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Practical aspects of the detection and location of partial discharges in power cables

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Abstract:

For enhancement of the reliable operation of power cables network preventive PD diagnosis tests are increasingly performed. In order to assess the insulation condition on the basis of the obtained data, fundamental knowledge on the PD occurrence is required. The Brochure No 297 deals with both, theoretical analysis and experimental studies on the wave propagation of PD pulses in power cables. Furthermore, practical aspects of the detection and location of PD faults are discussed.

Introduction

The conventional PD measuring method specified in the relevant IEC standards [1; 2] has well been proven under laboratory condition. Presently, this technique is increasingly used under on-site condition, in particular for PD testing of installed power cables [3]. One issue of the brochure is to develop an approach which can simply be handled for assessing the sensitivity, which can be achieved for the detection and location of PD defects in long power cables under on-site condition [4]. Furthermore, the PD occurrence is discussed from a practical point of view, such as the impact of the superposition of PD pulses as well as the different wave propagation velocities in mixed cable sections on the location uncertainty [5]. For better understanding first some fundamentals of the very complex PD occurrence in power cables will be presented.

PD occurrence in power cables

As known from the literature, partial discharges (PD) are caused by insulation imperfections and bridge only a part of the insulation between the electrodes [6, 7]. The occurrence of internal discharges, which may appear in gas-filled voids, cavities and cracks, is usually explained by the a-b-c model, where the test object is substituted by a lumped capacitor. In geometrically extended test • • •

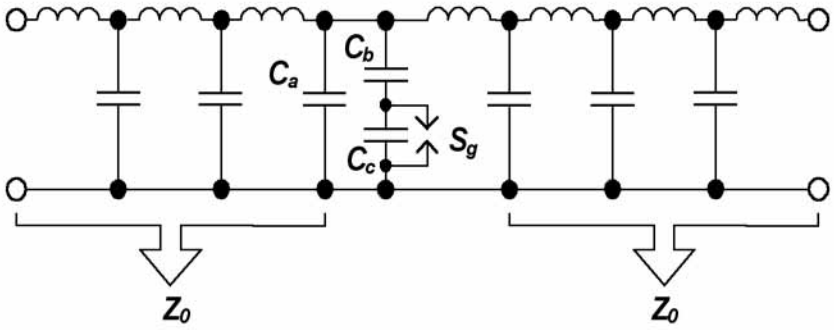
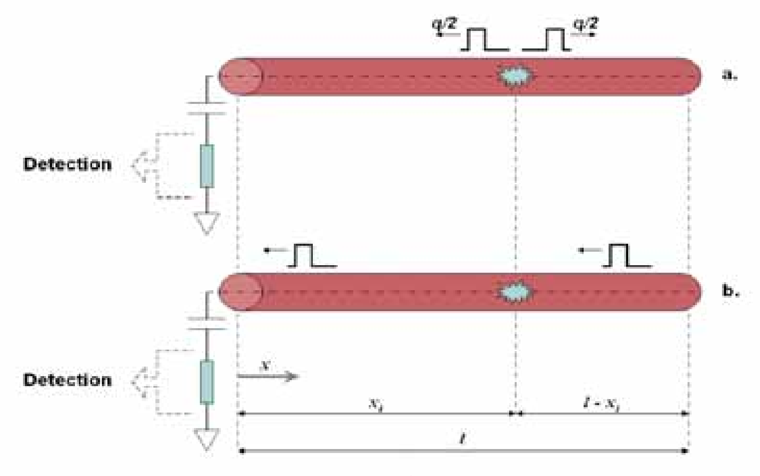


Fig. 1: Equivalent circuit for PD defects in power cables



a) just after PD ignition, both pulses travel in the opposite direction

b) after reflection at the "remote end", both pulses travel in the same direction

Fig. 2: Principle of PD pulse propagation in power cables

objects, such as power cables, power transformers and rotating machines, the PD pulses propagate like traveling waves. Under this condition the classical a-b-c approach has to be modified accordingly, as evident from Fig. 1. Here the insulation defect is also represented by the capacitor C_c connected in series with C_b which represents the remaining healthy insulation, but the lumped capacitor must be substituted by the characteristic impedance Z_0. If the resulting voltage across C_c becomes higher than the breakdown voltage of the defect, i.e. a puncture of the parallel connected spark gap S_g occurs, a current pulse of extremely short duration, usually in the ns-range, is ignited. For such short pulses long power cables behaves like a traveling wave guide and can therefore not be treated as a lumped capacitor C_a, but by the characteristic impedance Z_0, as mentioned previously. Due to the symmetrical configuration of power cables each PD event produces two equal current pulses, i.e. the pulse charge magnitude $q / 2$ travels away from the PD source in both directions, as schematically reflected in Fig. 2.

At the "remote end" of the cable section, which is generally open during the PD measurement, a full reflection occurs. Therefore at the "near end" of the cable, where the PD coupling unit is connected, not only the direct pulse but also the reflected pulse can be detected.

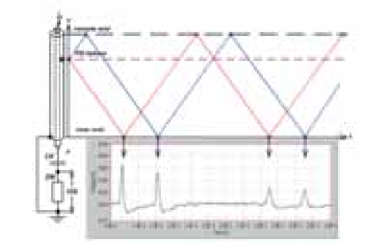


Fig. 3: Principle of the PD fault location using the time domain reflectometry, cable length 1705 m, PD failure site from near end 1297 m

This occurrence is used for location of the PD site using the time domain reflectometry (TDR), as known from the relevant literature, as for instance [3; 4; 5; 7; 8; 9] and schematically shown in Fig. 3.

Attenuation of PD pulses traveling through power cables

For assessment the attenuation of the magnitude of propagating PD pulses experimental studies were performed on power cables of current production.

After injecting artificial PD pulses by means of a PD calibrator the pulse response was recorded by a digital scope. Because both, the output impedance of the calibrator and the input impedances of the digital scope, were several orders above the characteristic impedance of the power cables under investigation, the near and remote cable end could be considered as "open". Consequently, subsequent pulse sequences appeared at the measuring site, due to multiple pulse reflections at both cable ends. Consequently, experimental results could be obtained for virtual cable lengths much longer than the investigated geometrical cable length. Based on these experiments the PD detection sensitivity versus the propagation distance could be approximated by a simple formula for power cable lengths up to about 10 km, as exemplarily reflected in Fig. 4.

Practical aspects of PD fault location

If a PD source is active in a power cable line, the occurring pulses will travel away from the PD ● ● ●

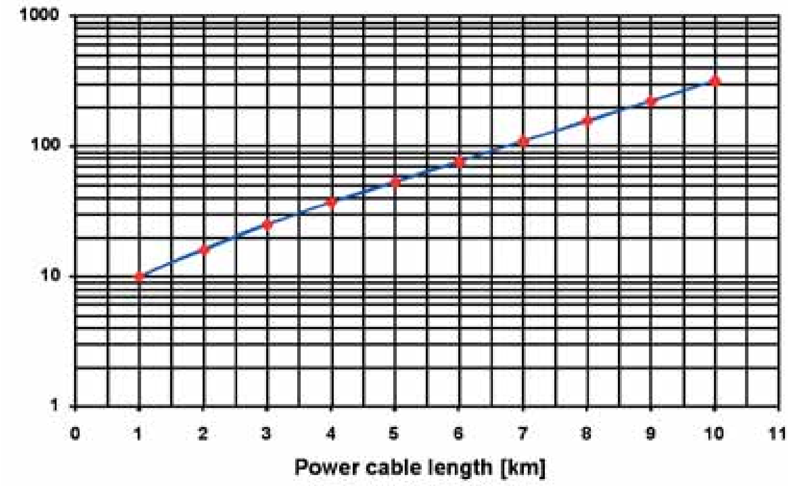


Fig. 4: PD detection sensitivity versus the cable length calculated on the basis of a reference value 10 pC for a cable length of 1 km

source towards both cable ends, as already reported in figures 2 and 3. For location of PD defects generally the time domain reflectometry (TDR) is used. Fig. 5 shows an example obtained for a 610 m PILC section. The indicated PD events *Y* and *Z* are originated from the same defect, because the time differences Dt_Y and Dt_Z between the direct and the reflected pulse are equal. In general the overlapping pulse diagrams for different PD events are dependent on the following three factors:

1. Number of PD defects
2. Length of the power cable
3. Frequency of the test voltage

If the number of defects in a cable sample increases, the number of PD events will naturally increase. The time interval, where the matching PD pulse may occur, is proportional to the length of the cable sample. Thus the probability for overlapping reflectograms will increase for longer power cables. Furthermore, an increased test frequency means a higher *dU/dt*. Consequently the time difference between succeeding PD events may be shortened.

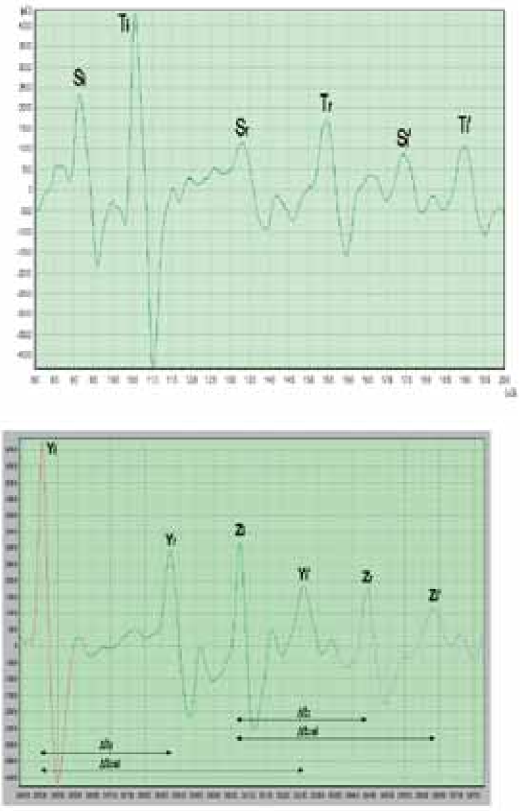


Fig. 5: Examples for PD location diagrams with overlapping PD pulses from different PD sources (a) and from the same PD source (b)

During HV energizing of a cable section in the field, multiple PD sources can also become active simultaneously. As a result, in just a small time interval, multiple PD pulses can be detected from different locations along the cable length. Due to changes from impregnated paper insulation to plastic insulation for power cables, more and more situations will occur where different insulation types are mixed in cable networks. Because of the different propagation velocities for the different insulation types, errors and misinterpretations may occur in the PD fault location, as reflected in Fig. 6.

Results

Based on theoretical analysis and experimental studies of the PD occurrence in long power cables the following conclusions can be drawn:

1. For assessment the attenuation of PD pulses in principle the classical traveling wave theory based on the electric line model is applicable.

2. Because for the measurement and location of partial discharges in power cables generally a frequency spectrum below 10 MHz is of interest, the radial semicon loss model proposed in the relevant literature can essentially be simplified.

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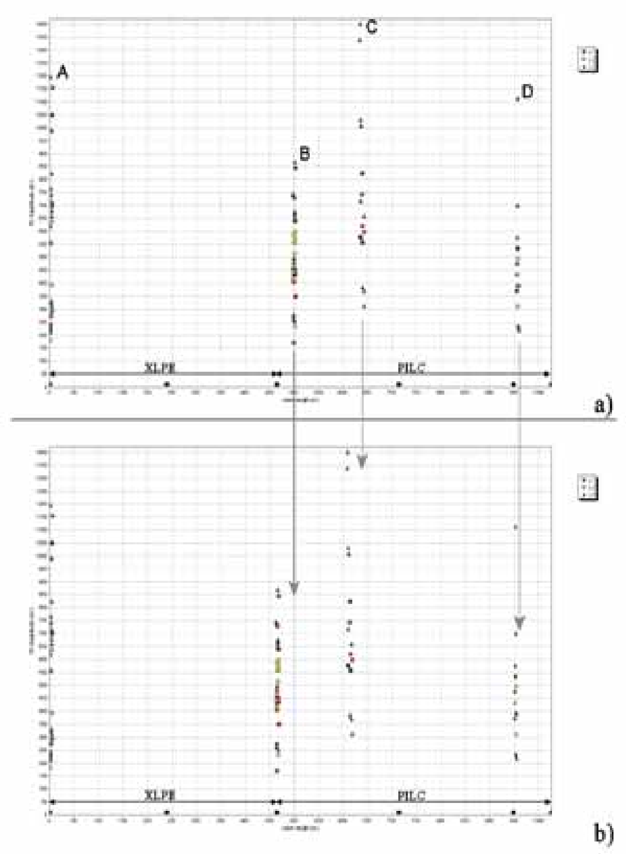

Fig.6 : Practical example for errors in PD mapping of mixed power cables (XLPE + PILC) using conventional single cable location technique (a) and modified location technique (b)

3. The theoretical analysis can further be simplified if the calculation refers only to the inner semicon layer, whereas the impact of the outer semicon layer is taken into account by a correction factor, which ensures a comparatively simple estimation of the frequency dependent attenuation and dispersion.

4. It is supposed, that the excessive reduction of the traveling wave velocity below the theoretically expected value is caused by a fictive enhancement of the capacitance per unit length due to a fictive reduction of the insulation thickness by the inner and outer semicon layer.

5. The simplified approach has successfully been proven for quantitative assessment of the wave attenuation in the frequency domain. For evaluation of the PD detection sensitivity, however, the analysis must be done in the time domain. In order to get the necessary parameters practical studies on the PD wave propagation in long power cables have been performed.

6. Using an instrumentation of comparatively high input impedance the injected pulses were fully reflected at both, the near and the far end. Thus results could be obtained for virtual cable lengths much longer than the investigated geometrical cable lengths.

7. Based on experimental data an empirical approach was derived which allows a simple estimation of the attenuation PD pulses versus the traveling distance and thus an assessment of the PD detection sensitivity, which can be expected for very long power cables.

8. If on-site PD tests of power cables are executed, besides the attenuation also superposition phenomena of the direct and reflected pulses have to be taken into consideration. This may happen if the PD site is close to the far end as well as if multiple PD sources, distributed along the cable length, ignite simultaneously.

9. The uncertainty in PD location may be enhanced for mixed cable sections because of the different wave propagation velocities in different cable types, such as XLPE and PILC.

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