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Partial Discharge Characteristics and Insulation Life with Voltage Waveform

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Abstract - The high voltage (HV) motor suffers from insulation failure due to long term partial discharge (PD) which is a great threat to its normal operation. This is why online monitoring and fault diagnosis of PD activities of HV motors is becoming more and more important to date. To perform the online monitoring of the PD activity, pattern distributions of the harmful PD should be understood to guarantee detecting accuracy in the fault identification process. Polymer materials are susceptible to electro thermal coupled stresses, which may cause changes of microstructure and degradation of physical and chemical properties, or even bring about accelerated insulation aging and premature failure. These failures have been due to poorly made electrical connections between stator bars, loose bars in the stator slot, vibration sparking, poorly designed corona suppression coatings and inadequate spacing of the stator bars in the end windings. These problems are reviewed, and ways to avoid premature failure with the better specification of new machines and modern diagnostic monitoring are discussed. This paper focuses on the effect of voltage waveform with high frequency on partial discharge characteristics, the insulation aging process and the insulation lifetime.

Keywords—voltage waveform; partial discharge; aging; lifetime;

I. INTRODUCTION

The high-voltage electrical insulation in large motor and generator stator windings gradually deteriorates over time [I], [2]. Both types of machines may eventually suffer from loose windings (leading to slot discharge), partly conductive contamination (leading to end turn tracking), and determination due to overheating or load cycling. Furthermore, air-cooled machines can deteriorate due to degradation of the semiconductive and grading coatings on the stator surface. Partial discharges (PD) are associated with each of these deterioration mechanisms. Heavy MOTORS are the work horse of the industries. The energy consumption of all the motors is approximately 70% of the total energy produced in the power system. Any change in the technology which could reduce power consumption will result into major economic impact. Electrical insulation is used in the stator and rotor windings of motors and generators, as well as in the stator core. Degradation of the insulation is a main cause of motor and generator failure, and is one of the main factors which determines the remaining life of such machines. The goal of this project was to establish the present state-of-the-art in assessing the remaining life of motor and generator insulation, and to develop improved methods for determining remaining life.

Effects of partial discharge in insulation systems

Once begun, PD causes progressive deterioration of insulating materials, ultimately leading to electrical breakdown. The effects of PD within high voltage cables and motors and equipment can be very serious, ultimately leading to complete failure. The cumulative effect of partial discharges within solid dielectrics is the formation of numerous, branching partially conducting discharge channels, a process called treeing.

PD dissipate energy, generally in the form of heat, but sometimes in as sound and light as well, like the hissing and dim glowing from the overhead line insulators. Heat energy dissipation may cause thermal degradation of the insulation, although the level is generally low. For high voltage equipment, the integrity of the insulation can be confirmed by monitoring the PD activities that occur through the equipment's life. To ensure supply reliability and long-term operational sustainability, PD in high-voltage electrical equipment should be monitored closely with early warning signals for inspection and maintenance.

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II. PROBLEM IDENTIFICATION

There are also different factors that can lead to failures in the electric motors.

Low insulation resistance in Electric motors

Low insulation resistance is one of the most common causes of motor failures and also one of the most difficult to handle. A low insulation resistance leads to leakages or short circuits in the coils and finally the motor malfunction and failure. When the insulation becomes weak, it eventually breaks down and does not provide the required isolation between the conductors or motor windings. The initial resistance of the insulation of the windings is usually very high – in the order over one thousand mega ohms (> 1MΩ).

Electric motor faults due to over-Current

An electrical overload or over current condition occurs when excessive current flows inside the motor windings. This is usually more than the design current the motor winding can carry efficiently and safely. An over current may occur due to various reasons; in particular a low supply voltage will cause the motor to draw more current in an attempt to maintain its torque. Another reason is when there are short circuited conductors, excess voltage etc. An overcurrent condition leads to overheating of the motor and damage to the insulation. And it is possible to minimize the risk of motor failures due to over current. This can be done by using reliable over current protection, to detect any over current condition, and interrupt the supply and hence stop the current.

Overheating problems in electric motors

Overheating in the motor occurs from a variety of reasons, the main one being bad power quality such as overvoltage or under voltage condition. If the supply voltage is higher that rated voltage, the excess voltage is dropped in the motor windings, resulting in to heat dissipation. An overheating condition existing for a prolonged period of time regardless of the cause will lead to insulation damage and damage to the motor.

Fig:1 A faulty electric motor winding

Vibration in Electric motors

Vibrations can lead to several mechanical issues inside the motor and likely to happen when the motor is installed in an unstable surface. In addition, other faults in the motor such as loose bearings, misalignments, and corrosion related issues like wear may cause the motor to have internal vibrations. This reduces the accuracy and efficiency while accelerating the tear and wear on the moving parts that are in contact with one another.

Moisture in AC electric motors

The moisture can cause a lot of problems to the motor by causing corrosion of various parts of the motor. In particular, the moisture will corrode the insulation, and lead short circuit between the windings, corrode the bearings, motor shaft and rotors.
This will prevent the smooth rotation, decrease efficiency and lead to complete failure of the motor.

Faults in Electric motors due to dirt

Dirt such as dust and other debris can block the flow of air in the motor cooling fans, and lead to over heating. In addition, dust particles and other small objects inside the motor may introduce some resistance that will slow down the motor, meaning that it will have to work harder to overcome this resistance. The dirt particles may also be abrasive in a way to damage the insulation.

III. AGING TESTS

A. Specimen and Electrode Arrangement

The insulation system of power equipment is mostly made of epoxy resin, polyimide and other polymer materials. Polyimide films of 25 μm in thick belonging to the Kapton series of DuPont firm were used as tested specimens. Before the electrical aging tests, specimens were firstly cleaned with anhydrous alcohol, and then dried for 2 hours under 60º C to remove surface moisture. To avoid scatter of test results caused by random factors, test five samples under per voltage waveform and compare the test results. Figure 1 shows the sphere-to-plane electrode arrangement made of copper. There are both normal and tangential electrical field in the small air gap between spherical high voltage electrode and specimens. When the local voltage in the air gap exceeds partial discharge inception voltage (PDIV), partial discharge occurs and the damage gradually accumulates, eventually leading to breakdown of pecimens.

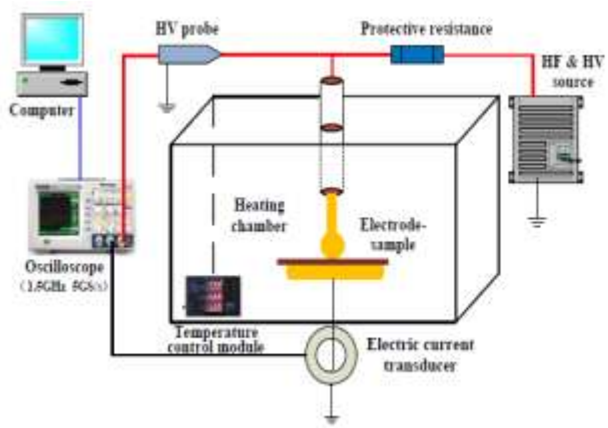


Fig:2 PD test system

B. PD Test System

As shown in Figure 2, PD test system consists of the following several parts: a) high-frequency and high-voltage source, which is composed of the signal generator and power amplifier, and high frequency signals with different

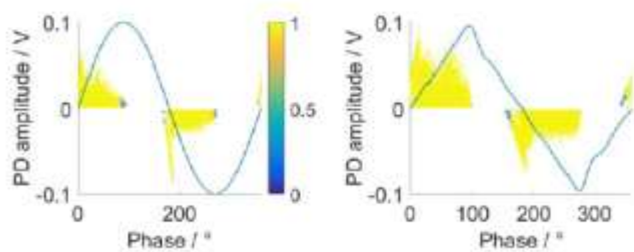
waveforms are generated by the signal generator, then amplified by the power amplifier, whose over-current protection device can automatically trip when specimens break down; b) test chamber with temperature control module whose tolerable temperature ranges from 25º C to 220ºC; c) voltage probe used to measure the high frequency voltage with different waveforms; d) data acquisition and storage system, composed of electric current transducer, high speed digital oscilloscope and computer: i) electric current transducer is used to capture the impulse current caused by the partial discharge which flows through the grounded wire, and its bandwidth is 500 kHz~120 MHz, sensitivity is 1 mA-4.2 mV; ii) high speed digital oscilloscope whose maximum sampling frequency is 5 GS/s and sampling bandwidth is up to 1.5 GHz. iii) digital signal of partial discharge and applied voltage sampled by the oscilloscope is sent to the computer to complete data storage and further processing and analysis.

IV. RESULTS

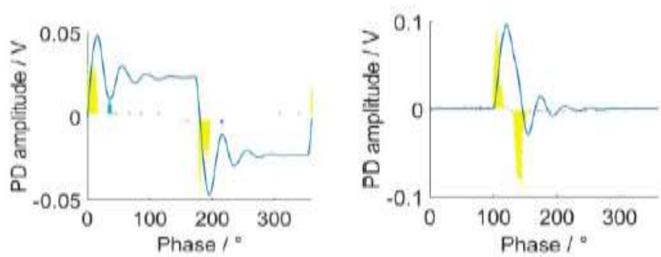
A. Phase Resolved Partial Discharge

Based on partial discharge measurement data during the whole lifetime of PI films, phase resolved PD pattern under

high frequency voltage with different waveforms can be obtained and is shown in figure 3. It is obvious that discharges mainly congregate at the rising and falling edges of voltage where applied voltage has larger changing rate, while there is few discharges at other phases. Besides, under sinusoidal and triangle wave, discharge clusters like rabbit ear will appear at the reversal moment of voltage polarity. Charge generated by the pre-discharge will accumulate at the interface. Before the voltage polarity reversal, a reverse discharge occurs when the difference between the charge-induced voltage and the applied voltage exceeds PDIV. The reason why the same polarity discharge can cover the entire voltage rising edge especially the voltage zero crossing is that the residual charge generated in the first half cycle can enhance the applied electric field after the voltage polarity is reversed. The asymmetry of the discharge spectrum in positive and negative half cycle is related to the asymmetry of the electrode structure.



(a) sinusoidal wave (b) triangle wave



(c) bipolar square wave (d) pulse

Fig. 3. Phase resolved partial discharge

Space charge accumulation will significantly affect PD characteristics. When the voltage polarity reverses, the applied electric field is enhanced by the space charge electric field, which is conducive to the occurrence of partial discharge; while at other times, the presence of space charge brings down the internal electric field strength, and will weaken PD. Therefore, PD amplitude is larger at the voltage polarity reversal moment. Space charge accumulation varies with different voltage waveforms. Shorter rise time, more concentrated discharge under bipolar square wave and pulse leading greater impacts caused by space charge accumulation on PD, and the unipolar characteristic of pulse will aggravate the accumulation of charge and distortion of local electric field, which caused more increasing of resultant electric field and larger PD amplitude at the time of voltage polarity reversal.

V. CONCLUSIONS

Over 40 years of experience have shown that partial discharge tests are sensitive to many stator winding insulation problems which can lead to motor and generator failure. The difficulty with conventional partial discharge tests is that they require an expert to perform the test, especially if the test is done during normal motor or generator operation.

Faults in AC electric motors are caused by simple things and can be prevented through regular maintenance, observing the recommended operating conditions such as well ventilated, dust free environments with no moisture. In addition, it important to have a stable supply to the motor and the appropriate over current and over voltage protection gear.

Space charge accumulation varies with different voltage waveforms and will significantly affect PD characteristics. Due to the existence of space charge, the same polarity discharge can cover the entire voltage rising edge and PD amplitude is larger at the voltage polarity reversal moment.

Experiment results prove that there is a strong negative correlation between total PD amplitude per cycle and lifetime, which verify the partial discharge is indeed the main reason for insulation aging.

Future work

In the present work, several soft computing techniques have been presented for the detection and location of stator inter-turn short circuit fault in the stator winding of an motor.

• Discrete wavelet transform approach is successfully used to detect and locate stator inter turn short circuit fault together with identification the severity of this fault in the stator winding of an induction motor. The same approach can be extended to identify the other faults such as bearing fault, rotor broken bar fault, and eccentricity related fault of an induction motor.

• Neural network ensembles are receiving increasing attention in the field of research such as control, fault diagnosis, decision making, identification, robotics etc. due to their learning and generalization abilities, nonlinear mapping, and parallelism of computation. However, for solving fault detection problems the neural networks may get stuck on a local minimum of the error surface, and the network convergence rate is generally slow. A suitable approach for overcoming these disadvantages is the use of wavelet functions in the network structure. Wavelet function is a waveform that has limited duration and an average value of zero. A wavelet neural network has a nonlinear regression structure that Suggestions for Future Work uses localized basis functions in the hidden layer to achieve the input-output mapping. The integration of the localization properties of wavelets and the learning abilities of neural network results in the advantages of wavelet neural network over neural network for the detection and location of an inter-turn short circuit fault in the stator winding of an induction motor.

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