



The partial discharge detection in medium voltage three phase cables used in the power system

Pankaj Khandelwal, Inderjeet Singh

Assistant Professor, I.E.T. College, Alwar, Rajasthan, India

Abstract

Cable distribution networks are inherently complex and inaccessible systems; many of them are coming to the end of their original design life. As assets, they represent a dynamic and challenging issue with regard to the tasks of maintenance and management. Partial discharge (PD) has long been recognized as both a cause and symptom of the degradation of dielectric materials that protect high voltage plant. Utilities use the analysis of PD activity to make pre-fault decisions in areas such as maintenance, supply continuity and asset management. On-line PD monitoring systems are still in their relative infancy. An EDFEnergy Networks funded research is investigating and identifying trends in PD activity associated with specific faults that commonly occur in distribution networks. In this paper an experiment to mimic the conditions experienced by on-line cable sections in the field is described. PD measurement has been obtained using conventional techniques covered in IEC 60270 in parallel with a commercially available substation monitor that is employed in distribution networks worldwide. Later work will involve using this experiment to PD test cable samples that contain a range of defects. It is hoped that each defect mechanism will produce an unique trend in PD activity as it degrades towards failure.

Keywords: partial discharge

1. Introduction

Partial discharges are defined in IEC 60270 as: “a localized electrical discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor. Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. Generally, such discharges appear as pulses having duration of much less than 1 μ s.”

A partial discharge (PD) is short release of current caused by the buildup of electric field intensity in a finite region. In high voltage devices, such as transformers, PDs can be symptomatic of problems within the device such as floating components and insulation flaws.



Fig 1: Cable Heating Current Transformer

When a transformer is first manufactured, PD detection can be used as a tool to judge the state of the device and the quality of its manufacture. In addition, as the transformer ages, faults in the device can be created. Over time, electrical and mechanical stresses can damage materials within the

transformer, including the winding and the paper insulation lining the walls of the transformer tank. If the damage is not detected or corrected, the faults can cause the transformer to operate outside of its normal parameters and eventually a catastrophic failure will occur, causing potential damage to surrounding equipment and facilities, as well as lost revenue due to an unscheduled power outage. In a modern high voltage power system, PD detection is used to monitor the state of health of a transformer in service and helps plant managers schedule device maintenance.

The analysis of partial discharge (PD) signals is widely accepted as an effective method to identify the relative health of power cables. Extensive research has considered location, quantification and characterization of PD signal data. However, there is a limited reported result on the relationship between long term PD behavior and the various failure mechanisms experienced by three-phase cable circuits in the field. By developing a greater understanding of the characteristic PD signals produced by assets approaching their end of life, it is hoped to inform the process of planning suitable maintenance and management strategies.

This paper details an experiment that is designed to enable three-phase belted cables to be stressed in a manner representative of the conditions met by cable circuits in active use. The experiment provides control of voltage, current and cable temperature, allowing for complete three-phase PD data acquisition of cables experiencing realistic stresses under controlled laboratory conditions. The aim of this research is to investigate the trends in PD activity over time and relate them to specific failure mechanisms that are commonly reported in the field. PD measurement in accordance with IEC 60270 is implemented in parallel with a commercially available on-line

monitoring system.

The cable sections under test have had known defect during construction. Now recently Cross linked poly ethylene (XLPE) Three-phase cables are extensively used in India 1kV to 220KV in distribution, Generation and transmission network. As the majority of this extensively loaded network is reaching the end of its design life, huge interest is focused on developing techniques that could be used to provide real-time information regarding the health of the ageing cable asset. Traditionally, off-line PD testing of three-phase commissioned cable circuits involves the use of single phase energization, this is known to produce a linear electric field, rather than the rotating field generated under three-phase conditions. It is thought that due to the marked difference in electrical field distribution over time, different PD characteristics are observed during testing compared with the activity that occurs in the field. For this reason, the experiment utilizes a three-phase supply at the rated voltage, to more closely match field conditions.

2. Partial Discharge Testing

A partial discharge in an HV transformer (HVT) occurs when the electric field in a localized area changes in such a way that a localized current is created. This localized current manifests itself as an electrical pulse that is measurable at the output of the transformer. The most likely sources of PDs can be broken down into three categories: floating components, coronas, and voids. Information on the importance and mechanisms of floating components and coronas in HV transformers. However, the detection of PDs created by these two sources does not yield any useful information about the insulation because their appearance is not directly related to the condition of the insulation. Insulation breakdown is physically manifested as small cracks, *i.e.* voids, in the insulation; therefore, only void sources will be considered here. Voids are defined as gaps in a more dense dielectric material, such as gas bubbles in oil that fills the transformer tank, or cracks and fissures in the paper insulation lining the transformer walls. The void region has a lower dielectric constant than the surrounding material, creating a capacitance. A partial discharge can then occur when the electric field difference across the void exceeds minimum breakdown field strength. However, reaching this minimum field strength does not guarantee an immediate partial discharge.

In order for a PD to occur, two criteria must be met. First, the electric field difference across the void must be higher than the breakdown value, which is determined by the field's ability to accelerate an electron to the point that if it impacts another molecule, more electrons are knocked loose than are absorbed. Second, there must be a free electron present within a specific volume, whose size is proportional to the voltage across the void, to accelerate within the field. If these conditions are met, then the buildup of electrons in motion grows exponentially and a streamer, or electron channel, is created and current can flow across the void and return the voltage across the void to zero*. However, the presence and location of a free electron is a random process dominated by the presence of ambient radiation knocking electrons loose from surrounding materials. Even the largest source of ambient radiation in most systems, cosmic rays, creates very

few free electrons.

In summary, in order for a PD to occur, a free electron must be present within a voltage dependent volume while the electric field strength is high enough to cause a cascading flow of electrons from the movement of a single free accelerated electron. This need for free electrons makes the PD phenomenon very unpredictable and a PD can occur within minutes or within hours of reaching the breakdown field strength within the void. The resulting discharge manifests itself as an observable electrical, acoustic, and sometimes optical signal. It should be noted at this time that the exact mechanisms and resulting signal properties of a partial discharge are not completely understood, though there are loose guidelines that device designers can use in building detection systems.

3. Detection Methods

Over time, the insulation within an HVT begins to breakdown due to mechanical, thermal and electrical stress. Because partial discharges are both symptomatic of insulation breakdown and a mechanism for further insulation damage, PD detection is used to evaluate the condition of and diagnose problems with the HVT insulation. Over the past forty years, several methods have been developed to detect PDs within HVTs. These can be grouped into four categories, based on the PD manifestation that they measure: chemical, electrical, acoustic and optical detection.

Table 1: IS 7098 Part-2 1985 Medium voltage test voltage

Sr. No	Voltage Grade KV	Test Voltage bet conductor & screen or Armour KV rms	Test Voltage bet conductor KV rms
1	1.9/3.3	10	10
2	3.3/3.3	-	-
3	3.8/6.6	12	-
4	6.35/11	17	-
5	11/11	28	-
6	12.7/22	32	-
7	19/33	48	-

4. History of partial discharge

The Association of Edison Illuminating Companies (AEIC) specification CS5-69 was the first specification to address PD testing requirements above the PD extinction voltage. At that time, cables were manufactured with semiconducting tape shields or extruded thermoplastic semiconducting materials. In the 1970s, extruded semiconducting shields replaced semiconducting tapes. Cable was manufactured by simultaneously extruding a conductor shield and insulation material (using two extruders in tandem) onto a conductor in one operation. The cable was then taken to another extruder to apply the thermoplastic semiconducting insulation shield. In those early days, extrusion methods as just described were state-of-the-art. However, this sometimes resulted in cables with voids at the insulation-insulation shield interface. Admittedly, the extrusion process could also introduce voids within the insulation wall, but this could be controlled more easily than shield interfacial voids. These interfacial voids made it impossible to produce a PD-free cable at the AC test voltage.

Therefore, allowable PD limits were introduced by the AEIC Cable Committee. In 1976, one cable manufacturer introduced the extrusion of a strippable cross-linked insulation shield that was extruded through a common extrusion head with the insulation. By 1978, all XLPE cable manufactured by Phelps Dodge Cable and Wire was made using this process improvement. It was not until 1981 that a commercially produced triple extruded cross-linked insulation shield material was made available to the entire industry. This evolution in process and material improvements enabled the industry to make periodic reductions in the maximum allowable PD levels as further improvements were also made in the extrusion processes and testing facilities. By the late 1980s, PD on cables tested at $\sim 3Vg$ were practically eliminated.

It should also be noted that prior to 1987, PD testing and the AC voltage test level did not exceed 5.9 kV/mm (150 V/mil). Partial discharges (PD) have been recognized as a harmful ageing process for electrical insulation at the beginning of the last century when the HV technology was introduced for the generation and transmission of electrical power. Since that time numerous papers and books appeared, dealing with the physics and recognition of partial discharges. First industrial PD tests of HV apparatus were introduced at the beginning of 1940. The method applied was based on NEMA 107, which specifies the measurement of radio influence voltages (RIV) expressed in terms of μV . One disadvantage of this method is, however, that the RIV level is weighted according to the acoustical noise impression of the human ear, which is not correlated to the PD activity. Therefore, the IEC Technical Committee No. 42 decided the issue of a separate standard on electrical PD measurement associated with the PD quantity apparent charge, which is expressed in terms of pC.

The first and second editions of the IEC Publication 270 appeared in 1968 and 1981, respectively. IEC 60270 [High-voltage test techniques-Partial discharge measurements, third edition], Published in December 2000, covers besides classical analogue instruments also requirements for digital measuring systems. Moreover, the maintaining of specific characteristics of PD measuring systems by the user in a record of performance is recommended.

For better understanding the background of the current standard IEC 60270, WG D1.33 "High-Voltage Testing and Measuring Techniques" decided the edition of a Technical Brochure, which is intended as a guideline for engineers dealing with conventional electrical PD measurements. In this context it should be noted that currently the new standard IEC 62478 is under preparation, which covers non-conventional electromagnetic and acoustical PD detection methods. These topics, however, are outside of the scope of this brochure.

Partial discharges are defined in IEC 60270 as: "a localized electrical discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor. Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation generally, such discharges appear as pulses having a duration of much less than 1 μs ."

From a physical point of view self-sustaining electron avalanches may happen only in gaseous dielectrics. Consequently, typical discharge types occurring in ambient

air, such as glow, streamer and leader discharges, may also happen in gaseous inclusions due to imperfections in solid and liquid dielectrics. The pulse charge of glow discharges is in the order of few pC. Streamer discharges may create pulse charges ranging from about 10 pC up to some 100 pC. A transition from streamer to leader discharges may occur if the pulse charge exceeds few 1000 pC.

Original PD current pulses are characterized by a duration as short as few ns, as exemplarily shown in Fig.1. Consequently, the frequency spectrum covers the VHF and UHF range. The shape of such pulses, however, is strongly distorted if traveling from the PD site to the terminals of the test object. Different to this behavior the current-time integral is more or less invariant. As a consequence, not the peak value of the PD current pulses but the current-time integral, i.e. charge of the captured PD pulses, is most suitable quantity for assessment the PD intensity.

5. Partial Discharge Experiment

In the Partial Discharge testing laboratory whole lab is completely enclosed noise free area and that area known as Faraday cage. Due to Faraday cage outer atmosphere noise and electromagnetic fields not create any disturbances in the experiments. Laboratory is totally separated from atmosphere and required following instruments for conduct PD test.

1. Power Supply
 - a. Step Down transformer 415V/330V
2. Resonance Reactor or HVT (LVDT) Step up Transformer 330V/220KV 200KVA
3. Coupling Capacitor
4. Blocking Capacitor
5. Measuring Impedance device
6. Inductor for PI filter
7. Die elec Jiate complete set up for HV and PD testing
8. Pulse Generator

After several different type test passes by cable then its bring for conducting special test PD test. For conducting this test on XLPE cable both side cable termination done and separated each core of 3-phase cable and remove semiconducting layer or screen about one foot. All three terminal conductor insulation completely remove for connection of high voltage supply through PI filter to specimen.

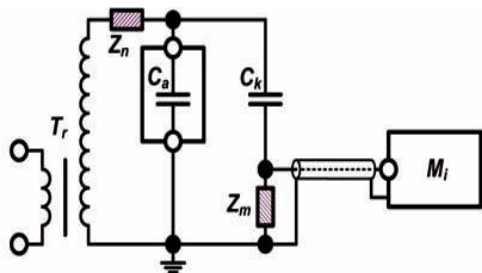


Fig 2: Partial Discharge test under progress on 185mm sq. 3-phase 11KV XLPE cable at diamond power ltd. Vadadatala, Vadodara, Gujarat.

6. PD measuring circuit

To ensure reproducible and comparable PD measurements in IEC 60270 three basic measuring circuits are recommended, which differ by the arrangement of the measuring impedance Z_m . The most common circuit employed in practice is shown in Fig. 2, where Z_m is connected in series with the coupling capacitor C_k . An option of the PD coupling unit is the so-called bushing tap coupling mode which is generally utilized for induced voltage tests of liquid-immersed power transformers. Here the high voltage bushing capacitance C_l represents in principle the coupling capacitor C_k . The measuring impedance Z_m is connected to the tap of a capacitive graded bushing, usually intended for loss factor measurements.

External electromagnetic noises disturbing sensitive PD measurements can be eliminated at certain extent if a balanced bridge is employed. Here both, the measuring and the reference branch, consist of a coupling unit comparable to Fig. 2. Balancing the bridge by adjusting both measuring impedances, external common mode noises can be rejected effectively by means of a differential amplifier.



T_r – HV test transformer
 C_a – Virtual test object capacitance
 Z_m – Measuring impedance as part of the coupling device
 Z_n – Noise blocking filter
 C_k – Coupling capacitor
 M_i – PD measuring instrument

Fig 3: PD measuring circuit

7. PD Instruments

7.1 YKTY Resonance Reactor Dielec technique- JIATE electric

Rated output capacity-2500KVA,
 Rated output voltage-250/120/75 KV
 Rated output current-10/16.7/33.3 Ampere
 Inductance range-7 Henry to 298 Henry
 Work & rated frequency- 50Hz weight- 14000kg
 Factory no-0708219

7.2 Control system Dielec technique- JIATE electric

Type: JTKZ-IV
 Rated capacity- 2KVA
 Rated voltage-380V
 Rated current- 5Amp
 Output No. 1005480, Manufacturer Date-10.5

7.3 Separate Transformer Dielec technique- JIATE electric

Type- Dist-2500
 Rated capacity- 125KVA
 Input Voltage- 415V, Input Current- 301 Amp
 Output Voltage- 380/220V, Input Current- 315/23 Amp
 Production Date- 08.1, Factory No. 0708219

7.4 Low Voltage Filter Dielec technique- JIATE electric

Type-LVF-125 KVA
 Rated Capacity- 125KVA
 Output Voltage- 380V
 Input Voltage- 380V
 Production Date-1-2008, Factory No. 0708219

7.5 Large Capacity Voltage Regulator of Touch (AUTO Transformer)

Type- TDGZ- 2500
 Rated capacity- 125KVA, Rated Frequency- 50Hz
 Input Voltage- 380V, Input Current- 328.9 Amp
 Output Voltage- 0 to 420V, Output Current- 207.6 Amp
 Production Date- 08.1, Factory No. 0708219

7.6 Excitation Transformer Dielec technique- JIATE electric



Fig 4: Resonance (LVDT) Transformer With Excitation Transformer

Type- EXC-2500

Rated capacity- 125KVA, Rated Frequency- 50Hz
 Input Voltage- 380V, Input Current- 328.9 Amp
 Output Voltage-12.5/7.5/3.765 KV, Output Current-
 10/16.7/33.3 Amp
 Production Date- 08.1, Factory No. 0708219

Resonance System: (Blocking Capacitor)



Fig 5: PD HV Resonance Set Of Transformer, PI Filter

7.7 High Voltage Wave Filter (03 Nos) Dielec technique- JIATE electric

Type- HVF-2500, Capacity-0.004 micro Farad, Inductance-
 0.2 Henry Rated Voltage- 250 KV, Rated Current- 35A

7.8 Coupling Capacitor (Implant Capacitor)

Type- 2500

Rated Voltage- 250 KV

Production Date- 08.1, Factory No. 0708219

8. PD circuit calibration

The quantitative assessment of the apparent charge transferred from the PD source to the terminals of the test object is based on the approach of Gemant and Philipp off, often referred to as a–b– c model due to the characteristic capacitances $C_a - C_b - C_c$, Due to the series connection of C_b and C_c , where the condition $C_b / C_c \ll 1$ is always satisfied, the apparent charge q_a detectable at the test object terminals can be written as:

$$q_a = q_c * C_b / C_c \tag{1}$$

That means the measurable apparent charge q_a is only a small fraction of the true pulse charge q_c created in the PD source. Consequently, the PD severity of HV apparatus cannot be estimated on the basis of the apparent charge alone, because the ratio C_b / C_c is not known at all. Therefore, knowledge rules for PD diagnosis have been established in the past which are based on practical experiences gained from comprehensive PD studies in laboratory and on-site. Each PD event causes a reading R_i of the PD instrument which is proportional to q_a . To measure this quantity in terms of pico Coulomb (pC) the Standard IEC 60270 specifies a calibration method which is based on the simulation of the internal charge transfer between the PD source and the terminals of the HV apparatus by means of an external adapted calibrator. Based on this calibration procedure the apparent charge of a PD pulse is defined in IEC 60270 as:

“That charge which, if injected within a very short time between the terminals of the test object in a specified test circuit, would give the same reading on the measuring instrument as the PD current pulse itself.”

The PD calibrator is generally equipped with a pulse generator connected in series with a calibrating capacitor. In order to simulate the transient voltage across the PD defect the pulse generator creates equidistant voltage steps of known magnitudes U_0 . If the value of the calibrating capacitor C_0 is substantially lower than the value of the virtual test object capacitance C_a , the calibrating charge injected in the test object terminals,

$$q_0 = C_0 * U_0 = C_a * U_1 \tag{2}$$

If real PD events appear, the apparent charge is given by:

$$q_a = C_a * U_2 \tag{3}$$

Introducing equation (2) in equation (3) the unknown value of C_a can be eliminated and we get: $q_a = q_0 * U_2 / U_1$ (4) Because the transient voltages U_1 and U_2 , which appear across the test object capacitance C_a , cause the readings R_0 and R_i , equation (4) can also be written as:

$$q_a = q_0 * R_i / R_0 \tag{5}$$

Where the ratio R_i / R_0 represents the scale factor S_f of the PD measuring circuit applied.



Fig 6: Partial Discharge Lab HV Transformer and Coupling and blocking capacitor with Inductor with toroide.

9. Test results

In this thesis we had tested some fresh cable in the lab of 185 sq. mm 3-phase XLPE cable after manufacture in the Diamond power company. Before testing platform of specimen both side six terminal are open and armour, screen and insulation completely removed of 2 foot. As we can see in the fig. 5.1 only 5.36 pC on voltage stress of 7KV upto 20KV. This PD charge value is with in the limit.



Fig 7: Partial Discharge test result in new manufactured 185 sq. mm cable drum tested.



Fig 8: PD testing Set up panel with HV testing and PD calibrator.

In testing we had created faulty condition by provide sharp age at the testing area then result comes 47 pC. By PD calibrator only sent 20 pC. But faulty condition present so it sense fault and pC value almost double to calibrator.



Fig 9: Artificial Faulty condition creates by Sharpe edge in testing area near cable terminal and coupling capacitor. Following test result of 3Cx300 sq.mm 6.35KV, 250 meter XLPE cable tested in PD laboratory.

Table 2: PD Test results of cable with and without artificial fault create.

Sr no	I/P Volt	I/P Current Amp	O/P Volt KV	O/P Current Amp	pC	Remark
1	13.9	10	9	0.7	5	Normal test
2	5.9	7.1	10.3	.29	53	Artificial fault create

10. Conclusion

Partial discharge detection and location in medium voltage cable is an essential diagnostic tool for identify the state of health of electrical insulation. The insulation breaks down over time due to mechanical and electrical stresses and if the insulation damage becomes severe, the device could suffer a catastrophic failure that not only causes an unscheduled service outage, but also causes damage to surrounding equipment and threatens the safety of onsite personnel. Partial discharges are one symptom of insulation breakdown because the developing faults in the insulation cause a local build up of electrical charge, which is then dissipated in the form of an electrical and mechanical pulse of energy.

In addition, PDs make insulation damage worse because the event adds more electrical and mechanical stress to the developing flaw. Therefore, accurate detection and positioning is required to maintain these devices and limit the amount of diagnostic and repair time required. This thesis presents convention detection system consisting HVT with measuring Instruments. This facility available only in cable manufacturer and testing institute like CPRI, ERDA, PD detection equipment, allows the sensor to measure higher signal amplitudes.

11. References

1. Zhang Hao, Duan Yubing, Wang Bin, Liu Hui, Lin Ying, Hu Xiaoli, *et al.* Wang Miao Case Analysis on Partial Discharge Signal of XLPE Cable T-Joint by Using High-Frequency Pulse Current Method 4th International Conference on Power and Energy Systems Engineering, CPESE, (ELSEVIER), Berlin, Germany. 2017; pp. 25-29.
2. Joshua Perkel, Jean Carlos Hernandez-Mejia. Medium Voltage Cable System Partial Discharge Chapter 7, Georgia Tech, NEETRAC, 2016.
3. Halim HAS, Ghosh P. Condition assessment of medium voltage underground PILC cables using ppartial discharge mapping and polarization index test results, proccs from the IEEE International Symposium on Electrical Insulation Conference. 2008; pp. 32-35.
4. Wester FJ, Guilski E, Smith JJ. Detaction of partial discharge at different AC voltage stresses in power cables, IEEE Electrical Insulation magazine. 2007; 23:28-433.
5. Van Der Wielen PCJM, Steenis EF, Wouters PAAF. Fundamental aspects of excitation and propagation of on-line partial discharge signals in three-phase medium voltage cable systems, IEEE Trans. on Dielectrics and Electrical Insulation. 2003; pp. 678-688.
6. Boggs S, Densley J. Fundamentals of partial discharge in the cables” A protection system has been developed to ensure safe context of field cable testing, IEEE EElectrical Insulation magazine. 2000; 16:13-18.
7. Franklin AC, Franklin DP. The J&P Transformer Book, 11th ed., London: Butterworth’s, 19.