EXPERIENCES WITH ON-SITE AC TEST COMBINED WITH PARTIAL DISCHARGE MEASUREMENTS

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ABSTRACT

Most observed defects in today's power cable systems are due to partial discharges (PD) under AC voltage stress. Partial discharge diagnostic testing of cable systems in the field is intended to measure and locate those singular or multiple clusters of PD producing defect sites, that would result in a near term cable failure. The results of PD diagnostic tests are used to assess the condition of the cable insulation. High voltage testing should provide the information required for the decision whether a defect in the insulation is dangerous. On the other hand, experience also shows that the On-site PD measurements by using frequency tuned resonant test systems give high sensitivity and calibration is possible using partial discharge calibrator on the cable terminations. In this paper, the authors used a new technology for On-site withstand tests combined with partial discharge measurements of power cable systems. The results of many On-site tests carried out on 66 kV cable systems are presented.

Keywords: On-site Test- Partial Discharge- XLPE Power Cables- Frequency Tuned Resonant – HV Commissioning Test.

INTRODUCTION

The use of XLPE insulation for medium and high voltage power cables is increasing in distribution and transmission of electrical networks. Consequently, the number of new installed 66 kV - XLPE power cables is increasing in power networks. The new cable systems can exposed to inaccurate assembling of cable accessories and could result in the presence of defects during installation. External damages of cable installation are usually detected by DC testing of the over sheath. In consequence, after-installation tests of the insulation can focus on defects in cable accessories, e.g. interfacial problems, improper positioning, cuts or scratches, contaminations etc. Such defects do not necessarily lead to breakdown within testing time, bearing the risk of breakdowns later in service. Sensitive on-site PD measurements significantly reduce this risk [1, 3, 4, 5]. Detecting PD on long cables is a good start to the diagnosis of the system condition. However, it is only a start, and the obvious next stage after detection is to locate where the PD originated from. Once located, the final stage is to understand the problem which has generated the PD activity, and to make some sort of remedy plan which may include replacement of the offending cable or plant item. After installation or long time use, the insulation of cable or accessories may include small voids and cavities, conductive or insulating contaminants, or conductive protrusions in different interfaces causing partial discharge (PD). Partial discharge measurements have received much attention in recent years. Apparent charge, partial discharge inception voltage as well as number and distribution of PD pulses are most important quantities. Different ways to suppress external noise are applied to detect signals with high sensitivity in difficult on-site conditions. The cables on-site testing have to check the insulation condition after installation and assembly of cable system, as well as ageing of cables and accessories [5]. If an on-site test is completed with a partial discharge (PD) measurement, all the experience from the various factory tests can be transferred to the on-site test. The after laying test of new cables fills the quality assurance gap between the type and routine tests of the cable at the manufactures site and the commissioning of the complete cable system on-site.

PARTIAL DISCHAGE MEASURING SYSTEM

High voltage tests should provide the information for the decision whether a defect in the insulation is dangerous or not for the later operation. That means the failure mechanism during the HV test and the later operation should follow the same physical process. To accelerate this process, the test voltage is usually higher than the corresponding stress during operation. Frequency tuned resonant test system is meanwhile, the state of the art for on-site testing and diagnostics on high voltage XLPE insulated cables. The components of the HV test system and load (power cable to be tested) form an oscillating circuit of a certain natural frequency, this system operates in resonance. It establishes a powerful high voltage at minimum power input. The test voltage is pure sine-shaped in the case of series resonant circuit. Its frequency depends on the load capacitance according to the equation:

$$f = \frac{1}{2\pi\sqrt{lc}}$$

The control of test system searches for the resonant frequency automatically and the HV test is carried out at this frequency, the system is shown in Figure (1). This figure shows the frequency tuned resonant test system (20 Hz -300 Hz) of 66 kV circuits. The measurements set-up of this work is carried on site by using coupling capacitor (CC) and High Frequency Current Transformer (HFCT). Figure (2) shows On-site Measurement set-up for PD detection using High Frequency Current Transformer (HFCT) for 66kV – XLPE Insulation. PD sensitivity using HFCT the central measuring frequency is recommended to lie between 9 KHz and 3 MHz in a flat zone of the frequency spectrum. Furthermore, the measuring frequency must be set in order to obtain the greatest possible PD signal/noise ratio. In addition, an "on-site performance check" is carried out for the selected measuring frequency before the PD measurement starts [6].

Figure (1) Frequency tuned resonant test system (20 Hz -300 Hz) - connected with XLPE- cable circuits 66 kV

HFCT method at earth wire of 66 kV for XLPE cable systems showed high sensitivity and calibration is possible using PD calibrator on the cable terminations. Another type of measurement by using coupling capacitor according to IEC 60840 [2]is based PD detection of high frequency signal generated from PD activities. Measurement set-up for PD detection using coupling capacitor around the earth wire of the 66 kV cable is given in figure (3)

Figure (2) On-site Measurement set-ups for PD detection using HFCT for 66kV – XLPE Insulation

TEST SET-UP FOR ON-SITE

AC Cable Systems Testing after Installation

The most favored on-site test voltage of power frequency, is 50 Hz [7]. But for on-site testing a larger frequency range is being used. The tests have been carried out on-site according to IEC 60840. These standards offer an alternative for AC test procedure. Besides the testing voltage sinusoidal waveforms have the frequency between 9 KHz and 3 MHz .The voltage is applied for 1 h, either with a voltage according $\sqrt{2}\,U_0$, it is also possible to test with U_0 for 24 h [2, 8] for 66 kV cables (where U_0 is the phase voltage).

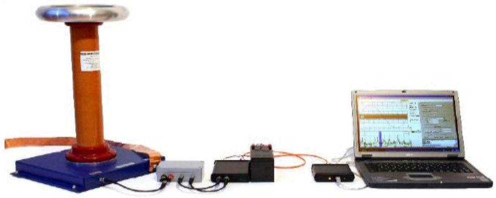


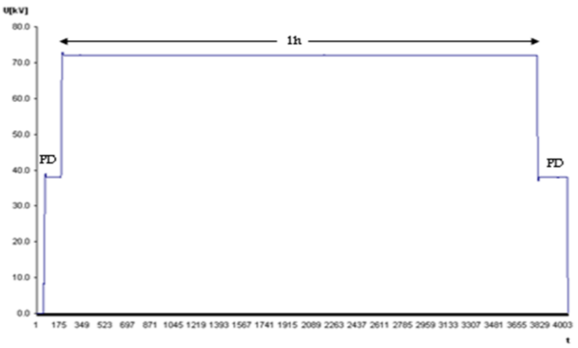
Figure (3) Measurement set-ups for PD detection using coupling capacitor

Therefore, the XLPE cable insulation was subjected to AC tests after assembling and at the same time partial discharge measurements were done on all accessories simultaneously for three-phase PD measurement. By controlling the resonant circuit using capacitance and inductance elements the resonance occurs and the energy is absorbed at any instant by one reactive element within the system. The control of test system searches for the resonant frequency automatically and the HV test is carried out at this frequency. It is known, that HV power cables failure can occur as a result of the normally applied operational voltage or during a transient voltage lightning or switching surges. The failure can occur if localized electrical stresses are greater than the dielectric materials in the area of localized stress or the bulk dielectric material degrades to the point where it cannot withstand the applied voltage. Therefore performing non-destructive diagnostics on-site could be an important issue to determine the actual condition of the cable system and to determine the future performances. Figure (4) shows the breakdown for 66 kV cable during test with frequency 27.05 Hz after 00:31:55.

Figure (4) Breakdown during withstand voltage for 66 kV cable after 00:31:55 with 27.05 Hz

Partial Discharge measurement

Measurement of partial discharges is carried out using the MPD 540 measuring instruments with frequency tuned resonant test system as a source at the terminations and the clamp-on type High Frequency Current Transformer Sensors (HVCT) on the earth wire of 66 kV for XLPE cable systems showed high sensitivity and calibration is possible using PD calibrator on the cable terminations. And another type of measuring by using coupling capacitor is physically limited to a maximum detectable cable length of proximally 2 km is gives too low sensitivity, depending on cable parameters and PD background noise. Before applying the voltage, the noise level is measured. Partial discharge measurements are carried out before and after withstand voltage at 72 kV for 1 hour of cable 66 kV XLPE, PD measurements are recorded at 38 kV. The test procedure is given in Figure (5).



Applied time in sec

Figure (5) Withstand voltage at 72 kV for 1 hour of cable 66 kV XLPE combined with PD measurements before and after at 38 kV

The center frequency sets the nominal frequency at which charge integration takes place; the bandwidth selects a window around the center frequency. The following bandwidths: 3 MHz, 1 MHz, 300 kHz, 100 kHz, 30 kHz, and 9 kHz can be selected. Hence an optimal frequency band can be chosen to avoid disturbances and to reach a high signal-to-noise ratio (SNR) even under noisy conditions on site. Figure (4) shows the variation of PD with change of center frequency. Furthermore, the test voltage signal is digitized in acquisition unit to document the test voltage during the PD measurement. For higher measurement frequencies, under or over estimation of PD level of different phases is probable. Lower measurement frequencies would cause the disadvantages of lower cable damping, resulting in higher external interference from both ends of the cable link. The results of the on-site PD measurements with the alternating voltage of variable frequency have been performed in conjunction with test at earth wire using HFCT sensors showed the discharge activity. The variation of noise level which is experienced during all measurements resulted in higher external interference from ends of the cable.

TEST RESULTS AND EXPERIENCE

The tests have been carried out on-site according to IEC for 66 kV cables system at √2 U0 having different lengths to determine the faulty joints and cable defects., The XLPE cable insulation was subjected to AC tests after assembling and at the same time partial discharge measurements were done for one minute on all accessories simultaneously for three-phase PD measurement on the relevant earth wire.

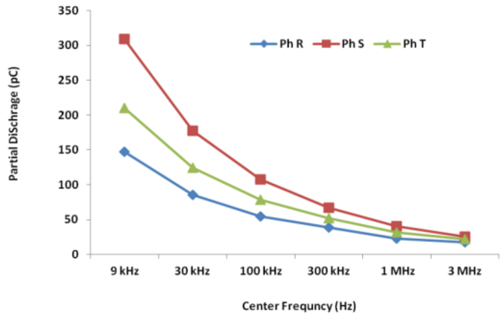


Figure (6) PD measurement relation center frequency

The results of the on-site PD measurements at 38 kV with the alternating voltage of variable frequency (9 KHz and 3 MHz) and withstand voltage at 72 kV for 1 hour of cable 66 kV XLPE are given in figure (7). Similar measurements are carried out on 66 kV, 2.5 km long. The results are given in Figure (8). From Figures (7) and (8) it is noticed that the difference between the two methods is in the range between 1 to 3 pC which can be ignored. The effect of withstand voltage on the onsite PD test of 66 kV XLPE is investigated by measuring the PC before and after the withstand voltage.

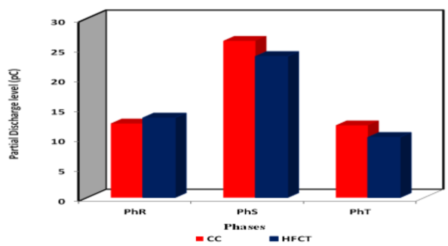


Figure (7) PD Measurements of cable 66 kV by using coupling capacitor (CC) and HFCT sensors for 1.8 km long

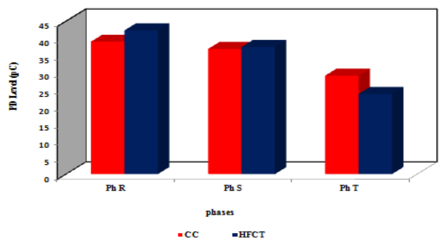
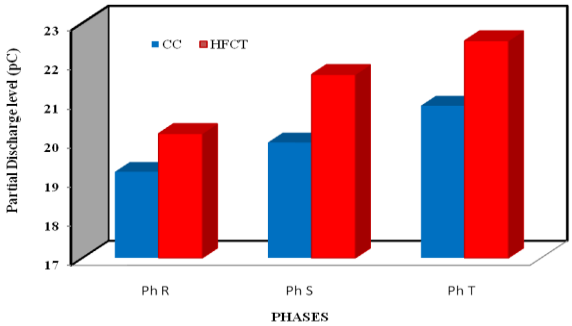


Figure (8) PD measurements of cables 66 kV by using coupling capacitor (CC) and HFCT sensors about 2.5 km long

PD measurements are carried out by using coupling capacitor (CC) and HFCT before and after withstand voltage. Measurements are carried out at 38 kV with the alternating voltage of variable frequency (20Hz - 300 Hz) and Withstand voltage at 72 kV for 1 hour at resonant frequency 48.8 Hz. The obtained results are compared in Figure (9). As seen in this Figure the partial discharge test after withstand voltage gives more than twice pC before conducting the withstand voltage test. The on-site PD measuring level for cable system doesn't have a limit in the standards but depends primarily on the experience of those involved in the measurements, and the experience learned about the diagnostics of the PD limit. We always ask this question to the manufacturers and owner customers, "What is the safe level for PD activity in the cable systems? The answer to this can only be, "there is no safe level for internal PD in the cable systems", and all internal discharges will be damaging [9, 10, 11, 12, 13,14].



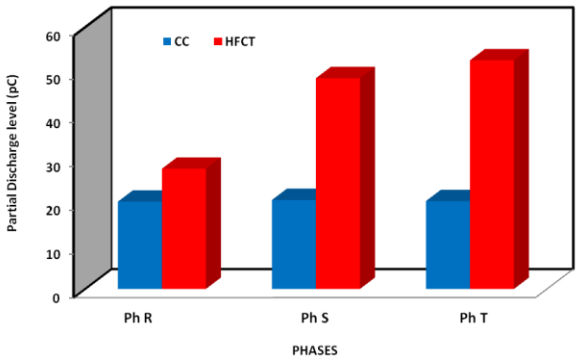


Figure (9) PD test results of 66 kV in PC before and after the withstand voltage.

CONCLUSION

Two partial discharge detection methods measurements set-up of this work are used on site by using coupling capacitor (CC) and High Frequency Current Transformer (HFCT). IEC 60840 standards is used as reference. The experiences show that the test voltage with U0 for 24 hours is not feasible for incidence of failure after the test could occurr. Also the on-site withstand voltage test of XLPE cable systems with variable frequency test system (20Hz - 300 Hz) combined with PD detection are performed by using HFCT sensors after installation of power cable systems reduces the risk from the service.

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