Bulletin of Electrical Engineering and Informatics
Vol. 9, No. 5, October 2020, pp. 1747~1754
ISSN: 2302-9285, DOI: 10.11591/eei.v9i5.2182

Prediction of surface leakage current of overhead insulators under environmental and electrical stresses

F. S. Abdullah[1], M. A. M. Piah[2], N. A. Othman[3], A. Din[4]
[1]School of Electrical System Engineering, Universiti Malaysia Perlis, Malaysia
[2]Universiti Teknologi Malaysia and Institute of High Voltage and High Current, Malaysia
[3]Universiti Tun Hussein Onn Malaysia, Malaysia
[4]Universiti Teknikal Malaysia Melaka, Malaysia

Article Info

Article history:

Received Nov 3, 2019
Revised Feb 3, 2020
Accepted Mar 15, 2020

Keywords:

Dimensional analysis (DA)
Insulators
Leakage current (LC)
Mathematical modeling
contamination

ABSTRACT

Leakage current is one of the critical aspects to consider for overhead transmission line insulator's condition and performance assessment. As the leakage current increase, the size of the dry band also will increase leads to the dry band arcing, deteriorate the insulator performance and contribute to the development of insulator flashover. Based on the literature study, other than the existence of contaminations on the surface of insulator combined with moisture, the variation in leakage current is also affected by the environmental and electrical stresses. Previous researches have shown the effect of environmental and electrical stresses on surface leakage current based on experimental and simulation results. This paper outlines an analytical approach based on dimensional analysis to propose a new mathematical model of leakage current under environmental and electrical stresses. To justify the applicability of the derived dimensional model, the new model has been validated using previous researcher's experimental results. The validation indicated that the proposed model had shown a good agreement with the previous experimental results. The proposed dimensional equation for this research work can be potentially used as a predictive performance model to evaluate and monitor the leakage current and insulator's performance.

Corresponding Author:

M. A. M. Piah,
School of Electrical Engineering,
Faculty of Engineering,
Universiti Teknologi Malaysia,
UTM Johor Bahru, 81310, Johor, Malaysia.
Email: fendi@utm.my

1. INTRODUCTION

Transmission line insulator, also known as overhead insulator is greatly affected by the environmental stresses produced by the weather and surroundings. Insulator is usually exposed to uncertain weather and environmental pollution [1] such as inert material, soluble salt, water, electronic conductive dust, chemicals, industrial contaminants, and agricultural pollutants [2, 3]. Due to this variety of pollutions, insulator's external surface becomes contaminated and tends to accumulate the contamination, allowing the leakage current (LC) to flow. The contamination deposited on the insulator surface combined with the presence of moisture dissolves the salt deposited and encourages the formation of the conductive layer that acts as a highly variable and nonlinear resistor to be formed for LC to flow [3, 4]. With high LC flowing between the high voltage and grounded side of insulator, flashover occurrence that will lead to power outage from the system is more likely to happen [5-7]. Flashover phenomenon reduces the power system reliability and efficiency, contributes to economic losses, and permanent insulator impairment [8, 9]. Due to these reasons, LC monitoring is one of convincing way to examine the insulator performance especially under contaminated conditions [2, 10, 11]. LC monitoring describes the insulator's surface condition and is capable to act as an accurate indication tool for flashover warning and hence prolonging the insulator's lifetime [12, 13].

In recent years, researchers have investigated the effect of environmental and electrical factors on LC. However, most of the research results come from experiments and simulations. Testing on high voltage prototype sometimes causes costly mistakes, requires a relatively long considerable time, and there are cases when the analytic expression of the variables is not available or inaccurately known [14, 15]. Some research efforts were also directed towards establishing a mathematical correlation and modeling, which is adapted from empirical approach [16-20]. However, the models developed only effective as the LC prediction and unable to represent the actual physical equation that explains the characteristics of the LC. This paper presents the mathematical relationship to describe the LC, considering the environmental and electrical factors using the analytical approach of dimensional analysis (DA). DA is an analytical technique which applies the concept of similarity to explain the relationship among the physical quantities [14, 15, 21]. By using DA approach, the physical phenomenon is represented by dimensionally correct equation among certain variables [22, 23].

2. DEVELOPMENT OF DIMENSIONAL MODEL

From the literature studies, it can be concluded that the LC characteristics have a strong relation with many physical variables from the environmental and electrical stresses. The LC that flows on insulator's surface depends on the dominant variables such as equivalent salt deposits density (ESDD), humidity, electrolyte conductivity, environmental temperature, applied voltage, environmental pressure, ultraviolet radiation, and insulator's creepage distance. A mathematical relationship to describe the LC is established between these variables using DA. The base dimension of the target variables is shown in Table 1. Among the target variables, I_L is considered as a dependent variable and E_{SD}, h, σ_E, T_a, V_S, p_e, S_{uv} and L_C as independent variables. The unit system used in developing the LC mathematical model is SI unit standard system and the base dimensions are mass (*M*), length (*L*), time (*T*), charge (*Q*) and temperature (*θ*).

Table 1. Base dimension of the target variables

Variables	Symbol	Base dimension
Leakage current (LC)	I_L	QT^{-1}
Equivalent salt deposits density (ESDD)	E_{SD}	ML^{-2}
Humidity	h	ML^{-3}
Electrolyte conductivity	σ_E	$M^{-1}L^{-3}TQ^2$
Environmental temperature	T_a	θ
Applied voltage	V_S	$ML^2T^{-2}Q$
Environmental pressure	p_e	$ML^{-1}T^{-2}$
Ultraviolet radiation	S_{uv}	MT^{-3}
Insulator creepage distance	L_C	$M^{-1}L^{-1}T^2Q$

From the target variables, the relationship between the independent and dependent variables are established as follows, where f is an unknown function.

$$I_L = f(E_{SD}, h, \sigma_E, T_a, V_S, p_e, S_{uv}, L_C) \quad (1)$$

From the list of the target variables, the number of variables, $N_V = 9$ and the number of dimensions, $N_d = 5$. DA adopts the Pi Buckingham's theorem in its analysis. Buckingham method starts by examining the number of variables involved and the number of dimensions [15]. The final result is a relation between N_V and N_d which provides the number of dimensionless variables (no of Π's). Therefore, by applying Pi Buckingham's Theorem, the no of independent set of product (Π's) is Π's= $N_V - N_d = 9 - 5 = 4$. The dimensionless product can be written in a form as in (2).

$$\Pi = E_{SD}{}^{\varepsilon_1}.h^{\varepsilon_2}.\sigma_E{}^{\varepsilon_3}.T_a{}^{\varepsilon_4}.V_S{}^{\varepsilon_5}.p_e{}^{\varepsilon_6}.S_{uv}{}^{\varepsilon_7}.L_C{}^{\epsilon_8} \quad (2)$$

where $\varepsilon_1 \dots \dots \varepsilon_8$ are the exponent of the corresponding target variables. The dimensional matrix of the variables correspond to their base dimensions with $MLTQ\theta$ combination is arranged as follow;

	I_L	E_{SD}	h	σ_E	V_S	T_a	p_e	S_{uv}	L_C
M	0	1	1	-1	1	0	1	1	-1
L	0	-2	-3	-3	2	0	-1	0	-1
T	-1	0	0	1	-2	0	-2	-3	2
Q	1	0	0	2	1	0	0	0	1
θ	0	0	0	0	0	1	0	0	0

The rank of the dimensional matrix is established as 5. To compute the independent set of product, the dimensional matrix is partitioned into two submatrices, Matrix *A* and Matrix *B*. Matrix *A* must be a square matrix and not singular. If Matrix *A* is singular, there is no possibility to produce the independent set of products (Π's). The number of independent set of product (Π's) is generated by using the formula (3)-(4) [15].

$$P = E.Z \tag{3}$$

$$Z = \begin{bmatrix} \epsilon \\ q \end{bmatrix} \quad \text{and} \quad E = \begin{bmatrix} I & 0 \\ -A^{-1}B & A^{-1} \end{bmatrix} \tag{4}$$

where: P : Independent set of product
B : Matrix *B*
A : Matrix *A*
q : Exponent of dimension
I : Identity matrix
ϵ : Exponent of variable
0 : Null matrix

Matrix *P* established in (5) described the target variable and product of variables [15].

$$P = E.Z = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ -1/5 & -1/5 & 0 & 1/5 \\ 2/5 & -13/5 & -3 & -2/5 \\ -1 & 2 & 2 & -1 \\ -4/5 & 1/5 & 0 & -11/5 \end{bmatrix} \tag{5}$$

The last step of the DA modeling is to produce the set of dimensionless target variables. The complete set of dimensionless products is now rewritten as in (6)-(9).

$$\pi_1 = \frac{I_L.p_e^{\frac{2}{5}}}{V_S^{\frac{1}{5}}.S_{uv}.L_C^{\frac{4}{5}}} \tag{6}$$

$$\pi_2 = \frac{(E_{SD}).S_{uv}{}^2.L_C^{\frac{1}{5}}}{V_S^{\frac{1}{5}}.p_e{}^{\frac{13}{5}}} \tag{7}$$

$$\pi_3 = \frac{h.S_{uv}{}^2}{p_e{}^3} \tag{8}$$

$$\pi_4 = \frac{\sigma_E.V_S^{\frac{1}{5}}}{p_e^{\frac{2}{5}}.S_{uv}.L_C^{\frac{11}{5}}} \tag{9}$$

By referring to the Buckingham's Theorem, the established dimensionless product is given as in (10).

$$\Pi_1 = f(\Pi_2, \Pi_3, \Pi_3, \Pi_4) \tag{10}$$

To show the relationship between the LC and other independent variables, monomial power form [24] is applied as shown in (11). Factors α^1, α^2 and α^3 is assigned by considering the relationship between the dominant variables and leakage current. It is found that the leakage current is directly proportional to ESDD, relative humidity, and applied voltage.

$$\pi_1 = f(\pi_2^{\alpha 1}.\pi_3^{\alpha 2}.\pi_4^{\alpha 3}) \text{ where } \alpha_1 = 1, \alpha_2 = 1 \text{ and } \alpha_3 = 1 \quad (11)$$

In (11) is rearranged to show the relationship of LC to the other dominant variables.

$$I_L = \left(\frac{V_S.S_{uv}^5.L_C^4}{p_e^2}\right)^{\frac{1}{5}}.f(\pi_2^{\alpha 1}.\pi_3^{\alpha 2}.\pi_4^{\alpha 3}) \quad (12)$$

Finally, the resulting model of LC characteristics can be expressed as a function of environmental physical variables in (13) where D_C is the dimensional constant and can be defined from the experiment. The dimensional constant established in this research will vary depends on experimental conditions.

$$I_L = D_C(E_{SD}.h.\sigma_E.S_{uv}^4)\left(\frac{V_S}{p_e^{32}.L_C^6}\right)^{\frac{1}{5}} \quad (13)$$

From (13), it can be proved that the derived dimensional equation obey the dimensional homogeneity principle. The principle of dimensional homogeneity helps in describing the consistency and completeness of an equation in physical algebra [21]. Therefore, (13) is projected to be used as a predictive model in estimating the LC in this research.

3. VALIDATION OF THE PROPOSED DIMENSIONAL MODEL

For validation purposes, the proposed leakage current dimensional model is verified with other researcher's experimental results. The value of the dimensional constant or test parameter is recommended to fit the proposed model with other researcher's experimental results by using Mathcad Software. This section discusses the verification of the model at different ESDD, electrolyte conductivity, relative humidity, applied voltage and insulator's creepage distance.

3.1. Validation of the model at different electrolyte conductivity

Validation of the proposed model at different electrolyte conductivity is achieved by comparing it to the experimental results, Suwarno et al. [25] on polymeric insulator subjected to inclined plane test under various levels of kaolin-salt pollutions. All the dominants variables $(E_{SD}, h, V_S, p_e, S_{uv}, L_C)$ in (13) are assumed to be constant except the levels of electrolyte conductivity. By assuming all the mentioned variables are constant, the proposed model can be simplified as follows;

$$I_L(\sigma) = D_1.\sigma + I_o \quad (14)$$

where D_1 is the recommended dimensional constant to fit in the model with experimental results. In (14) is altered by adding I_o to adapt the experimental result. Based on the simplified model, it is found that the LC flows on insulator surface is significantly increase with electrolyte conductivity. Figure 1 shows the comparison of the LC from the model developed and the doted data from the experimental result [25]. It can be observed that the proposed model fitting is very close to the experimental results. Table 2 shows the proposed LC equation in relation to the electrolyte conductivity with its data error and standard deviation.

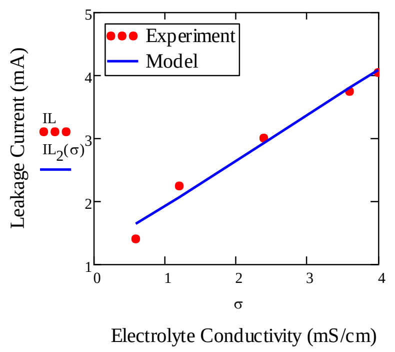

Figure 1. Comparison of LC of experimental and proposed model at different electrolyte conductivity [25]

Table 2. Empirical equation of LC in relation with electrolyte conductivity

Empirical equation	$I_L = 0.72\sigma_E + 1.2$
Error	0.0592
Standard deviation (Model)	1.0824
Standard deviation (Exp)	1.0601

From Table 2, it shows that the model has a quite low deviation of 5.92% with reference to experimental surface LC. By varying D_1, the curve can be adjusted to suit the experimental data. This provides an approximation to form the equation between LC and ESDD as in Table 2.

3.2. Validation of the model at different ESDD and applied voltage

The proposed model is verified with the experimental data, Banik et al. [26], at different ESDD and applied voltage. Experiment was performed on porcelain insulator to measure surface LC with different pollutions conductivity and increasing of applied voltage in steps of 5 kV to maximum 40 kV under control environmental [26]. The independent physical variables except for ESDD and applied voltage are assumed to be constant. Hence, (13) can be formulated in a function of ESDD and applied voltage.

$$I_L(E_{SD}, V_S) = D_2.E_{SD}.V_S^{\frac{1}{5}} + I_o \quad (15)$$

By referring Figure 2, it can be observed that the model is in complete agreement with the previous experimental results [26].

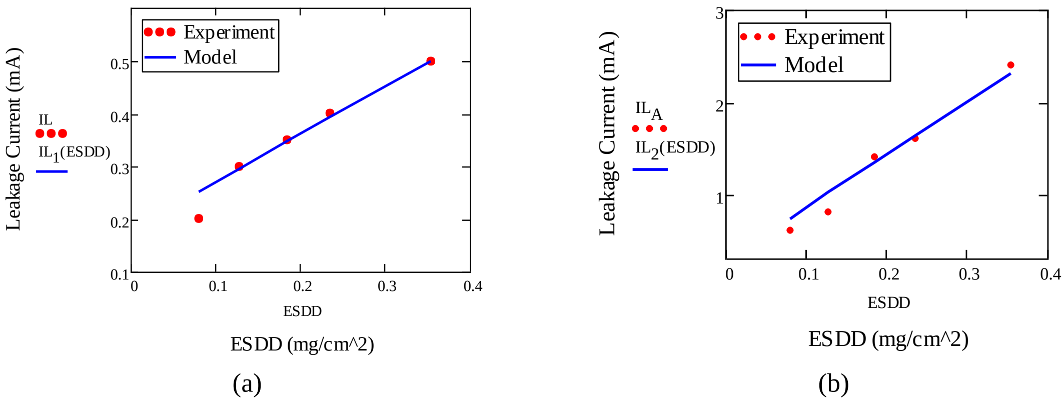

Figure 2. Comparison between model and experimental result of LC at different ESDD and applied voltage [26], (a) 10 kV, (b) 20 kV

The model able to compute the LC for different ESDD and applied voltage with deviation of 6.04% and 11.86% for 10 kV and 20 kV of applied voltage respectively (refer Table 3). The LC is in linear relationship with ESDD and applied voltage. Increasing the applied voltage will increase the electric field distribution and affect the LC variation [27, 28]. The dimensional constant of D_2 also shows an increment in its value with increasing of the applied voltage.

Table 3. Empirical equation of LC in relation with ESDD and applied voltage

Empirical equation	$I_L = 0.57E_{SD}.V_S^{\frac{1}{5}} + 0.18$ (Applied voltage 10 kV)	$I_L = 3.15(E_{SD}).V_S^{\frac{1}{5}} + 0.28$ (Applied voltage 20 kV)
Error	0.0604	0.1186
Standard deviation (Model)	0.0956	0.6066
Standard deviation (Exp)	0.1118	0.7127

3.3. Validation of the model at different relative humidity and ESDD

In (13) is written in a function of relative humidity and ESDD as shown below. From (16), it is found that LC is in linear proportion with relative humidity and ESDD. LC increases with the increasing of contamination severity and relative humidity. Increasing of contamination severity combine with high relative humidity add up the moisture content, reduce the insulator surface resistance and lead to a high LC flows on insulator surface [29].

$$I_L(h,\ E_{SD}) = D_3.E_{SD}.h + I_o \quad (16)$$

The proposed model is verified with experimental results, Tousi et al. [2]. Figure 3 shows the verification of the proposed model using the data from the experiment [2]. It can be observed that the deviation of the model is quite low (see Table 4) which are 4.51% and 4.01% compared to the experimental result. This identify that the model is capable to predict the LC at different relative humidity and ESDD.

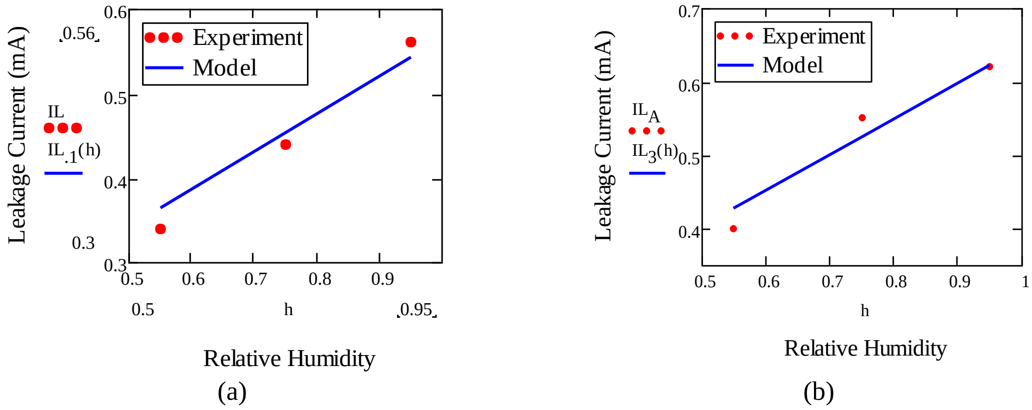

Figure 3. Verification of proposed model at different relative humidity and ESDD using the results from experimental [2], (a) ESDD 0.26 mg/cm^2, (b) ESDD 0.358 mg/cm^2

Table 4. Empirical equation of LC in relation with relative humidity and ESDD

Empirical equation	$I_L = 1.71E_{SD}.h + 0.12$ ESDD 0.26 mg/cm^2	$I_L = 1.36E_{SD}.h + 0.16$ ESDD 0.358 mg/cm^2
Error	0.0451	0.0401
Standard deviation (Model)	0.0889	0.0974
Standard deviation (Exp)	0.1102	0.1124

3.4. Validation of the model at different insulator's creepage distance

To validate the LC model at different insulator's creepage distance, (13) is simplified in a function of specific creepage distance as shown in (17) by assuming all independent variables except creepage distance as constant.

$$I_L(L_C) = D_4.L_C^{-\frac{6}{5}} + I_o \tag{17}$$

The model is compared to previous research data, Parihar et al. [30], which presents the leakage current on composite long rod insulator with different specific creepage distance and contamination severity. Figure 4 shows the LC in dependency on the specific creepage distance of the proposed model and the previous research data [30]. From the graph, it can be observed that the LC is inversely proportion to the specific creepage distance. With a higher value of specific creepage distance, conducting layer could be prevented thus decreases the LC flows on insulator surface. From Table 5, it may simply have verified that the model has a very close agreement with the previous experimental results [30] with a deviation of 0.23%.

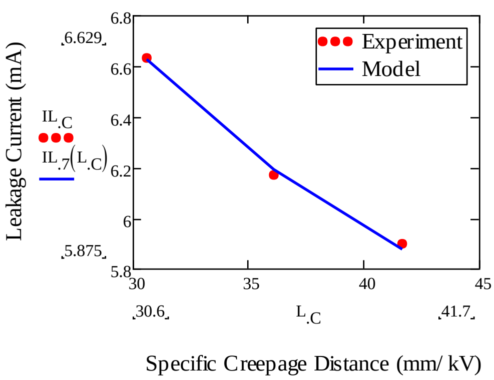

Figure 4. Comparison of model and previous research result at different insulator's creepage distance [30]

Table 5. Empirical equation of LC in relation with insulator's creepage distance

Empirical equation	$I_L = 147.3L_C^{-\frac{6}{5}} + 4.2$
Error	0.0023
Standard deviation (Model)	0.3783
Standard deviation (Exp)	0.3702

4. CONCLUSION

The present article describes an analytical approach on modeling the LC of insulator under environmental and electrical stresses based on DA technique. The proposed dimensional model derived in this article complies with homogeneity condition and expressible by a dimensionally homogeneous equation in terms of specified parameters. The proposed method also able to present the dominant parameters associated to the LC behavior and recommends the appropriate correlation of the test parameter value to be used when executing the test. Throughout this paper, it has been observed that the dimensional model has a good agreement with the experimental results. This clearly shows that the model able to estimate the surface leakage current on insulators under the influence of environmental and electrical stresses and contribute to an indication mechanism of flashover warning. Furthermore, the proposed work also might help in reducing the cost of testing and labor work for the study of the insulator subjected to environmental and electrical factors.

ACKNOWLEDGEMENTS

This research was supported by Research University Grant (UTM-TDR 46, Vot.Q.J130000.3551.07G60 and UTM-TDR 46.3, Vot.Q.J130000.3551.06G14) provided by Universiti Teknologi Malaysia. The first authors would like to gratefully acknowledge the financial assistance supported in part by Ministry of Higher Education (MOHE) Malaysia and in part by the Universiti Malaysia Perlis.

REFERENCES

[1] Darwison, S. Arief, H. Abral, A. Hazmi, M. H. Ahmad, E. K. Waldi, and R. Fernandez, "A leakage current estimation based on thermal image of polymer insulator," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 16, no. 3, pp. 1096-1106, 2019.

[2] A. Azizi Tousi and M. Mirzaie, "The effect of severity and location of pollution on leakage current characteristics of porcelain insulators under different humidity condition," *J. Electr. Eng.*, vol. 13, no. 4, pp. 356-362, 2013.

[3] J. S. T. Looms, "IET power and energy series 7-insulators for high voltage," The Institution of Engineering and Technology, United Kingdom, 2006.

[4] N. R. M. Putra, N. Sartika, Rachmawati, and Suwarno, "The Study on leakage current waveform characteristics and computer simulation of ceramic insulator under artificial tropical condition," *12th Int. Conf. on the Properties and Applications of Dielectric Materials*, pp. 320-323, 2018.

[5] M. M. Hussain, S. Farokhi, S. G. McMeekin, and M. Farzaneh, "Effect of cold fog on leakage current characteristics of polluted insulators," *Int. Conf. Cond. Assess. Tech. Electr. Syst., CATCON 2015*, pp. 163-167, 2016.

[6] F. K. Abo-Elyousr and L. S. Nassrat, "Evaluation of flashover voltage levels of contaminated hydrophobic polymer insulators using regression trees, neural networks, and adaptive neuro-fuzzy," *TELKOMNIKA Telecommunication Computing Electronics and Control.*, vol. 16, no. 2, pp. 495-512, 2018.

[7] M. R. B. M. Shariff, M. F. L. Abdullah, M. Y. B. A. Latiff, A. B. Mohamad, and I. B. Ismail, "Detecting leakage current by infrared thermography method," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 16, no. 1, pp. 1-16, 2019.

[8] M. M. Daha, M. E. Ibrahim, and M. A. Izzularab, "Effect of washing water flow rate and pollution level on leakage current of a fixed washed high voltage insulator," *2016 18th Int. Middle-East Power Syst. Conf.*, pp. 234-239, 2016.

[9] H. Rosli, N. A. Othman, N. A. M. Jamail, and M. N. Ismail, "Potential and electric field characteristics of broken porcelain insulator," *International Journal of Electrical and Computer Enginering*, vol. 7, no. 6, pp. 3114-3123, 2017.

[10] S. Deb, R. Ghosh, S. Dutta, S. Dalai and B. Chatterjee, "Condition monitoring of 11kV porcelain pin insulator extracting surface current from total leakage current," *3rd Int. Conf. Condition Assesment. Tech. Electr. Stystems*, pp. 403-406, 2017.

[11] R. Ghosh, B. Chatterjee, and S. Chakravorti, "A novel leakage current index for the field monitoring of overhead insulators under harmonic voltage," *IEEE Trans. Ind. Electron.*, vol. 65, no. 2, pp. 1568-1576, 2017.

[12] D. Fauziah, H. Alfiadi, Rachmawati, and Suwarno, "The effect of coating on leakage current characteristic of coast field aged ceramic insulator," *4th Int. Conf. Electr. Eng. Comput. Sci. Informatics*, vol. 4, pp. 371-376, 2017.

[13] I. Ahmadi-Joneidi, A. A. Shayegani-Akmal, and H. Mohseni, "Leakage current analysis of polymeric insulators under uniform and non-uniform pollution conditions," *IET Generation Transmission and Distribution*, vol. 11, no. 11, pp. 2947-2957, 2017.

[14] S. Sudalai Shunmugam, N. Vasudev, K. N. Ravi, and K. A. Venkatesh, "Applicability of dimensional analysis for the prediction of pollution performance of insulators: an experimental study," *IET Gener. Transm. Distrib.*, vol. 11, no. 5, pp. 1319-1324, 2016.

[15] T. Szirtes, "Applied dimensional analysis and modeling-2nd edition," Butterworth-Heinemann, United Kingdom, 2007.

[16] A. Ananth and M. Ravindran, "Investigation of leakage current of insulator using artificial neural network," *Int. J. Eng. Sci. Res. Technol.*, vol. 5, no. 8, pp. 667-672, 2016.

[17] M. A. Pinotti and L. H. Meyer, "Mathematical model for prediction of the leakage current on distribution insulators of 25 kV class," *2017 IEEE Electr. Insul. Conf.*, pp. 256-260, 2017.

[18] H. Ali, "Leakage current prediction for high voltage insulators flashover based on extreme value theory," *2016 Int. Symp. Comput. Consum. Control*, pp. 870-873, 2016.

[19] R. Ghosh, B. Chatterjee, D. Dey, and S. Chakravorti, "A low-complexity parametric modeling technique for insulator leakage current based on synchronous detection," 2015, *Int. Conf. on Ener. Econ. and Env.*, pp. 1-4, 2015.
[20] L. Zhao, J. Jiang, S. Duan, C. Fang, J. Wang, K. wang, P. Cao, and J. Zhou, "The prediction of post insulators leakage current from environmental data," *2011 Int. Conf. Electr. Control Eng.*, vol. 2, pp. 5103-5106, 2011.
[21] B. S. Massey, "Units, dimensional analysis and physical similarity-1st edition," Butler & Tanner Ltd, London, 1971.
[22] H. L. Langhaar, "Dimensional analysis and theory of models," John Wiley & Sons, United States of America, 1957.
[23] S. S. Shunmugam, N. Vasudev, K. N. Ravi, and K. A. Venkatesh, "Pollution performance of HVAC insulators: An interpretation using dimensional analysis technique," *19th Int. Symp. High Volt. Eng., Czech Republic*, pp. 3-6, 2015.
[24] M. A. M. Piah, P. A. Ping, and Z. Buntat, "Development of mathematical equation for determining breakdown voltage of electrodes gap," *PECon 2008-2008 IEEE 2nd Int. Power Energy Conf.*, pp. 1509-1514, 2008.
[25] Suwarno and S. K. Ardianto, "Study on leakage current characteristics of epoxy resin for outdoor insulators," *Proc. 6th WSEAS Int. Conf. Power Syst. Port.*, pp. 201-206, 2006.
[26] A. Banik, S. Dalai, and B. Chatterjee, "Condition monitoring of overhead line insulator by measuring surface leakage current," *11th IEEE India Conf. Emerg. Trends Innov. Technol. INDICON 2014*, pp. 1-5, 2014.
[27] L. Shu, Z. Wu, Y. He, W. Yuan, and Q. Hu, "The influence of DC electrical field on composite insulators icing and leakage current characteristics," *Annu. Rep. Conf. Electr. Insul. Dielectr. Phenom.*, pp. 16-19, 2013.
[28] A. M. Diffni Gomez, A. B. Rafiq Mathersa, and N. Vasudev, "Experimental and simulation studies on room temperature vulcanization (RTV) coatings by inclined plane tracking and erosion test method," *3rd Int. Conf. Cond. Assess. Tech. Electr. Syst., CATCON 2017*, pp. 302-305, 2017.
[29] Rachmawati, D. Fauziah, H. Alfiadi, and Suwarno, "Leakage current characteristics study on electrical equivalent circuit of field-aged RTV silicone rubber coated and noncoated insulators in a coastal area," *Int. Conf. High Volt. Eng. Power Syst. ICHVEPS 2017*, pp. 455-459, 2017.
[30] V. S. Parihar and A. K. Kori, "Effects of creepage distance on leakage current of 220kv long rod insulators at different severity," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 4, no. X, pp. 219-225, 2016.

BIOGRAPHIES OF AUTHORS

Farrah Salwani Binti Abdullah (F. S. Abdullah) was born in Terengganu, Malaysia on December 21, 1986. She received B. Eng (Hons) and M. Eng in Electrical Engineering from Universiti Tun Hussein Onn Malaysia (UTHM). She is a member of Board Engineer Malaysia and Institute Engineer Malaysia. She is currently pursuing her PhD at the Institute of High Voltage and High Current (IVAT), School of Electrical Engineering, Universiti Teknologi Malaysia (UTM). Her main research interest includes high-voltage engineering and outdoor insulator condition monitoring.

Dr. Mohamed Afendi Mohamed Piah (M. A. M. Piah) is an associate professor at Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM) and a fellow member of the Institute of High Voltage and High Current (IVAT). He is also a Signatory of High Voltage Testing accreditation lab of ISO/IEC 17025. He received the B.Elect. Eng. degree from UTM in 1986, M.Sc in Power System from University of Strathclyde, UK in 1990 and PhD in High Voltage Engineering from UTM in 2004. He was appointed as an assistant director (Test and Calibration Division) of IVAT from 1996-2000 and Deputy Director of IVAT from 2007-2009. He has been involved in testing and calibration of high voltage equipments. His research interests include high voltage insulation diagnostic and co-ordination, electrical discharges, polymer nanocomposites insulating materials and insulator condition monitoring.

Nordiana Azlin Othman (N. A. Othman) was born in Johor, Malaysia on January 19, 1986. She is currently a Lecturer at the Department of Electrical Power Engineering, Universiti Tun Hussein Onn Malaysia. She received B. Eng. in Electrical Engineering from Universiti Teknologi Malaysia (UTM) in 2010 and PhD in High Voltage Engineering from UTM in 2016. Her research interest includes the detection and diagnostics of partial discharge and space charge in insulation for condition monitoring.

Asri Din (A. Din) was born in Melaka, Malaysia on June 11, 1977. He has received the B. Eng in Electrical and Electronics from Universiti Teknologi Malaysia (UTM) in 2000 and M. Eng in Electrical Energy and Power System from Universiti Malaya, Malaysia in 2008. He is a senior lecturer of Universiti Teknikal Malaysia Melaka and has been working there since December 2002. Prior to this, he used to work as a Product Engineer at Ceemax Technology in Melaka from 2000-2002. Currently he is undergoing his PhD study on the outdoor polymer insulator degradation performance monitoring at the Institute of High Voltage and High Current (IVAT) under School of Electrical Engineering, UTM.