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Electric Field Analysis of High Voltage Underground Cable using Finite Element Method

Kartik Patel[1], Dr. Ashok Kumar Jhala[2], Mr. Pramod Kumar Rathore[3]
[1]*M.Tech. Student,* [2,3]*Associate Professor, Electrical & Electronics Engineering, RKDF-CE, Bhopal (M.P.)*

Abstract: ***Transmission and Distribution of electric power through underground cables is a viable alternative to overhead lines, particularly in residential or highly populated areas. The electrical stresses are consequences of regular voltages and over voltages and the thermal stresses are related to heat produced inside the conductor due to flow of high rated current which is the main factors that affect its reliability. The performance of these underground power cables is important for proper operation of the power system. Long-term problems with them are related to the degradation of polymer materials used for the insulator due electrical, thermal or environmental stress. Most of these problems are related to the electric field stress on the insulation of the underground cables. The objective of the electric field analysis by using different numerical techniques is to find electric field stress and other parameters, which are an inevitable tool in various electricity concerned technologies; in particular for analyzing discharge phenomenon and designing High Voltage (HV) underground cables. In this paper Finite Element Method (FEM) numerical method has been discussed and used to find 2-D electric field stress and other parameters of HV underground cables with given boundary conditions using 2-D electric field analysis software package which is based on the finite element method (FEM).***

Index Terms: High Voltage; Underground Cable; Finite Element Method; Cross Linked Polyethylene; Ethylene Propylene Rubber; Electric Field Analysis.

I. INTRODUCTION

Underground cable systems represent a significant investment and are a vital part of the power delivery distribution network. In an increasingly competitive and deregulated environment, it is essential that utilities maximize the profitability of their assets. This requires utilities to have knowledge of power cable systems and their diagnostics to make the right decisions about what cable system equipment to purchase and to have a general idea of how well it will perform in service, how it ages, degrades, and fails, and how it should be diagnosed for repair or replacement. An underground power cable is designed to carry electric current and withstand a certain operating voltage, which together allow it to deliver electric power. In some cases, it is simply defined as " a conductor with insulation". Generally, distribution power cables are
described by their type of insulation material, voltage class, conductor material, conductor type, conductor size and sheathing materials.

II. HIGH VOLTAGE CABLE UNDERGTOUND CABLE SPECIFICATION

High voltage cable may have one or more than one conductor in the core depending upon the type of service for which it is intended. High Voltage (HV) underground cable consists of different layers as shown in Fig.1. The conductor in the center of the cable is the main part that
transfers energy and is under applied voltage Normally copper is used as conductor for cables but aluminum can also be used as a conducting material depending upon some technical requirements and circumstances . The insulating material of the cable used here are Cross Linked Polyethylene (XLPE) and Ethylene Propylene Rubber (EPR) separately and their effects are discussed. There is a semi-conductor layer around the copper conductor and insulation of the cable. Semi-conductor layer is used for smoothing the field distortion caused by stranded structure of conductor and roughness of the lead-sheath. The role of the Lead (Pb) sheath and seamless Aluminum (Al) sheath is shielding. The outer layer of the cable is made of High Density Polyethylene (HDPE) which protects cable from external factors. In present era the use of HV underground cables has increased tremendously due to its more advantageous role for transmitting high power, so it is necessary to analysis the overall parameters of cable for longer reliability. Therefore a lead sheathed HV underground cable with copper conductor is taken here for analysis. The technical specification of the above mentioned cable is given in Table I.

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III. FINITE ELEMENT METHOD

Finite Element Method (FEM) is to find the solution that minimizes energy equation. Five steps should be followed in order to solve a problem of this kind with FEM:

1) Boundary conditions, material and geometry of problem must be defined.
2) Mesh should be given (Meshing).
3) Obtain equations for all mesh element.
4) Combining all elements in solution domain.
5) Solving the obtained equations.

In, V=V(x,y,z) is defined electrical potential, quadratic homogenous differential solution as in Equation (1) requires for solution of static electrical field problem (also

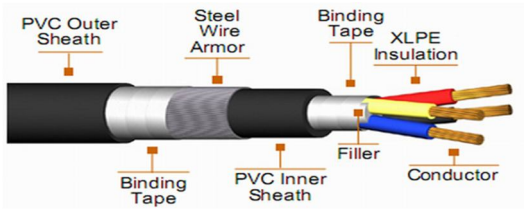


Fig.1. Detail View of High Voltage (HV) underground cable

Laplace Equation). FEM (Finite Element Method) is employed to solve equation by the principle of minimizing the electrical energy equation in solution domain as in equation (2).

$$\Delta V = \frac{\partial V^2}{\partial x^2} + \frac{\partial V^2}{\partial y^2} + \frac{\partial V^2}{\partial z^2} = 0 \qquad (1)$$

$$W = z \iint \{ \frac{1}{2} \left(\varepsilon_x \left(\frac{\partial V}{\partial x} \right)^2 + \varepsilon_y \left(\frac{\partial V}{\partial y} \right)^2 \right) \} \partial x \, \partial y \qquad (2)$$

The solution that is obtained in this way is also desired solution of the Laplace equation [9]. Cartesian coordinates is used in this method. Principally, mentioned area is divided into finite elements called “Discretizing the area”. Generally, triangle finite element is used for Discretizing. Afterwards by using boundary conditions, known potentials and material properties, lateral polynomial approach functions, equations of the elements and general equation of the problem is derived.

Table-I. Technical Specification Of Selected High Voltage (HV) Underground Cable

Parameter	Values	
Nominal Voltage	33 [kV]	
Diameter of Conductor	25.80 [mm]	
Thickness of insulation	44.20 [mm]	
Overall diameter	70.00 [mm]	
Conductance (Mho) over 1m depth	XLPE	8.334e-14
	EPR	6.449e-20
Free-space Inductance (Henry) over 1m depth	XLPE	1.817e-07
	EPR	1.279e-07
Capacitance (Farad) over 1m depth	XLPE	1.959e-10
	EPR	2.784e-10
Free-space Capacitance (Farad) over 1m depth	XLPE	6.122e-11
	EPR	8.700e-11

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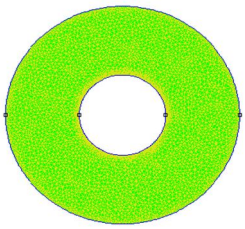


Fig.2. Finite element model of Discretized High Voltage (HV) underground cable

Acquired equation is a big dimensional matrix with many zeros. By solving this linear equation system with an iterative numerical solution method, node potential of triangle elements are obtained. Depending upon potential values and element's potential approach functions, potentials and electrical field values can be calculated in any point of the area. HV underground cable is modelled with IES (Integrated Engineering Software) package (ELECTRO module) and is shown in Fig. 2.

IV. RESULT AND DISCUSSION

Any insulation defects of power cables can cause power failure, which subsequently result in economic loss including power cut cost, compensation cost, replacement cost and health/safety cost. Therefore, the study on the insulation system of power cables has great benefit to the cable manufacturing. As the first step, a 2-D model of the High Voltage (HV) underground cable was developed. Then two different insulating materials were assigned to the model and analysis was done for each to obtain the voltage distribution and electric field stress parameter. As mentioned earlier, the software divides the simulation area into many triangular regions/meshes. The more meshes, the more accurate the simulation results, which means there is a trade- off between the number of meshes and the computation time/memory. The software itself resolves the problem: the mesh resolution is determined by the change in the electromagnetic field in the area: the large the change, then the more meshes. In order to solve the problem using IES software, required data and specification of the system is given in Table II. In the discussion below only the final results for each configuration are given.

Table-II. Data And Specification Of Selected High Voltage (HV) 33kv Underground Cable

Parameters	Values
Number of finite elements	8638
Relative permittivity of Copper	1
Relative permittivity of XLPE	2.4
Relative permittivity of EPR	2.3
Boundary condition of Conductor	33[kV]

Table-III. Circuit Parameter Comparison Of Selected High Voltage (HV) 33kv Underground Cables

Parameter	XLPE based Cable	EPR based Cable
V_{max}(kV)	3.135e+04	3.135e+04
V_{min}(kV)	0.000	0.000
V_{avg}(kV)	15.675	15.675
E_{max}(kV/mm)	2.6e+006	2.675e+006
E_{min}(kV/mm)	0.000	0.000
E_{avg}(kV/mm)	1.3	1.3375

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A. Analysis of the 33kV XLPE Underground Cable

The underground cables modeled using 4768 triangular elements per region. An Intel core 2 duo (1.83

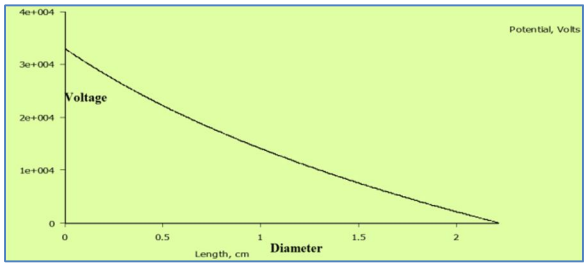


Fig.3. Voltage Distribution of XLPE based 33kV cable Using FEM in radial direction

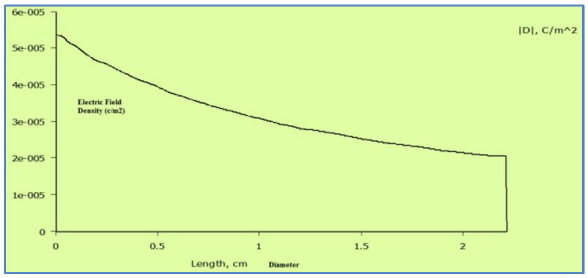


Fig.5. Electric field Density of XLPE based 33kV cable using FEMin radial direction

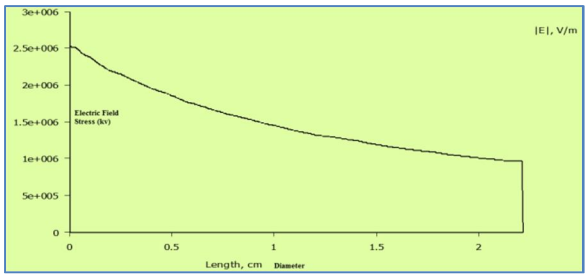


Fig.7. Electric field stress of EPR based 33kV cable using FEM in radial direction.

GHz) computer was used for the analysis. The accuracy of the solution depends on the number of elements and methods used during the modeling of the geometry. An accurate solution requires a basic knowledge of the method i.e. Finite element method and experience with ELECTRO. The voltage distribution and electric field stress and their contours have been obtained along the diameter of the cable. The voltage distribution along the diameter of the 33kV XLPE based underground cable using Finite Element Method (FEM) is observed and shown in fig.3 where maximum voltage is on the conductor surface and it is decreasing as we move from the conductor to the metallic sheath. The voltage distribution at the metallic sheath is approximately zero as shown in the fig.3.The electric field stress plot along the diameter of the 33kV XLPE based underground cable using FEM is shown in fig.4 where maximum electric field stress is on the

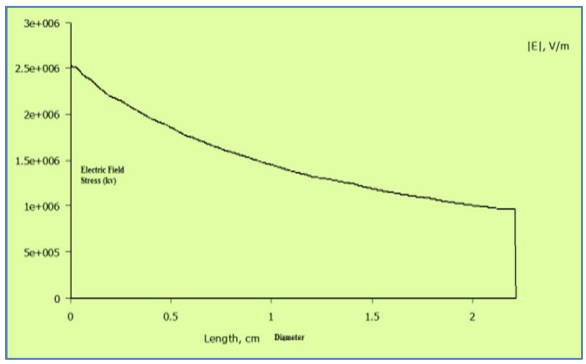


Fig.4. Electric field stress of XLPE based 33kV cable using FEM in radial direction

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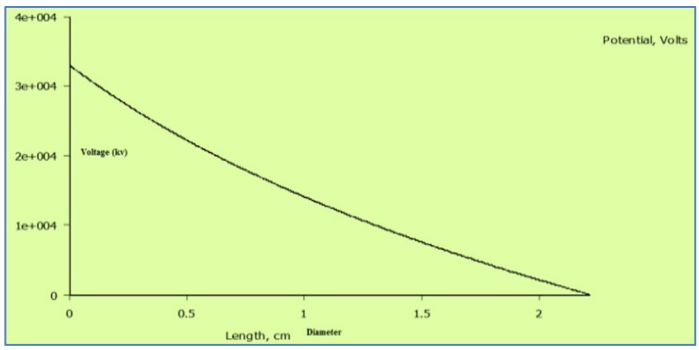


Fig.6. Voltage Distribution of EPR based 33kV cable using FEM in radial direction

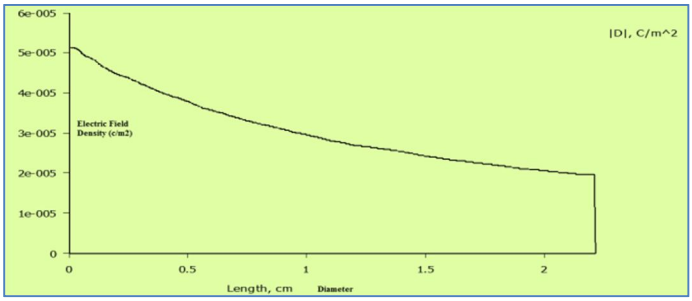


Fig.8. Electric field Density of EPR based 33kV cable using FEM in radial direction

Interface of the conductor screen and the insulation of the cable and it is weak in other parts of the underground sheath is approximately zero as shown in the fig.4. The cable. The electric field stress at the metallic deviation in the both graphs i.e. at the a) interface of conductor screen and insulation b) interface of insulation and insulation screen are due to the different relative permittivity values of the insulating material (XLPE) and semiconducting material. The electric field density plot along the diameter of the 500kV XLPE based underground cable using and FEM is shown in fig.5 where maximum electric field stress is on the surface of the conductor of the underground cable and it is decreasing gradually from the conductor surface to the metallic sheath of the underground cable. The electric field density at the metallic sheath is approximately zero as shown in the fig.5.

B. Analysis of the 33kV EPR Underground Cable

The voltage distribution along the diameter of the 33kV EPR based underground cable using and FEM are shown in fig.6 where maximum voltage is on the conductor surface and it is decreasing as we move from the conductor to the metallic sheath. The voltage distribution at the metallic sheath is approximately zero in the fig.6. The voltage distribution of EPR based cables is greater than the XLPE based underground cable as shown in the plots.

The electric field plot along the diameter of the 33kV XLPE based underground cable using FEM is shown in fig.7. The electric field stress of EPR underground cable is greater than the XLPE underground cable. The electric field stress at the metallic sheath is approximately zero in the fig.7. The deviation in the both graphs i.e. at the a) interface of conductor screen and insulation b) interface of insulation and insulation screen are due to the different relative permittivity values of the insulating material (EPR).

The electric field density plot along the diameter of the 500kV EPR based underground cable using FEM is shown in fig.8. The electric field stress of EPR underground cable is greater than the XLPE underground cable. The electric field density at the metallic sheath is approximately zero in the fig 8.

V. CONCLUSION

The voltage distribution, electric field stress and electric field density of High Voltage (HV) 33kV underground cables is analyzed and discussed. Also analyzed two different insulating materials based cables first one is Cross Linked Polyethylene (XLPE) and second is Ethylene Propylene Rubber (EPR) with Finite Element Method (FEM). It is observed that XLPE based HV underground cable works better due to its low electric field stress than EPR based HV underground cable. So the results show that XLPE based underground cable is the better choice for the replacement of EPR based HV underground cable. Circuit parameters of XLPE and EPR based HV underground cable also compared.

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REFERENCES

[1] VAIDEKI.S, NIVETHA.M, JAYAPRAKASH, PUGAZHENDIRAN.P " Electric Field Analysis of High Voltage Submarine Cables" 2017 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC) 978-1-5090-4324-8/17/$31.00 ©2017 IEEE.

[2] S.Bhattacharyya, A.Chakraborty, B.Saha, S.Chatterjee "Electric Stress Analysis of a Medium Voltage Cable Termination Subjected to Standard and Non-Standard Lightning Impulse Voltages" 2016 International Conference on Intelligent Control Power and Instrumentation (ICICPI) 978-1-5090-2638-8/16/$31.00©2016 IEEE.

[3] Jiao You, Zhidong Jia,Yong Wang, Weinan Fan, Ye Yuan, Zhicheng Guan "Evaluation Analysis of XLPE Cable's Electrical Condition 2014 Annual Report Conference on Electrical Insulation and Dielectric Phenomena 978-1-4799-7525-9114/$31.00 @2014 IEEE.

[4] Aziz Suhaimi, Failure Investigation TNBR QATS Sdn. Bhd. Malaysia and Huzainie Shafi Abd Halim, Transmission and Distribution TNB Research Sdn Bhd. Malaysia, "Failure Analysis of Cable Accessories Using Finite Element Method Magnetics (FEMM) Software" 2012 IEEE International Conference on Condition Monitoring and Diagnosis, 23-27 September 2012.

[5] H. A. Illias, Q. L. Ng, A. H. A. Bakar, H. Mokhlis, UMPEDAC Electrical Engineering Department Faculty of Engineering, University of Malaya Kuala Lumpur, Malaysia, and A. M. Ariffin, College of Engineering Universiti Tenaga Nasional Selangor, Malaysia, "Electric field distribution in 132 kV XLPE cable termination model from finite element method", 2012 IEEE International Conference on Condition Monitoring and Diagnosis, 23-27 September 2012, Bali, Indonesia.

[6] N. H. Malik, A.A. Al-Arainy, M. I. Qureshi and F. R. Pazheri, Saudi Aramco Chair in Electrical Power, EE Department, College of Engineering, PO Box.800, King Saud University, Riyadh-11421, Saudi Arabia, "Calculation of Electric Field Distribution at High Voltage Cable Terminations", Journal of Energy Technologies and Policy, Vol.1, No.2, 2011.

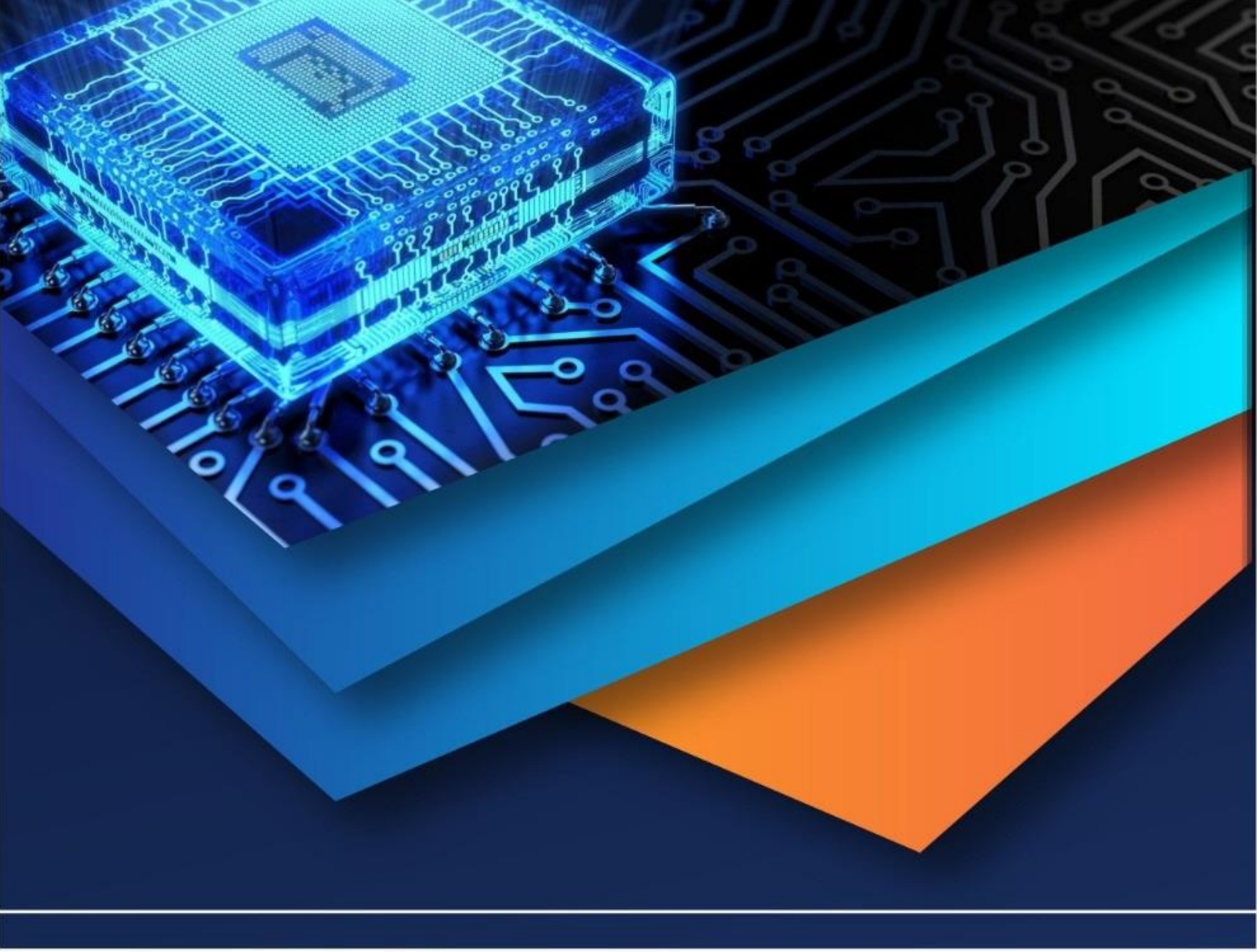
[7] Mohamed ALSHARIF, Caledonian University - UK Glasgow, Peter A WALLACE, Caledonian University - UK Glasgow, and Donald M HEPBURN, Caledonian University - UK Glasgow, "Partial Discharge Resulting From Internal Degradation In Underground Mv Cables: Modelling And Analysis", IEEE Transactions, 2009.

[8] H. N. O, T. R. Blackburn, B. T. Phung, H. Zhang and R. H. Khawaja, School of Electrical Engineering and Telecommunication, The university New South Wales, Australia Sydney, NSW, Australia, "Investigation of Electric Field Distribution in Power Cables with Voids" IEEE Transactions, 2006.

[9] H. S. B. Elayyan and M. H. Abderrazzaq, Electric Power Engineering Division Hijjawi Faculty for Engineering Technology Yarmouk University, Irbid 21163, Jordan, "Electric Field Computation in Wet Cable Insulation Using Finite Element Approach", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 12, No. 6; December 2005.

[10] David meeker, "Finite element method Magnetics", FEMM software manual, Version 4.2, may, 2009

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