# Partial Discharge detection methods in High Voltage Power Capacitor Equipment

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***ABSTRACT: This paper explains the effects of Partial Discharge in High Voltage Power Capacitor Equipment and its detection methods. The primary characteristics that detectors have in common and that are used as a basis for classification are the number of inputs used, the bandwidth of the detector, and the method of display processing. Ancillary test components, which complete an integrated test system, are discussed. PD measurements for quality assurance require not only a detector, but an entire system coordinated to maximize the measurement sensitivity for the specific type of apparatus under test. To illustrate how a coordinated system is applied, examples of some systems in commercial use are discharge measurements on capacitor units are reported. For large capacitance objects the inception and extinction levels are very clear and distinct in the HFCT technique. The technique can be extended to the in-site diagnostic testing of power capacitors***

**Key Words: Partial discharge detector, Liquid Nitrogen**

## 1. INTRODUCTION

MV/HV power cables represent a large capital investment in the electrical industry and have to be highly reliable to prevent forced outages. Failure of those transmission or distribution-class power cables can cause long periods of service interruption and blackouts, with costly repairs and loss of revenue. 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 spouts It 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

## 1.2 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.

The physics of partial discharges has been considered in another review. A largely independent matter is that of what associated quantities we get to measure, and how these relate to the PD event. This independence exists because the PD event happens generally more rapidly than the external circuit can respond, and the change in voltage at the test object terminals is generally a very small proportion of the applied voltage: the event can be regarded as a rapid change in dipole moments, affecting, but not affected by, the external circuit. Here I consider, in more detail than I've done before, my use of PD measurements. This draws partly on ideas and models I have used earlier (sometimes slightly erroneously) and partly on some points that this review stimulated me to consider, about analysis ofthe detection circuit and about the fields in the cavity and insulation. the advantage of multiple pulses not interfering with each other. Schering bridge and current-comparator methods are used, looking at tip-up, often on individual phases (this we know as common practice still).

## 2. PARTIAL DISCHARGE USING LIQUID NITROGEN

Recent investigations of liquid breakdown have shown that it is based on complex interactions between hydrodynamic and electrical phenomena. These interactions lead to a complex temporal and spatial structure of the conducting channel, especially in self-breakdown mode. Basic theories of field emission, local heating, electro-hydrodynamic effects, density changes and development of electron avalanches are investigated and how they relate to the overall breakdown and conduction mechanisms. The next two chapters will discuss the specific effects noticed in both liquid nitrogen and Univolt 61 transformer oil.

## 2.2 PRE-BREAKDOWN CURRENT AND LUMINOSITY

Measurement of current and luminosity from pre-breakdown events helps characterize the breakdown process. A series of three fiber optic fibers and cylindrical lenses are arranged to observe the discharge across the gap. Figure 1 is a sketch of the general layout of the gap and lens configuration. The configuration of the lenses, limits their field of view to about +/- 3mm on either side of the axis of the gap. The setup for liquid nitrogen is a point/plane geometry. Larger gaps are more difficult to breakdown therefore only two of the three lenses observe the test gap.

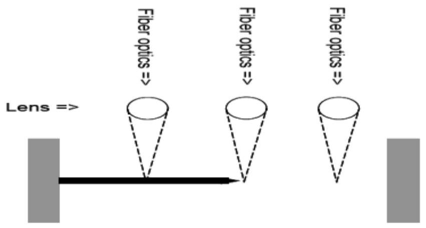

**Fig. 1** : Sketch of cylindrical lens configuration and point/plane geometry for optical diagnostics in liquid nitrogen.

## 2.3 CURRENT PULSES AND LUMINOSITY

Pre-breakdown current pulses are observed in many liquids and are often precursors to final breakdown by generating bubbles at the electrode tip [11,12,17,36,37]. Figure 2 represents a typical test result with pre-breakdown spikes occurring several microseconds prior to breakdown and shows the pulses increasing in amplitude as they approach final breakdown. It also establishes that the light pulses correlate directly with the current spikes. The multiple smaller spikes in the graph are cable reflections, since the cables were not terminated into a matched load. Assuming that negative breakdown develops in a gas phase, luminosity can be expected to be more intense since electron impact ionization produces many ions and excited state molecules that release visible light when recombining or returning to a lower energy state.

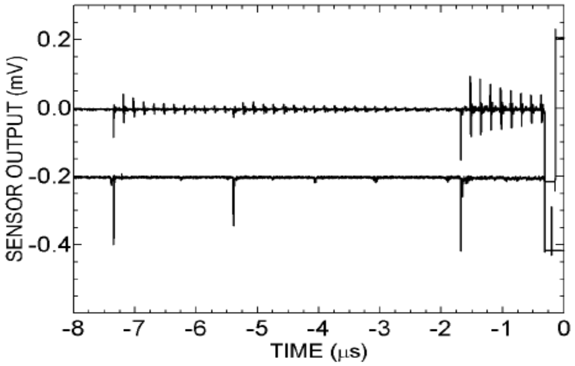

Fig. 2: Graph of pre-breakdown current pulses and luminosity in $LN_2$. Negative tip. Point/plane geometry. Current = top trace. Luminosity = lower trace. Decaying current signals are cable reflections.

Data collected from the current and luminosity spikes provides some insight into the mechanisms of breakdown. The figures indicate that negative polarity pre-breakdown events are larger in amplitude and have a shorter duration than current pulses for the positive needle case. However, closer inspection indicates that the PMT in the middle of the gap sees light prior to the tip for the positive case. For this case, the discharge appears to originate from the volume region nearer the negative plane instead of the positive needle tip. Positive pre-breakdown current pulses in $LN_2$, typically, are broader than negative pulses and lower in amplitude. The large amplitude, narrow current pulses for cathode initiated events match well with observed current waveforms for oil providing support for the gaseous development of liquid breakdown. The data indicates that positive breakdown may be similar to negative breakdown for liquid nitrogen at atmosphere. Since it is not possible to take shadowgraph images in the liquid nitrogen chamber as configured it is difficult to reach a conclusion about the mechanisms.

## 2.4 ENERGY INJECTION

Using the data it is possible to estimate the energy injected by the current pulses. Assuming that injection originates from the cathode and that 25%

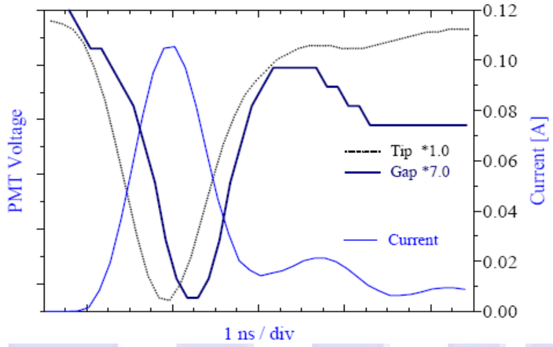

**Fig.3:**Graph of pre-breakdown current and luminosity pulses 0.460 µs before breakdown. Luminosity pulses are normalized to the PMT at the tip. Negative tip. 0.1A peak, 5ns FWHM. Fast pulse.

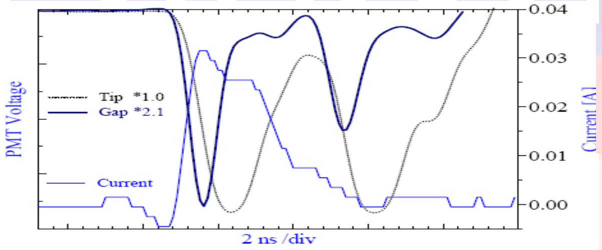

**Fig.4:** Graph of pre-breakdown current andluminosity pulses 0.200 µs before breakdown. Luminosity pulses are normalized to the PMT at the tip. Positive tip. 0.030 A peak, 13 ns FWHM. Slow pulse.

The physical and electrical properties of $LN_2$ control the mechanisms of breakdown development. The average energy per molecule required to heat the liquid to vaporization is approximately 60 meV. This is comparable to values for n-hexane (~100 meV) [21], which will affect the conduction mechanisms. Small vaporization energy means that a phase change is very easy and tunneling charge carriers could have sufficient energy to initiate a phase change.

## 2.5 .PARTIAL DISCHARGE EMISSION SPECTRA

An important step in using the emission spectra as a diagnostic is to trigger the spectrograph readout, iCCD camera, as early in the breakdown as possible. Breakdown in liquid nitrogen typically reaches 50% of the final impedance limited current in a few nanoseconds in self-breakdown mode, which is very fast, and an indication of an ideal switching medium. The fast risetime of the breakdown current makes timing the optical gate to catch the earliest moments of breakdown difficult.

## 2.6 EMISSION SPECTRA

The primary goal is to investigate the early development of the plasma channel to detect any mechanisms that may contribute to the development. Spectroscopic data can provide information about plasma temperature and electron density given knowledge of well defined emission lines and transitions

### *2.7 Band Structures*

It is possible to identify broadband band structures for $N_2$ and $N_2^+$ [39]. The first band head appears at 391 nm with the direction of shading primarily to the red, this corresponds to the transition of $N_2^+$ from $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$. Two other band heads fit the data reasonably well. A possible transition at 275nm for $N_2$, the $m^1\Pi_u \rightarrow a^1\Pi_g$ and a second transition possibly at 280nm, the $d^r \rightarrow a^1\Pi_g$, both shade towards the red. These band heads would explain the sharp drop in intensity observed in figure 4.6. Other bands might exist outside of the measured range of wavelengths but are not distinguishable with the current experimental setup. Frayssines et al. observed similar spectra in pulsed experiments with more defined structure [38]. Given that the transition for $N_2^+$ goes into the ground state from the upper electronic level with energy of 3.1 eV and that both N2 transitions occur at energy levels of about 13 eV, it is clear that the upper energy level N2+ would be more densely populated assuming that the energy is distributed in a thermal distribution. Since the intensities differ by approximately an order of magnitude, it is a reasonable conclusion. The degree of ionization, which is an unknown, determines the population density. The spectral shape is different at the electrode tip compared to the center of the gap nearest the plane. Also, the intensities are very different indicating a variance in the electronic temperature and degree of ionization at each location. The third fiber located 5mm behind the tip electrode, exhibits a different spectra from the other two.

## 2.8 CONDUCTION CURRENT

Measuring the conduction current in liquid nitrogen was much more difficult than in transformer oil. Liquid nitrogen does not have a permanent dipole moment and is difficult to polarize. Also, the molecular configuration makes electron attachment unlikely and field ionization at very low fields is unlikely for a diatomic molecule. Combined with a high volume resistivity, $\rho > 10^{13}$ Ω-cm, it was not possible to establish a stable conduction current within the measuring limit of a few pA. However, on several occasions a slow rising current for a fixed voltage was established. For example, an applied voltage of 10 kV produced a current that rose from 5 nA to 66 nA over a period of 4 minutes. This slow rising current was only observed a few times during conduction tests of nitrogen. Since the case was not easily reproducible, it is likely that it was an artifact of liquid contamination. The liquid nitrogen is not filtered or strained before it is used in the test chamber. The presence of small particles in the liquid could significantly alter the conduction mechanisms and mobility of the liquid. At very low temperatures the water vapor condenses out of the air in the laboratory and immediately freezes. The system remains closed during the tests and is backfilled with "dry nitrogen" gas, however limited exposure is unavoidable. Any water in the chamber immediately freezes when it enters and will sink to the bottom because of its much higher density than liquid nitrogen. During this time some ice could pass through the gap. The permanent dipole moment of water combined with fields applied to the gap for several minutes, allows a build up of charge carriers in the liquid and current will flow. These particular results are consistent with the suspended particle theory of liquid breakdown.

## 3. NOISE SUPPRESSION USING A GATING TECHNIQUE

Noise suppression can be realized in a gating circuit, The PD measurement circuit in the detector is inserted with a fast analogue or digital switching circuit S. The circuit is controlled by a triggering circuit that is activated whenever a noise is detected. The switch is kept open for a certain period, depending on the behavior of the noise and its oscillating nature. The PD measurement circuit is then temporarily blocked and no noise can enter the detecting circuit. After the noise passes, the switch is reclosed and is ready to measure the subsequent PDs. For noise from corona discharges and PD from outside of the generator, it usually last for 1-5s for high frequency band measurements (up to 10MHz)and 10-20s for lower frequency band measurements(up to 500kHz). In order to block noise from thyristorexcitors, the blocking window should be 20-100slong.

### 3.1 PARTIAL DISCHARGE DETECTOR

Based on the techniques above explained, a new partial discharge detector has been developed for insulation condition monitoring of generators. This detector uses advanced digital signal processing techniques and multiple noise gating channels for noise discrimination and blocking. With a specially designed dual CT sensor or capacitive coupler installed at the neutral of a generator, partial discharges of an in-service generator can be continuously monitored. Test results are recorded and analyzed by the computer software. After analysis, the discharge magnitude and various statistical distributions can be displayed on the screen or printed can also be saved in a database so that further analysis can be done to determine the trend of insulation deterioration. The measurement circuit connection is shown The detector has the following key features  Easy to use The signals are detected, analyzed and calculated by the computer-based measurement system. There is no need for expert explanation of test User-friendly interface: The window-based computer software has all functions in pull-down manual or push button format. On-line instructions and help are also available. Noise discrimination Using advanced sensors, noise gating channels and digital signal processing techniques, most interference such as the thyristor switching pulses and noise from the HV terminals can be identified and blocked. The HF and LF components of each PD are analyzed. From comparison between their peak voltages and time delays, discharges from different positions can be grouped and displayed in different forms for its identification.

### 3.2 PARTIAL DISCHARGE IS AN ELECTRICAL BREAKDOWN PHENOMENON

Partial Discharge (PD) [1] is an electrical breakdown phenomenon restricted to the localized region of the insulating system of a power apparatus. PD, which may consequently lead to deterioration of the insulation system due to chemical degradation of a power apparatus, occurs as internal discharges in cavities, voids, blow-holes, gaps at the interfaces etc., as external or gliding discharges on the surface imperfections, as corona discharges at sharp points and protrusions etc. Hence, it is of considerable practical relevance to researchers and operators handling utilities, to be able to distinguish the sources of PD, its geometry and location since such aspects are intimately related to the condition monitoring and diagnosis of the insulation system of the equipments.

## 4. CONCLUSION:

This paper explains the effects of Partial Discharge in High Voltage Power Capacitor Equipment and its detection methods. Various detectors are available for

PD measurements. Quality assurance require not only a detector, but an entire system coordinated to maximize the measurement sensitivity for the specific type of apparatus under test. To illustrate how a coordinated system is applied, examples of some systems in commercial use are discharge measurements on capacitor units are reported.

## 5. REFERENCES

1. G. C. Crichton, P. W. Karlsson and A. Pedersen, “Partial Discharges in Ellipsoidal and Spherical Voids”, IEEE Trans. on Dielectric and Electrical Insulation, Vol. 24, No. 2, , pp. 335-342, April 1989.
2. R. J. Van Brunt, “Physics and Chemistry of partial discharges and corona”, IEEE Transaction on dielectric and Electrical Insulation, Vol. 1, No. 5, pp. 761-784 October1994.
3. R. E. James, J. Austin and P. Marshall, ‘Application of a capacitive network winding representation to the location of partial discharges intransformers,’ Electrical Engineering Trans. I. E. Australia, pp. 95-103,1977.
4. R. E. James, B. T. Phung, Q. Su, 1989 ‘Application of digital filtering techniques to the determination of partial discharge location intransformers,’ IEEE Trans. Electrical Insulation, vol. 24, no. 4, August1989.
5. Guardado, J. L., Cornick, K. J., ‘A computer model for calculating steep fronted surge distribution in machine windings’, IEEE Trans. EnergyConversion, Vol. 4, No. 1, March., 2018.

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