ADVANCED SOLUTION FOR ON-SITE DIAGNOSIS OF DISTRIBUTION POWER CABLES

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ABSTRACT
This paper describes important aspects of partial discharge (PD) diagnostics of distribution power cables. PD parameter were discussed under consideration of attenuation and dispersive effects of cable characteristics. Field experiences with PD diagnosis on paper insulated cables (PILC) and cables with cross linked polyethylene insulation (XLPE) by energizing with Damped AC Voltage demonstrate relevant demands and the effective outcome for asset management decision support. The main difficulty is to evaluate the risk of PD occurrences on the reliability of the cable system.

INTRODUCTION
The importance of high reliability of distribution cables increases in times of higher competition between utilities and due regulator requirements. Customer’s time lost has to be monitored and the asset management departments are requesting clear indication about the condition of medium voltage (MV) cables and their accessories. It is known, that the insulation failures in a cable network may be caused by lower dielectric strength due to aging processes and by internal defects in the components of the cable systems. A huge amount of failures in distribution cables is related to defects which show as typical symptom partial discharges. These defects are mainly located in the accessories. From several failure statistics it can be stated that more and more insulation failures in old paper insulated cables reduces the reliability in distribution networks. Off line PD diagnosis by temporarily energizing the cable system with damped alternating voltage (DAC) provides enough information to assess the condition of the insulating system and support asset management decisions for necessary repair or replacement activities.

ATTENUATION AND DISPERSION OF PD PULSES
To assess PD occurrences in cable systems the physics of PD defects in XLPE and PILC cable systems must be understood.
In cable systems basically, three parameters are important for the judgment of the PD activities.

(1) PD Inception Voltage $U_i$
(2) PD Extinction Voltage $U_e$
(3) PD Level at $U_o$

During propagation through the cable, the PD Pulses are changed in their frequency spectrum due to the low pass characteristics of the cable system. This means, that the high frequency portion of the PD-pulse is strongly attenuated.
This results in a reduction of the amplitude of the pulses. With longer distances the pulses are highly dispersed, meaning, they contain only the low frequency parts of the original pulse. This is influenced by the type and length of cable, mixed cable systems and the type and number of joints in the system. In distribution networks it could be found very different construction of cable circuits, e.g. cable systems with a huge length up to 10 km and longer, mixed cable systems with transition joints PILC / XLPE, sometimes close to new installed switchgear and also short cable links in substations.

Resulting from this situation a modern PD-diagnostic system should be able to accomplish the following requirements:
- detection and localization of high dispersed PD signals on long cable systems
- high resolution for locating PD occurrences from PD failures which are located close to cable terminations

Figure 1 show the modeled effect of attenuation and dispersion of PD pulses propagated several distances in a cable system.

![Figure 1. Modeled propagated PDs](image-url)
cables the measuring system should be therefore adapted to lower bandwidth. The available amplification range can be than used effectively to detect PD signals which are very attenuated and dispersed.

3 IMPROVED DAC TECHNOLOGY

To generate damped ac voltages with duration of a few tens of cycles of ac voltage at frequencies between 50Hz and 500Hz a system has been developed [1;2] and is world-wide in practical use for more than eight years. This method Oscillating Wave Test System is used to energize, measure and locate on-site partial discharges in power cables in accordance with IEC 60270 recommendations. Due to the resonance principle the PD test is performed by exiting the cable with a voltage shape close to service voltage. The short duration of the exiting voltage is non-destructive which is also very important.

The experience of 8 years field application lead to some improvements in the new generation of DAC technology (Figure 2).

Besides the hardware optimization for a complete integrated system with light weight and small size, a new technology for automatically adjustment of the bandwidth of the PD measurement circuit for optimized signal detection and PD fault location was developed.

The PD measuring impedance is designed with a bandwidth selection circuit, which could be operated automatically or manually. In Figure 3 the significant difference between high and lower bandwidth selection is to be seen. The example shows calibration traces on an EPR-cable with high attenuation.

The end reflection in case of low bandwidth selection (Figure 3a) is much better to recognize than in high bandwidth setting (Figure 3b). The same is to be expected in case of PD fault location on longer cables or cable types with higher attenuation like PILC and mixed cables.

On the other hand the high bandwidth setting is very useful in case of shorter cable length and PD failures close to the remote termination. Due to the possible bandwidth setting up to 40 MHz the high resolution allow also to locate PD occurrences in a few meter distance to the far end termination (Figure 4 and 5). In the time domain trace (Figure 4) the direct received pulse and its shortly ensuing reflection from the open cable end are clearly separated.

Figure 3. Influence of bandwidth setting on cables with high attenuation; a) 3 MHz; b) 25 MHz

Figure 4. TDR trace of PD fault located 15 m to far cable end.

Figure 5. Mapping with PD concentration in a joint located 15 m before the far cable end.
4 ASSESSMENT OF PD DEFECTS IN CABLES AND ACCESSORIES

It is obvious, that continuous PD activities at operating voltage causes degradation and deterioration of insulating materials and field stress components in the cable insulation and accessories [1 to 3]. Most of the PD occurrences in XLPE cables are related to accessories due to bad workmanship. The variety of such defects is really wide. In the XLPE insulation itself normally no PD should be present because XLPE is a homogenous material and the cable well routine tested at the manufacturer site. Paper insulated MV cables were originally not designed to be complete free of partial discharges. In PILC PD activities can vary because of temperature variation due to load cycles and mass migration. The laminated insulation and oil filled accessories can withstand PD activities over a long time, often more than 40 to 50 years.

To evaluate seriously the results of PD measurements knowledge about the test object is required. Type of cable insulation, length of cable sections, position and the information about type of joints are necessary to assess the severity of the defects on bases of PD parameter PDIV, PDEV and PD levels at voltages up to 1,7 Uo.

From more than 8 years field experience of on site PD measurements at DAC excitation it is known that severe PD defects in oil filled cables (PILC) and accessories of XLPE cables are in a range of some hundred or thousand of pC. Therefore typical ground noise level on site up to 100 pC does not affect the assessment of PD test results.

For evaluation of PD occurrences in cable systems the PD sources must be localized in the mapping and detailed information about the locations of joints and type of accessory is required.

The severity of a PD defect depends strongly from the nature of defect, which can be only recognized by a visual inspection of the defect. Often PD on site diagnosis is triggered from breakdowns in a certain type of joint or termination to investigate the condition of the remaining population of same type of accessory. If typical PD pattern can be related to the specific type of mounting mistake, assessed by the visual inspection and the time to breakdown from failure statistics is known, a severity estimation of the specific defects can be made.

Taking all to described topics into account the following procedure is recommended to assess PD on-site-measurements (Figure 6).

4.1 PD in Polymeric Cable and Accessories

It is quite known that a polymeric material will degrade rapidly under continuous exposure of PD. Although show several materials a higher resistiveness against degradation, carbonization and tracking.

As already mentioned the nature of mounting mistake has a huge influence on the characteristic of PD and time to failure. From extensive field experiences the following correlation between typical PD pattern and pd level at Uo, nature of defect and mean time to failure are derived.

Due to insufficient warming the insulation tube of heat shrink joints or wrong sizes of the conductor connector voids or gaps between the field stress sleeve and insulation sleeve are created (Figure 7.)

In such cases a typical pd pattern with PD pulses over a certain number of cycles at DAC excitation is to be found (Figure 8.).

Although those faults can have PD levels up to 10 nC at nominal voltage the time to complete breakdown through the joint insulation is in a range of 5 to 6 years!

If the mounting mistake causes a bridging between high and ground potential at the interface layer underneath the field stress sleeve (Figure 8.), a different pattern will be observed. The discharges are occurring along the interface layer and came up with a high number of pulses per cycle and a phase angle which is characteristic for sliding discharges – starting at the zero crossing of the voltage (Figure 9.).
The severity of such kind of interfacial failure is extremely high, already at low PD levels in a range of some 100 pC. The time until a complete flashover along the interface layer and the service interruption occur is in a range of 3 to 6 months of operation only.

Similar “Void type” and “Sliding discharge type” pattern have been observed in accessories with cold shrink or slip-on technology. Mostly mistakes were made with wrong positioning of the joint body and bad preparation during cut back the outer semicon layer. Generally is the durability against degradation caused by PD activities in those accessories lower. Cavity discharges in a range up to 1000 pC will lead to failure within 2 to 4 years.

Interfacial PD must be judged with similar severity as in heat shrink accessories.

4.2 PD in PILC and Oil filled Accessories

The presence of PD at nominal voltage in PILC is not necessarily a dangerous situation [2]. So far the PD occurrences are scattered and not locally concentrated in a certain area of the cable insulation, the self-healing effect by mass migration prevents a serious degradation. The DAC excitation creates again typical pd pattern, which are related to a specific nature of the pd fault situation [3].

Typical pattern from PD in a oil filled joint or termination (Figure 10) can clearly distinguished from PD in voids, gaps (Figure 8) or for example from PD between paper layers in a dry area of PILC cables.

4 CONCLUSION

From more than 8 years experience of on site PD diagnosis with DAC technology sufficient information about the nature of defects: typical PD pattern and time to failure was collected, to estimate the severity of PD defects. Trending methods are useful in PILC, not so much in case of polymeric accessories, because the PDIV and PD level does not vary significantly during the progressing degradation. The assessment of PD measurement results based on this empirical experience can be used to support the asset management decision for the time scheduling of replacement activities.

6 REFERENCES