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SENSITIVITY ASSESSMENT FOR PARTIAL DISCHARGE MEASUREMENTS ON SOLID DIELECTRIC TRANSMISSION CABLES

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ABSTRACT

Over the last decade, partial discharge testing has gained acceptance as a valid diagnostic tool for condition assessment of cable insulation. As a result, PD testing has become the corner stone of most asset management programs. However, the results obtained from a partial discharge test depend not only on the conditions under which the test was performed but also on the test equipment it self including the type of sensor used and its location. The issues related to attenuation and dispersion of partial discharge pulses is well known. For testing long lengths of cable, performing a terminal measurement is often not possible. Still, such tests are performed on long lengths of transmission class cable with claims that sensitivities of down to 5pC can be achieved. This paper provides a brief review of partial discharge detection, signal propagation and discusses so called calibration procedures. As well, this paper also presents a framework for a model providing a meaningful sensitivity assessment prior to performing a partial discharge test. Data acquired on different classes of transmission class circuits is presented.

KEYWORDS

Partial Discharges, Pulse Propagation, Calibration, Sensitivity Assessment.

INTRODUCTION

Partial discharges occur in the bulk of high voltage insulation materials where local electrical field conditions are sufficiently high to sustain PD activity. In the case of extruded cables (EPR or XLPE cables) partial discharges typically occur in cavities at the conductor shield, cavities in the insulation due to shrinkage or gas-formation, near defects in the insulation shield, near loosely bound solid particles in the insulation, at protrusions, at splinters or fibers or near contaminants in the insulation shield. In cable joints or terminations, partial discharges typically occur along dielectric interfaces, along stress interfaces, in cavities near the conductor or insulation shield due to, for instance, misalignment during installation or thermal movement as a result of normal operation. Finally, partial discharges may also occur within the cable insulation itself around mechanically degraded spots and or impurities resulting in the formation of electrical trees.

Partial discharges are a high frequency phenomenon. Fundamentally, whenever a partial discharge occurs internal to a cable section or a cable joint, high frequency currents are induced in both the cable core and the cable shield. The magnitude of a measured partial discharge signal depends partly on the magnitude of the partial discharge current itself, i.e. the higher the actual partial discharge current the higher the induced currents, and partly on the radial proximity of the partial discharge location relative to the cable conductor, i.e. the closer to the cable conductor, the higher the induced current on the conductor [2, 3]. The specific relationship between the induced partial discharge current and the actual discharge current it self may be evaluated by the λ- function [2, 3]. The frequency of the induced partial discharge current is similar to the frequency of the actual partial discharge current itself. The frequency of the partial discharge current itself depends on path and velocity of the partial discharge (avalanche) itself. Consequently, the frequency depends primarily on (1) the strength of the electrical field (the higher the strength of the electrical field the higher the velocity of the avalanche itself, the faster the rise time of the PD current and the higher the frequency of the PD current) and (2) the size of the void relative to the direction of the electrical field (the longer the void, the longer the duration of the PD pulse, the longer the rise time of the PD current and the lower the frequency of the PD current).

In addition, as the induced PD currents propagate through the cable towards the cable ends, they are subjected to attenuation and dispersion. In other words, the magnitude and main frequency component of the currents decrease with increasing travel length. The further an induced PD current travels before being detected, the lower the magnitude and the lower the frequency content.

It can thus be intuitively seen that for shorter cable runs induced currents as a result of partial discharge activity may be readily detected via a terminal measurement, i.e. via a capacitive or inductive sensors connected to the conductor or shield at the end of a cable. For longer cable runs, dispersion and attenuation will prevent the measurement of inducted currents related to PD activity occurring from the opposite cable and thus a distributed PD measurement must be performed. A distributed PD measurement refers to the scenario where sensors are connected to joints and splices throughout the length of the cable.

A key step to assess when a terminal PD measurement is sufficient and when a distributed PD measurements is required. To assess this, a meaningful sensitivity assessment must be performed.

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REQUIREMENTS FOR A PD SENSITIVITY ASSESSMENT

In order to discuss and identify requirements for a meaningful sensitivity assessment, the relationship between measured partial discharge current and actual discharge current must be further discussed. From the condensed description in the previous section, the relationship between the actual partial discharge and the measured current can be described as sketched in Figure 1.

As can be seen, the attenuation and dispersion of induced high frequency PD currents traveling along the cable conductor or shield may be evaluated by the transfer function of the cable itself $H_{cable}(s)$. It should be noted that determining the transfer function of a cable in a non trivial matter as, for terminal PD measurements, the transfer function contains a length factor and, thus, the transfer function for the cable may be mathematically described as multiplier of individual transfer functions of individual cable section and joints. The transfer function for each PD pulse would depend on where, axially, the PD pulses originated in the cable system relative to the position of the PD sensor.

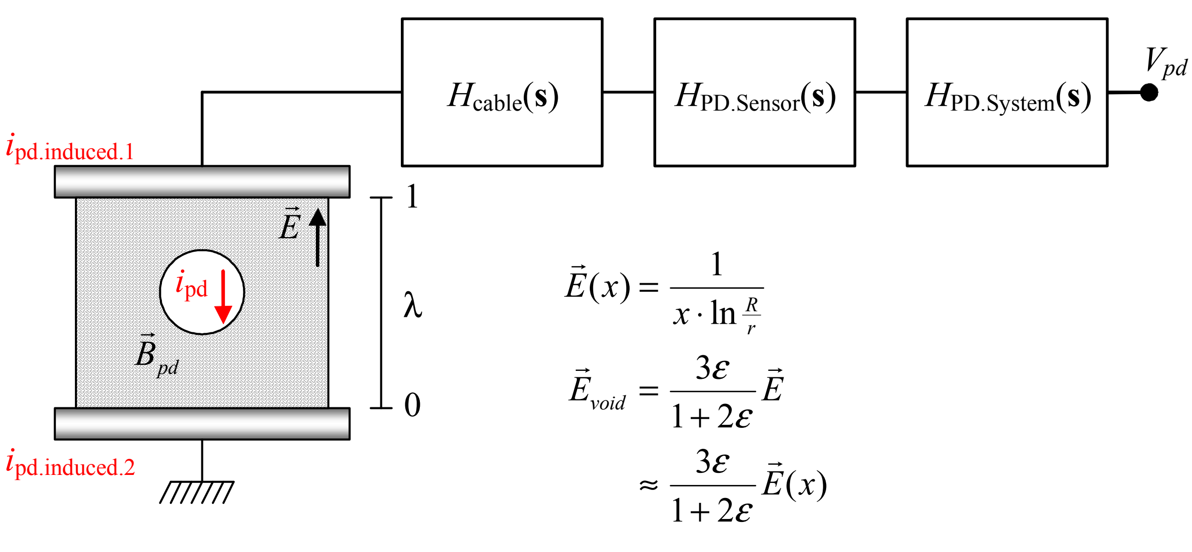
The coupling of the induced PD current as measured by a capacitive sensor or inductive sensor can be described by the transfer function of the sensor itself, $H_{PD.Sensor}(s)$. Finally, for completeness, the transfer function of the PD instrument, $H_{PD.System}(s)$ itself should be considered.

It should be noted that, as discussed in the previous section, the frequency of the induced partial discharge as measured at the sensor location will depend on (a) the nature of the partial discharge source itself and (b) its proximity to the partial discharge coupler. Consequently, when performing PD measurements in the field, the PD sensor itself should be should be able to detect pulses across a wide band of frequencies. A similar requirement is thus imposed on the measurement system itself. Consequently, a meaningful PD sensitivity assessment does not rely on narrow band-pass measurements to increase the signal-to-noise ratio

However, from Figure 1, it can be readily be seen that even if $H_{cable}(s)$, $H_{PD.Sensor}(s)$ and $H_{PD.System}(s)$ were analytically known, any direct correlation between measured partial discharge charge (pC) and the actual PD charge cannot be established since the location radially with reference to the measuring electrode (conductor or shield) for a given partial discharge is unknown. Thus, it can be argued that a meaningful sensitivity assessment does not attempt to correlate discharge pulses measured in mV or mA to charge associated with the partial discharge current itself.

Furthermore, from Figure 1, it can also be seen that for a PD sensitivity assessment to be meaningful, pulses reminiscent of partial discharge pulses should be injected, i.e. the pulses injected for the sensitivity assessment should have rise times and magnitudes similar to the currents induced by typically partial discharge pulses. Numerous laboratory experiments performed on needle-plane insulation systems - where the attenuation and dispersion (H_{cable}) is negligible - has shown the rise time of partial discharge pulses to range between 500 ps and up to tens of nano-seconds with measured PD magnitudes ranging from sub-mV to hundreds of mV [7, 8].

Lastly, due to fact that rarely is a partial discharge source



$$\vec{E}(x) = \frac{1}{x \cdot \ln \frac{R}{r}}$$

$$\vec{E}_{void} = \frac{3\varepsilon}{1+2\varepsilon}\vec{E} \approx \frac{3\varepsilon}{1+2\varepsilon}\vec{E}(x)$$

$\Rightarrow i_{pd}$ (and thus pC) to mV cannot be assessed due to primarily lack of knowledge on void location and void geometry

Figure 1: Relationship between actual PD current, induced current anad measured current.

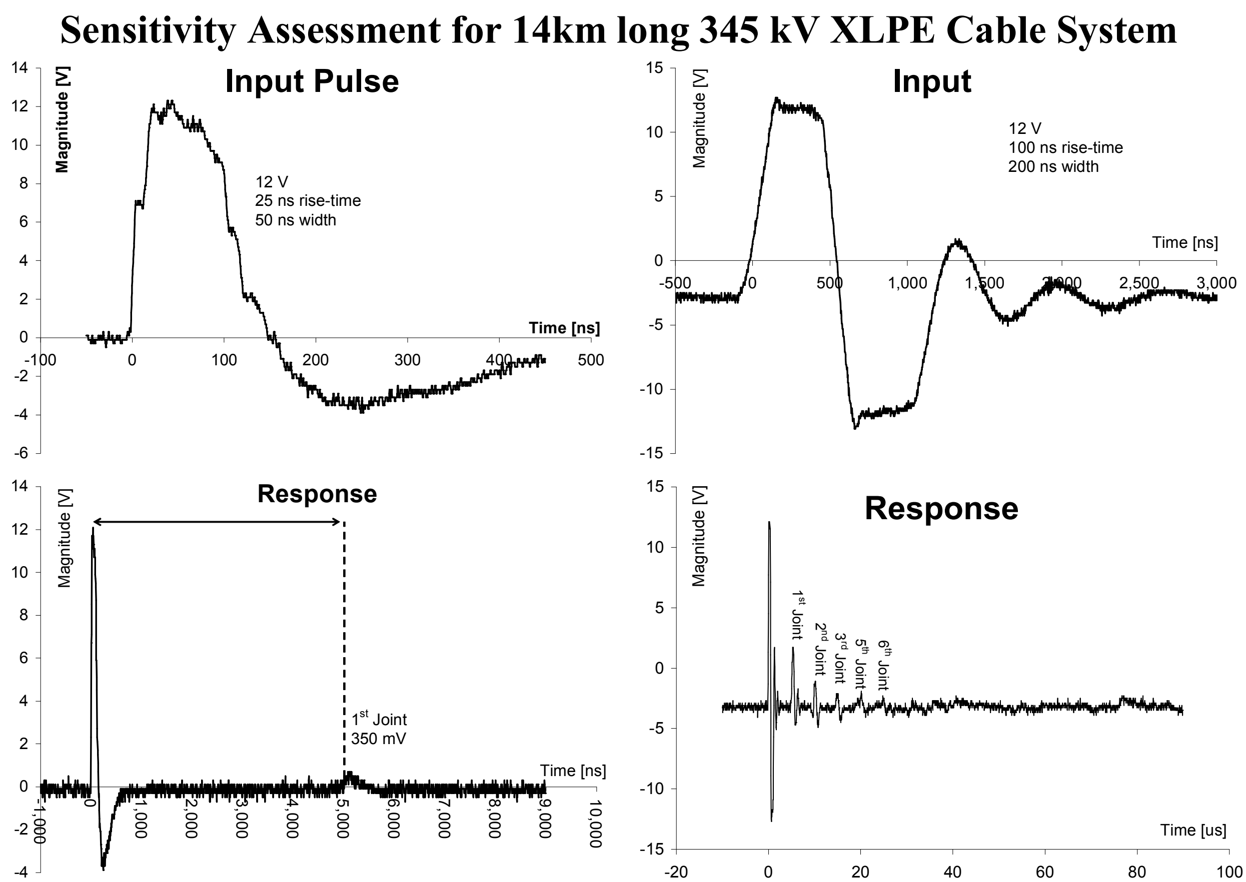


Figure 2: Sensitivity Assessment for 345 kV XLPE Cable System

giving rise to sustainable repetitive PD pulses, a sensitivity assessment should not rely on averaging to increase the signal to noise ratio.

SENSITIVITY MEASUREMENTS

Following the criteria developed in the pervious section, sensitivity assessments have been performed on a number of transmission class XLPE cable circuits. The shortest cable was rated 138 kV and approximately 3.8 km long with 4 joints whereas the longest was rated 345 kV and approximately 14 km long with 25 joints. The closest joint was 274 m away from the termination (injection point).

Using an HP8012B pulse generator pulses of varying magnitude, rise-time and pulse width were injected onto the current carrying conductor of the cable system under test. The pulse generator was internally terminated into 50Ω. A digital THS730A 1GS 200 MHz Tektronix oscilloscope was connected in series between the pulse generator and the cable conductor. The duty cycle of the pulse generator was set such that any reflections from the cable opposite end of the cable would arrive at the injection side before a new pulse was injected into the system. The trigger output of the pulse generator was connected Channel 2 of the scope thus providing an external trigger.

In some cases, the grounding system of the cable was in its in-service configuration whereas in other cases, a continuous ground path had been provided by short-circuiting any Sheath Voltage Limiters.

In all cases, when injecting pulses reminiscent of partial discharge pulses, i.e magnitudes of 250 mV and rise-times of 25 ns no reflections from the first joint were clearly detected.

An example of pulse injections performed on a 14 km 345 kV XLPE cable circuit is provided in Figure 2. The cable consists of 25 joints and two terminations. When injecting pulses characteristic of PD pulses, no reflections from the first joint could be detected. The pulse magnitude had to be raised to 12 V (with 25 ns rise time) for a reflection from the first joint to be detected. Note that reflections from the subsequent joints were not detected. Also note, as expected, when increasing the rise-time and pulse width, reflections from up to the 7th joint could be detected. Even in this case, reflections from joints beyond joint no 7 could not be detected.

The sensitivity measurements performed here suggest that for transmission class cables, a distributed partial discharge measurements should be performed to ensure adequate sensitivity. That is, sensors should be placed at each joint and partial discharge measurements should consequently be performed at each joint location.

CONCLUSIONS

A framework for providing a meaningful sensitivity assessment for partial discharge measurements performed on transmission class cable circuits were discussed. The framework is based on the field macroscopic model for detection of partial discharge pulses. The framework suggests that meaningful sensitivity assessment…

1. Does not attempt to correlate discharge pulses measured in mV or mA to charge associated with the partial discharge current itself.
2. Does not rely on averaging to increase the signal-to-noise ratio.
3. Does not rely on narrow band-pass measurements to increase the signal-to-noise ratio.
4. Does inject pulses that have rise times and magnitudes similar to the currents induced by typically partial discharge pulses.

When using the criteria above, measurements on transmission class cables ranging from 3.8 km to 14 km in length, no reflections were detected from the first joint from the termination. This suggests that for transmission class cables, in order to perform a reliable partial discharge test, a distributed measurement should be performed. In other words, partial discharge sensors should be placed at each joint and partial discharge data should following be obtained at each measurement location.

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