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Influence of Electric Field Distribution on 33kv Non-Ceramic Insulator with Different Shed Configurations using 3D Finite Element Method

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Abstract: ***In last decade, influence of electric field (E-field) distribution is plays a major concern in estimating the service life of Non-cermaic insulators. One of the foremost troubles met by the utilities is the breakdown of insulator owing toward high electrical stress on end fittings. The present work is intended to focus on the impact of different shed configurations on 33kV Non-Ceramic insulators by 3-Dimensional (3D) Finite Element Method (FEM). Totally seven different shed configurations of 3D simulation studies is performed on 33kV non-ceramic insulators. Optimum result is obtained by alternate shed configured insulator and the first shed near to the metal end fittings. It is whispered that obtained results will be helpful to the utility and design engineers.***

Keywords: ***Non-ceramic insulators, 3D-Finite element method, Shed configurations and E-field computation***

I. INTRODUCTION

Non-Ceramic insulator has been progressively used in power transmission around the world [1]. Owing to their excellent dielectric properties, composite insulators become an alternative for porcelain and glass insulators. Apart from that, composites have enhanced thermal, mechanical, and chemical characteristics than conventional dielectrics. Once composite insulators have been used in high voltage (HV) systems, additional advantages such as the decrease of weight and long term performance under ageing conditions [2, 3].

Stability is the most important property of both ceramic and non-ceramic insulator. The consistency of an insulators are mainly depends upon its breakdown strengths. Due to the advancement of modern technology in manufacturing, mechanical moulding and fixture technique, the mechanical strength of the material is quite reliable. However the electrical strength of insulator over the decades is not fully assured [4-6].

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The potential distribution along the end fittings are a large amount high stress when compared to the center portion of an insulators. This is mainly due to the lower value of self-capacitance: calculation of the voltage distribution along a 34.5 kV composite insulator stated that 70% of the input supply was intense on 22% of the insulation distance gap [7, 8]. Survey result indicates that electric field distribution along the whole insulator sheds appears to be a “U” style distribution [9, 10].Many researchers proposed various stress controlled techniques to make the forms of E-field and potential distributions as uniform. In [12], the influence of inorganic fillers in composite insulators would enhance the electrical characteristics of the materials, were discussed. In [7], a technique called stacked type of sheds was used to share the heavy E-field from HV to LV end. In [13], it shows that insulator with straight type of sheds have higher E-field distribution than alternate type shed in salt fog ageing test.

In [11], optimal fitting of an arcing horn at the end fittings in the composite insulator with silicone rubber overlapping the edges of metal end fittings made a significant reduction in E-field stress on 33kV non-ceramic insulators.

Preceding studies were mainly concentrated on initiating outside services, such as corona rings, grading rings, grading materials and silicon rubber jacket to balance the uneven E-field and potential distribution on composite insulators. Such techniques need an additional accomplishment of supplementary apparatus, and may cause compatibility problems. It is a new direction to solve the electrical stress problems of composite insulators by changing their shed configuration.

Various researches perform their computation of E-field and potential distribution using numerical techniques such as, BEM, Finite Difference Time Domain Method, random walk method and FEM. Apart from the above numerical techniques, FEM is most convenient for complex field computations with many dielectrics, heterogeneous, highly curved, thin electrode surfaces and nonlinear materials. With the progression of calculating influence nowadays, mathematical methods, particularly FEM, have become promising tools for computation of field and design of electrical apparatus [14-16].

In this paper, a new attempt has been made to enrich the electrical performance of the composite insulators. The proposed concentrates on reducing the E-field distribution by designing seven different configurations based on the geometry modification near the end fittings, water shed and under-rib conditions.

The computation of E-field and potential distribution is made in 3D FEM analysis because 2D model of E-field and potential distribution and electric stress dispensation results are deviated from the original results due to lack of conducting material properties representation as well as the occurrence of non-symmetric parts on the insulators. So, it is necessary to analyse the insulator in 3D FEM analysis for better performance.

The paper is organized as follows: Section 2 shows the composite insulator modelling. Section 3 demonstrates the computation method. Section 4 presents the results and discussions which includes the determination of external insulation parameter validation. Section 5 concludes the paper.

II. COMPOSITE INSULATOR MODELLING

Based on industrialized modus operandi, electrical equipments design and excellence of materials composite industries are categorized. Thus, composites materials are majorly working in HV transmission and distribution systems. A 33kV Non-ceramic insulator is used in this study for better operation under environmental factors. The structure of composite insulator is composed of three components. They are Housing material (Insulation), Core (mechanical strength) and Metal end fittings. silicone rubber (SIR) were mostly commonly used for composite insulator in outdoor application HV network, because of higher resistance to Ultra Violet (UV) radiation and heat generated by dry band arcing than EPDM. In this work for investigating purpose the metal end fittings are made of forged steel with the length of 690 mm and a thickness of 20 mm. Fig. 1. shows the structure of a composite insulator. The seven different designs which have been considered for this study are illustrated in Fig. 2. Table I. shows the main dimensions of the 33kV Silicone rubber insulators.

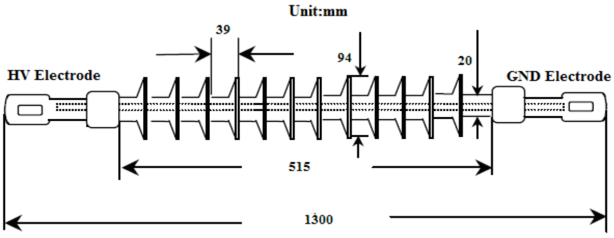
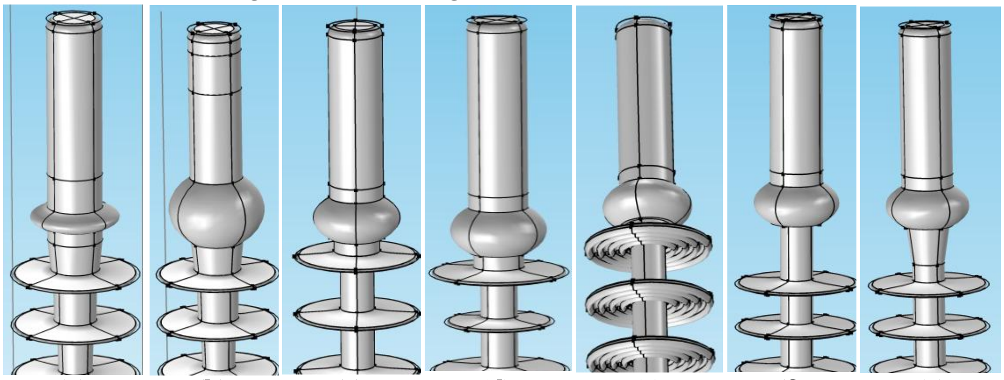


Fig. 1. Structure of 33kV Composite Insulator

The first insulator (C1) is the original 33kV composite insulator as shown in Fig. 2.a. The second insulator (C2) is characterized by silicone rubber overlapping the edge of metal end fittings as shown in Fig. 2.b. The third insulator (C3) is considered as first watershed placed near to the metal end fittings in Fig. 2.c. The fourth design (C4) is similar to the third one in terms of shed near the end fittings, but having alternate sheds as shown in Fig. 2.d. The fifth insulator (C5) is is similar to the third one in terms of shed near the end fittings, but under-rib in shed design as shown in Fig. 2.e. The sixth design (C6) is similar to the third one in terms of shed near the end fittings, but without the First shed next to the energized side as shown in Fig. 2.f.



(a) (b) (c) (d) (e) (f) (g)

Fig. 2. Different Designs of Composite Insulators

The seventh insulator (C7) is similar to the third one in terms of shed near the end fittings, but modification of shed next to the energized end as shown in Fig. 2.g.

TABLE I. Dimensions Of Composite Insulators

Design Parameters	Values (mm)
Shed Diameter	94
Water Shed Spacing	39
Creepage Distance	1300
Arc over Distance	515
Core Length (FRP)	690
Core Thickness	20

A supply of 33kV is used at the HV electrode whereas, the LV electrode is grounded. Dirchlet's boundary condition is used in this simulation model. In general, the property of the material is mainly determined by relative permittivity ε_r and conductivity σ . The material property of each device is scheduled in Table II.

TABLE II. Material properties for each domain

Material	Relative Permittivity	Conductivity (s/m)
Air background	1	$1.0\text{x}10^{-13}$
Forged steel	1	$5.9\text{x}10^{7}$
Silicone rubber	4.3	$1.0\text{x}10^{-13}$
Grading material	10-30	$1.0\text{x}10^{-6}$
Arcing Horn	1	$5.9\text{x}10^{7}$

In this model, tetrahedral type of elements is used in meshing process. The maximum element size of the object is 0.065m and the minimum element size of the object is 0.00812m. Refined mesh is applied to the object concern. The design is surrounded by a cylindrical object, where air is used as medium for better and accurate results with fast response. The whole model includes 1674740 elements. The time required for completing a meshing is about 5 minutes for meshing using Intel i7 processor.

III. COMPUTATION METHOD:

The gauss law for E-field is applied here to evaluate the resultant E-field strength. If the given surface S is closed, the E-field is computed by considering all sums of integrals. The negative gradient of potential is given in equation (1),

$$E = -\nabla V \qquad (1)$$

The equation (2) illustrates the gauss law for non-isotropic medium

$$\nabla.\varepsilon(\nabla.V) = -\rho \qquad (2)$$

In case of isotropic permittivity distribution ε_0 is common for all integrated surface, equation (2) can be reformed as

$$\nabla.E = \rho / \varepsilon \qquad (3)$$

where Q is the point charge located on the surface, through this E-field is calculated. ε_0 and ε_r are relative and absolute permittivity of the medium is given in Equation (2). Electric potential is directly obtained by minus of integral part of E-field distribution is in equation (4).

$$V = -\int_A^B E.ds \qquad (4)$$

Initially the solution region is divided into no. of sub regions. At first the potential V_e within an element e calculated and then interrelate the potential distributions in various elements. The appropriate solution for the whole region

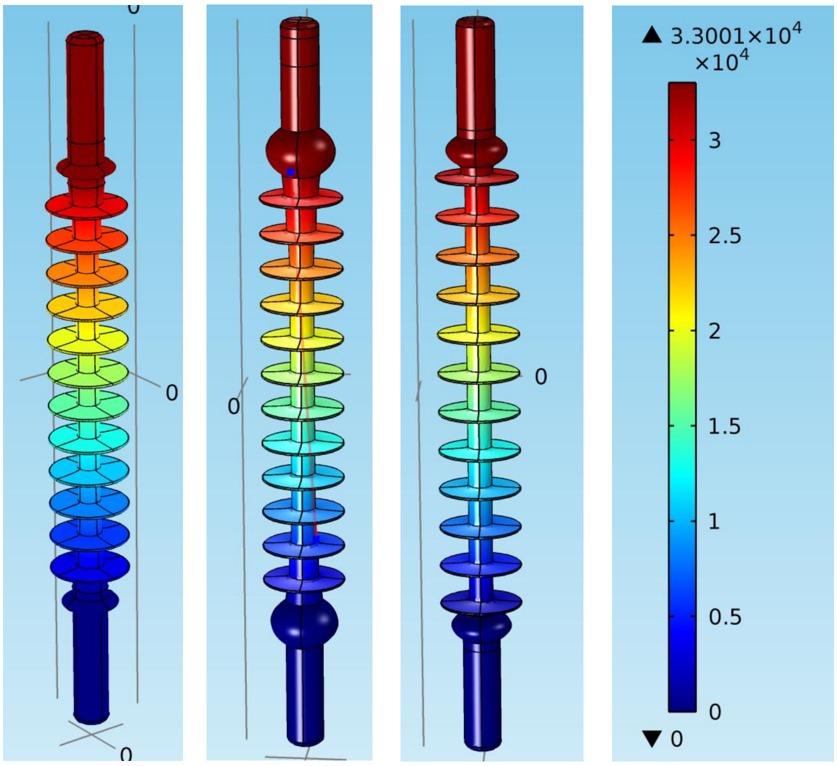
$$V(x, y, z) = \sum_{e=1}^{N} V_e(x, y, z) \qquad (5)$$

where N is the number of elements in equation (5). In general for a triangular element the appropriate solution is in equation (6)

$$V_e(x, y, z) = a + bx + cy + dz \qquad (6)$$

IV. RESULT AND DISCUSSION:

The potential plot along the surface of composite insulator for C1, C2 and C3 are shown in Fig. 3. (a-c). From the plot it is clearly illustrate that C3 shows better potential distribution (uniform) along the sheds of the insulator by the color indicator.

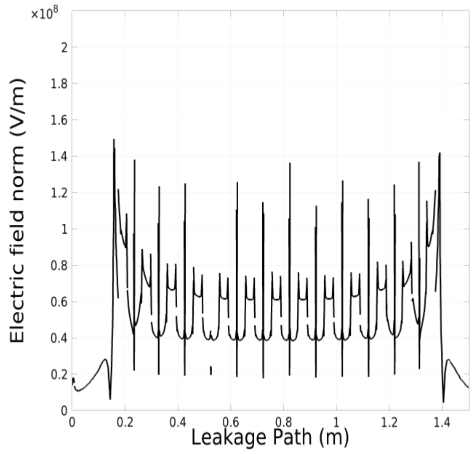


(a) (b) (c) (d(

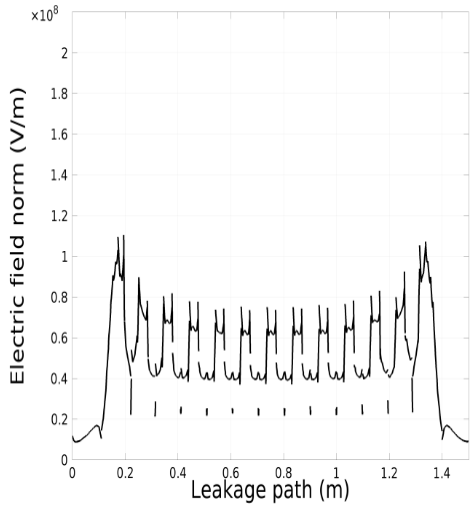
Fig. 3(a-c). Potential plot along the surface of the insulators with C1, C2 and C3

The investigation of E-field distribution on the insulator surface has revealed several significant results which were shown in Fig. 4. For the C1, the highest E-field obtained was $1.5*10^8$ V/m at an input voltage of 33kV. The above E-field was found at the tip of the first shed. Due to the thermal effect of electrical discharges, is thought to be one of the factors which affect the performance of insulators. By investigating the E-field distribution for the C2 type of insulator, the maximum stress was take part at the sharp edges of the shed one. A field value is $1.15*10^8$ V/m at an input voltage level of 33kV was obtained.

For the C3, the maximum E-field is $1.01*10^8$ V/m which take part in the first two sheds of the insulator and the E-field distribution along the first two sheds become linearized. From the graphical observation of Fig. 4, it is clearly pointed out that C3 shows better performance when compared the above two model.



(a)



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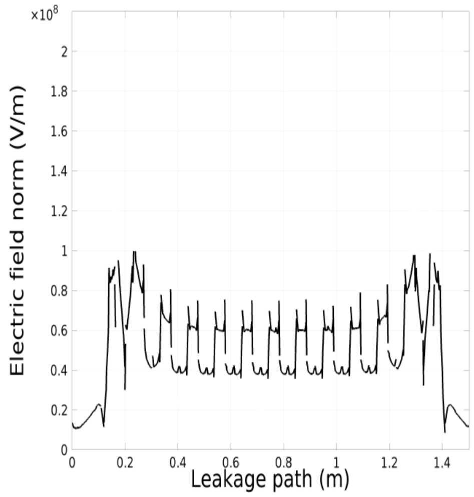


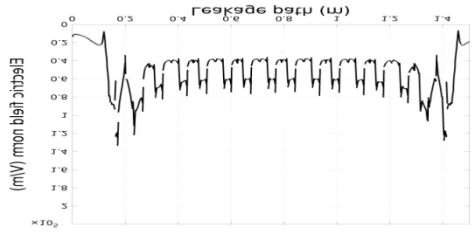
(c)

Fig. 4(a-c). E-Field distribution along the surface of the insulators with C1, C2 and C3

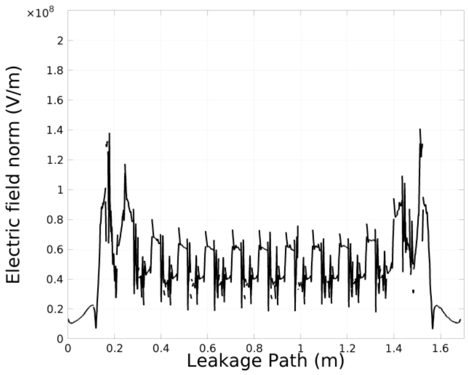
A. *Influence of Alternate and Under-Rib shed design*

The potential plot along the surface of composite insulator for C4, C5, C6 and C7 are shown in Fig. 5. (a-d). From Fig. 5.a, it is clearly inferred that C4 (alternate shed) is a good way to increase the creepage distance of the composite insulator. Because of its shed diameter changing property it is better to cope with hard pollutant environment.

The composite insulator with under-rib C5 represents moderate performance in Fig. 5.b. Because of its under-rib profile during contamination condition, pollution will formed in the under-rib and causes breakdown due to high electrical stress.In C6, the electrical stress is heavily concentrated on the first shed of the both end fittings due to the absence of shed near to the energized end as illustrate in Fig. 5.c. In C7, due to modification of shed next to the energized end the potential plot distribution is uneven on the surface of the insulators as shown in Fig. 5.d. From the Fig. 5, it is inferred that C4 shows better field distribution (uniform) along the sheds of the insulator.For the C4, the highest E-field obtained was $1.37*10^5$ V/m at a voltage of 33kV. The above E-field was uniformly distributed along the sheds as shown in Fig. 6.a. By investigating the E-field distribution for the C5 type of insulator in Fig. 6.b, the high stress was observed at the edges of the initial two sheds when compared to other sheds.



(a)



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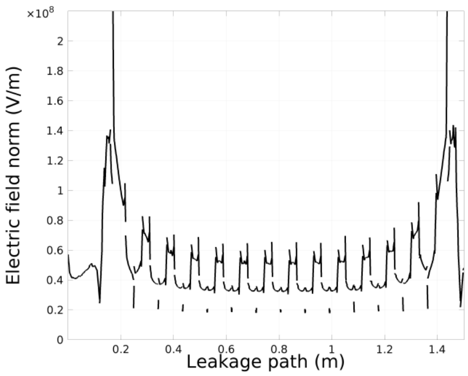
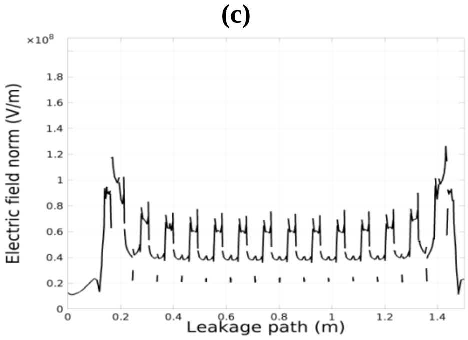


(c)



(d)

Fig. 6(a-d). E-field distribution along the surface of the insulators with C4, C5, C6 and C7

For the C6, the maximum E-field is $2.2*10^8$ V/m which takes part in the first shed of the insulator as shown in Fig. 6.c. From the graphical observation, it is clearly pointed out the maximum stress distributed near the end fittings and it is easily damaged because of its extreme high E-field. For the C7, by modifying the shed near to the energised end the maximum E-field is $1.01*10^8$ V/m which take part in the first shed of the insulator and the field is moderately distributed along the surface of the insulator as shown in Fig. 6.d

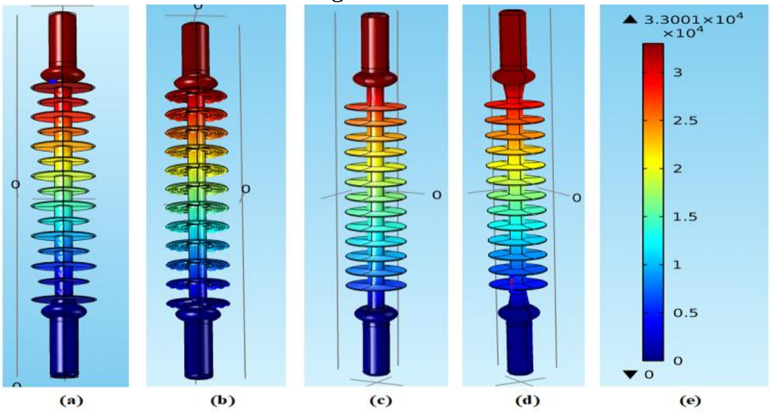


Fig. 5(a-d). Potential plot along the surface of the insulators with C4, C5, C6 and C7

V. CONCLUSION

E-field analysis plays a major role in design and application of composite insulators to ensure long life performance. In the present work, the role of modification of shed configurations and arcing horn in reducing E-field stress in composite insulators was discussed. Since composite insulators are completely affected by the field concentrations on the ends fittings, thus these types of problems are observed by 3D FEM analysis.The optimum design of alternate shed configuration will reduce the high electric stress near the end fittings results the best options on 33kV insulators. Without proper shed configuration (C1 – C7), the end fittings and silicone rubber shed near the HV line are affected by high electric stress, which causes corona effect and rubber shed can be easily damage.

REFERENCE

1. Rowland, S.M., Robertson, J., Xiong, Y. and Day, R. (2010), “Electrical and material characterization of field-aged 400 kV silicone rubber composite insulators”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 17, No. 2, pp. 375-383
2. Pinnangudi, B., Gorur, R.S. and Poweliet, C.D. (2007), “Degradation dynamics of polymeric housing materials used for HV line and station apparatus”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 14, No. 5, pp. 1215–1224.
3. Hackam, R. (1999), “Outdoor HV composite polymeric insulator”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 6, No. 5, pp.557–585.
4. Reynders, J.P., Jandrell, I.R. and Reynders, S M. (1999), “Surface aging mechanisms and their relationship to service performance of silicon rubber insulation”, 10th International Symposium on High Voltage Engineering, London, UK, pp. 54－58.
5. Gorur, R.S., Cherney, E.A. and Burnham, J.T. (1999), “Outdoor Insulators”, Phoenix, Arizona.
6. Phillips, A. (2002), “Ceramic vs. Polymer (Non-Ceramic) Insulators”, Electric Power Resrach Institute, United States.
7. Que, W.G., Sebo, S.A. and Hill, R.J. (2007), “Practical Cases of Electric Field Distribution along Dry and Clean Non-ceramic Insulators of High-Voltage Power Lines”, IEEE Transaction Power Delivery, Vol. 22, No. 2, pp.1070-1078.
8. Chenlong Zhao, Hongwei Mei, Hanqi Dai, Liming Wang and Zhicheng Guan (2015), “Influence on Voltage Distribution of Composite Insulator by Inserting Metal Electrodes in Weather Sheds”, IEEE Transactions on Dielectrics and Electrical Insulation ,Vol. 22, No. 3, pp. 1623 – 1629.
9. Mei, H.W., Peng, G.M., Dai, H.Q., Wang, L.M., Guan, Z.C. and Cao, L.F. (2011), “Installing insulation jacket to improve outdoor insulation performance of composite insulator”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 18, No. 6, pp. 2004-2012.
10. Dominguez, D.C., Espino Cortes, F.P. and Gomez, P. (2013), “Optimized design of electric field grading systems in 115 kV non-ceramic insulators”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 20, No. 1, pp. 63-70.
11. Murugan, Natarajan. Vigneshwaran, Basharan. Kannayeram, Ganapathya Pillai. Maheswari, Ramasamy Velayutham. and Willjuice Iruthayarajan Maria Silluvairaj. (2015), “Analysis of Stress Control on 33-kV Non-ceramic Insulators Using Finite-element Method”, Electric Power Components and Systems, Vol. 43 No. 5, pp. 566–577.
12. Cherney, E.A. (2005), “Silicone rubber dielectrics modified by inorganic fillers for outdoor high voltage insulation applications,” IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 12, No.6, pp. 1108 – 1115.
13. Marungsri, B., Onchantuek, W. and Oonsivilai, A. (2008), “Electric Field and Potential Distributions along Surface of Silicone Rubber Polymer Insulators Using Finite Element Method”, World Academy of Science, Engineering and Technology, Vol. 42, pp. 67–72.
14. Chari, M.V.K., Bedrosian, G., Dangelo, J. and Konrad, A. (1993), “Finite element applications in electrical engineering”, IEEE Trans. Magnetics, Vol. 29, pp. 1306-1314.
15. Xi Yang, Naiyi Li, Zongren Peng, Jintao Liao and Qingyu Wang , (2014), “Potential distribution computation and structure optimization for composite cross arms in 750 KV AC Transmission Line”, IEEE transactions on dielectrics and electrical insulation, Vol. 21, No. 4, pp.1660-1670.
16. Chi Yu, Gang Wang, Yingxi Liu and Xiuzhen Sun. (2006), “3D FE model reconstruction and numerical simulation of airflow for the upper airway”, World Journal of Modelling and Simulation, Vol. 2, No. 3, pp.190–195.

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