UNIVERSITI PUTRA MALAYSIA

ELECTRIC FIELD DISTRIBUTION ON PORCELAIN-TYPE INSULATOR UNDER CORONA DISCHARGE

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By

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Chairman : Professor Mohd. Zainal Abidin Ab. Kadir, PhD PEng CEng
Faculty : Engineering

Porcelain insulator is widely used in high voltage transmission due to its high stability and long service track record. However, despite the advantage, outdoor service insulator string is exposed to service conditions that lead to electrical discharge risk such as corona discharge. The side effect of corona discharge is difficult to mitigate and will degrade the performance of the insulator string. This project investigates the behaviour of corona discharge using laboratory test and computer simulation (ANSYS Maxwell-2D). Porcelain insulator unit was injected with AC voltage to study the behaviour of corona discharge on the insulator surface. Next, the result of the laboratory test was used in the simulation to visualise the electric field distribution around the porcelain insulator unit. As for a mitigation approach, corona ring is simulated with the insulator model and the electric field and voltage across insulator are obtained. The result of electric field on porcelain insulator surface applied with different condition was compared with and without corona ring. An optimisation of the corona ring parameter was also carried out by taking into account its effect on the electric field and voltage distribution. It is found that corona discharge occurs easily on the intersection part of porcelain insulator cap and porcelain insulator shell. In addition to that, it is found from the simulation that the electric field at the intersection of the porcelain insulator cap and porcelain insulator shell corona ring is about 63 $kVcm^{-1}$ whilst the electric field at the edge of the insulator surface is only 3 $kVcm^{-1}$. The electric field at the intersection of the insulator cap and porcelain insulator shell even higher when insulator surface condition such as coating and water droplet are considered. Furthermore, simulation showed that by adding the corona ring to the porcelain insulator string, the electric field on the insulator surface reduced to lower level as opposed to the one without the corona ring. At some point of interests, other results suggested that the corona ring able to reduce the electric field up to 34% and variations in dimensioning the corona ring also indicated significant effect in changing the electric field distribution on the insulator.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

TINGKAH LAKU PENGAHIHAN MEDAN ELEKTRIK DI PENEBAT JENIS PORSELIN DISEBABKAN OLEH PELEPASAN KORONA

Oleh

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Mei 2018

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Fakulti : Kejuteraan

Penebat porselin telah dipakai secara meluas di penghantaran voltan tinggi kerana kestabilan dan rekod perkhimatan yang lama. Walaupun penebat perkhidmatan luar mempunyai banyak kelebihan, tetapi ia juga terdedah kepada keadaan perkhidmatan luar yang menbawa kepada risiko pelepasan elektrik seperti pelepasan korona. Keburukan pelepasan korona adalah amat susah diselesaikan dan akan mengurangkan prestasi tali penebat. Projek ini menyiasat prestasi tingkah laku pelepasan korona dengan ujian makmal dan simulasi computer (ANSYS Maxwell-2D) . Penebat porselin unit telah diuji dengan voltan AC untuk belajar tingkah laku pelepasan korona di permukaan penebat. Selepas itu, hasil ujian makmal telah digunakan dalam simulasi computer untuk mengambarkan pengagihan medan elektrik sekitar unit penebat porselin. Untuk pendekatan penyelesaian, cincin korona telah disimulasi dengan model penebat dan medan elektrik dan voltan merentasi penebat telah diperolehi. Hasil simulasi di permukaan penebat selepas diapplikasi dengan pelbagai keadaan yang diperolehi telah dibandingkan dengan tali penebat yang ada cincin korona dan tanpa cincin korona. Pengoptimuman parameter cincin korona turut dijalankan dengan mengambil kira kesanya terhadap medan elektrik dan pengagihan voltan. Ia dijumpai bahawa pelepasan korona lebih senang berlaku di bahagian persimpangan topi penebat porselin dan shell penebat porselin. Sebagai tambahan, dari hasil simulasi ia dijumpai bahawa medan elektrik di persimpangan topi porselin dan shell penebat porselin adalah di sekitar 63 $kVcm^{-1}$ manakala medan elektrik di hujung permukaan penebat hanya 3 $kVcm^{-1}$ sahaja. Medan elektrik di persimpangan topi penebat dan shell penebat bertukar menjadi lebih tinggi lagi apabila keadaan permukaan penebat seperti salutan permukaan dan titisan air diambil kira. Tambahan pula, simulasi menunjukkan melalui tambahnya cincin korona kepada tali penebat porselin, medan elektrik di permukaan penebat dikurangkan kepada tahap yang lebih rendah apabila dibandingkan dengan yang tiada cincin korona. Pada beberapa titik yang penting, hasil lain mencadangkan bahawa cincin korona boleh mengurangkan medan elektrik

sehingga 34% dan variasi di dimensi cincin corona turut menunjukkan kesan yang ketara terhadap perubahan di agihan medan elektrik pada penebat

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I certify that a Thesis Examination Committee has met on to conduct the final examination of on her thesis entitled " " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

kV	Kilo Volt
RTV SiR	Room Temperature Vulcanise Silicone Rubber
2-D	Two dimension
3-D	Three dimension
M	Metre
Mm	Millimetre

CHAPTER 1

INTRODUCTION

1.1 Introduction

Electrical energy is very important to modern society due to very significant increase in population and development of industrial activity. Furthermore, power utility is required to provide uninterrupted electrical energy to users [1,2]. Normally, the electric power generating unit and the load centre are located far apart from each other and the distance between the two can be up to few hundred kilometers. For this reason, the bulk of electricity is transmitted from generating unit to distribution level using overhead transmission lines at high voltage up to hundreds of kilovolt (kV) in order to reduce power loss [3,4].

Overhead line must be at a minimum height from the ground or crossed object on ground. This is to avoid the live part of the overhead conductor getting into contact with humans or conductive objects on the ground. In this case, therefore, the overhead line is held in mid-air and attached to the transmission tower in order to provide the required minimum clearance from the ground based on the voltage level of the overhead line [5]. At the same time, the overhead conductor needs to be electrically isolated from the attaching transmission tower that is in ground potential. The equipment that performs the dual task mentioned is known as a transmission line insulator or simply insulator. Figure 1 show the overhead transmission line conductor connected to the transmission tower by the insulator.

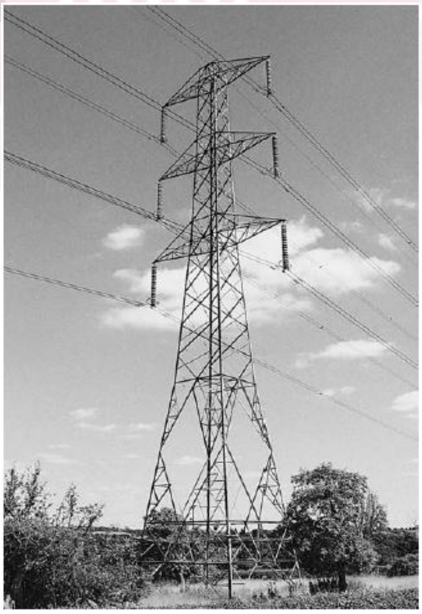

Figure 1.1 : Transmission line tower – A 400 kV double circuit line [4]

The transmission line insulator string working outdoors is exposed to all kinds of conditions, for example, pollution, vandalism, and foul weather. Insulator string is designed to work without problems outdoor under normal circumstances. However, the existence of service conditions will lower the tolerance or withstanding ability of the insulator string. The insulator string that cannot withstand the service conditions will face electrical discharge problems such as corona discharge. When this situation accumulates and continues for a long period on the insulator string, it will lead to deterioration of the insulator string and finally fail. The replacement of the failed insulator will cost utility money and time and disrupt the electric supply.

Figure 1.2 : Damaged insulators that need to be replaced

Corona discharge is a type of discharge that occurs when the electric field around the conductor exceeds a certain electric field limit. When the electric field limit has been exceeded, the air around the conductor is ionised and releases chemical gas and heat. The chemical gas and heat will react with the transmission line equipment and cause degradation. Hence, corona discharge is undesirable in electrical transmission and needs to be reduced.

Although corona discharge is unwanted as it brings risk to the transmission line, it is difficult to completely mitigate corona discharge in transmission lines. The severity of corona discharge activity increases proportionately to the electric field around the conductor. In such a case, corona discharge is more severe in transmission lines with higher system voltage. Currently, the solution applied by power utility companies to reduce corona discharge is to install a corona ring on the insulator string end. The purpose of installing the corona ring at the end of insulator string is to redistribute the high electric field and prevent corona discharge.

1.2 Problem Statement

The porcelain insulator unit has a complex shape to provide the required leakage distance. Porcelain insulator units are stacked up to form a long insulator string to provide the required basic insulation level. On the other hand, this situation causes the electric field distribution on the porcelain insulator string surface to be uneven and increase the electric field at certain locations of the insulator surface. In the case of an electric field gradient at that location exceeding the corona inception gradient, ionisation of the air will occur and lead to a corona discharge problem. The corona discharge problem could get more severe when the insulator string is affected by outdoor condition, for example, rain, and pollution.

A polymer insulator will undergo surface degradation when exposed to heat, ultra-violet light, and ozone gas produced by corona discharge. This situation causes the polymer surface to degrade in the form of chalking and cracking, which is obvious to inspection [6,7,8]. Meanwhile, a ceramic insulator that has high resistance to heat and chemicals can withstand the condition from corona discharge without surface degradation in the short term. Yet, corona discharge on ceramic insulator will still accelerate the ageing process in the ceramic insulator. Ageing process on insulator will lower the mechanical strength of the insulator shell and lead to puncture or surface cracks over time [9]. When that happens, the ceramic insulator will malfunction and needs to be replaced for the insulator string to provide the required basic insulation level.

Corona discharge problem has attracted much attention from researchers because it is harmful to the high voltage insulator in transmission lines, which is a major concern of the electric power supply industry. As such, many previous researches related to corona discharge on the transmission line insulator have been done. However, these researches have focused mainly on, the corona discharge problem in relation to polymer insulators [10,11,12,13,14]. Although there has been some research on corona discharge on ceramic insulator, the main initiative of such research fails to focus on understanding the corona discharge problem and proposed mitigation for it [15]. As a result, the body of research in the literature on the behaviour of corona discharge on the ceramic insulator surface is small, and efforts by manufacturers to produce better ceramic insulators are minimal because this issue has not received the attention from researchers proportionate to its severity and importance.

In relation to the situation mentioned earlier, corona discharge is caused by different environmental conditions and triggers many problems for transmission line equipment. Since there is little research focused on the corona discharge problem on porcelain insulator, the knowledge and information on this issue is scant and also not complete. In order to have better understanding of the issue of corona discharge on ceramic insulator, the outdoor conditions that affect the behaviour of corona discharge on ceramic insulator is investigated in this study. The findings of this study will add further knowledge to the subject of corona discharge on ceramic insulator and provide better understanding that will greatly influence manufacturers and help them to produce insulator strings with better performance.

There are many ways to investigate the behavior of corona discharge on ceramic insulator such as electric field distribution, leakage current, and radio noise. However, in this current study, electric field is chosen to study corona discharge on ceramic insulator because corona discharge is produced by high electric field. If the electric field on insulator surface can be measured or calculated, it can help to improve the electric field distribution on insulator surface especially on location where the electric field stress is high. This will help manufacture to produce insulator with higher performance and longer life span.

Moreover, the corona ring, which provides the mitigation approach to corona discharge on insulator, is also investigated in this study. Although studies have shown corona ring can redistribute the electric field distribution on the insulator surface [16]. However there is shortage of studies about corona ring application impact on electric field distribution on insulator string. Hence, the effect of adding corona ring to the electric field distribution around insulator surface is determined. Besides that, the optimum corona ring parameter design is study to serve as a reference data for power utility when design the insulator string and corona ring,

1.3 Research Objectives

The main aim for this work is to understand the behavior of electric field distribution around porcelain insulator when subjected to different surface condition and application of corona ring. In order to achieve this main aim, four detailed objective are defined as follow:

1. To determine the corona inception voltage of one single porcelain insulator unit using experimental work in laboratory.
2. To evaluate the electric field on one single porcelain insulator surface using computer simulation when subjected to RTV SiR coated surface condition and surface with water droplet condition.
3. To evaluate the electric field distribution around the porcelain insulator string when subjected to RTV SiR coated surface and surface with water droplet for insulator string with and without corona ring using computer simulation.
4. To investigate the impact of corona ring dimension on the electric field distribution of porcelain insulator surface.

1.4 Scope and limitation of Work

In this research, one unit of cap and pin porcelain insulator is used in the experiment. The porcelain insulator is subjected to many different conditions. However, the research will focus on the effect of applied RTV coating and adding water droplet to the insulator surface. The corona inception voltage of the porcelain insulator under the applied condition is observed and recorded in a table. When corona inception voltage is applied, the electric field on the surface of the insulator is exceeding the corona inception gradient and corona discharge will occur. Since electric field on the insulator surface cannot be measure, the method used to determine corona inception voltage is through observation of occurrence of corona discharge on the insulator surface. The porcelain insulator and condition of the experiment are then simulated using computer simulation package to observe the electric field distribution around the porcelain insulator under the applied condition when corona discharge occurs. The simulation of the porcelain insulator is continued with eight units of porcelain insulator stacked together to simulate porcelain insulator string in 132 kV transmission line. After that, the effect of applied RTV coating and adding water droplet on the electric field distribution around porcelain insulator string is investigated. However, due to drawing limitation from the simulation software, the coating on the insulator surface is not flat and not in the same shape like the analysis line. So when the electric field on the coated insulator surface is study, the electric field plot line is not perfect curve and will be uneven due to the uneven coating insulator surface. Moreover, the simulation of effect of corona ring on the electric field distribution around porcelain insulator is also done. Furthermore, the optimisation of the ability of corona ring to reduce the electric field distribution is done in simulation. This is achieved by changing the dimensions of the corona ring to get the best dimensions for the corona ring. The corona ring dimensions are the diameter of the ring, diameter of the tube and position of installation.

1.5 Thesis Layout

This thesis consists of five chapters which include introduction, literature review, methodology, results and discussion and also conclusion. The first chapter provides an overview of the corona discharge problem on polymer and ceramic insulators. This is followed by the problem statement, the research objectives, and scope of work.

Chapter Two discusses the literature review. This chapter presents some current knowledge on transmission line insulators and corona discharge. Previous work related to corona discharge on transmission lines is also identified from the literature and discussed.

Chapter Three explains the procedure of the experiment and simulation. For the experiment, the setup and procedure of the experiment are discussed in detail. On the other hand, the simulation of porcelain insulator is also discussed in this chapter. The electrical parameter and dimensions of the porcelain insulator has been list out in table. In addition, the dimension of the corona ring are also presented and full described.

Chapter Four presents the results regarding the objectives that have been proposed. These results are divided into two parts: the experimental work and simulation work. For the experiment part, the corona inception voltage and corona discharge location of porcelain insulator are determined. Meanwhile, the simulation part investigates the electric field around porcelain insulator surface subjected to different environmental conditions, and then electric field distribution is used to understand corona discharge on porcelain insulator surface. Moreover, the effects of corona ring the electric field distribution are discussed.

Chapter five provides the conclusion of this study, the results obtained in Chapter Four and summarises the findings to draw a conclusion based on the research objectives. Recommendations are made for some future work that can be considered pertaining to the polymeric insulator.

REFERENCES

[1] R. Tripathi, "Electrical degradation of 15 kV polymer insulators under accelerated tracking and erosion test conditions," Mississippi state, Mississippi , 2013.

[2] Electrical Power Research Institute, *Transmission Line Reference Book 345 kV and above Second Edition*. California: Electric Power Research Institute , 1982.

[3] R.D. Begamudre, *Extra High Voltage AC Transmission Engineering*. New Delhi: New Age International (P) Limited, Publisher, 2006.

[4] D. F. Warne, "The power System," in *Newnes Electrical Power Engineering Handbook Second Edition*. Burlington: Elsevier , 2005, pp. 375-389.

[5] F. Kiessling, P. Nefzger, J. F. Nolasco & U. Kaintzyk, *Overhead Power Lines Planning, Design, Construction*. Heidelberg: Springer-Verlag Berlin Heidelberg, 2003.

[6] B. K. Youn & C. S. Huh, "Surface Degradation of HTV Silicone Rubber and EPDM Used for Outdoor Insulators under Accelerated Ultraviolet Weathering Conditions," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 12, no. 5, pp. 1015- 1024, 2005.

[7] B.S. Reddy and S. Prasad D, "Corona Degradation of the Polymer Insulator Samples Under Different Fog conditions," *IEEE Transaction on Dielectric and Electrical Insulation*, vol. 23, no. 1, pp. 359-367, 2016.

[8] S.M. Gubanski, "Modern Outdoor Insulation - Concerns and Challenges," *IEEE Electrical Insulation Magazine*, vol. 21, no. 6, pp. 5-11, 2005.

[9] A.S. Jagtiani & J.R. Booker, "Aging of Porcelain Suspension Insulator under Mechanical and Electrical Stress on EHV AC Lines," in *Transmission and Distribution Construction and Live Line Maintenance, 1995. ESMO-95 Proceedings., Seventh International Conference on*, Columbus, OH, USA, 1995.

[10] B. Ma, J. Anderson & S.M. Gubanski, "Evaluating Resistance of Polymeric Materials for Outdoor Application to Corona and Ozone," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 17, no. 2, pp. 555-565, 2010.

[11] V.M. Monero & R.S. Gorur, "Effect of Long-Term Corona on Non-Ceramic Outdoor Insulator Housing Material," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 8, no. 1, pp. 117-128, 2001.

[12] A. J. Phillips, D. J. Childs & H. M. Scheneider, "Aging of Non-Ceramic Insulator due to Corona from Water droplet," *IEEE Transactions on Power Delivery*, vol. 14, no. 3, pp. 1081-1089, 1999.

[13] B. Pinnanggudi, R. S. Gorur & A. J. Kroese, "Quantification of Corona Discharges on Non Ceramic Insulator," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 12, no. 3, pp. 513-523, 2005.

[14] J. V. Vas & M. J. Thomas, "Surface Degradation of Silicone Rubber Nanocomposites Due to DC Corona Discharge," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 21, no. 3, pp. 1175-1182, 2014.

[15] Y. Cheng, C. Li & X. Huang, "Study of Corona Discharge Pattern on High Voltage Transmission Lines for Inspecting Faulty Porcelain Insulator," *IEEE Transactions on Power Delivery*, vol. 23, no. 2, pp. 945-952, 2008.

[16] S.Ilhan, A.Ozdemir & H.Ismailoglu, "Impacts of Corona Rings on the Insulation Performance of Composite Polymer Insulator Strings," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 22, no. 3, pp. 1605-1612, June 2015.

[17] J. S. T. Loom, *Insulators for High Voltages*.: Peter Peregrimus Ltd, 1998.

[18] D.A. Swift, "Insulators for Outdoor Applications," in *Advances in High Voltage Engineering*. London: The Institution of Engineering and Technology, 2004, p. 261.

[19] Department of Standard Malaysia, "MS IEC 60071-1 Insulation Co-ordination - Part 1 Definitions, Principles and Rules ," 2009.

[20] G. G. Karaday & R. G. Farmer, "Insulator and Accessories," in *Electric Power Generation, Transmission and Distribution, 3rd Edition*. Boca Raton: CRC press, 2012, pp. 11-1 - 11-24.

[21] A.P. Mishra, R.S.Gorur and S.Venkataraman, "Evaluation of Porcelain and Toughened Glass Insulator Removed from Service," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 15, no. 2, pp. 467-475, 2008.

[22] M. Costea & I. Baran, "A Comparative Analysis of Classical and Composite Insulator Behaviour," *Science Buletin Series C*, vol. 74, no. 1, pp. 147-154, 2012.

[23] R. Sundararajan, A. Mohammed & N. Chaipanit, "In service Aging and Degradation of 345 kV EPDM Transmission line Insulator in Coastal Environment," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 11, no. 2, pp. 348-361, 2004.

[24] B. Venkatesulu & M.J. Thomas, "Corona Aging Studies on Silicone Rubber Nanocomposite," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 17, no. 2, pp. 625-634, 2010.

[25] L. Xidong, W. Shaowu, F. Ju & G. Zhicheng, "Development of Composite Insulators in China," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 6, no. 5, pp. 586-594, 1999.

[26] M. Izadi, M.S.B.Rahman, M.Z.A.A. Kadir, "On the voltage and electric field distribution along polymer insulator," in *2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO 2014)*, 2014.

[27] R.E.T Kapal Sharma, "Polymeric Insulators," *Technical Article*, pp. 3-28.

[28] "History and Biblography of Polymeric Insulators for Outdoor Application," *IEEE Transactions on Power Delivery*, vol. 8, no. 1, pp. 376-385, 1993.

[29] B. Marungsi, W. Onchantuek and A. Oonsivilai, "Electric Field and Potential Distributions along Surface of Silicone Rubber Polymer Insulators Using Finite Element Method," *International Journal of Electrical and Electronics Engineering*, vol. 3, no. 10, pp. 611-616, 2009.

[30] H.C. Hillborg, "Loss and Recovery of Hydrophobicity of Polydimethysiloxane After Exposure to Electrical Discharge," Institude of Technology Stockholm , Stockholm, Sweden, 2001.

[31] S.H. Kim & E.A. Cherney, "Hydrophobic Behavior of Insulators Coated with RTV Silicone Rubber," *IEEE Transactions on Electrical Insulation* , vol. 27, no. 3, pp. 610-622, 1992.

[32] STRI Guide, "Hydrophobicity Classification ," *Guide 1*, vol. 92, no. 1, 1992.

[33] S. M. Braini, "Coating for Outdoor High Voltage Insulator," Cardiff, 2013.

[34] E. A. Cherney, "RTV Silicone - A High Tech Solution for a Dirty Insulator Problem," *IEEE Electrical Insulation Magazine*, vol. 11, no. 6, pp. 8-14, 1995.

[35] "IEEE Std 1523-2002," *IEEE Guide for the Application, Maintenance, and Evaluation of Room Temperature Vulcanizing (RTV) Silicone Rubber Coatings for Outdoor Ceramic Insulators*, 2003.

[36] Z. Guan, L. Wang, B. Yang & X. Liang, "Electric Field Analysis of Water Drop Corona," *IEEE Transactions on Power Delivery*, vol. 20, no. 2, pp. 964-969, 2005.

[37] H. El-Kishky & R.S. Gorur, "Electric Field Computation on an Insulating surface with Discrete Water Droplet," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 3, no. 3, pp. 450-456, 1996.

[38] R. S. Gorur, "Failure Modes of Porcelain and Toughened Glass Suspension Insulator," in *Electrical Insulation Conference (EIC),* Annapolis, MD, USA, 2011.

[39] M. Kumosa, L. Kumossa & D. Armentrout, "Failure Analyses of Non-Ceramic Insulators. Part 1: Brittle Fracture Characteristic," *IEEE Electrical Insulation Magazine* , vol. 21, no. 3, pp. 14-27, 2005.

[40] M. Farzaneh, "Insulator Flashover under Icing Conditions," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 21, no. 5, pp. 1997-2011, 2014.

[41] Inc Hubbell Power System, "What is Corona," *Bulletin EU1234-H*, 2004.

[42] M. Goldman, A. Goldman & R. S. Sigmond, "The Corona Discharge, Its properties and secific uses," *Pure and Applied Chemistry*, vol. 557, no. 9, pp. 1353-1362, 1985.

[43] J. S. Chang, P. A. Lawless & T. Yamamoto, "Corona Discharge Process," *IEEE Transacions on Plasma Science*, vol. 19, no. 6, pp. 1152-1166, 1991.

[44] T.Tanahashi et al., "Effect of Insulator Configuration on Ageing Deterioration of Polymer Insulator," in *2011 Electrical Insulation Conference* , Annapolis, Maryland, 2011, pp. 102-105.

[45] G.N. Trinh, "Corona and Noise," in *Electric Power Generation, Transmission, and Distribution*. Boca Raton: CRC Press, 2012, pp. 16-1 - 16-24.

[46] Electrical Power Research Institution, *EPRI AC Transmission Line Reference - 200 kV and Above Third Edition*. California: Electrical Power Research Institution, 2005.

[47] X. M. Bian, L. Chen, D. Yu, J. M. K. Macalpine, L. Wang, Z. Guan, F. Chen, W. Yao and S. Zhao, "Influenced of Aged Conductor Surface Condition on AC Corona-Generated," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 19, no. 6, pp. 2037-2043, 2012.

[48] F. W. Peek, "The Law of Corona and Dielectric Strength of Air," in *Anual Convention of the American Institute of Electrical Engineer*, Boston, 1911.

[49] H.H. Skilling, "Corona and Line Surge," *Electrical Engineering*, pp. 798-801, 1931.

[50] H. J. Ryan & H. H. Henline, "The hysteresis Character of Corona Formation ," *Transaction A. I. E. E.*, pp. 1118-1124, 1924.

[51] ARTICLE ARCHIEVE, "INMR," *Insulator Failure on 400 kV Lines Highlighted Importance of Corona Ring*, March 2017.

[52] Ravi Gorur, "INMR," *Arcing Horn and Corona Ring*, September 2014.

[53] S. Ilhan, A. Ozdemir, "Effect of Corona Ring Design on Electric Field Intensity and Potential Distribution Along an Insulator String," in *Proc. of the 5th International Conference on Electrical and Electronics Engineering*, Maslak Istanbul, 2007.

[54] Y. Zhu, K.Haji, M.Otsubo & C.Honda, "Surface Degradation of Silicone Rubber Exposed to Corona Discharge," *IEEE Transaction on Plasma Science* , vol. 34, no. 14, pp. 1094-1098, 2006.

[55] F.F. Bologna, J.P. Reynders & A.C. Britten, "Corona discharge activity on a string of glass cap-and-pin insulators under conditions of light wetting, light non-uniform contamination," in *2003 IEEE Power Tech Conference Proceedings*, Bologna, Italy, 2003.

[56] B. S. Reddy, B. S. Naik, U. Kumar and L. Satish, "Potential and Electric Field Distribution in a Ceramic Disc Insulator String with Faulty Insulators," in *Properties and Applications of Dielectric Materials (ICPADM), 2012 IEEE 10th International Conference*, Bangalore, 2012.

[57] E. Akbari, M. Mirzaie, M.B. Asadpoor & A. Rahimnejad, "Effect of Disc Insulator Type and Corona Ring on Electric Field and Voltage Distribution over 230-kV Insulator String by Numerical Method," *Iranian Journal of Electrical & Electronic Engineering*, vol. 9, no. 1, pp. 58-66, 2013.

[58] X. Wang & C. You, "Effect of Humidity on Negative Corona Discharge of Electrostatic Precipitators," *IEEE Transactions on Dielectrics and Electrical Insulation* , vol. 20, no. 5, pp. 1720-1726, 2013.

[59] *Getting Started: A 2D Electrostatic Problem*. Pittsburgh: ANSOFT Corporation, 2002.

[60] R. Fouladi, M. Mirzaie and M. Moradi, "Calculation of AC and Transient Potential Distribution along HV Insulator String under Polluted Condition based on FEM," *International Journa of Engineering Innovation & Research*, vol. 3, no. 1, pp. 74-78, 2014.

[61] S. Uckun. (2013, May) Digital Engineering. [Online]. http://www.digitaleng.news/de/when3disnotneeded/

[62] I.J.S.Lopes, S.H.Jayaram, E.A.Cherney, "A Study of Partial Discharges from Water Droplets on a Silicone Rubber Insulating Surface," *IEEE Transaction on Dielectric and Electrical Insulation*, vol. 8, no. 2, pp. 262-268, 2001.

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