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Study of 220kV 3 Core XLPE Submarine Cable using COMSOL Multiphysics

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Abstract: This paper presents a study and analysis of the electrical properties and electrical stress of a 220kV 3core XLPE insulated submarine cable. The model of electric cable is developed using COMSOL Multiphysics FEA software to simulate and determine the electrical properties such as capacitance, inductance, resistance, and power losses across the electric cable. The simulation model shows accurate results in capacitance compared to the analytical model. Inductance and resistance of cable greatly depend on the material and construction of the cable. Among all power losses, phase losses contribute the most due to skin effect and heat dissipation. Electrical stress data is determined as well through the plot of electric field distribution across the XLPE insulator. The plot shows an exponential decrease across the XLPE insulator with an initial maximum of 6.75MV/m electric field strength. Insulating medium must be selected with low permittivity constant to lower down the electric stress within the insulation layer.

Keywords: Submarine Cable, XLPE Insulator, COMSOL Multiphysics

1. Introduction

High voltage engineering is implemented in the transmission and distribution system to deliver power supply to end user efficiently over a long distance. In underground transmission system, submarine cable is used to transmit power underwater for application such as offshore windfarm harvesting, grid interconnection purposes and offshore oil and gas platform [1]-[4].

Design and construction of submarine cable consists of a series of complex procedures and requires specialized consideration. [5-7] It must be constructed to withstand sufficient mechanical and electrical strength in reference to IEC 60287 series of standards [8]-[13]. Electrical strength and stress of an electric cable is studied through the electrical properties of the transmission line. Hence, it is necessary to determine the electrical properties exhibited by the cable under the service rating of transmission.

This study is intended to simulate and analyze the electrical properties of an 220kV 3core XLPE insulated submarine cable by using Finite Element Analysis (FEA) software tool. Electric field

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*Corresponding author: saufi@uthm.edu.my distribution across the XLPE insulation layer is obtained in subsequence to figure out the electrical stress within the cable. In the simulation model setup, a 2D submarine cable model is developed with assumption that all 3 phases are operating at stable condition with balanced load.

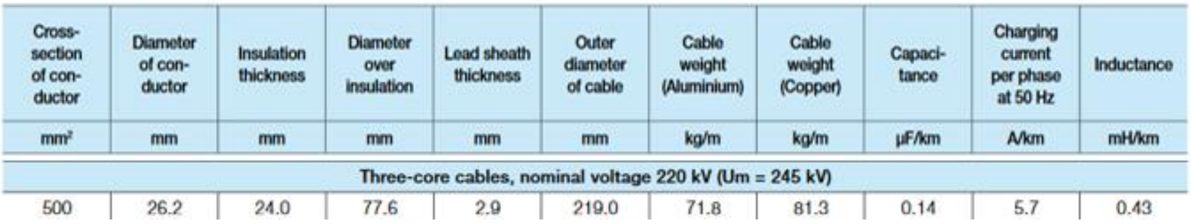
2. Simulation Techniques for Electrical Properties and Field Measurement in Cable

Simulation on the 220kV submarine cable is conducted by using COMSOL Multiphysics as a tool of Finite Element Analysis (FEA) software.

2.1 Cable Modelling

In the initial setup of the study, the geometric parameters are fed into the software in accordance to the technical specifications provided by ABB electric cable manufacturer, with reference on IEC 60287 series of standards. The chosen 220kV cable specification is provided in Table 1 as follows.

Table 1: Technical Data for 220kV Cable Specifications [14]



Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm^2	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km
Three-core cables, nominal voltage 220 kV (Um = 245 kV)										
500	26.2	24.0	77.6	2.9	219.0	71.8	81.3	0.14	5.7	0.43

Based on the cable specifications in Table 1, the geometric parameters are fed into the software setting to setup the object geometry of the cable model. The flowcharts on the modelling process are shown in Figure 1 and 2, which displays the geometry built and material assigned process.

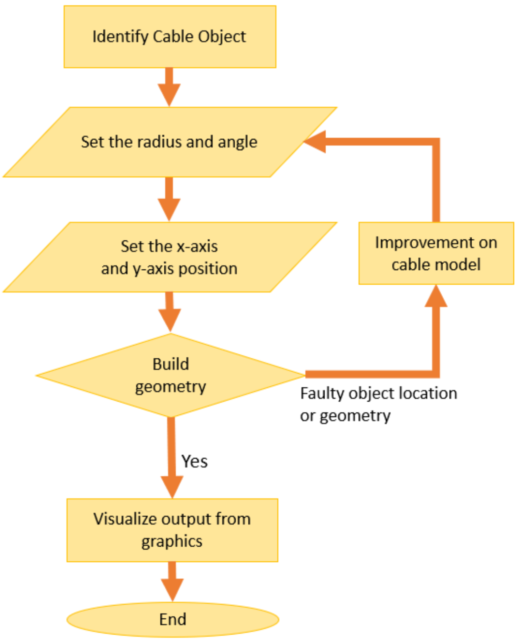


Figure 1: Block diagram of geometry built

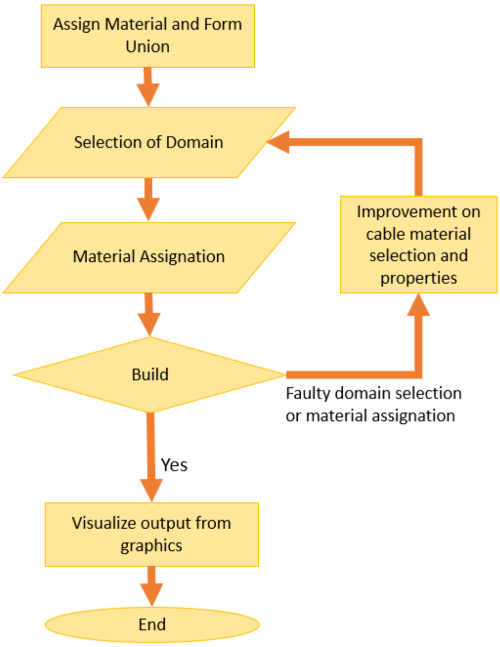


Figure 2: Block diagram of material assigned

The process of cable modelling is considered complete after the meshing of the model, as shown in Figure 3.

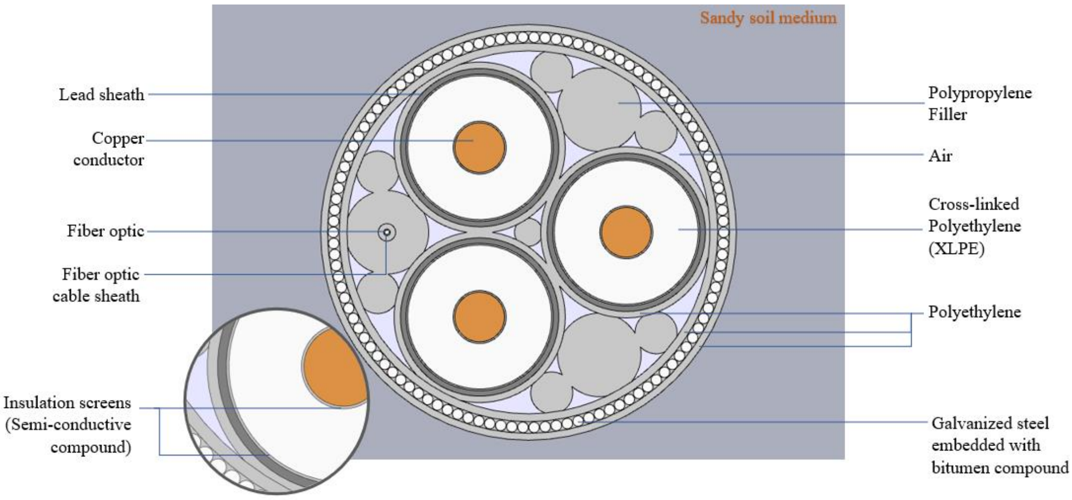


Figure 3: Complete modelling of submarine cable model

2.2 Solver Setting

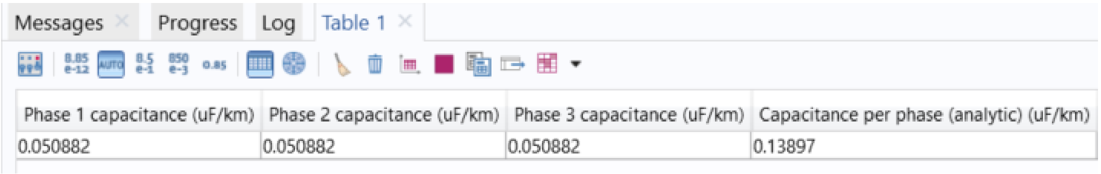
The physic solvers used in the study to figure out the electrical properties of cable are Electric Current (ec) and Magnetic Field (mf). Electric Current (ec) solver is applied to study the electric field across the cable. In subsequent, capacitance per phase of the electric cable is simulated as the result finding. On the other hand, Magnetic Field (mf) solver is applied to simulate the inductance and resistance across the cable. Power losses are obtained as well by simulating the losses across conductor, screen, and armor.

3. Electrical Properties and Field Measurement in Cable

The simulated result comprises of the electrical properties and electric field data across the electric cable. In the findings of electrical properties, capacitance, inductance, resistance, and power losses in the cable is discussed and compared through analytical model. The finding of electric field data is plotted and analyzed using a cut plot of electric field strength across the XLPE insulation layer in one of the phase conductors.

3.1 Capacitance

From Figure 4, capacitance per phase obtained from simulation is 0.050882uF/km whereas the result found using analytical model is 0.13897uF/km. This shows that the analytical model developed using capacitance of coaxial cable is not accurate and not suitable for the case of 3 core cable.

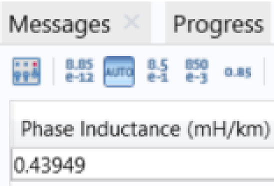


Phase 1 capacitance (uF/km)	Phase 2 capacitance (uF/km)	Phase 3 capacitance (uF/km)	Capacitance per phase (analytic) (uF/km)
0.050882	0.050882	0.050882	0.13897

Figure 4: Result of capacitance per phase

3.2 Inductance

Simulated result of inductance per phase is shown in Figure 5, which is 0.43949mH/km. The analytical model developed for coaxial cable is irrelevant to be used for comparison against simulated result as magnitude of inductance depends on material properties and geometry of the cable construction.

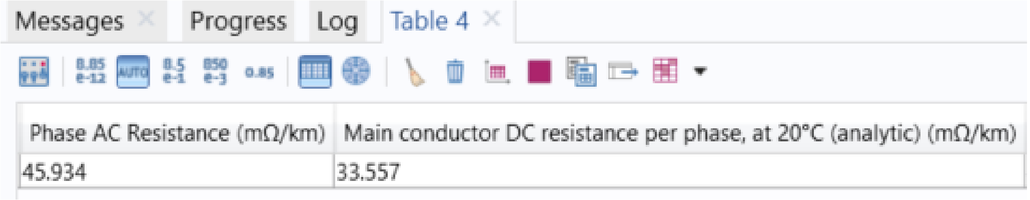


Phase Inductance (mH/km)
0.43949

Figure 5: Result of inductance per phase

3.3 Resistance

The result of resistance obtained from simulation consists of DC resistance and AC resistance as shown in Figure 6. DC resistance refers to the purely resistive component whereas AC resistance refers to the impedance of the cable, which is the combination product of resistance and reactance. Based on the simulated result, resistance is obtained at 33.557mohm/km while impedance is 45.934 mohm/km. The difference between the two value is contributed by the capacitive and inductive reactance.

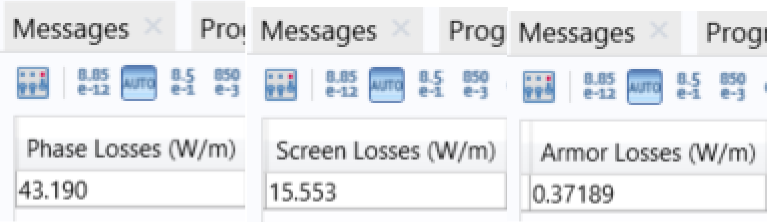


Phase AC Resistance (mΩ/km)	Main conductor DC resistance per phase, at 20°C (analytic) (mΩ/km)
45.934	33.557

Figure 6: Result of AC and DC resistance

3.4 Power Losses

Phase losses, screen losses and armor losses are the power loss induced within the cable as results of magnetic field induction and heat dissipation. Figure 7 displays and compares the phase losses, screen losses and armor losses.



Phase Losses (W/m)
43.190

Screen Losses (W/m)
15.553

Armor Losses (W/m)
0.37189

Figure 7: Results of phase losses, screen losses and armor losses

Phase losses recorded the highest losses at 43.19W/m while screen losses and armor losses are obtained as 15.553W/m and 0.37189W/m respectively. Power losses at phase conductor as a fact of skin effect and heat dissipation. High current flow along the phase conductor causes significant power losses during transmission. Screen losses and armor losses are the product of proximity effect where eddy current is induced in the screen and armor conductor due to the alternating magnetic field in adjacent.

3.5 Electric Field on Cable

A case study is setup to identify the electric field strength across the XLPE insulation layer among one of the 3 core submarine cable. A line cut is introduced across the XLPE insulation layer as shown in Figure 8, while the electric field strength across the line cut is plotted in Figure 9.

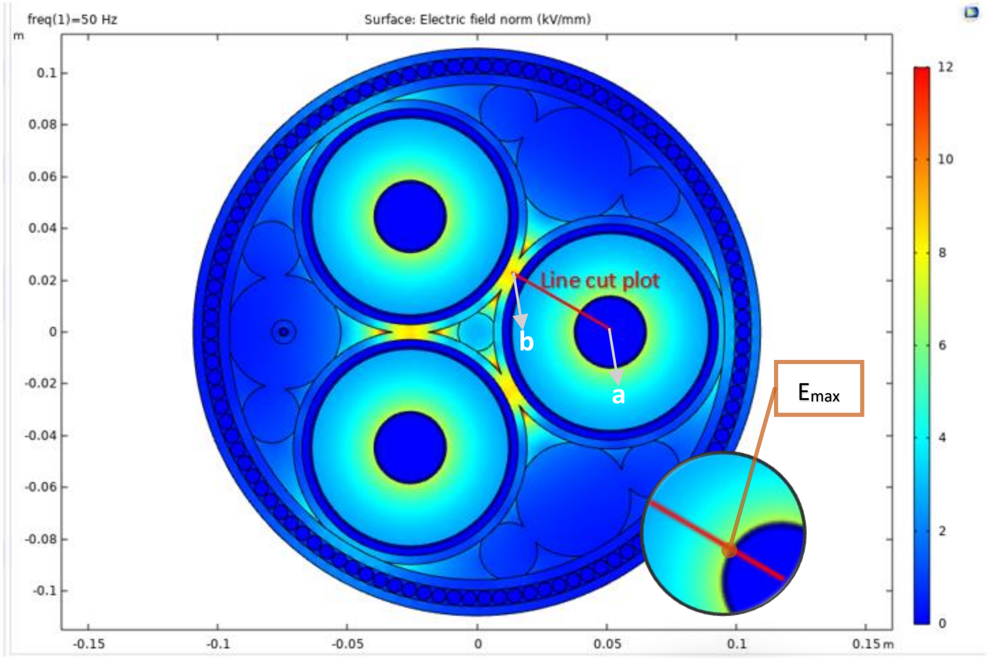


Figure 8: Plot of electric field norm

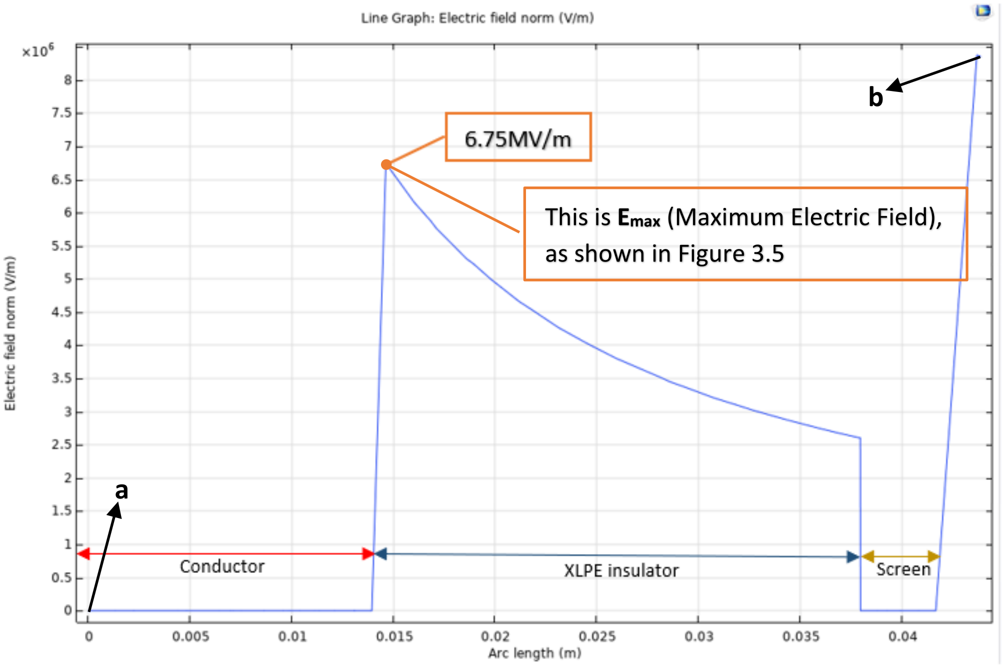


Figure 9: Electric field cut plot

Electric field exist only in the dielectric insulation layer, but not in the conductor and screen which exhibits metallic properties. Electrons can move freely across metallic conductor; no net charge will be formed across them. The result plot shows an exponential decrease across the XLPE insulator, with an initial maximum of 6.75MV/m electric field strength. Strength of electric field depends on the dielectric properties of the insulating medium. Higher permittivity level will lead to higher maximum electric field strength. Hence, it is wise to select insulating material with low dielectric constant to lower down the electric stress across the insulating medium.

4. Conclusion

In comparison of the simulation model developed from coaxial cable, capacitance obtained through analytical model is far more accurate. Resistance and inductance greatly depend on the material properties and construction of the cable conductor. Among the power losses across phases, screen and armor of cable, phase loss is the highest due to skin effect and heat dissipation whereas screen and armor losses occurs as results of proximity effect. Electric field strength across the XLPE insulator decreases exponentially from a maximum of 6.75MV/m. In future, studies can be done further to analyze the mechanical strength of the electric cable and simulate under varying case scenario of temperature and pressure.

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