

Electric Field and Thermal Properties of Dry Cable Using FEM

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Abstract

The Cross linked polyethylene (XLPE) insulated power cables are used for transmission and distribution of electrical power for higher voltage level. In this paper a Single phase medium voltage power cable buried in soil and it can be used to investigate electric field distribution, potential distribution and temperature distribution in a cable is analyzed and presented. In the present study the voltage distribution of an underground cable of 11kV is analyzed using FEM and its electric field and temperature distribution is calculated by analytical method. Result obtained indicates that the radial temperature distribution of the Single Phase cable do not flattened distribution. Further their performance parameter is verified using Comsol Multi Physics software. The results obtained using Comsol Multi Physics software is also compared with the analytical results which is obtained through literature review.

Keywords: Power cable, FEM, Comsol MultiPhysics, Electric field and temperature

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1. Introduction

Electric power system reliability start from generating, transmission comes up with distribution. At present, the power cable acts as the key role in power transmission. To operate cable networks for power transmission knowledge is needed of the maximum current load that can be applied without damage resulting to the cable. A maximum operating temperature limit for the cable core is set based upon the material chosen for the dielectric. The ampacity of the current-carrying conductor is limited by maximum operating temperature. That's because a cable dielectric is prematurely aged if thermally overstressed. So it is quite important to predict the temperature rise exactly when designing the cable.

Power losses occur in three regions of the cable: Joule's losses in the conductor, dielectric losses and sheath losses which are due to induced currents in the sheath. Generally the dielectric losses can be negligible when the rating voltage of the cable is greater than 66kV. So the temperature rise is mainly due to the Joule's losses in the conductor and the eddy losses in sheath. Both of them can be able to calculate in electromagnetic analysis based on the Finite-Element Method (FEM) and then used as thermal source to input into thermal field analysis. In this paper, based on the coupled electromagnetic-thermal theory, the temperature distributions in single phase Cable is calculated without taking into account the material properties to be variable with the temperature is shown in Figure 1.

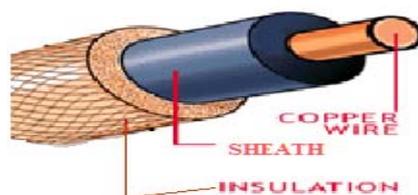


Figure 1. Power Cable Model

The FEM is a computer aided mathematical technique for obtaining approximate numerical solutions to the abstract equations of calculus that predict the response of physical systems subjected to external influences. The finite elements analysis of any problem involves basically four steps:

- (A) Discrediting the solution region into a finite number of sub regions or elements,
- (B) Deriving governing equations for a typical element,
- (C) Assembling all the elements in the solution region, and
- (D) Solving the system of equations obtained.

How these FEM is Preceded in Figure 2.

2. Comsol Multi Physics Algorithm

The finite element method is a numerical procedure that can be applied to obtain solutions to a variety of problems in engineering and science. Steady, transient, linear and non linear problems in electromagnetic, structural analysis and fluid dynamics may be analyzed and solved with it. Its main advantage is its capability to treat any type of geometry and material in homogeneity without a need to alter the formulation of the computer code that implements it providing geometrical fidelity and unrestricted material treatment [3]. Also FEM allows taking into account the actual field, voltage distribution over conductor surfaces. Then How to solve the problem in Comsol it can be shown in Figure 3.

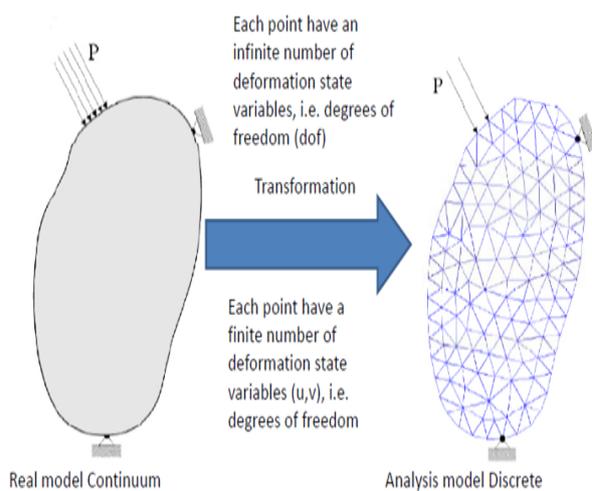


Figure 2. A Typical Finite Element Subdivision of an Irregular Domain

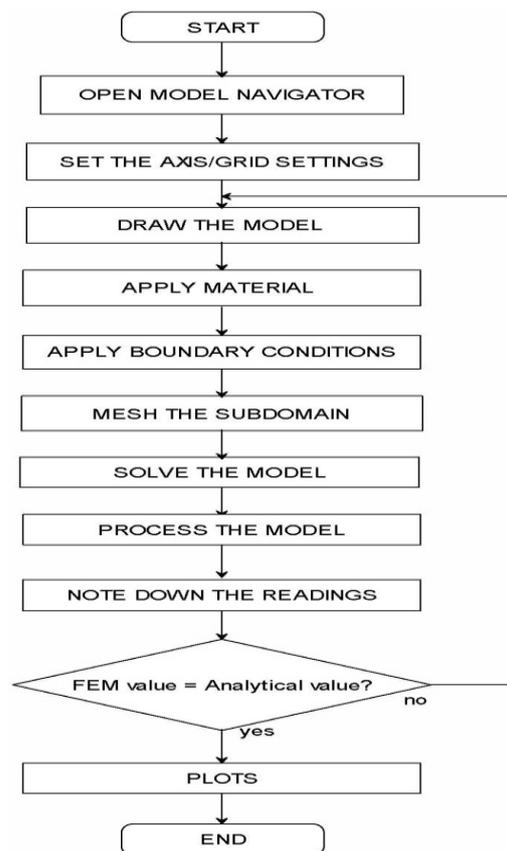


Figure 3. Flow chart cable modelling in COMSOL

3. Description of the Modelling

3.1. Cable Losses:

The cable consists of three especial components, that is: Conductor, insulation and sheath Shows in Figure 1. The losses are mainly due to the source current in the conductor and induced eddy current in the sheath. The power losses in the conductor and sheath per unit length are defined as:

$$P = \int \frac{J^2}{\sigma} ds \quad (1)$$

Where J- is source current in the conductor and Eddy current in the Sheath respectively. Accordingly, σ - is conductivity of conductor and sheath respectively. The power losses should be calculated according to Equation (1) and then used as the thermal source for thermal analysis [2].

3.2. Finite element formulation of electric field:

Comsol's electrostatic application mode solves Poisson's equation

$$-\nabla \cdot (\epsilon_0 \epsilon_r \nabla V) = \rho \quad (2)$$

And obtains the electric field E from the gradient of the potential

$$E = -\nabla V \quad (3)$$

The PDE (3) is solved subject to the following boundary conditions:

Sheath: $V = 0$ V

Conductor: $V = 11$ kV

The metallic sheath in cables consists of lead sheath with or without an additional insulation shield formed by application of non-magnetic metallic tape, a metalized paper tape or a semiconducting tape. In this paper while modelling, the sheath is treated as a non perfect conductor for the purpose of field computations. The insulating material surrounding the cable conductor is uniform with the relative permittivity of 2.3[4-7].

Table 1. Different Parameters of Different Layers of Cable

Parameter	Copper	XLPE
d[mm]	23	64.6
S[mm ²]	400	3277

Table 2. Parameters of Cable

Si.No	Item	Relative permittivity ϵ_r	Thermal Conductivity K(W/m °K)
1	Conductor	1.0	398
2	Conductor Insulation	2.3	6.034
3	Insulation	2.3	6.034
4	Sheath	1.0	35.3
5	Soil	1.0	1.0

3.3. Finite Element Formulation of Thermal Model:

3.3.1. Steady State Analysis:

In steady state temperature analysis temperature cannot depends on the time. The amount of heat flux is maximum at conductor surface and it will be minimum at sheath.

3.3.2. Transient Analysis:

The problem of temperature distribution at cable of XLPE selected by boundary type of Dirichlet-condition. Transient conduction occurs when the temperature within an object changes as a function of time. Analysis of transient systems is more complex and often calls for the

application of approximation theories or numerical analysis by computer, the heat flux is more in surface of the conductor and the remaining surfaces are very less.

The static thermal analysis theory, the material properties to be variable with temperature can be negligible. The heat transfer mechanism in the cable consists of heat conduction, convection and radiation. The Joule’s loss in the conductor which acts as the heat source for thermal field is transferred into the insulation layer and the sheath layer by conduction. In the sheath, the heat due to the eddy current loss and the transferred heat from the insulation layer are also transferred to the outer atmosphere by convection and radiation [7-8].

Differential equation applying to temperature distribution in steady state and transient condition is [10]:

$$\rho C \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = Q + h(T_{ext} - T) \tag{4}$$

Where

- T_{ext} : External temperature(°K).
- T: Conductor temperature (°K).
- k: Heat Conductivity(W/m.°K).
- h: Heat Transfer Conduction.
- Q: Heat Source(W/m).
- C: Heat Specific(J/m³.°K).
- ρ : Mass Specific(kg/m).

Table 3. Comparison of analytical and comsol results

Si.No	Parameter	Temperature(K) (Theoretical)	Temperature(K) (Using COMSOL)
1	Centre	362.587	363.001413
2	Conductor Surface	362.981	363.000000
3	XLPE surface	354 354.892567	354 354.892567
4	Sheath surface	345 346.657381	345 346.657381
5	Soil	293.000000	293.000000

Table 3 concludes that the theoretical calculation of steady state temperature analysis is almost similar to the COMSOL MultiPhysics results.

To the problem of transfer of heat at underground Single Phase cable only happens transfer of heat by Conductor; therefore formula used for settled state steady and transient is [5]:

$$- \nabla (k \nabla T) = Q \tag{5}$$

$$\rho C \frac{\partial u}{\partial t} - \nabla \cdot (k \nabla T) = Q \tag{6}$$

Calculation heat source for the conductor of copper (Q) utilize formula:

$$R_{DC} = \frac{1.02 * \rho_{20}(1 + \alpha_{20}[\theta - 20])}{S} = 4.6038e-5 \Omega/m$$

$$Q = I^2 R_{DC} \text{ Watt/m}$$

4. Results and Discussions

4.1. Electric Field and Potential Distribution

The electric field inside the conductor is zero but it should be Maximum at conductor surface. According to electro Field Theory, Electric Field is in Side the Body is Zero. But, Potential is non Zero Quantity. Here, The Applied Potential is 11kV and it goes on decreases

from conductor surface to the outer layer of sheath [7]. The Potential distributed at insulation level is 6kV, and Potential at sheath is Zero. It is shown in Figure 7.

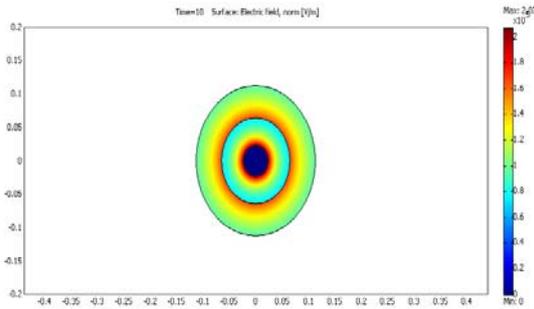


Figure 4. Surface Plot of Electric Field

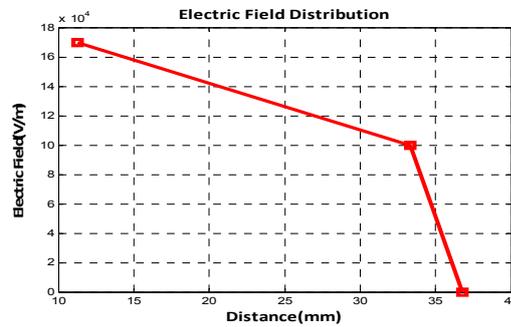


Figure 5. Electric Field Distributions of Cable

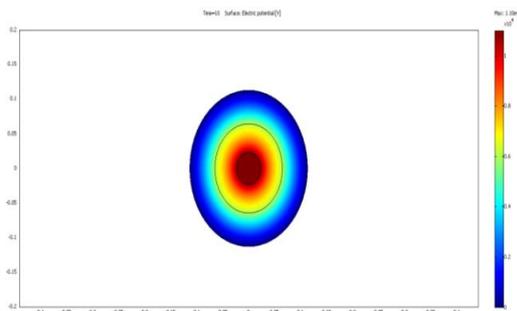


Figure 6. Surface Plot of Potential Distribution

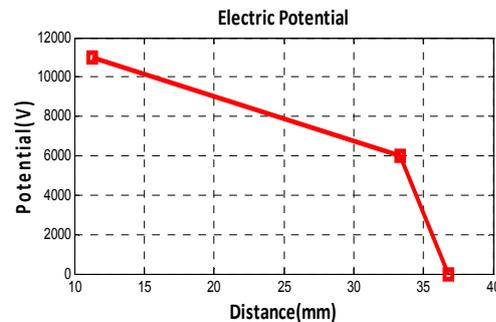


Figure 7. Potential Distributions of Cable

4.2. Temperature Distribution

Transient conduction occurs when the temperature within an object changes as a function of time. Analysis of transient systems is more complex and often calls for the application of approximation theories or numerical analysis by computer, the heat flux is more in surface of the conductor and the remaining surfaces are very less as shown in Figure 9.

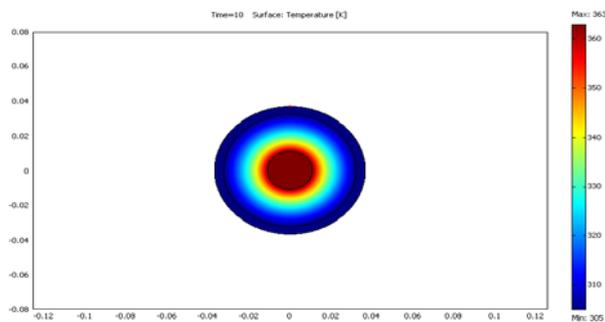


Figure 8. Surface Temperature Distribution

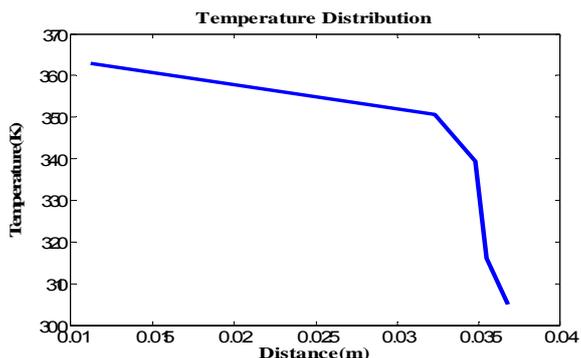


Figure 9. Temperature Distribution in Cable

5. Conclusion

From this study we can conclude that the radial distribution of the temperature for different layers. The curves are not flattened from centre to external shares on account of the difference in thermal conductivity in each layer. In point of view of the applied method, the Finite Element Method (FEM) presents a good tool to calculate the heat transfer problem in the high voltage cables because of its simplicity in the formulation of the problem and implementation of the method.

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