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Estimation of HVDC Partial Discharge Incident Occurrences

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Abstract*:* Similar to AC system, the insulation system of DC system also gets affected. The HVDC station is a challenging environment for measurement of partial discharge level due to very high interference levels caused from the switching of thyristor-controlled converters. There is also significant interference from external air-corona due to high electric stress at the surface of conductors and hardware that exceeds the corona inception level. In this review, lets us look at the scenario of HVDC system getting affected by partial discharge with methods of measuring it.

Keywords: Discharges, corona interference, noise, Inception Voltage, Interferences, HVDC, Converter Transformers, UHF signals, HFCT.

I. INTRODUCTION

Partial discharge (PD) in electrical insulation is a phenomenon that results from localized electrical breakdown, or discharge, which occurs at defects within an insulation system to which electric stress is applied. The physical nature of a defect that may cause PD can include small internal voids within an insulating material, or tracking across the insulation surfaces [1]. Over time, sustained PD activity will degrade the insulation level of the system and can cause eventual failure. Therefore, the occurrence of PD in electrical insulation is an indication that the integrity of an insulating system is compromised or degraded.

Presently within industry, continuous PD measurement to installed high-voltage direct current (HVDC) equipment is rare. Some reasons for the rarity of their application are that HVDC stations are a particularly challenging environment for the performance of on-line PD measurement due to high levels of electromagnetic interference caused from thyristor valve switching in the HVDC conversion process.

There is also significant interference from external air-corona due to high electric stress at the surface of conductors and hardware that exceeds the corona inception level. The interfering corona can occur from either alternating voltage or direct voltage sources. Another reason that on-line measurement of PD on HVDC equipment is rarely performed is that the occurrence of PD under high direct voltage inherently has lower repetition rates than high alternating voltage. It has in the past been assumed that PD is less likely to pose a significant degradation factor for HVDC equipment [2].

II. PD DETECTION-IMPORTANCE

HVDC is the preferred choice for long-distance bulk energy transmission. Moreover, back-to-back HVDC systems enable to interconnect HVAC power system with different frequencies, reliability levels and regulation policies. This makes HVDC system security all the more important. The growing numbers of HVDC systems & inter-links raising concerns about the reliability of HVDC links. As they often interconnect large generation plants with populated areas and the loss of a bulk power transmission link could compromise the network stability, causing widespread load shedding and domino effects. Doubling the design voltages is bringing a pretty mature technology to face relatively-new problems. As an example, the design of converter transformers at these voltage levels, also considering the effect of corrosive sulphur and static electrification, is a concern in HVDC system design. Another example is the space charge effect in HVDC cable insulation, which can cause early failures. [4]

HVDC system has converter transformers as the important components of these systems. The insulation used in converter transformer is a combination of pressboard and oil, which is a multi-dielectric system. To reduce the bulk insulation volume, barriers (pressboard) are used to enhance withstand voltage capability and reduce the working space of insulation. A significant problem in this type of insulation structures is due to the partial discharges, which are initiated from defect sites present in it. The manufacturers diagnose the quality of insulation of the converter transformer by carrying out certain routine tests, type test before installation, which include AC voltage withstand test, DC voltage test, polarity reversal test, partial discharge (PD) test etc.

III. PD MEASUREMENT IN HVDC

The field distribution in DC devices is strongly influenced by the value of the electrical conductivity of the dielectric material used, whose value is highly dependent on temperature and electric field.

Moreover, in high voltage cables the main cause of breakdown is the partial discharge (PD) in the internal gaseous cavities inside the insulation. In fact, there are invariably a certain number of gaseous cavities within the dielectric material which spreads and grow according to the degree of aging of the cable. Therefore, it is important to measure the inception voltage, applied to the device without having partial discharges. [5]

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The greatest challenge of PD detection in HVDC systems is, undoubtedly, noise and disturbance rejection. As a matter of fact, spurious signals can prevent to record accurately PD sometimes characterized by extremely low repetition rates. The problem is usually alleviated by shielding the Equipment under Test (EUT). By ramping up the test voltage in steps, it is used as a tool to achieve larger repetition rates and emphasize PD activities. Moreover, during laboratory/offline ramped voltage tests, the field inside the insulation system is capacitively graded, whereas resistive grading, influenced by temperature gradients, occurs during normal operation. The largest source of electromagnetic interference in an HVDC station environment is due to the regular switching of the thyristor controlled HVDC converter. The measurement can acquired from an online PD measurement performed on the valve-windings of a converter power transformer.

It is well known that the signal detection system in any partial discharge measurement system needs to very sensitive to low magnitude signals. The switching noise produced creates a dilemma for the Partial Discharge online measurement system, as it gets a confused image of true PD and the PD signals intermixed with the noise created. The measurement instruments shows poor signal to noise ratio, and the repetitive nature of the interference created can certainly blind the measurement of partial discharge signals that are produced in the insulation system, which occur in response to the transient switching stress.

IV. MEASUREMENT OF PD UNDER HVDC STRESS

Presently, PD measurements for high voltage direct current (HVDC) applications are more a quality check. This is mainly because the harmfulness of the different PD (levels) is not as well known as for AC. The measuring circuit for the detection of PDs is the same for AC as for DC. Various researchers have adopted techniques to measure PD due to HVDC stress, as discussed below.

1. Digital PD measurement based on number of pulse counter

In most PD detection systems based on Number of pulse counter technique, all PDs are recorded with a time stamp, and the performed measurements are in accordance with IEC 60270 or other relevant standard. After a measurement is finished, analysis of the measured PDs will be performed. A precise calculation of the number of PDs per minute and its distributions is made. These distributions will help in finding its origin.

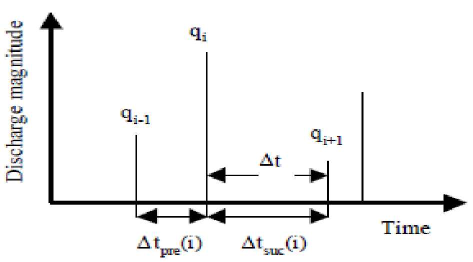

Figure 1 – PD signals due to HVDC stress [7]

For AC the discharge magnitude *q* and its phase position (*j*) are recorded. Since there is no phase position at DC voltages, the time of occurrence since the start of the measurement (*t*) is considered as phase position. The resolution of the time stamp can be set at around 5ms due to the low repetition rates of the PDs which occur at DC voltage. Each PD that is recorded will be stored in relevant memory of the testing device with its magnitude *q* and time *t*. As per IEC 61954 *Testing of thyristor valves for static VAR compensator, "In each of the four PD bands up to 1-10 PDs per minute are allowed"*. [7]

From the two measured quantities (q and t), derived quantities and distributions can be calculated. The most important derived quantity is the time between two consecutive discharges Δ*t*. It is the most important derived quantity because it is related to the discharge physics. After a PD has occurred, it takes a certain time until the voltage drop caused by the discharge has vanished and before another discharge can occur. Apart from *q* and *t*, the voltage across the test object is also required to be measured, which can be done using a separate voltage divider circuit. When changing the voltage during a test, the voltage dependency of the PDs can be observed. In a measurement process, the following records are needed to assess the PD discharge [7],

1. Highest PD measured between 2 screens (pC)
2. The discharge current (A)
3. The repetition rate (PDs/s)

2. PD measurement based on measuring UHF signals

In an attempt to properly figure out PD due to HVDC, methods based on UHF signal detection is widely studied by many researchers [4]. Studies on particle movement in transformer oil under AC and DC fields has been done and it's concluded that under DC voltages, conductive particles transport charge by contact with electrodes and observed the discharge current in the form of a fast rising current pulse and slowly increasing displacement current [8]. When partial discharge current pulses involves rise and fall times of a nanosecond or less, signals in the Ultra High Frequency (UHF) range (300-3000 MHz) are excited. On partial discharge monitoring in transformers using the UHF technique, sensors, signal interpretation and the applicability of the technique in a practical situation can be found in [9].

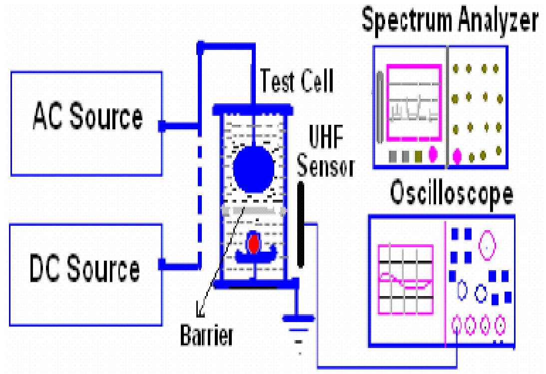

Figure 2- PD measurement setup based on UHF signal detection [4]

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The setup used for the measurement of UHF signal generated by partial discharges due to particle movement in the transformer oil, under the ac and dc voltages is shown in Figure 2. It is sectioned as high voltage source, the oil test cell, and the UHF sensor connected to oscilloscope. [4] The UHF sensors used for partial discharge detection must have broadband response, since the frequency content of signals from a PD varies depending on its location and the signal path. The output of the UHF sensor connected to the high bandwidth digital storage oscilloscope. The spectrum analyzer was used in full span mode and in zero span modes.

UHF signals generated by partial discharges formed due to the movement of the particle in oil electrode gap under DC voltages. The rise time and duration of UHF signal generated due to partial discharge formed by particle movement under AC and DC voltages is 2 and 5ns respectively, at the point of levitation voltage. The UHF signal attain to its maximum peak amplitude (in positive or negative half cycle), once it crosses 10% of its highest peak magnitude. This 10% is a threshold of the signal. The duration of the UHF signal is defined as the time from the point of crossing the threshold level of 10% of highest peak amplitude of the rising signal till the magnitude falls below threshold value.

3. PD measurement using High Frequency Current transformer

Partial discharges are sensed through a high frequency current transformer (HFTC) clamped around the ground connection of the test objects. The test object, HV supply, sensor and PD detector could be all segregated within a metal cabinet to minimize noise and disturbance from other PD sources. The test cabinet is set at a temperature of 25 °C with a relative humidity level in the range of 40-50%.

The PD signals are recorded using an Ultra-Wide Band (50 MHz) detector able to digitize pulses at a sampling rate of 200 MSa/s. The system is endowed with real-time signal processing capabilities able to evaluate in real time the equivalent time length (*T*) and bandwidth (*F*) of the incoming pulses.[2]

As the pulses coming from the same PD (or noise/disturbance) source should display similar characteristics, generally different from those due to other sources. By grouping, the pulses relevant to a specific source may be analyzed by statistical techniques to identify whether they originate from noise, disturbances or PD sources and, in the latter case, identifying the nature of the source.

4. Online PD Monitoring Method

For the measurement of PDs online, a wideband PD measurement device is used that utilizes a signal-processing technique to extract the various PD features. These methods allow for the isolation of interference in measurements and the separation of multiple PD phenomena. It is shown through isolation of phenomena that the ability to trend and perform condition assessment of the insulation system is enabled. Digital signal processing technologies have produced some modern PD measurement instruments with noise separation. These instruments use the so-called feature extraction methods to distinguish and separate multiple PD phenomena from noise, based on characteristics about the shapes of the pulse waveforms captured through measurement.

A popular feature extraction algorithm for online PD measurements is known as the method of Moments Algorithm. The algorithm captures information about the shape of individual PD pulses to allow for isolation of phenomena in online PD measurements. Because discharges occurring within the insulation system are likely to have differences in waveform shape, the algorithm provides an efficient method for separating discharge phenomena in a measurement. This improves the ability to analyze the measurement. For example, switching noise from the HVDC converter could be separated from PDs which occur in response to the transient voltage stress. The method produces clusters of PD pulse data plotted in a two-dimensional time-frequency classification map.

For proper monitoring of device, PD trending and comparison of PD data acquired over time is necessary. The magnitude of a PD pulse, acquired from a single measurement may be attenuated in propagation through the device before reaching the sensors.[10] Therefore, pulse magnitude is not adequate enough to quantify the severity of the discharge activity. For proper assessment, monitoring for changes in the magnitudes and repetition rate of a discharge phenomenon must be observed over time. If the magnitudes and repetition rate of the discharge activity are increased significantly over time, only then can it be assessed that the insulation has been degraded to a point that it becomes a greater risk for failure.

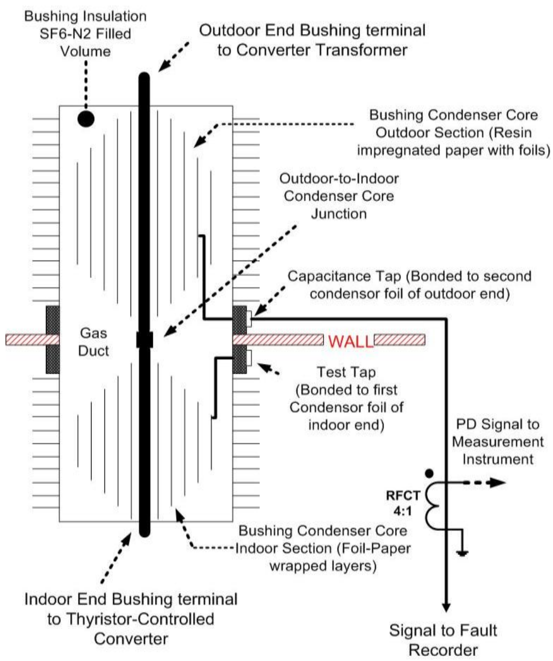

Figure 3 - HVDC wall-bushing online PD measurement[3]

The nature of the defect must be identifiable in order to have value for the condition assessment of the equipment. Without identification, the severity of the risk for failure cannot be established and thus there is no contribution to planning corrective maintenance. [3]

V. CONCLUSION

A thorough study of the PD levels due to HVDC stress is possible only with the development of better and sensitive PD measurement devices which can tell the extent of damage that is done to the insulator or device at a whole. Avoiding the interference noise signal is the most important challenge for any measuring method used for PD testing. When the applied electric field is enhanced, random movement of the particles causes irregular discharges of varying magnitude with reduction in number of discharges. Methods based on UHF noise sensor, HF CTs, Signal Processing Algorithms are an innovative step in devising circuits sensitive enough to detect PD signals in HVDC environment. For insulation under mixed voltage stresses, associated with the HVDC conversion process, interpretation and identification are more difficult.

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