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EXPERIENCE WITH PD MEASUREMENTS AND COMMISSIONING TESTS

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ABSTRACT

The commissioning of new HV cable systems is commonly performed by means of an AC voltage test. The experience has shown that a proper combination of test voltage and duration can indeed detect incipient failures. The combination of such an on-site test with partial discharge measurements is relatively new. This partial discharge measurement may give additional information about accessories installed in the circuit. This paper describes the development, advantages and limitations of on-site PD measurements.

KEYWORDS

TAI, commissioning test, partial discharge, PD, on-site, HV

INTRODUCTION

To check the correct installation of a cable circuit a commissioning test is to be performed. These on-site tests or tests after installation (TAI) on HV cables were originally performed with DC voltage and later on with oscillating wave voltages. Nowadays DC is recognised as being ineffective and even more being harmful for XLPE cable systems and oscillating wave voltages have become obsolete for HV cables. The alternative, series resonant testing, is now widely accepted. This is reflected in today's standards and requirements.

A series resonant circuit is made up of a reactor in series with the cable to be tested. This series connection of a capacitor and reactor is usually energised by means of a step-up transformer. In the early days of this type of testing on polymeric HV cables there was a clear preference for variable frequency test systems [1,2]. With a fixed inductance the frequency is tuned to achieve resonance. At resonance, the energy swings back and forth between the cable (electric energy, ½CU2) and the reactor (magnetic energy, ½LI2). Only the losses have to be supplied by the exciter transformer (and frequency converter), such as dielectric losses in the cable, the magnetic losses in the reactor and also e.g. the losses associated with corona. The ratio between the reactive power in this resonant circuit and the losses determines the increase in voltage on the cable as compared to the voltage applied by the exciter transformer. In practice this ratio varies between 100 and 200.

When testing with a sufficient voltage level and duration, e.g. 1,7 U0, 1h for 132-150 kV cable systems, this voltage test as such can do the job of discriminating between circuits without and with a defect, without overstressing the cable. Nevertheless, recent years have shown that there is an interest in combining partial discharge (PD) measurements with this on-site AC voltage test. For MV cable circuits, both extruded and paper insulated, on-site PD measurements are performed for more than a decade. It must be mentioned here that these measurements on MV cables serve a diagnostic purpose, rather than being applied as a commissioning test. But the effectiveness of PD measurements as a diagnostic tool for MV cables, together with a.o. the desire to have even more confidence in the absence of defects in a newly installed cable circuit, triggered requests for this kind of measurements in combination with a regular voltage withstand test.

In this paper the development of the present PD measurement system in use with KEMA's series resonant test set will be discussed. Also the experience with this system will be put forward. Since on-site partial discharge measurement is definitely not a straightforward kind of measurement, the limitations of these on-site measurements are discussed.

DEVELOPMENT

General

Several aspects have been investigated during the development of the present system for on-site PD measurements on HV cable systems: detection, sensor, calibration and processing of data. These investigations were based on the condition that it has to be able to measure on cable circuits not equipped with (integrated) PD sensors. This means that signal pick-up has to take place at one end of the cable. Furthermore, the system has to cope with disturbance pulses produced by the frequency converter that drives the resonance.

Detector and sensor

Unfortunately the traditional PD detectors have only limited use on-site as a consequence of the higher disturbance levels. A quite common solution for on-site PD measurements appeared to be a good means to overcome the problem of disturbance: the use of a spectrum analyzer as a detector. Selecting a proper frequency band results in the optimal S/N ratio. The frequency range where to look for such a low-noise band is largely determined by the condition of single-ended measurement. PD pulses attenuate while propagating through the cable. This attenuation is highly frequency dependant. Based on VLF diagnostic measurements on MV XLPE cable circuits, it has been experienced that small PD pulses propagating through 3 km of cable can still be distinguished from noise. A compromise between sufficient flexibility in choosing a proper frequency band and the ability to detect with sufficient sensitivity PD pulses originating from the far end, resulted in a frequency range up to 5 MHz.

The first sensor we used for the on-site measurements is the traditional laboratory sensor: a coupling capacitor and quadrupole, see figure 1. This enabled us to realise a basic system in a short time. The drawback of this solution became clear during field measurements. The coupling capacitor is to be placed preferably close to the termination.

While the termination is never at ground level, this coupling capacitor has to be lifted and since usually no cranes are available on-site and this coupling capacitor is quite heavy, we ended up in sometimes undesirable situations.
Fortunately a partial discharge pulse may not only be seen as a voltage pulse propagating through the cable, it is also a current pulse. This current pulse can be detected in the ground lead connecting the shield of the cable (lead sheath or concentric conductor) to ground, provided that the termination does not act as a reflection point. Then an inductive sensor can be inserted in this ground lead as pick-up. This inductive sensor is essentially a high frequency current transformer. In order to avoid saturation of the sensor's magnetic core by the charging current of the cable, two phases are connected in such a way to the sensor, that the charging currents cancel out each other.

Figure 1 Coupling capacitor next to termination

Calibration

With respect to calibration of the test set-up, our first approach was to find an alternative for the commonly used laboratory-type PD calibrators. The reason for this being the fact that we assumed that the frequency content of such PD calibrators is too small since these calibrators are designed for use with traditional PD detection equipment. The alternative turned out to be a PD source based on a floating electrode. This source appeared to be comfortably stable in producing the same magnitude of PD's under various circumstances (changes in air pressure, humidity, temperature, voltage). The inception voltage was only 15 kV and the PD magnitude was about 120 pC.
When using this source on-site, no difference could be found when calibrating with the floating electrode source as compared to calibrating based on the standard PD calibrator, disproving our previous assumption regarding bandwidth of PD calibrators. Since the standard PD calibrator is easier in use than the PD source based on a floating electrode, the latter has been disbanded in favour for the standard PD calibrator.

Data processing and interpretation

Processing of measured data is performed basically for storing purposes and enhancing the presentation of data. The spectrum analyzer is connected to a computer and an application based on a graphical development environment has been written. This application controls the spectrum analyzer, takes care of the transfer and presentation of data and finally it stores the data. No digital filtering is performed.
A powerful tool for the presentation of the measured data is a graph that not only shows all data but also gives insight in the rate of occurrence of discharges through a variation of colour. This so-called intensity graph is the basis for the interpretation of the measured data.
The interpretation follows the more or less classical rules used in the laboratory. The processing software presents the measured data in a phase resolved manner. This results in patterns that are similar to those measured in laboratories with the standard PD equipment. This implies that the test engineer can still use his expertise gained in the laboratory environment for interpretation of the measured patterns on-site.

EXPERIENCE

The previously described system, starting with a coupling capacitor as sensor and today a high frequency current transformer, is in use since early 2002. To date more than 80 PD measurements have been performed in conjunction with a commissioning test. In only 3 occasions we have found evidence of partial discharge activity in the cable circuit under test at the end of the voltage withstand test. Here the discharge activity ranged from a low 15 pC to 250 pC. Perhaps more interesting is the noise level which is experienced during all these measurements. This ranged from a surprisingly low 5 pC to as high as 70 pC. On average we experienced a noise level between 20 and 25 pC. The variation in this noise level seems to be determined by local circumstances. Figure 2 shows a measurement on a HV cable resulting in a noise level of approximately 10 pC. The four spikes in this figure are caused by the frequency converter, the measurement did not show any partial discharge activity in the cable circuit.
Unfortunately, a few PD measurements had to be cancelled because of extreme high noise levels, rangeing up to 200 pC. This practically implies that a PD measurement is not sensible, which resulted in the cancelation of the PD measurement. These extreme high levels were all experienced in a substation environment with live equipment in the vicinity and at the same time continuous rain.

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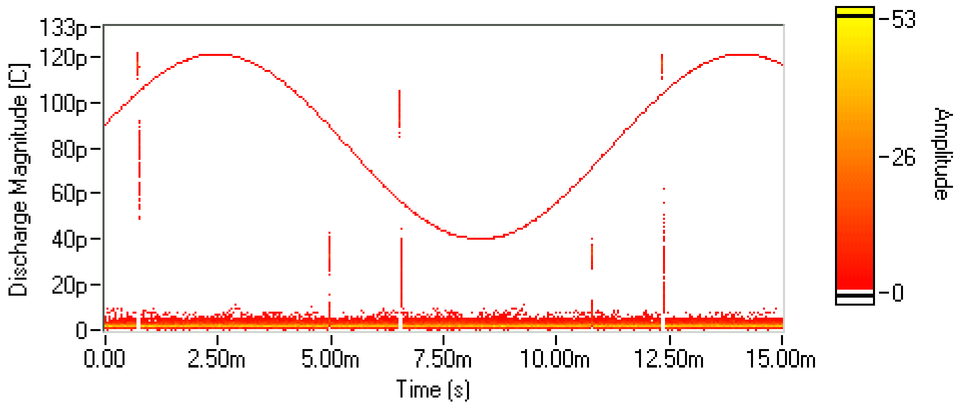

Figure 2 Example of a PD-free measurement, noise level approximately 10 pC

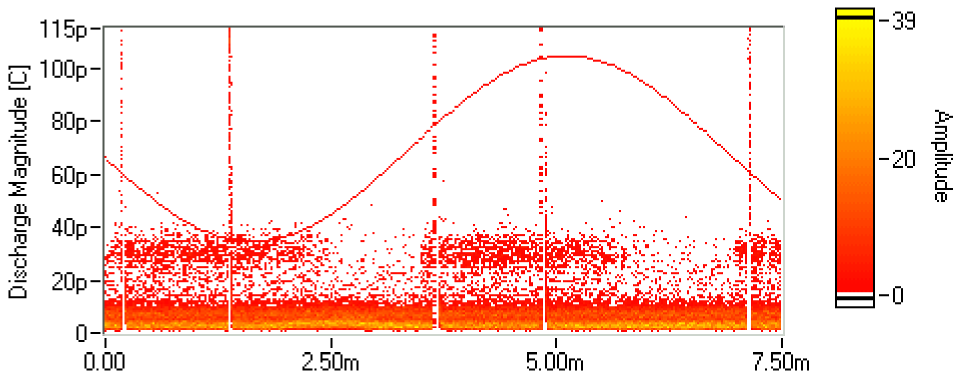

Figure 3 Example of discharges from an isolated metal structure in the vicinity of high voltage

As mentioned before, in 3 occasions evidence of PD activity in the cable circuit has been found. PD activity outside the cable circuit has also been measured. We have measured PD patterns caused by floating parts close to high voltage, see figure 3. Also discharges generated by a stick as a result of wear have been measured. The stick is used to support the tube connecting the reactor to the cable under test. After replacing the stick the disturbance has disappeared. We even measured corona activity inside GIS. Here it turned out that the GIS cable termination was not equipped with a (temporary) corona shield. After still installing such a shield, the discharges have disappeared. It has already been mentioned that the weather may disturb the measurements. Although continuous rain does not interfere the voltage withstand test, it makes a PD measurement impossible. But not only rain may influence a measurement, we have also seen dew may do so. During a measurement in the late afternoon, the last phase started to show corona activity although the set-up was exactly the same as for the previous two phases. It was noticed that in the mean time dew had appeared on the termination, causing the corona discharges.

Finally, the actual situation on-site with respect to the connections to be made, may influence the sensitivity. Most favourable is a situation where the trailer (reactor) can be manoeuvred close to the termination and everything is connected in short straight lines, say 5 to 10 m. On the other hand, it is a challenge to make the connections corona-free when you have to cross a fence with the HV connection, when you have to go around a transformer or when the termination is on a platform attached to a tower, see figure 4. Experience has learned how to solve these aspects properly. However, sometimes a proper solution does not exist, for instance in situations where things are very confined, like a boxed in termination: on one side immediately a transformer, on the other side in short distance a wall. Although the clearances in such circumstances are sufficient from a voltage point of view, disturbing influences for PD measurements can not always be excluded. Then a (slightly) disturbed measurement has to be accepted.

Figure 4 Difficult situation to connect PD free

CONCLUSION

A PD measurement system for on-site use during commissioning tests based on a spectrum analyzer has been developed. This system enables the measurement of partial discharges on cable systems without the need for integrated PD sensors in the accessories. The (external) sensor is based on a high frequency current transformer.

Almost four years of experience on more than 80 different cable circuits and hence many different measurement conditions, shows that these on-site PD measurements can reveal defects in cable systems with an average noise level between 20 and 25 pC.

Yet, experience has shown that these PD measurements are not possible in all circumstances. Bad weather, i.e. continuous rain, impedes the measurement to such an extent that a sensible measurement is no longer possible. Also, in substations where space is a limiting factor and neighbouring circuits are in close proximity, higher disturbances can be experienced.

Experience has also shown that it is possible to overcome obstacles as fences by proper shielding measures and maintaining a sufficient large distance by using sticks for support and/or ropes for suspension for the HV connection.

REFERENCES

[1] T. Aschwanden: Vor-Ort-Prüfung von Hoch-spannungs-Kabelanlagen (Bulletin SEV vol. 83, July 1992)

[2] M. Cloete, J.B.S. Cheek, M.A. Lang: The development of a variable-frequency series resonant test set for after-laying tests on XLPE cables (IEE conf. on Power Cables and Accessories 10 – 150 kV, November 1993, London, UK)