ADVANCED SOLUTION FOR ON-SITE DIAGNOSIS OF MEDIUM VOLTAGE POWER CABLES NETWORK

Osama GOUDA
Cairo University
Egypt

Adel ELFARASKOURY
Extra High Voltage Research Center – Egypt

Adel FARAG
South Cairo Electricity Distribution Company- Egypt

Abd Rabu ELSINNARY
Al-Azhar University
Egypt

prof_ossama11@yahoo.com dr.adel_elfaraskoury@yahoo.com adelfarag94@yahoo.comm El.senary@yahoo.com

ABSTRACT

The Medium Voltage (MV) cable network forms a large part of the distribution company's physical capital. The MV network has a huge influence on interruption which customers suffer, due to the defects in MV network. Defects are not only harm to customers, but also to the distribution network company workers. In the last four years in South Cairo Electricity Distribution Company (SCEDC) increasing in the rate of the failures in MV power cables numbers is observed. It is noticed that 47 % to 49 % of the recorded faults are caused by breakdown of joints and terminations of medium voltage cables. This paper describes the latest developments and the off-line PD measurements by using Very Low Frequency (VLF) as an energizing method according to IEEE. It is interesting in this paper to investigate the conventional method by 50 Hz AC voltages, VLF 0.1 Hz (Sinusoidal), VLF 0.1 Hz (rectangular) and DC waveform and compare the PD magnitudes of each source to others. Addition to use VLF-PD as diagnostic technique with the two previous detection methods simultaneously for MV XLPE single core cables and compare the measurement results of each other on-site.

INTRODUCTION

In recent years, because the high voltage DC is harmful for underground cables during testing, SCEDC have shown a growing interest in applying VLF testing to their existing cable network in order to detect, locate and access weak components of the cable system including accessories. One of the common mechanisms related to failure of cable insulation media is partial discharge (PD) activity. Indeed, the fastest aging mechanisms in cables are associated with PDs. Hence, diagnostic systems capable of monitoring this activity have attained significant popularity as a condition assessment tool, especially for medium and high voltage cable systems. The on-site testing of cables has to check the insulation condition after laying and assembly of cable systems, as well as ageing of cable systems, since the performance of the cables and accessories were tested during the routine and type tests. Off-line measurement of PDs requires an uncoupled and de-energized power cable, an external power supply and a measuring circuit. Several kinds of voltage signals can be applied to energize the cable. In contrast to DC, the reversal of voltage polarity every half cycle during AC testing ensures that potentially harmful space charges will not accumulate. Unfortunately, producing high voltage 50 Hz AC requires extremely large and expensive equipment that is not practical for many field testing applications since the source must supply a substantial capacitive charging current. Some of the practical disadvantages of power frequency tests are reduced while retaining the basic advantages by the use of VLF with a frequency of 0.001 – 0.1 Hz. The VLF testing is since several years an accepted method for voltage withstands tests for all types of distribution cables. Off line test voltage are normally higher than the normal operation voltage and the circuit is subject to more stress that when tested on line. It has been suggested and frequently observed, that when the applied voltage is increased, discharges will be initiated in voids that would not normally discharge. SCEDC as any utility faces some problems of power interruptions which cause major financial losses for utilities and the customers. One of the network components prone to breakdown is the cable. It is noticed that an increase was happened in the rate of the failure numbers in MV power cables during the years 2009 to 2013. By investigating the causes of these cumulative failures it is found that 48 % of these faults are caused by breakdown of joints and terminations, 19 % are happened by internal faults and 33 % of the failures are carried out by others such as digging activities. Figure 1 shows the percentage rate of cumulative failures of medium voltage cables rate through years from 2009 to 2013. These defects may be occurred due to inaccurate assembling of joints and terminations. Installed cables are, moreover, subjected to natural aging, or due to temporary extreme circumstances (overload, overvoltage...), degradation under design stresses (particularly electrical and thermal) or other factors of influence (digging, water…) [1,2 and 3]. Once the fault occurs in the cable, the utility isolates the faulted cable from grid and starts to pinpoint the location of fault. Figures 2 and 3 show samples of different faults happened on medium cables and their accessories.

PD DETECTION METHODS

Off-line Partial Discharge Testing offers a significant advantage over other technologies because of its ability to measure the cable system's response to a specific stress level and predict its future performance without creating a fault. Off-line PD detection can be performed either conventionally according to IEC 60270 [4] or unconventionally according to an IEC 60060-3 [5], that is still in preparation. One of the common mechanisms related to failure of cable accessories and internal faults is PD activity.

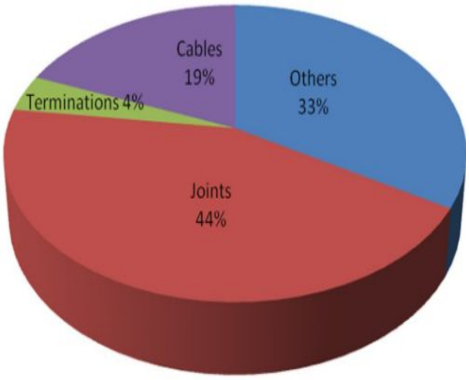

Fig. 1: Cumulative failure rate from 2009 to 2013

Fig. 2: Samples of different failures happened on medium cables and their accessories (1. Digging 2. Cable fault 3. Cable termination 4. Cable joint)

Fig. 3: Breakdown due to internal defect in the cable

If an on-site test is completed with PD measurement, all the experience from the various factory tests can be transferred to the on-site test. The most accepted test method of on-site diagnosis of MV cable networks is the so-called standardized off-line method. An off-line PD diagnostic test can be used as a commissioning and periodic predictive diagnostic maintenance tool to enhance the reliability of industrial cable systems by reducing the likelihood of service outages. Off-line PD can be measured with using VLF as an external power supply according to IEEE 400-2 [6]. Guides for field testing according to IEEE are reported [7 and 8].

Conventional PD method

Conventional PD detection method is standardized method based on international standard IEC 60270. Partial discharges that occur in the test object will produce current or voltage pulses. In contrast to the well-established PD measuring method according to IEC 60270 the described system operates in the UHF frequency domain, hence the derived and evaluated output PD pulse magnitude is more or less a measure of the PD current amplitude and not for the apparent charge as defined in the above mentioned standard. The sensor used for PD measuring is coupling capacitor (CC) as shown in Figure 4.

Fig. 4: PD detection set-up by using CC sensor

Unconventional PD method

To overcome the previous problems associated with conventional method and provide result with suppressed noise or high signal to noise ratio (SNR), unconventional measurements are needed. High Frequency Current Transformer (HFCT) can be used as a sensor to pick up the high frequency current pulses associated with the partial discharge in the cable by connecting it around the earth wire of the cable as shown in Figure 5. The calibrated HFCT sensor uses inductive coupling to detect PD pulses flowing between phases and earth, converter the high frequency current pulses from the discharges into high frequency voltage pulses on the PD test unit. The PD sensitivity using HFCT the central measuring frequency is recommended to lie between 2 MHz and 10 MHz in a flat zone of the frequency spectrum. The PD pulses occur in very short time, the width and rise time of the pulses are in the nanosecond region. Consequently, PD pulses with energy frequency up to hundred MHZ are generated [9, 10, 11 and 12]. These PD pulses travel through the cable earth conductor and finally can be recorded by the sensors. These types of sensors mostly are used in practice for the advantage that these sensors do not disrupt the normal configuration of the accessories and cable part. PD sensors work based on detection of high frequency current pulses that occur during PD in the cable system.

Fig. 5: Example of PD measurements by using HFCT

PD MEASUREMENT SETUP AND RESULTS

Partial Discharge can occur at voids, gaps and similar defects in medium and high voltage cable systems. If it is allowed to continue, partial discharge will erode the insulation, usually forming a tree shaped pattern of deterioration (electrical tree) and eventually result in complete breakdown and failure of the cable or accessory. Such failures cause unplanned power outages, loss of plant production, equipment damage, and/or personnel injury. Data obtained through Partial Discharge testing and monitoring can provide critical information regarding the quality of insulation and its impact on cable system health. This paper introduced advanced solutions for distribution companies to overcome the problems of increasing the faults in MV cables by using off-line PD measurements. There are two problems face an electrical engineers who are using this method. The first problem is using an external source to energize the cable under test; it can be solved by using very low frequency (VLF) as an energizing method according to IEEE400.2. The second problem is the lack of using PD conventional detection method for long cables and in noisy field; it can be solved by using unconventional method with HFCT sensor. So it is interesting in this paper to use combination of withstand voltage testing (VLF) and PD measurements acceptance on-site testing for MV cable system. Firstly tests are carried out laboratory tests on samples of 12/20 kV, 3x400 mm^2,PE/XLPE cable .The tests are done by applying 0.1 Hz Sinusoidal voltage, 0.1 Hz Rectangular, DC and 50Hz AC, on the same cable samples. The obtained partial discharge levels for each applied voltage type are given as shown in Figure 6.

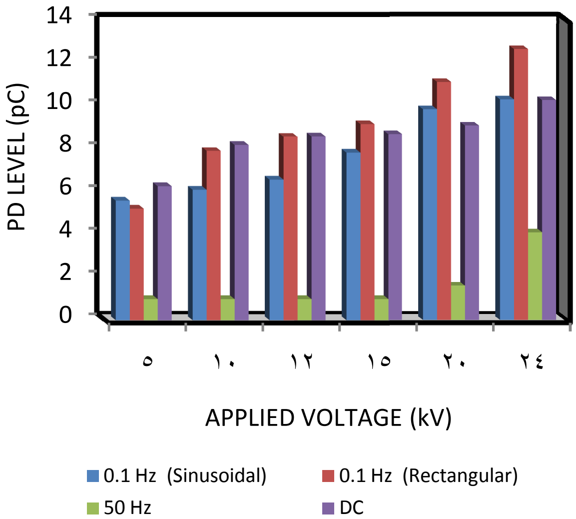

Fig. 6: PD magnitude as function of different applied voltage for cable specimen 3x400 mm^2, 12/20 kV

The results show by comparing different voltage sources (0.1 Hz Sinusoidal, 0.1 Hz Rectangular, DC and 50Hz AC) it was found, that especially the VLF Sinusoidal voltage is suitable for testing MV cables and especially PE/XLPE cables. While DC test for PE/XLPE cables is not suitable because the even serious defects are seldom detected and long term space charges can be created. These are the preconditions, to convert inhomogeneous defects and to bring partial-discharge defects rapidly lead to breakdown of the cable system.

ON-SITE COMBINATION OF WITHSTAND TESTING AND PD MEASUREMENTS

Withstand testing after installation or after repair of failures reduces significantly the failure rate during normal operation. Cable testing therefore is of increased importance to achieve an optimum reliability of the cable network and also to establish the priorities of replacement for optimum reliability and minimal investment. High voltage (HV) tests should provide the information for decision whether a defect in the insulation is dangerous or not for the later operation. The most important stress of a XLPE cable in service is the stress with the operational alternating voltage. The obvious advantage to using VLF rather than power frequency systems is the smaller size, lower weight, far less power consumed, and price. Several different VLF waveforms have been utilized with the most common being sinusoidal, rectangular and cosine-rectangular. Cable failures often occur at the worst possible time and result in costly down time, necessary emergency repairs, adjacent cables being damaged, annoyed customers, and loss of consumption revenue. This is neither a good nor a sustainable practice. The ability to determine all kind of different faults with widely different fault characteristics is turning on the suitable measuring equipment as well as on the operator's skills. Faults in general are categorized in low resistive and high resistive faults [13, 14, 15, 16 and 17]. On site testing is carried out on cable, 3X400 mm^2- XLPE - 12/20 kV, by using VLF 0.1 Hz as a source. Measurements of PD are done and the results are shown in Figure 7 when failure is happened at 1.5 kV on phase T.

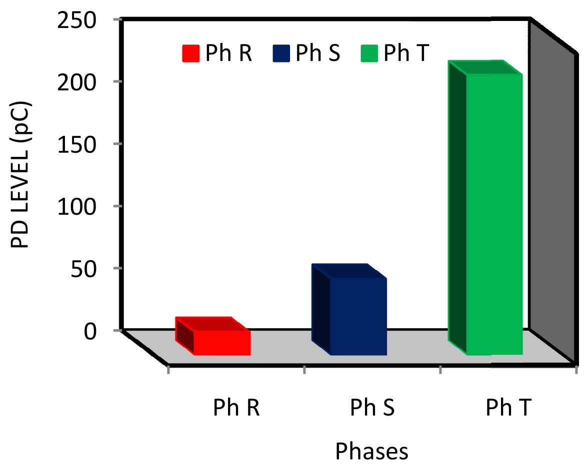

Fig. 7: PD measurements with defect on Ph T

Figure 8 shows the point of fault for Ph T with two waves, the healthy wave (blue) and the faulty wave (red). The two waves coincide with each other until the point of fault (green line), at which the healthy wave is reflected in a positive reflection and the faulty wave is reflected in a negative reflection. The point of fault is at distance of 61 m from the termination of the cable which connected to the testing device.

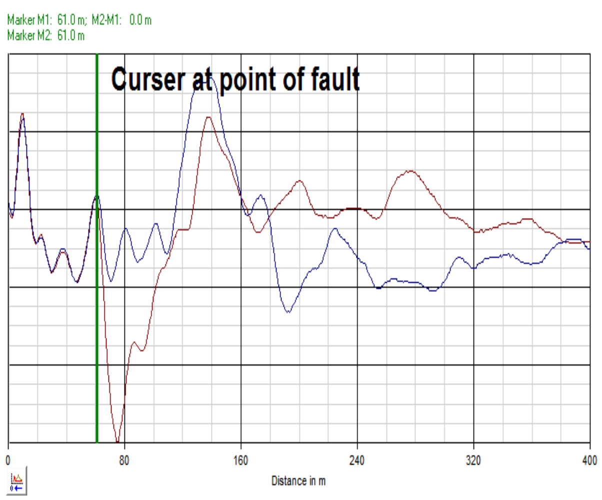

Fig. 8: Localization of PD defects, for Ph T under test

To avoid or reduce the burden that faced by the utility for repairing the faulty cable in short time especially in rural areas which feeding from radial arrangement, a suitable diagnostic method must be used to assess the condition of these cables. Calibration is done by injecting a short duration current pulse of known charge from the calibrator to the terminal of test object while the measuring system is de-energized. Interrelated calibration of PD measuring unit will be done by injecting a PD calibration pulse at one of the neighbored HFCT and used an integrated PD gating unit for gating purposes in order to provide the possibility to filter certain external background noise. The on-site PD measurements with VLF have been performed in conjunction with different two methods CC and HFCT sensors for eight XLPE cables 3x400 mm^2 - 3.6/6.3 kV at length of 1300 m approximately reported the discharge activity ranged from 4.2 to 26.01 pC as shown in Figure 9.

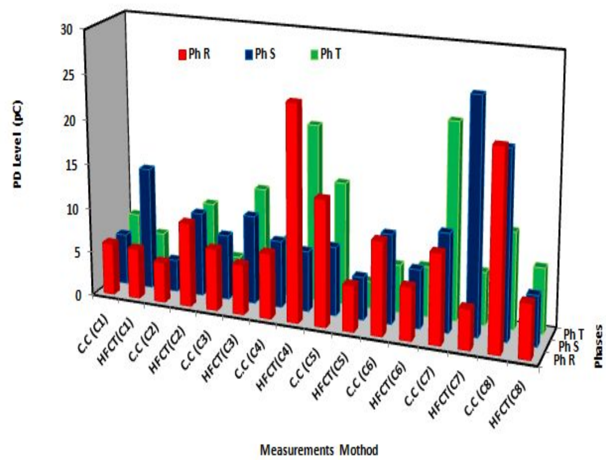

Fig. 9: PD measurements for XLPE cables 3x400 mm^2, 3.6 /6.3 kV by using CC and HFCT sensors

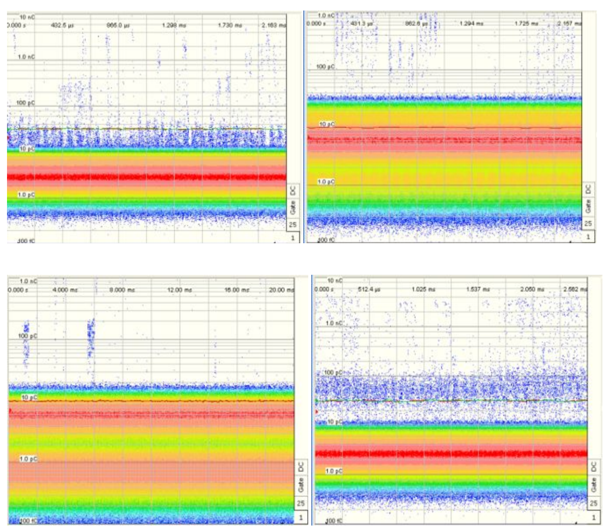

Fig.10: Example of PD patterns with variation noise level

Calibration of PD measuring instrument is important factor to ensure that the PD measuring system is able to measure the PD magnitude properly. The variation of noise level which is experienced during all measurements resulting in higher external interference from ends of the cables caused by the cables termination under test. Figure 10 shows an example of PD patterns with variation of noise level during measurements. The on-site PD measuring level for cable system doesn’t limit in the standards but depends primarily on the experience of those involved in the measurements, and the experience learned how to the diagnostics of the PD limit. The manufacturers and owner customers, always ask this question “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”, all internal discharges will be damaging.

CONCLUSION

Evaluating the cable failure data from utilities, it’s important to assess to condition of MV cables component based on diagnostic data. The cable failure location was demonstrated with two different methods by PD measurements. Within on-site PD measurements at an installed XLPE MV cables was done with 0.1 Hz sinusoidal by using CC and HFCT sensors. Experience has shown that testing at VLF does not come with the risk of damaging sound cable insulation, combined with an ability to reliably detect defects. By using off-line diagnostic technique is introduce for contributing to reduce the increasing of the rate of cable failures and enhance the reliability of MV cables in network of SCEDC.

ACKNOWLEDGMENT

The authors would like to express their great thanks to the partial discharge team work of the Extra High Voltage Research Centre for providing their facilities during this work

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