ASSESSMENT OF ELECTRIC FIELD ON POLYMERIC INSULATOR IN POLLUTED ENVIRONMENT

NUR IZZATUL HUDA BINTI MOHAMED ZIN

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

FEBRUARY 2021

For my beloved parents and grandparent

I dedicate this thesis to them for take care of me with affections and loves and dedicate their partnership for the success of my life. Thank for all of your quality time and supportive help

Also not to forget to all my supervisor, lecturers and colleagues for their kindness in this educational journey

.

ACKNOWLEDGEMENT

Foremost, I would like to acknowledge the Almighty God for His benevolence and for granting me wisdom and perseverance not only in the time of research and writing of this thesis, but indeed, throughout my life. I express, with heartfelt appreciation, my gratitude to my supervisor, Ir Dr Rahisham bin Abd Rahman for his sincere and invaluable intellectual guidance extended to me throughout the years of my postgraduate studies. His sincerity, vision and motivation has deeply inspired me. It was an honor to work under his guidance. There were so many this that I gain through this research process. I would like to thank him for his empathy and truly grateful for what he has offered me. I extend my appreciation to all my friends for their unwavering support and who have stood by me through so many tough times. Last but not least, special thanks to my beloved parents for their blessings and unflinching insistence, who have always encouraged me to never stop achieving my goals in life.

ABSTRACT

Insulators are among the most important electrical power transmission systems. Polymeric insulators are essential for better performance. Insulating polymers are widespread due to the wide range such as lightness, ease of installation and lower cost. Despite this advantage, the major cause of polymeric insulator failure is due to the polymer material aging and degradation which is caused by electrical stress on the high voltage terminal of the insulator. Thus, this project seeks to analyze the electrical field along the surface of the polymer insulator in the polluted environment. This can be achieved by creating a two-dimensional (2D) axisymmetric model by using Finite Element Tool COMSOL Multiphysics software. The results showed that the effect of uniform pollution layer with different thickness and conductivity on electrical along the insulator surface as the pollution layer thickness and conductivity electric field intensity increases. Electric fields along the insulator surface are highly influenced by the values of pollution layer conductivity and thickness. This indicates that effect of the dry band insulator surface towards electric field in a polluted environment shown the electric field is greatly influenced by the location of the dry band. The main goal is to evaluate the effect of uniform pollution layers with various thickness and conductivity and also analyze the effect of dry band insulator surface towards electric field performance in a polluted environment.

ABSTRAK

Penebat adalah antara sistem penghantaran kuasa elektrik yang paling penting. Penebat polimer adalah penting untuk prestasi yang lebih baik. Penebat polimer adalah meluas kerana pelbagai kelebihan yang ditawarkan, seperti berat ringan, kemudahan pemasangan dan kos yang lebih rendah. Di sebalik kelebihan ini, penyebab utama kegagalan penebat polymer adalah penuaan dan degradasi bahan polymer tersebut yang disebabkan tekanan elektrik pada terminal voltan tinggi penebat. Oleh itu, projek ini berfungsi untuk menganalisis medan elektrik di sepanjang permukaan penebat polimer dalam persekitaran yang tercemar. Ini boleh dicapai dengan mencipta pemodelan asimetri dua dimensi (2D) dengan menggunakan perisian Finite Element Tool COMSOL Multiphysics. Hasil kajian menunjukkan kesan lapisan pencemaran seragam dengan ketebalan dan kekonduksian yang berbeza pada elektrik di sepanjang permukaan penebat apabila ketebalan lapisan pencemaran dan keamatan medan elektrik kekangan meningkat. Medan elektrik di sepanjang permukaan penebat sangat dipengaruhi oleh nilai-nilai kekonduksian lapisan pencemaran dan ketebalan. Ini menunjukkan bahawa kesan permukaan penebat jalur kering terhadap medan elektrik di persekitaran yang tercemar menunjukkan medan elektrik sangat dipengaruhi oleh lokasi jalur kering. Tujuan utamanya adalah untuk menilai kesan lapisan pencemaran yang seragam dengan pelbagai ketebalan dan kekonduksian dan juga menganalisis pengaruh permukaan penebat jalur kering terhadap prestasi medan elektrik di persekitaran yang tercemar.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

BEM	-	Boundary Element Method
Q	-	Charge
CSM	-	Charge simulation method
σ	-	Conductivity
E	-	Electric field
EPDM	-	Ethylene Propylene Diene Methylene
ESDD	-	Equivalent Salt Deposit Density
FEM	-	Finite Element Methods
FDM	-	Finite difference method
FRP	-	Fiber Reinforced Plastic
F	-	Force
HV	-	High Voltage
kV/mm	-	Kilo volt per milimeter
μS/cm	-	micro Siemen per centimeter
m	-	Meter
ε_r	-	Relative Permittivity
SiR	-	Silicone rubber
2D	-	Two-dimensional
V		Volt

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

For the efficiency of an electric power system, the reliability of the power networks and equipment is important. High-voltage power lines have been commonly used to transfer electricity to customers from power stations. Insulators are one of the most critical elements of electrical power transmission systems. Distribution insulators are widely used in Malaysia in 33 kV, 11 kV and 400/230 V distribution networks [1]. Not only regular voltages and overvoltages, such as lightning and switching events, but also various environmental stresses such as fog, snow and emissions, must be withstood by the insulators [2]. Back from the time of the discovery of electricity, electrical insulation was always outstanding. The demand for electricity has been steadily increasing in recent times. Therefore, power systems had to improve the efficiency of electrical equipment. The objective of every system is to operate without interruptions, resulting in economic losses for businesses and consumers. In order to maintain its continuity, the performance and characteristics of the insulating system and its components must remain at an excellent level in the power system.

Electrical insulators are used in terms of giving mechanical protection to the conductors of power lines and to separate conductors from the systems of the ground [3]. Optimum electrical and mechanical strength should be given by a good insulator. Polymer insulators are located at different locations, such as high altitude sites, substations, near industrial plants, seaside coastal areas, and train roofs. They are also exposed to the various weather conditions provided by the atmosphere. The surface of the insulators is contaminated uniformly, or more frequently, non-uniformly, when working in a polluted area.

1.2 Problem statement

Polymeric insulators are considered to be a cylinder dielectric that can be set up between terminals with a potential difference. Now, nonconventional insulators are widely used because of their advantages compared to conventional insulators such as relatively, low cost, lightweight, easy to handle, high mechanical strength, superior insulation performance, excellent dielectric strength, and resistive to vandalism. And because of all these excellent characteristics, there are still some concerns about composite insulators. They are difficult to standardize because of the various shapes and materials [4]. Some of the remaining problems are also the uncertainty about their lifetimes and the need for appropriate testing techniques. For this purpose, it is essential to find ways of testing isolation conditions using laboratory experiments, software simulations or suitable tools. Life expectancy and ageing processes are vital concerns of utilities regarding the use of polymer insulators. Unfortunately, there is still no method available to accurately predict the life cycle of polymer insulators, even though different laboratory techniques have been developed to assess the nature of their ageing due to environmental impact. One of the main issues concerning the unreliable operation of polymer insulators is the impact of environmental stress on their performance [5].The environmental pollution in which they operate has a significant impact on their reliability. Pollution is one of the leading causes of flashover activity on the insulator surface [6]. For this reason, this paper is an attempt to analyze the effect of dry band insulator surface towards electric field performance in a polluted environment. The main objective is to simulate the effect of the uniform pollution layer with different thickness and conductivity on electrical along the insulator surface.

1.3 Objectives

The objectives to be achieved are:

i. To design and model a polymeric suspension insulator by using a finite element method in COMSOL Multiphysics.
ii. To evaluate the effect of uniform pollution layers with different thickness and conductivity on electrical along the insulator surface.
iii. To analyze the effect of dry band insulator surface towards electric field performance in a polluted environment.

1.4 Scopes of study

The scope of this project including :

i. Using Finite Element Methods i(FEM) in COMSOL Multiphysics software.
ii. To carry out a model of i11kV polymeric insulators two-dimentional (2D) design.
iii. Pollution layer relative permittivity set by 80, with pollution type salt water.
iv. Simulation and analysis work on the pollution layer conductivity in 150μ(s/m), 400μ(s/m), 700 μ(s/m) and 1000 μ(s/m) of electric field distribution.
v. Simulation and analysis work on the pollution layer thickness in 0.3mm, 0.6mm, 0.9mm and 1.2mm of electric field distribution.

1.5 Outline of the report

The report is organized into a few main chapters. Chapter 1 reflects on the background of the project, which is the problems faced by the polymeric suspension insulator and the priorities driving this project. Project limitation was discussed in the project scope section.

Chapter 2 provides a review of previous related research enclosing polymer insulator, electric field distribution. Also, systematically explain the electric field with the selected simulation software.

In chapter 3 it explains the method used in simulation software in order to investigate electric field distribution using computer software simulations on the surface of the polymer rod style suspension insulator. For insulator simulation, the finite element method is used to evaluate the electric fields distribution along with clean dry and polluted conditions, varied of thickness and conductivity. A model of 11 kV polymer insulators is used to characterize the effect of insulator surface.

Chapter 4 describes the outcomes of the simulation and graphically related interpretation according to the stated objectives. Both the data, discussion and analysis of the simulation. Finally, Chapter 5 describes the implications based on the results of this analysis. Referring to the findings, such recommendations are outlined for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The polymer insulator stack is used to separate the power lines from the metal tower. The non-metallic material used for the insulator completely blocks the electrical flow. Various modelling parameters for computer simulation should be considered when deciding the electric field [7].

In this chapter, selected articles, journals and scientific papers on the propagation of electrical fields over suspension insulators of the polymer rod form are discussed. Since the beginning of this century, high voltage insulators have evolved quickly, starting with basic porcelain insulators. This chapter will explain about polymer rod type suspension insulator, which consists of an introduction to a polymer insulator, advantages, and disadvantages. Application and a previous study of a polymer insulator are also explained in this chapter. It is also covered about the electric field, which consists of theory on the electric field and previous study of an electric field. This chapter also explains about the polluted environment, which consists of a polluted process.

2.2 Polymer Insulator

An electric insulator is a critical part of electrical power grids, including substations and distribution lines. For electrical experts in the field of electrical power, extensive study and practical expertise on this subject are important. Initially, ceramic and glass insulators were manufactured. However, in 1963 polymer insulator were made, and in recent years they have attracted utilities for the design and production growth of polymer insulators. It consists of a central rod of fiberglass wrapped in weather hanging skirts such as silicone rubber, polytetrafluoroethylene, EPDM, and metal-end fittings. It is also called composite insulators, which means that it consists of a heart and a housing with fittings, at least two isolating parts. Polymer insulation systems have many benefits over glass and ceramic insulation, such as high contaminated efficiency, light weight, safe handling, maintenance free and very cost-effective [8]. The popularity of ceramics and glass insulators worldwide is rising and new thanks to these features. Figure 2.1 demonstrates the insulation grading.

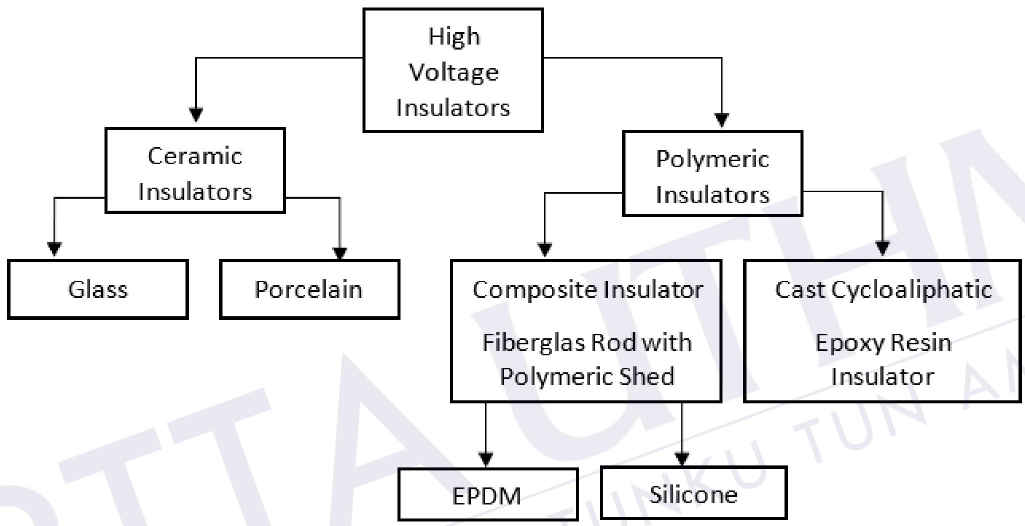

Figure 2.1: Classification of insulator

J.Vokalek et al. [9] discovered composite insulators with a 110 kV overhead composite test of about 1000 hours and a rapid flashover in labs, compared the various composite insulators. They concluded from their work that the loss caused by the ageing of salt fog depends not only on the type of the insulation material but also on the following procedures. Today, one-shed molding is the most used process [10]. The entire insulator housing is molded directly around the core in one piece. The housing may then be chemically added to the core. There is a major difference in the intent of using composite insulators between utilities [11]. Service experience has indicated that silicone rubber (SIR) insulators usually perform better in polluted environments than EPDM, porcelain, and glass insulators and that the high pollution flashover is key factors for the hydrophobic properties of insulating surfaces [12].

An experimental foundation analysis was then performed with the leakage current of polluted polymer insulators. Researchers are particularly involved in recovery of hydrophobicity and hydrophobic pollution. Polymer insulator thin coating contributes to less current [13]. The thickly laminated polymer insulators create higher currents and drop the medium-level insulation current. More specifically, materials for transmission of hydrophobicity, such as SiR and other materials, are required to ensure improved outcomes in contaminated areas [14,15]. In the presence of moisture, the hydrophobicity eliminates the opportunity for a water film, minimizing the leakage and possibility of dry band arcing.

2.2.1 Polymeric Insulator Construction

Polymeric insulators are used to decrease the amount of the broadcast lines with exceptional pollution tolerance and mechanical effects. Figure 2.2 defines the mounting portion of the regular polymer insulator.

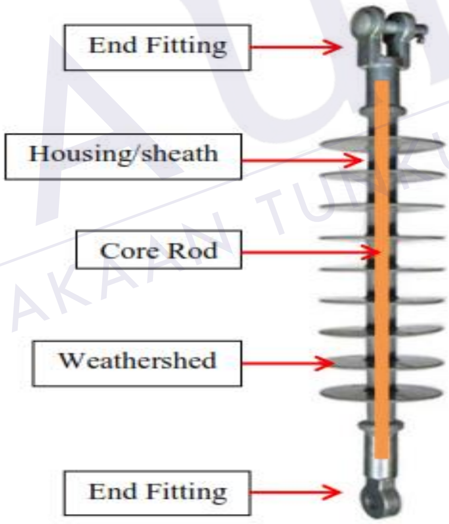

Figure 2.2: Construction details of polymeric insulators

i. **Core** - The heart of the composite insulator is the central insulation portion. It is mechanically loaded. It is expected. This involves mostly glass fibers in a resin matrix, which maintain highest tensile power.

ii. **Sheath** - The building is built outside the heart and is weatherproof. The sheds for the weather may be built. Many types of composite insulators are using a sheath between the insulator material weather sheds and the center of the sheath is part of the housing

iii. **Weather sheds -** The wetter sheds are insulation sections designed to increase the leakage distance of the cabinet or sheet to have a disturbed water direction.

iv. **End Fitting -** Mechanical charge is transferred through the heart by the end fitting. The most widely used approach is to compact the metal fit on the bar.

2.2.2 Advantages and Disadvantages of Polymeric Insulator

For high voltage transmission lines, polymer insulators offer major benefits over porcelain and glass insulators. While polymeric materials are vulnerable to aging than traditional ceramic and glass objects, polymeric items provide many benefits as regards higher voltage insulation from the outside [16]. The specific advantages of polymeric insulator are:

- Better performance in high contamination areas
- Lighter in weight, weight reduction of nearly 90%. This reduction in weight makes handling, shipping and installation costs easier.
- More appealingly satisfying to the eye
- More vandalism prone and due split
- Better handling of shock wave heaps
- Strong in tension

The main drawbacks of polymeric insulators are:

- Dimensions vary.
- Dry arc distance is lower.
- Harder to check for inconsistencies or damages.
- Storage concerns
- Weaker in compression

2.2.3 General Comparison

Table 2.1 shows comparison and general discussion of ceramic insulators and polymeric insulators and advantages over ceramic insulators [16].

Table 2.1: Advantages of polymer insulators over porcelain insulators

Factor	Ceramic	Polymer Insulators
Weight	Heavy weight, approximate weight of 400 kV is about 135 kgs.	90% lighter than porcelain insulators, but with a power that is equal or greater. The weight is less than 14 kg roughly 400 kV.
Frangibility	Highly fragile to shock & vibration	Not fragile to shocks
Packing and Transport	Risky & expensive	Easy & economical
Installation	Difficult	Easy
Handling	High	Low
Vandalism	More susceptible	Highly resistant
Breakages and Secondary Damage	Extremely fragile - splits of 10 to 15 percent in shipping, storage and Setup of the framework are reported	Flexible and thus particularly resistant to fracture, ceramic insulators.

2.3 Electric Fields

The electrical field propagation in and about high-level voltage insulators is an essential aspect of insulator architecture. The electrical field covers charged particles and magnetic fields that change time. The electric field indicates the surrounding effect on other electrically charged particles of an electrically charged object [17]. When studying electrical discharge operations, field determination and distribution on the insulator surface are important. The leaking flow is primarily driven by the tangential electric field in the wet contamination film.

An electric field is defined as a vector quantity for the load power per unit depending on the direction of the field. The field position is referred to as the position of the force on a good test load. The electric field is radially around and within the positive load of a negative point load.

The equation for electric field strength is Electric Field Strength = $\frac{Force}{Charge}$

In mathematical term:

$$E = \frac{F}{q} \qquad \text{Equation (1)}$$

The electrofield power, where the unit is Newton/Coulomb, quantitatively represents the force of an electric pitch at one spot. The unit is normal in volt (v /m or vm-1). As seen in Figure 2.3, the line of a positive charge electric pitch goes perpendicularly towards the outside of the charge and heads in the inner direction for a negative charge.

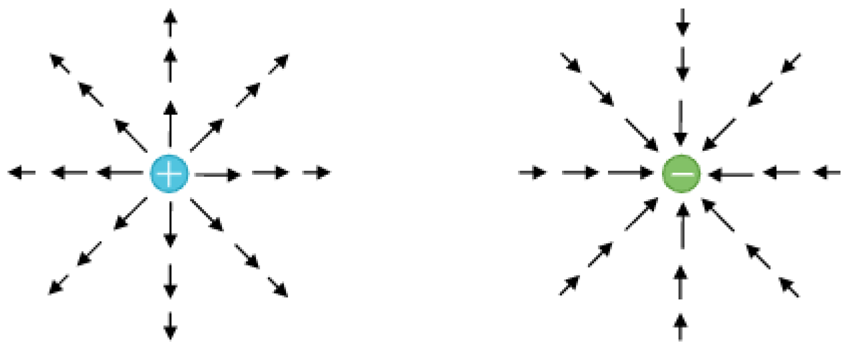

Figure 2.3: Electric field line of positive and negative charges

High-voltage electrical fields induce polarity and electrical losses in polymeric insulators. Greater fields cause significant processes of insulating agents such as cavity discharge and spatial buildup during conduction and polarization. Divergence occurs as electro field effects begin to rearrange electron and polymer molecules. Once the polymer tends to a dielectric breakdown, the insulator remains conductive. Long-term space charges can accumulate both inside and outside insulation that can lead to localized breakdowns in regions with intense electric fields and cause insulator erosion [18].

2.3.1. Conductivity

In recent times, composite insulation materials are gaining attention as outdoor insulating structures particularly silicone rubber. Silicone rubber has excellent pollution performance and high hydrophobicity. Conductivity tests water's ability to transmit electricity. Water conductivity due to the presence of dissolved inorganic solids. Adding cool water reduces conductivity due to poor conductivity of rainwater and mineral dilution of water. During low fluxes, high levels of dissolved solids increase the conductivity. Natural rainwater conductivity was between 50 and 150µS/cm [19]. Whereas routine checks are conductivity tests with porcelain and glass insulators of 2500 µS/cm .

2.3.2 Relative permittivity

Relative permittivity describes the ability of a material can become polarized when subjected to an electric field on an insulator. The polarization initiates from a few sources such as dipolar, space charge, and movement of ionic charges. Typically, permittivity is represented by the symbol ε. Permittivity is one of the electrical properties which can affect the overall material’s performance. In electromagnetic, permittivity is one of the basic electrical properties affecting the propagation of the electric field.

REFERENCES

[1] T.N.B. Handbook, Electricity supply application Handbook. Malaysia: Distribution Division. 2011.

[2] J. F. Hall, “History and bibliography of polymeric insulators for outdoor applications,” IEEE Trans. Power Deliv., vol. 8, no. 1, pp. 376–385, 1993, doi: 10.1109/61.180359.

[3] W. L. Vosloo and J. P. Holtzhausen, “The electric field of polluted insulators,” SAIEE Africa Res. J., vol. 95, no. 1, pp. 24–27, 2004, doi: 10.1109/afrcon.2002.1159977.

[4] A. Schwalm, “Insulators 101,” IEEE/PES 2010 Transmission and Distribution Conference and Exposition. 2010.

[5] M. Batalovic, H. Matoruga, S. Berberovic, and M. Matoruga, “Influence of Environmental Stresses on High Voltage Polymer Rod Type Insulator Performances,” 2018 3rd Int. Conf. Smart Sustain. Technol. Split. 2018, pp. 4–9, 2018.

[6] K. Wang et al., “Analysis on flashover performance of polluted porcelain insulators in high conductivity fog environments,” Annu. Rep. - Conf. Electr. Insul. Dielectr. Phenomena, CEIDP, vol. 2015-Decem, pp. 193–196, 2015, doi: 10.1109/CEIDP.2015.7352058.

[7] A. Nekahi and S. G. Mcmeekin, “Distribution along a Polymeric Insulator,” pp. 612–615, 2015.

[8] A. L. Souza and I. J. D. S. Lopes, “Study of electric field enhancement along polymer insulators under service conditions,” 2010 IEEE/PES Transm. Distrib. Conf. Expo. Lat. Am. T D-LA 2010, pp. 759–764, 2011, doi: 10.1109/TDC-LA.2010.5762969.

[9] S. . and J.Vokalek, “Laboratory comparative tests of composite insulators,” Ninth ISH Engg, Austria Eur., vol. pp3182-318, 1995.

[10] R.Hackam, “Outdoor HV Composite Polymeric insulators,” IEEE Trans, Dielectr. Electr. Insul., vol. Vol.6 (5)., 1999.

[11] M. S. T.Kikuchi, S.Nishimura, M.Nagao, K.Izumi, Y.Kubota, “Survey on the use of non-ceramic Composite insulators,” IEEE Trans, Dielectr. Electr. Insul., vol. Vol.6 (5), 1999.

[12] P. R. Rohit and R. P. R. June, “Simulation Studies of Composite Insulators used in High Voltage Transmission,” pp. 1–6, 2018.

[13] N. S. Sunitha, K. N. Ravi, R. Prakash, and Pushpanjali, “A study on leakage current characteristics of polymeric insulators for different pollution layers,” Proc. 2015 IEEE Int. Conf. Power Adv. Control Eng. ICPACE 2015, pp. 383–387, 2015, doi: 10.1109/ICPACE.2015.7274977.

[14] A. I. Elombo, J. P. Holtzhausen, H. J. Vermeulen, P. J. Pieterse, and W. Vosloo,“Comparative evaluation of the leakage current and aging performance of htv sr insulators of different creepage lengths when energized by AC, DC+ or DC-in a severe marine environment”, IEEE Transactions on Dielectric and Electrical Insulation,vol.20,no.2,pp.421–428,2013.

[15] G. Bruce, S. Rowland, and A. Krivda, “Performance of silicone rubber in DC inclined plane tracking tests”,IEEE Transactions on Dielectric and Electrical Insulation, vol.17, no.2, pp.521–532, 2010.

[16] Nekeb, Abdelbaset 2014. Effect of some climatic conditions in the performance of outdoor HV silicone rubber insulators. PhD Thesis, Cardiff University.

[17] K. Eleperuma, T. P. Saha, and T. Gillespie, “Electric field modelling of non-ceramic high voltage insulators,” Aust. J. Electr. Electron. Eng., vol. 4, no. 3, pp. 239–248, 2008, doi: 10.1080/1448837X.2008.11464190.

[18] R. J. and D. K. . Varlow B.R., “Nonlinear fillers in electrical insulating materials,” IET Sci. Meas. Technol., vol. ol 1 (2), 2007.

[19] Michael G. Danikas, RamanujamSarathi, PavlosRamnalis and Stefanos L. Nalmpantis, “Analysis of Polymer Surface Modification due to Discharge Initiate by Water Droplet under High Electric Field”, ”, International Journal of Electrical and Electronic Engineering, 2010.

[20] Muniraj, C. & Dr.S., Chandrasekar. (2012). Finite element modeling for electric field and voltage distribution along the polluted polymeric insulator. World Journal of Modelling and Simulation. 8. 310-320.

[21] Krzma, Adnan & Khamaira, Mahmoud. (2018). Computation of the Electric Field and Voltage Distributions over the Polluted Surface of Silicone-Rubber Insulators. Elixir International Journal. 116. 50009-50012.

[22] Algheilani, Ammar & Rowe, Wayne & Li, Yongxiang & Wong, Khoi. (2017). Stress Control Methods on a High Voltage Insulator: A Review. Energy Procedia. 110. 95-100. 10.1016/j.egypro.2017.03.112.

[23] Kristjansson, Leo. (1985). On the Drawing of Lines of Force and Equipotentials. Physics Teacher. 23. 10.1119/1.2341779.

[24] S.Priya & Dr. S.V.Saravanan (2017) Analysis And Computation Of Electromagnetic Fields In Various Configurations. *International Journal of Emerging Trends in Engineering and Development*, Issue 7, Vol. 3. doi: 10.17632/ijerd/may2017/0003

[25] Abd Rahman, R. (2012). Investigations of ZnO microvaristor for stress control on polymeric outdoor insulators (Doctoral dissertation, Cardiff university).

[26] Jian-bo, Zhou & Bo, Gao & Qiao-gen, Zhang. (2010). Dry Band Formation and Its Influence on Electric Field Distribution along Polluted Insulators. Asia-Pacific Power and Energy Engineering Conference, APPEEC. 10.1109/APPEEC.2010.5449442.

[27] M. Izadi, F. A. Rahman, M. Z. Abidin Ab Kadir, J. Jasni and M. S. Ab Rahman, "On the behaviour of polymer insulator with deposited moss on the surface against lightning in polluted air condition," 2018 34th International Conference on Lightning Protection (ICLP), Rzeszow, 2018, pp. 1-5, doi: 10.1109/ICLP.2018.8503299.

[28] Hernanz, J.A., Martín, J.J., Gogeascoechea, J.M., & Belver, I.Z. (2006). Insulator pollution in transmission lines. *Renewable energy & power quality journal*, *1*, 124-130.

[29] Ravi S. Gorur and S. Venkataraman (Ph. D Student), "Predicting Contamination Flashover of Insulators: Successes and Shortcomings of Tests and Simulations".

[30] M. Farzaneh, and J. Kiernicki. "Flashover problems caused by ice build-up on insulators." IEEE Electrical Insulation Magazine, 11.2 pp. 5-17, 1995.

[31] X. Zhang, and S.M. Rowland. "Modelling of dry-band discharge events on insulation surfaces." IEEE International Symposium on Electrical Insulation (ISEI), 2010.

[32] L. Xidong, W. Shaowu, H. Lengceng, S. Qinghe, and C. Xueqi, "Artificial pollution test and pollution performance of composite insulators." Eleventh International Symposium on High Voltage Engineering, 1999.

[33] I.A. Metwally, A. Al-Maqrashi, S. Al-Sumry, and S. Al-Harthy, "Performance improvement of 33kV line-post insulators in harsh environment." Electric power systems research 76.9 (2006): 778-785.

[34] 'Environmental Stresses On External Insulation',http://electrical- engineeringportal.com/environmental-stresses-on-external-insulation, Retrieved on 22th october 2020.

[35] Zhou P. B, Numerical Analysis of Electromagnetic Fields. Springer-Verlag,Berlin, ISBN 0387547223,1993.

[36] Chinnusamy Muniraj and Subramaniam Chandrasekhar "Finite Element Modeling for Electric Field and Voltage Distribution along the Insulators"World Journal of Modelling and Simulation Vol. 8 (2012) No. 4, pp. 310-320 march 2012.

[37] Peter.P.Silvester & Ronald L.Ferrari, "Finite Elements For Electrical Engineers", Third Edition, Cambridge University Press.

[38] S. Chakravorti and H. Steinbigler, "Boundary element studies on insulator shape and electric field around HV insulators with or without pollution," in IEEE Transactions on Dielectrics and Electrical Insulation, vol. 7, no. 2, pp. 169-176, April 2000, doi: 10.1109/94.841805.

[39] Khan, M. J.; Alexander, P. H., "Charge Simulation Modeling of Practical Insulator Geometries," IEEE Transactions on Electrical Insulation, Vol. EI17,No.4, August 1982, pp. 325-332.

[40] Faiz, Jawad & Ojaghi, Mansour. (2002). Instructive Review of Computation of Electric Fields using Different Numerical Techniques. International Journal of Engineering Education. 18.

[41] C. Multiphysics, "AC / DC Module User ' s Guide," Comsol, vol. 5.2, 2015.

[42] "Environmental Stresses On External Insulation,"http://electrical-engineeringportal.com/environmental-stresse-on-external-insulation.

[43] H. Joneidi, I. A., Shavegeni, A. A. and Mohseni, "Electric Field Distribution Under Water Droplet and Effect of Thickness and Conductivity of Pollution Layer on Polymer Insulators Using Finite Element Method," Int. J. Comput.

[44] S. Mohammad, H. Nabavi, A. Gholami, A. Kazemi, M. Ali, and S. Masoum, "Evaluation of leakage current measurement for site pollution severity assessment", Leonardo Journal of Practices and Technologies, vol. 10, pp. 39-54, 2004.

[45] M. Farzaneh, and W.A. Chisholm, Insulators for icing and polluted environments (Vol. 47). John Wiley & Sons, 2009.

[46] Arshad, A. Nekahi, S. G. McMeekin and M. Farzaneh, "Effect of pollution severity on electric field distribution along a polymeric insulator," 2015 IEEE 11th International Conference on the Properties and Applications of Dielectric Materials (ICPADM), Sydney, NSW, 2015, pp. 612-615, doi: 10.1109/ICPADM.2015.7295346.

[47] IEC 60507:2013,Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems", 3rd edition.

[48] S.Z. Moussavi, B. Sheikhdoragh, and A.A. Shayegani-Akmal, "Investigation on Pollution Factors on Electric Field and Potential Distribution of Polymeric Insulator," J. Basic. Appl. Sci. Res., vol. 2, pp. 12482-12491, 2012.

[49] Othman, Nordiana & M. Piah, M. Afendi & Adzis, Zuraimy & Ahmad, H. & Ahmad, Azlinda. (2015). Simulation of Voltage and Electric-Field Distribution for Contaminated Glass Insulator. Proceeding - 2013 IEEE Student Conference on Research and Development, SCOReD 2013. 10.1109/SCOReD.2013.7002554.

[48] R. Abd-Rahman, A. Haddad, N. Harid and H. Griffiths, "Stress control on polymeric outdoor insulators using Zinc oxide microvaristor composites," in IEEE Transactions on Dielectrics and Electrical Insulation, vol. 19, no. 2, pp. 705-713, April 2012, doi: 10.1109/TDEI.2012.6180266.

[49] Arshad, A. Nekahi, S.G. McMeekin, and M. Farzaneh, “Effect of Pollution Layer Conductivity and Thickness on Electric Field Distribution along a Polymeric Insulator,”50th Int. Univ. Power Eng. Conf., pp. 1-4, 2015.

[47] Arshad, A. Nekahi, S. G. McMeekin and M. Farzaneh, "Effect of pollution severity on electric field distribution along a polymeric insulator," 2015 IEEE 11th International Conference on the Properties and Applications of Dielectric Materials (ICPADM), Sydney, NSW, 2015, pp. 612-615, doi: 10.1109/ICPADM.2015.7295346.

[50] Sunthrasakaran, N. & Jamail, N. & Shee Kandar, Mohd Haris Asyraf & Muhamad, N.A.. (2018). Electric Field and Current Density Characteristics of Contaminated Solid Insulator. International Journal of Integrated Engineering. 10. 120-126. 10.30880/ijie.2018.10.08.018.

[51] Zhang, Da & Meng, Fancui. (2019). Research on the Interrelation between Temperature Distribution and Dry Band on Wet Contaminated Insulators. Energies. 12. 4289. 10.3390/en12224289.

[52] Arshad, A. Nekahi, S. G. McMeekin and M. Farzaneh, "Effect of dry band location on electric field distribution along a polymeric insulator under contaminated conditions," 2015 50th International Universities Power Engineering Conference (UPEC), Stoke on Trent, 2015, pp. 1-4, doi: 10.1109/UPEC.2015.7339957.