra steps had to be taken to increase the dataset size. The images were first split into training data (~90% of the images) and testing data (~10% of the images). Each image was split into 16 smaller images (120 by 120 pixels each), these smaller images were then rotated and saved in each of four orientations. Finally, all the images were flipped horizontally and vertically and saved in each orientation. These transformations were performed on both the training and testing data. As a result, our dataset was increased to 66304 training and 7168 testing examples.Different convolutional neural network (CNN) topologies will be investigated. It has been found that the prediction accuracy using CNN is similar to classical ML algorithms with the advantage of being easier to implement.

Paper ID: 2142

The Effect of Insulator Angles on Leakage Current Characteristics In Wet Fog

Plaengpraphan, Chorphaka (1);Cotton, Ian (2)

1: University of Manchester, United Kingdom;2: University of Manchester, United Kingdom

Composite insulators have been designed to isolate high voltage conductors from their support structures while retaining the conductors in a specific position. These insulators may be used in orientations that are neither vertical nor horizontal – typically these non-standard angles are seen in railway applications but also increasingly in new forms of aesthetically pleasing overhead line towers that are designed to make better use of space. As a result of the unusual installation angle, the ways in which the insulators are subject to contamination and the way water flows over the surface, wetting the pollution and then cleaning the insulator will be different. As a result, the leakage current and partial discharge activity that will be seen on the insulator is likely to be altered with resulting implications for life. A HV test under an artificial fog was performed using a simple fibre-glass reinforced in silicone rubber rod as a sample which was set at different orientations. The discharge activity was imaged by a camera. The current was monitored and collected by a data acquisition system. The leakage current magnitudes and harmonic components were analysed. In general, the current magnitude is low at the beginning of the test while the rod is clean and dry. As the level of moisture on the sample grows, the current increases at different rates depending on the angles with third and fifth harmonic components being clearly visible. The highest current magnitude is seen in the case of the vertical sample. Discharges are clearly seen when the current flow is higher than 1 mA and occur at different positions on the rod surface. Based on the experimental results, the positions of discharge and the magnitude of the leakage current flowing on the rod surface are directly influenced by the orientation of insulator core.

Paper ID: 2144

The Effect of Stress Grading on the Selection of Stator Coil Dissection Locations Related to Voids in Groundwall Insulation

Cotner, Scott

Hydroelectric Design Center, US Army Corps of Engineers, United States of America

The benefits of the use of voltage stress grading materials on high voltage stator coils and bars are widely known and the application of these materials is common in hydro-generator windings. Numerous papers appear in the literature that describe surface voltage profile testing performed to demonstrate the effectiveness of the materials in eliminating partial discharge on the surfaces of stator coils in the region outside the slot. Several technical papers have also been published related to voids (or cavities) within coil ground insulation and the partial discharge that can occur in such voids. Some generator owners perform destructive dissections of a limited number of new stator coils to, among other things, inspect for the presence of voids in several areas of the coil insulation. This paper suggests a rationale for choosing the coil dissection locations under the stress grading. The paper briefly describes some ways in which voids can occur during manufacturing, reviews the fundamentals of voltage stress distribution within insulation containing voids, reviews laboratory measurements of coil surface voltage profile in the stress grading area, and offers guidance for identifying locations to take dissection samples under the stress grading to evaluate whether any voids that may be observed are possible internal discharge sites.

Paper ID: 2145

Observations on the Polarization Index Test as Applied to Strip-on-edge Field Windings of Salient Pole Hydro Generators

Cotner, Scott

Hydroelectric Design Center, US Army Corps of Engineers, United States of America

A test commonly used to determine the condition of salient pole hydro generator stator and field windings is the Insulation Resistance and Polarization Index test. The insulation systems applied to field windings are simpler and contain fewer components than those used in stator windings, which can result in reduced levels of absorption (polarization) current being observed during the test. This has led some to conclude that Polarization Index test results are of little value when the test is applied to hydro-generator field windings, particularly those with “strip-on-edge” field windings. This paper reviews the basic theory of the test, field winding insulation systems, when and how to perform the test, and the current industry standard guidance on the applicability of the test to salient pole field windings. A summary of the results of Polarization Index tests on both service-aged and new “strip-on-edge” field windings is presented, and a further review of the usefulness of the test for field windings is proposed.

Paper ID: 2157

Electrical Characterization of Carbon Fiber Reinforced Polymer Composites

Gupta, Himanshu;Agnihotri, Prabhat K.;Basu, Sumit;Gupta, Nandini

Indian Institute of Technology, Kanpur, India

Carbon fiber reinforced polymer (CFRP) composites are a promising alternative to metals for aircraft structures. The applicability of CFRP composites to electromagnetic shielding and immunity to lightning strikes depends largely on their electrical conductivity. In this work CFRP composite laminates were prepared with pre-pregs carbon fiber (fiber pre-impregnated with epoxy resin), and their electrical conductivity and shielding effectiveness (SE) were measured. Four-point probe method is used to measure electrical conductivity of CFRP as this method avoids errors due to contact resistance. SE is a measure of how effectively a material blocks an electromagnetic field and is measured in X-band (8.2-12.4 GHz) frequency using a Vector Network Analyzer (VNA). Composite slabs made with ten plies of prepregs, aligned unidirectionally seen to provide better electromagnetic attenuation (>90%).

Paper ID: 2165

Potential distribution on stress grading system of coil end under operating temperature of rotating machines

Hasegawa, Yuki (1);Hidaka, Kunihiko (1);Kumada, Akiko (1);Okamoto, Tetsushi (2);Umemoto, Takahiro (3)

1: The University of Tokyo, Japan;2: Toshiba Mitsubishi-Electric Industrial Systems Corporation, Japan;3: Mitsubishi Electric Corporation, Japan

Stator coil end of a rotating machine has a structure of electric field grading system (SG system). The SG system relieves the high electric field created between the high potential coil and the grounded stator. Stress grading tape (SGT), one of the materials that make up the SG system, changes its resistivity as a function of the electric field strength. Although a rotating machine is operated at higher than 100℃, the effect of temperature on SG system is not well understood. To investigate the relationship between the performance of the SG system at high temperatures and the occurrence of PD emission, experiments were conducted using a model bar simulating the end of astator coil. AC 50 Hz sinusoidal wave was applied to a virgin model bar at room temperature(RT)(Stage1) and then the model bar was heated up to140℃(Stage2). After the sequence of this heating experiment, it was cooled to RT(Stage3) and then heated again to 140°C(Stage4). Potential distribution of the model bar at each stage was measured using a Pockels sensor. Comparing the potential distribution at Stage1 and Stage2, the amount of accumulated charge, which is a consequence of field relaxation, decreased as the temperature increased. It means that the decrease of SGT performance affects the potential distribution of the coil. Under RT conditions, t he stress grading function of the SGT at Stage3 is degraded compared to Stage1. Related to the model bar once it has cooled, SG system at Stage3 had worse performance than at Stage4. The experimental results suggest that there is an effect of thermal history on the properties of SG system. The PD luminescence on the model bar under AC 50 Hz field was also observed by a digital camera with an image intensifier. Related to the virgin model bar (Stage 1 and 2), the luminescence of PDs decreased as the temperature increased. It suggests that not only the potential gradient on the model bar but also someother factors such as adsorbed H2O on the bar surface may affect the PD occurrence. The effects of heating time and frequency of temperature change on SG system will be reported in detail.

Paper ID: 2167

Reliable InterTurn Fault Detection on Low Voltage Motors Using SFRA Measurements and Comparison with Surge Testing Results

Mayer, Maximilian (1);Oettl, Fabian (2)

1: Vienna Technical University;2: Omicron electronics, Austria

The sweep frequency response analysis (SFRA) is a known diagnostic tool in the area of power transformer testing. In the past years several investigations have shown, that this technique is highly sensitive to detect various defects in high and low voltage motors too. Although it has been proven that the method can prevent early machines faults, comparisons to other methods as well as best practice to assess the measurement have not been or have hardly been scientifically researched.The investigations described in this contribution try to close this gap and to propose a practice to assess the winding. Statements regarding the influence of different winding parameters are investigated.Three brand new stators, two of them with identical physical properties except for the core length, were manipulated in such a way, that single turns can be shortened along different locations in the windings. The results show the possibility to detect faults either with a fingerprint comparison or by a phase to phase comparison. Both methods identify single inter turn faults in a 124-turn winding, which means that a reliable winding loss detection of less than 1% is feasible.A phase comparison of two healthy windings (phases V and W) for example and phase U with a single inter turn fault show clear deviations in the SFRA curves. The fault indications are the shifted trend in the lower frequency range, as well as the deformation and displacement of the first resonant peak, resulting in a clear phase displacement.The same faults measured with the common surge test (Impulse FRA) exhibits an equal fault sensitivity, although in some cases the SFRA is capable to detect malfunctions in the winding where the IFRA measurement reveals no defects.Additionally, characteristic similarities of the stators with the common properties and similarities between inter turn and inter winding faults were found.

Paper ID: 2169

Frequency Dielectric Spectroscopy and Dissipation Factor during Thermal Cycles on different Types of MV Cable Joints

Contin, Alfredo (1);Borghetto, Johnny (2);Pirovano, Giovanni (3);Tornelli, Carlo (4)

1: University of Trieste, Italy;2: RSE s.p.a. Milano, Italy;3: RSE s.p.a. Milano, Italy;4: RSE s.p.a. Milano, Italy

Insulation diagnosis is of great importance for evaluation of premature ageing of MV underground cables and accessories. Among the different non-destructive diagnostic techniques, the Frequency Dielectric Spectroscopy (FDS) is gaining popularity for the possibility to monitor the ageing progression from the analysis of the polarization processes occurring within the insulation.FDS technique has been applied to monitor the ageing progression of twelve underground cables rated 23kV of about ten meters of length provided of joints in the middle. In particular, 2 XLPE-XLPE, 2 paper/oil and 8 mixed XLPE and oil/paper joints, were considered in the experiment. Among the mixed joint, two are of new construction while six joints have been taken out of the field after a service period. These twelve cables have been subjected to thermal cycles having a period of one day with 11 hour of heating, from the ambient to a maximum value that depends on the ambient conditions. Cables were covered by felts to simulate the underground conditions in laboratory. Temperature was controlled by connecting cables in a ring in short circuit and inducing the rated current of 285A by means of external coils while the rated voltage of 13 kV has been constantly applied to the ring. Periodically, the ring was disconnected and the ageing progression of each cable has been investigated by means of FDS in a frequency range of 0.001~10000 Hz. Complex permittivity and dissipation factor data are obtained as a function of frequency for each cable. To verify the validity of FDS, dissipation factor has been measured at different voltage levels using a commercial instrument based on the Schering Bridge and compared with the FDS result at power frequency.Results indicate that FDS evaluation is a reliable tool to distinguish the ageing progression of the insulation from the seasonal and reversible changes while dissipation factor values recorded at different voltage levels show a non-regular behavior particularly in XLPE cables.These results clearly suggest that the systematic use of FDS in condition assessment of underground cables can provide more diagnostic information with respect the traditional tanδ measurements.

Paper ID: 2178

Discharges Pattern Recognition on Uniformly Polluted Glass Surface Using an MLPNN Classifier

Ferrah, Imene;Teguar, Madjid;chaou, khaled ahmed

National Polytechnic School of Algiers, Algeria

this paper propose an approach for electrical discharges recognition using an MLPNN based on an image-processing tool. In fact, our proposed algorithm aims to detect and monitor the apparition of electrical discharges, from the apparition of smallest discharge to the flashover arc, through analysis of colors on the recorded images. For this purpose, first, we perform the acquisition of images using a High Definition (HD) camera in laboratory. These images are collected on a plan glass insulator model, where we dispose the polluted solution uniformly (using a spray, then a sieve). Second, we proceed to encode these images in RGB system. Therefore, each image has a corresponding feature vector that informs about the quantity of six colors that are contained in each discharge image. Third, an MLPNN algorithm is elaborated to detect the evolution of the discharges of the flashover phenomenon. Our algorithm is using the feature vector of each image as input, while the output of this classification algorithm is a class (from 1 to 5) indicating the stage of discharges on the plan insulating surface.

Paper ID: 2211

An intelligent cross-connected box door for power cable partial discharge detection

zhou, jie (1);wang, wei (2);zhou, jingjing (1);he, he (1);zhang, wei (1);wang, pingyu (1);yang, shuting (1);xu, wei (1)

1: State Grid Shanghai Cable Company, China, People's Republic of;2: North China electric power university, China, People's Republic of

At present, the detection of partial discharge of high-voltage cables is mostly carried out at the cross interconnection position. For some cable defects, long-term continuous detection is required. Due to the need for external working power, the cross interconnection box door is opened, and the cross interconnection is in an exposed state. The inspectors must monitor and test at the same time The implementation of the work is extremely inconvenient. For this reason, this article designed an intelligent cross-connected box door and applied it in the power supply cable of Shanghai World Expo Park. The intelligent cross-connected box door comes with a partial discharge sensor, an automatic data acquisition and storage system and a large-capacity battery, which can seamlessly replace the current cross-connected box door to achieve plug-and-play partial discharge detection. After starting, it does not need to be concerned and no inspection personnel are required. Monitoring, self-sustaining power not less than 7 days, can significantly improve the efficiency and safety of the existing high-voltage cable partial discharge detection implementation.

Paper ID: 2212

GIS discharge induced by vibration, metal particles and VFTO

xin, weifeng (1);wang, wei (2)

1: Henan electric power research institute, China, People's Republic of;2: North China electric power university, China, People's Republic of

Some GIS break down after the disconnector is operated. The reason for this phenomenon is not clear. We believe that the vibration and VFTO caused by the disconnector action, as well as the metal particles inside the GIS, together cause this phenomenon. In order to confirm our idea, we carried out simulation calculation and experimental verification. In this paper, we present the methods and results of experiments and simulation calculations. The research results show that the vibration and VFTO caused by the disconnector action greatly increase the lifting height of the metal particles inside the GIS, which may be the main cause of breakdown and discharge. On this basis, we propose a test method for synchronous disconnector action during the withstand voltage test to improve the detection rate of metal particles.

Paper ID: 2214

Performance of a Bio-based Hydrocarbon type Insulating Liquid

Nunes, Jayme;Wolmarans, Carl;Pahlavanpour, Bruce;Fairholm, Robert

NYNAS AB, Sweden

The paper presents the development of a bio-based hydrocarbon type insulating liquid of low viscosity and compares its properties to a naphthenic mineral insulating oil and ester liquids. Due to very low kinematic viscosity, 3.7 cSt at 40°C, the bio-based hydrocarbon provides improved convective heat transfer in power transformers. Depending on the transformer design, temperature reduction of both winding and hot spot is achievable. A simulated example and a real test are provided for a power transformer which shows a significant reduction in a hot spot can be achieved compared to the other two liquids. Fast and complete solid Insulation impregnation with the liquid is a vital aspect as it ensures there are no trapped voids or air bubbles, which are a common cause of the partial discharge. The use of a lower viscosity liquid will mean fast impregnation speed compared to one of higher viscosity. Oxidation stability differs between natural esters, synthetic esters, uninhibited mineral and inhibited mineral oils. The bio-based hydrocarbon has excellent oxidation stability which allows use in free-breathing transformers. The bio-based hydrocarbon is also readily biodegradable and complies with the criteria of aquatic non-toxicity providing reduced environmental impact in the case of oil spills.

Paper ID: 2215

Research on High voltage Cable Insulation on-line Monitoring Technology Based on Double differential CT Method

Wang, Tingting (1);Suo, Changyou (2);Gong, Xun (2);Zheng, Huan (2)

1: Power Grid Technology Research Center of China Southern Power Grid Co., Ltd., China;2: Harbin University of Science and Technology, China

Power cables are developing towards higher voltage level and large capacity, which leads higher requirements for on-line insulation monitoring technology of high-voltage power cables. The traditional on-line monitoring methods of cable insulation mostly use electromagnetic induction to obtain the signals of voltage and current. Due to the angle difference and interference of the voltage and current signals, and the influence of the cross interconnection of the cable lines, the measurement accuracy cannot meet the requirements. Therefore, they are difficult to be applied in ultra-high voltage level. Referring to the previous on-line monitoring technology of cable insulation, an on-line monitoring technology of high-voltage cable insulation based on double differential CT method is proposed in this paper.The principle of double differential CT is to install current transformer (CT) at the headend and end of each phase cable. The A, B and C three-phase current transformers at the headend and the end of the cable line are connected in series, and the zero sequence current at the headend and end is obtained by current difference. And then the zero sequence current of the insulation leakage current of the three-phase cable is obtained by the difference between the zero sequence current of the headend and the end. At the same time, the phase information of zero sequence current of the leakage current of cable insulation is identified by taking the differential current at the headend and end of any phase cable as reference. After that the insulation state of the fault cable can be distinguished. Based on the theoretical analysis, the simulation model of double differential CT is built by using Simulink component of MATLAB. The simulation results show that there is a positive correlation between the output value of the secondary differential and the specific determination of the aging state of the phase insulation. That is, the deeper the aging degree is, the greater the output value of secondary differential is.In order to eliminate the influence of load current, a compensation winding is added to the headend CT. Through physical compensation, the problem that the mathematical difference between the headend and the end measurement results is larger than the aging leakage current of cable insulation is solved, and the correctness of the proposed improvement scheme is verified by simulation. Based on the simulation, a test system of double differential CT with compensation is built. The test system includes real-time system, current transformer and voltage controlled current source. The physical simulation experiment were carried out in the laboratory with the test system. The feasibility of the double differential CT method with compensation is verified by monitoring the leakage current of cables insulation under different aging degree.

Paper ID: 2232

Influence of fillers based on different types of tubular halloysite on dielectric properties of epoxy-based composites

Kadlec, Petr;Polanský, Radek

University of West Bohemia, Faculty of Electrical Engineering, Czech Republic

Tubular halloysite used as a filler for electrical insulating composites is becoming more common, but it is still not as researched as, e.g., geologically related montmorillonite kaolinite. This clay mineral is unique in its natural tubular structure, thanks to which halloysite shows, in some cases, rather different properties compared to other clay minerals. Currently, tubular halloysite is quite often used mainly as a fire-retardant additive for thermoplastics, and cases of its practical use in thermosetting resins, including epoxy resin, also exist. It turns out that in addition to emphasizing composites' production with improved heat resistance, increased fire retardation, better mechanical properties, etc., it is still necessary to closely evaluate changes in prepared composites' dielectric properties. The addition of the mentioned mineral filler, even in only a few weight percent, can significantly affect the dielectric properties. The resulting dielectric properties of the composite could also depend on the type of selected tubular halloysite. Specified types of tubular halloysite obtained from different deposits can differ significantly in the shape and dimensions of individual nanotubes and even in the amount and composition of impurities in the resulting filler; all of these influences can affect dielectric properties, as well as conditioning and treatment of the filler before incorporation into the polymer. This paper evaluates the effect of the choice of halloysite-based filler from different suppliers (different deposits) on composites' dielectric properties with the epoxy matrix. Firstly, several different types of halloysite-based fillers were tested to determine the effect of the filler type on prepared composites' dielectric properties. After that were performed analyses on prepared composites with epoxy resin, cured at elevated temperature, with filling levels in the order of a few weight percent. All realized dielectric analyses were performed by dielectric broadband spectroscopy, and the values of the real part and imaginary part of permittivity or dissipation factor were evaluated as a measure of dielectric losses. It was found that the differences in estimated dielectric parameters between tested types of fillers are not as significant as expected, and considerable differences in the measured parameters were not observed for prepared composites too. The effect of filler drying to a temperature of about 200 °C before incorporating into the polymer was positive and very similar for all types of filler, and differences in the dispersion of various fillers in the epoxy resin were observed.

Paper ID: 2233

Dielectric analysis of selected polyimide films and derived epoxy-based sandwich composites

Kadlec, Petr;Pihera, Josef;Prosr, Pavel;Polanský, Radek

University of West Bohemia, Faculty of Electrical Engineering, Czech Republic

Epoxy-based composites containing glass fibres and other particulate fillers are often used as a standard insulating material in high-voltage applications, e.g., for electrical rotating machines or structural elements of overhead power lines. The glass fibres, its orientation, density, and type determine the mechanical properties and the epoxy resin that determine the thermal endurance and the base dielectric properties of composites. The additional particulate filler can perform more functions and provide higher dielectric strength and better mechanical resistance or fire retardation. In higher dielectric withstand and endurance necessity, the additional dielectric barrier is a possibility for necessary improvement. Polyimides are used as a material with excellent heat resistance and high electrical strength for application, where high endurance and reliability even under extreme operating conditions is needed. The combination of the polyimide film and the epoxy-based composite, e.g., in the form of a prepreg, leading to the formation of a multicomponent sandwich composite, is relatively simple and the resulting material properties can be very advantageous. However, the detailed analysis of polyimide films is necessary for a suitable oversizing of the mentioned composites. The study of selected dielectric properties, e.g., volume resistivity, permittivity and dissipation factor, of several types of polyimides, are presented in this contribution in the first step. Two-component composites (epoxy resin with polyimide film) as a basic variant of the mentioned composites as well as the pure epoxy resin were analyzed in the second step. The results show the impact of polyimide type on the final composite properties from the dielectric point of view. The polyimides incorporated in the composite generally decrease the volume resistivity but increase the breakdown voltage and electrical strength. The increasing/decreasing of loss factor depends on the polyimide type.

Paper ID: 2245

Study of the evolution of DC and DCPR Stresses in LDPE

Sriram, Balaji;Gupta, Nandini

Indian Institute of Technology Kanpur (IIT-k), India

Apart from continued DC stress, DC-Polarity Reversal (DCPR) stresses are very common in HVDC systems. Space charge accumulation is of serious concern in HVDC systems, and can cause significant material degradation. This is further aggravated by polarity reversal. In this work, a computational model based on Bipolar Charge Transport (BCT) is developed to map the time dependent space charge, electric field and electron recombination within LDPE insulation for constant DC stress, and validated with exiting literature. The model is further extended to study the effect of DC-Polarity reversal. The effect of charge trapping frequency on the space charge distribution and the electric field enhancement during DCPR is analyzed. Trapping frequency is seen to significantly affect field enhancement. Leakage current magnitudes were also observed to vary with trapping frequency as well as time to polarity reversal.

Paper ID: 2253

Influence of the pulse voltage injection configuration on the electromagnetic distortion

Mier, Guillermo Andres;Rodrigo Mor, Armando

University of Technology, Netherlands, The

The Pulsed Electroacoustic Method is one of the most common methods for space charge measurements in solid dielectrics. This method involves applying a voltage pulse across the dielectric under test, which modifies the electrostatic force balance across the dielectric, creating an acoustic signal that can be measured externally. The pulsed voltage has an electromagnetic interaction with the acoustic sensor, which results in a measured transient distortion signal. If this distortion's time duration is long enough, it overlaps with the measured space charge signal, which can result in errors at the post-processing and interpretation of results. The objective of this work is to analyze the influence that both, the PEA test cell grounding and the location of the pulsed voltage circuit connection at the PEA test cell have on the generated distortion due to the electromagnetic interaction between the pulsed voltage and acoustic sensor. The work focuses on PEA measurement at full-size HVDC cables. Experimental tests were performed to measure the distortion at different connection scenarios; these scenarios were then compared and discussed. For the experiments, a PEA test cell was built considering the full-size HVDC cable's physical dimensions used as a sample, which had an insulation thickness of 21.5 mm. The acoustic sensor built for the test cell consisted of the combination of polarized PVDF piezo film and non-polarized PVDF, together with the use of battery-powered amplifiers. Several tests were performed, each with a different configuration of the grounding and pulsed voltage connection at the test cell. A comparison and analysis were performed from these tests between the different measured distortions that each test case produces. From the tests, it can be observed that the connection locations of the pulsed voltage circuit directly connected to the test cell have a significant influence on the distortion magnitude. The results also revealed that the PEA test cell's grounding connection plays an important role, where the configuration with the grounding most electrically separated from the PEA test cell showed the best results. The results demonstrated that the current distribution of the pulsed voltage across the PEA test cell in relation to the acoustic sensor's location has a direct impact on the distortion signal magnitude, which means that the generated distortion can be significantly diminished by modifying the physical location that the pulsed voltage is connected at the PEA test cell. This paper's results could serve as a guideline for the construction of PEA measurements to minimize the signal distortion caused by the pulsed voltage, which can also reflect in simpler post-processing.

Paper ID: 2267

Electric Field Analysis of Stress Grading System Delamination in the Stator End-winding of High Voltage Rotating Machine

Liu, Ping;Liu, Xuezhong

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

Stress grading system is the necessary structure of the stator end-winding of high voltage (HV) rotating machine, whose effectiveness is vital to the safe operation of HV rotating machine. The stress grading system of the stator end-winding of HV rotating machine is generally composed of three-segment stress grading coatings with different nonlinear characteristics, named medium, medium-high and high resistance coating respectively. In recent years the delamination in stress grading system of the stator end-winding was discovered during HV hydro-generator maintenance. The severe delamination can create air gap between the stress grading system and the ground-wall insulation, the length of which is from a few mm to dozens of mm, and even the medium resistance coating and the corona armor coating are separated at the position of the lap layer. Aiming to this phenomenon, whether it will cause damage to the end-winding insulation or not is studied by simulation calculating in this paper. A three-dimensional stator end-winding simulation model of a rated 24kV class hydro-generator was built in FEM software, including the end-winding of the adjacent stator coil. The delamination between the ground-wall insulation and stress grading system of a stator coil was built, while there is no delamination in the end-winding of the adjacent stator coil. The transient electric field of this model was calculated, as well as the impact of the position and thickness of the delamination and the potential amplitude of copper conductor on the electric field of the delamination was studied. The electric field of the delamination and the stress grading system were analyzed. The simulation results show that there is no obvious change in the surface electric field of the stress grading system if the medium resistance coating and the corona armor coating are not separated at the position of the lap layer. On the other hand, the electric field maximum in most areas of delamination between the medium resistance coating and the ground-wall insulation may exceed the threshold in a cycle, which means that there is the discharge in delamination. The discharge in delamination will cause damage to the ground-wall insulation and the stress grading system of the stator end-winding. Furthermore, with the thickness of the delamination between the medium resistance coating and the ground-wall insulation increasing, the electric field maximum in delamination decreases in a cycle. As the potential amplitude of copper conductor decreases, the electric field maximum in delamination decreases in a cycle.

Paper ID: 2290

Limitations of magnitude guidelines for PD Measurements on Stator Windings

Lachance, Mathieu (1);Sze, Matthew (1);Oettl, Fabian (2)

1: OMICRON electronics Canada Corp, Toronto, Canada;2: OMICRON electronics GmbH, Klaus, Austria

Partial discharge (PD) measurements have been performed on rotating machines for many decades and have proven to be a reliable and useful tool to detect potential issues in their insulation system. Ever since PD measurements were established, engineers have been looking for ways to distinguish between an asset in a good condition or a deteriorated one. Several possibilities of interpretation have been investigated and some of them are described in the relevant documents IEEE-1434 and IEC-60034-27 such as a trending over time or the phase resolved pattern. An absolute global limit of the PD magnitude in rotating machines is not within these possibilities for good reasons.However, in 2016, IEEE-3004.8 published PD-level guidelines for stator windings for 10 kV to 15 kV industrial motors. Unfortunately, very limited information is provided to explain how, and under which circumstances these guidelines should be applied.This paper presents the results from an experiment that was performed on a 12.5 kV induction motor to expose the limitations of using limits of magnitude for PD measurements on stator winding. In addition, the results of other experiments performed in the past and the influence of using different sensors are also briefly discussed.It is shown that many factors influence the PD measured quantity in a stator winding. Thus, PD-level guidelines should only be used under specific circumstances and should not be applied to a wide range of high-voltage motors and generators. Therefore, the presence of these guidelines in an IEEE document is questionable.

Paper ID: 2294

Impulse discharge voltage prediction of complicated engineering gaps based on machine learning of spatial electric field features

Qiu, Zhibin (1,2);Zhang, Louxing (2);Liao, Caibo (2);Liu, Jianben (1);Liu, Yan (1);Hou, Huasheng (2)

1: State Key Laboratory of Power Grid Environmental Protection (China Electric Power Research Institute);2: Department of Energy and Electrical Engineering, Nanchang University

Discharge voltage prediction of engineering gaps with complicated arrangements is a long-term goal in high voltage studies. This paper proposes a spatial electric field feature set for transmission line – tower gaps. A strong correlated electric field zone was defined between the energized bundled conductor and the grounded tower body or the cross arm. This zone is a conical region with an assumptive cone angle and a circular arc boundary delimited by the equipotential surface. After electric field simulation, 13 features were extracted from this conical zone, and 15 features were extracted from the shortest path. These spatial electric field features were input to a machine learning model based on support vector machine (SVM). Trained by the features and the experimental data of 15 gaps used in 500 kV, ±660 kV, and 750 kV transmission lines, the SVM model was used to predict the 50% discharge voltages of ±800 kV and 1000 kV engineering gaps. Six prediction cases were carried out with two cone angles and three equipotential surfaces used in definitions of the conical feature extraction zone, and the mean absolute percentage errors (MAPE) are within 10%. When the cone angle is 90° and the equipotential surface is 30 percent of the applied potential, the MAPE is only 4.85%, and the relative errors are within 7.02%. In addition, the predicted U50-d curves have similar variation trends compared to the experimental curves, which demonstrates the feasibility of the proposed method.

Paper ID: 2312

The Relationship Between Electrical Tree Growth and Partial Discharge Characteristics in XLPE

Wu, Shiyou;Zheng, Shusheng;Zhang, Zongheng;Zhong, Aixu;Cao, Renjie;Wang, Cong

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

In this paper, an "integrated" cross-linked polyethylene (XLPE) needle-plate model is made to generate electrical tree. Changing the curvature radius of the steel needle, comparing the differences of morphology of treeing and partial discharge (PD). A set of experimental platform is built, the detection sensitivity of PD is 1pC. The experimental results show that the larger the curvature radius of the steel needle is, the greater the probability that electrical tree will develop into a bush tree, while the smaller the curvature radius is, it will develop into a branch tree. Under the voltage that generates electrical tree (VGET), the growth rate of branch tree is fast within 1 hour, breakdown time of model is about 6 hours. It is obtained that phase resolved partial discharge (PRPD) and discharge charge quantity-time (DCQ-T). For PRPD in 0-20min, in the positive half-cycle it is similar to a triangle, while in the negative half-cycle it is similar to a wing-shape. The maximum discharge quantity is about 216pC, which is reached it at about 5th minute, and then it is relatively stable. The VGET of bush electrical tree is higher, but the growth rate of bush tree is slower than that of branch tree, breakdown time of model is about 9 hours. The PRPD of bush electric tree is wing-shape in both positive and negative half cycle in 0-20min. However, the maximum discharge quantity is larger than that of branch tree, which is reached it at about 2.5th minute.

Paper ID: 2314

Space Charge Simulation of Electric Tree Before Germination in XLPE at DC Voltage Based on Improved Bipolar Carrier Transport Model

Wu, Shiyou;Zheng, Shusheng;Zhong, Aixu;Zhang, Zongheng;Cao, Renjie;Wang, Cong

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

The existence of electrical tree (ET) will reduce the insulation performance of XLPE cables, and long-term development may lead to cable breakdown. The impact of space charge is one of the causes of ET, the phenomenon of charge accumulation in high voltage DC (HVDC) cables is more common. In this paper, based on the bipolar carrier transport (BCT) model, the improved carrier dynamic equilibrium model is used to simulate the charge distribution before the generation of ETs. The results show that the maximum charge density accumulated at the negative voltage is larger than that at the positive voltage, besides, the process of charge accumulation reaches the steady state faster. The charge density at the tip is the highest. Because the electron mobility is larger and the injection barrier of needle/XLPE is lower, the area of charge accumulation is larger and the steady state can be achieved faster. The accumulation of charges with the same polarity near the tip of the needle will weaken the field strength, and the reduction of the field strength is greater under the negative voltage. Therefore, under the negative voltage, the impact of the space charge on the material is more severe, and the probability of producing ET is greater than that under the positive voltage.

Paper ID: 2316

A feature set of electrostatic field distribution to predict rod-plane gap breakdown voltage

Liu, Jianben (1);Qiu, Zhibin (1,2);Hou, Huasheng (2);Liu, Yan (1);Liao, Caibo (1)

1: State Key Laboratory of Power Grid Environmental Protection (China Electric Power Research Institute);2: Department of Energy and Electrical Engineering, Nanchang University

Air gap discharge results from electric field enhancement and the breakdown voltage is mainly determined by the electrode geometry and the gap distance, which can be characterized by the electrostatic field distribution. Traditionally, the maximum electric field strength is concerned to analyze its relation with discharge inception and gap breakdown. However, the breakdown voltage is also related to more distribution features. In this paper, a feature set including multiple quantities related to electrostatic field distribution is proposed and assumed to be equivalent to the geometric structure of rod-plane gaps. Based on the fact that the discharge incepts from the rod tip, propagates along random paths and may end at different positions on the surface of the plane electrode, a hypothetic discharge channel was defined for electric field feature extraction from the finite element calculation results. This channel is with a fan-shaped region, while the vertex locates at the center on the rod tip surface, and the outside circular arc is overlapped at the equipotential lines with a certain percent of the applied potential on the rod electrode. Some features related to electric field strength, energy, inhomogeneity, and potential were extracted from this fan-shaped channel, thus to characterize the distribution in this strong field area. Some additional features were extracted along the shortest path connected the rod and plane electrodes, thus to reflect the influence of the gap distance on the breakdown characteristics. A correlation analysis was carried out to study the relevance degree between these features and the rod-plane gap breakdown voltages. Strongly correlated features of electrostatic field distribution were input to a breakdown voltage prediction model based on support vector machine. By model training and test, the prediction results of rod-plane gap breakdown voltages were compared with experimental values to evaluate the validity of the proposed feature set, which demonstrate a good agreement. This study may be inspirational for air gap discharge and insulation prediction researches.

Paper ID: 2318

Study of parameters affecting heat dissipation in an impregnated random wound stator

Ferraris, Mattia (1);Campanini, Fabio (1);Cuminetti, Nicola (1);Bergemann, Nils (2)

1: ELANTAS Europe srl, Italy;2: ELANTAS Europe GmbH, Germany

Heat dissipation from stator windings is one of the most important topics regarding the design of an electric motor, driving the definition of the rated power and thermal class of the machine. As the demand for higher efficiency motors has increased, the request for insulating materials that can improve thermal exchanges has become more frequent. Thus, a study of the impact of impregnating resins with different thermal conductivities and in different slots filling factors has been carried out. A standard production stator has been chosen as the specimen for this investigation; using a Finite Element Model (FEM) simulation, temperatures inside a powered stator have been evaluated, considering initially a stator without any insulating resin and stator with a typical impregnating resin applied to them. These figures have been compared with direct measurements taken from actual stators to assess the computational models. Finally, a parametric study on the thermal conductivity and slots filling factor impact of the applied resin was carried out. The FEM stator model has been validated by data measured on real objects with a good correlation between the two. A parametric study highlighted the main variables that have an impact on the temperature distribution within the impregnated stator whilst considering different boundary conditions. From this study it has been determined that a 100% void free impregnation of an electric motor stator has an overall measurable impact for the attainment of a reduced temperature distribution which can also be improved greatly by the application of the appropriate machine cooling.

Paper ID: 2319

Preliminary investigations of the electrical tree growth at frequencies of 50 Hz and 2.2 kHz by means of partial discharge analysis.

Gallesi, Federico (1);Guastavino, Francesco (1);Nett, Isabella (2);Puffer, Ralf (2);Soppe, Bastian (2);Vocke, Jan (2)

1: University of Genoa, Italy;2: RWTH Aachen University, Germany

During fault situations within high voltage direct current (HVDC) links, transient overvoltages with frequency components of several kHz, can occur and incept electrical trees inside the cable insulation. Since the relationship between applied voltage and frequency and the growth of the electrical trees is not completely understood, a deeper investigation is necessary. In particular, starting from cross-linked polyethylene (XLPE) samples obtained from a commercial HVDC cable, electrical treeing tests have been performed by applying a voltage level with two different frequencies: 50 Hz and 2.2 kHz. During the tests, the partial discharge (PD) activity has been monitored. The obtained results show that the time to breakdown obtained from the samples subjected to the 50 Hz power supply is shorter than those obtained with 2.2 kHz. Analyzing the PD activity and the sample by means of digital microscope, different tree shapes were visible,which influence the degradation time of the performed test. The obtained results of this preliminary study suggest that increasing the frequency does not necessarily lead to a reduction of the time to breakdown but influences the shape and the growth of the electrical trees.

Paper ID: 2323

Electrical Tree Aging Characteristics of Epoxy Resin under High Frequency at Different Temperatures

Zhou, Yuanxiang (1,2);Xing, Weiwei (3);Gesang, Quzong (1);Zhang, Yunxiao (1);Cheng, Zixia (3);Zhang*, Ling (1)

1: State Key Lab of Power System, Department of Electrical Engineering, Tsinghua University;2: The Wind Solar Storage Division of State Key Lab of Power System, School of Electrical Engineering, Xinjiang University;3: School of Electrical Engineering, Z

Electrical tree aging is a typical electrical aging phenomenon caused by partial discharge within polymeric insulation materials. Understanding and even suppressing electrical tree aging is of great significance for insulation design, reliability evaluation, and performance improvement of electrical equipment. With the increasing proportion of power electronic devices used in modern power system, more and more attention has been paid to the insulation of power electronic devices. Power electronic insulation is easily affected by high frequency and high temperature and accelerates aging. Voltage frequency and temperature have an important influence on the initiation, growth, and evolution of electrical tree. In this work, according to the characteristics of electrical tree aging of epoxy resin at higher voltage frequency (10 kHz), electrical tree aging of epoxy resin at high temperature (90℃) and low temperature (0℃) were compared and analyzed, respectively. It is found that low temperature can inhibit the growth of electrical tree of epoxy resin. But the lower the temperature, the denser the electrical branches and the more complex the morphology of branches. Moreover, the fractal dimension increases with the decrease of temperature. Electrical tree develops in the direction perpendicular to the electric field, and the expansion coefficient becomes larger, so that the deterioration area caused by electrical tree increases, and the damage becomes more serious. At low temperature, the intensity of partial discharge decreases, so as the speed of charge carrier impacting molecular chain. The energy is not enough to crack molecular chain quickly, thus the growth of electrical branches slows down. However, high temperature promotes the development of electric branches, and with the increase of temperature, the channel color of electric branches becomes lighter. The length of electric branches growing along the electric field direction and perpendicular to the electric field direction becomes longer. At high temperature, the movement of charge carrier is accelerated, partial discharge activity is more intense, leading to the crack and gasification of epoxy molecules. Higher air pressure is accumulated, and more heat is generated, which promotes the fracture of the molecular chain of epoxy resin and leads to the rapid development and extension of electric tree to the ground electrode. The electrical tree aging characteristics of epoxy insulation commonly used in power electronic packaging obtained will provide an important reference for the future research and development of new materials.

Paper ID: 2324

Research on shunt coefficient calculation and insulation gap design of overhead ground wire

Qiu, Annan;Zhan, Huamao;Li, Min

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

The thermal stability check, model selection and reasonable design of insulation gap of optical-fiber composite overhead ground wire (OPGW) are all based on the shunt coefficient. Correct calculation of the overhead ground wire shunt coefficient can improve the rationality and economy of overhead line design.Some of the existing research on shunt coefficient uses double-side elimination method, loop method and other theoretical calculation methods, and some uses software for modeling and simulation solution.However, some of the theoretical calculation methods are complex in principle, difficult to obtain some parameters, and software simulation takes time to build the model, the simulation results are not intuitive, and the existing studies are less concerned about the existence of ground wire segmenting insulation, single point grounding and other ground wire operating modes.Based on existing research, the first part of this study is the first established the double ground by tower grounding, not graded insulation of transmission line network model, and then established a common ground graded insulation, single point grounding network model and other ground wire operation mode of transmission line network model, and finally uses the node method to solve the transmission line network model, to obtain the shunt coefficient of each step distance of overhead ground wire, and on the basis of theoretical derivation and relevant calculation software is developed with the aid of matlab platform.In order to verify the correctness of the algorithm, the second part of this study takes a 220kV circuit as an example to compare and verify the calculation results of the calculation software with the simulation results of ATP/EMTP's shunt coefficient.Finally, the third part of this study uses the calculation software to calculate the shunt coefficient of OPGW with the combination of common ground wire and the common ground wire insulation in different sections and single point ground operation mode, and on this basis calculates the insulation gap voltage in the case of ground wire insulation in different sections.The conclusions are as follows: ground wire operation mode affects the shunt coefficient of the overhead ground wire. When the OPGW is set up on the left and right side of the common ground wire, the maximum shunt coefficient of the OPGW will increase by about 5.13% if the common ground wire is insulated in sections and the insulation gap is not broken down.Based on the overhead ground wire shunt coefficient of each step distance, the thermal stability can be checked to ensure the economy and reliability of ground wire selection. The calculated insulation gap voltage can provide a reference for the design of insulation gap.

Paper ID: 2331

Understanding ageing condition of epoxy micro nanocomposites using space charge characteristics and by adopting PCA and ANN analysis

Babu, Myneni Sukesh (1);Sarathi, Ramanujam (1);Imai, Takahiro (2)

1: Department of Electrical Engineering, Indian Institute of Technology Madras, Chennai, India;2: Infrastructure Systems Research and Development Center, Toshiba Infrastructure Systems & Solutions Corporation, 1, Toshiba-cho, Fuchu-shi, Tokyo, 183-8511,

Epoxy micro-nanocomposites are subjected to gamma irradiation for a dosage of 8 kGy and water ageing at 90℃ for a period of 240 hours respectively, to study the characteristic variation in their space charge behavior after ageing. Exposing to gamma irradiation can alter the molecular structure of the material through radiation induced degradation reactions. Water ageing at high temperatures helps in understanding the long-term consequences of water intake phenomenon. Homo-charge accumulation near the electrode-specimen interface of test specimens, is observed with increment in poling time. A significant increment in the magnitude of space charge density after one hour of poling time, is noticed in aged specimens compared to unaged specimen. The gamma irradiated and water aged specimens are classified from unaged specimens by adopting principal component analysis (PCA) and Artificial neural network (ANN) analysis with its input from space charge characteristics. The number of hidden layer neurons in the neural network architecture are optimized based on classification accuracy and number of epochs required to converge. Artificial neural network analysis reflects good classification accuracy compared to principal component analysis in classifying the gamma irradiated and water aged epoxy micro-nanocomposites.

Paper ID: 2335

Design of warm dielectric terminations and ceramic breaks for high temperature superconducting power cables

Cheetham, Peter;Mensah, Paul;Kim, Chul;Pamidi, Sastry

Florida State University, United States of America

Electric insulation is one of the critical elements of the design of high temperature superconducting (HTS) power cables. The two electrical insulation designs used for HTS power cables are a warm dielectric or a cold dielectric. The warm dielectric refers to the electrical insulation being at room temperatures and on the outside of the cryostat which houses and maintains the HTS cable at the cryogenic operating temperature. The cold dielectric refers to electrical insulation directly on the cable and stays at the same cryogenic operating temperature as the cable. Often cold dielectric design is used for HTS cable as it allows for multiple cable to be installed within a single cryostat which increases the overall power density of the system. Large electric transportation systems such as electric aircraft and electric ships will have multiple HTS power cables as part of superconducting power distribution networks. HTS cables terminate at common nodes within the power system where they either connect to another HTS device operating at cryogenic temperature or to a conventional device operating at room temperature. The terminations of a HTS cable represent a location of significant and electrical and thermal stresses. The use of a warm dielectric termination is seen as a potential solution to reduce the electrical standoffs required as part of the design and allow for a high power dense termination design. To enable the use of a warm dielectric termination design it is necessary to use ceramic breaks to electrically isolate the termination from the cable cryostat which would be at the ground potential. Depending on the location of the ceramic break within the system its design may vary to serve additional functionality such as a method to decouple the electrical and thermal systems of the HTS cable from one another. This paper explores the electrical insulation design requirements for both a warm dielectric termination and ceramic breaks for HTS power cables in electric transportation systems. The electrical insulation design will also be influenced by the thermal requirements of the HTS cable to ensure a feasible and practical solution. Details of the design requirements of warm-dielectric HTS cables and the proposed solution will be discussed.

Paper ID: 2350

Computational study on the positive streamer inception in air at high altitude

Che, Junru (1);Ding, Yujian (2);Yao, Xiuyuan (2);Ma, JiangGong (3);He, Hengxin (1);Cheng, Chen (1);Xia, Dezhi (1)

1: State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Wuhan, China;2: China Electric Power Research Institute, Beijing, China;3: Xinjiang Electric Power Research Institute, Xinjian

The streamer inception is the initial stage of long air gap discharges. In order to predict the breakdown voltage of long air gaps at high altitude of 4000m and above, it is necessary to establish a computational model to identify the streamer onset voltage and the inception time-lag at low pressure. However, traditional critical volume method didn't consider the impact of air pressure. In this paper, the seed electron generation process due to the detachment of O2- and its hydrated ions is simulated by considering different air pressure and humidity. Combined the computed generation rate of seed election and the critical volume method, a computational model for the streamer onset condition is proposed. The mean electric field for streamer onset and the distribution of inception time delay under different air pressure were calculated and compared with measured data. Finally, the impact of air pressure on the streamer inception for different applied voltage waveforms and electrode curvatures are analyzed.

Paper ID: 2351

Visualization of Positive Leader Channel Expansion in a 3m rod-plane gap by Schlieren Method

Wu, Yutong (1);Ding, Yujian (2);Yao, Xiuyuan (2);Ma, JiangGong (3);He, Hengxin (1);Chen, Cheng (1);Xia, Dezhi (1);Che, Junru (1)

1: Huazhong University of Science and Technology, China, People's Republic of;2: China Electric Power Research Institute, Beijing, China;3: XinJiang Electric Power Research Institute, XinJiang, China

Long air gap discharge plays an important role in the breakdown of external insulation and lightning physics, and leader propagation is the cause of long air gap breakdown. The leader channel is a thermal ionization dominated plasma with high conductivity. The thermal radius of the leader channel is an important macroscopic parameter to represent the expansion of a continuously propagating leader. In this paper, the schlieren diagnostics were employed to record the leader channel expansion in a 3m rod-plane air gap under positive switching impulses. The change of thermal radius with time was derived from the recorded Schlieren images under the breakdown and the withstand scenario, respectively. The observed thermal radius changes are compared with prediction results by using the Gallimberti model. Finally, the impact of thermal conduction and convection loss on leader expansion is discussed.

Paper ID: 2356

A high-speed dynamic measurement system for transient space charge in insulation materials

Zhang, Ling (1);Xu, Yuxuan (1);Wang, Zhaowei (2);Wu, Wangsonng (1);Zhou*, Yuanxiang (1)

1: State Key Lab of Power System, Department of Electrical Engineering, Tsinghua University, Beijing 100084, China;2: Wuwei Electric Power Supply Company of the State Grid, Wuwei 733000, China

It is of great significance for insulation design, reliability evaluation, and new material development to obtain the transient evolution process of space charge in insulation materials by actual measurement. With the development of hardware technology in recent years, it is possible for high-speed, dynamic, and continuous space charge measurement. This article adopts an oscilloscope with 500 MB storage, a high-frequency pulse power supply (up to 1 MHz), and the high-speed dynamic measurement of space charge is realized based on the PEA method. Meanwhile, in the strong electric field conditions, the average sampling mode is no longer used, reducing the time interval of the measured waveform. But the signal-to-noise ratio becomes worse and corresponding strategies for signal recovery is put forward as well. In this paper, transient space charge is measured in the polyethylene or oil-paper insulation samples under the conditions of DC prebreakdown test, high temperature, and polarity reversal. It is found that a large amount of space charge, including packet-like space charge, could inject and migrate in millisecond time scale, and caused severe distortion and oscillation of the electric field inside the insulation. The high-speed dynamic space charge measurement technology and system introduced in this paper provide an important perspective to solve the bottleneck problem in the research of transient process of insulation materials.

Paper ID: 2357

Algae Distribution on the HVDC Composite Insulator and the Influence of Algal Activity on Electrical Characteristics of Silicone Rubber

Tan, Jieying (1);Xiao, Wei (2);Xu, Chi (1);Zhang, Fuzeng (2);Wei, Xiaoxing (3);Jia, Zhidong (1)

1: Engineering Laboratory of Power Equipment Reliability in Complicated Coastal Environments,Tsinghua Shenzhen International Graduate School, Tsinghua University;2: Electrical Power Research Institute China Southern Power Grid;3: Maintenance & Test Cent

In warm and humid areas, algae are found on the surface of composite insulation materials, reducing their electrical performance. In this paper, the axial distribution of algae coverage and algae growth density on the HVDC insulator was analyzed based on digital image processing technology, and the reasons of the distribution were explored. Then algae were partially inactivated by high temperature, and the effect of algal activity on the electrical properties of silicone rubber was studied. The results showed that influenced by sunlight, rainfall, inorganic pollution and electric field, algae growth density decreased gradually from the low-voltage side to the high-voltage side, and algae coverage on the sheds near the high-voltage side and the low-voltage side was higher than that near the medium-voltage side. Algal growth significantly reduced the hydrophobicity of silicone rubber, and the death of algae was conducive to the recovery of hydrophobicity of silicone rubber and reduced the leakage current after wetting. However, despite the death of algae, the surface of silicone rubber could not return to the hydrophobic interface.

Paper ID: 2359

Effect of annealing rate on low-temperature impact strength and space charge characteristics of isotactic polypropylene

Zhang, Ling (1);Wu, Wangsong (1);Xu, Yuxuan (1);Zhou*, Yuanxiang (1,2)

1: State Key Lab of Power System, Department of Electrical Engineering, Tsinghua University, Beijing 100084, China;2: The Wind Solar Storage Division of State Key Lab of Power System, School of Electrical Engineering, Xinjiang University, Urumqi 830047,

Isotactic polypropylene (iPP) is one of the most promising substitutes for XLPE material, which has attracted wide attention in recent years. Hot melting and annealing processes have great influence on the crystallization characteristics of iPP. To study the effect of annealing rate on iPP property, three kinds of non-isothermal crystallization samples with different annealing rates, namely iPP-Ice (ice water cooling), iPP-Air (room-temperature cooling), and iPP-Slow (slow cooling), were prepared, and their properties were studied by thermal analysis, low-temperature impact testing system, and pulsed electroacoustic method. The results show that with the increase of cooling rate, the crystallization temperature of iPP increased, while the melting point decreased. In contrast, the change of crystallinity increases first and then decreases. The 50% brittleness temperatures of iPP-Ice, iPP-Air, and iPP-Slow are 0.3℃, -5.6℃, and -7.5℃, respectively. Among three groups of iPP samples, iPP-Ice has the most obvious space charge accumulation, the largest electric field distortion rate, and the lowest carrier mobility during depolarization. The accumulation degree of space charge in iPP material is positively correlated with the interface area of semi-crystalline polymer crystal region/amorphous region.

Paper ID: 2105

Defect diagnosis technology based on multispectral point cloud

Yang, Yang;Yang, Ning;Li, Lihua;Gao, Fei

China Electric Power Research Institute, China, People's Republic of

Smart and intelligence are the general trend of future power grids worldwide. During more than 100 years development of power grids, electrical equipment, such as transformers and circuit breakers, have been playing the most influential and important parts to transmit electric power from power plants to customers. Millions of electrical engineers spent millions of hours to improve the robustness of electrical equipment. Nowadays, Digital Twin (DT) modeling technology provides the platform to transfer physical entities into digital model, so that operation and maintenance personnel can easily get access to the operation condition of electrical equipment.Among different digital modeling methods, Light Detection And Ranging (LiDAR) reconstruction provides a real 3D view of DT by acquiring high-density 3D point cloud. LiDAR modeling technology has been widely used in the engineering construction stage, but temporarily only used for digital display in the operation and maintenance stage. The value of 3D point cloud data is not fully utilized.Meanwhile, more than 50% reported electrical equipment defects in substations were visual defects, which can be detected in daily inspection using visible light cameras, infrared camera or ultraviolet camera. Due to the rapid development of Artificial Intelligence (AI) in 2D image identification, 2D electrical equipment image analysis has become a hot spot for electrical equipment defect diagnosis. However, owing to the lack of depth/distance in 2D images, sometimes it is hard to distinguish the subjects and backgrounds in 2D images especially in 2D infrared images. It would be futile to decrease the rate of misdiagnosis of defects by only increasing the number of 2D image samples. Fortunately, the fusion of 3D point clouds and 2D images show a promising future to enhance the ability of defect recognition in electrical equipment.In this paper, 2D image RGB information was fused with 3D point cloud by calibrating the locations of cameras and LiDAR and transforming the coordinate systems of cameras and LiDAR. According to the components in 2D images, point cloud was semantically divided into different groups. Visual appearance defects and abnormal temperature distribution in the segmented point cloud can be recognized with less misdiagnosis. The point clouds collected at different times were compared to realize the abnormal appearance of equipment components. This application showed an Improvement of the reliability of power equipment and reduction of the work pressure of operation and maintenance personnel.

Paper ID: 2107

Advantages vs. risks with on-line monitoring of transformer bushings

Jonsson, Lars

Hitachi ABB, Sweden

High voltage capacitance graded bushings are critical component found in all electrical networks and whose failure can have serious consequences. Condition assessment reduces the risk of failures and thereby substantially increasing transformer availability in particularly high-risk applications where transient stress, fluctuating load and repeated events in the grid occurs.One of the most common off-line screening methods is based on the measurement of the dissipation factor and capacitance at power frequency. It is easy to perform but may not capture early changes in the dielectric constitution of the insulation. More advanced off-line methods combine Dielectric Frequency Response analysis, Dissolved Gas in oil Analysis and the consolidated information from specific product type, voltage, age, service conditions, application and previous events in the grid. This provide a solid base for decisions regarding future service as well as capturing very early signs of degradation.The various on-line diagnostic methodologies are usually based on measuring the dissipation factor and capacitance at power frequency. It has the advantage of evaluating the insulation at full voltage and at operating temperature. In addition, the diagnostic performance is also much improved for problems that develop fast since the measurement is done continuously while the transformer is in service. However, it should be recognized that most monitoring systems require connection to the bushings main insulation. Removing the regular grounding exposes bushings to a different physical environment controlled by the monitoring equipment compared to was originally intended.• Most monitoring systems have included voltage protection schemes, but it should be verified that the scheme provides adequate long-term protection and offers sufficiently fast reaction against Very Fast Transients.• The mechanical connection of monitoring equipment is also critical and the materials of the monitoring equipment must be compatible with those of the bushing to prevent galvanic corrosion and the monitoring device construction must be such that the components of the bushing are not damaged and that connections are robust.Bushing on-line monitoring adds complexity and some associated risk to the integrity of a bushing and should be done carefully applying only robust components.

Paper ID: 2119

Prediction of the most probable dielectric strength of large systems and St. Petersburg paradox

Geilikman, Mikhail Boris

Milleboswe Consulting LLC, United States of America

The relationship between dielectric strength and the size of the system (or for electric cable - its length) belongs to a broad class of statistical problems of material strength vs. its scale, including mechanical strength as well, despite the difference in underlying physics. The most frequently used statistical distribution for the description of these phenomena is the Weibull distribution despite there is no theoretical foundation of its applicability. The Weibull distribution yields a power-like dependence of the most probable breakdown voltage as a function of the system size. However, as it has been shown in recent tests (Fontana, Palfy-Muhoray, 2020), the mechanical strength of long cables exhibits logarithmic behavior as a function of its length. That has been attributed to the manifestation of the so-called St. Petersburg paradox which is due to an increased occurrence of large defects at a higher scale, be it either mechanical or dielectric breakdown. The paradox is in the fact that the outcome of the tests is strongly different from the typically expected one (see e.g. Feller, 1957; Introduction to Probability Theory and Its Applications, vol.2).In order to clarify this problem for the matter of dielectric strength, we have used historical data for the dielectric strength of oil-impregnated paper capacitors. In order to perform a quantitative Gedanken enlargement of the original set of data for small capacitors, we split the set of initial data points into equal groups, each with "n" tests data points. The lowest value of breakdown voltage in each group is taken as the strength of the sample with the scale, n-times larger than the initial small sample. Different degrees of enlargement have been performed by changing the number, n, of data points in the group. As a result, we obtained a set of data of breakdown voltages for samples of different sizes. This set of data has been approximated by two different statistical distributions: the Weibull and the Extreme Values distributions. As it turned out, the Extreme Values distribution provided a better fit. The Extreme Values distribution yields a logarithmic dependence of the most probable breakdown strength vs. system size which is in agreement with the prediction of the St. Petersburg paradox.

Paper ID: 2123

Comparative Analysis of Partial Discharge Denoising Techniques

Andrade, Gabriel de Oliveira;Avelar, André Souza Oliveira;Mota, Hilton de Oliveira

Federal University of Minas Gerais, Brazil

The Partial Discharge (PD) detection is a way of verifying the dielectric condition. It is based on the fact that when the insulation has imperfections, an ionization may occur, originating a PD. However, when the PD pulse is electrically detected, it may have a high noise level, which demands an efficient denoising technique in order to avoid PD detection problems and false alarms. This article presents a comparison among the techniques Undecimated Discrete Wavelet Transform (UDWT), Local Modulus Maxima (LMM) and Morphological Component Analysis (MCA) for the filtering of PD signals. The performance was evaluated considering synthetic and measured PD signals containing Gaussian, harmonic and impulsive noises. The synthetic PD pulses were generated according to the impulse response of a parallel RLC circuit which led to two wide-band and two narrow-band types of responses. The evaluation metrics, named signal to reconstruction error ratio (SRER), cross correlation (CC), pulse amplitude deviation (PAD) and pulse number error (PNE), were used to determine the efficiency of each method regarding synthetic signals. On the other hand, measured PD signals were generated in noisy environments and a visual inspection of the denoised signal was the main parameter to determine the most efficient method, by observing the noise attenuation level and the PD pulse waveform. The results were conclusive and it was possible to determine that the higher performance method, considering the signals, the metric results and the visual inspection, was the Morphological Component Analysis, in spite of the efficient results of the Local Modulus Maxima method. For the synthetic signals, MCA and LMM achieved, respectively, an average value of 15.62 dB and 7.10 dB for SRER, 91.32% and 88.64% for CC, 20.27% and 26.39% for PAD, 13.70% and 15.60% for PNE. For the measured signals, MCA could better reconstruct the shapes and amplitudes of the PD pulses, but it was not able to completely attenuate the noise, which resulted in a very small noise vestige throughout the signal. The LMM could attenuate all the noise in the signal, but presented difficulties to deal with noises superimposed to the PD pulses, which resulted in shapes and amplitudes divergences.

Paper ID: 2128

Numerical Simulation of Partial Discharge in Air-Polyimide Insulation under High Frequency Electrical Stress

Guo, Yujin (1);Han, Zhiyun (1);Li, Zhihui (1);Dong, Ziwei (1);Liu, Tao (2);Gao, Haoyu (1);Li, Qingmin (1)

1: North China Electric Power University, China, People's Republic of;2: China Electric Power Research Institute, China, People's Republic of

Partial discharge is one of the main reasons leading to premature failure of high-frequency power equipment insulation. However, there is still a lack of complete understanding on the development rules of partial discharge process. In order to inquiry the evolution of partial discharge, a set of simplified but effective reactions was used to describe all reactions of air discharge. On this basis, a non-equilibrium plasma model of air-polyimide partial discharge under the sphere-plate electrode structure was presented with fluid dynamic theory. This model solved the continuity equations for charged species and the electron energy balance equation, coupled with Poisson's equation. Then, the temporal and spatial evolution laws of the charged particle density, surface charge density and discharge current during the discharge process were obtained. Accordingly, the influence of voltage amplitude and frequency on partial discharge was also studied and revealed. The results indicate that the process of partial discharge is mainly controlled by the change of air gap voltage, and the superposition effect of electric field and external electric field caused by charge accumulation on the dielectric surface is significant. At the moment of discharge, electrons, positive and negative ions are mainly concentrated near the cathode sheath which leads to serious distortion of the air gap electric field. The number of discharges in a single cycle is positively correlated with the voltage amplitude and negatively correlated with the voltage frequency.

Paper ID: 2146

Comparison of Methods for the Interpretation of Dissolved Gases in Soybean Based Natural Ester

Meira, Matias (1);Álvarez, Raúl (2);Verucchi, Carlos (1);Catalano, Leonardo (2)

1: INTELYMEC (UNCPBA) and CIFICEN (UNCPBA-CICPBA-CONICET), Olavarría, Argentine Republic;2: Faculty of Engineering, National University of La Plata, Argentine Republic

In this work, the performance of several criteria for the interpretation of gases generated in soybean-based natural ester as a consequence of thermal and electrical faults are analyzed. For this purpose, a database of collected information from the specialized literature with contributions from various authors is used. The thermal faults that are analyzed are T1 and T2 type according to IEC 60599 classification. The electrical faults are partial discharges (PD) and arcs (D1/D2). The interpretation criteria of dissolved gases compared are the IEC ratios, Doernenburg ratios, Roger ratios, Duval triangle 1, Duval triangle 3 for soybean-based natural ester, Duval triangle 4, Duval triangle 6, and CIGRE ratios.

Paper ID: 2147

Simulation Study on the Effect of PD Pulse Shape on Electromagnetic Wave Propagation in L-type GIS Structure

Zhao, Tao (1,2);Judd, Martin D. (3);Stewart, Brian G. (2)

1: North China Electric Power University, China, People's Republic of;2: University of Strathclyde;3: High Frequency Diagnostics Ltd

The UHF method has been widely used in PD detection and localization in GIS systems. Modeling of electromagnetic (EM) wave propagation inside a GIS structure can be helpful for understanding and improving the sensitivity of PD detection by providing information to help determine more optimal positioning of UHF PD sensors. Propagation characteristics of radiated PD EM waves in GIS systems are complicated. When an EM wave spreads in a GIS system, several phenomena may occur (such as reflection, refraction, resonance, wave mode conversion and attenuation), which combine to cause complex EM wave behavior. The electric field distribution reveals that electric field is very different for different positions after the EM wave signal passes through a GIS pipe. Therefore, for the electric field detection, the outputs of the sensors may be very different for different installation locations. Obviously, many factors can affect the electric field distribution, such as the geometry and structure of GIS. A time-domain Gaussian current pulse with very narrow pulse width is most commonly used to represent a PD source in electromagnetic simulation methods, and the PD pulse width is found to have a strong influence on the distribution of UHF electric field detected at sensors installed on the GIS.This paper focuses on the effect of different Gaussian pulse width sources for the EM wave propagation behaviors. Firstly, the time dependent EM wave propagation behaviors are simulated for an L-type GIS structure using COMSOL Multiphysics and a comparison based on different Gaussian pulse width sources for the EM wave propagation behaviors is conducted. Then based on the attenuation characteristic analysis of UHF sensor locations along the GIS tank and around its circumference, the resulting influence of different Gaussian pulse width sources on the UHF sensor signals is presented and discussed. The results in this paper give rise to understanding the limitations and optimization of PD sensor positions for UHF signal detection.

Paper ID: 2170

PD Positioning of Electrical Transformers Based on the Designed Pressure-balanced EFPI Sensor Array

Xi, Yingjie (1);Luo, Chuanxian (2,3);Yang, Xu (2,3);Zhang, Chongxing (1);Dong, Ming (1);Liu, Yang (1)

1: State Key Laboratory of Electrical Insulation & Power Equipment, Xi'an Jiaotong University, China, People's Republic of;2: Wuhan NARI Co Ltd., State Grid Electric Power Research Institute, China, People's Republic of;3: Nanjing NARI Group Corp., Stat

Electrical transformers play an important role in the power system, which could result in serious safety and economic losses in case of insulation failures. Such insulation faults are generally accompanied with PDs which are therefore important indicators for the status diagnosis and assessment of transformers. Thus, the on-line PD monitoring system is of great significance to guarantee the safe and reliable operation of the transformers. PD positioning technology is aimed to locate the discharge source, which contributes to the fault diagnosis and equipment maintenance. Because of the advantages of slower signal propagation speed, the ultrasonic-based PD detection method is appropriately used to PD positioning. Presently, the PD positioning accuracy in practice depends on both the performance of ultrasonic sensor itself and positioning algorithm optimization. Due to the excellent performance of higher sensitivity and strong anti-interference, optical fiber ultrasonic sensors are markedly superior to the traditional piezoelectric ceramic sensors and have a good application prospect.This paper proposed and designed a novel structure of extrinsic fabry-perot interferometric (EFPI) fiber optic ultrasonic sensors. In order to put the sensor into the transformer and achieve the build-in detection, we used transformer oil to replace the previous air atmosphere in the F-P cavity of the sensor to avoid the potential additional insulation defects. Meanwhile, the pressure inside and outside the sensor could be kept equalized. According to the simulation and experimental analysis, the optimized installation position of ultrasonic array made it possible to monitor the single-phase windings separately instead of monitoring the whole transformer directly, which resulted in the better positioning accuracy. Based on the sensor array, a positioning algorithm was developed, which combined time difference of arrival (TDOA), steered response power (SRP) and multiple signal classification (MUSIC) algorithm. Based on the analysis of the recorded waveforms, the positioning results of the algorithms were weighted by calculating the confidence degree to give a more accurate positioning result. An experimental double-winding model was used to test the performance of the designed sensor array and positioning algorithm in several typical cases, in which five PD sources at different positions were established.Compared with traditional ultrasonic positioning methods, the positioning results of the designed sensor array and positioning algorithm show good accuracy, which illustrates that the designed optical fiber sensor array and its installation position make it more accurate and sensitive to capture ultrasonic signals generated by PDs. The study provides reasonable guidance for the design of sensor array and application mode. The experimental results show that under all kinds of experiment condition, the error of the PD positioning algorithm is less than 10cm, which satisfies the actual requirements of transformer monitoring.

Paper ID: 2174

Green Substation: Dream or Reality?

Negri, Fabrizio (1);Kaineder, Kurt (1);Giovanelli, Lorenzo (2);Yazdani, Mana (2)

1: Siemens Energy, Germany;2: Trench Group

Esters, especially synthetic ones, are not a novelty in the high voltage insulation applications, but their usage has shown a rapid growth in the recent years due to the numerous studies about their technical advantages. Nevertheless, the majority of the latter is focused on distribution or power transformer applications. In this paper, the application of esters as an alternate insulation for the instrument transformers will be discussed.The results presented in this paper are based on experiments conducted on natural and synthetic esters. Their high saturation point due to high concentration of oleic acid makes them an attractive option for applications such as instrument transformer with long-life operation expectancy without any fluid change.The experiment was initiated by a series of tests to verify the compatibility of various material with the ester. A test procedure was defined to assess the performance of the material in combination with ester. The testing was started by prioritizing materials such as gaskets, that prevent fluid oxidation.In order to investigate the cellulose impregnation and the resulting dielectric performance within the instrument transformers, prototypes filled with esters were built and tested. The impregnation was done at lower pressure (less than 0.02 mbar) and higher temperature in comparison to mineral oil filling. The result of dielectric tests performed according to IEC61869-IEEE C57.13 standards is reported in this paper. The theoretical response of the units during endurance testing is also evaluated. The thermal performance will be evaluated as part of an investigation for station service voltage transformers.While synthetic esters are more aggressive than natural esters in compatibility with other materials, the test results have revealed that the majority of the materials used inside the instrument transformers are still compatible with both types of esters. The impregnation of the insulation is another major challenge in the instrument transformers due to the compact paper insulation structure within the units. Although the viscosity of esters is higher than the mineral oil, the Poiseuille’s law suggests a square relation between the impregnation and the viscosity, hence minimizing the difference of the impregnation time length. A comparison of the dielectric performance based on theoretical calculations of the dielectric breakdown shows that the distribution of the electric field in oil-paper insulation with esters is more concentrated in the paper and thus the liquid is less prone to electrical breakdown.The results reported here showed that the use of esters in instrument transformers is feasible without major changes related to the production process and, unlike power or distribution transformers, without big changes in the design and manufacturing procedures.

Paper ID: 2176

Electrical Studies to Understand the Water Absorption Behaviour of Polyoxymethylene Used for Deep-Sea Applications

Arumugam, Saravanakumar (1);Krohmann, Sascha (1);Haba, Yvonne (1);Pieterse, Petrus (2);Uhrlandt, Dirk (2);Kosleck, Sascha (1)

1: University of Rostock, Institute of Marine Engineering, LMT/MSF, Germany;2: University of Rostock, High Voltage and High Current Technologies, IEF/IEE, Germany

Modern maritime technologies anticipate using innovative solid-state power solutions designed to meet the requirements of underwater or deep-sea applications. Pertinent attempts involve insulation materials that are robust, hydrophobic and can be used for making pressure tolerant enclosures. Naturally, polyoxymethylene (POM) may be considered as a popular choice for underwater applications as they exhibit better mechanical, electrical, and thermal properties. Nevertheless, it is important to understand their typical response well before their underwater deployment and validate their usage prior to deep-sea application. This implies studying the water absorbtion and saturation of POM and their direct influence on the material properties and ageing phenomena. Currently, there are few information regarding the water absorbtion and saturation of POM material is available in public domain. In addition to this, it is important to understand and if possible quantify the significance of water ingress in the POM material and its typical influence on the electrical properties. In this context, an experimental study that monitors the typical absorption behaviour of an insulation material which is hydrophobic and well suited for underwater application is initiated.Currently used solid-state components has mostly plastic packaging and encapsulation without watertight sealing and resistance to high pressure. So, direct use of these components for underwater or deep-sea applications are out of the question. Alternatively, these components and/or the corresponding converter modules can be encapsulated in dielectric gel and housed inside a box made of POM materials. Such an arrangement is expected to prevent water ingress and can appear as pressure tolerant. Prior to this, the adequacy of these materials in further usage for under water application must be experimentally verified.The present study is restricted to experimental investigations on samples extracted from POM material. Initially, five test samples are selected and earmarked as ‘virgin’, ‘dry’, ‘wet-1’, ‘wet-2’ and ‘wet-3’ respectively. In all, the samples ‘virgin’ is maintained as it is while the dielectric parameters (i.e., loss factor, complex permittivity, capacitance, resistance and impedance) of ‘dry’ is recorded over a wide time and frequency. The samples identified as ‘wet-1’, ‘wet-2’ and ‘wet-3’ are immersed in water for specific duration. Subsequently, the dielectric parameters of these wet samples are duly recorded in regular interval of times and the same is compared and analyzed with reference data. The pertinent deviations in the measured dielectric parameters are analyzed and the respective trend is studied in detail. It is expected that in due course of time, the deviations in the dielectric parameters would cease to vary henceforth indicate, atleast in apparent sense that the material has reached to a high lever closer to the full saturation. Following this, the loss factor is matched with an existing in-built model and compared to estimate the moisture content in the insulation. Pertinent data collected from the measured samples is expected to provide a clear picture about the influence of water on the chosen POM material and may quantify the water saturation (atleast in apparent sense) through correlating the same to the changes in the measured parameters.

Paper ID: 2177

A setup for measuring bubbling from paper in transformer oil under simulated sudden overload.

Linhjell, Dag;Lundgaard, Lars E.

SINTEF Energy Research, Norway

Paper insulation on transformer windings may contain moisture, from ageing or moisture ingress through breathers. A sudden overload will cause the insulation to heat much faster than the oil, and the moisture forced out of the insulation may not dissolve in the much colder oil, with bubbling as a result. Several studies have addresses bubbling temperature depending on winding moisture, aging state or pre-overload temperature, but some results are conflicting between studies. A setup has therefore been built to study bubbling. One heating system circulates oil with "pre-overload" temperature of up to 120℃. Moisture level is controlled by circulating through a cellulose reservoir with cellulose of known moisture. Another system heats one paper covered electrode controlled from 20℃ to 200℃ in about 15 minutes. Shock heating with a temperature increase of 80℃ in 30 seconds is possible. Bubbling can be detected optically through viewports, or by resulting discharges if applying a 20 – 30 kV between the covered electrode and a high voltage electrode, with an adjustable gap of normally 2mm. The covered electrode is insulated from ground and has a connection for current or discharge measurements. The setup has been tested with low density pressboard with 6% moisture, resulting in a bubbling temperature of 163℃, which other studies with paper only have found for about 1% moisture. Presently, the setup does not have adjustable pressurization, but it is made for easy expansion with pressure control, both higher than and lower than normal atmosphere.

Paper ID: 2181

Study on Nest Material Flashover Risk Level Assessment of AC Overhead Transmission Line

Wang, Shenghui (1);Wang, Ximing (2);Guo, Fengtian (2);Han, Bing (3);Wang, Xiaoyu (3)

1: North China Electric Power University, Beijing, People's Republic of China;2: North China Electric Power University, Baoding, People's Republic of China;3: Heilongjiang Province Electric Power Research Institute, Harbin 150000, People's Republic of C

In recent years, the number of transmission line faults caused by bird activities has increased significantly. Bird's nest fault is one of the main causes of transmission line accidents in China among all bird related faults. The flashover of overhead transmission lines caused by nest material is mainly related to various factors such as the conductivity of rainwater, and spatial position. In this paper, a typical nest material was immersed in different conductivity solution to simulate rainwater, and the situation of nest material hanging was simulated by adjusting the spatial structure of the nest material, the insulated cross arm and the equalizing ring. Afterwards the flashover characteristics of conductor-tower gap with nest material under AC voltage were studied. This study found that the flashover process can be equivalent to the breakdown process of the rod-rod gap. Based on the previous tests and investigations of risk factors, an improved fuzzy comprehensive evaluation method was used to establish a nest material potential risk assessment model.

Paper ID: 2184

Theoretical Calculation and Experimental Study on the Effect of Gas Content on Heat - Induced Bubble Formation of Oil-paper insulation

Xiaohui, He;Rui, Zhang;Chong, Guo;Qiaogen, Zhang;Tao, Wen

Xi 'an Jiaotong University, China, People's Republic of

Increasing temperature will cause heat-induced bubbles to form in oil-paper insulation, which will threaten its insulation performance, and the gas content will affect its inception temperature. In order to clarify the influence of gas content in oil on the inception temperature, the calculation model of heat- induced bubbles (ITBE) was improved to calculate the inception temperature under different gas content. Meanwhile, the corresponding experimental platform and winding model were built to carry out the corresponding experimental research. The results show that the calculated results were in good agreement with the experimental results. The increase of gas content will lead to the decrease of inception temperature. The lower the water content of paper, the more obvious the influence of gas content. This can be explained qualitatively by the relation of pressure in the bubble germ. The research is helpful to provide reference for the condition evaluation of oil-paper insulation.

Paper ID: 2186

Research on Discharge Characteristics of Nest Material of Overhead Transmission Line under AC Voltage

Wang, Shenghui (1);Guo, Fengtian (2);Dong, Xinghao (2);Han, Bing (3);Wang, Xiaoyu (3)

1: North China Electric Power University, Beijing, People's Republic of China;2: North China Electric Power University, Baoding, People's Republic of China;3: Heilongjiang Province Electric Power Research Institute, Harbin 150000, People's Republic of C

With the expansion of the power grid and the improvement of ecological environment, the number of transmission line faults caused by bird activities has increased significantly, in which birds nesting is the main reason for the transmission lines trip in China. The flashover is mainly related to various factors such as the electrical conductivity of rainwater, the length of the nest material and its spatial position. In this paper, various situations of the nest material setting on the tower were simulated by changing the length and spatial position of the nest material under different conditions, and AC flashover performance of line-tower gap, where nest material was placed, was investigated. In order to study the influence of the overlapping nest material on the electric field distortion of air gap, a three-dimensional simulation model of the side phase of the 110kV cup type tower was established by using finite element analysis software. The results show that, under the fixed gap distance, the larger the conductivity of the simulated rainwater sprayed on the nest material is, the smaller the gap breakdown voltage and breakdown field strength are; In severe cases, when the gap distance between the nest material and the grading ring is 20 cm, the breakdown field strength is 3.96 kV/cm, and the flashover process can be equivalent to the breakdown process of the rod-rod gap.

Paper ID: 2187

Study on Adaptability of Transient Calculation Model for MOA under Lightning Impluse

Shen, Lin;Chen, Zhe;Fang, Chonghao;Ma, Zixin;Li, Pengfei;Guo, Jie

Xi'an Jiaotong University, China, People's Republic of

Due to the extreme nonlinearity and multivariable influence of the V-A characteristics of MOA, the MOA models are significantly different under different transient conditions. In order to explore the adaptability of the simulation calculation model of MOA under different transient conditions and improve the accuracy of transient overvoltage calculation and analysis, the impulse current test platform is established in this paper for the four simulation models of MOA proposed at home and abroad. the differences between the current waveform, residual voltage and energy absorption characteristics of different simulation models under various shock waves and the experimental values is analysed and verified, and the adaptability of the calculation model under different impulse currents is obtained , which is of great significance for the correct selection of MOA models in the subsequent electromagnetic transient simulation research.

Paper ID: 2188

Breakdown Characteristics of Transformer Oil under Vibration and Electric Field

Guo, Chong (1);Zhang, Qiaogen (1);He, Xiaohui (1);Zhang, Rui (1);Wen, Tao (1);Wu, Xingwang (2)

1: Xi'an Jiaotong University, China, People's Republic of;2: The Electric Power Research of State Grid Anhui Electric Power Corporation, China, People's Republic of

Converter transformer is the core equipment of HVDC grid. Its oil-paper insulation structure is in a state of vibration for a long time under operating conditions. The pressure wave produced by vibration can cause periodic change of pressure in the narrow gap of oil-paper insulation, and the local stress appears negative value. When the amplitude of vibration reaches the cavitation threshold of transformer oil, the acoustic cavitation process in the oil were excited and a large number of micro-bubbles were formed. Microbubbles flow with transformer oil and tend to build up in the narrow oil duct and the gap between insulating pressboard, induce partial discharge in transformer oil under AC/DC electric field. Partial discharge acting on oil-paper insulation for a long time can cause irreversible insulation defects and eventually lead to insulation breakdown and equipment failure. This greatly enhances the potential operation risk of converter transformers. Therefore, study on the breakdown characteristics of transformer oil under vibration and electric field can further understand the insulation fault mechanism of converter transformer, provide a theoretical basis for equipment state monitoring, and comprehensively guarantee the safe operation of the equipment.The present study was conducted to analyze the breakdown characteristics of transformer oil under vibration and electric field. The influence of vibration intensity and electric field form on the breakdown characteristics of transformer oil is studied based on the theory of acoustic cavitation bubbles. The influence mechanism of the presence of bubbles in transformer oil on the process of oil breakdown is discussed. The increase of vibration intensity can significantly reduce the AC/DC breakdown voltage of transformer oil, causing a threat to the insulation performance of converter transformer. Variation of bubble size and density in the gap of transformer oil caused by the change of vibration intensity are the main reason for the significant reduction of AC/DC breakdown voltage of transformer oil. AC breakdown electric field strength of transformer oil is more sensitive to vibration intensity change than DC breakdown electric field strength, which is closely related to the polarization process of bubbles in electric field. With the increase of vibration intensity, the AC/DC breakdown electric field strength of transformer oil changes in three stages: slow reduction, rapid reduction and stabilization, which correspond to the existence form of bubbles between poles under different vibration intensity. When the driving power is 111.3W, the impact degree of vibration on the breakdown electric field strength of transformer oil tends to be saturated, and the gas content is the main reason affecting breakdown process.

Paper ID: 2190

Research on Discharge Characteristics of Plastic Cloth on Overhead Transmission Lines under AC VoltageResearch on Discharge Characteristics of Plastic Cloth on Overhead Transmission Lines under AC Voltage

Wang, Shenghui (1);Dong, Xinghao (2);Wang, Ximing (2);Han, Bing (3);Wang, Xiaoyu (3)

1: North China Electric Power University, Beijing, People's Republic of China;2: North China Electric Power University, Baoding, People's Republic of China;3: Heilongjiang Province Electric Power Research Institute, Harbin 150000, People's Republic of C

The environment of transmission lines is relative complex, making the transmission lines face the threat of foreign matter intrusion. When the air humidity increases, moisture on the surface of plastic cloth will increase its surface conductivity and reduce the insulation strength between phases. In severe cases, plastic cloth short-circuit the air gap and cause flashover failure. In view of the above situation, this paper measured the equivalent salt density and gray density of the surface of the plastic cloth, and prepared solutions with different conductivity, sprayed on the plastic cloth to simulate the floats under different rainwater conductivity, the resistance of the float was measured by using a megohmmeter, and this paper also studied the conductivity of the plastic cloth. The plastic cloth sprayed with the simulated liquid are lapped on the simulated transmission line in different ways, and in order to analyzed the impact on its flashover characteristics, this paper studied the geometrical size and lap method of the plastic cloth under different rainwater conductivity under AC voltage by changing the geometrical size of the plastic cloth. This article consisted of following parts: Firstly, this paper studied the electrical conductivity of plastic cloth, and it was found that as the rainwater conductivity increases, the resistance of the plastic cloth gradually decreases. Meanwhile, the resistance of plastic cloth also decreases with the increase of its width. When the conductivity of rainwater is large enough, its resistance is close to 0 MΩ. Then, we studied the influence of the geometrical size and the lap way of the plastic cloth on the discharge characteristics by analyzing the conductivity of different solutions. When the plastic cloth completely overlaps the two transmission lines, flashover is most likely to occur in this case. When the conductivity of rainwater is 5.2mS/cm, the average flashover voltage gradient is 0.38kV/cm. The flashover voltage of plastic cloth decreases with the increase of rainwater conductivity, and it has similar characteristics with the increase of its width; When the plastic cloth does not completely overlap the transmission line, as the voltage increases, corona discharge can be observed on the plastic cloth. When the voltage increases to a certain extent, a light blue arc will appear between the plastic cloth and the high-voltage wire, and a dendritic slip flash discharge will also occur on the plastic cloth. When the plastic cloth flashes, there will be a bright orange discharge channel, accompanied by a huge noise. In this situation ,rainwater conductivity has a great influence on the flashover voltage of plastic cloth; When the plastic cloth is wound around the insulator, as the voltage increases, the gap between the plastic cloth and the equalizing ring is broken down, there is a bright arc connecting the plastic cloth and the equalizing ring, and a dendritic gliding discharge appears on the upper part of the plastic cloth. In this case, the conductivity of rainwater has a general effect on the flashover voltage when the plastic cloth is wrapped around the insulator.

Paper ID: 2192

Research on the discharge evolution law of the needle-plate defect in oil-paper insulation at AC voltage

Liu, Yang;Dong, Ming;Hu, Yizhuo;Xing, Yadong;Xi, Yingjie;Ren, Ming

State Key Laboratory of Electrical Insulation & Power Equipment, Xi'an Jiaotong University, China, People's Republic of

Power transformer is the core equipment of power system and the key equipment for power transmission and voltage conversion. With the improvement of manufacturing level, the capacity of a single transformer is becoming larger and larger, which will inevitably bring considerable economic damage in case of fault. Therefore, to make the changes of relevant physical parameters in the evolution process of internal defects of transformer, and to establish the mapping relationship between the changes of relevant physical parameters and the fault development process, can help to build "active" pre-protection, and effectively improve the safe operating level of transformer.In this paper, the discharge evolution law of needle-plate defect in oil-paper insulation based on multi-parameters was studied. Firstly, a discharge test platform for typical defects in oil-paper insulation was established, and a typical needle-plate defect was designed. And, the discharge process of the needle-plate defect was detected by high frequency current transformer, ultra high frequency, ultrasonic sensor and Silicon photomultiplier simultaneously. Secondly, in order to compare the sensitivity of various detecting methods for the discharge of the needle-plate defect, the discharge initial voltage of the defect by different detection methods was determined by gradual voltage-rising method. Then, the signals of high frequency current transformer, ultra high frequency , multispectral and ultrasonic were studied under constant voltage. Finally, the change law of the characteristics of different signals were analyzed, and the discharge process of the needle-plate defect was divided into three stages by the corresponding statistical characteristics.Based on the above research, with comprehensive analysis of the relevant parameters of different detection methods, the results showed that: the sensitivity of different methods to the needle-plate defect is different, the discharge initial voltage of multispectral method is the lowest under the needle-plane defect, followed by the initial voltage of high frequency current transformer and ultrasonic method, and the discharge initial voltage of ultra high frequency method is the highest. For the needle-plate defect, according to the change law of multi-parameters, the process of discharge can be divided into development stage, stagnation stage and pre-breakdown stage. In the development stage, the statistical parameters such as apparent discharge of high frequency current transformer, pulse repetition rate of ultra high frequency signal, peak value of ultrasonic signal and intensity of optical signal increase significantly. In the stagnation stage, except the amplitude of high frequency current transformer, other characterization parameters decrease significantly until entering the pre-breakdown stage.According to the above results, it can be seen that the traditional stage division relied on the change trend of certain characteristics under a single means to divide the discharge process has limitations and sometimes cannot reflect the actual operating conditions of the power equipment, while combining different means for multi-parameters analysis can more effectively classify the stage of the discharge and help judge the severity of discharge. In addition, it was found in this paper that analyzing the proportion of light radiation intensity in different spectral bands can also be used as an auxiliary means to judge the severity of discharge development.

Paper ID: 2199

Dynamic Behavior of Micro-droplets in Liquid Dielectric and Its Effect on Partial Discharge

Zhang, Rui (1);Zhang, Qiaogen (1);Zhou, Junjie (1);He, Xiaohui (1);Sun, Yuhan (1);Wen, Tao (1);Zhang, Shuqi (2);Yu, Xinru (2)

1: Stare Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, China;2: China Electric Power Research Institute Co. LTD

In the process of manufacturing, transportation, installation, and operation of power transformers, moisture can invade due to inadequate sealing, and drastic changes in the load during operation can also cause moisture to be exchanged in oil and paper. The influence of moisture on the insulation system is closely related to its form of existence, micro-water droplets suspended in the oil in an emulsified state have a great influence on the insulation performance of the oil. For a long time, researchers have only qualitatively believed that the presence of water droplets will greatly reduce the breakdown voltage of liquid dielectrics, but the specific impact mechanism remains to be clarified. In order to clarify the role of water in the breakdown of engineering liquid dielectrics, it is necessary to study the dynamics of water droplets under electric field. Therefore, this paper established a multi-physics simulation model that couples the flow field, electric field and phase field to study the influence of the dynamic behavior of water droplets on the breakdown characteristics of liquid dielectrics. The results show that the suspended micro-water droplets exhibit tensile deformation along the direction of the electric field under electric field, and the deformation rate is introduced to quantitatively characterize the degree of deformation. It is found that the degree of deformation increases with the increase of the electric field intensity and the radius of the water droplet, and increases with the decrease of the surface tension coefficient of the oil. The deformation rate can be expressed as a function only related to the dimensionless electric capillary number. Interestingly, it is found that when the electric field intensity exceeds a certain value, the micro-water droplets become unstable, and the poles become "pointed and convex", forming a so-called Taylor cone. When the electric field is further enhanced, the tip of the water droplet forms a micro-jet. The critical electric field strength required for the instability of water droplets of different radii is calculated, and it is found that the larger the radius of the water droplet and the smaller the surface tension coefficient, the lower the critical electric field strength required. The influence of the dynamic behavior of water droplets on the breakdown characteristics of the liquid is discussed. By analyzing the electric field distortion phenomenon caused by water droplets, it is found that the electric field near the head of the water droplet will be severely distorted during critical instability, which easily leads to partial discharge and vaporization of the water droplet. In addition, the arrangement of micro jets or micro water droplets along the direction of the electric field can easily form a "water bridge", which in turn can easily lead to breakdown of the liquid dielectric. The research work done in this paper will help to deepen the understanding of the behavioral characteristics of conductive droplets in liquid dielectrics and the breakdown characteristics of engineering liquids, as well as provide a theoretical reference for evaluating the harm of moisture to liquid insulation systems in engineering applications.

Paper ID: 2201

Design of a Pulse Generator for Testing Partial Discharge Measurement Systems

Hejtmanek, Tomas (1);Judd, Martin D (2);Drexler, Petr (1);Stewart, Brian G (3)

1: Faculty of Electrical Engineering and Communication, Brno University of Technology, Czech Republic;2: High Frequency Diagnostics Ltd;3: Department of Electronic and Electrical Engineering, University of Strathclyde

This paper deals with the design and implementation of a pulse generator serving as a reference generator for setting up measuring systems for monitoring partial discharges (PD) in high-voltage power transformers or gas insulated switchgear (GIS). After installing the measuring device, it is advisable to test the entire measuring chain and, if necessary, set parameters that would validate the correct detection of PD signals. Fast pulse generators are important for this verification. In systems that sense the electromagnetic activity of PD. The proposed generator should serve as the output stage of a programmable generator, which did not reach sufficient parameters for output pulses. The goal was to achieve a rising time around 100 ps and an amplitude of more than 6 V using very fast operational amplifiers and step recovery diodes to sharpen the input pulse. The measurements show waveforms of the output voltage pulse to evaluate its performance.

Paper ID: 2202

Application of Distributed PD Detection synchronously with Wireless Communication during Withstand Voltage Test on Power Cable lines

Min, Chen (1);Zhipeng, Zhou (2);Daren, Pan (2);Tianyu, Su (2)

1: SE Technology Limited, Hong Kong S.A.R. (China);2: ZF Technology Limited, Guangzhou, China

The purpose of higher withstand voltage test for HV power cables is to find hidden defects easily with partial discharge (PD) detection, which is a means to improve the quality of handover test. However, the PD detection during cable withstand voltage test is often difficult to carried out on-site because of the problems of field communication. Distributed PD detection requires signals from the sensors and their local signals processing units distributed at each cable joint can be transmitted and collected to a central processing unit for analysis and display. For those from several kilometers to more than ten kilometers long buried cable only depends on wireless communication if there is no pre-wired communication network with fiber cable or Ether cable. Due to the complex test site conditions, it is difficult to ensure that the speed of wireless communication network is stable above 3 Mbytes/second required for PD measurement. A new type of wireless communication distributed PD synchronization detection system has been developed and applied to several 110 kV and 220 kV cable withstand voltage tests recently. A new hybrid wireless communication system is adopted, which uses 4G/3G communication between local distributed signal processors, and WiFi communication between the central signal processing unit and any one of the local signal processors. This communication method can not only satisfy the needs of single-point to multi-point PRPD and PRPS atlas, synchronization display for distributed PD detection synchronously, but also achieve the signal processing and display of the point-to-point signal waveform, ensuring the quality of distributed signals trend observation function and synchronization comparison function of multi-point signal atlas. This paper tries to give a brief description of the formation and technical parameters of the PD detection system, and introduces the field application of the system through a withstand voltage test on 110kV cable circuit.

Paper ID: 2207

PDIV Numerical And Experimental Estimation In A Needle/Dielectric Film/Plane Configuration

Van de Steen, Cyril;Abadie, Cédric;Belijar, Guillaume

IRT Saint Exupery, France

As the transition toward more ecological (or greener) transportations is running, the electric power demand is growing, especially in the aeronautic domain. Gradual electrification of aircraft systems comes with great advantages such as energy rationalization, improved power density, or easier maintenance. However, to keep the power density as high as possible increased network voltage is necessary. Increasing voltage leads to new issues that were not present at lower (current) voltages. Partial Discharges Inception Voltage will be reached with the increment of the voltage and this is not systematically taken into account by manufacturer during the design phase and could cause the degradation of the electrical insulation system and long term failure.To obtain the Partial Discharge Inception Voltage value, the usual method is to directly measure it. This method gives exact results but has some weaknesses. Indeed, it does not provide the location of the partial discharge, it is only representative of the tested configuration, if one wishes to improve the PDIV of a specific component, every design modification should be tested.A second method is to simulate, using a commercial electrostatic FEM software (Comsol for this paper), the component and to determine from this simulation the global PDIV value as well as the weakest areas.In the HighVolt project at IRT Saint Exupéry, an already presented specific numeric tool (AIRLIFT) was developed to predict the Partial Discharge Inception Voltage using Townsend's Theory. The accuracy and adaptability to different environmental conditions (Pressure and Temperature) was already presented for different twisted pair's cases.In this paper, a more complex geometry is studied. The setup is composed of a dielectric film placed between a needle electrode with controlled radius and a plane electrode. Contrary to the previous paper, no probabilistic approach will be used. The objective of this paper is to present the evolution of experimental and predicted PDIV as a function of the inter-electrode distance, needle curvature radius and dielectric thickness. Dependence of simulated PDIV value with Paschen equation's parameters for this case will also be discussed.

Paper ID: 2224

Platform phenomenon of insulation characteristics of SF6 under AC superimposed impulse voltage

Sun, Haochen (1);Li, Xiaoang (1);Li, Jie (1);Lv, Yufang (1);Zhao, Ke (2);Zhang, Qiaogen (1)

1: Xian Jiaotong University, China, People's Republic of;2: State Grid Jiangsu Electric Power Research Institute, Nanjing, P.R. China

Lightning impulse withstand test and power-frequency voltage withstand test are adopted to detect inner insulation defects of Gas insulated switchgears (GIS). During operation, GIS withstood power frequency voltage and impulse voltage caused by switch operation and lightning intrusion, resulting in unexpected insulation accidents under the effect of superposition. For this reason, this paper studied the influence rules of SF6 gas gap insulation characteristics under AC superimposed impulse voltage through experiments. Results show that: Under slightly non-uniform electric field, the amplitude of AC component hardly affects the insulation characteristics of the SF6 gas gap under AC superimposed impulse voltage. Under severe non-uniform electric field, there are two stages depending on whether the amplitude of the AC component is greater than corona onset voltage. When the amplitude of the AC voltage component is less than the corona onset voltage, the AC component has almost no effect on the gas gap breakdown voltage and a plateau phenomenon occurs in the meanwhile. The disappearance of the platform period is related to the change of the space charge distribution formed by AC corona, and when the amplitude of AC component is high, the space charge becomes a dominant factor which affects the insulation characteristics of SF6 gas gap.

Paper ID: 2230

Effect of Multiple Transposition Structures of Transformer Helical Low Voltage Winding on the Electromagnetic Force Distribution

Wen, Tao (1);Wang, Qing (2);Yu, Yinshu (2);Zhu, Xiaojie (2);Han, Bin (3);Zhao, Yi (4)

1: Hefei University of Technology;2: State Grid Zhejiang Electric Power Co., Ltd. Ningbo Power Supply Company;3: China Electric Power Research Institute Co. LTD;4: Xi'an Jiaotong University, China, People's Republic of

The failure rate of power transformer due to electromagnetic force caused by external short circuit is high. The structure of the transformer is complex. From macroscopic to mesoscopic, the structural scale spans three orders of magnitude. The winding damage accidents are mostly caused by the microscopic structural deformation. The typical microscopic structural, transposition structure, widely exists in the windings wound by multiple continuous transposed conductor cables (CTC cables) in parallel. The position change of the CTC cables during transposition process causes the asymmetry of the structure. The asymmetry of the transposition structure affects the overall magnetic field distribution of the winding, and then changes the electromagnetic force distribution of winding disks. In this paper, the 110 kV transformers with a large number and high failure rate in the power grid are selected as the research object. Based on the previous research, three-dimensional finite element method (FEM) models of the transformers considering the winding transposition structure is constructed. The electromagnetic force distribution characteristics of two typical 110kV transformer low-voltage (LV) windings are obtained through calculation. The results show that due to the existence of the transposition structure, the electromagnetic force distribution of the wire cake near this area has been greatly distorted. When the winding contains only one transposition structure in the middle height, the electromagnetic force distortion range of winding disks is limited to windings disks near the transposition structure; when the winding contains three transposition structures in the 1/4, 1/2, and 3/4 height, the electromagnetic force distribution of the entire winding disks changes. The research results help to improve the short-circuit resistance of windings with transposition structure.

Paper ID: 2237

Stress Distribution Characteristics of Composite Wire-Paper Winding Structure under the Radial Electromagnetic Force

Jin, Mingkai (1);Zhao, Yi (1);Wen, Tao (1);Chen, Weijiang (2);Zhang, Qiaogen (1);Zhu, Taiyun (3);Wu, Jie (3);Wu, Zhengyang (3)

1: Xi'an Jiaotong University, School of Electrical Engineering,Xi'an,China;2: State Grid Corporation of China,Beijing,China;3: State Grid Anhui Electric Power Co.,Ltd.Electric Power Research Institute,Hefei,230022,China

The buckling of transformer windings caused by radial short-circuit electromagnetic force is one of the significant causes of transformer failures, threatening the safe operation of the entire power system. Comparing the maximum stress in the windings with the critical buckling stress is an essential criterion for analyzing whether the buckling will occur. Hence, it is vitally important to obtain an accurate stress distribution in windings under radial electromagnetic force. Studies have shown that the thin paper insulation wrapped around the conductors can affect the mechanical strength of windings. Therefore, it is necessary to consider the influence of paper insulation on stress distribution in the research. In this paper, the copper-paper layered ring winding model, which can be analyzed as a 2D stress distribution problem, has been constructed. The governing equation for this model in polar coordinate has been acquired. Because of the assumed close contact, the displacement and radial stress must match at the copper-paper interface. By solving the equations, the stress distribution can be obtained. As a calculation sample, the low-voltage (LV) winding of a type of 110 kV transformer has been studied. There are two Continuously Transposed Conductors (CTCs) that wound in parallel in one disk, so the model contains two layers of copper and one layer of paper. The hoop stress distribution and the radial stress distribution have been calculated. The results show that the hoop stress varies more than 15% from the innermost radius to the outermost radius and the radial stress is small in comparison. The hoop stress in the paper layer is much smaller than that in the copper layer. The obtained results have been verified using the finite-element method.

Paper ID: 2241

The influence of electrode materials on the emission spectrum in SF6 under AC corona discharge

Li, Yanfei (1,2);Han, Dong (1,2);Tang, Beibei (1,2);Qiu, Zongjia (1);Li, Kang (1);Zhang, Guoqiang (1,2)

1: Institute Of Electrical Engineering Chinese Academy Of Sciences, Beijing,China;2: University of Chinese Academy of Sciences, Beijing, China

As an important insulation medium for high voltage electrical equipment, sulfur hexafluoride (SF6) has excellent insulation and arc extinguishing performance. However, SF6 is sensitive to the non-uniformity of electric field. The increasing electric field, caused by inherent insulation defects such as partial discharge, will lead to the insulation deterioration of SF6 and further develop into insulation failures. Therefore, it is necessary to find an effective way to monitor and detect partial discharge. Over the years, based on the accompanying phenomen of partial discharge, a variety of partial discharge monitoring methods have been developed, such as pulse current method, ultra-high frequency method, ultrasonic method, and so on. With the development of optical technology, more and more attention has been paid to use optical methods for identifying the insulation state of power equipment. In this paper, the needle-plate electrodes with different materials were used to simulate the extremely non-uniform electric field under 50Hz AC voltage. According to the three-zone model of SF6 established by Van Brunt, the glow region near the needle electrode is the dominant zone of electron-impact ionization and dissociation, producing a wide variety of molecule fragments and ions. Thus, three kinds of materials (copper, stainless steel and pure aluminum) were used for the needle electrode, while the plate electrode is stainless steel. Then, the corona discharge emission spectra of SF6 were measured by a spectrometer. Ten groups of spectral data of each material were collected, where the spectral range was 200-1037nm and the integration time of the spectrometer was 9000ms. After deducting the background of the original spectral data, the Savitzky-Golay digital filter was used to smoothly filter the data. And then the characteristic bands of SF6 gas corona discharge were identified, that is, the band near 308nm and the band of 420-510nm. The former is the spectrum of OH radicals (A^2 Σ^+→X^2 Π ,Δv=0) produced by the inevitable presence of a small amount of water vapor during experiments. The latter is produced by the radiation of SF6 molecule itself. The materials of needle electrode have little effect on the spectral distribution, but an obvious effect on the spectral intensity. Compared with aluminum and copper, stainless steel has higher chemical activity, leading to greater spectral intensity. Moreover, the spectral intensity produced by the copper electrode is relatively weakest. The experimental results indicate that the emission spectroscopy has the potential to be applied to the partial discharge detection of SF6 insulated electrical equipment.

Paper ID: 2262

Electrical and optical partial discharge assessment of dielectric barriers in mineral oil and synthetic ester

ANAND, Somya (1,2);VAGNON, Eric (2);ZOUAGHI, Ayyoub (2);GUILLET, Martin (1);BUTTAY, Cyril (2);AGRI, Ouassim (2)

1: SuperGrid Institute, 69100 Villeurbanne, France;2: Université de Lyon, Ecole Centrale de Lyon, CNRS, INSA de Lyon, Laboratoire Ampère, F-69134, Ecully France

Many high and medium voltage apparatuses incorporate hybrid insulation system with both solid and liquid dielectrics, such as in transformers. In power transformers, mineral oil and pressboard are predominantly used as insulation system due to their reliability and reasonable service life. However, the hygroscopic nature of pressboard and temperature variations can lead to faster degradation of this hybrid insulation system. The partial discharge (PD) tests have been widely accepted as defect monitoring tool to estimate the quality of the insulation system. The PD in solid-liquid insulation system could develop either in the volume of the solid and/or liquid because of electric field enhancement by sharp points, impurities or gas voids, or propagate along the solid/liquid interface. Several studies have been done to understand PD mechanism at the interface of pressboard/oil for conventional AC 50 Hz transformers. However, the introduction of power electronic devices for future grids such as High Voltage Direct Current (HVDC) system will impose new constraints on transformers present in the transmission network, for which other solid/liquid insulation systems need to be investigated. This study aims at investigating the PD mechanism in solid/liquid interface for glass epoxy composite (FR4), polyvinyl chloride (PVC), ceramic and pressboard in mineral oil and synthetic ester fluid. Unlike pressboard, solid dielectrics chosen here for tests are non-porous and compact in nature. Also, synthetic ester possesses high flash point and is readily biodegradable, which makes it an attractive choice. The PD measurement setup under high voltage AC 50 Hz used in this work incorporates a photo-multiplier tube for optical detection besides the electrical detection which is compliant with IEC 60270 standard. Tests were carried out using a needle-barrier plane configuration immersed into the oil horizontally. The solid dielectric was resting against the grounding plane (vertically). Different thicknesses of the aforementioned solid samples of the same surface area were tested during the experiments. The Partial Discharge Inception Voltage (PDIV), Phase-Resolved Partial Discharge (PRPD) patterns and the number of partial discharges (NPD) obtained during experiments have been analyzed. Repetitive tests were performed in order to ascertain the reproducibility of PD measurements. The results showed that initial appearance of PDs were mainly concentrated during the rising voltage in both polarities of AC voltage. Also, an increase in voltage led to different PD characteristics for different combination of solid/liquid samples. The discharge mechanism seemed to be impacted by the impurities at the interface of composite insulation system and surface charge accumulation due to differences in surface homogeneity of solid samples. Also, the thinner sample was found to have lower PDIV which could be due to increase in electric field at triple junction in the thinner sample as compared to thicker one. Furthermore, higher PDIV value was observed with solid dielectric in synthetic ester fluid as compared to mineral oil. This might be due to higher viscosity of ester than mineral oil, which reduces the mobility of charge carriers thereby reducing the overall probability of PD occurrence.

Paper ID: 2266

Analysis on Characteristic Emission Spectrum of SF6 under 50Hz AC Corona Discharge

Tang, Beibei (1,2);Han, Dong (1,2);Li, Yanfei (1,2);Li, Kang (1);Qiu, Zongjia (1);Zhang, Guoqiang (1,2)

1: Institute Of Electrical Engineering Chinese Academy Of Sciences, Beijing,China;2: University of Chinese Academy of Sciences, Beijing, China

Abstract-Thanks to the excellent insulation and dielectric abilities, sulfur hexafluoride (SF6) has been widely used in gas-insulated electrical equipment, such as gas-insulated switchgears (GIS), circuit breakers, gas-insulated transmission lines (GIL), and so on. SF6 insulated electrical equipment is prone to insulation failure due to residues, manufacturing defects and other issues. Corona discharge caused by the tip or protrusion on the conductor is one of the most common insulation failures. Researches on air discharge show that the characteristic emission spectra during discharge process is closely related to the type and degree of discharge, which are formed when particles transition from a high energy state to a low energy state by electrical or thermal excitation, thereby providing criteria for insulation defect diagnosis. However, there are few studies on the characteristic emission spectra of SF6 discharge. In this paper, we firstly carried out a series of 50Hz AC corona discharge experiments under different applied voltages and partial discharge magnitudes. Herein, the material of the electrodes is stainless steel, the distance between electrodes is 10mm, the SF6 gas pressure is 0.1Mpa, and the applied voltage is from 14.5 kV to 26.5 kV by a 1kV or 2kV interval. Meanwhile, the spectrometer was used to measure the emission spectra from 200nm to 1037nm. Then, the emission spectra were analyzed and compared. It is shown that there are two characteristic spectrum bands under corona discharge, i.e. a line spectrum near 309nm and a band spectrum of 420-510nm. According to gas discharge theory, dissociation or ionization of SF6 molecule and other impurity molecules such as H2O or O2 only occur in the glow region near the needle electrode. Therefore, the 309nm line spectrum is excited by OH radical from H2O ionization, while the 420-510nm band spectrum is SF6 molecular species, namely SF6 molecule or low fluorides of sulfur that defined as the primary species (SF5, SF4, SF3, SF2, etc). Finally, the relationship between the discharge degree and spectrum intensity was discussed. The photon number of the characteristic spectrum bands was integrated to evaluate the emission spectrum intensity. The results show that the intensity of the 309nm line spectrum is closely related to the content of trace H2O, and the intensity of the 420-510nm band spectrum is mainly affected by the applied voltage and the discharge degree. The formation rates of the primary species depend on the mean energy of electrons in the glow region, which is determined by the electrical field intensity to gas density ratio (E/N). As the applied voltage increases, the degree of partial discharge is deepen and the electrical field is strengthened, further increasing the SF6 decomposition rate. That is, in the glow region, with the increase of SF6 decomposition rate, there are more active fragments of molecules and the low fluorides of sulfur. Consequently, the spectrum intensity in the 420-510nm band increases. It is indicated that the characteristic spectral intensity can be used as an indicator to measure the degree of partial discharge.

Paper ID: 2273

Dielectric Frequency Response of Transformers – Field Case Study

Chavda, Ashok (1);Patel, Jatinkumar (1);Bhatt, Hardika (1);Pandya, Vivek (2)

1: Gujarat Energy Transmission Co. Ltd.;2: PDPU, Gandhinagar

Dielectric Frequency Response is well-known as Frequency Domain Spectroscopy, now a days becoming more popular as effective tool for diagnosis of Power transformer insulation. Dielectric Frequency Response is non-destructive test and based on polarization phenomena. Dielectric Frequency Response of the composite insulation system of Power transformers depends on different parameters i.e. on the properties of insulating oil, paper, hardboard and on the configuration of Power transformers components. Power Transformer is key element of power system network, generally Power transformers are installed outdoor and exposed to varying atmospheric conditions. Chance of moisture ingress in Power transformers are high in the events of breathing defect, oil leakages, exposure of transformer active parts during internal inspection or repair/replacement work at site. Presence of moisture in insulation system accelerate the ageing effect. Degradation of insulation system due to ingress of moisture in Power transformers may prove quite detrimental for Power system network. If proper care is not taken, then service life of Power transformer reduces significantly and in some case failure of Power transformer may also take place. To know the moisture ingress in insulation system of Power transformer, various tests are available i.e. Insulation resistance test, polarization index test, Tan delta test, Oil BDV, Oil PPM and relative saturation measurement test. None among these tests provides adequate information about total moisture content in power transformer insulation. Dielectric Frequency Response diagnostic test gives inferences on moisture in liquid and solid insulation - oil, press board and paper etc. It also provides information about oil conductivity. Dielectric Frequency Response provide the most effective estimate regarding moisture content in oil, paper and pressboard of power transformers. It was observed that the results of dielectric frequency response are dependent on temperature during the experimental measurements and field testing. Presently, some manufacturers offer Tan-Delta and capacitance measurement kits with variable frequency range 10Hz - 400Hz for applied voltage signal. Where as in Dielectric Frequency Response test frequency range is generally 0.002Hz -1000Hz, specifically the lower frequency and higher frequency range results reveals more information about moisture content. This paper presents various field experiences on Frequency Domain spectroscopy testing – (1) Pre commissioning Frequency Domain spectroscopy results for a power transformer indicated higher moisture content compared to that of sister unit. On checking it was found that the transformer was shipped nitrogen filled; during storage period due to minor leakage nitrogen pressure inside main tank lowered down leading to moisture ingress. (2) Comparison of Frequency Domain spectroscopy results taken for a 400kv Class Reactor after oil replacement with previous results confirmed effective removal of moisture. (3) Frequency Domain spectroscopy testing carried out on 66kv Class current transformer taken out from service – with oil, without oil and after increasing water content. Frequency Domain spectroscopy results/outcomes of field testing/experiments found encouraging in estimation of moisture content in transformer/reactor insulation.

Paper ID: 2283

Experimental Research on Overvoltage Suppressing Measures Caused by 10-kV Vacuum Circuit Breakers Switching-off Shunt Reactors

Li, Xin (1);Xu, Puming (1);Zhao, Shihua (1);Zhou, Tong (2);Yang, Qing (2);Chen, Song (3)

1: Hunan Electric Power Company Limited Research Institute;2: State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing University;3: State Grid Zhengzhou Electric Power Company

When the vacuum circuit breakers (VCBs) switch the shunt reactors (SRs), the overvoltage with high amplitude and frequency will be produced by multiple restrikes. It is easy to cause switchgear explosion and insulation breakdown of power equipment. These accidents are detrimental to the stable operation of the power system. This work is based on the 10 kV side of a 220 kV substation. The VCB was operated multiple times to switching-off the SR in the substation, and the overvoltage characteristics were analyzed. The experimental result shows that the maximum overvoltage amplitude at substation transformer (ST) and SR side caused by VCB multiple separating SRs can reach 8.16 p.u. and 6.43 p.u. without any suppression measures. To suppress the overvoltage, surge arresters were and resistance-capacitance (RC) snubbers were installed. The experimental results show that the VCB opening process will produce three different frequency oscillation processes, and will cause multiple restrikes between the contacts. RC snubber can suppress the oscillating frequency, and the number of restrikes between the contacts compare with installing the surge reactor. The influence of lightning arrester and RC snubber on the transient process of overvoltage is discussed. It is showed that the RC snubber suppresses the three-stage oscillation frequency and the restrike between the VCB contacts. Finally, as for the 220 kV substation, the reasonable suppression measure is installing a RC snubber at the end of the SR cable, which has an excellent suppression effect on overvoltage transient process.

Paper ID: 2284

Operating Status Diagnosis of Power Equipment Based on Rule Engine

LI, Chen (1);QIAN, Ping (2);XU, Ning (1);JIANG, Chen (3);WANG, Yawen (3);WANG, Yuan (3);MA, Guoming (3)

1: State Grid Zhejiang Electric Power Company Research Institute, Hangzhou 310014, Zhejiang, China;2: State Grid Zhejiang Electric Power Co., LTD., Hangzhou 310014, Zhejiang, China;3: State Key Laboratory of Alternate Electrical Power System with Renewa

During the daily inspection and maintenance of power equipment, the operation and maintenance department has accumulated a large number of equipment operating status documents. Operating status documents accumulated by power companies can provide guidance for defect diagnosis, and documents record defect phenomena, diagnosis and solutions, etc. However, due to the complex operating status of the equipment and the low utilization of the documents, status documents still cannot provide sufficient reference. In order to realize equipment diagnosis based on status documents, this paper developed a knowledge discovery technology based on frequent itemset mining of FP-growth. In this paper, an FP tree was constructed, and data got stored in it. During the construction of the FP tree, the database was scanned twice, which enables the FP-growth algorithm to have a faster calculation speed. In the case study, this paper used FP-growth-based frequent itemset mining to classify effective key information and build the relationship between failure causes and failure phenomena. Through this method, fast and accurate defect diagnosis based on status documents can be realized.

Paper ID: 2301

Impact of Benzotriazole on the degradation Performance of Ester Fluid

Amalanathan, A J (1);Sarathi, R (1);Harid, Noureddine (2);Griffiths, Huw (2)

1: Indian Institute of Technology Madras, Chennai - 600 036, India;2: Khalifa University, PO Box 54224, Abu Dhabi, UAE

Ester fluids are now being widely considered as an alternative insulating liquid for application to transformers. One of the major reasons for internal flashover and fire hazards occurring in power transformers is due to static electrification. It is well known that benzotriazole (BTA) is used to suppress the charging tendency of insulating fluids at the pressboard interfaces. This paper addresses this issue and reports the results of an experimental investigation on the thermal degradation of ester fluid with and without the effect of BTA. The results show that addition of BTA to ester fluid upon degradation reduces the surface potential of pressboard material and dielectric dissipation factor (DDF) of fluid. The study also indicates a reduction in the flow current with degraded ester fluid containing BTA due to its neutralization of positive ions at the pressboard/fluid interface but the reduction in corona inception voltage (CIV) is inferred because of increased charge carrier formation.

Paper ID: 2317

Investigation on pyrolysis and aerogenesis of Irgamet 39 in oil-immersed transformer

Gao, Sihang (1);Zhang, Guowen (1);Ke, Tingjing (2);Liu, Yang (3);Zeng, Xisong (1)

1: Key Laboratory of Industrial Internet of Things & Networked Control, Ministry of Education Chongqing University of Posts and Telecommunications, College of Automation, China, People's Republic of;2: State Grid Chongqing Electric Power Company Chongqin

The addition of metal passivator into oil-paper insulation has been widely used to control the sulfur corrosion. Aminomethyl-substituted toluylbenzotriazole (Irgamet 39) is one of the most commonly applied metal passivators and deactivators. In this paper, the molecular model system of Irgamet 39 was established based on ReaxFF (Reactive Force Field), the molecular dynamics simulation was conducted to analyze the pyrolysis process of Irgamet 39 molecule. Combined with the accelerated aging experiment of oil-paper insulation with and without Irgamet 39 under thermal field condition, the effects of Irgamet 39 degradation and aerogenesis on the dissolved gases characteristics of oil was further investigated. The simulation results showed that Irgamet 39 can be pyrolyzed to form small molecular hydrocarbon free radicals, H• and N• free radicals, which leads to the formation of low molecular hydrocarbon gas, H2, N2 and carbon oxides gas. The experimental results showed that Irgamet 39 was pyrolyzed continuously as the temperature increase. Moreover, significant amounts of H2 and carbon oxides gas were released when some amount of Irgamet 39 was dissolved in the insulating oil. The generation of dissolved gases in oil containing Irgamet 39 can be an indication of the effects of metal passivators degradation and aerogenesis on the dissolved gases characteristics of oil, which may interfere the operation condition evaluation of oil-immersed transformer based on DGA technology.

Paper ID: 2321

Voiceprint Recognition of Transformer Fault Based on Blind Source Separation and Convolutional Neural Network

Li, Min;Zhan, Huamao;Qiu, Annan

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

The transformer operation sound contains the transformer state information, hence voiceprint recognition technology can be used for transformer fault detection. The accuracy of voiceprint recognition is affected by the interference sound in substation. A method based on blind source separation and convolutional neural network is presented in this paper for transformer fault diagnosis by voiceprint recognition. Different types of sounds in substation are collected and their time domain and frequency domain characteristics are analyzed. A database containing interference sound and transformer fault sound has been built. The blind source separation algorithm is used to separate the interference sound and fault sound. The mel spectrum of the sound is extracted to train the convolutional neural network. Convolutional neural network is used for voiceprint recognition. The result shows that the blind source separation algorithm can effectively separate the interference sound and the fault sound, and the accuracy of voiceprint recognition reaches 98.89%.

Paper ID: 2329

Investigation on activation of inactive sulfur in oil-immersed transformer based on molecular dynamics simulation

Gao, Sihang (1);Zeng, Xisong (1);Liu, Yang (3);Ke, Tingjing (2);Zhang, Guowen (1)

1: Key Laboratory of Industrial Internet of Things & Networked Control, Ministry of Education Chongqing University of Posts and Telecommunications, College of Automation, China, People's Republic of;2: State Grid Chongqing Electric Power Company Chongqin

Some amounts of inactive sulfur with high antioxidant are still retained in the mineral oil to improve the oxidation stability of oil, such as thiophenic compounds. However, whether the inactive sulfur in the oil-immersed transformer will be activated under thermal field has been not gained attention. In this paper, the molecular model of thiophene was established based on ReaxFF (Reactive Force Field), the molecular dynamics simulation was conducted to analyze the pyrolysis process of thiophene molecule, the product formation was obtained and analyzed. In addition, the distribution of sulfur corrosion deposit on a 500 kV electric reactor was investigated and analyzed, and the sulfur types and content of oil of electric reactor was also measured. The simulation results indicated that thiophene was pyrolyzed to form low molecular sulfide with carbon atoms and some sulfur-containing inorganic product under molecular simulation pyrolysis condition, especially H2S with strong corrosion. It may lead to sulfur corrosion in the oil-paper insulation due to the strong corrosive of pyrolysis product. The analysis of the oil-paper insulation of 500 kV electric reactor indicated the corrosion pits and particles were observed on the sampling areas of the copper winding surface, the oil contained thiophene, but not any active sulfur. It is preliminarily confirmed that thiophene lead to sulfur corrosion in the oil-paper insulation from macroscopic and microscopic aspects.

Paper ID: 2340

Non-linearity of Hysteresis and Eddy current Losses of Single-phase Distribution Transformers

Santos, Filipe Freire;Lopes, Gustavo Paiva;Wanderley Neto, Estacio Tavares;Villibor, Jansen Paula;Faria, Gabriel Henrique;Pereira, Matheus Penha

UNIFEI Federal University of Itajuba, Brazil

Studies involving power transformers started in the end of 19th century and extended to the present due to its importance in the electrical grid. As any other electrical machine, they have intrinsic power losses and their evaluation in detail is essential for planning and operation of a power system. This paper aims to analyze the non-linearity of hysteresis and eddy current losses of single-phase distribution transformers of 15 kV and 25 kV, looking for a reliable modeling of the magnetization resistance. The methods for the separation of hysteresis and eddy current losses are currently based on hysteresis determination through magnetization loop, two-temperature method and two-frequency method. In the last method, the losses separation considers no-load test under different frequencies. The mathematical modeling that provides the separation of no-load losses is based on the equations that define the hysteresis, linearly dependent, and eddy current losses, which varies with frequency squared. For the tests, it is necessary to adapt the input voltage for each frequency. The development of simulation model is based on the equivalent circuit of a single-phase transformer considering the saturation characteristic of the core. In order to verify the mathematical modeling, the no-load tests were performed in five single-phase transformers with 81 distinct frequencies. The no-load losses are measured and the two-frequency is applied, obtaining the hysteresis and eddy current losses, which resulted in 3240 combinations for each tested transformer. The results are arranged in boxplot graphics. Finally, the short-circuit test is performed to acquire the remaining parameters for the simulation model, comparing the results of the inrush currents with those obtained in laboratory. The hysteresis and eddy current results were obtained with the mean value of the combinations, resulting the ratio of 43/57, 50/50, 57/43, 47/53 and 43/57, respectively. The maximum error is 0.1% comparing with the traditional no-load component’s equations.

Paper ID: 2344

Understanding of incipient discharges in transformer insulation by reconstruction of Digital Twins for the discharges using Generative Adversarial Networks

Mahidhar, G D P (1);Kumar, Aneesh (1);Sarathi, R (1);Taylor, Nathaniel (2);Edin, Hans (2);Ashwin Desai, B M (3)

1: Department of Electrical Engineering, Indian Institute of Technology Madras, Chennai, 600036,India;2: School of Electrical Engineering and Computer Science, KTH - Royal Institute of Technology, SE-10044, Stockholm, Sweden;3: Department of Electrical

In recent times, with the advancements in the smart grid technology, the demand for the digitalization of power apparatus is growing for improving the condition monitoring systems. In order to improve the reliability of the transformer it's important to monitor it continuously. With the increasing needs for reliability centered asset management and quicker corrective measures under fault condition, a digital twin of the power apparatus can be very beneficial. Partial discharge (PD) monitoring is one technique that is very useful in identifying the defects in transformer. Ultra high frequency (UHF) technique is gaining importance due to its ability to continuously monitor the transformer for incipient discharges in a transformer without being in contact with active electrical network. There can be different type of incipient discharges arising from defects like protrusion, surface discharge, particle movement etc. It is important to identify such defect so that a corrective action can be taken to avoid the failure of transformer. By means of UHF technique, the incipient discharge activity can be studied in multiple defect models like needle-plane model, surface discharge model, floating particle and particle movement model. In order to identify the defects, different parameters of the UHF signals will be measured and studied. From the past few years different methodologies involving signal processing and machine learning algorithms for discharge identification have been proposed by many researchers. There can be challenging situations in the actual conditions where the discharge signal can have noise and overlapping of signals from other discharge sources. If the commonly occurring discharges can be reconstructed as the digital twins for the discharges, such information can be helpful in recreating the noisy conditions that are prevalent in the field digitally, which can be helpful in improving the detection accuracy of the PD monitoring systems. Generative Adversarial Networks (GAN) is a technique that can be used to reconstruct the partial discharge signals with high accuracy. The GAN is composed of two networks: one is used for generating data, and the second is used for differentiating artificially generated data from real data. Structurally the networks are setup to play a zero-sum game, where one network's gain is another network's loss. The generating network is trained to fool the discriminative network and once the discriminative network reaches the precision of 50%, we can conclude that the discriminative network no longer differentiates artificial generated data from the real one. By means of the GAN technique's mathematical framework, the digital twins of the incipient discharge signals from the UHF sensor will be reconstructed in order to improve the detection accuracy to the maximum. Another important application of it is the reconstructed UHF discharge signal data can be useful for calibration of the PD monitoring systems without the need to conduct any real time experiments. Performance of different type of GAN networks will be investigated in the study.

Paper ID: 2353

The property evaluation of oil-paper insulation after long-term storage by dielectirc modulus

Hu, Yizhuo;Liu, Yang;Xing, Yadong;Xie, Jiacheng;Dong, Ming

State Key Laboratory of Electrical Insulation & Power Equipment, Xi'an Jiaotong University, China, People's Republic of

Oil-immersed power transformer is the key equipment in electrical power system. According to requirements of transpotation and installation, power transformers are often filled with nitrogen gas for long-term storage, even more than 5 years, in which their insulating properties will be affected by lots factors, such as moisture instrusion, ambient temperature variation and so on. So how to evaluate the insulating properties after long-term storage became an important issue before transformers are put into operation. The current researches of power transformer after long-term storage only focus on the qualitative analysis of the reason for insulation deterioration and the recovery methods of insulating property, but no experimental details of the change law of insulating property or influence factors during long-term storage.Based on simulation experiments, this paper aims to figure out the changes of insulating properties of oil-immersed paper filled with nitrogen gas by dielectric response methods. Firstly, based on the conductance and the polarization mechanism, the complex permittivity and dielectric modulus methods to evaluating the oil-paper insulating states were discussed, and the advantages and disadvantages of both were compared. Secondly, a well sealed tank with oil-immersed pressboard samples was designed to simulate long-term storage condition. Thirdly, the complex permitivity and dielectric modulus curves of oil-paper samples were measured under different conditions, i.e., temperature, moisture, aging degree, nitrogen gas environment, etc. And the relationships between aformentioned measured parameters and insulting states are analysized. Then, the tendency of moiture variation could be obtained. And futher, thermal-cold cycling treatment was also employed to simulate ambient temperature difference during long-term storage. Finally, several methods of reducing the moisture in oil-paper samples were discussed.The study results show that moisture intrusion is the main reason of insulation degradation of oil-immersed pressboard during long-term storage filled with nitrogen gas. In addition, the moisture rate also increases with the increase of moisture content. By dielectric modulus, the ambient temperature, moisture content and aging degree of oil-paper insulation systems can be obtained. The dielectric modulus curves of oil-immersed pressboard can reflect the changes of insulation during long-term storage, and the dielectric modulus would be an effective parameter for the evaluation of oil-paper insulation.

Paper ID: 2360

A universal method for frequency domain response curve decomposition and its application

Hu, Yizhuo;Xing, Yadong;Liu, Yang;Song, Bo;Xia, Changjie;Dong, Ming

State Key Laboratory of Electrical Insulation & Power Equipment, Xi'an Jiaotong University, China, People's Republic of

Dielectric response technology is a useful method on state detection and properties characterization of dielectric materials, and is applied widely to polymers, oil-impregnated paper and ceramics. In theory, the state of dielectric material will affect the dielectric response in alternating electric field. Therefore, the change of insulation state can be reflected by measuring the frequency domain dielectric response curve of dielectric material and extracting characteristic parameters. However, the research on the frequency domain dielectric response is limited to summarizing the experimental rules and establishing the mathematical model, which is due to the lack of effective methods to study the composition and mechanism of dielectric response curve of dielectric materials.In this paper, a general mathematical method is proposed for the curve decomposition and composition analysis of dielectric material in frequency domain. Firstly, on the basis of Kramers-Kronig theory, the meaning of real part and imaginary part of complex permittivity and the relationship between them are discussed. Secondly, considering the simple Debye model of single polarization process, the derivative of real part of complex permittivity with respect to angular frequency is figured out, to obtain the expression of imaginary part of complex permittivity. Then, the decomposition method of imaginary part curve is obtained for imperfectly dielectric material. Finally, the decomposition method is verified by the measured dielectric response curve of oil paper insulation material.The test and analysis results of oil paper insulation material show that the imaginary part spectrum curve of complex permittivity of oil paper insulation material can be decomposed into two parts: conductivity loss curve and polarization loss curve. The conductivity loss curve shows a linear downward trend in the double logarithmic coordinate system, and the polarization loss curve increases first and then decreases in the double logarithmic coordinate system. The peak value is a typical relaxation polarization process. The polarization loss curve shifts to the right with the increase of temperature, which is consistent with the relaxation theory. The above research shows that there is a quantitative functional relationship between the real part and the imaginary part of complex permittivity. By calculating the derivative of the real part with respect to the angular frequency, the polarization loss curve in the imaginary part of complex permittivity can be obtained, and the conductivity loss and polarization loss in the imaginary part curve can be separated. This provides a mathematical means for the mechanism analysis and further application of the frequency spectrum curve of dielectric materials.

Paper ID: 2100

Evaluation of Asynchronous Wind Generator Stator Magnetic Slot Wedge and Coil Movement Using Electrical Signature Analysis

Penrose, Howard W

MotorDoc LLC, United States of America

Two significant issue in wind power asynchronous generators are magnetic wedge loss and coil movement resulting in winding faults. A majority of time the failures occur unexpectedly or require borescope or visual inspections of the generator stators. In this paper we will identify how both conditions can be detected during operation through Electrical Signature Analysis. The application of the technology provides an opportunity to correct issues prior to insulation failure or to schedule generator replacement.

Paper ID: 2102

REMOTE TECHNICAL SUPPORT DURING GENERATOR MAINTENANCE

Maughan, Clyde

Maughan Generator Consultants, United States of America

Cost containment initiatives over the past several years have encouraged the move to more offsite technical support of outages in power plants. The amazing recent-year advances in communications technologies have greatly contributed to the value of this off-site support. Being able to send better and better photographs back and forth via email starting 20 years ago was a huge benefit. The same will be true of video cameras and video chat systems for offsite support. As a result offsite support via video-chat technology is becoming more commonly used.The shorter time requirements of offsite support provide an additional benefit in that a true expert can now be available for more jobs. An expert skill register is being developed that will allow utilities to find experts most suited to the specific job needs. Once on-line this register should allow more efficient use of the highly skilled generator consultants.An additional value of these advancements in communications technologies is that they have vastly broadening training opportunities. Thus conferences such as this EIC Conference are being held “virtually”, with participation expected to be much higher. Also training seminars for utility personnel can much more conveniently be help virtually, particularly for engineers in remote locations.This evolution in technical support toward offsite support is inevitable. Hopefully it will to done to optimum value to the industry.

Paper ID: 2113

Automatic Classification of 2D Partial Discharge from Generator

Hudon, Claude (1);Lévesque, Mélanie (1);Kokoko, Olivier (1);Zemouri, Ryad (2);Amyot, Normand (1)

1: Hydro-Quebec IREQ, Canada;2: CEDRIC laboratory, Conservatoire National des Arts et Métiers

Quantification of on-line Partial discharge (PD) measurements is a challenge in the industry for several reasons, amongst them: instrumental characteristics, type of sensors, location of the sensors in the machine (line terminals, parallel circuits, neutral point) and the measurement procedure used. PD can be measured in picocoulombs, in millivolts or in dB and is most commonly displayed in 2D or 3D representation. All of these variations make comparison difficult and partially explains why no acceptable PD level has yet been defined for generator diagnostics. Another problem is to select the best parameter for quantification: maximum PD amplitude, discharge current, repetition rate, number of pulses… The former is one of the most common one, but it often neglects the identification of the discharge source causing the PD signal. Differentiation between PD sources is not straightforward and cannot only rely on simple quantification rules. In the present work, a methodology to automatically recognize individual PD sources from 2D PDA files was implemented using deep learning techniques. A Deep Convolutional Variational Autoencoder (DCVAE) was used to help PD experts through an iterative process in separating PDA files in different classes representing each type of PD sources (symmetric, positive asymmetry, negative asymmetry, gap type discharges…). The approach was tested on the entire Hydro-Quebec database of about 33 000 files and each group of files associated with each PD source was then selected to carry out independent discharge rate as a function of amplitude analysis. The statistics of each group were thereafter compared between themselves, but also with statistical analysis of data including the global PD activity when no PD source separation is done.

21-Jun-2021

Session 1 Rotating Machines

Paper ID: 2114

Initial Experience with Acoustic Imaging of PD on Stator Winding Components

Wendel, Christoph (1);Herold, Christoph (2);Stone, Greg (1)

1: Qualitrol-Iris Power;2: Von Roll

Directional ultrasonic microphones have been used for decades to locate surface PD sites in high voltage equipment. However, there was always some uncertainty of exactly where the PD sites were, and scanning a complete winding took some time. Recently, a significant advance in this technology was achieved with the commercial development of an acoustic “camera” that can show where the sound is occurring with respect to a normal visible light image of the test object. That is, the device produces a sound image of the PD on the test object, much like UV camera locates the ultraviolet light from PD on an image of the test object. The acoustic camera takes advantage of a large array of wideband “microphones” and is able to display the acoustic signal in selectable frequency ranges in the sonic and ultrasonic ranges. The effectiveness of this new tool was evaluated on different stator bars with known surface PD and PD occurring within embedded voids (caused by thermal delamination). It is clear that intense PD in internal voids can also be detected, albeit at a lower frequency than for surface PD. Examples of video images from acoustic scanning of an energized complete stator windings will also be presented. Precise locations of the multiple discharge sites are rapidly identified.

Paper ID: 2115

The Correlation Between PRPD Patterns and Dissection on Individual Stator Coils

Levesque, Melanie (1);Seol, Yoon Duk (2);Hudon, Claude (1);Provencher, Helene (1);Cloutier-Rioux, Emilie (2)

1: IREQ Hydro-Quebec, Canada;2: Ingenierie de Production Hydro-Quebec, Canada

In order to ensure the quality of stator windings, Hydro-Québec introduced specific diagnostic tests such as partial discharge (PD) measurements and dissections of individual bars and coils to the qualification program. Although PD measurements have been used for decades, this diagnostic test is still a matter of discussion, mostly because there is no standard procedure or rules specifying how to quantify the detected PD activity. However, there is an ongoing effort in the draft of the IEEE P2465 by the working group to propose a set of criteria to measure individual bars and coils. In the present work, quantification of PD activity on individual coils were made using phase resolved partial discharge (PRPD) patterns obtained using the combination of two types of PD sensors, a capacitive coupler and a near field probe. Parameters extracted from PRPD patterns were used to identify all active PD sources within the insulation system. Results indicate that PRPD patterns obtained in the lower frequency range with the capacitive coupler give the overall activity of all active PD sites within the insulation system. When PD sites were detected at higher frequencies, PRPD patterns made with the capacitive coupler correlate very well with those obtained with the near field probe in the same frequency range. Measurement with the near field probe in this range makes it possible to localize those PD sites within the insulation system. The combination of PRPD patterns obtained with both types of PD sensors is a powerful technique to identify the active PD sources within the insulation system of individual bars and coils. To validate the identification of the detected PD activity, dissections using microscopic observations were performed on two coils. In both cases, microscopic observations confirmed the PRPD recognition.

Paper ID: 2136

Performance of Corona Resistant Insulation for Aerospace

Rumi, Alberto (1);Marinelli, Jacopo Gabriele (1);Seri, Paolo (1);Kohler, Mario (2);Cavallini, Andrea (1)

1: Department of Electrical, Electronic and Information Engineering (DEI), University of Bologna, Italy;2: Liebherr Aerospace, Germany

Purpose/AimAerospace applications of electrical systems require operation under challenging operating conditions. Those are known to be the cause of premature failure of insulating materials and an overall reduction of the reliability of the whole system. Indeed, the usage of impulsive waveforms such as the one being output by a power inverter, with fast transients (i.e. fast rise times) introduces a known stress enhancement factor on the insulation system. It has already been proven that the energetic content of Partial Discharges (PD) is greatly affected by the reduction of pressure that insulations designed for aerospace applications might experience in operating conditions. The common solution that is often proposed in case of PD activity with Type I insulations is the usage of the so-called “Corona Resistant” (CR) materials. While those are certainly having an advantage and might be a solution at atmospheric pressure, the same might not be said when at high altitude. Life tests at constant voltage and different pressures on both non-CR and CR Grade 2 enameled wires were performed in order to address this potential issue.Experimental/Modeling methodsPD measurements were performed on typical test objects for Type I insulation, that is, twisted pairs which simulate a turn-to-turn insulation system. The energy characterizing the discharges were measured by estimating the rotational temperature of the 0-2 and 0-3 ro-vibrational bands of the nitrogen C3Πu–B3Πg second positive system transition and comparing them to synthetic spectra. Life tests were performed at room temperature, maintaining specimens under a pulsed supply reproducing the output of an inverter with peak voltage of 1.08 kV until breakdown occurred.Results/discussionA substantial increase of electronic energy distribution lead to strong decrease of insulation life when pressure is reduced. CR materials performed much better than the other samples only at atmospheric pressure, while the advantages coming from the usage of those insulations were much milder at lower pressures, from 30 kPa and below.ConclusionsWhile it is usually helpful to resort to CR materials in the presence of some PD activity, when the operating pressure of the electrical system is reduced those materials are not able to withstand the increased energetic content of discharges, and different solutions should be seeked.

21-Jun-2021

Session 1 Rotating Machines

Paper ID: 2179

Condition Assessment of Rotating Electrical Machines using SFRA - A Survey

Mayora, Hernan (1);Alvarez, Raúl Emilio (1);Bossio, Guillermo (2);Calo, Emilio (1)

1: IITREE-LAT, Argentine Republic;2: GEA-IITEMA, Argentine Republic

Sweep Frequency Response Analysis (SFRA) is a widespread technique for transformer condition assessment. In this field, there has been a lot of research and development of standards. The test is based on the comparison of a measurement of transformer in good condition, with another measurement in some other state (after transportation, failure, service time, etc.).Today, proven sensitivity and ease of testing of SFRA has generated interest for its application on rotating electrical machines. However, lack of experience and little understanding about the expected results has limited its application as a diagnosis tool. The aim of this paper is to summarize the experimental applications that have been given for the use of SFRA in rotating electrical machines. To this end, an exhaustive analysis of research work presented in conferences and journals was made.

Paper ID: 2196

UNDERSTANDING ALTERNATE METHODS OF MACHINE ON-LINE CONDITION MONITORING, AN INVESTIGATION BASED ON YEARS OF EXPERIENCE AND FIELD CASE STUDIES

Haq, Saeed Ul (1);Schartner, Chris (2);TS Moorthy, Madu (3)

1: General Electric, Canada;2: General Electric, Canada;3: General Electric, Canada

Rotating machines health assessment is an important aspect of machine operation. There are approximately twenty on-line tests and techniques available to assess machine condition while in service. On-line condition monitoring and assessment helps to detect changes in machine operating condition at an early stage as well as to determine the degree of degradation over time. Assessing machine condition can help estimate the risk of failure and the potential vulnerability to unexpected or unintended operating events. The objective is to promptly initiate corrective measures preventing costly shutdowns and production losses. In this paper, individual on-line tests and monitoring techniques are discussed along with their pros and cons. A systematic approach based on years of experience and field studies is presented to provide a clear concept for selecting appropriate tests and to choose optimized monitoring techniques.

Paper ID: 2204

Partial discharge, glass transition temperature and dissipation factor as tool to assess insulation with history of failures

Ferreira, Rafael Freitas

CGT Eletrosul, Brazil

The Partial Discharges Analysis in electrical machines is an important tool that helps to diagnose health of insulation. Weather combined with historical data from factory tests, commissioning and maintenance, it can provides important information about the intrinsic characteristics of insulation and other inheritances of manufacturing and assembly process.The paper starts by addressing established aspects of subject such as: the test conditions recommended by IEC 60034-27-2, probabilities of failures in synchronous machines, main causes of damage in insulation systems, and interpretation of partial discharge patterns aiming demonstrate the importance of periodic performance of this type of test and other complementary ones.The case of a HPP which has two 44.1 MVA synchronous generators, 13.8 kV, class F, with online monitoring system TGA-B from IRIS Power will be presented.It will be shown that partial discharge measurements data indicated problems of factory nature besides others issues that were developed in assembly procedure.Eleven bus bars did not withstand when hypot AC tests had been held. To ensure insulation quality the company sent a set of bars (new ones, used and failed) to complementary tests. It was found that percussion test on pierced bars indicated a detachment of the insulation and copper, which was seen in partial discharges pattern probably caused by an inappropriate brazing procedure. The glass transition test showed that the transition temperature is very high, making the insulation too brittle. In most manufacturers this transition temperature is close to upper limit of class. In this case 155 ºC (311 ºF) was expected. The value found was 240 ºC (464 ºF).A raised bumps found in stator iron combined with a brittle insulation could be a key point to eleven bus bars short-circuit in hypot AC.At last it will be presented the elevation of dissipation factor related to temperature. In according with reference studies the peak value of dissipation factor is the value of glass transition temperature. And these tests: glass transition and elevation of dissipation factor related to temperature are corroborative, and indicate that insulation, despite being electrically resistant, would not have a good capacity to absorb mechanical impacts.The paper will show that besides electrical and temperature tests, mechanicals withstands tests also should be carrying on over bus bar insulations to ensure quality of system.

Paper ID: 2209

Heat flow simulations of epoxy-based stator insulation at 100 kHz.

Wilder, Aleta T.;Pearce, John A.

Center for Energy and Environmental Resources, The University of Texas at Austin

High thermal conductivity epoxy composites, especially those with inorganic fillers, have received significant attention in the last few decades for possible use in power-dense electric machinery. Trends toward higher thermal conductivity usually result in higher permittivity. Heat flow studies with an idealized Roebel bar model compare temperature profiles with either a commercial VPI epoxy or a highly filled epoxy. Anticipating faster inverter drives, the switching frequency is set at 100 kHz. A demonstration in this power regime is interesting due to the trade-off between thermal conductivity and dielectric heating in the insulation. The computational simulations were produced using COMSOL 3.5a. The Finite Element Model was implemented in 2-D Cartesian space under the assumption that the minimum radius was large enough that an X-Y space would provide sufficient accuracy. Two modes are used: 1) a quasi-static electric field at an excitation frequency of 100 kHz to predict dielectric heating in the insulating layer; and 2) a transient heat transfer mode with volumetric heat source terms for the electric field heating and Joule heating in the copper conductors. A voltage difference between the first two turns is set at +500 V. External boundary conditions were either forced air on all four sides or magnetic core on three of the four sides. Time-temperature profiles show that the simulations reached steady-state within a few minutes.

Paper ID: 2229

Ageing in aircraft electromechanical chain: design of thermal cycling bench for winding elements

Dreuilhe, Sarah (1);Pin, Samuel (1);Fetouhi, Louiza (1,2);Stemmer, Sebastien (1);Belijar, Guillaume (1);Albert, Laurent (1)

1: IRT Saint Exupery, France;2: Leroy Sommer - Angoulême

The study of the reliability of electric motors is of growing interest in the aircraft industry. The electrification of the electromechanical chain towards hydraulicless and bleedless systems, as well as perspectives of electric or hybrid propulsion, increase the need to have higher power density. This pushes the industry to raise the voltage levels inside the aircrafts, increasing the likelihood of failure within cables, connectors, windings, bus bars and printed circuit boards. High voltage phenomena such as partial discharges, space charges and electric arcs are investigated within the Highvolt project. In this project, the reliability of electrical insulation systems (EIS) inside those components is studied. In particular, actual mission profiles of motors (ON, OFF and load or speed change) can cause cyclic thermal gradients. The differences between the coefficients of thermal expansion (CTE) produce thermomechanical stresses at the interface between materials assembled together. Motorettes, which are random-wound assemblies with organic insulation materials aimed at reproducing the EIS of motors, are prone to such stresses. Markers like partial discharge inception voltage (PDIV), capacitance, dissipation factor and insulation resistance are expected to be affected by thermal cycling because of the degradation of the EIS (delaminations, defects, creep). Failure modes of such ageing are studied here. In order to carry out an ageing campaign on motorettes under active temperature cycling (ramps of a few °C per second) and passive temperature cycling (ramps of a few degrees per minutes), a preliminary experimental bench is being built. Surface temperature and surface strain measurements of a motorette have been performed, with the aim to model the thermal capacity and stresses within the assembly, and to help to tune the bench design parameters. Models simulating the behaviour of motorette with thermal gradients have been implemented in commercial finite element software COMSOL Multiphysics. This work will be presented alongside the initial results on accelerated ageing tests on active temperature cycling and passive temperature cycling.

Paper ID: 2302

Three-Phase Model for Studying Turn-to-Turn Transient Voltage Distribution in Rotating Machine Stator Windings

Sousa Ferreira, Rodrigo;Carlos Ferreira, Antônio

Federal University of Rio de Janeiro, Brazil

The expected turn-to-turn transient voltage distribution in machine stator windings shall be correctly known during the insulation design. The turn-based models commonly used in the literature do not consider all the coils of one winding group because the worst overvoltages are found in the turns of the first coil. To optimize the insulation design, the amplitude and waveform of the overvoltages shall be known as accurate as possible by using more complex models. This paper presents the transient turn-to-turn and turn-to-ground voltages obtained by a three-phase model. All the turns from the three phases of one winding group are analyzed by a model in which transient magnetic fields and electric circuit elements are coupled. The transient simulation and the calculation of electric circuit elements are carried out using the Finite Elements Method (FEM). The results of the three-phase model are also compared with those obtained using simpler models, which consider one phase, and other that considers only one coil. According to the results, different overvoltages are found for the models other than the three-phase one. Therefore, to optimize the insulation design the three-phase model is suggested.

Paper ID: 2303

Influence of the Surge Rise-Time on the Turn-to-Turn Transient Voltage Distribution in Rotating Machine Stator Windings using a Three-Phase Model

Sousa Ferreira, Rodrigo;Carlos Ferreira, Antônio

Federal University of Rio de Janeiro, Brazil

High-voltage motors are submitted to overvoltages during normal operation due to transient surges which stress the insulation system. The expected transient voltage shall be correctly known at the machines' design phase in order to obtain the suitable thickness of the insulation layers. The turn-based models commonly used in the literature do not consider all the coils of one winding group, by justifying that the worst overvoltages are found in the turns within the first coil. In order to optimize the insulation design, the amplitude and waveform of the overvoltages shall be known as accurate as possible by more complex models. This paper verifies the influence of surge rise time on the transient turn-to-turn voltages using a three-phase turn-based model. All the turns of the three phases from one winding group are analyzed by a model in which transient magnetic fields and electric circuit elements are coupled. The transient simulation and the calculation of electric circuit elements are carried out by using Finite Elements Method (FEM). According to the results, the surge rise time influences the overvoltages in the turns of the three phases.

Paper ID: 2332

Recommended On-site Smart Assessment Techniques for Stator Winding of Large Rotating Machines

Trivedi, Ashish (1);Haq, Saeed (2);TS Moorthi, Madu (3);Peset, Gregory (4)

1: Delom/Wajax;2: General Electric Canada;3: General Electric Canada;4: Delom/Wajax

Large rotating machines stator winding insulation system degrades over time due to presence of several types of stresses. The level of degradation mainly depends upon the application, environment and machines service life. Several types of diagnostic tests are defined in Industry standards that can be performed to assess the winding insulation condition. It is critical to initiate assessment by conducting a visual inspection as it provides evidence of the physical condition of various components. The visual inspection also helps to understand what types of stress windings have been exposed while under operation, e.g. electrical degradation associated with partial discharges, endwinding vibration, surface discoloration due to thermal excursions or deposit of surface contamination. In this paper an on-site smart assessment technique using combination of different Industry standards have been proposed. In addition, based on several years of experience and lessons learned, new assessment protocols for different machine ratings are outlined for effective heath assessment along with predictive maintenance.

Paper ID: 2109

Oil flow related damage to Kraft paper 1: thermal aging

Hosier, Ian Lee (1);Lewin, Paul Leonard (1);Wilson, Gordon (2)

1: University of Southampton, United Kingdom;2: National Grid, United Kingdom

Thermal aging was used as a tool to prepare samples of Kraft paper spanning its entire life cycle in a high voltage transformer, from new to end of life. After characterization of DP and mechanical properties, selected samples were exposed to oil flows mimicking ONAN, OFAF and reclamation conditions. Aging combined with high flow rates, led to significant surface roughening but despite this, no significant erosion was detected even under reclamation conditions. Whilst the tests need to be repeated at higher oil temperatures which more closely reflect conditions in plant, these preliminary findings indicate that the paper insulation component is unlikely to be damaged by normal reclamation activities, even in significantly aged assets.

Paper ID: 2110

Oil flow related damage to Kraft paper 2: UV irradiation

Hosier, Ian Lee (1);Lewin, Paul Leonard (1);Wilson, Gordon (2)

1: University of Southampton, United Kingdom;2: National Grid, United Kingdom

Ultraviolet (UV) irradiation was used as a tool to degrade Kraft paper. Using measurements of the DP as a function of irradiation time, a theoretical model was used to predict the local value of DP in the surface layer of the paper. After characterization of their mechanical properties, selected samples were exposed to oil flows mimicking ONAN, OFAF and reclamation conditions. The presence of a surface layer of low DP led to significant surface roughening under high rates of oil flow, but no significant erosion. The findings indicate that the DP value at the surface is more critical than the average (or measured) DP in determining the extent of oil flow related damage.

Paper ID: 2116

Factory and Retro-Filled Natural Ester Distribution Transformers Subjected to Overload Conditions

Breazeal, Robert Craig;Sbravati, Alan

Southern California Edison, United States of America

Southern California Edison (SCE) began utilizing natural esters in all overhead distribution transformers in 2018. In addition, they began a retrofill program for all useable units which had been removed from service. It immediately became apparent that the measured parameters normally associated with condition assessment of mineral oil filled units did not compare to those from ester filled units. Without a clear understanding of the dielectric changes in the ester fluid and cellulose in response to thermal stress, condition assessment and failure analysis was problematic. In addition, questions were raised in regard to performance of retrofilled units where the winding insulation was initially saturated with mineral oil. It was decided that a simulation should be performed to compare factory filled vs retrofilled units to document the incremental changes in dielectric response and winding insulation.Four 25 kVA 15 kV class overhead transformers were connected to a voltage source with the secondary windings shorted. Two of the units were factory filled with Cargill FR3, and 2 mineral oil filled units were retro-filled with FR3. The factory units had an impedance of 1.9%, while the other units had an impedance of 1.5%. In order to equalize the load for the two loading groups, an inductor was placed in series with the retro-filled units to equalize the energizing current. Immediately after retro-filling, the units were energized for 6 weeks at rated load. This began the process of diffusing the ester into the winding cellulose to provide a measure of protection to the winding insulation before subjecting the units to overload conditions. The applied loads ranged from 181.4 to 188.9 %. External tank temperature at top oil line ranged from 96 to 100^{o}C, with average winding temperatures of 135-140^{o}C. Later in the process it was discovered that one unit had an air leak at the lid gasket which profoundly influenced the fluid changes in response to thermal stress. This accidental leak resulted in a wealth of information in regard to the effects of oxygen on fluid quality and DGA.After 1 year at 135-140^{o}C, the fluids from the factory filled units were in excellent condition. The fluid from the retro-filled unit without the air leak was also in pristine condition despite the fact that it contained the residual mineral oil from the winding cellulose. Changes in dielectric response at 1 hertz and line frequency over time were remarkably consistent for these three units, as were the winding resistance values. Final DGA was also consistent and within the normal limits for the entire gas profile. The unit with the gasket leak above the oil line showed striking differences in dielectric response, insulation resistance, and gas profile.

Paper ID: 2118

Quick fault severity determination using Dissolved Gas Analysis with different gas ratio fault identification techniques

Kimani, George;Akumu, Aloys

Tshwane University of Technology, South Africa

When a fault is first identified in oil-filled electrical equipment, it is vital to determine the extent of its severity. Numerous techniques have been frequently used such as; amount of volume of gases generated, type of fault identified, key gas produced and/or composition of gases evolved. These methods require judicious expertise for reliable and accurate interpretation. However, simple methods using established gases ratio techniques may be applied to quickly estimate roughly the extent of fault severity. This work seeks to find the variabilities and applicability in fault severity approximation using four known fault identification methods. These are CIGRE, IEC, Rogers and Doernenburg gas ratio techniques. The fault severity is evaluated based on the extent of how far are the ratios lying from the maximum or minimum value which is considered as signifying a fault presence. To aid in this rapid faulty severity estimation, faults are basically divided into three categories; partial discharges, electrical discharges and thermal faults. Statistical analysis parameters; mean, standard deviation, correlation coefficient and range are applied for the variability study. One hundred and thirty nine fault cases of physically examined equipment mainly found in IEC TC 10 databases and other published literatures are used for verification. The aggregate level of severity is calculated as the mean of fault severities emanating from various combinations of gas ratios applicable in each technique. The results show that the four techniques may be applicable but somewhat depends on the fault category as some gas ratios from these techniques might produce very high ratio values. Partial discharges and thermal faults severity are best determined by CIGRE, IEC or Rogers techniques, as Doernenburg gives severity extremely high which may not be dependable. Electrical discharge severity can be estimated by all methods. This is based partly by the number of data outliers given by each ratio for each technique for the various faults classes which may highly skew the end statistic.

Paper ID: 2159

Estimation on degradation rate of insulating paper in power transformers using historical load and thermal data

Doolgindachbaporn, Atip (1);Callender, George (1);Lewin, Paul (1);Wilson, Gordon (2)

1: University of Southampton, United Kingdom;2: National Grid

Life expectancy of power transformers is limited by the integrity of insulating cellulosic paper wound around transformer winding. The insulating paper is subjected to thermal, electrical and mechanical stresses. Typically, a transformer expires when the paper is not able to withstand required mechanical stresses. There are three main factors causing degradation in the paper, i.e. moisture, oxygen and temperature. In this work, the degradation rate due to temperature is only discussed. According to IEEE standards, insulating paper needs to last at least for about 20 years under conditions of well-dried, oxygen-free and temperature of 110 °C. The degradation rate of the paper varies with the temperature. That means that transformer life could be extended by decreasing loads which results in lower temperature conditions and vice versa. The temperature, namely the hot-spot temperature is typically used to estimate the remaining insulation life. Being able to estimate the hot-spot temperature accurately given load and weather data helps operators to plan about transformer replacement properly. This could also reduce costs of early replacement due to a conservative estimation. In this work, thermal models have been developed using machine learning techniques to learn thermal behavior from historical data. The data are comprised of the hot-spot temperature estimated by winding temperature indicator (WTI), load profiles, ambient temperature, wind speed and direction and solar radiation. The proposed method has been validated using data for five 400kV/275kV, four 400kV/132kV and two 275kV/66kV autotransformers and has been shown to work effectively. Full results and analysis will be included in the submitted paper.

Paper ID: 2189

Simulation of bubble dynamics in liquid under impulse voltage

Zhang, Rui (1);Zhang, Qiaogen (1);Guo, Chong (1);Wang, Shaoqi (1);Wen, Tao (1);Wu, Xingwang (2)

1: Stare Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, China;2: The Electric Power Research of State Grid Anhui Electric Power Corporation, China, People's Republic of

Bubbles are the subject of extensive research because they are everywhere. However, bubbles in liquid insulation systems have always been an object that bothers engineers and equipment managers. For example, power transformers will cause bubbles in oil-paper insulation under conditions such as overheating, dampness, discharge, and material decomposition. Also, the liquid nitrogen of superconductor power equipment will form nitrogen bubbles after the superconductor quenches. Bubbles pose a serious threat to the safety of equipment operation, because bubbles can easily induce partial discharge and even insulation breakdown. The dynamic behavior of the bubble under the action of an electric field has a significant impact on its discharge characteristics. There have been studies on the behavior of bubbles under steady-state electric fields, but there are few reports under transient electric fields. In order to clarify the dynamic behavior of bubbles under the action of transient electric field, a multi-physics simulation model coupling electric field, flow field and phase field was established in this paper. Through simulation, the influence of electric field strength, bubble radius, voltage rise rate, surface tension coefficient and liquid viscosity on bubble dynamic behavior was clarified. Firstly, the simulation results showed that under the action of the transient electric field, the bubble stretched and deformed in the direction of the electric field. The bubble deformed in an ellipsoidal shape at a lower electric field intensity, and became a dumbbell shape at a higher electric field intensity. The deformation rate was introduced to quantitatively characterize the deformation degree of the bubble. It was found that the maximum deformation degree of the bubble increased with the increase of the applied electric field strength and the bubble radius, and decreased with the increase of the surface tension coefficient and viscosity. Secondly, it was found that there is a hysteresis phenomenon in the deformation of the bubble under the action of the transient electric field. The maximum deformation of the bubble lagged behind the time when the electric field amplitude appears, and the greater the voltage rise rate, the more obvious the hysteresis. The analysis showed that this is caused by the characteristic time of the fluid. According to the definition of characteristic time, it could be predicted that the increase of bubble radius and the decrease of liquid viscosity would increase the characteristic time, and then affected the hysteresis of bubble deformation. The simulation results confirmed our conjecture. The difference of bubble dynamic behavior under the action of steady-state electric field and pulsed electric field and the influence of bubble behavior characteristics on the discharge characteristics of liquid under pulsed electric field were discussed. The research work done in this paper will help to deepen the understanding of bubble behavior and discharge characteristics in liquid insulation systems, and provide a theoretical reference for evaluating the threat of bubbles to liquid insulation systems in engineering applications.

Paper ID: 2198

Initial investigation of the thermal performance qualification method for the transformer insulating liquids

Sbravati, Alan (1);Casserly, Edward (2);Wilhelm, Helena (3);Su, Paul (4);Levin, Aleksandr (5);Gyore, Attila (6);Masood Cheema, Muhammad Ali (7);Wirtz, Kevin (1);Lukenda, Nikola (8)

1: Cargill, United States of America;2: Ergon Refining, Inc., United States of America;3: Vegoor, Brazil;4: FM Global, United States of America;5: Weidmann Electrical Technology Inc., United States of America;6: M&I Materials Ltd, United Kingdom;7:

During the development of IEEE C57.154 - IEEE Standard for the Design, Testing, and Application of Liquid-Immersed Distribution, Power, and Regulating Transformers Using High-Temperature Insulation Systems and Operating at Elevated Temperatures - in 2012, there was a need to define quantitatively an operating temperature limit for insulating liquids. The limits for transformer hottest spot and average winding temperature are based on the thermal class of the solid insulation in the insulation system, while the top liquid temperature depends on the performance of the liquid insulation itself. The suggested limits for mineral oils, from Table 9 in IEEE C57.91-2011, are 105 °C for continuous loading and 110 °C for loading above nameplate rating. However, these ratings, and those for silicone liquids and natural and synthetic esters, lack quantitative validation.Based on the experience and tests presented by supplier members of the working group at that time, temperature limits were included in Tables 4 and 6 of IEEE C57.154-2012. For natural and synthetic esters the values of 130 °C / 140 °C were defined, respectively, for “normal life” and “loading above nameplate rating”. For silicone liquids 155 °C / 165 °C values were used. When a working group was formed in 2019 for the revision of this standard, a task force was created to revisit these limits and propose a testing procedure for defining such temperatures. This was considered especially relevant for defining limits applicable for new brands and types of alternative liquids.This paper presents the first round of an accelerated aging test performed by this task force. Three liquid classes were chosen for this initial test: mineral oil (HyVolt® II), natural ester (FR3® fluid) and synthetic ester (Midel® 7131). Sealed stainless steel bottles containing only the investigated liquids were aged in ovens at 180 °C in four different laboratories; namely, Cargill R&D Laboratory in Plymouth, MN, U.S.A., Weidmann in St. Johnsbury, VT, U.S.A., FM Global in Norwood, MA, U.S.A., and Vegoor in Colombo, PR, Brazil. After defined time intervals reaching up to 2,688 hours (112 days), one bottle was removed from the oven and the liquid was analyzed for commonly measured properties, excluding dissolved gases. By tracking the variation of properties over time, we hope to better understand the liquids’ key degradation indicators over the associated time periods and improve the accuracy of thermal class ratings for the insulating liquids.

Paper ID: 2219

Electrical stress suffered by medium voltage medium frequency transformer

Changjiang, Zheng;Qian, Wang;Huai, Wang;Zhan, Shen;Leth Bak, Claus

Aalborg University, Denmark

Transformers working in modern power electronic systems are called medium voltage medium frequency transformers. The working voltage of these transformers brought from semiconductor switches is usually PWM voltage that has the characteristics of medium frequency and fast voltage front comparing with the AC sinusoidal voltage for traditional power transformers. These transformers suffer from unusual electrical stress. When a winding is added with PWM voltage, voltage overshot would be caused between adjacent turns, which can induce partial discharge including internal discharge inside the insulation and corona discharge in the air ducts. Continuous discharge can degrade the insulation quickly and lead to premature breakdown. This phenomenon has already been confirmed by previous researches in inverter-fed motors. For transformers which also have multi-turn windings like inverter-fed motors, the same problem may also exists. In addition, a transformer's winding is usually designed to have more than one layer. Under this circumstance, not only the inter turn but also the inter layer insulation may be threatened by unconventional PWM electrical stress.Recently power electronic switches are developing to further reduce the on-off time in order to decrease the switching loss. Meanwhile, medium frequency transformers are trying to reach smaller size to achieve lower cost and higher power density, which means that the insulation distance between turns and layers may inevitably be shorter. Both factors mentioned above can make the insulation problem of the medium frequency transformers more serious. Therefore, to guarantee the long term reliability of the transformer working in medium voltage and medium frequency applications, electrical stress investigation is necessary. Previous researches in this domain mostly focus on static electric field and inter turn voltage analysis. Yet for medium frequency transformer with multi-layer windings, transient inter turn and inter layer voltage analysis is also needed to have a more objective look into its realistic electrical stress when the transformer is in operation.In this paper, a practical transformer prototype designed by previous literatures used in a cascaded 10 kV power electronic transformer system is selected as a study case. Its equivalent circuit model is constructed based on FEM calculation. In this model, stray parameters including resistance, self inductance of each turn and mutual capacitance and inductance between different turns are considered. Based on this model, inter turn and inter layer voltage simulations are conducted under different pulse voltage rise times, insulation relative permittivity and winding structures. The simulations confirm the existence of inter turn and inter layer overvoltage on the winding of transformer when it is working under pulse voltage. The results also show that 1) shorter rise time and higher relative permittivity can give rise to higher inter turn and inter layer voltage overshot; 2) Z-type winding can not only reduce the maximum static inter layer voltage drop but also reduce transient inter turn overvoltage effectively under pulse voltage compared with C-type. Based on simulations, it's recommended that medium frequency transformers use insulation material with lower relative permittivity and Z-type winding instead of C-type to reach higher insulation reliability.

Paper ID: 2220

The increase in insulation power factor of transformer oil due to urban dust contamination

Parsons, Greg;Ziomek, Waldemar;Vijayan, Krishnamurthy

PTI Transformers LP, Canada

Insulation power factor of transformer oil is very sensitive to impurities. Even though the initial values can be low, the environment in which the transformer operates and the type of oil preservation system can have significant effect on the quality of the oil. This paper includes details of a practical study of the oil contamination due to urban dust and its effect on oil quality especially the power factor of oil.Samples of oil were taken during the commissioning of three transformers, located in an urban environment. At that time, the power factor was within normal range for new oil, i.e. lower than 0.3%. After a period of approximately 10 months – when transformers were de-energized entire time – the oil samples were drawn from the units by the power utility and tested at their laboratory and the power factor was high in all units (>1.4%).The oil samples were taken from the main tanks and conservators. The oil in conservators has higher power factor, as well as particle count. The samples were thoroughly investigated for chemical composition, using FT-IR spectroscopy, metal analysis, microscopic analysis and particle count.The FT-IR spectra show that there are little, if any chemical based contaminates in the oil, because they are almost identical to the standard transformer oil after processing. This further implies that the contaminants may be a salt that slightly changes the properties of the transformer oil.The particle counts being higher in the conservator than the main unit and the fact that there are other particles, such as tire wear particles and limestone dust particles in the conservators that is not found in the units, are strong physical evidence to indicate that the contamination is originating in the conservators. These transformers are equipped with conservators and breathers, but don’t have the air bags in conservators, hence the only barrier for air-born contaminants are the filters in breathers.As well, the tracer metals found in the oil are also found in the dust samples taken from the substation, which is more physical evidence pointing directly to the dust from substation as a source of the transformer oil contamination. In an urban environment in a downtown area, the dust may be complex and consists of concrete dust, tire wear particles, brake wear particles, and many more particles with anthropogenic origins. Construction areas will have a large concentration of dust originating from the building material present and activity at the site, as well as dust blown up from the ground nearby. It is this combined dust that is being inhaled into the units through the breathers during the cooling phase in daily heating and cooling cycle.

Paper ID: 2221

Design, manufacture, testing and betterment of insulation system for high voltage mobile transformers

Ziomek, Waldemar (1);Vijayan, Krishnamurthy (1);Kuby, Kyle (1);Kalicki, Tomasz (2)

1: PTI Transformers LP, Canada;2: Hydro One Networks Inc.

Mobile transformers were introduced to power delivery systems several decades ago, mostly to manage emergency power outages, but also to support the planned maintenance and overhauls in specific substations. Their usage was not widespread though, as the existing insulation systems, based on cellulose, did not allow for a significant reduction in weight and dimensions required for effective transportation of a mobile transformer or substation. The significant progress came with implementation of high-temperature insulation, most prominently with aramid based solid insulation, which took place some 30-40 years ago. Since then mobile transformer design with high-temperature insulation reached transmission voltage levels (230kV and higher).The insulation systems for mobile transformers, especially for higher voltage class applications, are very complex. High temperature of winding conductor also requires usage of the aramid-based insulation, while small tank volumes force the designers to use elaborate systems of molded cellulose insulation for the windings and multiple cellulose tubes for the lead runs. These two requirements – operation at high temperature and high electric stress – contradict each other and designers need to carefully find some compromise between these conditions. Moreover, high electric stresses result in elevating sensitivity of insulation systems to contaminants, oil quality, material and/or material imperfections.This paper will review some problems encountered while developing mobile transformers for transmission voltage application. These specific units were designed to operate at both 230 and 115kV and voltage adjustment was realized with series-parallel switches. Design challenges, problems and betterments will be discussed: (i) contaminations, related to new cooler application, (ii) electrode profile modeling, for core shields and bushing corona shields, (iii) series-parallel switch performance improvement, (iv) electric stresses during lighting and switching impulse tests, (v) and winding conductor insulation.In conclusion, improved practices are proposed: (i) expanding the design process to include analysis of purchased components, (ii) adding inspection and monitoring of shield installation, (iii) collaborating on improved design of coolers for future units, (iv) more rigorous and improved oil processing, (v) improving conductor insulation lapping process at the supplier, (vi) series-parallel switch’s improvements for a switching impulse test.After solving the issues discussed above, four 230 kV mobile transformers were delivered and almost immediately were placed in service by the power utility.

Paper ID: 2235

Monitoring of the dielectric dissipation factor during oil reconditioning process for transformer drying

Meira, Matias (1);Álvarez, Raúl (2);Verucchi, Carlos (1);Mayora, Hernán (2)

1: INTELYMEC (UNCPBA) and CIFICEN (UNCPBA-CICPBA-CONICET), Olavarría, Argentine Republic;2: Faculty of Engineering, National University of La Plata, Argentine Republic

In this work, the dielectric dissipation factor test is proposed for determining the duration of reconditioning process for transformer drying out. For this purpose, a case study of a three-phase rectifier power transformer with high moisture content in the solid insulation, in which the drying out process was carried out, is presented. The original oil was replaced with new oil, and this new oil is used as the medium for drying out the cellulose through a recirculation process. Thus, in this procedure, the oil reconditioning process is required. The resistivity, breakdown voltage, and water content are also monitored during the reconditioning of the oil. The results show that this strategy improves the efficiency of the reconditioning of the solid insulation process, mainly by reducing processing times where the modifications in the oil properties do not change significantly. The results are validated with dielectric frequency response analysis.

Paper ID: 2240

Estimation of Activation Energy of Transformer Insulation from Frequency Domain Spectroscopy Measurement performed at a Particular Temperature

Chowdhury, Soumyadeep (1);Haque, Nasirul (1);Chatterjee, Soumya (2);Pradhan, Arpan Kumar (3);Chakravorti, Sivaji (4)

1: National Institute of Technology Calicut;2: Techno India University;3: University of Stuttgart;4: Jadavpur University

In recent years, Frequency Domain Spectroscopy has emerged as a popular non-destructive electrical technique for insulation assessment of power transformers. This measurement technique shows the variation of real and imaginary parts of complex capacitance and dielectric dissipation factor (tanδ) measured over a range of frequencies typically spanning from 0.1mHz to 1kHz, which is also known as the frequency domain spectrum. Investigations into frequency domain spectrum provide important conclusions regarding the moisture content and ageing status of the insulation. However, one important factor that affects the Frequency Domain Spectroscopy data is the temperature of the insulation. Existing literature shows that temperature causes both horizontal as well as vertical shift of the frequency domain spectrum. Therefore, when comparing Frequency Domain Spectroscopy measurements of transformers conducted at two different temperatures, temperature correction becomes necessary. A possible solution of this problem is estimation of activation energy of the transformer insulation. Existing literature shows that if the activation energy of the insulation is known, then it is possible to normalize the measurement data for different temperatures by shifting the frequency domain spectrum so that they coincide in one single curve called the “master curve”. Besides, activation energy can also be used for estimating the remaining life of the power transformer. Therefore, estimation of activation energy is of primary importance from the perspective of insulation assessment of power transformers. Moreover, as activation energy reflects the average rate of thermally activated reaction occurring inside the material, its value is affected by numerous factors i.e. moisture content, oil condition, presence of ageing by products such as acids and furans etc. Hence, considering a constant value of activation energy for all power transformers may lead to incorrect conclusions. The main difficulty of obtaining activation energy of an individual transformer using Frequency Domain Spectroscopy measurement is that the measurements need to be conducted at least at two different temperatures, which is not practically feasible in most of the cases. Considering the aforesaid difficulty, in the present work, a method has been proposed that can evaluate the activation energy of transformer insulation based on the frequency domain data recorded at a particular temperature. In order to investigate the effectiveness, the proposed technique is applied to a test sample having preset moisture content to estimate its activation energy. The activation energy value of the abovementioned sample, having 3.9% moisture content was found to be around 97 kJ/mol. Investigations revealed that the value of activation energy obtained using the proposed technique shows very good agreement when compared with the result obtained using other existing techniques. Thus, the usage of the proposed technique can reliably estimate the activation energy of oil-paper insulation in power transformer while eliminating the requirement of Frequency Domain Spectroscopy measurement at two different temperatures.

Paper ID: 2243

An optical fiber magnetic field sensor based on Faraday effect for transformer leakage magnetic field measurement

Jiaxun, Li (1);Yi, Zhao (1);Tao, Wen (1);Xing, Fan (1);Weijiang, Chen (2);Qiaogen, Zhang (1);Zhengyang, Wu (3)

1: Xi'an Jiaotong University School of Electrical Engineering Xi'an, China;2: State Grid Corporation of China Beijing, China;3: State Grid Anhui Electric Power Co.,Ltd. Electric Power Research Institute Hefei, China

Transformers occupy a pivotal position in the power system. When an external short-circuit fault occurs in the transformer, the amplitude of short-circuit current of the windings will be much higher, and the electromagnetic force generated may cause the winding structure to be deformed in the axial or radial direction, endangering the stability of the winding, and causing inter-turn discharge, insulation failure, etc.Studies have shown that the instability process of transformer windings caused by external short-circuit faults is the result of the coupling of electromagnetic force and winding deformation. The short-circuit electromagnetic force acts on the electromagnetic wire, causing the winding to deform. At the same time, the deformation of the winding will affect the distribution of the short-circuit electromagnetic force on the winding. When studying the dynamic process of the coupling of electromagnetic force and winding deformation, it is necessary to accurately and real-time measure the distribution and change of the leakage magnetic field of the transformer winding under short-circuit test.Currently, coil type sensors are mainly used when measuring the internal magnetic field of a transformer. This type of sensor has a huge defect, that is, the insulation problem. The huge potential difference between the sensing probe and the winding may cause insulation breakdown, damaging the winding and the sensor, bringing danger to test personnel. In addition, the complex electromagnetic environment inside the transformer also makes the signal inevitably interfered during the transmission process, thereby introducing additional measurement errors.The optical fiber magnetic field sensor has the advantages of small size, light weight, flexibility, good insulation performance, high temperature resistance, strong chemical corrosion resistance, excellent thermal and chemical stability, and Excellent resistance to electromagnetic interference. It has wide application prospect in transformer leakage magnetic field measurement. Among a variety of optical fiber magnetic field sensors, the sensor based on the Faraday effect is relatively simple in principle and has high measurement stability, thus is suitable as a transformer leakage magnetic field sensor.Based on the method of using the Faraday effect for light intensity modulation, TGG crystal is selected as the magneto-optical sensitive material, and a fiber optic magnetic field sensor is designed and manufactured. At the same time, a magnetic field sensor calibration system with Helmholtz coil as the standard magnetic field source is built. The optical fiber magnetic field sensor is calibrated by the calibration system, and compared with the numerical calculation results, the validity and reliability of the measurement system are verified. The optical fiber magnetic field sensor can accurately measure the internal leakage magnetic field of the transformer under normal operation and short-circuit conditions, and the measurement result has extremely high linearity.This research is a technical exploration of the measurement of the leakage magnetic field inside the transformer. With this technology, it is expected to realize online monitoring of the internal magnetic field parameters of transformers and other large power equipments, as well as magnetic field measurement in other harsh electromagnetic environments.

Paper ID: 2103

Water immersion test approach for dry type inductors for railway applications

Wezelenburg, Margaretha Geertruida (1);Duinmayer, Peter (2)

1: EIC High Energy, Netherlands, The;2: NS (Dutch Railways), Netherlands, The

During the winters 2009/2010 and 2010/2011 dry type inductors mounted in trains of the Dutch railways failed during service due to exposure to powdery snow. The insulation system of these inductors turned out not to be sealed. Investigation showed that exposure even to a small amount of water reduced the insulation resistance to such extent that breakdown occurred as a result of repetitive flashovers combined with high leakage currents.Standard IEC 60310 provides the requirements and describes testing of inductors for railway applications on board of rolling stock. The applicable standard at that time, edition 2004, did not provide any requirements nor a testing procedure to assure that an insulation system of an inductor is sealed, not only after manufacture but also during its life, and thus will be suited for environmental conditions applicable to railway applications. In such an environment exposure to (powdery) snow, water, ice, condensation, electrically conductive particles and salt is possible. Depending on the insulation design this kind of pollution can have serious effects on the dielectric properties of an inductor. A proper insulation system design should be able to cope not only with the dielectric, thermal and mechanical stresses but also with these environmental stresses.Due to the lack of a directly applicable standard for testing inductive components in such an environment a testing procedure was set up to obtain inductors with a suitable insulation system. An important focus of this test procedure was to assess the water tightness of the insulation system in combination with thermo-mechanical cycling. This contribution will describe the testing procedure and the obtained measurement results of two prototype dry type inductors.The measurement results showed a high insulation resistance and high polarisation index in immersed condition after manufacture. The results also showed that this property remained stable over time during thermal cycling of the component. The first series of components (more than 300 pieces) of which the prototypes passed this water immersion test are in service without any issues for 9 years now.

Paper ID: 2129

On-line three-phase differential partial discharge localization in transformer bushings

Meyer, Hans Kristian Hygen;Eberg, Espen;Lundgaard, Lars

SINTEF Energy Research, Norway

Detecting partial discharge (PD) sources in transformer bushings under service conditions is challenging as it requires separation of different PD sources from each other and from external noise. In this study, a new method for PD detection in transformer bushings was tested both in a laboratory setup and on a 132/49 kV transformer in service. The bushings were of resin-bonded paper (RBP) type. Both conventional (IEC 60270) and non-conventional PD integration settings were used. The PD measurement impedances were connected both directly to the bushing measurement taps and differentially between the measurement taps of each of the three bushing phases. The differential measurements allowed location of the PD sources to specific bushings. The results show that the differential PD measurement method can be a useful technique for condition assessment of transformers and other multi-phase high voltage apparatus energized from the grid.

Paper ID: 2131

Insulating liquids at free breathing conditions

Sbravati, Alan (1);Wirtz, Kevin (1);de Oliveira, Lucas (2)

1: Cargill Bioindustrial, United States of America;2: Cargill Bioindustrial, Nederland

Sealing systems for transformers were developed several decades ago aiming to limit contact of ambient air with the internal components of the transformer. Minimizing exposure to oxygen and moisture from ambient air brings several advantages to all transformer fluids, such as: avoiding degradation of paper by oxidation, reducing the need for maintenance interventions, preserving the quality of the insulating liquid, and most importantly, keeping moisture away from high voltage areas. Therefore, the importance of a reliable sealing system is crucial, a system failing to do so would allow for the ingress of ambient air without any type of filtering or desiccant process.The question this research is trying to answer is, what would happen to a sealing system and the insulating materials if there was a breach in the seal and oxygen and moisture can enter freely. This study focused on understanding the difference between the most commonly used dielectric fluids in power and renewables transformers, where timely maintenance of the transformer sealing system is costly and difficult to achieve timely, especially for offshore transformers.To answer this question, two different accelerated aging conditions were designed, one aiming to create accelerated oxidation conditions, and the other focused on the impacts of excessive moisture. For the accelerated oxidation set, stainless-steel bottles were separately filled with the three insulating liquids and previously dried paper was placed within each of the containers. The containers were left open and in a hot air circulation oven at 130°C with an additional vessel containing salt water. For the excessive moisture set, similar stainless-steel bottles with the three fluids and dried pieces of paper where placed in a water bath set to 80°C inside a climatic chamber. After 5 weeks of aging, samples of the fluid were analyzed for their key insulating properties and paper samples were measured for the retained tensile strength.

Paper ID: 2182

Improved thermal resistance and overload capability of the new Ester Bushings

FERDJALLAH KHERKHACHI, Esseddik (1);RICHER, Olivier (1);Kaineder, Kurt (2);Negri, Fabrizio (2)

1: Trench Group;2: Siemens Energy Global

The recent energy transition targets are highly motivated by environmental reasons. Such targets create new technical difficulties due to operation modes of power installations, as well as cyclical conditions of renewable energy and the overloading necessary to ensure continuous supply of energy if required. The use of esters insulation has been widely promoted for power and distribution transformers over the past years to overcome these difficulties. Indeed, Ester-based dielectric fluids were found to outperform mineral oils in terms of their thermal and environmental benefits. The recently developed Ester Impregnated Bushing (CET) comes to bring more flexibility and sustainability to the conversion chain, but also more technical benefits to surmount these challenges.Often, overload capability of power transformers is limited by the resistance of bushings to the thermal stress in case of standard Oil Impregnated Paper (OIP). The new CET bushing will increase the thermal capability of the transformers and allows more overload capacity.In fact, international standards organizations IEEE and IEC agreed that the thermal class of the complex kraft paper/ synthetic ester is 120° (E); as opposed to 105° (A) for the complex kraft paper/mineral oil (IEEE C57.154 and IEC 60076-14). For liquid-filled bushings, it is a huge improvement to allow more design margin for transformer manufacturer and more overload capability.Furthermore, thanks to the higher flash point and high fire point of ester insulation used in the new bushing, if any risk of thermal failure is present, which is extremely rare, the synthetic ester will avoid any fire on transformer because it is classified according to IEEE C57.147 and IEC 61039 as a Class K3 fluid, which provides many advantages in addition to fire resistance.In this paper, we will present the technical advantages of the ester bushings for applications up to 245kV. Besides, we will share experimental results of special electrical tests comparing the thermal behavior of two identical designed bushings with different filling liquids: mineral oil and synthetic ester. The thermal comparison will allow to analyze not only the normal loading conditions, but also the overloading capability beyond the rated current. The results reveal a significant temperature margins at service conditions for ester bushings compared to mineral bushings according to IEEE C57.154 and IEC 60076-14.

Paper ID: 2193

Influence of Slope on Thermal Class Calculations During Accelerated Aging Tests

Greaves, Brad (1);Prevost, Thomas (1);Casserly, Ed (2);Holden, Andy (2);Acosta, Juan (2)

1: Weidmann Electrical Technology Inc., United States of America;2: Ergon Refining Inc., United Stated of America

Accelerated aging studies are used to determine the thermal class of insulation systems. For liquid filled transformers these tests are completed according to IEEE C57.100. The Industry-proven system within this standard has a defined minimum life expectancy curve with a specified influence of temperature (slope) and end of life point. When evaluating a candidate system according to this standard, accelerated aging must be completed at a minimum of three temperatures in order to create a minimum life expectancy curve for that system which can be compared to that of the industry-proven system. Due to the extrapolation of results, the slope of the minimum life expectancy curve can have a significant impact on the calculated thermal class of the candidate insulation system. This paper presents accelerated aging data for thermally upgraded Kraft paper aged with seven different liquids, five mineral oils and two natural esters, and discusses three methods of defining the slope of the minimum life expectancy curve and the subsequent impact of each method on the thermal index calculation results.

Paper ID: 2218

Research on On-line Detection Technology of Transformer Winding Deformation

Sha, Yufei (1);Cheng, Yangchun (1);Bi, Jiangang (2);Chang, Wenzhi (2)

1: North China Electric Power University, China, People's Republic of;2: China Electric Power Research Institude, China, People's Republic of

The Frequency Response Analysis (FRA) method is used widely in the winding deformation diagnostics of power transformers. An on-line FRA method of injecting high-frequency excitation signals from the neutral point of the transformer by means of electromagnetic coupling and measuring the response current signal at the root of the bushing has been applied in the field. However, this method encounters the problems of core saturation of the Rogowski coil sensor, excessive power frequency interference, and susceptibility to the outside devices on the operating transformer. Therefore, a Rogowski coil sensor with double windings is designed, in which the measuring coil is responsible for detecting the high-frequency current signal and the anti-saturation coil is used to cancel the magnetic potential of power frequency interference. Theory proves that this method can effectively reduce the influence of power frequency interference. A new transfer function that is used to eliminate the influence of the outside loads is put forward to conduct online FRA for the winding deformation diagnosis on power transformers. The results of experiments demonstrate that the amplitude-frequency curves under different loads have relatively good consistency and are not affected by load changes.

Paper ID: 2246

Simulation of the Movement Characteristics of Micro-bubbles in the Gap of Transformer Windings

Zheng, Yameng (1);Zhao, Tao (2);Tong, Yixin (3);Chao, Nijie (4)

1: North China Electric Power University, China, People's Republic of;2: North China Electric Power University, China, People's Republic of;3: North China Electric Power University, China, People's Republic of;4: North China Electric Power University,

As one of the critical equipment of power transmission and distribution, power transformeris directly related to the safety and stability of the power grid. The oil-paper insulation is widely used in power transformer and the moisture content will increase with the running time increasing and the aggravation of material aging. The moisture content of oil-paper insulation in transformers is a very serious operating problem and oil-paper insulation with high moisture content becomes very dangerous particularly in transformer overload. With winding temperature increasing rapidly, the moisture in the oil-paper insulation will be converted into micro-bubbles emerging and moving in the oil gap. Micro-bubbles move in the oil gap under the action of dielectrophoretic force, drag force and buoyancy force and the electric field inside the bubble is larger than that in the oil surrounding the bubble. When the bubble moves into the concentrated electric field region, it may lead to partial discharge or even breakdown. Therefore, it is necessary to study the movement characteristics of micro-bubbles in the gap of transformer windings.In this paper, the dynamic force analysis of bubble movement in transformer oil under power frequency AC voltage is carried out, the models of oil gap in transformer winding are built in COMSOL Multiphysics. On this basis, the electric field distribution in oil gap and heating effect of the winding are calculated. The trajectory of micro-bubble in the gap of transformer winding is simulated and analyzed as well. The results of this paper give rise to understanding of bubble discharge phenomena in dielectric liquid and providing a theoretical reference for how to reduce the risk of discharge caused by bubbles in the oil-paper insulation.

Paper ID: 2256

Dielectric and mechanical assessment of cellulosic insulation during transformer manufacturing

Sanz-Asensio, Jaime;Sancibrian-Lana, Oasis;Fernandez-Diego, Inma;Ortiz-Fernandez, Alfredo;Vila-Montañes, Carlos;Mendez-Gutierrez, Cristina

University of Cantabria, Spain

In oil-filled power transformers, the dielectric system is a combination of an insulating fluid, such as ester or mineral oil, and solid cellulosic materials (papers). Due to the hydroscopic nature of cellulose, this insulation needs to be dried during transformer manufacturing as water is detrimental to transformer integrity. Moisture in the transformer can accelerate the degradation of the paper, lead to an increase in partial discharges and decrease the dielectric strength of the insulation.During manufacturing, two drying processes are commonly applied to the cellulosic insulation: hot air at 120 °C in a fan oven and vapor phase drying, where vacuum is combined with heating via a vaporized solvent. In the air-drying stage, cellulose suffers degradation due to thermal stresses and oxidative processes.In this work, different commercial papers were studied to quantify the possible degradation induced by the drying process using two different techniques: degree of polymerization and dielectric properties. Additionally, due to the influence of moisture on dielectric properties, the moisture content of the samples needed to be determined. Internal water saturation curves were measured for samples after the drying process to verify if the lower hygroscopic capacity upheld at different conditioning conditions.The samples were prepared by drying in a fan oven at 120 °C for different times, simulating the actual drying process that takes place in manufacturing. To obtain the dielectric curves and the moisture, the samples were conditioned in a climate chamber at 24 °C and 50% relative humidity for 3 days. To quantify the degradation of the paper, its mechanical strength was assessed using the average viscometric degree of polymerization.The results of the mechanical strength analysis showed a reduction on the degree of polymerization from 1100 to 850 after 4 days of drying, indicating that the paper is degrading.Water content in degraded samples exhibited lower hygroscopic capacity than new samples. Thus, when conditioning all the samples to the same ambient humidity, the degraded samples presented a reduction in internal water content.The dielectric analysis of the samples showed a horizontal shift of the tanδ curve, which moves to the right with longer drying times. This allows us to conclude that this displacement is due to the difference in the internal equilibrium water content of the samples at different degradation states.However, a different dielectric behavior was found in diamond pattern coated insulation paper, with the curve shifting in the opposite direction. The dielectric analysis was also performed on new samples conditioned to different relative humidity and all verified the right-shift, concluding that the difference is due to the presence of epoxy.In order to determine the validity of the dielectric analysis and whether dielectric properties are lost during drying, it is necessary to study the samples with the same internal moisture content to rule out the effect of moisture.In summary, dielectric response together with moisture analysis was used to research the effect of the drying process on different commercial papers used in power transformers manufacturing.

Paper ID: 2260

Capacitively graded oil-paper insulation behavior under repeated flashover conditions

Zupan, Tomislav (1);Novko, Ivan (1);Ziger, Igor (2)

1: Končar – Electrical Engineering Institute Inc., Fallerovo šetalište 22, 10002 Zagreb, Croatia;2: Končar – Instrument Transformers Inc., Josipa Mokrovića 10, 10090 Zagreb, Croatia

In order to ensure the withstand capability of the high voltage apparatus against high-frequency transients, multiple chopped impulse test is usually defined. Such tests serve as a basis of replicating in-field phenomena produced by the operation of switching devices located in the vicinity of the apparatus. However, the testing procedure methodology proposed within the IEC/IEEE standards may not simulate the severity ofactual effects in an adequate way. This work presents a novel approach in simulating such transient voltage stresses in the laboratory and gives insight on improving the standard testing procedures. Simplified insulation models are tested using the presented approach and standard diagnostic measurements are done on the models to investigate the insulation behavior during testing. The results show that mentioned high voltage transients' effect on insulation, occurring during the disconnector pre-strikes or re-strikes, can be provoked by the given testing approach.

Paper ID: 2296

Dissection of Wind Power Transformers for Determining the Cause of PD.

Arvidsson, Lars

VPdiagnose, Sweden

PD in windpower generation transformers is a very common problem in certain transformer types. This paper reports the investigation outcome of two dissected transformers of foil wound type and also suggest the reason for PD in this particular transformer make.

Paper ID: 2322

Experimental and numerical study of the polyimide film insulation characteristics in the liquid nitrogen of superconducting transformers

Zhou, Qibin (1);Tang, Feipeng (1);Wang, Xi (2);Jin, Zhijian (3)

1: Shanghai University;2: Shanghai Dianli University;3: shanghai Jiao Tong University

The traditional transformer technology can no longer meet the requirements such as large capacity, small volume and high efficiency of transformers in modern power system. The superconducting materials possess the characteristics of zero resistance, low loss and high current density in a specific low-temperature working environment. With the development of second-generation high-temperature superconducting materials, the requirements for cooling conditions of superconducting materials have been greatly reduced. So, the superconducting materials can be applied to traditional electrical equipment such as current limiters, cables and transformers. With the increasing voltage level of superconducting equipment, the insulation strength is critical to ensure the safe operation of the equipment. However, there is still a lack of the design specifications of high-voltage insulation in the low-temperature liquid nitrogen environment, which has become the main obstacle to the development of high-voltage, large-capacity and compact superconducting transformers. In order to guarantee the turn-to-turn insulation and inter-layer insulation inside a high-voltage, large-capacity and compact superconducting transformer, the polyimide film is usually selected as the main insulation material because of its good insulation performance. In this paper, the insulation properties of polyimide films in liquid nitrogen environment were studied experimentally. Firstly, a cryostat container with vacuum insulation layer, named as Dewar, was built in this paper to keep the temperature of liquid nitrogen for a certain period of time. Then a voltage withstand test platform was established to study the insulation properties of polyimide films in liquid nitrogen experimentally. Secondly, the extremely uneven electric field was established by the rod-rod electrodes in the air environment at ambient temperature and in the pure liquid nitrogen environment inside the cryostat container respectively. Between the rod-rod electrodes, the power frequency voltage withstanding experiment and the impulse voltage withstanding experiment were both carried out on polyimide films with different thickness. After the experiment, the data obtained in two environments were compared to analyze the influence of pure liquid nitrogen on the insulation performance of the polyimide film. Thirdly, the power frequency voltage withstanding and impulse voltage withstand impact characteristics of polyimide film were studied by a multi-physical field simulation software. The electric field distribution on the surface of the polyimide film in the rod electrode was calculated to reveal the breakdown position and the breakdown field strength. Finally, in order to analyze the influence of immersing the polyimide film in liquid nitrogen for different time, 10 polyimide film samples of each thicknesses were immersed in the liquid nitrogen environment. Take out one polyimide film of various thicknesses from liquid nitrogen every 3 days. Use a scanning electron microscope to observe whether nitrogen atoms penetrate the surface of the film and analyze the influence of intruding nitrogen atoms on the insulation strength of the film. The research results of this paper will provide the design specification of insulation for high voltage level, large capacity and compact superconducting transformers.

Paper ID: 2328

Research on neutral grounding mode in 35kV system of transformer in wind farm station

Xiang, Nianwen (1);Yuan, Chenchen (1);Wang, Qiong (2);Dou, Bingjie (2);Yang, Bo (2)

1: Hefei University of Technology, China, People's Republic of;2: Inner Mongolia Electric Power Science &Research Institute, Inner Mongolia Grid Hohhot,China

When the wind farm line fails, the unreasonable neutral grounding mode leads to the simultaneous disconnection of multiple wind turbines, resulting in increasingly serious power loss. Therefore, it is necessary to study the selection of neutral grounding mode. Firstly, taking typical wind farm as the research object, the electromagnetic transient lumped parameter calculation model is established. In addition, the neutral grounding modes are ungrounded, grounded through arc suppression coil and grounded through resistance. Under the condition of different transition resistance, the overvoltage and overcurrent levels of three grounding modes are calculated when single-phase short-circuit grounding fault occurs. Besides, the advantages and disadvantages of different grounding modes are compared and analyzed. Finally, the suggestions for the selection of grounding modes on the 35 kV side of the transformer in the wind farm are given: The 35kV system of transformer in wind farm gathering station is not suitable for neutral ungrounded mode; The compensation function of arc suppression coil greatly reduces the energy of arc reburning, and the arc can extinguish itself; However, due to the large capacitive current of the typical wind farm, the fault overvoltage phenomenon is obvious. It is more suitable to adopt the neutral point grounding through resistance.

Paper ID: 2333

Partial Discharge Inception Voltage in Liquid Dielectrics and its Definition

Pompili, Massimo (1);Calcara, Luigi (1);Baur, Martin (2);Knauel, Jens (2)

1: University of Roma "La Sapienza", Italy;2: BAUR GmbH, Austria

Insulating liquids represent the largest part of the insulating system in HV transformers and similar components; they are used for their excellent insulating and cooling performances and, for these reasons, they must also have high dielectric strength, high thermal conductivity and low viscosity.An important test able to give important information on the properties of the same insulating liquids is the Partial Discharge Inception Voltage (PDIV) determination. PDIV measurement of liquid dielectrics is presently standardized by IEC TR 61294 (Determination of the partial discharge inception voltage - Test procedure), issued in 1993. This test is more sensitive than that used for the determination of the breakdown voltage (IEC 60156 or ASTM D1816 test methods) but requires a more complex experimental setup and, for this reason, it is less used.In IEC TR 61294 is also defined the Partial Discharge Inception Voltage (PDIV) as the lowest value at which at least only one partial discharge occurs of an apparent charge equal to or exceeding 100 pC, when the oil sample is tested under some specified conditions. This definition is slightly different from that given in the IEC 60270 (High-voltage test techniques - Partial discharge measurements) which reports that the PDIV is the applied voltage at which “repetitive partial discharges are first observed in the test object, when the voltage applied is gradually increased from a lower value at which no partial discharges are observed”.The present paper reports an experimental investigation for comparing PDIVs which may be found in different insulating liquids adopting the two different definitions, taking into account that in the nearest future the IEC TR 61294 will be revised and the ongoing project (WK65707) for preparing an ASTM Standard with the same scope.

Paper ID: 2122

Preliminary Experimental Investigation of the Effect of Superimposed Switching Impulses on XLPE-insulated HVDC Cables

Mazzanti, Giovanni;Seri, Paolo;Diban, Bassel

University of Bologna, Italy

Purpose/Aim: electrical grid components, including HVDC cables, are frequently subject to switching impulses. Due to the progressive increase of the rated voltage of HVDC cables, overvoltages are becoming higher and more critical for the insulating materials. This paper aims at studying the experimental effect of superimposed switching impulses on the aging of the XLPE material. This aim is to be achieved by studying the changes in the dielectric properties of the aged XLPE material. This study is carried out in the framework of a project assessing the severity of Temporary Overvoltages (TOV) on the degradation of insulations.Experimental/Modeling methods: the 0.15-mm DC-XLPE specimens were aged by 1000 consecutive superimposed switching impulses over the DC voltage generated by a high voltage generator at a given frequency. The nominal voltage 3.75 [kV] generates an electric field = 25 [kV/mm]. The superimposed switching impulses are defined according to CIGRE technical Brochure 496 where the equivalent peak voltage is 1.2U0 superimposed on the DC voltage giving a total peak voltage = 2.2U0. The rise time and time to half-value on the tail are respectively 250 and 2500 µs. Those are much shorter values than the duration of Temporary overvoltages TOV, lasting tens of seconds. After this aging procedure, samples were characterized by means of a dielectric analyzer, to measure the real and imaginary parts of complex permittivity. FTIR measurements are also carried out to figure out changes of the aged specimens as a comparison with unaged samples of the same material.Results/discussion: the experiments are still ongoing to analyze the aged specimens. Results are expected to show changes in the imaginary part of the dielectric constant and FTIR pattern referring to a possible aging compounds formation. FTIR tests will investigate the formation of aging compounds in the specimens and identify the type of those compounds. Tests will also show the aging level to which the specimens are subjected under the superimposed switching impulses. The results of this study will be compared to that of Temporary overvoltages TOV.

Paper ID: 2126

DC Conductivity Fluctuation Due to Temperature Dependence and Cross-linking Byproducts of XLPE Insulation Material in HVDC Cables

Ahmed, Muneeb;Zhong*, Lisheng;Li, Fei;Xu, Nuo;Ren, Haiyang

State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China

This research clarifies the significance of DC conductivity for XLPE insulation material used in extruded high voltage DC cables. The DC conductivity is a vital dielectric property, especially for cables operating at HVDC conditions. For HVDC cables, XLPE insulation with greater thickness exhibits a specific radial inhomogeneity depending on cross-linking byproducts and morphological structure. The DC conductivity of XLPE material is influenced by the morphological structure, cross-linking byproducts, and temperature fluctuation within the XLPE insulation. The removal of cross-linking byproducts is essential to improve the cable properties. In this research, XLPE insulation is degassed for 0 to 30 days respectively to measure the DC conductivity on five sliced layers namely inner, inner middle, middle, middle outer, and outer insulation at 30 °C to 90 °C temperature under 10 kV/mm to 50 kV/mm field stress condition. This DC conductivity is used to analyze the DC conductive response and temperature conductivity dependence of degassed and non-degassed five-layered XLPE insulation. The cross-linking byproducts in XLPE insulation are analyzed by using Fourier transform infrared spectrum (FTIR) method. It is concluded that the byproducts such as acetophenone, α-methyl styrene, and cumyl alcohol exhibit a radial distribution in the XLPE insulated regions. Moreover, the uncertain behavior of DC conductivity with or without the degassing process is mainly due to the decreasing behavior of acetophenone. Also, it is investigated that the DC conductivity is disturbed by the variation in temperature and byproducts content, mainly acetophenone within the XLPE insulation. DC conductivity influential factors and reasons to attain uniformity of DC conductivity within HVDC XLPE cable insulation has to be further studied.

Paper ID: 2130

Power Capacity of High Voltage Cables for Future Electrical Aircraft

Xu, Hang;Lowndes, Robert;Cotton, Ian

University of Manchester, United Kingdom

Efforts to reduce CO2 emissions from future electrical aircraft have focused on improving fuel efficiency by replacing hydraulic and pneumatically powered systems with electrically powered components. Voltage and current levels continue to increase to support the demand for the electric power level. The frequency level is also high in some parts of the AC system. This paper describes the analysis carried out to understand the power transfer capacity of screened and unscreened cables under various frequencies and pressures. The analysis has been supported by electrical testing. Increasing frequency can lead to a decreasing current capacity given issues with the skin effect and proximity effect but this depends on the cabling topology used. Screened cables are shown to be particularly advantageous in an aerospace environment given the thinner insulation and the improved thermal performance. The results will deliver improved guidance in the current rating design of high voltage cables applied in an unpressurized environment.

Paper ID: 2133

Avoiding Medium Voltage Cable Joint Failure: Development of a Real-Time Prognostic Tool

Lewin, Paul (1);Coleman, Toby (1);Koumbari, Nicos (1);Liu, Yixuan (1);Christou, Stelios (2)

1: University Of Southampton, United Kingdom;2: RINA Tech UK

Cable failures are disruptive, costly to repair and have a serious impact on customer confidence. Thus, developing a reliable on-line prognostic tool is of a great interest. An experimental setup has been installed within a distribution substation in Cyprus for a period of 5 years. Temperature condition monitoring units were installed on selected underground cable joints. Real-time current loading data, weather conditions as well as surface temperature by the cable joints are used for the development of the thermal prognostic models which predict the likely temperature along the cable thirty minutes into the future. This paper introduces a series of novel thermal condition monitoring machine learning techniques that can be used to effectively monitor the performance of cable joints.Obtained results demonstrate the benefits of a prognostic approach to the real-time health of power network systems as it can significantly assist distribution/transmission companies with tasks such as planning, asset management, identifying possible weaknesses of their networks and increasing their network reliability and ultimately customer confidence.

Paper ID: 2135

Principal Component Analysis of Nuclear Cable Insulation Subjected to Elevated Temperature and Gamma Radiation

Li, Donghui;Spencer, Mychal;Pallaka, Madhusudhan;Bisel, Tucker;Ni, Yelin;Zwoster, Andy;Murphy, Mark;Fifield, Leonard

Pacific Northwest National Laboratory, United States of America

In nuclear power plants (NPPs), the aging of electrical cable insulation occurs due to elevated temperature, ionizing radiation, and other environmental factors. To ensure the safe and efficient operation of NPPs, determination of key indicators of cable aging is critical to predict the remaining useful lifetime of electrical cable insulation. In this work, the effects of simultaneous and sequential thermal and gamma radiation on the aging of cross-linked polyethylene (XLPE) electrical cable insulation are investigated. The chemical changes of the insulation were monitored non-destructively through the use of Fourier transform infrared (FTIR) spectroscopy. The FTIR spectra were measured stepwise after predetermined exposure intervals, with a total irradiation dose up to 320 kGy at a dose rate of 300 Gy/hr in two exposure scenarios; simultaneously aged samples were heated at 150 °C during irradiation, while sequentially aged samples were heated at 150 °C for designated durations followed by corresponding times of irradiation at ambient temperature. A data-driven approach using principal component analysis (PCA) was developed to highlight changes in the carbonyl region of the infrared spectra of the aged samples due to oxidation and to differentiate oxidation rates under the simultaneous and sequential exposure conditions. Findings indicate that the sequential aging scenario in which irradiation follows thermal aging may be more conservative than the simultaneous aging scenario for XLPE electrical cable insulation.

Paper ID: 2141

Forecasting the Partial Discharge Inception Voltage (PDIV) of Insulated Busbars for High Voltage Interconnects for Future Aircraft Power Distribution Systems

Lowndes, Robert;Cotton, Ian

University of Manchester, United Kingdom

Electrification of aircraft propulsion requires the development of busbars and cables that can deliver higher power levels of up to 4 MVA for hybrid electric and 40 MVA for an all-electric aircraft while still operating in a safe and reliable way. Voltage levels on aircraft are presently relatively low compared to most ground-based applications (+/- 270 DC bus on the Boeing 787 Dreamliner) but with future levels expected to rise further, the risk of partial discharge is increased. Sharp corners on insulated busbars can enhance the electric field strength providing a potential location for partial discharge initiation. In this paper, we present the results of finite element analysis of electric fields in the air around a busbar and use the streamer inception criteria to estimate the PDIV for a range of insulation thicknesses and radii of curvature on the busbar edge. The use of screens to retain the electric field within the insulation to prevent partial discharge in the air surrounding the interconnect has the potential to reduce the insulation thickness required and lead to weight savings. The use of screens does not eliminate the risk of partial discharge in air-filled voids within the insulation, so we also calculate the maximum void size that can be tolerated for screened busbars. As aircraft operate at high altitude where the PDIV of air is lower, a pressure equivalent to 50000 ft (15240 m) is used in the calculations.

Paper ID: 2151

Peroxide Decomposition Products in Factory Joints for DC XLPE Submarine Cable

Sonerud, Björn (1);Mäkelä, Timo (2);Kjellstrand, Jerker (3)

1: VerdiLink Consulting AB, Sweden;2: Maillefer Extrusion Oy, Finland;3: Arcus IP GmbH, Switzerland

Factory joints are a requisite for long length extruded XLPE insulated submarine cables. Land cables typically need many premanufactured joints which can be installed in the field. The installation length of land cables is limited by the weight of the cable and the associated transport limitations. Submarine cables are typically not limited in installation length by weight due to the capacity of the laying vessels. Instead, limitations in continuous extrusion capability, testing and storage capacity decide the installation length. Flexible joints are needed when installing submarine cables - stiff joints are difficult or impossible to handle with the chute/lay wheel on the vessel.Flexible joints are manufactured by using the same insulation material used in the cable, extrusion molded, or tape lapped, while crosslinked under pressure. This technology is well established for AC cables but less so for DC applications. It is well established that limiting of the amount of peroxide decomposition products (PDP) in HVDC XLPE is essential for the long-term electric withstand strength. The underlying mechanisms are either related to space charge accumulation or increased conductivity. Materials with reduced peroxide content, alternatively thermoplastics, as well as tailored curing and degassing manufacturing procedures have been proposed to alleviate this problem. In addition to the removal of liquid decomposition products, methane also needs to be removed as per XLPE AC flexible joints. This is to avoid trapping flammable gas in the cable which might migrate during storage, installation, and operation causing health hazards as well as potentially dislodging accessories. As a rule of thumb, 30-50 ppm methane is deemed acceptable. Heat treating cables after extrusion with the aim of redistributing liquid decomposition products, rather than removing them, has been proposed as a method for improving the robustness of extruded HVDC cables. Some aspects of this proposed method can be found in the literature. In this paper the curing and degassing process of a flexible factory joint has been studied. Curing conditions and degassing procedures has been studied with the aim to establish proper curing and degassing times for industrial production. A detailed study of the distribution and development over time of methane and liquid decomposition products is presented here.

Paper ID: 2162

Preliminary Analysis of the Impact of the Leakage Current on HVDC R&D and Qualification Tests on Power Cables

Guerrini, Nicola (1);Troia, Ivan (2);Mazzanti, Giovanni (3);Diban, Bassel (3)

1: Prysmian Cables & Systemes, France;2: Scapa Italia SpA, Italy;3: University of Bologna, Italy

HVDC cable technology is becoming more and more important in the last years and the trend will increase in the next years due to the need to transport a big amount of renewable energy from the source to the countries, and to connect different countries to exchange energy. Big projects as the “German Corridors” started to open the path to the 525kV HVDC technology, and this step forward will lead to an increase in voltage also inland and submarine HVDC connections in the next years.Regarding the HVDC cable technology, the research phase is usually divided into 3 steps, being the last step an official R&D test on a full-size cable, for a given technology and materials. This last testing step can include a voltage thermal stability test, a type test and even a PQ test. Throughout these tests, the current absorbed by the insulation (or “leakage current”) is one of the most important parameters to check for assessing the insulation performance in DC. The leakage current is usually monitored and kept under control, because an increase of current absorbed in a steady-state condition means a possible instability of the insulation properties and can lead to a breakdown of the power cable.The DC current absorbed by the power cable is usually monitored by recording the DC load current supplied by the HVDC generator. With the new generation of PC controls, HVDC generators can easily make recordings and plots of voltage, temperature and current, which can be used to predict the behavior of the insulation during the R&D test. Especially on tests with full-size cables, where the voltage may exceed 1000 kV, the DC current is recorded directly by the HVDC PC panel, and this current is also used for resistivity calculations and thermal stability evaluation.This paper presents the results of experimental tests on power cables and prototypes to validate the idea that the real current absorbed by the power cable can be very different from the current given by the HVDC generator, depending on different variables, as the test voltage, the test clearances, the ambient conditions and so on. In particular, the impact of this difference on the R&D tests results and on the insulation evaluation is discussed. Experimental conditions and methods utilized are shown in the paper as well.

Paper ID: 2172

Modelling Harmonic Propagation in HVDC System Power Cables

Arshad, .;Stewart, Brian G.

University of Strathclyde, United Kingdom

High Voltage Direct Current (HVDC) transmission offers many advantages over HVAC when it comes to undersea transmission over long distances. There is increased interest in HVDC in recent years due to the increase deployment of renewable energy resources such as offshore wind farms. Along with other HVDC system components, undersea cables are critical part of any HVDC chain. These undersea cables are exposed to various type of stresses during service such as electrical, thermal, and mechanical. When DC current is transmitted through HVDC cables, ripples are modulated upon the DC current. These ripples are either due to the switching of converters or the presence of background harmonics in AC systems propagated through the converters. The presence of high frequency ripples in DC cables may lead to partial discharges, electrical treeing, space charge accumulation and increased thermal influences in cable insulation. Therefore, understanding the harmonic profile of HVDC cables under different conditions is important for an improved understanding of its useful service life.In this paper a three level Voltage Source Converter (VSC) based HVDC system is implemented and simulations are carried out to monitor the harmonic profile along HVDC cables. The VSC HVDC system considered here consists of two 230 kV, 2000 MVA, 50 Hz systems connected through a 75km, ±100kV HVDC cable. The harmonic profile of the sending and receiving end of the cable is analysed under different conditions. The impact of changes in background harmonic sequence on the harmonic profile of the HVDC cables is analysed. The obtained simulation results can be used to visualise the complete harmonic frequency spectrum of HVDC cables. The potential impact of harmonic distortion on cable insulation is discussed in terms of the correlation between harmonic frequency and the different mechanisms responsible for cable ageing and degradation such as partial discharges and electrical treeing. The simulation results presented in this paper will help improve understanding of the potential harmonic propagation within HVDC cables and the harmonic impact on cables insulation.

Paper ID: 2203

Characterisation of Verdigris Contamination in Cable Sealing Ends

Thakur, Soumya (1);Shaw, A. V. (2);Andritsch, T. (1);Lewin, P. L. (1);Cwikowski, O (3)

1: Tony Davis High Voltage Laboratory, University of Southampton, Southampton, UK;2: Department of Chemistry, University of Southampton, Southampton, UK;3: Engineering and Asset management National Grid Electricity Transmission Warwick, UK

A Cable sealing end is a crucial power system component as it is responsible for the vital task of successfully terminating cables. Recent reports on the diagnosis of ex-service units have led us to investigate possible contaminations that could impact the dielectric properties of a cable sealing end. Verdigris, often blue/green in color, is one such contaminant that is observed on the surface of a cable stalk. This investigation aims to understand the possible cause of this contamination and its impact on the dielectric liquid used inside a polymeric cable sealing end. To achieve this, the current study is devised in two parts. First, a sample of the verdigris is scraped off from the cable stalk surface and analyzed. The elemental composition of the blue verdigris is analyzed using energy-dispersive X-ray methods on a scanning electron microscope. Second, sonication ageing tests are performed on samples of silicone oil that have been contaminated with verdigris. Elemental analysis shows traces of carbon, oxygen, sodium, silicon, tin and copper contaminations as the primary components of the verdigris present in different percentage. The results from the second half of the study obtained shows an increment in dielectric permittivity and a significant increase in moisture content, whereas not much change was reflected in the UV-vis analysis when compared with the fresh oil sample.

Paper ID: 2236

Identification of Defects in MV Equipment through Advanced Partial Discharge Diagnostics

Naderian Jahromi, Ali;Ketharam Pattabi, Pranav

METSCO Energy Solutions, Canada

Partial discharge (PD) testing is a critical procedurefor diagnosing the condition of medium voltage (MV) equipmentsuch as power cables and switchgear. During the commissioningphase of such assets, PD testing is applied to verify the integrity ofthe insulation, following transport from the factory and erectionon-site. PD testing is also a very useful diagnostic procedure toanalyze the actual condition of in-service equipment, based on thetimely capture of any insulation degradation mechanisms. Theinterpretation of PD results and the subsequent localization (ifnecessary) are quite complex, thereby requiring a multi-facetedapproach through advanced PD diagnostics. This paper presentsthe use of offline PD testing in the field to identify the various typesof defects that occur in MV assets (especially power cables andswitchgear), through practical utility case studies. Some of the PDanalysis tools covered include phase resolved partial discharge(PRPD) pattern, 3-PARD (3-phase amplitude relation diagram),and time-of-flight analysis. This paper also highlights the bestindustry practices for on-site PD testing and provides practicalguidance on the aspects to consider for the proper interpretationof PD results.

Paper ID: 2286

The effect of Alumina Nanoparticles on Increasing the Lifespan of Aged XLPE MV Cable Insulations

Hosseini, S. M. Hassan;Merati Shirazi, Amir Hossein

Islamic Azad University South tehran branch, Iran, Islamic Republic of

This study presents a method for rejuvenation, life elongation and Restoration of XLPE cables insulation by a silicone rejuvenation fluid containing alumina nanoparticles. The rejuvenation fluid included a type of silane coupling agent and alumina (aluminum oxide) nanoparticles. The silane coupling agents react with the water in the cable insulation and water tree regions, remove the water molecules and dry the cable insulation. In this way, they fill the water tree voids and bond the alumina nanoparticles with polymer matrix of the cable and improve the dielectric properties of the cable. After injecting the rejuvenation fluid into the aged XLPE cables, tanδ test was repeated on rejuvenated samples every week for one month and its variations were compared with new and aged samples. Microstructural analysis of the aged and rejuvenated samples was carried out and compared by SEM microscope. FTIR analysis evaluates and compares the chemical bonds in the rejuvenated and aged cable insulations. EDX spectroscopy determined the type and amount of absorbed elements on the rejuvenated sample surface. The impact of rejuvenation fluid on aged XLPE cables was determined according to the 4 mentioned tests.

Paper ID: 2310

Microscopy Study of Inception Sites of Vented Water Trees in a HV XLPE Cable Aged in Salt Water

Lesaint, Cedric (1);Hvidsten, Sverre (1);Hestad, Øystein (1);Olsen, Elise (2);Bengtsson, Karl Magnus (2)

1: SINTEF Energy Research, Norway;2: Nexans Norway

Subsea cables are today protected from ingress of humidity by a watertight barrier such as an extruded lead sheath. Due to their potential vulnerability to fatigue damage, extruded lead barriers cannot be used for dynamic subsea cables. An alternative design includes a thin metal foil wrapped or welded as tubes around the cable core. It is however considered economically favorable to use cables without any metallic barriers. So-called wet cable designs can today be used for voltages up to and including 66 kV (Um = 72.5kV). Without a metallic barrier the water molecules can slowly diffuse into the insulation system of the cable. This may in turn result in growth of interconnected structures of sub-micro sized water-filled voids and channels called water trees. They are slowly degrading the cable insulation and may reduce the service lifetime significantly.The goal of this investigation is to determine the cause for vented water tree ageing in a super-clean insulation system in a high voltage subsea cable aged in the laboratory according to CIGRE TB 722.The main inception sites for water trees are ionic contaminations at the interface between the semi-conductive layers and the insulation, or within the insulation. Since the 1980s a lot of effort has been done to reduce the concentration of these critical ions in the semi-conductive screens by improving the materials that are used but also how they are manufactured and handled. Nevertheless, despite the continuous technological progress on the materials, water trees still grow in new and modern insulation and the semi-conducting layers play an important part in the treeing process when ions are present.High voltage cables with a modern insulation system were aged under controlled conditions for 3000 hours, at 500 Hz and 10 kV/mm at the conductor screen. Traditionally, to visualize vented water trees in the insulation the cables are dyed in methylene blue. In this work, the samples were left in water for two weeks at 90 °C to avoid a chemical pollution from the dye. The vented water trees will then appear as milky-white when studied in a light microscope. To investigate the local concentration of ions in the vicinity of the inception site, the semiconductor, insulation and their interface were studied using microscopes (light, SEM or STEM, AFM), and chemical analysis (ICP-MS, GC-MS coupled with the TGA, EDX and µ-FTIR). ICP-MS measurements of the chemical compositions of semi-conductors indicate a very low concentration of various chemical species. However, the results of SEM coupled with an EDX show a high localized concentration of specific ions inside the semi conductive screen at the interface with the insulation in the vicinity of the inception of a vented water tree.

Paper ID: 2337

Characterization of a superconducting gas insulated cable under ac and dc voltage

Cheetham, Peter (1);Darbha, Bhanu (1);Talikapalli, Srikar (1);Kim, Chul (1);Pamidi, Sastry (1);Park, Chanyeop (2);Graber, Lukas (3)

1: Florida State University, United States of America;2: Mississippi State University, United States of America;3: Georgia Institute of Technology, United States of America

The extent of electrical stress placed on dielectric insulation depends on the waveform of the voltage source. For ac fields the electric field is driven by permittivity which is a function of the frequency of the waveform and has a negligible variation due to temperature change. For steady state dc the electric field is driven by the conductivity of the insulation material which can change significantly based on the operating temperature. For electric transport applications such as electric aircraft and ships, high temperature superconducting power cables are being considered as a solution to meet the required power capacity and density targets. Medium voltage dc systems in the voltage range of 6-20 kV is are being developed for large scale electric transport applications. Given superconducting cables operate at cryogenic temperatures it is necessary to understand how the dc electric field can be influenced by the lower operating temperature. This paper discusses measurements on a 1 m long model superconducting gas insulated (S-GIL) cables under dc voltages at both room temperature and at 77 K. The voltage ramp applied to the model cable will also be varied to understand the difference during a transient where the electric field is governed by both the electrical conductivity and permittivity of the electrical insulation. A comparison will be made to the experimental results on the S-GIL at room temperature and 77 K both under ac and dc voltages.

Paper ID: 2104

Validating discharge and ground electrode effect on the lightning strike damage of materials and its implication to composite structures by modeling lightning discharge

Yousefpour, Kamran (1);Aider, Youssef (1);Wang, Yeqing (2);Rostaghi Chalaki, Mojtaba (1);Park, Chanyeop (1)

1: Mississippi State University, United States of America;2: Syracuse University, United States of America

The importance of lightning strike damage tolerance is growing as metal components are increasingly being replaced with composite materials that provide light weight and high structural strength. However, the lightning strike damage evaluation methods used in laboratories are prone to misinterpretation due to the lack of specific assessment guidelines in the standards. Previously, we have shown that lightning strike damage could appear to be more or less severe depending on the size of discharge electrode and the configuration of ground electrode. In this study, we numerically show the effect of testbed configuration on the temperature of lightning arc channel and test samples assuming continuous discharge current. We use COMSOL Multiphysics, a Finite Element Analysis (FEA) tool, for the modeling of lightning arc discharge. The results of the simulation are compared with the experimental results to fundamentally understand the impact of lightning channel diameter and ground electrode configuration on the lightning strike damage evaluation of the composite samples. The results of this study aid in the development of standards for lightning strike damage evaluation.

Paper ID: 2125

Application of D-dot Sensor for Partial Discharge Waveform Measurement

Rostaghi Chalaki, Mojtaba (1);Haque, Farhina (2);Yousefpour, Kamran (2);Park, Chanyeop (2)

1: G&W Electric Company, United States of America;2: Mississippi State University, United States of America

Partial discharge (PD) measurement is a well-known method used for the assessment of insulating materials including solids, liquids, and gases for power applications. There are a variety of methods and sensors available for measuring PD that are sensitive to specific characteristics and operable over a wide range of frequency. The goal of most PD measurement techniques is providing patterns that enable PD interpretation much easier for users. For example, in the case of AC applications, the phase-resolved partial discharge (PRPD) technique provides clearly identifiable patterns that are used for distinguishing various types of PDs. However, the establishment of meaningful patterns for various types of PD's in DC systems requires more sensitive and accurate measurements of individual PD pulses waveshape. The measurement of PD pulse waveshapes depends on the measurement circuit elements. For example, a similar type of PD discharge will appear differently depending on the measurement circuit, sensor, and acquisition unit (i.e., transfer function). Moreover, there should be a significant difference among the measured PD pulses in the field compared to the waveshapes captured in laboratories due to the unpredictable disturbances. This work addresses the requirements of precise individual PD pulse measurements for both AC and DC systems using electromagnetic field D-dot sensors. The accurate measurements of individual PD pulses allow the extraction of useful information about PD waveshape characteristics which leads to the classification and recognition of various PD types caused by distinct types of defects.D-dots are capacitive coupling electromagnetic field sensors with a low price, simple design, compact size, and very high frequency response ranges. The geometry and the location of D-dot sensors determine the sensitivity and upper-band frequency of sensor. In this paper, we explain the necessities of a suitable D-dot sensor design, which enable accurate DC PD pulse waveform measurements. Also, comprehensive finite element analysis (FEA) simulation results are presented that analyzes the impact of sensor dimension and location on its sensitivity. Furthermore, numerous PD signals under both AC and DC stresses are captured and classified according to the waveshape characteristics measured by the D-dot sensor.

Paper ID: 2148

Low Pressure Partial Discharge Tests with Ultra High dv/dt PWM Voltages for Aircraft Motor Windings

Wei, Zhuo (1);Grosjean, Dennis (2);Schweickart, Daniel (3);Fu, Pengyu (1);Wang, Jin (1)

1: The Ohio State University, United States of America;2: Innovative Scientific Solutions, Inc.;3: Air Force Research Laboratory/RQQE

Partial discharge (PD) is a common and detrimental phenomenon that can cause damage, and potential breakdown in insulation systems. In a gaseous medium, such as air, the partial discharge inception voltage (PDIV) will generally decrease with decreasing pressure. Currently there are several standards for PD detection and measurement at atmospheric pressure under sinusoidal (up to 400 Hz) voltages. However, there is a lack of clarity on PD test methods for inverter-fed motors in aircraft where low pressure environment and pulse width modulated (PWM) voltage are involved. Researchers have tried to approach the issue with triangular impulses and PWM waveforms with relatively low dv/dt (<1 V/ns) to estimate the PD behavior under square-wave impulses. But the expected implementation of wide bandgap power device based inverters, which generate PWM voltages with much higher dv/dt, calls for new test methods and more in-depth studies of PD mechanisms under high dv/dt PWM waveforms.This paper aims to provide more insights on PD mechanisms under high dv/dt excitations and possible ways to improve existing PD test standards for inverter-fed motors in aircraft systems.A test setup including an ultra-high dv/dt PWM generator, associated PD sensors, and the test layout will be introduced. Experimental results and associated analysis for a simplified motorette in the air at various pressures under PWM excitations with ultra-short rise times, starting from tens of nanoseconds, will be presented. Typical test waveforms of the applied voltage and detection signals from a photon multiplier tube (PMT) and a high frequency current transducer (HFCT) will be shown. The effect of the voltage rise rate (dv/dt) will be discussed in detail. Since test results with the same test sample under 60 Hz and triangular impulse voltages have been reported in previous papers, a comparison between the previous results and the newly acquired results will also be included.

Paper ID: 2158

270 Vdc Arcing at Flight Altitude Pressures: Comparison with Ground Level

Grosjean, Dennis (1);Schweickart, Daniel (2)

1: Innovative Scientific Solutions, Inc., United States of America;2: Air Force Research Laboratory/RQQE, United States of America

Unwanted electric arcing creates numerous undesirable effects including the possibility of severe thermal damage in its vicinity. Eliminating—or, at least, minimizing—energetic arcing events is an important endeavor of electric-systems designers. Historically, design guidelines have been based on characteristics of, and experience with, arcing under conditions existing in terrestrial environments. Aerospace vehicles create some unique situations including the fact that air pressure can be sufficiently low at flight altitudes to alter arc initiation, propagation, and damage. Because of the reduced gas density at typical flight altitudes of 20, 000 – 50,000 ft, electron mean-free-paths are significantly increased leading to a change in the dominant mechanisms of energy transfer into an arc. This difference can significantly alter the electron energy distribution such that arc effects may be altered. Focused experiments were utilized to demonstrate arcing under various scenarios with 270-Vdc aircraft power. Waveforms of relevant electrical parameters and high-speed videos were recorded to show similarities and differences in arcing characteristics at ground-level and at 50,000-ft equivalent air pressure.

Paper ID: 2197

A Finite Element Analysis Model for Internal Partial Discharges in an Air-Filled, Cylindrical Cavity inside Solid Dielectric

Borghei, Moein (1);Ghassemi, Mona (1);Kordi, Behzad (2);Gill, Puneet (2);Oliver, Derek (2)

1: ECE Department, Virginia Tech, Blacksburg, VA, USA;2: ECE Department, University of Manitoba, Winnipeg, MB, Canada

The reliability of electrical equipment is closely tied with the health of their insulation system. A well-known symptom of the aging phenomenon in dielectrics is partial discharge (PD) which can occur in all media. Internal PDs in solid dielectrics occur in air-filled voids which are difficult to eliminate thoroughly and may appear simply during the manufacturing process. Although much research on PD measurement for solid dielectrics has been conducted, this is not the case for PD modeling. Besides, the simulation of a case study and its comparison with experimental results can provide further insights into the possibility of other PD sources. In this paper, a finite element analysis (FEA) model for internal PD in an air-filled cylindrical void inside a solid dielectric under 60 Hz sinusoidal voltage is developed. For the estimation of the parameters of the model, experimental data is needed. To this end, a cylindrical void was artificially made within a 3D-printed polylactic acid (PLA) block. Then, phase-resolved partial discharge (PRPD) patterns were measured for the mentioned samples. Using deterministic PD measurement data, an FEA model was developed. This model will help us understand and explain internal PD behavior for the case of a cylindrical void and study the influence of void size on PD behavior.

Paper ID: 2223

Partial Discharge Inception Voltage: Precise and Robust Numerical Estimation Based on Extensive Dielectric Spectroscopy Measurements

KEMARI, Youcef (1,2);BELIJAR, Guillaume (1);LAUDEBAT, Lionel (2);DIAHAM, Sombel (2);VALDEZ-NAVA, Zarel (2)

1: Institut de Recherche Technologique IRT Saint-Exupéry, France;2: LAboratoire PLAsma et Conversion d'Energie LAPLACE, France

Due to the concept of More Electrical Aircraft, substantial efforts are being paid on increasing the voltage in the onboard systems. For instance, in the Airbus A350, a 230/400 VAC system has been adopted. In the future, a further voltage level increase is very likely for power density concerns. However, high electric fields, high operating temperatures combined with low ambient pressure will increase the risk of partial discharges (PD) occurrence in aeronautical cables and connectors.In fact, experimental measurement of PD is not trivial to be performed in every test configuration and does not always provide sufficient information about the location of the discharge. Thus, a lot of work is still needed to make significant progress on PD modeling and prediction. On the other hand, dielectric properties of insulating materials can play a key role in the occurrence of partial discharges. These properties strongly depend on temperature, frequency and also on the electric field magnitude itself. This study will investigate the impact of material properties on electric field distribution, hence on PDIV estimation, by proposing an extensive measurement of material dielectric properties. The obtained data will then be used to compare PDIV estimation and measurement.The case study considered in this paper for PDIV calculations and measurements consists in an insulating film deposited between a needle and a flat electrode. These results can be the groundwork to study more complex geometries of real aeronautical components such as cables and connectors.Two materials used in standard aeronautical components are chosen here to examine the proposed PDIV estimation approach, a Polyimide (Kapton) and a Polyetheretherketone (PEEK). The real part of permittivity and the AC electrical conductivity for both materials are defined in our model from spectroscopy characterizations under different constraints (temperature, frequency and electric field). Measurements span from room temperature up to the maximum rated temperature (200 and 260 °C), in the frequency range from 1 to 1000 Hz for different applied voltages ranging from 100 V to 1.4 kV.Results show that the permittivity and the conductivity of Kapton increase with electrical field up to 46 kV/mm. Also, the permittivity of PEEK significantly rises between 20 and 180 °C. At 180 °C and for low frequency, the conductivity begins to be frequency independent and the plateau corresponding to the DC conductivity value starts to appear. However, the dielectric properties of PEEK are electrical field independent up to 3.3 kV/mm.Thereafter, the electric field and potential are computed by finite element method. The PDIV can be estimated using a specific numerical software named “pArtial dIscharge Risk evaLuatIon soFTware” (AIRLIFT) developed by IRT Saint Exupéry. AIRLIFT uses Paschen equations and electric potential distribution as inputs. To examine the accuracy of the model, experimental PDIV values will be presented for both materials and compared to the modeled ones.

Paper ID: 2225

OVERHEAD LINE TRANSMISSION COMPOSITE INSULATORS. EVALUATION OF THEIR TECHNICAL CONDITION IN THE LABORATORY AFTER THEIR REMOVAL FROM SERVICE.

Morcelle del Valle, Pablo;Álvarez, Raúl Emilio;Catalano, Leonardo Javier;Calo, Emilio;Mayora, Hernán

Instituto de Investigaciones Tecnológicas para Redes y Equipos Eléctricos, Argentine Republic

A sequence of tests accomplished in the laboratory on composite insulators removed from service is presented. The object of the tests was to evaluate the technical condition of the insulators in order to provide an indication of population health or life expectancy and therefore determine whether to live the population or individual units in-service or to take any countermeasures such as removal of the units. The tests and their results analysis were performed under the methods, philosophies and tools described and/or suggested by CIGRE Technical Brochure 481, December 2011. The tests involved in this research were, in the following sequence: visual inspection, hydrophobicity, measuring of leakage current under both dry and wet conditions, ESDD and NSDD measuring, hardness of the housing and sheds measuring. Samples of suspension and line post composite insulators removed from several 132 kV overhead transmission lines were used in this study. As a result of this evaluation it was possible to determine which model/brand had overcome its life-time limit and which has still a residual life expectancy.

Paper ID: 2234

Test-bench and frequency response of a Magnetic Antenna used in GIS PD measurements

Mier, Christian;Rodrigo, Armando

Delft University of Technology, Netherlands

Gas insulated substations (GIS) have increased in the electric power system in recent years and is expected to continue increasing in the following years. The GIS has remarkable advantages over air insulated substation in offshore windfarms where the installation space is limited. The outlying location of the GIS demands a robust monitoring system. It is well known from literature that partial discharge (PD) measurements are an accepted method for insulation diagnosis and in many cases a required part of the acceptance protocol for many high voltage (HV) assets. In a recent investigation, a new concept of PD measurements in GIS using a Very High Frequency (VHF) Sensor (so-called Magnetic Antenna) has been demonstrated. Unlike Ultra High Frequency (UHF) technology, the presented PD sensor has a sensitivity better than 5 pC and yield an estimation of the charge magnitude, thus providing information about the severity of the insulation degradation. In this paper, a test bench for the characterization of the magnetic antenna is proposed. The magnetic antenna and a traditional UHF antenna are tested in the frequency domain up to 1 GHz, and in the time domain using different wave-shapes. Additionally, using the test bench, it is demonstrated the homogeneity of the PD current propagating in the GIS in the transverse electromagnetic (TEM) mode. The charge is estimated using the double integral voltage method, showing low errors. The results from the research gives a preface for further investigation in the design of the magnetic antenna.

Paper ID: 2255

Development, testing and aging of reference insulation defects for the improvement in partial discharges diagnosis.

Arcones, Eduardo (1);Ortego, Javier (2);Camuñas, Álvaro (1);Rosete, Alejandro (1);Gómez, Pablo (1);Garnacho, Fernando (1);Álvarez, Fernando (1)

1: Universidad Politécnica de Madrid, Spain;2: DIAEL

During the last two decades several partial discharge (PD) monitoring systems have been developed in order to determine the insulation condition of high-voltage (HV) electrical grids. Once PD activity is detected the main challenges that arise are the determination of the defect associated and the estimate of the action time available to repair it before the disruptive failure occurs. In other words, when a diagnosis is made, those responsible for the proper functioning of the electrical installations want to know the criticality of the defects with the aim of taking appropriate corrective actions. In order to assess the criticality of a defect and decide when the red light on the alarm should be activated, a thorough study of the defects evolution over time is required. Although in recent years various companies have acquired valuable knowledge from on-site monitoring applications, the study over time of defects in controlled laboratory test cells can significantly strengthen this knowledge. In the research presented in this paper reproducible test cells, each containing a reference insulation defect, have been developed, tested and aged for the improvement in PD diagnosis. For each characteristic defect considered (internal void, surface, floating potential and corona), three test cells have been tested. The evolution of PD charge, amplitude, rate (pulses per second), phase resolved patterns and pulses shape has been analyzed. The temporary study of the above-mentioned variables provides valuable information for adopting adequate criteria when evaluating the criticality of defects in the electrical assets. The capability to reach the correct decision is a very important issue for electrical companies. In addition, the information gathered in this research is useful to train the learning processes of artificial intelligence systems. These systems are developed to perform assisted or automatic PD diagnoses. Finally, it is worth mentioning that as a result of this research the reproducible test cells developed are useful to perform long lasting laboratory tests with real insulation defects, which results interesting not only for scientific purposes but also for didactic issues.

Paper ID: 2257

Error in the measurement of partial discharge pulses according to the frequency response of HFCT sensors

Khamlichi, Abderrahim (1);Garnacho, Fernando (2);Álvarez, Fernando (2);Ortego, Javier (3);Arcones, Eduardo (2)

1: FFII - LCOE;2: Universidad Politécnica de Madrid;3: DIAEL

The measurement of partial discharges (PD) in HV installations by means of high-frequency current transformers (HFCT) is being extended progressively in recent years, as they are affordable non-invasive sensors that can be easily installed. Several manufacturers provide in their data sheets the technical characteristics considered most relevant, such as the transfer impedance expressed in mV/mA, the conversion rates for millivolt values measured at equivalent pico-coulombs (mV/pC), the frequency range and the saturation levels of the sensors. However, there are no objective procedures to measure and quantify these parameters, nor criteria to establish the minimum requirements to be met based on the expected pulses; the latter depending on the defects in the dielectrics present in the equipment or installation to be monitored (cable system, power transformer, GIS, rotary machine, etc.). The main objective of this article is to analyse different measurement circuits to determine the transfer impedance of a HFCT sensor and establish the most appropriate in order to avoid common measurement errors. On the other hand, the strong dependence of the length and characteristics of the coaxial cables on the transfer impedance of the sensors is analysed. Likewise, it is studied how the bandwidth, the characteristic impedance and the offset affect the distortion produced in the pulses to be measured. The characteristics that an HFCT type sensor should have in order to reliably measure pulses of a certain frequency content are established. In this way, a correlation between pico-coulombs and millivolts can be determined for a reasonable criterion of applicability. The characterization in the frequency domain in combination with pulse measurements representative of HV networks in the time domain, enables the correlation of the measurements made. In this way, the ratification of the correlation between millivolts and picoculombs for PD pulses of certain characteristics is possible and errors in the measurements can be evaluated. A specific test setup that combines the standardized method according to IEC 60270, with the unconventional method that uses HFCTs is presented. The research carried out enables the establishment of robust measurement procedures, with known uncertainties and clear requirements to be met by HFCT sensors used in HV networks. These procedures should be included in the technical specifications and in the application standards.

Paper ID: 2268

On-line Estimation Method for Internal Temperature of Lithium-ion Battery Based on Electrochemical Impedance Spectroscopy

FAN, Wenjie;Zhang, Zhibin;Dong, Ming;Ren, Ming

Xi'an Jiaotong university, China, People's Republic of

The electrochemical reaction in lithium ion power battery is easily affected by temperature, which results in the variation of battery output power and capacity.In order to accurately predict the internal temperature of the battery and provide the basis for the battery management strategy, this paper measured and studied the lithium-ion batteries with different State of Charge (SOC) in a wide temperature range based on the electrochemical impedance spectrum, so as to propose an online estimation method of the internal temperature of the battery based on the electrochemical impedance spectrum.The experimental results show that the imaginary part of the impedance spectrum is not affected by SOC in the range of frequency 10-1000Hz within the range of normal operating temperature of lithium battery (5-55 ℃).At the same time, it is sensitive to temperature change and can be used as the characteristic parameter of temperature evaluation.After that, 10Hz is selected as the excitation frequency of the estimation of the internal temperature of the battery, and the internal relationship between the imaginary part value of the battery impedance spectrum and the internal temperature is explored to effectively establish the internal temperature evaluation model of the lithium-ion battery.Finally, the test results show that the temperature evaluation model established in this paper can control the temperature evaluation error within 1.5℃. In this paper, it is proved that the imaginary part of impedance spectrum has a good characterization ability for the battery temperature, which can provide reference for the battery temperature control strategy and improve the temperature rise in the battery working process.

Paper ID: 2280

On-Line Condition Monitoring and Aging Management System for Nuclear Power Plant Cables

McConkey, J. Bryan;Dungan, Nathan A.;Ferree, Codi R.;Ellis, Patrick N.;Connatser, Elijah B.

AMS Corporation, United States of America

This paper describes a current research and development project with the goal of producing a continuous cable on-line monitoring system for fault location and trending degradation. The cables of interest are energized, in-service nuclear power plant cable circuits, including the cable, connectors, and end devices. This goal will utilize both established and innovative reflectometry techniques, as well as other cable testing methods, to optimize signal injection into energized cable circuits.The ability to monitor critical cable circuits while the plant is operating without disconnecting the cable under test will save the nuclear power industry significant time, cost, and personnel resources while increasing efficiency of maintenance outages. Currently many nondestructive evaluation techniques exist for cable condition monitoring, but most of these cable analysis methods are applied to de-energized cables and require disconnecting the cable from one or both ends of the circuit. These limitations can allow some cable circuit problems to go undetected for extended periods of time.Nuclear plant environments have areas of heat, radiation, and humidity that cause electrical cable insulation to become brittle, crack, or degrade over time. Polymer degradation creates cable circuit problems that can be intermittent, such as signal spiking caused by degraded insulators inside a cable connector exposed to vibration or thermal cycling. Additionally, polymer aging degradation can cause progressive cable degradation such as decreased insulation resistance and susceptibility to moisture intrusion. Loose connections, equipment failure, and environmental degradation reduce the reliability of an entire circuit or control loop. Cable failure mechanisms such as these have resulted in unnecessary safety system actuation, loss of indication, spurious alarms, time lost for troubleshooting, and unnecessary component replacement.Many cable faults are produced by changes in conditions such as temperature and vibration during normal plant operation that can be very difficult to locate without a continuous monitoring system. The sustainability of the current fleet of nuclear power plants depends on the performance of key components such as cables that cannot easily or economically be replaced. This project will develop technology to continuously monitor cable systems to identify faults and age related degradation.

Paper ID: 2306

Partial Discharge Activity on Polymeric Insulating Surfaces under Positive Trapezoidal High Voltages

Mikropoulos, Pantelis Nikolaos;Samaras, Pavlos Klimantos

Aristotle University of Thessaloniki, Greece

Polymeric materials are increasingly used for insulators, allowing for reliable and cost-effective high voltage insulation systems. In service polymeric insulators suffer the effects of combined electrical, mechanical and environmental stresses. Their field-performance is crucially affected by surface partial discharge activity causing, depending on their intensity, surface material ageing and eventually even insulator failure, affecting reliability of the insulation system. Partial discharge activity on insulating surfaces depends on the spatial and temporal distribution of electric field strength, material electrical properties and surface state, as well as environmental conditions. These influencing parameters determine the ionization and attachment rates controlling discharge mode and growth as well as possible surface charging, affecting electric field distribution and discharge path. Several experimental and theoretical studies have been conducted on the inception and growth of electrical discharges along insulating specimens, differing in geometry and material synthesis, stressed by fast and slowly varying electric fields. It is well established that slowly varying electric fields have the advantage of easier controlling partial discharge activity, thus also assessing the different partial discharge characteristics. However, still in this case, quantifying partial discharge characteristics is a difficult task given the complexity of the physical processes involved in interactions between discharge and insulating surfaces. This study presents a detailed account of partial discharge characteristics on Polyoxymethylene (POM) and Polyvinyl Chloride (PVC) insulating surfaces, stressed by a highly non-uniform electric field (sphere-plane electrode geometry) slowly varying under the application of positive trapezoidal high voltages; the case of air alone is considered as reference. The trapezoidal high voltages were produced using a programmable Glassman FJ30R04 regulated high voltage DC power supply (120 W), with reversible polarity output up to 30 kV (stable within 0.05%, ripple <0.02%). Output was controlled via customized software developed in LabVIEW environment and a digital system, comprising a PC together with a National Instruments (NI) system (cDAQ-9184 chassis, analog input card NI 9221 fixed at 50 kHz sampling rate and digital input/output card NI 9402). The same control and data acquisition system was also used for continuously monitoring the applied voltage and the discharge current, thus I-U characteristics were obtained. This allowed for partial discharge mode of activity to be easily determined and the associated salient characteristics to be quantified, as affected by the presence of the insulating surface and its material properties. It is shown that, partial discharge inception occurs at a lower voltage in the presence of an insulating surface than in air alone, but the opposite applies for discharge extinction. As compared to the case of air alone, along an insulating surface the establishment of the stable glow discharge is hindered due to a favored inception of repeated streamers. These depend on its insulating surface material, due to electrical properties and surface charging effects.

Paper ID: 2346

Numerical simulation of glow corona discharge in air based on a plasma chemical model

Xiao, Mian (1);He, Hengxin (1);Liu, Lipeng (2);Luo, Bin (1);Che, Junru (1);He, Junjia (1)

1: Huazhong University of Science and Technology, China, People's Republic of;2: COMSOL AB, Stockholm, Sweden

Glow corona is one of the major forms of positive DC corona discharge. In order to reveal the microscopic physical process of glow corona in air, a plasma chemical model of glow corona discharge in 1D coaxial wire was established based on COMSOL, considering 28 species and 127 chemical reactions (CKS, a comprehensive kinetic scheme), and the photoionization process. The temporal and spatial distribution and evolution of the major species during the glow corona discharge were obtained. The results show that the major positive ions in the gap are O2+, which are distributed in a shell shape. Negative ions are O - ,O2 - and O3 - , which mainly exist in the ionization layer. O - and O2 - participate in the detachment and provide seed electrons for the next pulse. The classical fluid model (FPM, a fully coupled physical model) fails to fully consider the detachment process of negative ions, resulting in the steepness and peak-to-peak value of current waves are too large. In order to accurately predict the current oscillation waveforms, in addition to O2 - , it is also necessary to consider O - in detachment process.

Paper ID: 2124

Modeling of Interface Dielectric Constant in Nanodielectrics

Sharma, Asha;Basu, Sumit;Gupta, Nandini

IIT Kanpur, India

In the continuing bid to understand the nature of the interface surrounding each nanoparticle in a nanodielectric, Electrostatic Force Microscopy (EFM) has been employed by researchers in the recent past. The authors developed a Finite Element Method (FEM)-based model to computationally obtain the EFM phase shift images of the region around an isolated particle in a nanodielectric. This model was used in conjunction with extensive experimental data to estimate interfacial parameters like dielectric constant, volume charge in the interface and its thickness. In this work, the developed model is extended to include the variation in the dielectric constant in the interfacial regions. The dielectric constant is modeled as an exponential function of distance from the nanoparticle for the estimated interface thickness. Comparison with experimental data is seen to support this hypothesis.

Paper ID: 2156

Theoretical Investigations on the Mechanisms for Dielectric Failure of Heptafluoro-iso-butyronitrile in the Presence of Water Vapor

Yu, Xiaojuan;Hou, Hua;Wang, Baoshan

Wuhan University, China, People's Republic of

Heptafluoro-iso-butyronitrile (i-C3F7CN, in abbr., C4), a potential eco-friendly alternative to SF6, has attracted considerable interests for high voltage electrical applications. It is well recognized that the humidity is a failure mechanism of the gas insulated equipment, responsible for serious technical problems of the electrical circuit. Mechanisms for the hydrolysis of C4 were calculated theoretically using the high-level ab initio quantum chemistry methods. All the intermediates and transition states were optimized at the M06-2X/AVTZ level and the accurate energetics were obtained with the CBS-Q and Gaussian-4 composite methodologies. The reaction of C4 with water takes place via the complex addition/elimination mechanism. The rate-determining step involves the four-center barrier to form imidic acid and subsequently isomerize to amide. Further degradation of amide leads to NH3 and carboxylic acid, which decomposes to form various by-products including CO2, C3F7H, CF3H, C2F4, C3F6, HF, etc., as indicative of the potential characteristic gas molecules for the failure diagnostic technique. Moreover, the hydrolysis of C4 could be effectively catalyzed by one or more water molecules, implying the increasing risk of dielectric failure of C4 with the increment of the high humidity levels. The yield of imidic acid is significant at temperatures below 500 K. The recombination of imidic acid and the addition reaction of imidic acid with C4 can produce formamido imine. The present work provided a comprehensive theoretical picture for the effect of moisture on C4.

Paper ID: 2171

Temperature dependence of relative permittivity and dielectric dissipation factor of nano-modified mineral oil for use as insulating liquids in transformers

Khan, Suhaib Ahmad (1);Khan, Asfar Ali (2);Tariq, Mohd (3)

1: Aligarh Muslim University, India;2: Aligarh Muslim University, India;3: Aligarh Muslim University, India

Nano-modified mineral oil is the new age dielectric insulant as well as a coolant for transformers. Over the past many years, power transformers have grown in terms of ratings, technology, and performance. But, today mineral oil that is used as the insulating liquid in transformers needs an environment-friendly alternative in the form of mineral oil-based nanofluids. The operational reliability of power transformers is primarily determined by the dielectric properties of the insulating liquid used. The dielectric properties of insulating oil can be expressed mainly concerning the relative permittivity and dissipation factor. This paper presents the effect of nanoparticles and temperature on the dielectric properties (relative permittivity and dissipation factor) of pure mineral oil as well as mineral oil-based nanofluid. Nanoparticles used in the study are Fe2O3, TiO2, and SiO2. A 0.02 weight% nanoparticle concentration is used to prepare the nanofluids using the two-step method with mineral oil used as base oil. The PE-ORDF-2 model consisting of a heating chamber with oil cell is used to vary the temperature of oils starting from room temperature up to 80oC at an interval of 20oC. The apparatus is a three-piece set consisting of a heating chamber, Insulation resistance meter, and oil dissipation factor meter that is used to determine the relative permittivity and dissipation factor of the oils according to the IEC60247 standard. The main contribution of this paper lies in developing a better insulant in the form of nano-oil that are highly reliable and perform transformer operation efficiently during overloads and extreme weather conditions. The mechanism of dielectric modification due to nanoparticle addition is thoroughly explained in the paper, and the advantage of adding surfactant in the oil to improve the dispersion stability as well as long term stability of nanofluids is also discussed in this paper. The oil cell with three-electrode systems (high voltage, low voltage, and guard electrode) is used to determine relative permittivity and dielectric dissipation factor. The experimental testing is done at 230 V, 50 Hz supply. Three samples of nano-oils are prepared by incorporating Fe2O3, TiO2 and, SiO2 nanoparticles in the pure mineral oil, and tested for relative permittivity and dissipation factor for different temperatures starting from room temperature up to 80oC with a difference of 20oC. The results for the dielectric properties of mineral oil as well as nanofluids are tabulated at four different temperatures and correspondingly graphs are plotted to compare the results. The results show that the nanoparticles have a positive influence on the dielectric characteristics of oils whereas the temperature negatively affects the insulation capabilities of the insulating liquids tested. From the results, it has been found that Fe2O3 nanofluid possesses the higher relative permittivity among all the insulating liquids tested followed by TiO2 nanofluid and then SiO2 nanofluid, but exhibit poor dielectric dissipation factor that further deteriorates with temperature increase. The SiO2 nanofluid gives a minimum value of dissipation factor and has a negligible effect of temperature on it. And, TiO2 nanofluid is the only nanofluid that shows enhancement in both the dielectric characteristics.

Paper ID: 2208

Electret Fabrication Under Various Discharge Conditions of Triode Corona Charging and the Partial Discharge Mitigation Performance

Haque, Farhina;Park, Chanyeop

Mississippi State University, United States of America

Partial discharge (PD) is an inevitable dielectric challenge in high-power-density applications due to the high electric field caused by medium-to-high voltage operation. PD does not cause full breakdown events, but it causes insulation degradation and aging. In the long term, the recurrence of PD would lead to the failure of devices. The main cause of PD is the intensified local electric field that appears around sharp edges, triple points, airgaps, and bubbles. Because these defects are not completely avoidable, the complete mitigation of PD has been impossible.In this study, we present a completely new approach that could mitigate PD regardless of the existence of sharp edges, triple points, bubbles, and airgaps. Electrets, which are equivalent to magnets in magnetostatics, are dielectric materials that emit electric fields. Electric charges embedded on the electret surface are the sources of the electric field. There are various dielectric materials that could be used to produce electrets including silicon dioxide (SiO2)-based inorganic materials or polymer-based organic materials such as polytetrafluoroethylene (PTFE), high-density polyethylene (HDPE), and polyvinylidene fluoride (PVDF). The most widely used fabrication technique is the triode corona charging method. Here, we use the triode corona charging method to fabricate electrets from PVDF. The main objective of this study is to investigate the impact of various discharge conditions of corona charging on electret properties. Various discharge conditions are utilized by varying two parameters. The first is to vary the grid voltage and the other is to vary the duration of the applied grid voltage. To study the effects of these charging conditions on electrets performance, a series of PD measurements is conducted under square voltage stimuli. PD magnitude on the rising edge of the square voltage waveform is compared for the PD mitigation performance assessment of the electrets fabricated under various charging conditions.

Paper ID: 2242

Effect of theTiO2 film thickness deposited on the surface of different electrodes on the space charge injection of liquid dielectric

Xian, Tianhua (1);Yang, Qing (2);Zhang, Zhaotian (2);Wu, Shilin (2)

1: Tianshengqiao Branch, China Southern Power Grid, Xingyi, China;2: Chongqing University, China, People's Republic of China

Liquid dielectrics are widely used in power equipment such as transformers and capacitors, and their insulation properties are critical to the stable operation of power systems. Under the action of a strong electric field, the insulating properties of liquid dielectrics are closely related to the types of electrode materials and the properties of the solid-liquid interface. The difference in liquid insulation performance with different electrode materials is often reflected in the nature of the solid-liquid interface, which can affect the injection of space charges, cause electric field distortion, and influence the insulation performance of the liquid dielectric. Low-temperature plasma surface modification technology can improve the surface properties of the electrode, and the different degree of modification has different effects on the breakdown voltage of the liquid dielectric. In order to explore the influence of the thickness of the TiO2 film deposited on the surface of different electrode materials on the liquid insulation performance, films of different thicknesses are deposited on the copper, aluminum, and stainless steel electrodes by the radio frequency reactive magnetron sputtering method. We use Weibull distribution method to calculate the breakdown voltage of liquid dielectrics before and after coating on the surface of different electrode materials. The results show that the liquid breakdown voltage of different materials after deposition of TiO2 film has a certain degree of improvement. As the film thickness increases, the increase of breakdown voltage of the liquid with different electrode materials from small to large is stainless steel, copper, aluminum, while the breakdown voltage stability of liquid dielectric is decreased in sequence. This is due to the fact that the increase in the thickness of the deposited film on the electrode surface has a small increase in the low probability of breakdown voltage, but a large increase in the high probability breakdown voltage. Based on the Kerr electro-optical effect measurement platform, the influence of film thickness on the charge distribution of different electrode materials injected into liquid dielectric is measured. We found that the amount of space charge generated inside the liquid shows a decreasing trend with the increase of the film thickness, and the amount of change of space charge corresponding to different materials is also different. The space charge injection of the aluminum electrode has a larger decrease, followed by copper and stainless steel. To a large extent, the decrease of space charge accumulation in liquid dielectrics will lead to the increase of breakdown voltage, which is consistent with our measurement results. According to the space-time distribution of space charge and electric field, we estimated the change of the average carrier mobility at different times, which is very helpful for subsequent dynamic characteristics and simulation research of space charge in liquid dielectric.

Paper ID: 2269

Nonlinear dielectric composites with Calcium Copper Titanate filler ceramics for power applications

Ghosh, Dipankar

3M, United States of America

This paper describes nonlinear dielectric composites potentially suitable for electrical stress control in power cable lines. In this case, the polymer composite contains an electric field switchable dielectric ceramic Calcium Copper Titanate (CaCu3Ti4O12, CCT), in a suitable polymer matrix.The dielectric characteristics of the CCT filler polymer composites are characterized under both DC and AC conditions. The CCT filler composites exhibit reversible nonlinear dielectric characteristics, high dielectric permittivity values along with low dielectric loss values that are stable over a wide temperature range which might be suitable as an electrical field grading material to control electrical stress for medium and high voltage components for the power industry. In this contribution, we describe the nonlinear field grading material, and report on the development of a novel micro varistor filler polymer composite using CCT based varistor ceramics.

Paper ID: 2289

Influence of Nano Sized Fillers on Suppressing DC Erosion of Hybrid Silicone Rubber Composites

Alqudsi, Alhaytham Y. (1);Ghunem, Refat A. (1,2);David, Éric (1)

1: École de technologie supérieure, Montreal, Canada, H3C 1K3;2: NRC Metrology Research Center, National Research Council Canada, Ottawa, Canada, K1A 0R6

This paper investigates the influence of nano sized alumina trihydrate and fumed silica fillers on suppressing the DC erosion of hybrid silicone rubber composites containing micron-sized alumina trihydrate filler. Fumed silica was found to be more influential on enhancing the thermal conductivity of the composites compared to nano alumina trihydrate, which is possibly a result of the better filler dispersion of the former. Thermogravimetric analysis suggests the effectiveness of fumed silica in suppressing depolymerization of silicone rubber as a result of silica’s favourable interaction with the silicone polymer. Furthermore, the thermal analyses outcomes indicate a significant absorbed moisture content in nano alumina trihydrate which could have adversely impacting the residue characteristics and poorly suppressed silicone rubber depolymerization. In addition, a high temperature endotherm for micro sized alumina trihydrate filler was found indicating the possible decomposition of boehmite to release water molecules promoting the internal oxidation of silicone rubber at high temperature. Outcomes of the +DC inclined plane tracking erosion test correlate with those of the thermal analyses indicating a more influential role for fumed silica’s interface in enhancing the DC erosion performance of silicone rubber despite the silica hybrid composite having a lower thermal conductivity than micro alumina trihydrate filled silicone rubber.

Paper ID: 2308

A Simple Group-Additivity Method to Predict the Dielectric Strength of Insulation Gases for Molecular Design

Hou, Hua;Yu, Xiaojuan;Wang, Baoshan

Wuhan University, China, People's Republic of

In view of the extremely significant impact on global warming of sulfur hexafluoride (SF6), extensive experimental and theoretical studies have been carried out to seek for the viable alternative insulation gas to SF6. The remarkable dielectric strength with respect to SF6 is the most important criteria for molecular design on the novel gaseous dielectrics. Many structure-activity relationship models to predict the dielectric strength were proposed in literature. However, these techniques either showed unacceptable deficiency (e.g., weak correlation) or are too complicated (e.g., with the computer-intensive quantum chemical calculations) to be used conveniently. Because the phenomenological dielectric strength is usually related to the structural characteristics of a gas, it would be ideal to obtain dielectric strength straightforwardly from the functional groups. A group-additivity approach is proposed herein to estimate dielectric strength. A training set including 51 dielectric strengths were prepared by the critical evaluation of the experimental tests. Functional groups are developed systematically by minimization of the mean absolute deviation of the observed and calculated dielectric strengths. The present model shows better performance on average than the previous models. Several interesting trends in constructing novel dielectric gases have been found. A serial of eco-friendly dielectric molecules are rationally designed.

Paper ID: 2327

Enhancement of Low-temperature Impact Strength of Isotactic Polypropylene Filled with Thermoplastic Elastomer for HVDC Cables

Zhang, Ling (1);Wu, Wangsonng (1);Jia, Shiqi (1);Xu, Yuxuan (1);Zhou*, Yuanxiang (1,2)

1: State Key Lab of Power System, Department of Electrical Engineering, Tsinghua University;2: The Wind Solar Storage Division of State Key Lab of Power System, School of Electrical Engineering, Xinjiang Universit

Compared with thermosetting crosslinked polyethylene (XLPE), thermoplastic isotactic polypropylene (iPP) has better electrical properties and heat resistance, and can be recycled after the end of its life, which meets the need of sustainable development of environmental protection, and is expected to replace XLPE material as the next generation of high-performance insulation materials for HVDC cables. However, iPP has a high degree of regularity in its molecular structure, which leads to its lack of impact resistance, and it has the disadvantages of insufficient flexibility at room temperature and poor impact strength especially at low temperature. In this work, 25% ethylene propylene diene monomer (EPDM), polyolefin elastomer (POE), styrene-ethylene/butylene-styrene (SEBS) and maleic anhydride grafted SEBS(SEBS-g-MAH) were added to iPP matrices to improve its mechanical toughness, respectively. Scanning electron microscope (SEM), polarizing microscope (POM), differential scanning calorimeter (DSC), low temperature impact testing system, electronic universal experimental machine, space charge testing system, DC breakdown and conductance system were used to analyze and characterize the morphology, crystallization behavior, mechanical properties, space charge, and other electrical properties of iPP composites. The results show that the mechanical toughness of iPP/elastomer composites is better than that of pure iPP, especially its low-temperature impact strength has been significantly improved, and its brittle fracture temperature has dropped from -15.6℃ to below -50℃. Under the DC electric field of -50kV/mm, space charge accumulation and electric field distortion of iPP/elastomer composites are higher than those of pure iPP, and the volume resistivity and DC breakdown strength decrease to some extent. Among them, iPP/EPDM composites have a large amount of space charge accumulation. The low-temperature impact strength of iPP/SEBS and iPP/SEBS-g-MAH composites were largely improved, but the DC breakdown strength of the two composites decreased the most. SEM observation shows that POE has the best compatibility with iPP matrix, thus showing a good dispersion effect, which makes iPP/POE composites achieve a good balance in mechanical and electrical properties. In this work, several typical thermoplastic elastomers were selected, combined with microscopic observation, thermal, and electrical characterization, and the improvement degree and reasons of elastomers on room-temperature flexibility and low-temperature impact properties of iPP materials were systematically determined, which provided important basic data support for further development of iPP polymers.

Paper ID: 2336

The Effect of Voltage Polarity Reversal on Space Charge Behavior of Epoxy MgO nanocomposites

G, Nagaraju;R, Sarathi

Indian Institute of Technology Madras, India

In the present study, the epoxy nanocomposites with different weight percentage of MgO nano filler were prepared. The accumulation of space charge within the bulk of the insulation would distort electric field distribution under polarity reversal voltage condition. In the present study, pulsed electro acoustic (PEA) method was adopted for space charge measurement. The space charge density and electric field were measured during both poling periods. The accumulated space charge cannot dissipate immediately after the polarity reversal, which aids the redistribution of the electric field with in the specimen. The addition of MgO nanoparticles showed suppressed space charge accumulation and reduced the electric field distortion during polarity reversal with 1, 3 and 5 wt% MgO filled epoxy nanocomposites.

Paper ID: 2343

Image Segmentation Method for Unbalanced Background in Water Droplets from Insulators Based on Discrete Cosine Transform and Morphological Processing

Santos Macedo, Matheus;Vilela Ferreira, Tarso;Costa dos Santos, Adrielly

Department of Electrical Engineering, Federal University of Sergipe, Brazil

Water droplets segmentation is one of the main issues when proposing an automatic method capable to evaluate or classify the surface hydrophobicity in high voltage insulators. In general, two factors pose a challenge in the process of segmenting water droplets images: Irregular or unbalanced brightness on the background, due to lighting conditions, and the transparency of water which cause the color levels of the object and background to be fairly close to each other. This paper presents an effective method to segment water droplets images with unbalanced background based on the discrete cosine transform. The proposed method uses the discrete cosine transform to reconstruct the background image regardless of any brightness disturbances and then uses image differentiation and morphological processing techniques to segment the water droplets from the background. When compared to other techniques, the proposed method diminishes the impact of irregular lighting while reducing the computational effort demanded by methods that rely either on processing the image at the HSV color space or on edge detection and processing algorithms. Experimental results on an image database containing water droplets of multiple sizes and shapes demonstrate that the proposed method is capable of successfully segment the expected objects. Thus, the algorithm described in this paper archive similar or better results, for this particular dataset, than the other analyzed techniques.

Paper ID: 2347

Measurement of gas density recovery of a post-spark channel in a 1.0m air gap

Huang, Yubin (1);Ding, Yujian (2);He, Henxing (1);Cheng, Chen (1);Chen, Weijiang (3);Wu, Yutong (1);Hu, Jingyang (1)

1: State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Wuhan, China.;2: China Electric Power Research Institute,Beijing,China.;3: State Gride Corporation of China,Beijing,China.

The insulation recovery property of long air gaps is crucial for the relay protection setting of HVDC system. The withstand electric field of post-arc channel is inverse proportion with the gas density. In order to investigate the relaxation process of a post-spark channel, a time-resolved moiré deflectometry technique was established in this paper. The spatial resolution and temporal resolution of this system are 28.87μm/pixel and 1μs, respectively. The gas temperature and gas density changes of a post-spark channel in a 1.0m air gap are obtained. It is found that the gas temperature in the post-spark channel decays exponentially with time. The relationship of the temperature decay time constant and the injected charge by post-discharges is analyzed. Since the air pressure in the post-spark channel stays at 1.0 bar approximately, the recovery characteristics of gas density is derived by using the state equation of ideal gas, and its impact on the withstand electric field of post-arc channel is discussed in the last.

Paper ID: 2363

On the partial discharge behavior of a low-density polymeric foam for hollow-core composite insulators

Machetti, Diego (1);Moal, Eric (2);Seifert, Jens (3);Puffer, Ralf (1)

1: RWTH Aachen University, Germany;2: Reinhausen France SAS (France);3: Reinhausen Power Composites GmbH (Germany)

Hollow-core composite insulators (HCIs) have been in use since the 1980s as an alternative to hollow-core ceramic insulators. These type of insulators can be found in outdoor high-voltage (HV) facilities where they are used as housing for circuit breakers, instrument transformers and surge arresters, among others. Moreover, HCIs are characterized by their lightness and high mechanical strength. In the last years, these properties have enabled new areas of application such as ultra-high-voltage (UHV) station post insulators (SPIs).To be used as SPIs, the internal volume of HCIs is typically filled with a light insulating medium to avoid internal flashovers caused by humidity condensation on the internal surface of the fibre-reinforced plastic (FRP) tube. Possible insulating media for this purpose are either gases, such as sulphur hexafluoride (SF6) or nitrogen (N2), or foams, normally based on polyurethane (PU) formulations. Although the latter are preferred to the former for not requiring a monitoring system to detect gas leakages, PU foams release a significant amount of energy during their manufacture. Moreover, this exothermal behaviour increases for larger insulators. Due to this reason, alternative light insulating fillers that can ease the production are being investigated.Experimental/Modelling methodsThe proposed paper presents a series of investigations on a new type of polymeric foam named Dry Syntactic Foam (DSF). This material is based on a mixture of two sorts of plastic-hollow microspheres (HMS), which expands under temperature forming a stiff polymeric foam. The AC breakdown process is experimentally investigated by analysing seven different material densities in plate-shaped geometries in a broad density spectrum from ρ = 0.45 g/cm3 to ρ = 0.03 g/cm3. Within the experiments, these specimens are stressed with a step voltage profile, being the partial discharge (PD) activity inside the pores registered until the electric breakdown takes place.Results/discussionThe inception and breakdown field strengths are derived from the measurements taking into account the homogeneity factor of the electrode arrangement. For the high density samples the inception field strength lies further from the breakdown field strength than in the case of the lower density samples. This is explained by the different pore sizes of the foams, which are related to the density of the same. Moreover, the average amplitude of the partial discharges is found to be higher for the lower densities.

Paper ID: 2101

Effect of Free Radicals induced by thermal aging on electrical and optical properties of BOPP film for capacitors

Umran, Haider (1,2);WANG, FEIPENG (1);HE, YUSHUANG (1)

1: School of Electrical Engineering Chongqing University;2: University of Kerbala

Thermal aging is one of the complex problems facing the reliable performance of capacitor dielectrics. This work is to investigate the effect of thermal oxidation on the electrical and optical properties of biaxially oriented polypropylene (BOPP) film at temperatures ranging from 50 °C to 110 °C. The chemical composition, thermal oxidation, changes in microstructural, surface topography, and morphology are confirmed by attenuated total reflection-Fourier transform infrared (ATR-FTIR) spectroscopy, field emission electron microscopy (FE-SEM), and atomic force microscopy (AFM), respectively. In contrast, of the film's electrical properties is identified with dielectric relaxation spectroscopy (DRS). Molecular dynamics (MD) simulation is performed on the basis of density functional theory to determine the mechanisms behind. Analysis of Three-dimension (3D) surface maps and Ultraviolet-visible (UV–Vis) spectra, as well as the calculation of energies of a highest occupied molecular orbital (HOMO) - lowest unoccupied molecular orbital (LUMO) and density of states (DOS), confirms the degradation of optical properties due to the influence of hydroxyl -OH and carbonyl C = O groups. It has found that the long-term heat causes serious chemical-physical changes that lead to a loss of dielectric properties of BOPP film.

Paper ID: 2106

Analysis of a hydro-generator stator winding failure

Raymond, Alexandre (1);Millet, Charles (1);Provencher, Hélène (2)

1: Hydro-Québec, Canada;2: IREQ, Canada

When a winding failure occurs in a hydro-generator, an investigation should first be organized to locate and assess the extent of the fault. A visual inspection and electrical tests are used to accomplish this task. The goal is not only to determine what must be repaired to return the generator to service as soon as possible, but also to find the root cause of the failure and collect valuable data for use in winding insulation condition assessment. These two aspects of failure analysis provide important information that complements the information obtained during periodic generator inspections.This paper presents a case study of winding failure on a 51 MVA, 11 kV generator stator. It describes the stator condition assessment carried out to determine the root cause of the failure and obtain additional information on the winding condition assessment, as well as the findings of the visual inspection and details of the dissection and measurement campaign performed prior to returning the repaired generator to service.

Paper ID: 2150

Online Partial Discharge Monitoring and Failure Analysis of a 132kV Current Transformer

Ward, Brody (1);Whyte, Thomas (2)

1: Powerlink Queensland, Australia;2: EA Technology, Australia

This paper describes how an online partial discharge monitoring system has been used to identify the correlation between network events and the degradation of insulation within an oil filled 132 kV Current Transformer. It will cover 4 months of online Partial Discharge data as well as the failure analysis and dissection of the 132kV current transformer. It will explain the reasoning for a permanent online monitoring system as well as the constraints of outdoor switch yard monitoring. The business case will be discussed, focusing on how the obtained data was used operationally in order to increase safety and reduce the probability of unplanned outages. The paper will focus on correlating increases in partial discharge activity with network and environmental events to determine a relationship between common operational data and events with the inception of partial discharge and insulation breakdown.

Paper ID: 2160

Modelling of an electrochemical double layer capacitor using cyclic voltammetry

Chatterjee, Kingshuk;Basu, Sumit;Gupta, Nandini

IIT Kanpur, India

An Electrochemical Double Layer Capacitor (EDLC) bridges the gap between a battery and an electrostatic capacitor in terms of energy and power density. High surface area of the electrode materials and an extremely small thickness of the double layer results in exceptionally high capacitance values compared to electrostatic capacitors. Electrical modeling of the EDLC is crucial for understanding of the behavior of the device, and for evolving a better design. Cyclic Voltammetry (CV) is an experimental technique to obtain the overall capacitance of an EDLC. The present work proposes an analytical approach for estimation of the porosity of EDLC electrode from the CV experiment, with the help of its electrical model. A voltage-dependent capacitance model is used to model the charging and discharging behavior of the EDLC. The manner, in which the modeled circuit parameters relate to the shape of the cyclic voltammetry curve, and the physical implications thereof are discussed.

Paper ID: 2161

Electrical tree progression in the presence of micro-voids due to thermal aging

Bordeori, Moon Moon;Gupta, Nandini

IIT Kanpur, India

Thermal aging irreversibly changes the chemical structure of polymer causing formation of oxidized carbonaceous layers and micro-voids. Voids also increase in size and number due to thermal aging. The presence of voids is known to affect electric tree growth inside the epoxy resin. The current work aims to understand the effect of thermal aging on electrical tree growth using a stochastic 3D model. The numerical stochastic model is developed based on the WZ model for electrical tree growth. Spherical voids of varying diameters are inserted into a computational sample. The tree is assumed to initiate from a needle tip of a needle-plane electrode configuration, and grow in a step-wise manner from the existing tree structure. The location of the new branch is chosen stochastically, with the probability depending on the local electric field. After the addition of each tree branch, the electrical field is recalculated with appropriate boundary conditions. Partial discharges (pd) within the tree tubules result in charge redistribution along the channel walls, and on the tips of tree tubules. Similarly, pd within existing voids cause charge deposition on the void walls. The effect of charge on tree tubules, tips and void walls is taken into account in simulating tree progression. The effect of the size and distribution of the voids is investigated in this work. Computationally generated trees are compared with experimentally obtained trees.

Paper ID: 2166

Study on characteristics of surface discharge of silicone rubber under high-speed airflow

Zhang, Guangquan;Zhang, Xueqin;Guo, Yujun;Wang, Bo;Yang, Feng;Wu, Guangning

Southwest Jiaotong University, China

High-speed train roof insulators are the key equipment for train high-voltage isolation and pantograph mechanical support. Their good insulation performance is the basic condition to ensure the safe operation of trains. With the rapid development of high-speed trains, the speed of trains is getting faster and faster. The silicone rubber insulators on the train roofs are exposed to the atmospheric environment. The silicone rubber insulators are affected by operating conditions and atmospheric movement, and the surface of the insulating medium is often in an air current environment. High-speed trains run in the atmospheric environment and move relative to the airflow. Compared with static gas discharge, frequent collisions between molecules and charged particles in the flowing gas in the direction of the airflow will inevitably have a great impact on the surface discharge process of the insulator. Silicone rubber insulators have a big difference between the creeping discharge characteristics under high-speed airflow and the creeping discharge characteristics under static conditions. When the discharge distance is the same, the creeping discharge voltage of the insulating medium is lower than the breakdown voltage of the pure air gap. Therefore, the creeping discharge of the insulator under high-speed airflow is more likely to occur than the discharge of the air gap, which leads to the occurrence of the discharge accident of the insulator on the train roof. When the train is out of service, once the train is out of service, it poses a great threat to people's lives and property. The external insulation system of the train roof is the weak link in the insulation performance of the train. Therefore, it is necessary to carry out related research on the creeping discharge characteristics of the roof silicone rubber insulators under high-speed airflow, and to prove the creeping discharge characteristics of the high-speed train insulators. This is an important issue that urgently needs to be resolved during the safe operation of high-speed railways. In this paper, silicone rubber is used as the research object, and the surface discharge test is carried out on the silicone rubber insulating sheet through the wind tunnel system. Through experiments, the creeping discharge voltage of silicone rubber under different airflow speeds, the discharge path of the silicone rubber surface under different airflow speeds, and the change characteristics of silicone rubber surface temperature under different airflow speeds are obtained; the creeping discharge change law of silicone rubber with the change of airflow speed is obtained. Through theoretical analysis reveals the creeping discharge characteristics of silicone rubber under high-speed airflow. This study provides theoretical support for the external insulation design of high-speed trains to ensure the safe and stable operation of high-speed trains.

Paper ID: 2194

Microstructure investigation of reference voltage and leakage current trends in varistor arresters

Muremi, Lutendo;Bokoro, Pitshou;Doorsamy, Wesley

University of Johannesburg, South Africa

Recent literature in this study field shows that during electrical degradation process of Zinc Oxide (ZnO) varistors, the reference voltage (V_1mA) may show an increase or decrease trends. Decrease in the reference voltage following rise in leakage current are common symptoms of degradation or failure of these devices. However, increase in the reference voltage following drop in leakage current could also be experienced after exposure of varistor arresters to degradation agents. This work makes use of microstructure analysis in order to probe whether or not high reference voltage and low leakage current, experienced after continuous electro-thermal stress, constitute valid indication or symptoms of electrical degradation. Low voltage ZnO varistor samples (3 per temperature) are exposed to electro-thermal degradation test. The electro-thermal test is consisted of magnitude of 80% of voltage required to cause 1 mA leakage current through the arrester (0.8 V1mA), and three point temperature 110℃ ,120 ℃ and 135℃ for a period of 48 hours. During the experiment, the leakage current is measured using an ammeter. Varistor voltage is also measured before and after degradation test. The experiment conducted in this work shows samples with decrease in the leakage current and increase in reference voltage (V1mA) trend under each temperature. SEM micrographs shows that even though the current was decreasing the samples has many holes as applied temperature increases. Energy dispersive X-ray (EDS) spectroscopy used to study the sample chemical compositions also shows the increase in the zinc oxide composition as the temperature increases

Paper ID: 2217

Study on the Performance Degradation of a Plasma Jet Gun for Triggering High Pressure SF6 Gap

Gao, Gan (1);Li, Xiaoang (1);Zhang, Ningbo (1);Lv, Yufang (1);Li, Zhibing (2);Zhang, Qiaogen (1)

1: Xi'an Jiaotong University, Xi'an,China;2: China Electric Power Research Institute,Beijing,China

Plasma jet gun (PJG) has been proven to be an effective method to repetitively trigger the gas gap into conduction at a very low working coefficient. The performance degradation characteristics of the PJG are always the key parameters determining its lifetime. In this paper, the performance degradation of the PJG operated in high pressure SF6 atmosphere was investigated in two different kinds of PJG structures, namely, laminated and integral structures. In each structure, the trigger pulse was applied to the PJG, and the time delay of breakdown, residual capacitor voltage, and peak voltage output of the pulse transformer were measured to characterize the performance variance versus shot time. The results showed that the time delay of both structures increased while the residual capacitor voltage decreased as the shot number increased. The peak voltage output of the pulse transformer gradually went up in the first 100 shots and then kept stable. Compared with the integral structure, the laminated structure had not only lower time delay and jitter of breakdown but also a longer lifetime. By analyzing the results of the two different structures, it was found that the performance of the laminated structure degraded more slowly. Based on the research, the performance monitoring method and life change rule of the PJG during the whole life cycle are mastered, which is of great significance for the application and life improvement of the PJG.

Paper ID: 2244

PD energy as a marker of low-voltage insulation aging

Szczepanski, Mateusz (1,2);Fetouhi, Louiza (1,2);Sabatou, Marie (1);Pin, Samuel (1);Belijar, Guillaume (1)

1: IRT Saint Exupéry, Toulouse, France;2: Nidec Leroy-Somer, Angoulême, France

The aging of the insulation system is, in most cases, due to 4 factors known as TEAM: thermal, electrical, ambient and mechanical. In this study we focused on the first two (thermal and electrical), as often being the most severe and problematic ones. Type I electrical insulation system, widely used in low-voltage machines, is not designed to withstand the partial discharge activity, which can easily damage the polymer insulators. For this reason the partial discharge inception voltage (PDIV) is one of the key factors to be taken into consideration when designing the insulation system. This factor is crucial especially for inverter-fed machines, where fast changing PWM voltage with very high dV/dt results in significant overvoltage at the machines' terminals which can lead to PD activity and premature breakdown.The aims of this study are: to verify to what extent the repetition of partial discharge inception voltage measurements is detrimental for the turn-to-turn insulation; to determine if the PDIV can be a good marker of insulation aging. As in random-wound machines especially the turn-to-turn insulation is mainly endangered by thermal and electrical stresses, all the tests were performed on twisted pairs samples. They were placed inside an oven and wired to apply both thermal aging and repetitive PDIV measurement as electrical stress. The PD measurements are coupled with the monitoring of other electrical markers, such as insulation resistance and capacity, in order to gain better understanding of the nature of insulation faults.The obtained results show that the final impact of PDIV measurement depends on the exact protocol used by the operator, especially the total time during which voltage higher than PDIV is applied.As second outcome, the slight change of PDIV value during aging was stated, although in some cases it can be difficult to measure due to the dispersion. Nevertheless, PD measurements coupled with other electrical markers, such as insulation resistance and capacity of such EIS, can give a more complete picture of its state. Better understanding of aging mechanisms of insulation system will help to design more reliable machines and may be useful in diagnosing some insulation faults at the early stage.

Paper ID: 2248

Assessing the Condition of Propulsion Coils of Superconducting Maglev Systems Using an On-Board Radio Interferometer System with a Vector-Antenna

Kawada, Masatake

Tokushima University, Japan

A large number of ground coils: propulsion coils and levitation-guidance coils are used in superconducting magnetic levitation (Maglev) systems. We have been developing an on-board radio interferometer system with a vector-antenna to detect partial discharges (PD) occurring in propulsion coils. A mock-up of propulsion coil with a PD source and/or insulation breakdown could be located from a test bogie running at the speed of 200km/h on the test track with the length of 500m. The propulsion coil has multiple holes penetrating through insulation to the inner conductor for attaching a needle-electrode; one or some of the holes can be voluntarily chosen to generate PDs. The vector-antenna composed of vertical and horizontal dipole-antennas is set to the center of the antenna-array of the on-board radio interferometer system.Simultaneous measurement of PDs generated in the mock-up of propulsion coil was carried outby combining high-voltage test techniques described in the IEC60270 and the on-board radio interferometer system with the vector-antenna. Apparent charge of PDs was measured as described in the IEC60270; PDs with the apparent charge of 3pC or higher could be detected by using the on-board radio interferometer system with the vector-antenna. Dynamic spectra of electromagnetic (EM) waves emitted from PDs leading to electrical breakdown differ from those of PDs occurring repeatedly. Lower UHF components and/or VHF components appear strongly in the dynamic spectra of the EM waves from PDs leading to electrical breakdown.It is envisaged that PDs with the apparent charge of 3 pC or higher occurring in propulsion coils will be detected; propulsion coils with defects will be found before electrical breakdown from the superconducting Maglev trains running at the speed of 200 km/h.

Paper ID: 2304

Maximum Likelihood Classification for Transformer Fault Diagnosis Using Dissolved Gas Analysis

S M, Sreelakshmi;Tharamal, Lakshmi;P, Preetha

National Institute of Technology Calicut, India

Transformers are important assets in the existing electrical grids and their failure have a huge impact on the entire power generation, transmission and distribution system. As these transformers act as a vital link that connects the power system, they have to be continuously monitored. Dissolved Gas Analysis (DGA) is a worldwide accepted diagnostic technique for detecting transformer incipient faults. Unavailability of the historical data to efficiently identify the transformer condition and uncertainty in the measurement are the drawbacks of DGA analysis.DGA interpretation methods include IEEE methods, IEC ratio codes and graphical methods. Among them Duval triangle is the most frequently used technique. Triangle coordinates depicting relative concentrations of the three hydrocarbon gases (CH4, C2H4 and C2H2) from 0% to 100% for each gas expresses the three sides of the Duval triangle. The position where the relative percentages meet is the fault type .Even though Duval triangle interprets the DGA data and relates them to the transformer condition, classifying the faults that fall in the overlap region is still a tedious task. The overlapping region mainly occurs due to the absence of a clear cut boundary involving faults produced by similar stresses. Also, faults falling under the boundary regions of the Dual triangle causes difficulties while classifying.In this work, an attempt is made to improve the accuracy of the fault classification by assigning a probability to each fault falling in the overlap region and boundary region of the Dual triangle. A total of 286 DGA data were collected from different 110kV substations, and the fault classification was performed using Dual triangle method. The statistical learning techniques are adopted for the faults falling in the overlapping region, which helps in obtaining an underlining relationship between the input and output. Maximum Likelihood Classification (MLC) technique is used for maximizing the likelihood of predicting the fault belonging to a particular class. MLC assumes that the statistics for each fault in a unique DGA data are normally distributed and predicts by calculating the probability of the given DGA data belonging to a specific fault class. In the overlapping and the boundary regions, MLC assigns DGA data to the corresponding fault class that has the highest probability of likelihood.

24-Jun-2021

Session 7 Switchgears, Capacitors, Transport, Failure Analysis & Dissection

Paper ID: 2365

Effect of Reliability Principles on Insulation Life Cycle Management

Ross, Alan

EPRA - Electric Power Reliability Alliance, United States of America

For too long, utility, industrial and commercial facilities have depended upon resilience and redundancy principles when looking at the life cycle of assets, often leaving insulation factors as secondary considerations. When we view assets, whose reliability and safety depend upon insulation, under the principles of asset reliability, it is clear we need a different approach to testing, maintenance and life cycle management.