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A Review Partial Discharge Activity in Electrical Insulation

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ABSTRACT: **This paper discusses electrical insulation characteristics of liquid nitrogen (LN2) / polypropylene (PP) laminated paper composite insulation system for the practical electrical insulation design of high temperature superconducting (HTS) cables. Partial discharge (PD) inception, propagation and breakdown (BD) characteristics under ac voltage application were obtained and discussed at atmospheric and pressurized conditions. Experimental results were analyzed quantitatively and revealed that void- type discharge was categorized as an important form of discharge to characterize the transition of PD activity leading to BD.**

Keywords: Superconducting cables, dielectric liquids, paper insulation, partial discharges, electrical breakdown, laminated paper.

I. INTRODUCTION

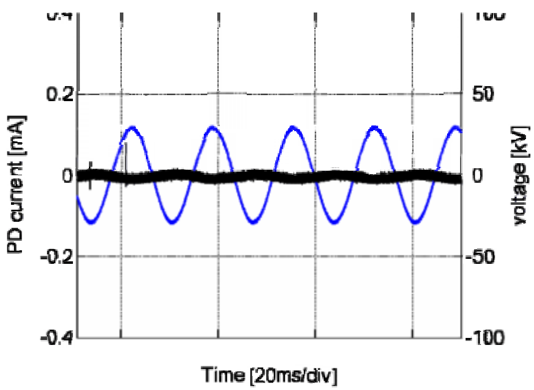
High temperature superconducting (HTS) cables have been developed and demonstrated in field tests in Japan, USA and Korea [1-5]. The electrical insulation system of HTS cables consists of liquid nitrogen (LN2) / polypropylene (PP) laminated paper composite insulation system. However, the electrical insulation design and test schemes of HTS cables have not yet been fully established, due to the lack of dielectric data applicable to the practical development of the HTS cables. Especially, understanding of partial discharge (PD) characteristics is crucial to prevent the degradation of electrical insulation performance. From the above background, we have been investigating the PD characteristics of LN2 / PP laminated paper composite insulation system under ac voltage application, and evaluated the volume effect of ac PD inception strength at atmospheric and pressurized conditions [6]. We have already proposed a novel technique for PD measurement and analysis, Partial Discharge Current Pulse Waveform Analysis (PD-CPWA), which is expected to elucidate PD mechanisms and physics in different electrical insulating materials [7]. Using PD-CPWA, we can obtain not only individual PD current pulse waveform, but also its transition characteristics of PD activity with the elapse of time and / or for different stresses of electric field and liquid pressure. In this paper, we describe the transition characteristics of PD activity from PD inception to breakdown (BD) in LN2 / PP laminated paper composite insulation system. Experimental results revealed that PD changed into void-type discharges ata certain applied electric field strength higher than PD inception strength. The results suggested that the large PD in the void-type discharges could be closely related to BD and distinguished from the other PDs. The void-type discharge inception strength (VDIE) can be regarded as the electric field criteria for the electrical insulation design of HTS cables.

II. SETUP

The electrode configuration of coaxial cylindrical cable sample for PD measurement. The coaxial cylindrical cable sample consists of high voltage electrode as an inner cylinder, inner semi-conducting layers, PP laminated paper layers, outer semi-conducting layers, and grounded electrode as an outermost sheath. In this paper, we used 8-layer sample of PP laminated paper layers (0.125 mm thickness / layer). The effective length of quasi-uniform electric field was 150 mm Partial Discharge (PD), as its name would suggest, is an electrical discharge that occurs across a portion of the insulation between two conducting electrodes, without completely bridging the gap. PD's are caused when there is a discontinuity in the insulation system and as a general 'rule-of-thumb' PD will occur in systems operating at voltages of 3000V and above (although it should be noted that PD can occur at lower voltages than this). Partial discharges can occur in voids in solid insulation (paper, polymer etc), along the interfaces of multi-layer solid insulation systems, in gas bubbles in liquid insulation or around an electrode in a gas (corona discharge). Partial Discharge activity can initiate under normal working conditions in high voltage equipment where the insulation condition has deteriorated with age, has been aged prematurely by thermal or electrical over-stressing or due to improper installation (this leads to 'infant mortality').

Tracking in paper insulation PD can often be observed with the commissioning of new equipment due to improper installation, poor design and/or workmanship (this is seen particularly in cable joints and terminations which are made-up on site). It is known that poor workmanship can lead to 'infant mortality' of MV/HV networks with a disproportionate percentage of insulation failures being observed within the first 1-3 years of service compared to the rest of the service life of the cables/plant. After initiation, the PD can propagate and develop into electrical trees and interfacial tracking until the insulation is so weakened that it fails completely with breakdown to earth or between the phases of a 3-phase system. Depending on the discontinuity in the insulation system and where it is positioned, a failure can take anything from a few hours up to several years to track through to produce a complete earth or phase-phase fault. It is known that whilst some discharges can be extremely dangerous to the health of the insulation system (e.g. discharges within polymeric cables and cable accessories) whilst other types of discharge can be relatively benign (e.g. such as corona into air from sharp, exposed points on HV overhead networks or on the outside surfaces of outdoor cable sealing ends). The key to on-line, diagnostic PD testing is to be able to differentiate between the dangerous and the benign. This becomes more difficult as the voltage of the system increases. Start of tracking on VMX spoutsIt is necessary therefore, when testing for PD, that the Test Engineer is able to ascertain the type of discharge present and its origin. HVPD provide our customers with the highest level of diagnostic support and test services presently available in the marketplace to make these decisions correctly. Failure of High Voltage insulation is the No. 1 cause of HV system failures with IEEE statistics indicating that electrical insulation deterioration causes up to 90% of electrical failures of certain high voltage equipment. On-line PD testing of MV and HV plant gives an advance warning of pending insulation failure, thereby allowing the plant owner to take remedial maintenance action during planned outages. Past projects by HVPD have shown that, in general, the earlier the advance warning can be made, the cheaper the maintenance or intervention costs will be. Unlike off-line testing, on-line PD testing and monitoring gives an accurate picture of the HV plant's health and performance under normal service conditions including the effect of load, temperature and humidity. Failure site in XLPE insulation, with bow tie trees accompanied by electrical trees HV Plant Asset and Risk Management PD testing is particularly important where the MV/HV plant has a high 'criticality' to the operation of a client's network. This may be due to its age, historical failures or the consequences of its failure (position in the network). Qualification of PD 'criticality' within the plant owner's HV network can be achieved quickly and easily using HVPD's on-line, screening and diagnostic PD test technology to provide an 'early warning system' for these incipient insulation faults. PD Monitoring and Trend Analysis On-line PD monitoring allows for analysis trends in PD activity to be observed over time. This may reveal correlation with environmental (temperature, humidity etc) or service conditions (changes in load etc).

As PD activity is often present well in advance of insulation failure it is possible by observing its development that strategic decisions can be made about refurbishing and renewal programmes. Tracks on SOHI epoxy resin busbar The Benefits of On-Line Partial Discharge Field Measurements It is truly a predictive test, indicating insulation degradation in advance of the failure. It is a no intrusive test, requiring no interruption of service and is performed under normal operating voltage, load and environmental conditions. It is a nondestructive test; it does not test to failure or adversely affect the equipment under test in any way. It does not use any over voltage, thereby not exposing the tested equipment to higher voltage stresses than those encountered under normal operating conditions. Trending can be accomplished by storing baseline measurement results to allow comparison with future tests. In many instances the site of the partial discharge occurrence can be located within the cable/plant under test, so the localized problem can be repaired. The cost to perform a PD survey is relatively inexpensive compared with off-line testing, allowing annual surveys to be performed economically at most facilities.



Partial discharge monitoring is an effective on-line predictive maintenance test for motors and generators at kilo volt and above, as well as other electrical distribution equipment. The benefits of online testing allow for equipment analysis and diagnostics during normal production. Corrective actions can be planned and implemented, resulting in reduced unscheduled downtime. An understanding of the theory related to partial discharge, and the relationship to early detection of insulation deterioration is required to properly evaluate this predictive maintenance tool. This paper will present a theory to promote the understanding of partial discharge technology, as well as various implementation and measurement techniques that have evolved in the industry. Data interpretation and corrective actions will be reviewed, in conjunction with comprehensive predictive maintenance practices that employ partial discharge testing and analysis. Reliable manufacturing operations will always be concerned with process production motors.

Comprehensive programs to maintain electrical equipment for peak performance have been recommended and implemented at various plants [1].

Detailed motor failure analysis has been completed; resulting in the identification of approximately 30% of failure causes being related to electrical failures [2]. A summary of the IEEE transaction entitled: "Report of Large Motor Reliability Survey of Industrial and Commercial Installations, [3] included both the results of an IEEE survey and an EPRI survey. The two sources of information proved extremely useful since the IEEE survey identified the "Failure Contributor", and the EPRI survey identified the "Percentage Failure by Component." The IEEE survey includes an objective opinion, whereas the EPRI survey includes actual failed components. The summary of the electrically related causes of the two studies is shown in Table 1, and will be referred to, when discussing root cause failures related to partial discharge test results.

Table 1 – Motor Electrical Failure Causes

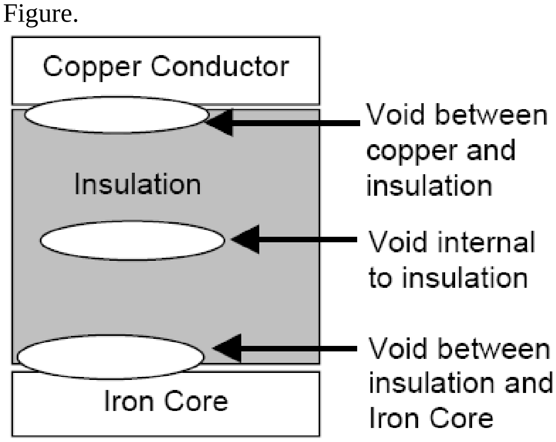
IEEE Study		EPRI Study	
Failure Contributor	%	Failed Component	%
Persistent Overloading	4.2	Stator Ground Insulation	23.0
Normal Deterioration	26.4	Turn Insulation	4.0
		Bracing	3.0
		Core	1.0
		Cage	5.0
Total	30.6	Total	36.0

The IEEE publication under development, "IEEE P1434-Guide to Measurement of Partial Discharges in Rotating Machinery" [4] also identifies similar failure causes for motor insulation systems. These include thermal, electrical, environmental and mechanical stresses. These factors correlate to the two studies, since they result in the stator ground insulation and turn insulation failure (EPRI Study); as well as can be interpreted as normal deterioration (IEEE Study). The next section provides a review of partial discharge theory. It is interesting to note that over 25 years ago, large motor manufacturers recognized the need for partial discharge testing in the slot area between the winding insulation and the iron [5]. The testing was called the "Slot Discharge Test" and involved applying a test voltage while observing the waveform on an oscilloscope. At that time only minimal partial discharge measurement technology was available, therefore limiting the wide spread use of such testing.

III. PARTIAL DISCHAGE THEORY

Partial discharge theory involves an analysis of materials, electric fields, arcing characteristics, pulse wave propagation and attenuation, sensor spatial sensitivity, frequency response and calibration, noise and data interpretation.

It is obvious from the above that most plant engineers will not have the time, or available energy, to pursue such a course of study. In an effort to promote a better understanding of partial discharge (PD), this paper attempts to provide simplified models and relates the characteristics of these models to the interpretation of PD test results. First, we will present a few technical concepts relating to partial discharges. Partial Discharge can be described as an electrical pulse or discharge in a gas-filled void or on a dielectric surface of a solid or liquid insulation system. This pulse or discharge only partially bridges the gap between phase insulation to ground, or phase to phase insulation. These discharges might occur in any void between the copper conductor and the grounded motor frame reference. The voids may be located between the copper conductor and insulation wall, or internal to the insulation itself, between the outer insulation wall and the grounded frame, or along the surface of the insulation. The pulses occur at high frequencies; therefore they attenuate quickly as they pass to ground. The discharges are effectively small arcs occurring within the insulation system, therefore deteriorating the insulation, and can result in eventual complete insulation failure. The possible locations of voids within the insulation system are illustrated in Figure.

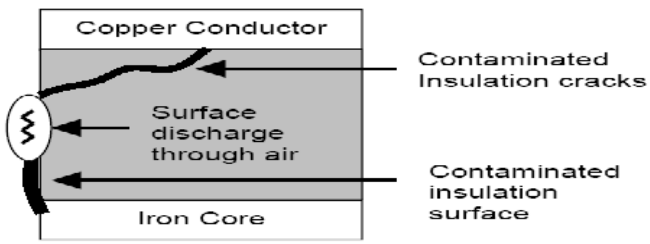


A. PD within Insulation System

The other area of partial discharge, which can eventually result, is insulation tracking. This usually occurs on the insulation surface.

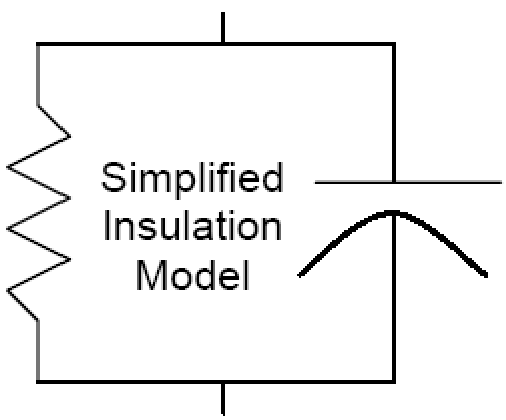
These discharges can bridge the potential gradient between the applied voltage and ground by cracks or contaminated paths on the insulation surface. This is illustrated in Figure The above can be illustrated by development of a simplified model of the partial discharges occurring within the insulation system.

B. Surface Partial Discharges



C. Insulation System Model

A simplified model of an insulation system can be represented by a capacitance and resistance in parallel [6]. This is the concept employed in the use of power factor testing of insulation systems. The leakage current is split between the resistive and capacitive paths. The power factor is the cosine of the phase angle between the total leakage current and the resistive component of leakage current [5].



Simplified Insulation Model and Model for an Electronic Attenuator.

The above model is also used for attenuator circuits in electronics [7]. Signal attenuation results in reducing the amplitude of the electrical signal. This underlies the problem with partial discharge detection. The insulation medium, which is being exposed to the partial discharges, acts to attenuate the signal, therefore weakening this damaging signal which we are trying to identify at our sensor locations. In addition, the attenuated partial discharge signal can be masked by sources of electrical noise, which shall be reviewed later in this paper. The above concept of the insulation system being an effective attenuator circuit gives rise to critical detection issues, such as:

- Sensor locations and sensitivity
- Measurement system response to attenuated signals
- Noise detection and elimination

IV. CONCLUSION

Partial discharge monitoring is an effective on-line predictive maintenance test for motors and generators at kilo volt and above, as well as other electrical distribution equipment. Partial discharges in volt equipment can also be observed depending on the equipment design, level of partial discharge activity and sensor placement. The benefits of on-line testing allow for equipment analysis and diagnostics during normal production. Corrective actions can be planned and implemented, resulting in reduced unscheduled downtime. Understanding of partial discharge theory allows for improved interpretation of results, and the benefits of such measurements. Data interpretation and corrective actions can be clearly identified with cost effective field corrections implemented, prior to further equipment deterioration. Advanced noise analysis techniques and new diagnostic measurement methods using existing RTD’s rather than permanently installed sensors, allow for the implementation of a partial discharge predictive maintenance program with a small initial investment. Partial discharge monitoring technology fully satisfies the cornerstone of a maintenance program designed to address the critical process support equipment, which can be identified by a Reliability Centered Maintenance study. The technology as advanced, with improvements resulting in a minimal initial investment, thereby allowing for partial discharge testing to become a part of everyday predictive maintenance.

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