Partial Discharge Analysis on Crossed-linked Polyethylene (XLPE) Cable 150 KV

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Abstract. Partial discharge is the flashover of sparks that occur in an insulating part, as a result of the high potential difference in the insulation. Partial discharge can occur in solid insulation materials. It is a play an important role in the electrical power system to separate two or more conductor of electric voltage. So, between these conductors do not occur flashover. The material was chose as the insulation material for high voltage equipment is polymer material, it is because in addition to having a high breakdown voltage. Polyethylene is one of the materials included in the polymer group, generally better known as plastic because the material is thermoplastic. There are several methodologies before conduct this research, that includes literature studies. Literature Studies is a research method by finding material from various libraries on topics that will be discussed in this research. Do Partial Discharge testing. And then, record the data obtained. From the experiments that have been done, the results show that a good Partial Discharge value is below 10 pC, if the cable has more than doubled from the normal value, the cable have been damaged or have been consumed by the age of the cable.

1. Introduction

1.1. Partial Discharge

Partial discharge is the flashover of sparks that occur in an insulating part (in a deep cavity or on a surface) as a result of the high potential difference in the insulation. This phenomenon arises due to many factors including the quality of the dielectric material, the cavities in the dielectric material, as well as the damage or imperfections in the process.

Partial discharge (PD) phenomenon if it occurs continuously it will cause overheating in certain areas which will damage the insulating material and lead to system failure. Before all of this happens it is very important to do initial detection and identification to find the cause of electrical discharge that can reduce the quality of the dielectric material from a system that uses it. Some of these causes can be identified from the responses that arise in the electrical discharge test. In this test, the variety of responses that can be investigated with discharge detection devices for each type, shape or pattern of electrical discharge on the oscilloscope and its relationship with variations in voltage testing and voltage application within a certain time [1].

PD testing is related to quality and quantity values. The quality value is analyzed from the tendency of the data obtained from the characteristics of the material in a particular test. While the quantity value is the nominal value of PD which has the dimension of pico coulomb (pC). Both of these values must meet the standards on testing so that the quality of the equipment can only be assessed. In detecting Partial Discharge (PD) occurs at a certain voltage level called the inception voltage and does not occur at a certain voltage level called the Extinction voltage. If the voltage at the applied source is sinusoidal, the threshold and extinct stresses occur as described in Figure 1. Also, there are a lot of interference signals...
detected on the detector as noise, can cause misperceptions and reduced measurement sensitivity in testing. The correct interpretation of the characteristics of PD in the equipment being tested depends on the experience of the researcher in conducting the test.

**Figure 1.** Inception voltage and extinction voltage in sinusoidal waves

PD is a consequence of local electrical stress concentrations in the insulation or on the insulation surface. PD occurs under less than 1 µs, with various occurrence phenomena (internal, surface, corona, and treeing). The figure above shows a model that illustrates the appearance of cavities in partial discharges in a cable insulation system, voids are modeled as Cc capacitors with lower permittivity than insulation permittances [2].

### 1.2. Types of Partial Discharge

Partial discharge appears in electrical equipment, including cable insulation, Transformers (winding, oil insulation), Generators (Stator, Motor), Gas Insulated Substation, and so forth. Internal discharge is PD which is located inside the insulation (both solid and liquid insulation). The form of internal discharge varies, among others: shaped like a sphere/space, long - both perpendicular or intersecting with the electric field. Corona discharge is not related to insulation systems like other types of partial discharges, corona appears on the gas media because there is no homogeneous field between high voltage conductors.

Channel discharge or treeing arises because of internal discharges that occur continuously in the dielectric discharges that arise continuously cause erosion of the material which results in the formation of treeing patterns. Treeing can occur due to the presence of metallic particles (due to imperfect insulation manufacturing processes) or voids inside the insulation, delamination in the insulation, and rough structure on the inside of the conductor [3].

### 1.3. Properties of Electronic Materials

Dielectric is a material that has a very small or even almost no current conductivity. The dielectric material can be in the form of solid, liquid and gas. Unlike a conductor, in dielectric materials, there are no conduction electrons which are free to move throughout the material by the influence of the electric field. The electric field will not produce charge movements in the dielectric material. It is this property that causes the dielectric material to be a good insulator. In a dielectric material, all electrons are firmly bound to their nuclei so that a solid body structure (lattices) is formed, or in the case of a liquid or gas, the positive and negative parts are bound together so that each mass flow is not a transfer of charge. Therefore, if a dielectric is given an electric charge, this charge will stay localized in the area where the charge was placed.

According to Gauss’s law, the magnitude of the electric flux density that penetrates each closed surface is equal to the total charge covered by that surface can be calculated by the following equation [4].
\[ B = \frac{Q}{A} = \mu H \]  

(1)

where:

- \( B \) = Flux density (Wb m\(^{-2}\) or Tesla)
- \( Q \) = Big load on Coulomb
- \( A \) = Cross-sectional area \( m\(^2\) \)
- \( H \) = Electromagnetic field (A/m)
- \( \mu \) = Permeability (Henry/m)

The intensity of the magnetic field is affected by the permeability of the material and flux. So \( \mu \) can be calculated by the equation

\[ \mu = \mu_o \mu_r \]  

(2)

where

- \( \mu_o \) = Empty space permeability
- \( \mu_r \) = Material permeability

The use of dielectric material as isolation between electrodes affects the capacitance. This capacitance effect will have different characteristics depending on the permeability of the dielectric material. The capacitance effect has the same properties as two plates parallel to a permeability of material flowed by a voltage source. This capacitance is very closely related to the intensity of the magnetic field \( (H) \) and the flux density \( (B) \) and the permeability of the empty space \( (\mu_o) \) and the permeability of the material \( (\mu_r) \). According to Gauss’s law, the magnitude of the electric flux density that penetrates each closed surface is equal to the total charge covered by that surface can be calculated by the equation \([4, 5]\).

1.4. The Mechanism of Partial Discharge (PD)

The manufacturing process of the insulator is expected to provide an average distribution of electrical stress from the voltage electrode. This is very difficult to achieve because in every manufacture of insulation materials still produce cavities in it. One of the mechanisms of PD is caused by a gap or cavity in the insulating material. It was illustrated that when \( V \) is the applied voltage across the dielectric, the voltage \( V_c \) across the cavity will be given as \([6]\):

\[ V_c = C \frac{C_b}{C_b + C_c} \]  

(3)

This voltage may cause void breakdown depending on the instantaneous value of \( V_c \) and dielectric strength of air inside the void, since stress in the void \( (E_c) \) may become much higher than the average stress in the dielectric. The energy released in this discharge will cause deterioration of the dielectric.

In solid insulation materials, the cavity contained in the insulation material is usually filled by air or gas which has a permeability of material lower than the surroundings. The mechanism of the occurrence of PD can be explained in more depth by using the illustration as shown in Figure 1, in the cavity contained in this insulating material, there is a partial capacitance effect.

The capacitance effect that occurs has a lower material strength, thus causing a greater field intensity in the cavity. The intensity of this large field can cause arcs of fire. This arc indicates the load jump in the cavity. Furthermore, the arc will be muffled and start charging until it finds another cavity to release it again. The phenomenon of short discharge and the length of time it occurs repeatedly is referred to as partial discharge. If it happens continuously it will be able to damage the insulating material \([2, 7]\).
2. Experimental Method

2.1. Object Tester
In this research, there are two types of cables that we used, which is the new 150 KV Crossed-linked Polyethylene (XLPE) cable and the old of XLPE cable, the length of each cables is 1 meter.

2.2. Test Setup
This is the test setup that are used to this Partial Discharge Research.

![Image of test setup](image)

**Figure 2.** Test setup of PD measurement

The equipment to be used are: HV9105 (HV Test Transformer), HV9103 (Control Desk), HV9146 (Coupling Capacitor), HV9150 (AC Peak Voltmeter), HV9106 (HV Flexible Connector), HV9107 (Earthing Rod), and (HV9153) Partial Discharge Meter.

2.3. Partial Discharge Testing
Testing procedures that must be considered before carrying out Partial Discharge testing on the High Voltage test transformer are:

1. Preparation of tools and materials. In this preparation, we need to prepare partial Discharge test equipment including Coupling Capacitor, Transformer, Regulators, Resistors 100 M Ohm, Partial Discharge Meters, Jumpers, and Cable Grip. And, for the test material is the old of 150 KV XLPE cable and the new 150 KV XLPE cable

2. String up the Partial Discharge circuit in the test transformer by the experiment circuit guideline, after completing the stringing, apply voltage to the XLPE cable with a large 20 KV, 40 KV, 60 KV, and 80 KV. Apply each voltage in each side which are left side, right side and middle side of the cable and measure the Partial Discharge using Partial Discharge Meter and make sure the jumper is tightly connected to the grip of the cable.

3. Data Recording. In this test, data collection was carried out 4 times on each side, which is the right side, the left side and the middle, after each time the data was taken, the partial discharge meter must always be calibrated, so the data that taken will always be accurate.

4. Report: Entered data in the report is the result of data retrieval on each side of the cable, the amount of data obtained is as much as 12 for each cable.
3. Result and Discussion

3.1. Partial Discharge Test Results on the New XLPE Cable 150 KV

The data in the table below is the Partial Discharge test data on the new 150 KV XLPE cable.

| Voltage (V) | Partial Discharge Value (pC) |
|------------|-----------------------------|
|            | Left | Middle | Right |
| 20         | 6.13 | 3.43   | 7.15  |
| 40         | 7.83 | 4.07   | 7.83  |
| 60         | 8.06 | 4.19   | 8.34  |
| 80         | 8.94 | 3.52   | 9.80  |

Table 1. Partial discharge data on the new XLPE cable 150 KV

Figure 3. Partial discharge value on XLPE cable 150 KV

Table I and Figure 3 above show that on each side of the cable, showing different values, and when given a different voltage. From the picture above shows that the cable used is the new cable because it can be seen from the value of the Partial Discharge, each side shows below the maximum value of the IEC standard value 60270: 2000 which is 10 pC (pico Coulomb).

In terms of insulation, XLPE has a better work resistance but the price is more expensive compared to other types of synthetic insulation. XLPE has the best characteristics. But in general, synthetic insulation has advantages over paper insulation, that is, it is cleaner, the way to connect is easier, and the working temperature is higher.

Partial discharge (PD) is the flashover of sparks, which results from imperfections or inhomogeneous insulation materials. The standard value of partial discharges that do not hurt an object of insulating material is 10 pC, and the scale of partial discharges is up to 10000 pC.
3.2. Partial Discharge Test Results on the Old XLPE Cable 150 KV

Table 2. Table of partial discharge data on XLPE cable 150 KV

| Voltage (V) | Partial Discharge Value (pC) |
|-------------|------------------------------|
|             | Left | Middle | Right |
| 20          | 63.51 | 16.87 | 79.15 |
| 40          | 77.84 | 22.77 | 83.48 |
| 60          | 82.78 | 89.51 | 88.84 |
| 80          | 89.51 | 89.51 | 89.51 |

Figure 4. Partial Discharge value on XLPE cable 150 KV

From the data above, it can be seen that the resistance of the XLPE cable has reached its limit, it can be seen that there have been several points that have reached its maximum value, it is showing that the cable has been classified as a damaged cable because it has passed the standard value of Partial Discharge which is 10 pC.

There are several factors of underground cable damage that affect the value of each side of the cable, which are:

a. the level of soil moisture, when the cable has been aging, the cable surface can be easily penetrated by moisture causing corrosion around the cable.

b. ground movement causes the cable to shift, thus issue making it quickly damaged.

This factor plays a role in the destruction of underground cables and will damage to the cable so that Partial Discharge is very easy to penetrate in cable construction. If it is continuously, there will be a lot of energy losses that occur resulting in a decrease in efficiency in transmitting the electricity power.

4. Conclusion

The conclusions that can be drawn are:

1. Partial Discharge on the cable is influenced by the amount of the voltage that applied to the test object and is influenced by the physical condition of the cable and the quality of cable insulation.
2. The more partial discharge the cable produces, the more fully discharge are obtained.
3. Partial Discharge will easily penetrate to the core of the cable and will impact to the result of the amount of energy.
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