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UNDERGROUND CABLE

Problem Solving and Mitigation

INSTITUT TEKNOLOGI PLN

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We express our thanks to Allah SWT because it is only because of Allah SWT's permission that this book chapter has been arranged as we planned. This book chapter is a compilation of scientific articles presented at various "International Seminars & Call for Papers".

The preparation of this book chapter is an effort to disseminate ideas to the entire academic community, the idea is an effort to develop scientific substance in the field of High Voltage Engineering, especially underground cables. In this book chapter, we sort the ideas sent by the authors into several themes as follows. (1) Characteristics Testing on the Ground Cable, (2) Lifetime Estimation of Underground Cable, (3) Short Circuit Currents due to Thermal Instability on Underground Cable, (4) Thermal Instability on Underground Cable. The articles contained in this book chapter have been reviewed by the Reviewer Team according to their field of expertise.

Hopefully this book chapter will benefit us all. Perfection only belongs to Allah SWT, so this book chapter is not perfect. For this imperfection, we apologize and we welcome suggestions and criticism.

Thank you to all parties who contributed to the publication of this book chapter. May Allah SWT shower blessings on all of us. Amen.

Jakarta, February 2024

Editor

SYNOPSIS

Results in an increase in soil moisture that can degrade the dielectric strength of the SKTM and potentially SKTM interference. Therefore, Tan Delta testing method is carried out as a predictive step to analyze the cable health condition and an early method to determine the good/bad of the test cable. After testing tan delta, it was obtained that the acquisition of segment 1 data results were in good condition because the average value of delta tan in all three phases was 1.0, with the differential results being 0.0 and deviation standard 0.0.

The share of renewable energy in the global energy mix is increasing, so High-Voltage Direct Current (HVDC) Technology is growing rapidly. HVDC technology is a solution to accelerate the energy transition towards net zero emissions. In this regard. Power transmission HVDC through submarine cables very potential to be applied in Indonesia as sharing resources. The main component that needs attention to HVDC cables is the insulation part because it functions to withstand stress such as voltage so that breakdown does not occur. However, the main problem of the reliability of HVDC cables depends on the lifetime of isolation, especially under stress voltage. For a reliability system, a method that can predict HVDC cable lifetime is needed. In this study, HVDC cable lifetime prediction will be carried out based on stress voltage and partial discharge using the Inverse Power Model (IPM) and modifications.

Short circuit current constitutes one of the forms of disturbance on transmission system of electric energy, including transmission system through underground cable. Effects of short circuit current disturbance are, among other things: mechanical damage on cable due to electromagnetic force from repulsion between conductors or between conductor and wrapper; the sharp increased temperature due to joule heat on the conductor and wrapper causing thermal instability on the cable.

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through underground cable. Effects of short circuit current disturbance are, among other things: mechanical damage on cable due to electromagnetic force from repulsion between conductors or between conductor and wrapper; the sharp increased temperature due to joule heat on the conductor and wrapper causing thermal instability on the cable. This will further causes the occurrence of tree electric or the failure on insulation; the occurrence of aging on the cable. This is certainly of disadvantage since the continuity of voltage distribution may be disturbed and investment is of disadvantage.

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1

CHARACTERISTIC TESTING OF THE GROUND CABLE USING TAN DELTA (TD) TEST METHOD ON TWO SEGMENTS OF THE MEDIUM VOLTAGE CABLE MENTENG AREA

Christiono; Miftahul Fikri; Dani Maula Sattar; Andi Amar T.

Abstract

Results in an increase in soil moisture that can degrade the dielectric strength of the SKTM and potentially SKTM interference. Therefore, Tan Delta testing method is carried out as a predictive step to analyze the cable health condition and an early method to determine the good/bad of the test cable. After testing tan delta, it was obtained that the acquisition of segment 1 data results were in good condition because the average value of delta tan in all three phases was 1.0, with the differential results being 0.0 and deviation standard 0.0. Action to segment 1 is periodic maintenance of 5 years. Then in segment 2, the data obtained the average value of tan delta phase R 70.6, phase S 143.9, and phase T 83.92. For differential of phase R 161.7, phase S 33.7, and phase T 135.08. Finally, deviation standard at phase R 4.57, phase S 20.14, and phase T 2.43. From IEEE 400.2-2013 standard, it can be concluded that segment 2 is in poor condition and need action as soon as possible of PD Tests and cable replacement.

1.1. Introduction

Disruptions in the process of distributing electrical energy both in the scope of transmission and distribution are the most avoided things by the company, because of course it will harm the company with no energy sold or just lost. According to[1, 2], disturbances that occur, especially in medium voltage cable lines (SKTM) can be temporary such as abnormal currents and permanent disturbances that are difficult to localize the point of interference. Then, several permanent disturbances occur, some of which are caused by environmental factors ranging from water content, temperature, and high humidity in areas prone to flooding or with high rainfall so that the cable can feel environmental pressure (environmental stress). In addition, from internal cable factors such as water treeing, stress control, and aging (reduced life time) due to the long enough ground cable (SKTM) to operate [3, 4].

Testing of ground cables (SKTM) is one way to see how the condition of the cables is considering the difficulty of detecting interference points so that preventive maintenance must be carried out to prevent SKTM interference [3]. The test guidelines on ground cables based on research journals[5] refer to IEC 60502 – 2 in which one of the tests on ground cables (SKTM) is Tan Delta (TD). Tan Delta (TD) testing on cables serves to measure the magnitude of dielectric losses by looking at the extent of the delta angle shift, because the more the value of Tan Delta, the greater the dielectric losses on the cable and the faster the insulation of the cable undergoes aging [6, 7].

According to the disturbance data "Detailed Report of the Se 004 Disturbance Code Unplanned Outage of the Menteng Area Distribution Group", the disturbance that occurred in the Menteng Area in November – December 2021 where 8 out of 9 or 89% of disturbances that occurred in jointing were caused by indications of wet cables with weather conditions at the time the disturbance occurred, namely cloudy or conditions after rain and overcast, namely cloudy or cloudy or rainy. Meanwhile, 11% of it occurred in termination due to design errors in the indoor cubicle. For this problem, the title "Testing the Characteristics of Ground Cables with the Tan Delta (TD) Testing Method on Two Segments of Medium Voltage Cable Lines at PT PLN (Persero) Menteng Area" was raised to see the characteristics of the tan delta test and how the influence of soil moisture levels can affect the value of tan delta and on the insulation of the cable.

The isolation system that experiences a failure is certain to occur due to a penetrating voltage before being influenced by factors that cause insulation failure, both internal and external factors. Breakdown voltage is a voltage that has a minimum value to damage the insulation system, so that if the cable specification has a system voltage of 20 kV – 24 kV and then gets an abnormal voltage or impulse above the system voltage, the event can result in insulation failure. The standard in the Tan Delta test on SKTM is to use IEC 605022 (2005-02) for cables with a rating of 1 kV with Um = 1.2 kV to 30 kV with Um = 36 kV.

The isolation failure is an event that occurs if the function of the insulator as an insulating material does not work properly, namely separating the voltage or conductor part of one from another conductor that has different potentials or separating one conductor from the ground point. Self-isolation has the function of dielectric and mechanical characteristics. The meaning of the characteristics of the dielectric is that the cable must be able to withstand the working voltage or system voltage and impulse voltage in accordance with the specification rating of the cable. As for the mechanical characteristics, an isolation system must have attraction or other mechanical functions such as being flexible in ground cables to strengthen resistance in the SKTM line [8].

The insulating material can be said to be translucent if electrons flow in the material. If the insulating material continuously flows electrons, it will cause a leakage current on the insulating surface. This will result in the electrical pressure in the insulation which for a long time the electron pressure cannot be held by the dielectric so that it changes properties to be conductive and a voltage translucent occurs [9].

Water treeing as a result of cable insulation degradation is a form of poor insulation quality due to such high soil moisture. In a cable laid underground, the external thermal resistance of soil accounts for more than 70% of the temperature rise in cable [1, 10]. This phenomenon occurs because when high rainfall causes the soil to become wet so that the water content can enter the insulating pores of the cable and is destructive so that there is the potential for SKTM interference.

One form of insulation failure in SKTM is in the form of visualization of cable insulation marked by water treeing. Water treeing is a process that can result in degradation of cables, especially in the XLPE type and cause a reduction in the life time of ground cables. There are several factors that can cause this water treeing, namely there are contaminants in liquid substances to cable insulation materials, mechanical pressure, and environmental humidity.

1.2. Research Method

SKTM cable testing is one way to analyze the condition / health of ground cables, especially medium voltage cable lines that have been applied to big cities. The 20 kV SKTM cable testing carried out by this company is called cable assessment as a preventive maintenance measure to prevent consequences if the cable is in poor condition and avoid SKTM interference either in terms of jointing, termination, or the SKTM line itself [8]. Cable assessment carried out on SKTM uses 2 methods, namely partial discharge and Tan Delta (TD) testing with each test using a different tool [8]. The Tan Delta test is one of the test methods on the ground cable (SKTM) to find out the condition of the cable and that way we can estimate the remaining life of the cable as well as the top priority in terms of cable replacement to maintain the reliability of the 20 kV electrical system[11].

A. Tool

Tan Delta testing itself uses the TDM45 tool where there are several steps of data retrieval before tan delta testing or voltage firing on the ground cable (SKTM) such as finding out how long the SKTM line segment is from substation A to the opposing substation.

Figure 1. TDM45 for TD Test

B. Methods

1. Bending Test

Bending Test is one of the tests carried out to determine the feasibility of a cable in terms of installation later. Testing is carried out by doing some bending on the cable body to find out whether there are cracks in the cable after testing.

Based on iec 60502-2 standard, the bending test is carried out in a place or medium in the form of a cylinder which later the cable will be rolled at room temperature conditions for 1 reel. Testing was carried out 3 times. Seetlah the test is carried out the calculation of the diameter of the cable being tested. For the bending test standards, namely: 20 (d + D) ± 5%, for core cables 1 d = diameter of the conductor of the wire, and 15 (d+D) ± 5%, for 3D core cables = external diameter of the cable.

2. Heating Cycle Test

Heating Cycle Test or heat sikuls test is one of the test methods for conditioning the cable later when used, because when it is operated later there will be heat from the current flowing in the cable. Test the heat sikuls on the wires by spreading the wires above the floor and injecting current into the cable conductors for heating. Current induction uses a current transformer that is adjusted to the magnitude of the diameter of the cable being tested. The test was carried out for 8 hours with the first 2 hours for the heating process, the next 2 hours for the stable temperature process at a maximum temperature of 100°C and the last 4 hours for the cooling time until the initial condition. This 8-hour cycle is carried out for 20 times using a thermocorder tool[10, 12, 13].

3. PD Test

PD Test is a test to determine the discharge or dischage that appears and disappears during the firing process of a voltage of 1.73 U0 which is 21 kV. Such voltages will be seen PDEV and PDIV in the software. The test uses an OWTS tool and uses a DAC voltage which is used to energize the cable system at a frequency of 50 Hz-1.5 kHZ. OWTS consists of 2 main units: OWTS analyzer unit and OWTS coil unit. The OWTS analyzer unit consists of HV supply and data processing &control unit. HV supply is used to energize cable systems using damped AC (DAC) voltage. The data processing & control unit is used to process the measurement data and control the entire measurement process. There are several recommendations for the results of tests carried out according to the type of cable tested, whether pilc or XLPE insulation cables[11, 14, 15].

4. Tan Delta Test

Tan Delta testing is a test of cable characteristics in terms of their insulation resistance by looking at the value of tan delta or angular deviations that occur in the cable to be tested. If there is an increase in the value of tan delta, it will be ascertained that there is a defect or degradation of the cable insulation. Determination of the good or bad condition of a cable by conducting tan delta testing is seen in several categories for data analysis.

Insulation, which is a separator between the voltage and the non-voltage part, if there are contaminants, defects in the cable insulation, water treeing, and air humidity, then the resistance in the cable insulation will be reduced [14].

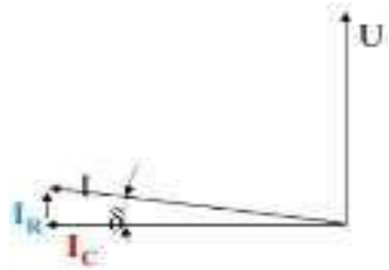

Figure 2. Phasor Diagram of Tan Delta

The tested value of angle shift or phase difference will determine how poor the insulation quality of the cable is or how large the level of contaminants in the insulation is. When measuring the IR/IC (Tangent) value, it will be seen how much the angle shift is and in terms of insulation quality. The Tangent value for the δ angle will show how good or bad a cable insulation is[14]. Under normal circumstances, a good insulation will show an angular value of δ close to zero (0). The greater the shift or deviation of the angle of the δ, it will indicate that the insulation of the cable is irrigated resistance current and means the poor quality of an insulation due to contaminants or pollutants. To determine how big the deviation of the angle or value of Tan Delta is, there are 3 criteria that will be used as an analysis of the determination of the results of the Tan Delta segment test, namely the average value of Tan Delta, the Change in The Value of Tan Delta (Differential), and the deviation of Tan Delta to Standard (Stability TD)[14].aaA

The voltage injected with 3 times and different voltage ratings will show how much the delta tan value is and its effect on the dielectric strength of the cable. If when firing the voltage is up to 3 times and there is no increase in the value of tan delta, the strength of the dielectric or cable insulation system is still good. However, if there is an increase in the value of the delta tan during the voltage injection, then there is a decrease in the insulation quality of the ground cable being tested. Tan Delta (TD) ground cable (SKTM) testing method is a test to see the angular deviations that occur in the insulation of the upper cable loss of dielectric strength because basically the cable can be likened to a capacitor that has a phase difference in voltage and current of 90° [4]. Voltage injection is carried out by regulating the value of the working voltage phase to ground (U0) which is 0.5 U0, U0, and 1.5 U0[14].

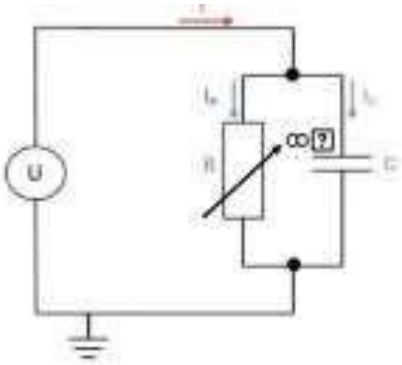

Figure 3. Wired Equivalent Circuit

This Tan Delta test uses the VLF (Very Low Frequency) method, which uses an AC signal with a frequency range of 0.01 Hz to 1 Hz. If the cable cannot withstand the firing voltage for a specified period of time with several firing times, it is certain that the cable is at an alarming level or there may be an isolation failure and even interference in a short period of time. This VLF method is used to test cables with existing insulation media as well as with a go and no-go system[14]. VLF AC testing allows the cable not to cause space charge so that it does not damage the cable itself (no repeated and frequent testing is carried out). Because the cable is likened to a capacitor that has a capacitance of several microfarads, VLF is used to test high-voltage AC cables.

As for the process of taking tan delta testing data which is carried out for data processing methods and analysis with observation methods carried out so that test data are obtained as follows.

1. Cable Measurement

Cable measurements are carried out to determine the length of the SKTM cable segment to be tested and find out the number of jointings of each segment using the TDR (Time Domain Reflectometry) tool. The use of TDR tools is so useful, especially on ground cables that are not visible to the naked eye so that a tool is needed that can read cables planted underground without having to dig on the SKTM line. TDR is connected to sktm indoor cables in each phase and sends a signal to be read by the tool itself. The TDR tool display displays the length of the cable segment to be tested by including information such as the signal given, the operating voltage of the cable, and others. If the tool reads a significant increase in signal then in that area there is a cable jointing between the 2 segments tested. Then the beginning and end of the segment there is also a sinusoidal wave indicating that it is the termination point of the cable as shown below.

Figure 4. TDR Display

Cable measurements using TDR cannot always be done for certain types of cables, because the TDR tool itself has its range. For example, the TDR used by researchers has the disadvantage of not being able to take measurements if the distance of the cable or segment is too close (less than 20 meters). Therefore, a higher series of tools is needed to overcome these problems if encountered in the field.

2. Data Entry

SKTM specification data starting from the name of the supplier, the length of the segment to be tested, the type of cable insulation, etc. will be entered into the software on the PC for further processing. In this data input process requires high accuracy because it must be precise in entering the specifications of the distribution substation, cubicle, and SKTM that are tested so that there are no errors when they have been tested. The process of entering data that takes place must be in harmony between the officers at the substation and in the place of data input so that the data entered is data that actually exists in the field. The data entered uses the "Start TDM" software and proceeds for the next step to choose the Near End or Far End Station for the name of the distribution substation and owner for the UP3 PLN area.

Figure 5. Start TDM Display

The picture above is a display during the process of entering the distribution substation specification data, the name of the supplier, the UP3 area where the substation is tested, SKTM data, etc.

3. Calibration

In this calibration process, it uses a calibration tool that is used to adjust the test equipment which will later be tested on the SKTM cable for XLPE insulation. This calibration uses a 0.1 Hz signal in accordance with the specifications of the test equipment used so that the data results obtained are in accordance with the standards of the tool and regulate the capacitance used by the tool which is adjusted to the magnitude of the capacitance value by the SKTM cable. The calibration process does not take a long time, however, this process is still an important step so that the data or test results obtained are real or not far from the standard TDM45 tool.

4. Cable Testing

The last step is testing the delta tan on the SKTM cable. Testing or measurement using the TDM45 tool where it uses the VLF voltage to produce a voltage of 0.5 to 1.5 U0 so that we can know the characteristics of the delta tan value as different test voltage levels are given. This tan delta test is carried out automatically because it uses a go / no-go system, namely through the TDM Start software and will automatically be carried out voltage firing 3 times according to the test voltage level.

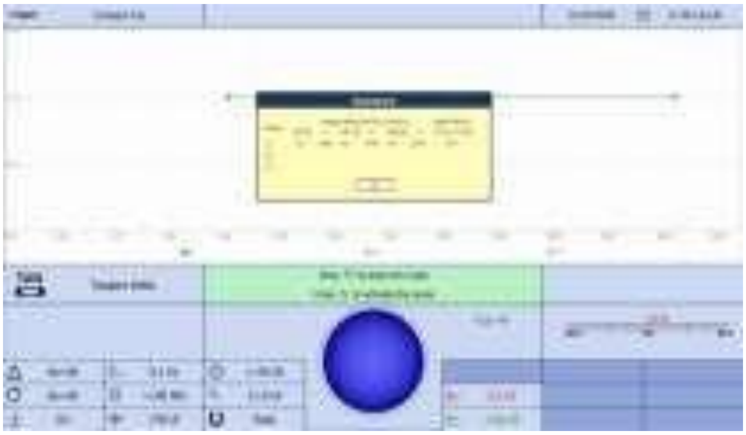

Figure 6. TD Test Result Display

The picture above is a display of the results of tests that have been carried out for each phase. After firing the voltage 3 times according to the test voltage level, results or data will be obtained as shown, namely there is a graph of the effect of the test voltage on the value of tan delta along with the average value of tan delta, standard deviation, and differential tan delta. The raw data will later be exported into a file which is then carried out data analysis to draw conclusions in the form of good or bad conditions of the SKTM cable.

The data analysis method used in this final project research is an inferential statistical analysis technique. This technique is one of the methods used to draw conclusions in the form of predictions (in the case of this study in the form of preventive steps from periodic maintenance) by analyzing test variable data compared to the standard.

Table 1. Standard IEEE 400.2-2013

Condition Assesment	*VLF-TD Time Stability (VLF-TDTS) measured by standard deviation at U_0, [10^{-3}]*	*Differential VLF-TD (VLF-DTD) (difference in mean VLF-TD) between 0.5 U_0 and 1.5 U_0, [10^{-3}]*	*Mean VLF-TD at U_0 [10^{-3}]*
No Action Required	*< 0.1*	*< 5*	*< 4*
Further Study Advised	*0.1 to 0.5*	*5 to 80*	*4 to 50*
Action Required	*> 0.5*	*> 80*	*> 50*

The data that has been obtained on the test results will be adjusted to the IEEE 400.2-2013 standard and will be analyzed and conclusions drawn according to the condition of the cable being tested whether the cable is in good or bad condition so that follow-up can be carried out on the results.

1.3. Results And Discussion

The Tan Delta (TD) test carried out is on XLPE-insulated cables and has 3 conductor cores (three-cores). The following are the results of cable measurements at the P90P – B29C and P90P – P88 substation barrel refinery ketapang substations according to the SLD listed in the attachment using the TDR tool according to the way the data was collected in the previous chapter to be included in the "Start TDM" software including the name of the supplier, the name of the distribution substation, the length of the cable, the number of jointing’s, and the type of cable insulation.

A. SKTM Cable TDR Measurement Results

Cables tested on 2 SKTM segments (top down direction substations) in 1 supplier showed that there was a difference in cable length and the number of joints. The length of a cable will determine how much the capacitance value of the cable is, the longer a cable is, the less the capacitance value will decrease along with the decrease in the resistance value of the cable for the time of the cable that has been aged. Furthermore, Tan Delta (TD) testing will be carried out for each segment and each phase.

Table 2. Cable Measurement Result

Feeder	Substation Segment	Cable Lenght	Number of Jointing	Cable Insulation
Feeder Gentong	P90P – B29C	605 m	6 (cold shrink)	XLPE
	P90P – P88	838 m	8 (cold shrink)	XLPE

B. Tan Delta (TD) Test Results

In the Tan Delta (TD) test conducted using the TDM45 tool to obtain some test result data which will later be adjusted to the IEEE 400.2-2013 standard according to the category in order to get the results or condition of the cable tested. As for the test results of the first segment of Tan Delta (TD), namely the P90P – B29C distribution substation, it is as follows.

Table 3. P90P – B29C Segment Test Results Phase R

Phase	L1		
Temperature & Moisture	30°C & 66% (Dry)		
Voltage	8.2 kV	16.3 kV	24.4 kV
Factor U_0	0.5	1.0	1.5
Capacitance	89.0 nF	89.0 nF	89.0 nF
Resistance	100.0 MΩ	100.0 MΩ	100.0 M Ω
Mean (10^{-3})	1.0	1.0	1.0

Deviation (10^{-3})	0.00	0.00	0.00
Tan δ (10^{-3})	1.0; 1.0; 1.0; 1.0; 1.0	1.0; 1.0; 1.0; 1.0; 1.0	1.0; 1.0; 1.0; 1.0; 1.0

The first segment data for phase R show when the voltage is raised according to the factor U0 that when 0.5U0, 1.0U0, and 1.5U0 are seen average capacitance values of 89.0 nF and an average resistance of 100.0 MΩ with a cable length of 605 meters. As for the deviation value, it looks 0.00 and the value of tan δ shows an average of 1.0 for 3 times voltage firing.

Table 4. P90P – B29C Segment Test Results Phase S

Phase	**L2**		
Temperature & Moisture	30°C & 66% (Dry)		
Voltage	8.2 kV	16.3 kV	24.4 kV
Factor U_0	0.5	1.0	1.5
Capacitance	89.0 nF	89.0 nF	89.0 nF
Resistance	100.0 MΩ	100.0 MΩ	100.0 M Ω
Mean (10^{-3})	1.0	1.0	1.0
Deviation (10^{-3})	0.00	0.00	0.00
Tan δ (10^{-3})	1.0; 1.0; 1.0; 1.0; 1.0	1.0; 1.0; 1.0; 1.0; 1.0	1.0; 1.0; 1.0; 1.0; 1.0

The data of the first segment for phase S showed the same results as the previous R phase, that is, when the voltage was increased according to the factor U0 that when 0.5U0, 1.0U0, and 1.5U0 it was seen that the average capacitance value was 89.0 nF and the average resistance was 100.0 MΩ with a cable length of 605 meters. As for the deviation value, it looks 0.00 and the value of tan δ shows an average of 1.0 for 3 times voltage firing.

Table 5. P90P – B29C Segment Test Results Phase T

Phase	L3		
Temperature & Moisture	30°C & 66% (Dry)		
Voltage	8.2 kV	16.3 kV	24.4 kV
Factor U_0	0.5	1.0	1.5
Capacitance	91.0 nF	91.0 nF	91.0 nF
Resistance	100.0 MΩ	100.0 MΩ	100.0 M Ω
Mean (10^{-3})	1.0	1.0	1.0
Deviation (10^{-3})	0.00	0.00	0.00
Tan δ (10^{-3})	1.0; 1.0; 1.0; 1.0; 1.0	1.0; 1.0; 1.0; 1.0; 1.0	1.0; 1.0; 1.0; 1.0; 1.0

The first segment data for phase T showed almost the same results as the previous R and S phases, that is, when the voltage was raised according to the factor U0 that when 0.5U0, 1.0U0, and 1.5U0, the capacitance value was seen that was different from the previous data, namely an average of 91.0 nF and an average resistance of 100.0 MΩ with a cable length of 605 meters. As for the deviation value, it looks 0.00 and the value of tan δ shows an average of 1.0 for 3 times voltage firing.

Furthermore, for the Tan Delta (TD) test data in the second segment, namely the P90P – P88 distribution substation by conducting tests obtained by the data results of each phase as follows.

Table 6. P90P – P88 Segment Test Results Phase R

Phase	L1		
Temperature & Moisture	26°C & 88% (Wet)		
Voltage	8.2 kV	16.3 kV	24.4 kV
Factor U_0	0.5	1.0	1.5
Capacitance	1.556 nF	1.556 nF	1.556 nF
Resistance	75.0 MΩ	75.0 MΩ	75.0 M Ω
Mean (10^{-3})	4.0	70.6	165.67

Deviation (10^{-3})	0.00	4.57	4.8
Tan δ (10^{-3})	4.0; 4.0; 4.0; 4.0; 4.0	67.8; 72.2; 64.6; 78.2; 70.0	160.0; 161.0; 165.1; 170.2; 172.0

The data above is the result of tan delta testing from segment 2 for phase R where it shows that the capacitance value of the cable with a segment length of 838 meters is 1,556 μF with a resistance value of 75 MΩ. Then for the value of Tan Delta has a number of differences at the time of 3 times the firing of the voltage is carried out to take its average value at the time of 1.0 U0 and the differential of tan delta between 1.5 U0 and 0.5 U0.

Table 7. P90P – P88 Segment Test Results Phase S

Phase	L2		
Temperature & Moisture	26°C & 88% (Wet)		
Voltage	8.2 kV	16.3 kV	24.4 kV
Factor U_0	0.5	1.0	1.5
Capacitance	1.555 nF	1.555 nF	1.555 nF
Resistance	15.6 MΩ	15.6 MΩ	15.6 M Ω
Mean (10^{-3})	129.8	143.9	163.5
Deviation (10^{-3})	10.66	20.14	22.79
Tan δ (10^{-3})	146.2; 136.2; 128.8; 122.5; 115.5	173.0; 149.9; 153.9; 125.1; 117.6	200.6; 178.5; 153.5; 145.0; 140.0

In the data of the second segment of phase S shows the value of the capacitance of the cable with a segment length of 838 meters is 1,555 μF with a resistance value of 15.6 MΩ. Then for the value of Tan Delta has a number of differences at the time of 3 times the firing of the voltage is carried out to take its average value at the time of 1.0 U0 and the differential of tan delta between 1.5 U0 and 0.5 U0.

Table 8. P90P – P88 Segment Test Results Phase T

Phase	L2		
Temperature & Moisture	26°C & 88% (Wet)		
Voltage	8.2 kV	16.3 kV	24.4 kV
Factor U_0	0.5	1.0	1.5
Capacitance	1.245 nF	1.245 nF	1.245 nF
Resistance	100 MΩ	100 MΩ	100 M Ω
Mean (10^{-3})	2.4	83.92	137.48
Deviation (10^{-3})	0.68	2.43	9.00
Tan δ (10^{-3})	1.0; 2.7; 2.7; 2.7; 2.7	82.4; 82.0; 82.2; 82.6; 88.4	120.8; 140.4; 136.0; 144.4; 145.8

The above is the test result for the second segment with phase T which shows the magnitude of the capacitance value of the cable with a segment length of 838 meters is 1,245 µF with a resistance value of 100 MΩ. Then for the value of Tan Delta has a number of differences at the time of 3 times the firing of the voltage is carried out to take its average value at the time of 1.0 U0 and the differential of tan delta between 1.5 U0 and 0.5 U0.

1.4. Data Analysis

The analysis process as a form of data processing results for testing or data collection that has been carried out on the Tan Delta (TD) test uses the IEEE 400.2-2013 standard as a reference for the process of drawing conclusions from the good or bad condition of the cable tested in the presence of 3 indications, namely the mean or average value of tan delta at the time of 1.0 U0, then the differential value of tan delta when the test conditions are 1.5 U0 and 0.5 U0, and from the magnitude of the deviation value against the standard.

This Tan Delta (TD) test uses the TDM 45 series of tools which performs voltage firing 3 times automatically with a go / no-go system for different voltage ratings in order to see how the insulation resistance characteristics of the Tan Delta factor on the cable tested or assess the dielectric strength of the XLPE isolation SKTM cable in two segments so that it can be classified according to quality / condition.

The data classification table for each of the average parameters of tan delta, differential tan delta, and standard deviation according to the IEEE 400.2-2013 standard from the test results of the SKTM cables isolated xlpe is as follows.

Table 9. TD Test Result Classification

Cable Indicator	**Segment P90P – B29C**			**Segment P90P – P88**		
	Line R	Line S	Line T	Line R	Line S	Line T
Mean TD at 1.0 U_0 (10^{-3})	1.0	1.0	1.0	70.6	143.9	83.92
Differential TD at 1.5 U_0 – 0.5 U_0 (10^{-3})	0.0	0.0	0.0	161.7	33.7	135.08
Standard Deviation at 1.0 U_0 (10^{-3})	0.0	0.0	0.0	4.57	20.14	2.43

The test result data on the parameters used above will be compared with the parameters of the IEEE 400.2-2013 standard to determine the condition of the tested cable. Based on table 3.1 of the IEEE 400.2-2013 Standard, then for the determination of the good and bad of the tested cables can be classified which will be marked with color. If the results of the field data show a good indication of the average value of tan delta, differential tan delta, and the standard deviation value at the No Action Required level, we can mark it in green stating that there is no need for execution on the cable. Then if the cable we are testing gets the average value of tan delta, differential tan delta, and its standard deviation value at the Level of Further Study Advised, then we will give a yellow color equivalent to the condition that the cable needs to be studied further. Furthermore, when the test results we obtain show that the cable has an average value of tan delta, differential tan delta, and its standard deviation value at the Action Required level, then we give a red color which means that the condition of the cable is bad and needs to be executed next.

In the data above for the first segment, namely the distribution substation segment P90P – B29C, it shows that the cables tested for all three phases indicate Good or No Action Required because for the average value of tan delta has a value of 1.0 (below 4) and is flat for each phase. Then for the differential value of tan delta has a value of 0.0 because the current value of tan delta is 1.5 U0 and 0.5 U0 is 1.0. the last for the standard deviation value in the first segment is 0.0 because for tan delta as measured on the observation data it is 1.0 for all test results. This means that by looking at the indicators/parameters of the standards used, making the P90P – B29C segment a cable with good condition.

In the second segment data, namely P90P – P88, it shows that in phase R, it can be seen that the average value of tan delta is 70.6. Because this value is greater than 50, according to the standards used, it will be given a red color. Then for the differential value of tan delta shows 161.7 (Action Required) because it ranges from 5 to 80. Finally, the standard deviation value in phase R indicates that the phase is in an Action Required state because it ranges above 0.5, which is 4.57. then in phase S experienced a fairly high deterioration looking at the test data obtained, namely the average value of tan delta and the standard deviation was at the Action Required level of 143.9 and 20.14, while for the differential value of tan delta was at the Further Study Advised level of 33.7. The last data in the second segment of testing, namely in phase T, showed the same results as the previous R and S phases, namely at the Action Required level because the average value of the resulting delta tan was 83.92, with a differential value of tan delta of 135.08 and a measured standard deviation of 2.43.

Then in terms of the resulting graph for the influence of the voltage applied to the value of the resulting delta tan on segment 1 is as follows.

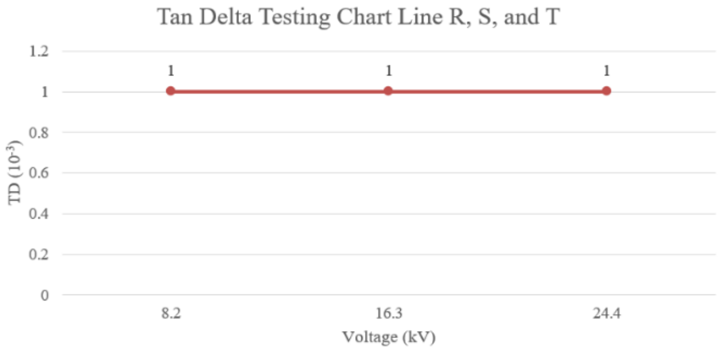

Figure 7. Tan Delta Testing Chart Segment 1

In the tan delta segment 1 test graph above, it shows that as the voltage increases given using a frequency of 0.1 Hz, the resulting delta tan value remains constant/significant. Each increase in voltage applied to the test cable, the value of the delta tan obtained for all three phases remains at 1. This means that there is no aggravation in the SKTM cable insulation system that was tested and there is no moisture judging from field conditions that have dry and not wet soil so as not to make the cable potentially disturbed in the future. The SKTM cable in segment 1 can be concluded that it is in good condition (No Action Required) because it is also resistant when given voltage at a condition of 1.5 U0.

Furthermore, the tan delta test chart to determine the condition of the dielectric strength in the SKTM cable in segment 2 for all three phases is as follows.

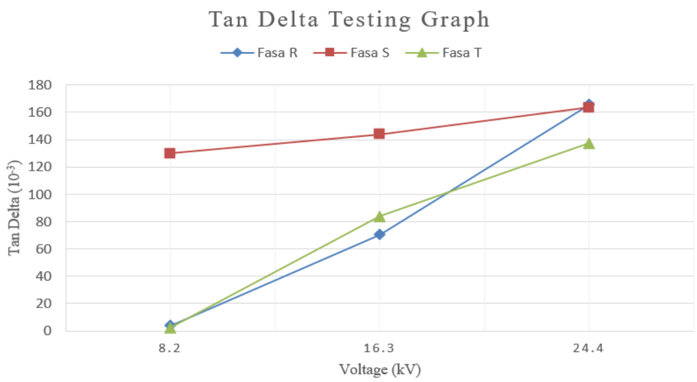

Figure 8. Tan Delta Testing Graph Segment 2

In the tan delta test graph for segment 2, almost all three phases show quite the same results, namely in the graph of the test voltage used against the measured delta tan value, which is increasing the test voltage from 0.5 U0, 1.0 U0, and up to 1.5 U0, it can be seen that there is also an increase in the value of tan delta. It can be concluded that there was a deterioration in the insulation of the cables tested because the insulation resistance on the cables decreased as seen in the increase in the value of the tan delta obtained. In addition, we can conclude that the segment 2 cable is in poor condition or Action Required.

The durability of the SKTM cable tested is seen from its dielectric strength when firing voltage with 3 different ratings. If during firing the first voltage (8.2 kV) to the third, which is 24.4 kV, there is an increase in the value of the tan delta, it can be ascertained that the dielectric strength of the cable tested is poor. Next, it will be seen how the value of the soil moisture level can affect the test results of the tan delta value. As for the table along with a graph of the relationship of soil moisture levels to the results of the tan delta test, it is as follows.

Table 10. Soil Moisture Value At The Time Of Tan Delta 2 Segment Testing

Segment	Line	Mean Tan Delta at 1.0 U_0 (10^{-3})	Soil Moistute
P90P – B29C	R	1.0	66%
	S	1.0	
	T	1.0	
P90P – P88	R	70.6	88%
	S	143.9	
	T	83.92	

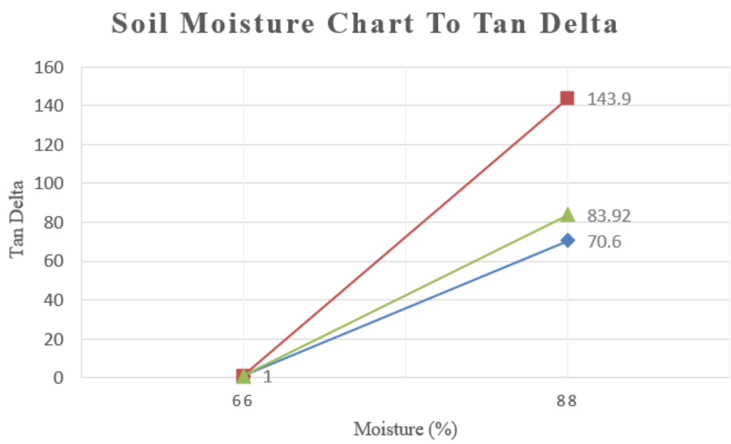

Figure 9. Soil Moisture Chart To Tan Delta

From the data and graphs above, results can be obtained that the higher the soil moisture value, it will increase the cable delta tan value seen when the humidity is 66% or dry conditions, the stable delta tan value is low at number 1. However, in wet conditions with soil moisture of 88% the value of tan delta increases at 70.6 in phase R, 143.9 in phase S, and 83.92 in phase T. So it can be ascertained that if soil moisture is high, it will increase the potential for an increase in the value of tan delta in the cable which will reduce the quality of insulation of the cable.

The results of the delta tan test carried out will get treatment recommendations or follow-up in accordance with the condition of the cable where repeated maintenance will be carried out within 5 years for cables with No Action Required conditions and maintenance in the form of PD Tests and cable replacement if action required conditions on the cables are indicated after tan delta testing. Therefore, this tan delta test is a predictive maintenance to determine the condition of the cable whether it needs further maintenance or not.

1.5. Conclusion

Based on research that has been carried out by analyzing data from Tan Delta (TD) testing in 2 segments that have been previously presented, it can be concluded that:

The delta tan test method is carried out as an early method of determining the condition of the SKTM cable and as a reference to carry out further maintenance such as PD tests and detection, because if it only directly leads to a PD test without tan delta testing, it will not be known whether the cable was initially in poor condition or good the insulation system and also would not be as accurate as determining the location of the cable. As well as for which segment indicators will be the recommendations for conducting PD tests as well as cable replacement, because if the PD is high without being noticed by the delta tan, it cannot be fully trusted or valid data. Therefore, tan delta testing is carried out first as an early predictive method of determining the condition of the cable.The characteristics of the delta tan value in segment 1 which has a good result (No Action Required) are that it has an average tan deltaketiga phase which is 1.0, a standard deviation of 0.0, and a differential tan delta of 0.0. Then for bad results with the recommendation of Action Required has the characteristics of the average value of tan delta in phase R of 70.6, phase S 143.9, and phase T of 83.92. Differential values of phase R 161.7, phase S 33.7, and phase T 135.08. Finally, the standard deviation values at phase R 4.57, phase S 20.14, and phase T 2.43. Thus, the data from segment 2 show that under adverse conditions according to the category in the IEEE 400.2-2013 standard.

Soil moisture data of 66% (dry condition) shows a delta tan value of 1.0. As for soil moisture, 88% (wet conditions) shows that the tan delta values in the R, S, and T phases are 70.6, 143.9, and 83.92 respectively. Thus, the higher the level of soil moisture in the SKTM line, it will increase the potential value of tan delta and water treeing so that it will reduce the dielectric strength or insulation quality of the cable itself. The follow-up that must be done according to the recommendation table from IEEE 400.2-2013, namely for cables with No Action Required results is to retest within 5 years. Meanwhile, the test results of segment 2 with action required conditions are to carry out follow-ups in the form of PD tests and cable replacement.

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2

SIMULATION INVERSE POWER MODEL FOR LIFETIME ESTIMATION OF HVDC CABLE UNDER STRESS VOLTAGE AND PARTIAL DISCHARGE

Muhammad Luthfiansyah Romadhoni; Muhammad Fadli Nasution; Muhammad Bondan Setiawan; Miftahul Fikri; Christiono; Iwa Garniwa M.K.

Abstract

The share of renewable energy in the global energy mix is increasing, so High-Voltage Direct Current (HVDC) Technology is growing rapidly. HVDC technology is a solution to accelerate the energy transition towards net zero emissions. In this regard. Power transmission HVDC through submarine cables very potential to be applied in Indonesia as sharing resources. The main component that needs attention to HVDC cables is the insulation part because it functions to withstand stress such as voltage so that breakdown does not occur. However, the main problem of the reliability of HVDC cables depends on the lifetime of isolation, especially under stress voltage. For a reliability system, a method that can predict HVDC cable lifetime is needed. In this study, HVDC cable lifetime prediction will be carried out based on stress voltage and partial discharge using the Inverse Power Model (IPM) and modifications. The data used in this study consists of all papers published in the previous research. The cable life prediction produces an error of 6.11%. Then when a partial discharge occurs, it produces a model obtained with artificial intelligence to find the values of a and b with a Mean Squared Error (MSE) of 3.0152%. The two models show that when the voltage increases, the lifetime of the cable will decrease, especially when there is a partial discharge, the lifetime of the cable decreases more quickly. In accordance with the

theory of the inverse power model which shows that the new formula is accurate for determining cable lifetime.

Keywords: *renewable energy, HVDC cable, lifetime insulation, partial discharge, inverse power model.*

2.1. Introduction

Power generation centers, especially those that use hydropower, are usually located far from load centers. Thus, electric power that has been generated must be channeled through transmission lines. These lines carry electric power from the generating center to the load centers either directly or through substations and rele substations. Transmission lines that can be used are overhead lines or underground lines. According to the type of current that can be generated, namely the alternating current system (AC or alternating current) and the direct current system (DC or direct current) [1].

Considering the condition of the Indonesian state, most of its area is ocean. This ocean is not a separation between one island and another, but the island is seen as a link between islands. Starting from this description, experts in planning the provision of electricity in this country should also respond to the unification of the electricity system, by implementing transmission using submarine cables. The distribution of electric power with a new direct current system is considered economical when the length of the overhead line is more than 640 km or the underground line is longer than 50 km [2].

Based on applicable standards, the service life of the power cable is 40 years. This means that under normal circumstances the power cable can last for 40 years until the insulation breaks down due to stress voltage. The greater the voltage stress value, the faster the cable damage will be [3]. Damage is aggravated when partial discharge occurs on the power cable. In this study, a method will be formed to predict cable life when it is affected by voltage and partial discharge values.

2.2. Cable Insulation

A. Factors Affecting Cable Life Time

DC Cable Performance is More Complex Compared to AC Cable. The insulation layer of the AC cable is mainly subjected to frequency AC voltage, and its electric field distribution is inversely proportional to the distribution of the dielectric coefficient. In general, the dielectric constant of the insulating material can be considered almost independent of temperature, so the distribution of the electric field and the distribution of temperature in the insulating layer of the cable are almost independent [4], [5]. In contrast, the insulating layer of DC cables is mainly subjected to DC voltage, and its electric field distribution is distributed in proportion to the resistivity of the volume. Since the resistivity of polymer insulating materials is very sensitive to temperature changes, in general, resistivity decreases exponentially with increasing temperature.

Therefore, in the normal operation of extruded DC cables will appear the phenomenon of electric field reversal, that is, the strength of the electric field from the largest place appears on the outer surface of the insulating layer.

Secondly, AC cables do not have the problem of space charge accumulation during operation because the polarity of the voltage at both ends of the insulation layer is constantly changing. DC cables, in addition, can accumulate space charge during operation because the polarity of the voltage remains constant. The accumulation of space charge is closely related to the occurrence of interference with DC cables. The accumulation of space charge on the insulating layer of the cable can distort the local electric field in the medium, which in turn leads to partial discharging and dielectric damage. In particular, the accumulation of space charge under the action of a strong electric field will accelerate the aging process of polymer dielectrics [6].

Comparison of the development status of high-voltage DC cables. International, European, and Japanese have many years of operating experience in extruded DC cables. Europe is a leader in the manufacturing, installation, and development of DC cables [7]. There are world-famous cable manufacturers ABB from Switzerland, Nexans from France, and Prysmian from Italy, as well as cable material supplier Nordic Chemicals. Japan has also invested a lot of effort in DC cable research and development and has achieved good results.

The main properties of DC cable insulation materials include electrical conductivity, thermal conductivity, mechanical, and space charge properties, and environmental friendliness. How to arrange the various properties of cable insulation materials is an old problem that scholars at home and abroad want to solve. The development of extruded DC cables needs to address two major scientific problems: generation, transport, accumulation, and dissipation of space charges in the medium under the action of multi-field coupling and synergistic regulation of various properties of the insulating medium.[8]

B. Partial Discharge

In the use of polymer insulation, there is often found a gas trapped in it. In general, gases have a small dielectric constant (close to 1) compared to the polymer insulating dielectric constant (between 2 - 6) so that the gas will get a greater electric field than the polymer insulation, even though its strength is lower. Thus the gas will penetrate there when the polymer insulation is far from penetrating. The translucency of gas in solid isolation is called partial discharge. As a result of partial dissolution in the air cavity (void), the air cavity (void) can grow into branching canals that form a structure resembling tree branches called electrical treeing[10].

2.3. Methodology

A. Inverse Power Model

Inverse Power Model also referred to as V-t characteristic. The ipl model for accelerated lifetime tests, with the stress (voltage/thickness) as the accelerating variable, is applicable if the underlying cumulative distribution function of the lifetime, t, can be de- scribed, according to Weibull [9], by:

$$F(t) = 1 - \exp\left[-\left(\frac{T}{\tau}\right)^{\beta}\right], \quad t \geq 0 \qquad (1)$$

Life models based either on the inverse power law, like the so-called inverse power model (IPM). F(t) is the failure probability at time t. Two additional assumptions are needed with respect to the two parameters:

a) The shape parameter £ is a constant, independent of the stress,

b) The scale parameter +, which is the time corresponding to F=1— l/e=.632 (the 63.2th per- centile of the distribution, also called the characteristic life time), is an inverse power function of the stress, E, that is:

$$L = C_1 E^{-n} \quad (2)$$

Where E is the electric field strength in kV/mm, t is the failure time or life in s. C is a constant representing the cumulative electrical damage required for material failure, and n is the voltage tolerance index representing the degree of influence. C and n are positive parameters, characteristic constants of the material and the test method since the inverse of the stress is raised to the nth power, that equation is called the inverse power law[9].

B. Artificial Inteligence

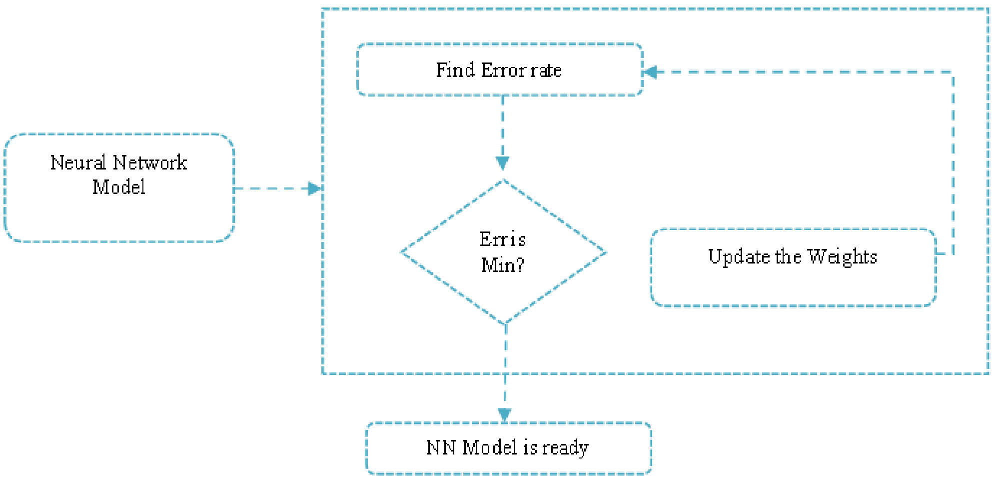

Figure 1 Flow diagram of the working mechanism of backpropagation

The above (Figure 1) shows that the everyday workflows of the backpropagation process mechanism. During the backwards propagation, these computation activities will happen as mentioned below [10].

- Find Error rate: Here we need to calculate the model output with actual output
- Minimum Error: Cross verifying whether the error is minimized or not.
- Update the Weights: The error is more than the acceptable range then, update the weights and biases. After that, again check the error. Repeat the process until the error becomes low.
- Neural Network Model: Once the error rate was acceptable range then the model is ready to use for forecasting the data

The generalized workflow and stepwise computation in Backpropagation given as pseudo- code as follows:

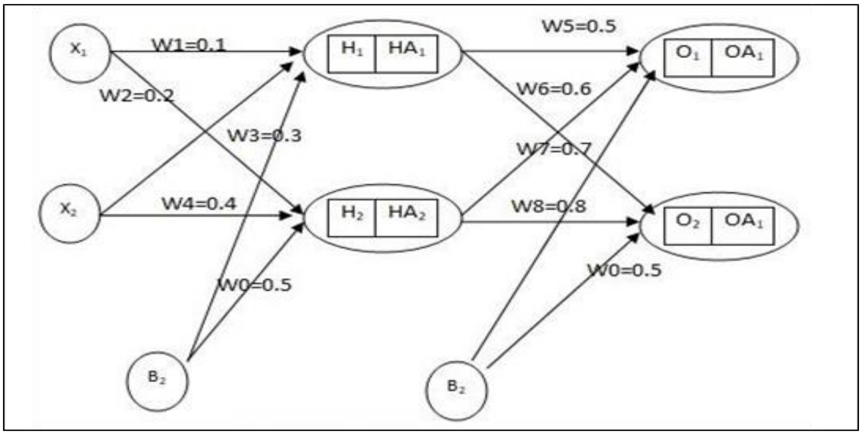

Figure 2. Feed forward ANN

The above shows the feedforward artificial neural network contains Input, Hidden and Output layers. Each layer contains two nodes with respective weights. All nodes are fully connected model, including the bias node [11].

Notions of the above network as follows:

X_1, X_2 : Input Nodes

H_1, H_2 : Hidden Layer Nodes with net out from respective inputs

HA_1, HA_2 : Hidden Layer Nodes with activation output

O_1, O_2 : Output Layer Nodes with net out from respective inputs

OA_1, OA_2 : Output Layer Nodes with activation output

W_1, W_8 : Weights of respective layers from input to output

B_1, B_2 : Bias Nodes for Hidden and Output layers respectively

By using the backpropagation method, alpha and beta values are obtained for the new formula for estimating cable listime

$$t = C_r^{\alpha} . E_r^{-\beta nr} \tag{3}$$

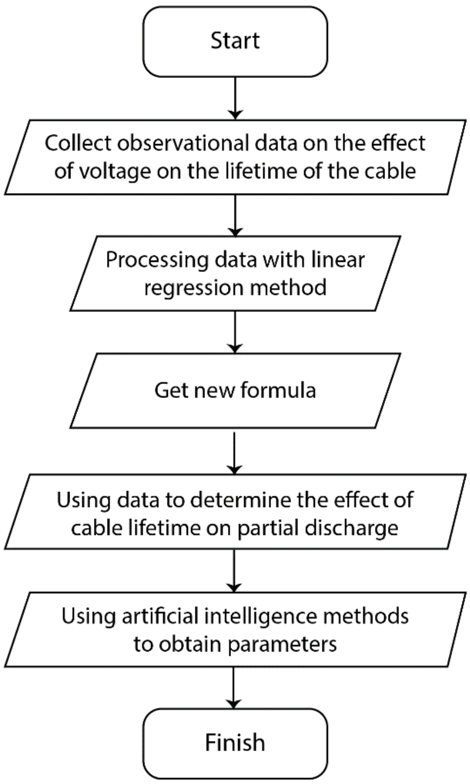

Figure 3. Feed forward ANN

2.4. Simulation

A. IPM modification for DC Voltage and partial discharge

Based on the observational data that we have obtained, it shows that the greater the value of the electric field per unit area, the faster the breakdown time of the cable insulation will be [12]. We summarize them in (table 1) below.

Table 1. Data Real

E (kV/mm)	T (minute)
361.40	1.35
219.00	135.00
157.10	550.00
122.40	1350.00
100.30	4250.00

After obtaining experimental data, then modeling was carried out using the Matlab 2022b program. In order to obtain a linear equation model to determine the lifetime of the cable when the voltage value increases. Each data has an error value which indicates the difference between the experimental data and the predicted results. By using the average, the error value generated by this method is 6.11%.

Table 2. Logarithmic data

E (kV/mm)	T (minute)	T Estimation	Error	$Error^2$	MSE	MSE Percentage
5.8899	0.3001	0.75	-0.45	0.20	0.33	6.11%
5.3890	4.9052	3.91	1.00	0.99		
5.0568	6.3099	6.00	0.31	0.09		
4.8072	7.2078	7.58	-0.37	0.14		
4.6081	8.3546	8.83	-0.48	0.23		

By using the Matlab program, you can display a graph of the HDI equation after inputting the experimental data. There are five experimental data which are concluded with dots. Then the line symbol shows a new model that can be used to predict cable lifetime. The y axis shows the voltage value tested on the cable insulation. While the x-axis shows the lifetime with units of time. From this graph it can be seen that the greater the stress voltage on the cable insulation, the faster the insulation damage or the lifetime of the cable will decrease.

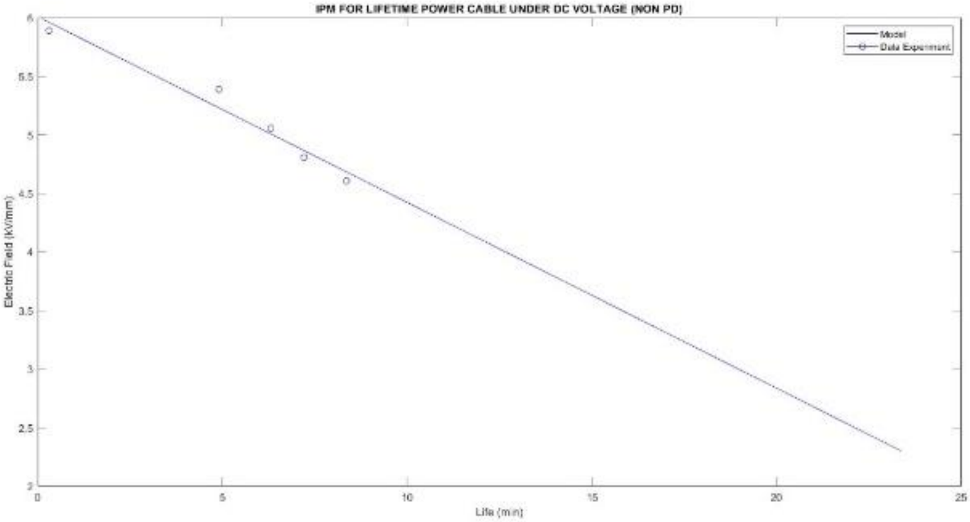

Figure 4. Graphic of IPM under Voltage Stress

The following is a model generated from the estimated lifetime value of the cable. This equation can be used to determine the lifetime value of the cable which is symbolized by the variable x by entering the voltage value.

With Matlab, model for lifetime power cable under DC Voltage:

$$y=-0.1586 (x) + 6.0091$$

With,

y : DC Voltage (KV/mm)

x : Lifetime (minutes)

B. IPM modification for DC Voltage and partial discharge

Based on the equation... there are parameters α and β whose values will be searched using the AI approach. To reduce the error value, iteration is carried out 250 times. As seen in figure 4.

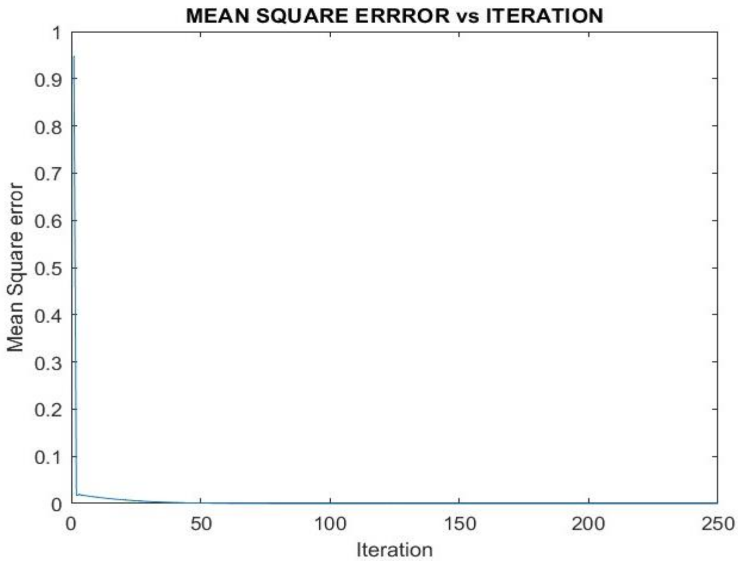

Figure 5. Graphic Mean Square Error vs Iteration

The results of processing the matlab program produce parameters α and β which are close to the experimental values. With an error of 3.0152%, it is accurate enough to predict the lifetime of the cable when a partial discharge occurs.

Table 3. comparison Experiment Parameter and Prediction Parameter

d (μm)	E_a (kV/mm)	Q (C/m^3)	Experiment Parameter		Prediction Parameter	
			α	β	α	β
60	80	56.95	1.092	1.178	1.0947	1.1929
60	100	74.09	1.092	1.178	1.0931	1.1789
60	120	113	1.092	1.178	1.1037	1.1681
60	140	124.26	1.092	1.178	1.0848	1.1942

60	160	133.16	1.092	1.178	1.0969	1.1753
70	80	45.15	1.210	1.327	1.1998	1.3215
70	100	67.06	1.210	1.327	1.2167	1.3297
70	120	86.46	1.210	1.327	1.2067	1.3257
70	140	100.3	1.210	1.327	1.2117	1.3316
70	160	121.19	1.210	1.327	1.2104	1.3206
80	80	50.38	1.326	1.472	1.3248	1.4571
80	100	57.59	1.326	1.472	1.3228	1.4899
80	120	70.76	1.326	1.472	1.3248	1.4605
80	140	91.37	1.326	1.472	1.3257	1.4767
80	160	108.06	1.326	1.472	1.3237	1.4644

With Matlab we have, Mean Squareed Error (MSE) = 3.0152%

2.5. Conclusion

Based on the data obtained, an inverse power model can be generated using the Matlab program. The resulting model is a linear equation to the power of one with the variable x as the lifetime of the cable. By entering the variable x, a prediction of the electric field is obtained which can reduce the quality of cable insulation. The cable life prediction produces an error of 6.11%. Then when a partial discharge occurs, it produces a model obtained with artificial intelligence to find the values of a and b with a Mean Squared Error (MSE) of 3.0152%. The two models show that when the voltage increases, the lifetime of the cable will decrease, especially when there is a partial discharge, the lifetime of the cable decreases more quickly. In accordance with the theory of the inverse power model which shows that the new formula is accurate for determining cable lifetime.

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3

SHORT CIRCUIT CURRENTS DUE TO THERMAL INSTABILITY ON TR-XLPE 12/20 KV GROUND CABLE

Syamsir Abduh

Abstract

Short circuit current constitutes one of the forms of disturbance on transmission system of electric energy, including transmission system through underground cable. Effects of short circuit current disturbance are, among other things: mechanical damage on cable due to electromagnetic force from repulsion between conductors or between conductor and wrapper; the sharp increased temperature due to joule heat on the conductor and wrapper causing thermal instability on the cable. This will further causes the occurrence of tree electric or the failure on insulation; the occurrence of aging on the cable. This is certainly of disadvantage since the continuity of voltage distribution may be disturbed and investment is of disadvantage. This paper explains calculation/ determination of short circuit currents by comparing two methods, namely adiabatic method and nonadiabatic method. Non-adiabatic method is applicable for all durations of short circuit. If compared to adiabatic method, non-adiabatic method will give significant addition to permissible short circuit currents in the case of choosing the type of backfill, cable burying depth, distance befiveen cables and distance between lines.

Key word: short circuit current; thermal instability.

3.1. Introduction

The calculation of capacity of thermally permissible short circuit currents in cable is determined by the transfer of heat occurring in cable parts into its surrounding, which in this case acting as the heat sink. The more heat that can be distributed by the cable parts to its surrounding, the more capacity of short current can be obtained by the cable [l]. Calculation conducted in general is divided into two phases [2]. In the first phase, initial cable temperature (especially conducting temperature) will be calculated for any load current that has been given/determined. In the second phase, we will calculate the capacity of cable short circuit current with initial temperature value that has been determined from the calculation of the first phase.

Cable's initial temperature constitutes the cable's temperature on continuous load that is also cable's temperature before undergoing short interference.The maximum temperature at conductor, which implicitly includes the capability to restrain heat of its insulating material, limits capacity of short circuit current of any cable. This restriction of temperature at insulating part has the purpose to avoid immediate aging on that part as well as to avoid insulation damage that may cause leak of voltage [3]. In the calculation of disturbing current to the ground at insulation, it is also required that there is limitation to the maximum temperature occurring in the cable's insulation. By entering the existing cable data into the calculation process, we will obtain the amount of capacity of short circuit current of cable 12/20 kV insulating polymer TR-XLPE.

3.2. Thermal Instability

Thermal instability can be determined through the following procedure: Calculating Cable 's Initial Temperature Calculation of cable's initial temperature relates to temperature of cable, at which interference of short current has not occurred. It is assumed that continuous load, which has reached steady condition, is flowing in the cable. From this continuous load, the cable's initial temperature can be calculated.

The larger amount of current that flows in the cable, the larger the cable's initial temperature will be produced. However, the load current that is given definitely may not exceed the cable's maximum temperature at normal operation condition, which for polymer cable of XLPE type is determined to amount to approximately 9^0C (IEC-949)[4]. To calculate the amount of cable's initial temperature of any given load current, we use heat equivalent circuit that constitutes an analogy of electric circuit.

Table 1. Analogy of Heat Circuit and Electric Circuit

Heat Circuit	**Electric Circuit**
Heat flow (q) Temperature difference (ΔT) Heat resistance (R)	Electric current (I) Potential difference (ΔE) Electric resistance (R)

From the said circuit of cable heat substitute, then equations are made to calculate initial temperature at the reviewed parts, in this case is cable system of 12/20 kV of polymer insulation XLPE.

Flow direction of heat losses is in radial from the most-inner part to the more-outer part, and it is deemed that the reverse does not occur. Side effect at the cable ends is so small that it is ignored. Heat substitute circuit in the cable can be expressed through figure l .

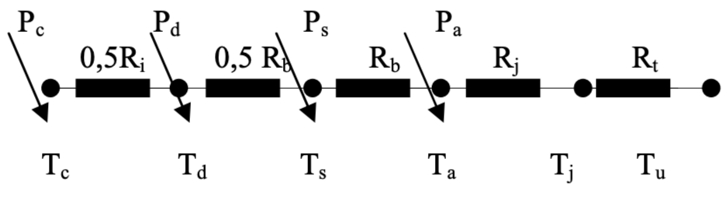

Figure 1, Heat Substitute Circuit in Cable

In which:

Tc, Tj, Ts, Ta, Tj, Tuare respectively temperature at the conductor, isolation, shield, insulation, cable insulation, and ground surface (^oC). Pc, Pd, Ps, Pa are respectively heat losses at the conductor, dielectric, insulation, and shield (W/m). Ri, Rb Rj, Rt are respectively heat resistance per unit of length of isolation, bearing, cable insulation, and ground (^{o}C.m/w). Heat resistance of metal material type is so small that the heat resistance at the conductor and metal insulation can be ignored [5].

Dielectric heat losses is put/injected at the center point of isolation heat resistance. This constitutes an approach that produces calculation of temperature that is close to the actual condition.

Based on heat substitute circuit in Figure (l) above, we can derive equations to calculate initial temperature of the cable parts at steady condition as follows:

Amount of conductor's temperature is provided through the following equation:

$$Tc=Pc.(0.5Ri+O.5Ri+Rb+Rj+Rt)+Pd(0.5Ri+Rb+Rj+Rt) +Ps(Rb+Rj+Rt)+Pa.(Rj+Rt)+Tu \quad (1)$$

Then temperature of cable isolation is:

$$T_i=(P_c+P_d)(0.5R_I+R_b+R_j+R_t)+P_s(R_b+R_j+R_t)+P_s(R_j+R_t)+T_u \quad (2)$$

Amount of temperature in insulation, shield, and cable insulator are also respectively provided through the following equations:

$$T_s=(P_c+P_d+P_s)(R_b+R_j+R_t)+Pa(R_j+R_t)+T_u \quad (3)$$

$$T_a=(P_c+P_d+P_s)(R_j+R_t)+T_U \quad (4)$$

$$Tj=(Pc+Pd+Ps)(Rt)+Tu \quad (5)$$

Value of ground surface temperature (Tu) is deemed as constant, and its value is taken in accordance with the climate in which cable is buried. For the condition of tropical region such as Jakarta city, ground surface temperature can be taken to amount to approximately 25 ^{o}C.

Calculation of Capacity of Short Circuit Current

To conduct calculation of capacity of thermally permissible short circuit currents, it is required to follow procedure/steps of systematic calculation in order to obtain good and satisfying result.

For initial step, it is required to calculate the value of fixed variable that will be made reference for the subsequent calculation. The value of temperature of maximum work at the conductor, insulation, and shield should be first assumed at a certain value.

Variable with changing value is the amount of nonadiabatic factors (in the calculation of short circuit current capacity in non-adiabatic manner), which will produce different value for each iteration phase.

3.3. Calculation Result

Calculation is conducted by making configuration of "cross-combining double channel and burying cable directly" with the amount of load current of 550 Ampere for copper cable, and 440 Ampere for cable with aluminum conductor. The configuration constitutes combination of variation of number of lines and the use of backfill. The capacity of short circuit current is calculated using non-adiabatic and adiabatic methods to obtain result that is closer to the real condition.

Effect of Backfill Type to the Short Circuit Current Capacity

The result of calculation of short circuit current capacity with the change of backfill type (i.e. by changing the value of heat resistance of backfill type) is presented in Figure 2. Type heat resistance used ranges from 0.2 ^{o}C.m/W to 0.8 ^{o}C.m/W.

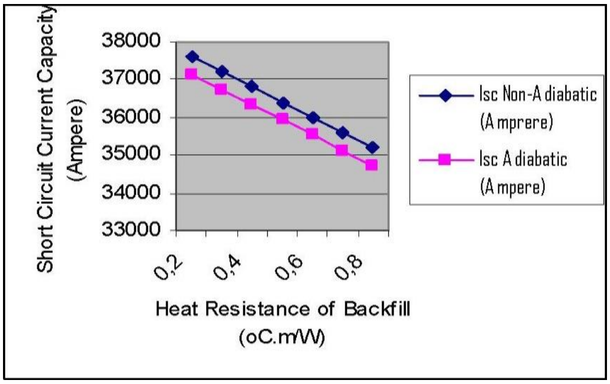

Figure 2. Effect of Backfill Type to Short Circuit Current Capacity

Effect of Burial Depth to Short Circuit Current Capacity

Result of calculation of short circuit current capacity is obtained by changing the depth of cable burial. Cable burial depth is changed with several depth variations ranging from 0.8 to 3.2 m (see Figure 3).

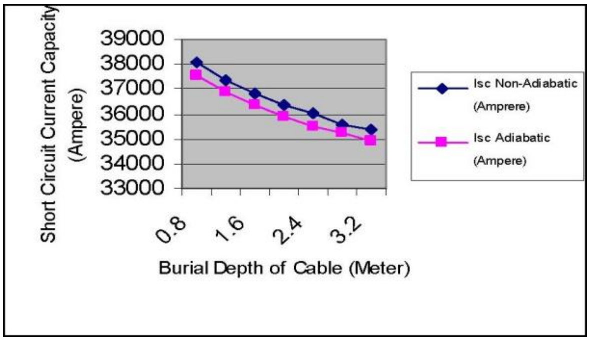

Figure 3. Effect of Burial Depth to Short Circuit Current Capacity

Effect of Distance among Cables to Short Circuit Current Capacity

Figure 4 will describe the effect of distance among cables toward short circuit current capacity. Distance between cables with value between 0.1 meter through 0.4 meter with the distance of one cable to the cable next to it in one channel is the same.

The time taken for the two conditions above is constant, namely I second with the current of 440A.

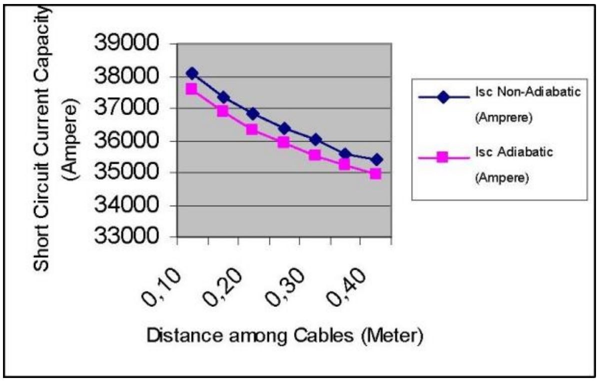

Figure 4. Effect of Change of Distance among Cables to Short Circuit Current Capacity

Effect of Change in Distance among Lines To Short Circuit Current Capacity

The calculation result of short circuit current capacity against change in distance among double lines with distance among lines ranging from 0.2 meter until 1.4 meters is presented in Figure 5.

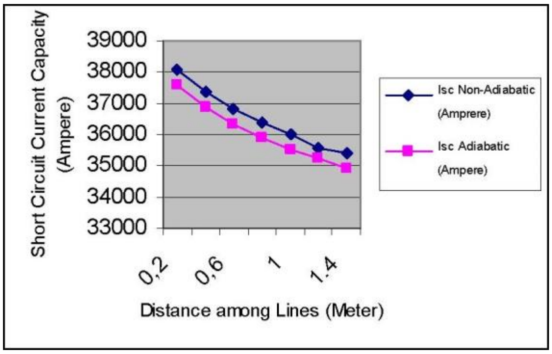

Figure 5. Effect of Distance among Lines to Short Circuit Current Capacity

3.4. Analysis And Discussion

Based on calculation result in the calculation result cub-chapter above, parameters that influence short circuit current capacity due to thermal instability in cable will be analyzed. Such parameters include:

Use of Backfill in Cable Burial

Compared with cable being buried directly into the ground, the backfill has low type of heat resistance, so that the flow of cable heat to its surrounding will flow more easily. By the more heat flowed to the surrounding, cable work temperature will decrease. As a result, short circuit current capacity that can be flowed in the cable will increase in line with the decrease in the cable temperature. Material of backfill type used in the burial also influences short circuit current capacity of the cable. The influence of material used as backfill will change the value of its specific heat resistance. The lower the value of specific heat resistance is, the lower cable temperature is, because more and more heat can be absorbed and flowed to the ground surface. As a result of this decrease in temperature, short circuit current capacity produced will undergo increase. The result of calculation through the method of nonadiabatic shows the value of short circuit current capacity that is higher than that using adiabatic method.

Depth of Burial

The deeper cable is buried into the ground, the lower short circuit current capacity produced. It shows that short circuit current capacity at the burial depth of 0.8 m has the greater current capacity compared to the burial depth of 2 m, and so on. If cable depth is half reduced (from 2.4 m to 1.2 m), cable temperature will decrease from 80,99 ^{o}c to 70.69 ^{o}c. The calculation result in this specific case shows higher value of short circuit current capacity (Non-adiabatic) compared to adiabatic method.

Distance among Cables

Based on the calculation result as presented in Figure 4, then the closer the cable distance is, the lesser short current capacity obtained will be. The more parted distance the cable is buried, the greater short circuit capacity is obtained. If the distance of cable is doubled, for example distance change from 0.1 meter into 2 meters, the short circuit current capacity will increase by approximately 4% with temperature decrease of approximately 9^{0}C. The calculation result in this specific case shows higher value of short circuit current capacity (Nonadiabatic) compared with adiabatic method.

Distance among Lines

In double lines, the change of distance among lines will also influence the value of short circuit current capacity that occurs. If distance among lines is doubled, then the value of short circuit current capacity will only increase to approximately 1.5% ,while the change to its temperature is 10^{0} 0.

To increase voltage capacity distributed to the load and to increase system capability, distribution of electric energy usually utilizes double or even more lines. However, the increase in this number of lines on the other side will decrease short circuit current capacity of each cable. This happens since by the more number of lines, there will also be more cables that will exist, and so on there will also be more heat sources that will influence one cable and the other. The more and more these heat sources are, will certainly cause the increase in temperature at the cable pans, so that in the end, this will influence the short circuit current capacity of the cable. Calculation result in this case shows higher value of short circuit current capacity (Non-adiabatic) compared with adiabatic method.

3.5. Conclusion

Non-adiabatic method shows better result compared with adiabatic method in determining value of short circuit capacity due to thermal instability on the use of underground TR-XLPE cable of 12/20kV especially on the selection backfill type, cable burial depth, distance among cables, and distance among lines. This is so since adiabatic method assumes that heat produced at the time of occurrence of short circuit is not distributed to cable's surrounding part, so that the heat that occurs is fully absorbed by the cable itself and not to its surroundings. This will certainly less suitable with the reality, because in reality, the heat that occurs is distributed by cable's parts to its surroundings. Therefore, we need to apply non-adiabatic method in calculating short circuit current capacity of a cable in order that the calculation result produced is more accurate and closer to the reality.

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4

THERMAL INSTABILITY ON TR-XLPE 12/20 KV GROUND CABLE : NON ADIABATIC AND ADIABATIC COMPARISON METHOD

Syamsir Abduh

Abstract

Short circuit current constitutes one of the forms of disturbance on transmission system of electric energy, including transmission system through underground cable. Effects of short circuit current disturbance are, among other things: mechanical damage on cable due to electromagnetic force from repulsion between conductors or between conductor and wrapper; the sharp increased temperature due to joule heat on the conductor and wrapper causing thermal instability on the cable. This will further causes the occurrence of tree electric or the failure on insulation; the occurrence of aging on the cable. This is certainly of disadvantage since the continuity of voltage distribution may be disturbed and investment is of disadvantage. The calculation of capacity of thermally permissible short circuit currents in cable is determined by the transfer of heat occurring in cable parts into its surrounding This paper explains calculation/ determination of short circuit currents by comparing two methods, namely adiabatic method and non-adiabatic method. The result of study shows that non-adiabatic method better than adiabatic method in determining value of short circuit capacity due to thermal instability on the use of underground TR-XLPE cable of 12/20kV especially on the selection backfill type, cable burial depth, distance among cables, and distance among lines and also non-adiabatic method is applicable for all durations of short circuit.

Key word : short circuit current; thermal instability.

4.1. Introduction

He calculation of capacity of thermally permissible short circuit currents in cable is determined by the transfer of heat occurring in cable parts into its surrounding, which in this case acting as the heat sink. The more heat that can be distributed by the cable parts to its surrounding, the more capacity of short current can be obtained by the cable [1]. Calculation conducted in general is divided into two phases [2]. In the first phase, initial cable temperature (especially conducting temperature) will be calculated for any load current that has been given/determined. In the second phase, we will calculate the capacity of cable short circuit current with initial temperature value that has been determined from the calculation of the first phase. Cable's initial temperature constitutes the cable's temperature on continuous load that is also cable's temperature before undergoing short interference.

The maximum temperature at conductor, which implicitly includes the capability to restrain heat of its insulating material, limits capacity of short circuit current of any cable. This restriction of temperature at insulating part has the purpose to avoid immediate aging on that part as well as to avoid insulation damage that may cause leak of voltage [3]. In the calculation of disturbing current to the ground at insulation, it is also required that there is limitation to the maximum temperature occurring in the cable's insulation.

By entering the existing cable data into the calculation process, we will obtain the amount of capacity of short circuit current of cable 12/20 kV insulating polymer TR-XLPE.

4.2. Thermal Instability

Thermal instability can be determined through the following procedure[4]:

A. Calculating Cable's Initial Temperature

Calculation of cable's initial temperature relates to temperature of cable, at which interference of short current has not occurred. It is assumed that continuous load, which has reached steady condition, is flowing in the cable. From this continuous load, the cable's initial temperature can be calculated.

The larger amount of current that flows in the cable, the larger the cable's initial temperature will be produced. However, the load current that is given definitely may not exceed the cable's maximum temperature at normal operation condition, which for polymer cable of XLPE type is determined to amount to approximately 9^0C (IEC-949)[5].

To calculate the amount of cable's initial temperature of any given load current, we use heat equivalent circuit that constitutes an analogy of electric circuit.

From the said circuit of cable heat substitute, then equations are made to calculate initial temperature at the reviewed parts, in this case is cable system of 12/20 kV of polymer insulation XLPE.

Flow direction of heat losses is in radial from the mostinner part to the more-outer part, and it is deemed that the reverse does not occur. Side effect at the cable ends is so small that it is ignored.

Table I. Analogy Of Heat Circuit And Electric Circuit

Heat Circuit	**Electric Circuit**
Heat flow (q)	Electric current (I)
Temperature difference (ΔT)	Potential difference (ΔE)
Heat resistance (R)	Electric resistance (R)

Heat substitute circuit in the cable can be expressed through figure 1.

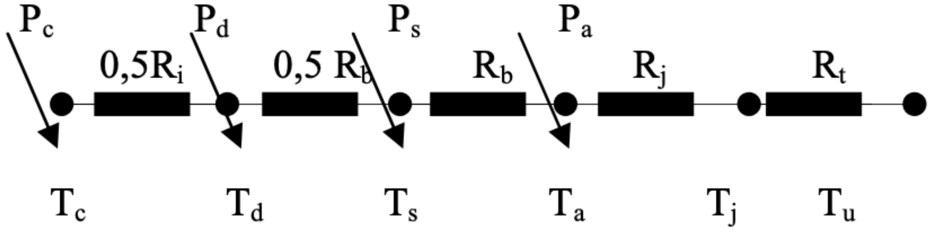

Fig. 1. Heat Substitute Circuit in Cable

In which:

T_c, T_j, T_s, T_a, T_j, $T_u$are respectively temperature at the conductor, isolation, shield, insulation, cable insulation, and ground surface (^{0}C). P_c, P_d, P_s, P_a are respectively heat losses at the conductor, dielectric, insulation, and shield (W/m).

R_i, R_b, R_j, R_t are respectively heat resistance per unit of length of isolation, bearing, cable insulation, and ground (°C.m/w). Heat resistance of metal material type is so small that the heat resistance at the conductor and metal insulation can be ignored [6]. Dielectric heat losses is put/injected at the center point of isolation heat resistance. This constitutes an approach that produces calculation of temperature that is close to the actual condition.

Based on heat substitute circuit in Figure (1) above, we can derive equations to calculate initial temperature of the cable parts at steady condition as follows:

Amount of conductor's temperature is provided through the following equation:

$$T_c=P_c.(0.5R_i+0.5R_i+R_b+R_j+R_t)+P_d(0.5R_i+R_b+R_j+R_t)+Ps(Rb+Rj+Rt)+Pa.(Rj+Rt)+Tu \quad (1)$$

Then temperature of cable isolation is:

$$T_I =(P_c+P_d)\ (0.5R_I + R_b + R_j + R_t) + P_s\ (R_b + R_j + R_t) + P_s\ (R_j + R_t) + T_u \quad (2)$$

Amount of temperature in insulation, shield, and cable insulator are also respectively provided through the following equations:

$$T_s=(P_c + P_d + P_s)(R_b + R_j + R_t)+ P_a\ (R_j + R_t) +T_u \quad (3)$$

$$T_a= (P_c + P_d + P_s)\ (R_j + R_t) + T_u \quad (4)$$

$$Tj= (P_c + P_d + P_s)\ (R_t) +T_u \quad (5)$$

Value of ground surface temperature (T_u) is deemed as constant, and its value is taken in accordance with the climate in which cable is buried. For the condition of tropical region such as Jakarta city, ground surface temperature can be taken to amount to approximately 25°C.

B. Calculation of Capacity of Short Circuit Current

To conduct calculation of capacity of thermally permissible short circuit currents, it is required to follow procedure/steps of systematic calculation in order to obtain good and satisfying result.

For initial step, it is required to calculate the value of fixed variable that will be made reference for the subsequent calculation. The value of temperature of maximum work at the conductor, insulation, and shield should be first assumed at a certain value.

Variable with changing value is the amount of nonadiabatic factors (in the calculation of short circuit current capacity in non-adiabatic manner), which will produce different value for each iteration phase.

4.3. Calculation Result

Calculation is conducted by making configuration of "cross-combining double channel and burying cable directly" with the amount of load current of 550 Ampere for copper cable, and 440 Ampere for cable with aluminum conductor. The configuration constitutes combination of variation of number of lines and the use of backfill. The capacity of short circuit current is calculated using non-adiabatic and adiabatic methods to obtain result that is closer to the real condition.

A. Effect of Backfill Type to the Short Circuit Current Capacity

The result of calculation of short circuit current capacity with the change of backfill type (i.e. by changing the value of heat resistance of backfill type) is presented in Figure 2. Type heat resistance used ranges from 0.2 ^{0}C.m/W to 0.8 ^{0}C.m/W.

B. Effect of Burial Depth to Short Circuit Current Capacity

Result of calculation of short circuit current capacity is obtained by changing the depth of cable burial. Cable burial depth is changed with several depth variations ranging from 0.8 to 3.2 m (see Figure 3).

C. Effect of Distance among Cables to Short Circuit Current Capacity

Figure 4 will describe the effect of distance among cables toward short circuit current capacity. Distance between cables with value between 0.1 meter through 0.4 meter with the distance of one cable to the cable next to it in one channel is the same.

The time taken for the two conditions above is constant, namely 1 second with the current of 440A.

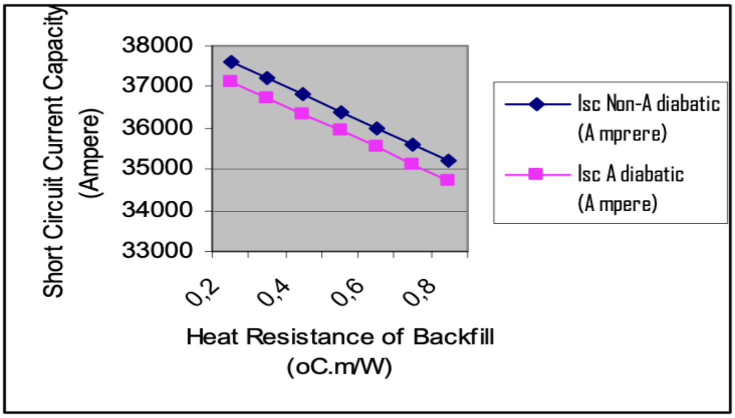

Fig.2. Effect of Backfill Type to Short Circuit Current Capacity

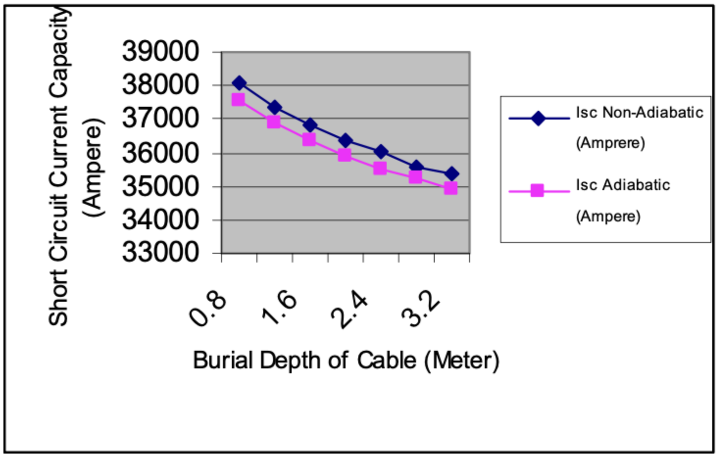

Fig. 3. Effect of Burial Depth to Short Circuit Current Capacity

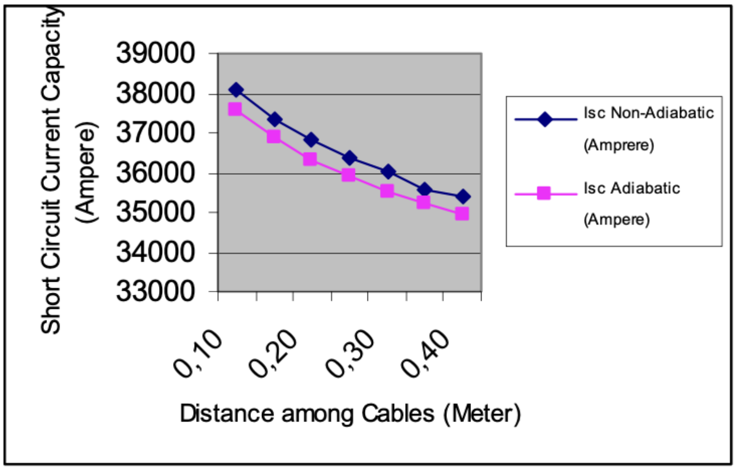

Fig. 4. Effect of Change of Distance among Cables to Short Circuit Current Capacity

D. Effect of Change in Distance among Lines To Short Circuit Current Capacity

The calculation result of short circuit current capacity against change in distance among double lines with distance among lines ranging from 0.2 meter until 1.4 meters is presented in Figure 5.

4.4. Analysis And Discussion

Based on calculation result in the calculation result cubchapter above, parameters that influence short circuit current capacity due to thermal instability in cable will be analyzed. Such parameters include:

A. Use of Backfill in Cable Burial

Compared with cable being buried directly into the ground, the backfill has low type of heat resistance, so that the flow of cable heat to its surrounding will flow more easily. By the more heat flowed to the surrounding, cable work temperature will decrease. As a result, short circuit current capacity that can be flowed in the cable will increase in line with the decrease in the cable temperature. Material of backfill type used in the burial also influences short circuit current capacity of the cable. The influence of material used as backfill will change the value of its specific heat resistance. The lower the value of specific heat resistance is, the lower cable temperature is, because more and more heat can be absorbed and flowed to the ground surface. As a result of this decrease in temperature, short circuit current capacity produced will undergo increase. The result of calculation through the method of non-adiabatic shows the value of short circuit current capacity that is higher than that using adiabatic method.

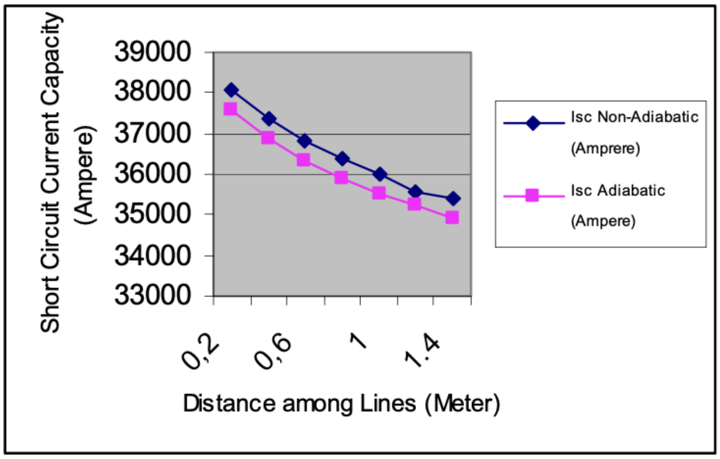

Fig. 5. Effect of Distance among Lines to Short Circuit Current Capacity

B. Depth of Burial

The deeper cable is buried into the ground, the lower short circuit current capacity produced. It shows that short circuit current capacity at the burial depth of 0.8 m has the greater current capacity compared to the burial depth of 2 m, and so on. If cable depth is half reduced (from 2.4 m to 1.2 m), cable temperature will decrease from 80,99 ^{0}C to 70.69 ^{0}C. The calculation result in this specific case shows higher value of short circuit current capacity (Non-adiabatic) compared to adiabatic method.

C. Distance among Cables

Based on the calculation result as presented in Figure 4, then the closer the cable distance is, the lesser short current capacity obtained will be. The more parted distance the cable is buried, the greater short circuit capacity is obtained. If the distance of cable is doubled, for example distance change from 0.1 meter into 2 meters, the short circuit current capacity will increase by approximately 4% with temperature decrease of approximately 9^0C. The calculation result in this specific case shows higher value of short circuit current capacity (Non-adiabatic) compared with adiabatic method.

D. Distance among Lines

In double lines, the change of distance among lines will also influence the value of short circuit current capacity that occurs. If distance among lines is doubled, then the value of short circuit current capacity will only increase to approximately 1.5%, while the change to its temperature is 10%.

To increase voltage capacity distributed to the load and to increase system capability, distribution of electric energy usually utilizes double or even more lines. However, the increase in this number of lines on the other side will decrease short circuit current capacity of each cable. This happens since by the more number of lines, there will also be more cables that will exist, and so on there will also be more heat sources that will influence one cable and the other. The more and more these heat sources are, will certainly cause the increase in temperature at the c able parts, so that in the end, this will influence the short circuit current capacity of the cable. Calculation result in this case shows higher value of short circuit current capacity (Non-adiabatic) compared with adiabatic method.

4.5. Conclusion

Non-adiabatic method shows better result compared with adiabatic method in determining value of short circuit capacity due to thermal instability on the use of underground TR-XLPE cable of 12/20kV especially on the selection backfill type, cable burial depth, distance among cables, and distance among lines. This is so since adiabatic method assumes that heat produced at the time of occurrence of short circuit is not distributed to cable's surrounding part, so that the heat that occurs is fully absorbed by the cable itself and not to its surroundings. This will certainly less suitable with the reality, because in reality, the heat that occurs is distributed by cable's parts to its surroundings. Therefore, we need to apply non-adiabatic method in calculating short circuit current capacity of a cable in order that the calculation result produced is more accurate and closer to the reality.

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Bunga Rampai

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Problem Solving and Mitigation

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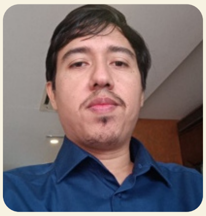

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