PARTIAL DISCHARGE MODELLING OF HIGH VOLTAGE XLPE CABLE

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Abstract :

Reliability of power system equipment mainly depends on the insulating system and detection of partial discharge (PD) plays a vital role to identify the insulation defects in the earlier stage. Partial discharge will takes place at the weak insulating regions such as voids in solid insulators and it may lead to heavy damage to the insulating system. The voids within the insulators can be represented with capacitor model thus the partial discharge is simulated. In this paper partial discharge are simulated using MATLAB Simulink for 110kV cross-linked polyethylene (XLPE) cable by implementing the standard PD model. The results reveal that the PD current decreases with the voids distance from the conductor core.

Key words: XLPE (cross-linked polyethylene) cable, Partial Discharge, Void, Void distance

1. Introduction

The majority of power system equipment like transformers, circuit breakers, surge arrester, transmission cables etc. involves insulators and reliability of these equipment depends on the insulation. Partial discharge occurs within the dielectric medium because of the high electrostatic pressure and it affects the life time of the insulating system. This PD causes local discharge within the dielectric medium and may connect the conductor ends and in case of cables it happens at the cable terminations and joints. [1-4]. When insulators consists of deficiencies like split, voids or flaw the dielectric strength will be less at that point and insulation become weak. This will cause partial discharge and may lead to major breakdown in dielectric medium. [5,6]This PD can be classified into three types namely, corona discharge, surface discharges and internal discharges. The discharge which takes place in liquid or gas dielectric medium around the conductor is corona discharges. Surface discharge will takes place from conductor into liquid or gas and appear on the exterior of the solid dielectrics. The discharges takes place inside the insulators due to voids is called internal discharges [7]. The sufficient awareness of the movement, occurrence, type and form of PD helps in its impediment and successful management. Deviations and unexpected changes in the dissipation factor with the supply voltage is a sign of PD inception. By doing
void simulations, the PD activity can be understood in a better way and the simulation work can be carried out by modelling the capacitance value perfectly.

A high voltage cable with XLPE (cross linked polyethylene) insulation, voltage rating of 110kV with void (spherical) is considered here and the two dimensional diagram geometry model is also created for better understanding[8]. The parameters which includes resistance and capacitance of insulator & void are calculated. Matlab Simulink is used for simulating partial discharge and the results are obtained for the voids at the various distances[9-11].

The PD activity in insulators with voids can be expressed by a capacitance equivalent circuit designed by Gemant & Philippoff [12], equivalent circuit of dielectric with voids is shown in figure 1.
Where C1 is the capacitance of the void
C2 – capacitance of the insulator that lies in series with the void
C3 – Capacitance of the remaining insulator parallel to C1 and C2.

![Fig. 1 Partial discharge in a void and its equivalent circuit](image)

**2. Construction of XLPE cable**

The construction of 110kV XLPE cable is shown in the figure 2. The copper conductor is considered in this work and it is surrounded by semiconductor screen. Over the semiconductor screen, XLPE insulation with semiconductor tape and final outer sheath. The outer sheath is made up of polyethylene sheathing, or PVC plasticate sheathing. As the XLPE cable does not require oil it is eco friendly and less maintenance cable. Its single design makes it flexible for laying.

![Fig. 2 Construction of XLPE cable](image)
3. Design of Parameters

3.1 Construction of XLPE cable with voids

The figure 3 shows the schematic diagram of the three capacitor model for insulators with void.

- $R_{\text{void}}$ - Resistance of the void
- $R_{\text{seri}}$ - Resistance of the insulator that lies in series with the void
- $R_{\text{parl}}$ - Resistance of the remaining insulator
- $C_{\text{void}}$ - Capacitance of the void

![Schematic diagram of Cable Insulation model](image)

Fig. 3 Schematic diagram of Cable Insulation model

- $C_{\text{seri}}$ - Capacitance of the insulator that lies in series with the void
- $C_{\text{parl}}$ - Capacitance of the remaining insulator

The cross sectional 2D diagram of XLPE cable construction including void is shown in the figure 4. The parameters like radius and distances are represented in the diagram. The parameters of 110 kV XLPE cable are referred from Estralin [13]

- $r_{\text{con}}$ - Radius of the conductor or core
- $r_{\text{void}}$ - Radius of the void
- $r_{\text{cs}}$ - Radius of Cable
- $d_{\text{ins}}$ - Distance between conductor and outer sheath
- $d_{\text{cv}}$ - Distance between conductor and centre of void
3.2 Parameter Calculation

The capacitance and resistance values of cable with void is presented as in [14]

As per the Gauss’s law (Nayfeh and Brussel, 1985), the potential difference between shell of any two concentric cylinders with radius $R$ and $r$ is given by

$$V_{R-r} = \frac{q}{2\pi \varepsilon_0 \varepsilon_r} \ln\left(\frac{R}{r}\right) \quad ....... (1)$$

Where $q$ is the charge of conductor in coulombs per metre length. The value of capacitance between the concentric cylinders of insulator can be derived as

$$C_{R-r} = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln\left(\frac{R}{r}\right)} \quad ....... (2)$$

From the above equation the capacitance value of the regions $C_{s1}$ (from core outer surface to void) and $C_{s2}$ (from void to outer sheath) can be derived as

$$C_{s1} = \frac{\varepsilon_0 \varepsilon_r \ln(t_v t_v)}{\ln\left(\frac{r_{con}+d_{cv}}{r_{con}}\right)} \left(\frac{r_{con}+d_{cv}}{r_{con}}\right) \quad ....... (3)$$

$$C_{s2} = \frac{\varepsilon_0 \varepsilon_r \ln(t_v t_v)}{\ln\left(\frac{r_{con}+d_{ins}}{r_{con}+d_{cv}}\right)} \left(\frac{r_{con}+d_{ins}}{r_{con}+d_{cv}}\right) \quad ....... (4)$$

Thus capacitance in series with the void can be found from equation

$$C_{seri} = \frac{C_{s1} C_{s2}}{C_{s1} + C_{s2}} \quad ....... (5)$$
Neglecting tv with respect to the length of the cable L (consider it as 1 m) the parallel capacitance \( C_{\text{parl}} \) is given by the following equation

\[
C_{\text{parl}} = \frac{2\pi \varepsilon_0 \varepsilon_r L}{\ln \left( \frac{r_{\text{con}} + \text{dins}}{r_{\text{con}}} \right)} \quad \text{....... (6)}
\]

The void capacitance can be found by substituting relative permittivity as 1, since it is filled with air the \( \varepsilon_r = 1 \). \( C_{\text{void}} \) is given by

\[
C_{\text{void}} = \frac{\varepsilon_0 l_v t_v}{\ln \left( \frac{r_{\text{con}} + \text{dcv} + r_{\text{void}}}{r_{\text{con}} + \text{dcv} - r_{\text{void}}/2} \right)} \quad \text{....... (7)}
\]

Similarly the insulation resistance values of void, series and parallel are given by the relation between insulation conductivity and insulation region [15]. Like capacitance, resistances in two regions \( R_{s1} \) and \( R_{s2} \) is

\[
R_{s1} = \frac{1}{\sigma \text{ins}} \frac{r_{\text{con}} + \text{dcv}}{l_c t_c} \ln \left( \frac{r_{\text{con}} + \text{dcv} - r_{\text{void}}/2}{r_{\text{con}}} \right)
\]

\[
R_{s2} = \frac{1}{\sigma \text{ins}} \frac{r_{\text{con}} + \text{dcv}}{l_c t_c} \ln \left( \frac{r_{\text{con}} + \text{dins}}{r_{\text{con}} + \text{dcv} + r_{\text{void}}/2} \right)
\]

\[
R_{\text{seri}} = R_{s1} + R_{s2}
\]

Similar to capacitance value the parallel and void resistances are given by

\[
R_{\text{paral}} = \frac{1}{2\pi \sigma \text{ins}} \ln \left( \frac{r_{\text{con}} + \text{dins}}{r_{\text{con}}} \right)
\]

\[
R_{\text{void}} = \frac{1}{\sigma \text{ins}} \frac{r_{\text{con}} + \text{dcv}}{l_c t_c} \ln \left( \frac{r_{\text{con}} + \text{dcv} + r_{\text{void}}/2}{r_{\text{con}} + \text{dcv} - r_{\text{void}}/2} \right)
\]

The electric field created inside the void is enlarged, so it is necessary to introduce correction factor \( K_r \) [16]. For spherical void with radius \( a \) the \( K_r \) is equal to

\[
K_r = \frac{3\varepsilon_0}{1 + 2\varepsilon_0} \quad \text{then}
\]

Corrected \( C_{\text{void}} = C_{\text{void}} \cdot \varepsilon_0 / K_r \)

Corrected \( C_{\text{seri}} = C_{\text{seri}} \cdot K_r \)

Corrected \( R_{\text{seri}} = R_{\text{seri}} / K_r \)
The above parameters are calculated for voids at various distances. The specification data [13] for 110kV XLPE insulator is given by

- $r_{\text{con}}$ - 9 mm Radius of the conductor or core
- $r_{\text{void}}$ - 1 mm Radius of the void
- $r_{\text{cs}}$ - 32 mm Radius of Cable
- $d_{\text{ins}}$ - 23 mm Distance between conductor and outer sheath
- $\varepsilon_0$ - 8.854 e-12 F/M
- $\varepsilon_r$ - 4
- $\sigma_{\text{ins}}$ - 7e-17 mho/m

The capacitance and resistance values are calculated for various void distances and are tabulated in Table 1.

<table>
<thead>
<tr>
<th>Calculated C and R values</th>
<th>Void Distance from Core (dcv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dcv = 0.25Xdins</td>
</tr>
<tr>
<td>$R_{\text{void}}$ (Ω)</td>
<td>1.429 X 10^{-16}</td>
</tr>
<tr>
<td>$R_{\text{seri}}$ (Ω)</td>
<td>1.9 X 10^{-17}</td>
</tr>
<tr>
<td>$R_{\text{paral}}$ (Ω)</td>
<td>2.88 X 10^{-13}</td>
</tr>
<tr>
<td>$C_{\text{void}}$ (F)</td>
<td>2.66 X 10^{-13}</td>
</tr>
<tr>
<td>$C_{\text{seri}}$ (F)</td>
<td>2.6467 X 10^{-12}</td>
</tr>
<tr>
<td>$C_{\text{paral}}$ (F)</td>
<td>1.754 X 10^{-10}</td>
</tr>
</tbody>
</table>

4. Result and Discussion

The three capacitor model of XLPE insulation cable is simulated using MATLAB Simulink and the simulink diagram is shown in the figure 5. The capacitor and resistance values obtained for various void distances are calculated and PD current for each value is obtained. The breaker opening time and closing time are set as 1/60 and 1/55 seconds respectively. The PD current value shows that when the void is nearer to the core the partial discharge current value is high and for the long distance i.e eighty percentage of dins the value of current is less.
5. Conclusion

The simulation obtained for XLPE insulating cable revealed that the PD activity of cable under void condition can be simulated with PD equivalent circuit. The circuit is simulated for void distance of 20%, 50% and 80% of total insulation thickness $d_{ins}$. The input voltage value is maintained same for comparison. The PD voltage and current wave forms are obtained and analysis of PD current value showed that the PD current value
depends on the void distance from the conductor. When the void is nearer to the conductor the partial discharge current value is higher than the void away from the core.

References

[13]. Estralin HVC Power Cables and Cable systems 6-220 kV modern solutions for power cables.