PREDICTION OF POLLUTED INSULATOR BASED ON LEAKAGE CURRENT RESISTANCE INSERTION PERFORMANCE OF SHORT AND MEDIUM TRANSMISSION LINE MODEL

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DEDICATION

To my beloved mother, my husband, Qusay Ali, and my daughters, Hiba, Dima, and NoorAiny for their encouragement and support.

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ABSTRACT

The main objective of the transmission lines is to deliver power from the generator to the customers, with less losses and without any interruptions. However, pollution sources are increasing around the world, which are affecting one of the most important components of a power line, namely, the high voltage outdoor insulators. The accumulation of pollution on the surface of the insulator can affect its physical properties and create leakage current resistance. Under suitable conditions, this resistance will lead to leakage current on the surface of the insulator. In previous studies, leakage current measurement on the insulator surface was ignored because it is negligible. However, increasing pollution levels and the large number of transmission line insulators should take into account the effect of leakage current resistance in the transmission line model. In this thesis, an improved model is introduced to examine the effect of leakage current resistance on the parameters of the transmission line, the amount of additional active power losses, voltage drop and increased real power generation in power networks for both short and medium transmission lines. Three levels of leakage resistance (high, medium, and low) that represent the three levels of pollution are incorporated into the transmission line model through a series of delta to star and star to delta conversion using a two-port network concept. Then, by inserting the leakage current resistance, a simulation model was used to measure leakage current and voltage of the leakage current resistance. A simulation sensor is used to predict the level of pollution on the insulator and the location of highly polluted insulators using Artificial Neural Network. This study was able to determine the changes in each parameter and the effects of these changes on the active power losses and voltage drop in three different systems. The application of the improved model have shown an increase in detection of power losses by 25.63% in high pollution conditions at the insulators in all short and medium transmission lines. Thus, to compensate for these high losses, the system needs to increase real power generation by 0.61% when compared with during normal conditions. The prediction results by the simulation model for the 5-bus system clearly demonstrated that the overall Correct Classification Rates for the predicted pollution levels were very high at 97.67% and 98.03%, for both short and medium models, respectively. Meanwhile, the Correct Classification Rate for the predicted locations of highly polluted insulators is 100% for both short and medium models. The results obtained in this study offer accurate information for polluted transmission line insulators, which could be used for maintenance and calculation of power loss for polluted insulators, in order to keep the power system in a reliable state.

ABSTRAK

Objektif utama talian penghantaran adalah menghantar tenaga elektrik daripada penjana kuasa kepada pelanggan, dengan jumlah kehilangan yang kecil dan tanpa gangguan. Walau bagaimanapun, sumber pencemaran yang semakin meningkat di seluruh dunia mampu mempengaruhi salah satu komponen paling penting dalam talian elektrik, iaitu penebat luar bervoltan tinggi. Pencemaran yang terkumpul pada permukaan penebat boleh menjejaskan sifat fizikalnya dan menghasilkan rintangan arus bocoran. Dalam keadaan yang sesuai, rintangan ini akan menyebabkan aliran arus bocoran berlaku pada permukaan penebat. Kajian terdahulu mengabaikan bacaan arus bocoran pada permukaan penebat kerana ianya boleh diabaikan. Namun, peningkatan paras pencemaran dan bilangan penebat talian penghantaran yang banyak menunjukkan bahawa kesan rintangan arus bocoran perlu dimasukkan ke dalam model talian penghantaran. Tesis ini memperkenalkan satu model diperbaiki untuk mengkaji kesan rintangan arus bocoran kepada parameter talian penghantaran, jumlah peningkatan kehilangan kuasa aktif, penurunan voltan dan peningkatan penjanaan kuasa sebenar dalam rangkaian kuasa talian penghantaran pendek dan sederhana. Tiga tahap rintangan bocoran (tinggi, sederhana, dan rendah) yang mewakili tiga tahap pencemaran dimasukkan ke dalam model talian penghantaran melalui suatu siri penukaran delta kepada bintang dan bintang kepada delta menggunakan konsep rangkaian dua liang. Setelah rintangan arus bocoran dimasukkan, model simulasi digunakan untuk mengukur arus bocoran dan voltan bagi rintangan arus bocoran. Sensor simulasi digunakan untuk meramal tahap pencemaran pada penebat dan lokasi penebat yang sangat tercemar menggunakan Rangkaian Neural Buatan. Kajian ini mampu menentukan perubahan dalam setiap parameter dan kesannya terhadap kehilangan kuasa aktif dan penurunan voltan dalam tiga sistem yang berbeza. Aplikasi model diperbaiki ini menunjukkan peningkatan dalam pengesanan kehilangan kuasa sebanyak 25.63% dengan keadaan pencemaran yang tinggi pada penebat di semua menara dalam talian penghantaran pendek dan sederhana. Untuk mengimbangi kehilangan yang tinggi ini, sistem janakuasa perlu meningkatkan penjanaan kuasa sebenar sebanyak 0.61% berbanding dengan keadaan biasa. Hasil ramalan model simulasi untuk sistem 5-bas menunjukkan bahawa Kadar Pengkelasan Benar secara keseluruhan untuk tahap pencemaran yang diramalkan adalah sangat tinggi, masing-masing pada 97.67% dan 98.03%, bagi kedua-dua model pendek dan sederhana. Kadar Pengkelasan Benar untuk ramalan lokasi penebat yang sangat tercemar adalah 100% bagi model pendek dan sederhana. Hasil kajian ini memberikan maklumat yang tepat untuk penebat talian penghantaran yang tercemar, yang boleh digunakan dalam penyelenggaraan dan pengiraan kehilangan tenaga elektrik untuk penebat yang tercemar, demi memastikan sistem kuasa dalam keadaan yang boleh dipercayai.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

D	-	Distance between two towers
G_{ij}	-	The conductance of the line
δ_i	-	The phase angle of voltage at the bus (i)
I_{LC}	-	Leakage current
δ_j	-	The phase angle of voltage at the bus (j)
N	-	Number of tower
n	-	Number of towers between bus and pollution tower
N_f	-	Total number of buses
N_S	-	Number of samples in the data set
P_{gen}	-	Real power generation
$P_{gen}\%$	-	Real power generation percentage
P_{loss}	-	Real power loss
$P_{loss}\%$	-	Real power loss percentage
$P_{loss\ old}$	-	Real power loss before insertion leakage current resistance
R	-	Regression correlation coefficients
R_{LC}	-	Leakage current resistance
T	-	Total distance between two buses i-j
$V_{bus\ new}$	-	Bus voltage after insertion leakage current resistance
$V_{bus\ old}$	-	Bus voltage before insertion leakage current resistance
V_i	-	Sending voltage
V_j	-	Receiving voltage

Y_B	-	New admittance after insertion leakage current resistance between bus i-j
Y_C	-	New admittance after insertion leakage current resistance between bus j-i
Z	-	Impedance of the line
Z_A	-	New impedance of the line

LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
AQ_K	-	Actual Output
ASDD	-	Additional Salt Deposit Density
BP	-	Back propagation
CCR	-	Correct Classification Rate
DQ_K	-	Desired Output
ESDD	-	Equivalent Salt Deposit Density
FFBP	-	Feed Forward Back Propagation
LII	-	Location Insulator Index
MCR	-	Misclassification Rate
MSE	-	Mean Squared Error
NRLF	-	Newton Raphson Load Flow
PLI	-	Pollution Level Index
RMS	-	Root Mean Square
USD	-	United States Dollar

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The electrical power system is one of the most complex human-made set-ups in the world. Its basic operating role is to deliver all electricity demand to customers with high efficiency and cost effectiveness [1]. However, the increasing demand for electric power, along with deregulation, has pushed the power system into putting more pressure on its infrastructure (generation, transmission, and distribution). This kind of operation will increase the risks towards the stable and reliable state of the power system to provide continuous power service for customers. Under this stressful operating condition, it is vital that the power system reduces all factors affecting the transmission of power to customers, especially power losses, to keep the system in a satisfactory condition.

Power losses often occur in three areas of the network system, namely, generation, transmission, and distribution. Power loss in an electrical system typically varies between 3 to 6%. In developed countries, power losses in an electrical system do not exceed 10%. Meanwhile, in developing countries, active power losses are almost 20% [2]. These losses can be classified into two kinds: the first one is economical due to energy lost in transmission [3], while, the second one is due to environmental pollution [4]. Power systems must use fuel resources, in general, to compensate for power losses, which mean more emissions of fossil fuels, like coal, gas, and oil to generate more power. Fossil fuels in particular, provide almost 80% of the global energy demands [5]. The increasing demand for energy sources have increased their prices and the cost of electricity, as well as exacerbating global warming [5].

High voltage transmission lines are an essential part of the power system network, bringing power from remote generating stations to consumers. These lines could span over thousands of miles [6], and the service fundamentally depends on the condition at transmission lines [7]. Therefore, the efficiency of the transmission lines in transmitting power with lower losses is crucial to power companies. Most electrical power is transferred via transmission and distribution overhead lines [8]. Despite the use of underground cables in certain urban areas to solve aesthetic and congestion problems, overhead lines are expected to continue being the major distributor and transmitter of electrical energy. There are different types of towers used to transmit power, both in the transmission or distribution, as depicted in Figure 1.1.

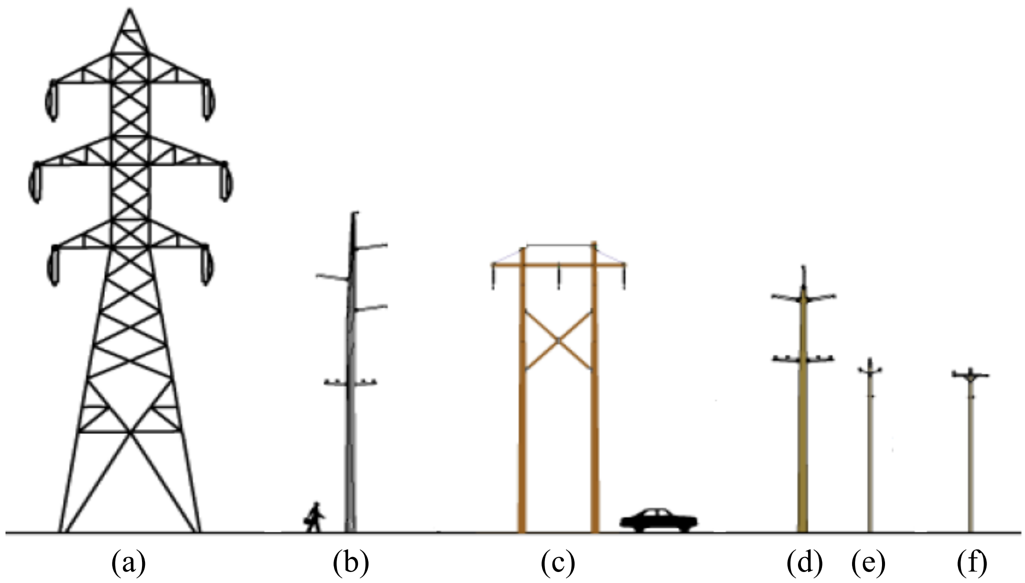

Figure 1.1 Various transmission and distribution line structures: (a) 345 kV; (b) 138 kV; (c) 138 kV; (d) 69 kV; (e) 34 kV; and (f) 12 kV [9]

Typically, overhead lines consist of towers, conductors, and outdoor insulators [6]. However, all transmission lines have losses in transmitting power process through it. The amount of these losses depends on transmission line design for example, material and length of transmission lines, as well the type of polluted insulators. Losses in transmission lines could be divided into reactive and active [1] losses. A reactive loss is created by the reactionary elements in the network, while real loss is caused by the physical properties of the transmission medium and the resistance to transmit power through it. Active power losses can directly impact the energy delivered to customers, thus, requiring more attention from utility companies [2]. Active power losses in the transmission lines are estimated to vary between 4 and 8% of the total power generated. In Brazil, half a billion U.S. dollars a year represent the cost of losses [10].

Insulators in overhead transmission lines provide support to line conductors, and physically separate one conductor from the other, while electrically insulating each of them [11]. Studying the performance of insulators under pollution is very important due to the high voltage of the transmission lines being subjected to different pollution sources, such as weather and factory emissions [12]. Depending on the severity of the pollution and the wetting conditions of the site, outdoor insulators may allow leakage current to flow from a line to ground over the surface of the insulators. Although the individual leakage current is small in value, the total leakage current may reach high values when multiplied by the total number of insulators that exist in a transmission line [13-15]. This could increase the power loss from insulators and increase the total real power loss in the power system because leakage current is drawn from the main supply [9]. In serious situations, flashovers may occur, which could lead to the loss of the insulator itself and the transmission line connected to this insulator. For example, in the northeast region of Brazil, 15.25% of transmission line faults are attributed to the effects of pollution deposits on insulators. These insulator failures could cause billions of dollars in losses [16, 17]. Figure 1.2 shows an example of a polluted outdoor insulator.

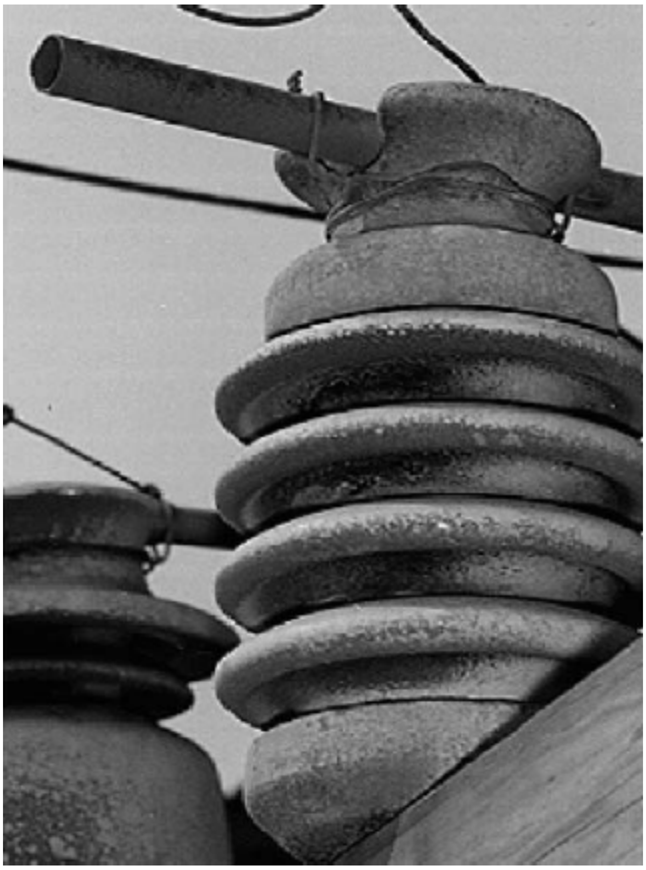

Figure 1.2 Outdoor pollution insulator [18]

An increase in the load demand can lead to an increase in voltage level in the transmission lines and the power generation [19]. Thus, increased power generation could increase the amount of pollution. In general, this condition could challenge the insulator's ability to withstand high electrical stresses and the accumulation of pollution. Therefore, numerous researches have looked into insulator performances in high voltage under polluted conditions to mitigate insulator failure in the power system [20]. From various literature, various methods, such as computer simulations and laboratory experiments are used to study the behaviour of the insulators under different pollution levels. Attempts have also been made to mitigate pollution in insulators via various techniques, such as insulator washing, silicone coating, or using leakage current as an indicator for a physical situation of the insulator under pollution [21]. However, to date, no attempt has been made to mathematically model and analyse the performance of the transmission line, under the influence of leakage current resistance, to study the effect of polluted insulators on transmission line parameters. This study proposes a novel method to assess the effect of changing the insulator resistance value on the parameter of the transmission line model, load flow, and total real losses of the power system. Moreover, this study presents a simulation for sensoring the amount of leakage current when the insulator resistance is changed, which would allow for the prediction pollution level on the insulator. All these information are vital in maintaining continuous power transmission.

1.2 Problem Statement

One of main problems when transmitting power in the overhead transmission lines is the accumulation of pollution on the surface of high voltage insulators due to increased sources of pollution [5]. Such condition could affect the performance of the insulator and in a worst case scenario, failure of the transmission line insulator. For example, 15.25% of faulty transmission lines in Brazil were due to pollution deposits on insulators [16, 17]. These insulator failures have caused billions of dollars in losses [10,22].

The polluted surface of the insulator could affect its physical characteristics, such as reducing its surface resistance and allowing leakage current to flow [23]. In a previous study, leakage current on the insulator surface was ignored [24] due to its small value. Nonetheless, with increased pollution sources that leads to raise up the probability of whiteness high voltage insulator to the accumulation of pollution. Thus, the total leakage current can reach high values when multiplied by the total number of polluted insulators existing in a transmission line. Consequently, this condition could increase power losses from insulators and increase real power losses in the power system because leakage current is drawn from the main supply [13-15].

Previous researchers have investigated the performance of high voltage insulators in transmission lines under different pollution levels and conditions. These studies were focused on how and when the insulators would experience breakdowns through computer simulations or laboratory experiments [25-35]. Then, they looked for ways to improve the insulator's surface to increase its resistance. Despite these efforts, there are still a need to develop a model that can represent the effects of leakage current resistance on transmission line parameters and study how affect load flow and total active losses. Moreover, by sensoring the amount of leakage current, control centre could predict the level of pollution on the insulator, which would be useful to utility companies. Such knowledge can be used for the maintenance of an insulator, which can reduce losses or prevent flashovers and keeping power continuously via transmission lines. All of these benefits will consequently improve the power system, making it highly efficient, economical, and reliable.

1.3 Objectives of The Research

This thesis is focused on investigating the effect of leakage current resistance on the insulator. The primary objectives of this thesis are:

1. To develop an improved model for transmission lines with the insertion of leakage current resistance.
2. To evaluate the performance of transmission lines, in terms of real power losses and bus voltage, in the presence of leakage current resistance.
3. To develop an assessment technique for predicting pollution levels and the location of highly polluted insulators via simulation instruments for leakage current levels, using ANN in the improved transmission line.

1.4 Scope of Research

The scope of this modelling and simulation study is focused on the following aspects:

1. Inclusion of the short and medium transmission lines only. Long transmission line was excluded from this study due to the complexity of the model.

2. Newton Raphson load flow (NRLF) was used with the leakage current resistance parameter.

3. Three levels of pollution for the test systems were used, depending on the leakage current, namely, low pollution stage (< 50 mA), medium pollution stage (< 150 mA), and high pollution stage (> 150 mA). Weather condition was also included, especially the increase of humidity, which could have an effect on the flow of leakage current on the surface of the insulator. However, the assumptions in this study were that the weather condition for the flow of leakage current was available and that it remained constant.

4. The 5-bus system was used to predict the pollution levels and the location of highly polluted insulators, to improve the model for transmission lines, with the insertion of leakage current resistance.

1.5 Organisation of Research

This thesis is organised into six chapters. Summarized descriptions of the remaining chapters are as follow:

Chapter 2 presents an overview of insulators and the types of pollutions on insulators. A discussion of the model for polluted insulator are also included. A detailed review, particularly on the leakage current on insulators and leakage current mitigation techniques, are also addressed. Previous studies that are related to leakage current resistances on insulators are also discussed in the final parts of this chapter.

Chapter 3 discuss the development of a model for the effect of leakage current resistance on two types of transmission lines i.e. short and medium line. High, medium, and low values of leakage resistances were incorporated into the model through a two-port network concept and a series of delta-star conversion and lastly, a star-delta conversion. Thus, the load flow equations were updated by changing the input impedances.

REFERENCES

1. Praetorius, B., Bauknecht, D., Cames, M., Fischer, C., Pehnt, M., Schumacher, K. and Voß, J. P. (2008). *Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions*. German: Springer Science & Business Media.
2. Ramesh, L., Chowdhury, S. P., Chowdhury, S., Natarajan, A. A. and Gaunt, C. T. (2009). Minimization of power loss in distribution networks by different techniques. *International Journal of Electrical Power and Energy Systems Engineering*, 2(1), 1-6.
3. Farzaneh, M., Farokhi, S. and Chisholm, W. (2012). *Electrical Design of Overhead Power Transmission Lines*. USA: McGraw Hill Professional.
4. Rohani, A., Mazlumi, K. and Kord, H. (2010). Modeling of a hybrid power system for economic analysis and environmental impact in HOMER. *Proceedings of the 2010 18th Iranian Conference on Electrical Engineering (ICEE).* 11-13 May. Isfahan University of Technology, Isfahan, Iran: IEEE, 819-823.
5. Asif, M. and Muneer, T. (2007). Energy supply, its demand and security issues for developed and emerging economies. *Renewable and Sustainable Energy Reviews*, 11(7), 1388-1413.
6. Murthy, S. S. and Santhakumar, A. R. (1990). *Transmission Line Structures*. USA: McGraw-Hill.
7. Grigsby, L. L. (Ed.) (2012). *Power System* (5th ed.). Boca Raton, FL: CRC Press.
8. Glover, J. D., Sarma, M. S. and Overbye, T. (2012). *Power System Analysis & Design, SI Version*. Boston, MA, USA: Cengage Learning.
9. Rahmat, M. F. (2010). Study of New Mid-Pole Bonding Mitigation System to Wooden Pole Ladder Network Model to address Pole-Top Fire Issue. RMIT University, pp. 04.

10. Belati, E. A. and Da Costa, G. R. M. (2008). Transmission loss allocation based on optimal power flow and sensitivity analysis. *International Journal of Electrical Power & Energy Systems*, 30(4), 291-295.

11. Looms, J. S. T. (1988). *Insulators for High Voltages*. London, UK: Peter Peregrinus Ltd.

12. Othman, N. A., Piah, M. A. M. and Adzis, Z. (2017). Charge distribution measurement of solid insulator materials: A review and new approach. *Renewable and Sustainable Energy Reviews*, *70*, 413-426.

13. Meyer, L. H., Oliboni, C. R. P., Graziano, G. C., Mustafa, T. I. A. H., Almaguer, H. A. D., Molina, F. H. and Cassel, G. (2011). A study of the correlation of leakage current, humidity and temperature of 25 kV insulators in urban and rural areas. *Proceedings of the 2011 Annual Report Conference on Electrical Insulation and Dielectric Phenomena (CEIDP).* 16-19 October. Cancun, Mexico: IEEE, 398-402.

14. Werneck, M. M., Santos, D. M., de Nazare, F. V., da Silva Neto, J. L., Allil, R. C., Ribeiro, B. A., Carvalho, C. C. and Lancelotti, F. (2014). Detection and monitoring of leakage currents in distribution line insulators. *Proceedings of the 2014 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*. 12-15 May. Montevideo, Uruguay: IEEE, 468-472.

15. Werneck, M. M., dos Santos, D. M., de Carvalho, C. C., de Nazaré, F. V. B. and Allil, R. C. D. S. B. (2015). Detection and monitoring of leakage currents in power transmission insulators. *IEEE Sensors Journal*, 15(3), 1338-1346.

16. Yang, H., Pang, L., Li, Z., Zhang, Q., Yang, X., Tang, Q. and Zhou, J. (2015). Characterization of pre-flashover behavior based on leakage current along suspension insulator strings covered with ice. *IEEE Transactions on Dielectrics and Electrical Insulation*, 22(2), 941-950.

17. Su, H., Jia, Z., Sun, Z., Guan, Z. and Li, L. (2012). Field and laboratory tests of insulator flashovers under conditions of light ice accumulation and contamination. *IEEE Transactions on Dielectrics and Electrical Insulation*, 5(19), 1681-1689.

18. Montoya-Tena, G., Hernández-Corona, R. and Ramírez-Vázquez, I. (2005). Experiences on pollution level measurement in Mexico. *Electric Power Systems Research*, 1(76), 58-66.

19. Su, Z. and LI, Q. (2010). Historical review and summary on measures against pollution flashover occurred in power grids in china [J]. *Power System Technology*, 12, 124-130.

20. Karamousantas, D. C., Chatzarakis, G. E., Oikonomou, D. S., Ekonomou, L. and Karampelas, P. (2010). Effective insulator maintenance scheduling using artificial neural networks. *IET Generation, Transmission & Distribution*, 4(4), 479-484.

21. Devendranath, D. and Rajkumar, A. D. (2002). Leakage current and charge in RTV coated insulators under pollution conditions. *IEEE Transactions on Dielectrics and Electrical Insulation*, 9(2), 294-299.

22. Dave, V., Gupta, H. O. and Chandra, R. (2012). Investigation of Hydrophobic and Optical properties of HfO 2 coating on ceramic insulator. *Proceedings of the 2012 IEEE 10th International Conference on the Properties and Applications of Dielectric Materials (ICPADM).* 24-28 July. Bangalore, India: IEEE, 1-4.

23. Swift, D. A. (2004). Insulators for outdoor applications. *Advances in High Voltage Engineering*, 40, 257.

24. Grigsby, L. L. (Ed.) (2012). *Electric Power Generation, Transmission, and Distribution*. Boca Raton, FL: CRC press.

25. Suwarno, S. and Parhusip, J. (2010). Effects of humidity and fog conductivity on the leakage current waveforms of ceramics for outdoor insulators. *WSEAS Transactions on Systems*, 9(4), 442-452.

26. El-Hag, A. H. (2005). A new technique to detect dry-band arcing. *IEEE Transactions on Power Delivery*, 20(2), 1202-1203.

27. Suda, T. (2005). Frequency characteristics of leakage current waveforms of a string of suspension insulators. *IEEE Transactions on Power Delivery*, 20(1), 481-487.

28. Gialketsi, A. A., Kontargyri, V. T., Gonos, I. F. and Stathopulos, I. A. (2005). Estimation of the flashover voltage on insulator using artificial neural networks. *WSEAS Transactions on Systems*, 4(5), 514-518.

29. Otsubo, M., Hashiguchi, T., Honda, C., Takenouchi, O., Sakoda, T. and Hashimoto, Y. (2003). Evaluation of insulation performance of polymeric

surface using a novel separation technique of leakage current. *IEEE Transactions on Dielectrics and Electrical Insulation*, 10(6), 1053-1060.

30. Suwarno, S. (2006). Leakage current waveforms of outdoor polymeric insulators and possibility of application for diagnostics of insulator conditions. *Journal of Electrical Engineering and Technology*, 1(1), 114-119.
31. Suwarno, J. P. (2008). Investigation on leakage current waveforms and flashover characteristics of ceramics for outdoor insulators under clean and salt fogs. *The WSEAS Transaction on Power Systems*, 3(6), 456-465.
32. El-Hag, A. H. (2005). A new technique to detect dry-band arcing. *IEEE Transactions on Power Delivery*, 20(2), 1202-1203.
33. Siderakis, K., Agoris, D., Eleftheria, P. and Thalassinakis, E. (2004) Investigation of leakage Current on High Voltage Insulators- Field Measurements, *WSEAS Transactions on Circuits and Systems*, 3(5), 1188-1191.
34. Suda, T. (2005). Frequency characteristics of leakage current waveforms of a string of suspension insulators. *IEEE Transactions on Power Delivery*, 20(1), 481-487.
35. Gialketsi, A. A., Kontargyri, V. T., Gonos, I. F. and Stathopulos, I. A. (2005). Estimation of the flashover voltage on insulator using artificial neural networks, *WSEAS Transactions on Circuits and Systems*, 4(5), 514-518.
36. He, J. Insulator flashover probability investigation based on numerical electric field. Ph.D. Thesis. Arizona State University; 2016.
37. Rizk, F. A. and Trinh, G. N. (2014). *High Voltage Engineering*. Boca Raton, FL: CRC Press.
38. He, L. and Gorur, R. S. (2016). Source strength impact analysis on insulator flashover under contaminated conditions. *IEEE Transactions on Dielectrics and Electrical Insulation*, 23(2), 1005-1011.
39. Gorur, R. S., Cherney, E. A. and Burnham, J. T. (1999). *Outdoor Insulators*. Phoenix, Arizona, USA: Ravi S. Gorur.
40. International Electrotechnical Commission (1986). *Guide for the Selection of Insulators in Respect of Polluted Conditions*. Bureau Central De La Commission Electrotechnique Internationale.

41. Bo, L. and Gorur, R. S. (2012). Modeling flashover of AC outdoor insulators under contaminated conditions with dry band formation and arcing. *IEEE Transactions on Dielectrics and Electrical Insulation*, 19(3), 1037-1043.

42. Yoshimura, N., Kumagai, S. and Nishimura, S. (1999). Electrical and environmental aging of silicone rubber used in outdoor insulation. *IEEE Transactions on Dielectrics and Electrical Insulation*, 6(5), 632-650.

43. Gençoğlu, M. T. and Cebeci, M. (2008). The pollution flashover on high voltage insulators. *Electric Power Systems Research*, 78(11), 1914-1921.

44. Braini, S. *Coatings for outdoor high voltage insulators*. Ph.D. Thesis. Cardiff University; 2013.

45. Hernanz, R., Jose, A., Martín, C., José, J., Gogeascoechea, M. and Belver, Z. (2006). Insulator pollution in transmission lines. *Proceedings of the 2006 International Conference on Renewable Energies and Power Quality (ICREPQ)*. 5-7 April. Balearic Island, Spain: IEEE, 124-130.

46. Gorur, R. S., Cherney, E. A. and Burnham, J. T. (1999). *Outdoor Insulators*. Phoenix, Arizona: Ravi S. Gorur, Inc.

47. Tsarabaris, P. T., Karagiannopoulos, C. G. and Theodorou, N. J. (2005). A model for high voltage polluted insulators suffering arcs and partial discharges. *Simulation Modelling Practice and Theory*, 13(2), 157-167.

48. Venkataraman, S. and Gorur, R. S. (2006). Prediction of flashover voltage of non-ceramic insulators under contaminated conditions. *IEEE transactions on dielectrics and electrical insulation*, 13(4), 862-869.

49. Current, L. Condor Application note 7/01. AN-113 (Condor DC power supplies, Inc. 2311, Stathan Parkway Oxnard, CA 93033).

50. Wong, K. L. and Rahmat, M. F. (2010). Feasibility study of leakage current shunting method based on the ladder network model. *IEEE Transactions on Power Delivery*, 25(2), 1133-1137.

51. Yao, C. G., Li, J. Y., Mi, Y., Sun, C. X. and Li, X. Z. (2007). Abstracting frequency spectrum characteristics of insulators leakage current in safety zone to forecast the contamination condition. *Zhongguo Dianji Gongcheng Xuebao. Proceedings of the Chinese Society of Electrical Engineering,* 27(30), 1-8.

52. Xueming, Z., Xiaobo, Y. and Wang, D. (2014). Improved compressed sensing matrixes for insulator leakage current data compressing. *Indonesian Journal of Electrical Engineering and Computer Science*, 12(6), 4258-4263.

53. Farzaneh, M., Baker, A. C., Bernstorf, R. A., Burnhan, J. T., Cherney, E. A., Chisholm, W. A., Fofana, I., Gorur, R. S., Grisham, T., Gutman, I. and Rolfseng, L. (2007). Selection of line insulators with respect to ice and snow - part ii: selection methods and mitigation options. *IEEE Transactions on Power Delivery*, 22(4), 2297-2304.

54. Kimoto, I., Kito, K. and Takatori, T. (1972). Anti-pollution design criteria for line and station insulators. *IEEE Transactions on Power Apparatus and Systems*, (1), 317-327.

55. Pelacchi, P. (1998). Automatic hot line insulator washing device positioned by helicopter. Proceedings of the 8th International Conference on Transmission & Distribution Construction, Operation & Live-Line Maintenance (ESMO'98). 26-30 April. Orlando, Florida, US: IEEE, 133.

56. de Parny, R. (1993). Helicopter airborne services live line work. Proceedings of the Sixth International Conference on Transmission and Distribution Construction and Live Line Maintenance (ESMO'93). 12-17 September. Las Vegas, Nevada, USA: IEEE, 74-87.

57. Fields, M.E. (1995). Silicone coating project [insulators]. *Conference Record of the 1995 Pulp and Paper Industry Technical Conference*. 12-16 June. Vancouver, Canada: IEEE, 178-182.

58. Hot washing of insulators. Retrieved from Elektrotechnik: A website on electrical engineering: http://www.electrotechnik.net/2010/12/hot-washing-of-insulators.html [01-06-2010]

59. Metwally, I. A., Al-Maqrashi, A., Al-Sumry, S. and Al-Harthy, S. (2006). Performance improvement of 33kV line-post insulators in harsh environment. *Electric Power Systems Research*, 76(9), 778-785.

60. Chang, R. J., Shah, M., Mazeika, L., Tsai, A. and Takaseki, M. (1997). Design of insulators for severe contamination. *Proceedings of the 5th International Conference on Properties and Applications of Dielectric Materials.* 25-30 May. Seoul, South Korea: IEEE, 778-781.

61. Grzybowski, S. and Disyadej, T. (2008). Electrical performance of fiberglass crossarm in distribution and transmission lines. *Proceedings of the 2008*

IEEE/PES Transmission & Distribution Conference & Exposition. 21-24 April. Chicago, IL, USA: IEEE, 1-5.

62. Shihab, S., Melik, V., Zhou, L., Melik, G. and Alame, N. (1994). On-line pollution leakage current monitoring system. *Proceedings of the 4th International Conference on Properties and Applications of Dielectric Materials*. 3-8 July. Brisbane, Australia: IEEE, 538-541.

63. Bennoch, C. J., Judd, M. D. and Pearson, J. S. (2002). System for on-line monitoring of pollution levels on solid insulators. *Conference Record of the 2002 IEEE International Symposium on Electrical Insulation.* 7-10 April. Boston, USA: IEEE, 237-240.

64. Metwally, I .A., Sumry, S. A. and Al-Harthy, S. S. (2006). Online condition monitoring of line-insulator leakage currents. *International Journal of Emerging Electric Power Systems*, 5(1).

65. Vlastos, A. E. and Orbeck, T. (1996). Outdoor leakage current monitoring of silicone composite insulators in coastal service conditions. *IEEE Transactions on Power Delivery*, 11(2), 1066-1070.

66. Portillo, M., Fernandez, L. and Andres, A. (1998). An innovative method for insulators washing in energised lines. Proceedings of the 1998 IEEE International Conference on Transmission & Distribution Construction, Operation & Live-Line Maintenance (ESMO'98). 26-30 April. Orlando, Florida, USA: IEEE, 132.

67. Cherney, E. A., Hackam, R. and Kim, S. H. (1991). Porcelain insulator maintenance with RTV silicone rubber coatings. *IEEE Transactions on Power Delivery*, 6(3), 1177-1181.

68. Cherney, E.A. (1993). RTV silicone rubber coatings for substation insulator maintenance. *Conference Record of 1993 Pulp and Paper Industry Technical Conference*. 21-25 June. Hyannis, MA, USA: IEEE, 170-174.

69. Basuki, A. and Lendy, F. (2012). Improving outdoor insulator performances installed at coastal area using silicone rubber coating. *Proceedings of the 2012 International Conference on Condition Monitoring and Diagnosis (CMD).* 23-27 September. Bali, Indonesia: IEEE, 1143-1146.

70. Siderakis, K. and Agoris, D. (2008). Performance of RTV silicone rubber coatings installed in coastal systems. *Electric Power Systems Research*, 78(2), 248-254.

71. Chen, J. Y. and Chang, R. J. (1996). Field experience with overhead distribution equipment under severe contamination. *IEEE Transactions on Power Delivery*, 11(3), 1640-1645.

72. Richards, C. N. and Renowden, J. D. (1997). Development of a remote insulator contamination monitoring system. *IEEE Transactions on power Delivery*, 12(1), 389-397.

73. Kumagai, S. and Yoshimura, N. (2004). Leakage current characterization for estimating the conditions of ceramic and polymeric insulating surfaces. *IEEE Transactions on Dielectrics and Electrical Insulation*, 11(4), 681-690.

74. Suda, T. (2005). Frequency characteristics of leakage current waveforms of a string of suspension insulators. *IEEE Transactions on Power Delivery*, 20(1), 481-487.

75. Chandrasekar, S., Kalaivanan, C., Cavallini, A. and Montanari, G. (2009). Investigations on leakage current and phase angle characteristics of porcelain and polymeric insulator under contaminated conditions. *IEEE Transactions on Dielectrics and Electrical Insulation*, 2(16), 574-583.

76. Banik, A., Dalai, S. and Chatterjee, B. (2015), January. Studies the effect of Equivalent Salt Deposit Density on leakage current and flashover voltage of artificially contaminated disc insulators. *Proceedings of the 2015 1st Conference on Power, Dielectric and Energy Management at NERIST (ICPDEN)*. 10-11 January. Itanagar, India: IEEE, 1-5.

77. Li, J. Y., Sun, C. X. and Sebo, S. A. (2011). Humidity and contamination severity impact on the leakage currents of porcelain insulators. *IET Generation, Transmission & Distribution*, 5(1), 19-28.

78. Dong, B., Jiang, X., Hu, J., Shu, L. and Sun, C. (2012). Effects of artificial polluting methods on AC flashover voltage of composite insulators. *IEEE Transactions on Dielectrics and Electrical Insulation*, 2(19), 714-722.

79. Ramirez-Vazquez, I. and Fierro-Chavez, J. L. (1999). Criteria for the diagnostic of polluted ceramic insulators based on the leakage current monitoring technique. *Proceedings of the 1999 Annual Report Conference on Electrical Insulation and Dielectric Phenomena.* 17-20 October. Austin, TX, USA: IEEE, 715-718.

80. Xia, Y., Jiang, X., Sun, C. and Dong, B. (2012). A method to estimate leakage current of polluted insulators. *Przegld Elektrotechniczny*, 88, 161-164.

81. Gouda, O. E. and Amer, G. M. (2004). Factors affecting the leakage current bursts of high voltage polluted insulators. *Proceedings of the 39th International Universities Power Engineering Conference (UPEC 2004)*. 6-8 September. Bristol, UK: IEEE, 114-117.

82. Sorqvist, T. and Vlastos, A. E. (1996). Hydrophobicity and leakage current statistics of polymeric insulators long-term exposed, to coastal contamination. *Conference Record of the 1996 IEEE International Symposium on Electrical Insulation.* 16-19 June. Montreal, Quebec, Canada: IEEE. 335-340.

83. Oliveira, S. C., Fontana, E. and de Melo, F. J. D. M. (2009). Leakage current activity on glass-type insulators of overhead transmission lines in the northeast region of Brazil. *IEEE Transactions on Power Delivery*, 24(2), 822-827.

84. Ramírez-Niño, J., Pacheco, M. J. O., Rodriguez, J. and Castaño, V. M. (1996). Design and construction of a pollution monitor for power line insulators. *Measurement Science and Technology*, 7(6), 876-881.

85. Jiang, X., Guo, Y., Meng, Z., Li, Z. and Jiang, Z. (2016). Additional salt deposit density of polluted insulators in salt fog. *IET Generation, Transmission & Distribution*, 10(15), 3691-3697.

86. Huang, X. B., Xie, C. and Li, H. (2017). Equivalent salt deposit density optical fiber sensor for transmission lines in power grid. *IEEE Sensors Journal*, 17(1), 91-99.

87. Naito, K., Mizuno, Y. and Naganawa, W. (1995). A study on probabilistic assessment of contamination flashover of high voltage insulator. *IEEE Transactions on Power Delivery*, 10(3), 1378-1384.

88. Habib, S. D. and Khalifa, M. (1986). A new monitor for pollution on power line insulators. Part 1: Design, construction and preliminary tests. *IEE Proceedings. Part C: Generation, Transmission and Distribution*, 133(2), 105-108. IET Digital Library.

89. Hampton, B. (1964). Flashover mechanism of polluted insulation. *Proceedings of the Institution of Electrical Engineers*, 111(5), 985-990. IET Digital Library.

90. Nasser, E. (1962). The Problem of Flashover Due to Contamination Layers on Insulator. *Eleklrotechnische Zeitschrift*, 83.

91. Rumeli, A. (1972). Discharge propagation over polluted insulation surfaces. *Proceeding of the 1st International Symposium on High Voltage Engineering.* Munich, German: IEEE, 498-500.

92. Fierro-Chavez, J. L., Ramirez-Vazquez, I. and Montoya-Tena, G. (1996). On-line leakage current monitoring of 400 kV insulator strings in polluted areas. *IEE Proceedings-Generation, Transmission and Distribution*, 143(6), 560-564.

93. Ahmad, A. S., Ghosh, P. S., Aljunid, S. A. K., Said, H. A. I. and Hussain, H. (2001). Artificial neural network for contamination severity assessment of high voltage insulators under various meteorological conditions. *Proceedings of the Australasian Universities Power Engineering Conference (AUPEC-2001*). 23-26 September. Perth, Australia.

94. Du, B. X. and Liu, Y. (2009). Frequency distribution of leakage current on silicone rubber insulator in salt-fog environments. *IEEE Transactions on Power Delivery*, 24(3), 1458-1464.

95. Li, J., Sun, C., Sima, W., Yang, Q. and Hu, J. (2010). Contamination level prediction of insulators based on the characteristics of leakage current. *IEEE Transactions on Power Delivery*, 25(1), 417-424.

96. Karamousantas, D. C., Chatzarakis, G. E., Oikonomou, D. S., Ekonomou, L. and Karampelas, P. (2010). Effective insulator maintenance scheduling using artificial neural networks. *IET Generation, Transmission & Distribution*, 4(4), 479-484.

97. Ramirez, I., Hernandez, R. and Montoya, G. (2012). Measurement of leakage current for monitoring the performance of outdoor insulators in polluted environments. *IEEE Electrical Insulation Magazine*, 28(4), 29-34.

98. Zhao, S., Jiang, X. and Xie, Y. (2015). Evaluating the contamination level of polluted insulators based on the characteristics of leakage current. *International Transactions on Electrical Energy Systems*, 25(10), 2109-2123.

99. Banik, A., Dalai, S. and Chatterjee, B. (2016). Autocorrelation aided rough set based contamination level prediction of high voltage insulator at different environmental condition. *IEEE Transactions on Dielectrics and Electrical Insulation*, 23(5), 2883-2891.

100. Jiang, Y., McMeekin, S. G., Reid, A. J., Nekahi, A., Judd, M. D. and Wilson, A. (2016). High voltage insulator contamination level online monitoring with conventional and novel methods. *Proceedings of the 2016 IEEE Electrical Insulation Conference (EIC). 19-22 Jun.* QC, Canada: IEEE*,* 206-209.

101. Jiang, Y., McMeekin, S. G., Reid, A. J., Nekahi, A., Judd, M. D. and Wilson, A. (2016). Monitoring contamination level on insulator materials under dry condition with a microwave reflectometer. *IEEE Transactions on Dielectrics and Electrical Insulation*, 23(3), 1427-1434.

102. Tousi, A. A. & Mirzaie, M. (2013). The effect of severity and location of pollution on leakage current characteristics of porcelain insulators under different humidity condition. *Journal of Electrical Engineering*, 13, 356-362.

103. Zhao, S., Jiang, X., Zhang, Z., Hu, J. and Shu, L. (2013). Flashover voltage prediction of composite insulators based on the characteristics of leakage current. *IEEE Transactions on Power Delivery*, 28(3), 1699-1708.

104. Dhahbi-Megriche, N., Arfaoui, W. and Beroual, A. (2013). Computer package for selecting high voltage insulators for different contamination conditions. *IEEE Transactions on Dielectrics and Electrical Insulation*, 20(4), 1428-1435.

105. Patel, K. and Parekh, B. R. (2013). Prediction of flashover of silicone rubber insulator under different contaminated surface conditions. *2013 IEEE 1st International Conference on Condition Assessment Techniques in Electrical Systems (CATCON)*. 6-8 December. Kolkata, India, 358-361.

106. Gonen, T. (2013). *Modern Power System Analysis*. (2nd ed.). Boca Raton, FL: CRC Press.

107. Bamigbola, O. M., Ali, M. M. and Oke, M. O. (2014). Mathematical modeling of electric power flow and the minimization of power losses on transmission lines. *Applied Mathematics and Computation*, 241, 214-221.

108. Onohaebi, O. S. and Kuale, P. A. (2007). Estimation of technical losses in the Nigerian 330KV Transmission Network. *International Journal of Electrical and Power Engineering (IJEPE)*, 1(4), 402-409.

109. Anumaka, M. C. (2012). Analysis of technical losses in electrical power system (Nigerian 330kV network as a case study). *International Journal of Recent Research and Applied Studies,* 12 (2), 320–327.

110. Ramesh, L., Chowdhury, S. P., Chowdhury, S., Natarajan, A. A. and Gaunt, C. T. (2009). Minimization of power loss in distribution networks by different techniques. *International Journal of Electrical Power and Energy Systems Engineering*, 2(1), 1-6.

111. Wang, C. and Nehrir, M. H. (2004). Analytical approaches for optimal placement of distributed generation sources in power systems. *IEEE Transactions on Power Systems*, 19(4), 2068-2076.

112. Celli, G., Ghiani, E., Mocci, S. and Pilo, F. (2005). A multiobjective evolutionary algorithm for the sizing and siting of distributed generation. *IEEE Transactions on Power Systems*, 20(2), 750-757.

113. Goudie, J. L. (2002). Silicones for outdoor insulator maintenance. *Conference Record of the 2002 IEEE International Symposium on Electrical Insulation.* 7-10 April. Boston, Massachusetts: IEEE, 256-259.

114. Montoya, G., Ramirez, I. and Hernandez, R. (2008). The leakage current as a diagnostic tool for outdoor insulation. *Proceedings of the 2008 IEEE/PES Transmission and Distribution Conference and Exposition: Latin America.* Sao Paolo, Brazil: IEEE, 1-4.

115. Gorur, R. S., Cherney, E., De Tourreil, C., Dumora, D., Harmon, R., Hervig, H., Kingsbury, B., Kise, J., Orbeck, T., Tanaka, K. and Tay, R. (1995). Protective coatings for improving contamination performance of outdoor high voltage ceramic insulators. *IEEE Transactions on Power Delivery*, 10(2), 924-933.

116. Yadee, P. and Premrudeepreechacharn, S. (2007). Analysis of tower footing resistance effected back flashover across insulator in a transmission system. *Proceedings of the International Conference on Power Systems Transients (IPST'07).* 4-7 June. Lyon, France: IEEE.

117. Tingtao, Z., Tianyu, L., Ke, C. and Xiaoguang, H. (2012). On-line monitoring system of insulator leakage current based on ARM. *Proceedings of the 2012 10th IEEE International Conference on Industrial Informatics (INDIN).* 25-27 July. Beijing, China: IEEE, 75-79.

118. Jiang, X., Shi, Y., Sun, C. and Zhang, Z. (2010). Evaluating the safety condition of porcelain insulators by the time and frequency characteristics of LC based on artificial pollution tests. *IEEE Transactions on Dielectrics and Electrical Insulation*, 2(17), 481-489.

119. Li, J. Y., Sun, C. X., Sima, W. X. and Yang, Q. (2009). Stage pre-warning based on leakage current characteristics before contamination flashover of porcelain and glass insulators. *IET Generation, Transmission & Distribution*, 3(7), 605-615.

120. Li, J., Sima, W., Sun, C. and Sebo, S.A. (2010). Use of leakage currents of insulators to determine the stage characteristics of the flashover process and contamination level prediction. *IEEE Transactions on Dielectrics and Electrical Insulation*, 2(17), 490-501.

121. Saadat, H. (1999). *Power System Analysis*. New York: McGraw-Hill.

122. Das, J. C. (2010). *Transients in Electrical Systems*. New York: McGraw-Hill Professional Publishing.

123. Smith, J. R. and Bell, W. W. (1984). Selection of transmission circuit models for power-system transient studies. *IEE Proceedings C (Generation, Transmission and Distribution)*, 131(1), 1-4. IET.

124. Salih, Q. A., Soomro, D. M. and Saeh, I. S. (2015). Optimal distributed generators location for power losses improvement using sensitivity based method. *2015 IEEE 3rd International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*. 24-25 November 2015. Kuala Lumpur, Malaysia, 1-4.

125. Deeb, N. and Shahidehpour, S. M. (1990). Linear reactive power optimization in a large power network using the decomposition approach. *IEEE Transactions on Power Systems*, 5(2), 428-438.

126. Warid, W. S. and Almusawi, E. A. M. (2010). A study of the optimal allocation of shunt capacitor based on modified loss sensitivity algorithm. *2010 1st International Conference on Energy, Power and Control (EPC-IQ)*. November 30-December 2. College of Engineering, University of Basrah, Iraq, 56-61.

127. Ghosh, P. S., Chakravorti, S. and Chatterjee, N. (1995). Estimation of time-to-flashover characteristics of contaminated electrolytic surfaces using a neural network. *IEEE Transactions on Dielectrics and Electrical Insulation*, 2(6), 1064-1074.

128. Kalyani, S. and Swarup, K. S. (2013). Static security assessment in power systems using multi-class SVM with parameter selection methods. *International Journal of Computer Theory and Engineering*, 5(3), 465.

129. Saeh, I. S. and Khairuddin, A. (2008). Static security assessment using artificial neural network. *Proceedings of the 2008 IEEE 2nd International Power and Energy Conference (PECon 2008).* 1-3 December. Johor Bahru, Malaysia: IEEE, 1172-1178.

130. Schulte, R. P., Larsen, S. L., Sheble, G. B., Wrubel, J. N. and Wollenberg, B. F., 1987. Artificial intelligence solutions to power system operating problems. *IEEE Transactions on Power Systems*, 2(4), 920-922.

131. Jahromi, A. N., El-Hag, A.H., Jayaram, S.H., Cherney, E.A., Sanaye-Pasand, M. and Mohseni, H., 2006. A neural network based method for leakage current prediction of polymeric insulators. *IEEE Transactions on Power Delivery*, 21(1), 506-507.

132. Azriyenni, A., Mustafa, M. W., Sukma, D. Y. and Dame, M. E. (2014). Backpropagation neural network modeling for fault location in transmission line 150 kV. *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, 2(1), 1-12.

133. Aggoune, M. E., Atlas, L. E., Cohn, D. A., Damborg, M. J., El-Sharkawi, M. A. and Marks, R. J. (1989). Artificial neural networks for power system static security assessment. *Proceedings of the 1989 IEEE International Symposium on Circuits and Systems.* 8-11 May. Portland, Oregon: IEEE, 490-494).

134. Negnevitsky, M. (2005). *Artificial Intelligence: A Guide to Intelligent Systems*. Australia: Addison-Wesley.

135. Stevenson, W. D. (1962). *Elements of Power System Analysis*. USA: McGraw-Hill.

136. Farzaneh, M. and Chisholm, W. A. (2009). *Insulators for Icing and Polluted Environments*. Canada: John Wiley & Sons.

137. Wei, X., Jia, Z., Sun, Z., Liao, W., Qin, Y., Guan, Z., Xu, Z. and Peng, X. (2012). Study of anti-icing performance of insulator strings bottom-coated with semiconductive silicone rubber coating. *IEEE Transactions on Dielectrics and Electrical Insulation*, 6(19), 2063-2072.

138. Hadid, A. H. (2005). Improvement of transient stability using braking element. Ph.D thesis, University of Mosul, pp. 85-87.

139. Alsac, O. and Stott, B. (1974). Optimal load flow with steady-state security. *IEEE Transactions on Power Apparatus and Systems*, (3), 745-751.

140. Oliveira, S. C. and Fontana, E. (2007). Optical system for flashover prediction in high voltage transmission lines. *Proceedings of the 2007 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC)*. 29 October - 1 November. Salvador, Brazil: IEEE, 224-228.

141. Witten, I. H., Frank, E., Hall, M. A., & Pal, C. J. (2016). *Data Mining: Practical Machine Learning Tools and Techniques*. Burlington, MA: Morgan Kaufmann.

142. Tuntas, R. and Dikici, B. (2016). An investigation on the aging responses and corrosion behaviour of A356/SiC composites by neural network: The effect of cold working ratio. *Journal of Composite Materials*, 50(17), 2323-2335.