Voltage stress reduction for distribution line covered conductor

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Abstract. Interruptions due to vegetation frequently occur at the distribution line in Indonesia. Follows to that, the distribution utility decided to replace the bare conductor with the one-layer XLPE cable. However, new problems occurred mainly at the link between the XLPE cable and the post insulator on each of distribution pole. The high permittivity material of XLPE and the ceramic insulator enhance the local electric field that produces pinholes on cables. In the later phase, the pinholes become more extensive and if there is a lightning strike that causes a voltage that exceeds the Basic Insulation Level of the insulator, then the electric arc will flow from the conductor to the ground isolator through the pinhole. This paper proposed a novel design to cover the cable, including its accessories. Based on a simulation using a finite element analysis, the electric field stress is reduced by the following steps: 1. Add a semiconductor layer on the XLPE layer, 2. Replace the ceramic insulator with the polymer one, 3. Modify the binding between the cable and the post insulator by using a unique clamping method.

1. Introduction

Many electricity distribution line in Indonesia pass through trees. This condition causes frequent temporary ground fault when the bare conductor comes in contact with the tree. To deal with these problems, the distribution unit replaces bare conductors using a covered conductor which by Indonesian standards, this covered conductor has only one insulation layer Cross-linked polyethylene (XLPE) [1].

As they are used in the field, many covered conductors are burn down. The burn down of the covered conductor is caused by a series of processes. It started with the occurrence of pinholes on XLPE material caused by the occurrence of operational stress on the material. When a pinhole has occurred in the insulating material, if there is a lightning strike that causes a voltage that exceeds the Basic Insulation Level of the insulator, then the electric arc will flow from the conductor to the ground isolator through the pinhole [2-3].

Based on the short circuit test results, it can be seen that the energy needed to burn the covered conductor down at a certain mechanical pull value, has a certain value which called as critical energy. If the value of arcing energy that flowing from pinhole to ground during a short circuit exceeds the critical energy value, the covered conductor will experience heating, melting and burn down. This critical energy is the multiplication result of voltage, current, and the duration of the short circuit. Melting speed due to arcing is linearly proportional to the cross-sectional area of the conductor [3-8].

Based on simulation result in Pramana et al [1], the current and voltage values of the short-circuit are greatly affected by the short-circuit resistance which is the sum of the grounding pole resistance and the
arcing resistance. However, to simplify the problem, the arcing resistances are considered constant due to there is no valid model to simulate this resistance value. Therefore, the voltage and current of short circuit is only affected by the earth grounding pole.

The duration of the short circuit to burn the covered conductor down varies with the magnitude of the grounding resistance of the pole where the short circuit occurs, the distance of the short circuit point to the source (150kV / 20kV transformer), and the size of the covered conductor cross section. The closer the short circuit point to the source, the shorter duration needed to burn the covered conductor down. Therefore, the ground fault relay will not detect the fault, because the working time of the ground fault relay will be greater than the duration of time to burn the covered conductor down. From the simulation results it is also known that in the greater ground resistance value, the relay will also be difficult to detect fault, then the covered conductor will burn before the relay can respond [9-10].

2. Methodology
In this study, design modification of the internal covered conductor construction and its post insulator material is performed to minimize the voltage operational stress of the covered conductor. The study is performed by the simulation process through the finite element software.

2.1. Covered conductor internal construction modification
Figure 1(a) shows the cross section of covered conductor current construction which consists of conductor beams and insulation material in the form of XLPE. Based on this construction it can be seen that the conductor beam is in direct contact with the XLPE insulation material without any separating material.

Based on the results of Pramana et al [1], it can be seen that by using the existing construction, the maximum voltage stress occurs in XLPE material so that if it used for a long time, the XLPE material will forming pinhole. To reduce the voltage stress that occurs, a finite element simulation is performed to find the appropriate covered conductor construction. In this simulation the internal construction of covered conductor is proposed as given in Figure 1(b). The thickness of the semiconductor and XLPE material used are respectively 1mm and 3mm.

Figure 1(b) shows the proposed covered conductor cross section construction to reduce voltage stress values. In this construction, covered conductor consists of conductor beams, semiconductor, and XLPE material. Conductor beams material serves as a conductor to conduct current, XLPE material is an insulating material for the conductor beams, and semiconductor material serves to reduce voltage stress that occurs in XLPE.

2.2. Post insulator with different material
This section discusses the simulation result for different post insulator material that used to support covered conductors. The type of insulator material used consists of ceramic, glass and polymer materials.

3. Results and discussion
The voltage stress simulation results for the internal construction of the covered conductor are given in Figure 2.
Figure 2. Voltage stress value with internal semiconductor.

If reviewed for each simulation time, the voltage stress that occurs in the covered conductor with internal semiconductor is given in Figure 3.

Figure 3. Voltage stress with internal semiconductor.

The vertical lines in Figure 3(a) show the lines for voltage stress simulations shown in Figure 3(b). Point 1 is the boundary plane between XLPE and the isolator, point 2 is the boundary plane that occurs between semiconductor and XLPE, and point 3 is the boundary plane that occurs between conductor beams and semiconductor. Figure 3(b) shows the voltage stress that occurs for each simulation time using sinusoidal voltage waves with a frequency of 50Hz and an amplitude of 16.332kV (representing the value of the phase-neutral peak voltage on the 20kV line). The time $t = 0$ shows the value of voltage stress when the voltage condition has a value of $V = 0$, $t = 0.0025$ shows the value of voltage stress when the voltage reaches the peak value (when it reaches a quarter of a wave) that is equal to 16,329kV, and so on for the other value of $t$.

From Figure 3(b) it can be seen that the maximum voltage stress that occurs is the XLPE material that is at point 2 with a maximum value of 1100kV / m, the voltage stress of this voltage decreases to reach a value of 900kV / m at point 1. On the other hand, the maximum voltage stress which occurs in semiconductor material (at point 3) has a value of 300kV / m. Based on the voltage stress of Figure 3 and compared with the results on [1], it can be seen that the utilization of semiconductor can reduce the voltage stress value experienced by XLPE material (from originally 1600kV / m to 1100kV / m).

On the other hand, based on simulation results, voltage stress that occur on the covered conductor with ceramic, glass and polymer materials are given in Figure 4, Figure 5, and Figure 6, respectively.
Figure 4. Voltage stress with ceramic post insulator.

Figure 4(a) shows an illustration of the covered conductor cross section shape and the description of the line (in red) whereas Figure 4(b) shows the voltage stress that occurs in covered conductor when used ceramic post insulators. The maximum voltage stress that occurs is 1600\text{kV/m} and it occurs in the boundary between XLPE and conductor beams.

Figure 5. Voltage stress with polymer post insulator.

Figure 5(a) shows an illustration of the covered conductor cross section shape and the description of the line (in red) whereas Figure 5(b) shows the voltage stress that occurs in covered conductor when used
polymer post insulators. The maximum voltage stress that occurs is 850kV / m and it occurs in the boundary between XLPE and conductor beams.

Figure 6. Voltage stress with glass post insulator.

Figure 6(a) shows an illustration of the covered conductor cross section shape and the description of the line (in red) whereas Figure 6(b) shows the voltage stress that occurs in covered conductor when used glass post insulators. The maximum voltage stress that occurs is 1200kV / m and it occurs in the boundary between XLPE and conductor beams.

As mentioned earlier, the covered conductor burns down process will go through several processes, namely the formation of a pinhole, the occurrence of over voltages due to lightning strikes, and the occurrence of short-circuit current from the phase to the ground through the pinhole. Thus, to prevent the burn down, it is necessary to prevent pinholes so that there is no short circuit flowing through the pinhole.

It is explained that pinhole will occur if initiation of partial discharge occurs continuously due to operational voltage stress [5-10]. At greater the voltage stress, the partial discharge and the potential for pinhole emergence will also be greater. The highest voltage stress tends to occur at the contact point between the XLPE insulator and post insulator and between the inner conductors to the XLPE insulator. For that reason, pinhole prevention method is carried out by reducing voltage stress on XLPE material (covered conductor isolation) that is in contact with the insulator or with the inner conductor.

The utilization of post insulator with polymer material creates the smallest voltage stress in the contact point between the XLPE insulator and post insulator due to the XLPE and polymer have smallest difference value of electrical permittivity. And also, the semiconductor material in the internal construction of covered conductor also reduces the voltage stress because it works as a bridge to reduce the permittivity difference between the XLPE and inner conductor.

4. Conclusion

The covered conductor burnt down process is started by the formation of pinhole which triggered by the continuous operational voltage stress in covered conductor insulation. Simulation of voltage stress reduction on the covered conductor material has been performed in this paper. The simulation results
show that changing the type of insulating material from ceramic to polymer and adding semiconductor material to the internal construction of the covered conductor can reduce voltage stress on covered conductor insulation, and it will reduce the probability of pinhole formation.

Acknowledgment
We would like to show our gratitude to the PLN Research Institute for funding this research.

References
[1] Putu A A P, Aristo A K, Nur W P and Buyung S M 2018 Covered Conductor Burn-Down Phenomena in Indonesia without Protection Relay Operation International Journal on Advanced Science, Engineering and Information Technology 8 5 2012-2017
[2] Ronaldo E D S, Rafael M G, Guilherme S L, Fernando H S, Alberto D C and Silvério V 2016 Preliminary analysis of the impulse breakdown characteristics of XLPE-covered cables used in compact distribution lines International Conference on Lightning Protection Estoril, Portugal 1-6
[3] Nakamura K, McKenny P J, Hammam M S A A, Adams G, Fernandes R and Rushden F 1986 Impulse breakdown characteristics of 13.2 kV covered conductor insulator/tie configurations IEEE transactions on power delivery 1 4 250-258
[4] Ostsemin A A 2010 Melting rate of electrode wire in arc welding Russian Engineering Research 30 7 677-679
[5] Narong M, Tanes T, Werachai C, Karun M, Panumat L, Warawut P and Toshifumi Y 2009 Problem Solving of Partial Discharge on The Distribution Line WSEAS TRANSACTIONS on POWER SYSTEMS 4 1
[6] Krishnamurthy S R and Selvan P 1995 Use of AAAC in a distribution network-a strategy for energy and cost reduction Power Engineering Journal 9 3 133-136
[7] Ya W, Zepeng L V, Xia W, Kai W, Chong Z, Wenpeng L and Dissado L A 2016 Estimating the Inverse Power Law Aging Exponent for The DC Ageing of XLPE and Its Nanocomposites at Different Temperatures IEEE Transaction on Dielectrics and Electrical Insulation 23 6
[8] Tao W, Ma Z, Wang W, Liu J, Zhou K, Li T and Huang M 2016 The mechanism of water tree growth in XLPE cables based on the finite element method IEEE International Conference on High Voltage Engineering and Application (ICHVE) 1-4
[9] Ghaderi A, Ginn I I I and Mohammadpour H A 2017 High impedance fault detection: A review Electric Power Systems Research 143 376-388
[10] Aucoin B M and Jones R H 1996 High impedance fault detection implementation issues IEEE Transactions on Power Delivery 11 1 139-148