Simulation of Potential and Electric Field Due to Defective Insulator in 115 kV Transmission Line

Pramuk Unahalekhaka and Siamrat Phonkaphon

Abstract— *This paper described to study the potential and electric field of suspension insulator in 115 kV transmission line associated with ANSI type 52-3. The suspension insulator type 52-3 was used by Provincial Electricity Authority (PEA) in Thailand. The suspension insulator was the disc insulators; it is an assembly of one or more shells with metallic fittings. This structure can enabled them form the insulator string by fitting into themselves one another as per voltage requirement. A suspension insulator set complete with the fittings was used to carry a line conductor or conductors at its lower end. The top of insulator string was fixed to the cross arm of the tower. The potential and electric fields were simulated by using the Finite Element Analysis (FEA) program. This simulation was compared the characteristic of suspension insulator due to defective insulator between normal and abnormal condition. The defective insulator was based on percentage of damage and surface pollution levels. However, the percentage of damage and surface pollution influence on the dielectric behavior of the insulators has been examined in order to reduce the effect of system.*

Keywords— **Potential field, electric field, suspension insulator, Finite Element Analysis.**

1. INTRODUCTION

Nowadays, PEA had a problem in the transmission line due to defective insulator, which was based on the damage of insulators and consideration of surface pollution level located nearby the sea and in industrial areas. The transmission line insulators are used to support the high voltage carrying conductors. The dimensioning of insulators must be such as to prevent flashover when the highest overvoltage occurs on the power line. Due to the geometry of the line and insulator the voltage distribution along the length of the insulator is non-uniform. This has been analysed theoretically in closed form for clean glass or porcelain disc insulator strings [1].

The insulators, which are used for the suspension of overhead transmission lines, constitute one of the most important parts of the transmission lines as flashover effects in polluted insulators can cause the breakdown of a transmission network. The electric field distribution within and around high voltage insulators is a very important aspect of the design of the insulators. Also the knowledge of the electric field could be useful for the detection of defects in insulators [2]. The lumped parameter representation of an insulator string consists of C_{sn} and C_{gn} C_{sn} is the self-capacitance of an insulation unit and C_{gn} is the ground stray capacitance between the tower and an insulator cap [3].

In the present paper, the insulator model was verified for several surface pollution levels. The surface pollution levels can divided into three levels which consist of light, moderate, and heavy pollution level follow to IEC standard [4]. This model was used in 115 kV system of PEA in Thailand as shown in Fig. 1

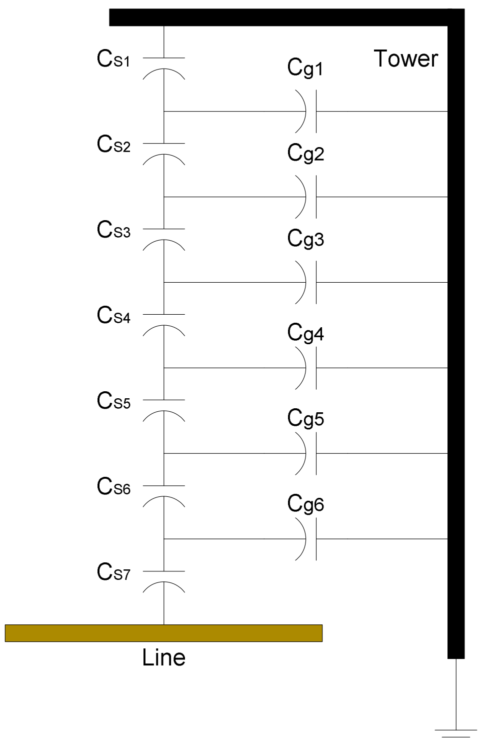

Fig.1. The lumped parameter of an insulator string.

2. SUSPENSION INSULATOR

The insulators standard of suspension insulators with high mechanical and electrical strength are designed to

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meet the most modern demands of high voltage transmission line usage today. The insulators makes one of the widest ranges of ANSI approved Ball–Socket and Clevis type distribution suspension insulators for overhead transmission systems in the world.

For the present study, the type of suspension insulator type 52-3 is chosen. The dimension of suspension insulator type 52-3 is used for the study as shown in Fig. 2. Technical data of suspension insulator type 52-3 are reported in Table 1.

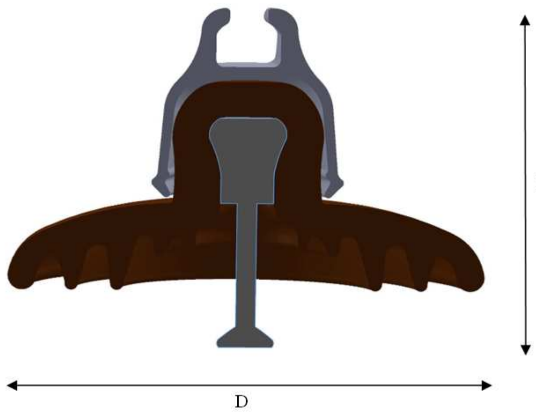


Fig.2. The dimension of suspension insulator type 52-3.

Table 1. Technical data of suspension insulator type 52-3

Class ANSI	52-3
Main Dimensions D	273mm
Main Dimensions H	146mm
Creepage distance	292mm
Power frequency puncture voltage	110 kv
Frequency dry flashover voltage	80 kv
Frequency wet flashover voltage	50 kv
Critical impulse flashover pos	125 kv
Critical impulse flashover Neg	130 kv
Test voltage to ground	10 kv
Maximum RIV at 1000HZ	50 uv
Electromechanical Load	6750kg
Mechanical Impact Strength in-1b(N-m)	55
Time Load Test Value1b	4500kn
Weight	4.6 kg

3. VOLTAGE DISTRIBUTION OF SUSPENSION INSULATOR

The transmission line is considered that the important issue of the suspension and the voltage insulator division of the disk of insulator string. The most of the disk and the metal pin comprising porcelain insulators.

The voltage across insulator strings are equally active in the division as well as a string of calculated predominates Capacitance. The voltage distribution of suspension insulator is defined by:

$$m = C_s/C_g \quad (1)$$

$$V_n = I_n/\omega C_{sn} \quad (2)$$

where:

m capacitance ratio of C_s and C_g
V_n voltage across each unit
I_n current in each unit

In this paper, the overhead line suspension Insulator consists of 7 units. Transport and land are the differences between the 66.4 kV splendors. If the land in each insulators mutual Capacitance and Capacitance ratio 5:1. The voltages across each unit are reported in Table 2 and Fig. 3.

Table 2. Calculation of the voltage across each unit

Unit	Voltage across the insulator (kV)
1	2.72
2	3.26
3	4.46
4	6.55
5	9.95
6	15.34
7	23.80

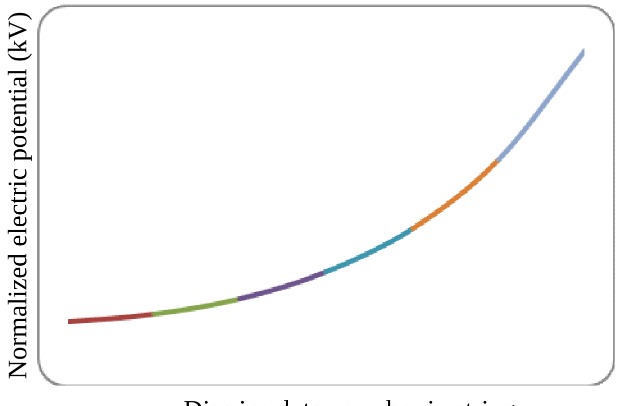


Fig.3. Normalized electric potential distribution

4. MATHEMATICAL MODEL

A simple model for the evaluation of the flashover process of a polluted insulator consists of a partial arc spanning over a dry zone and the resistance of the pollution layer in series. The critical voltage V_C, which is the applied voltage across the insulator when the partial arc is developed into a complete flashover, is given by the following formula (3):

$$V_C = \frac{A}{n+1} \cdot (L + \pi \cdot n \cdot D_m \cdot F \cdot K) \cdot (\pi \cdot A \cdot D_m \cdot \sigma_S)^{-\left(\frac{n}{n+1}\right)} \quad (3)$$

where L is the leakage distance of the insulator, D_m is the maximum diameter of the insulator disc and F is the form factor. The arc constants A and n have been calculated using the least square method. Their values are A=131.5 and n=0.374. The surface conductivity σ_s (in Ω^{-1}) is given by

$$\sigma_S = \left(369.05 \cdot C + 0.42\right) \cdot 10^{-6} \tag{4}$$

where C is the equivalent salt deposit density (ESDD) in mg/cm^2. The coefficient of the pollution layer resistance K in case of cap-and-pin insulators is given by

$$K = 1 + \frac{n+1}{2 \cdot \pi \cdot F \cdot n} \cdot \ln\left[\frac{L}{2 \cdot \pi \cdot R \cdot F}\right] \tag{5}$$

where R is the radius of the arc foot and is given by

$$R = 0.469 \cdot \left(\pi \cdot A \cdot Dm \cdot \sigma_S\right)^{\left(\frac{1}{2 \cdot (n+1)}\right)} \tag{6}$$

In case of stab-type insulators, K is defined as follows:

$$K = \frac{N \cdot (n+1)}{2 \cdot \pi \cdot F \cdot n} \cdot \left[\ln\left[\frac{4 \cdot L}{\pi \cdot N \cdot R}\right] - \ln\left[\tan \frac{\pi}{2 \cdot (n+1)}\right]\right] \tag{7}$$

where N is the number of sheds.

5. POTENTIAL AND ELECTRIC FIELD MODELING

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for differential equations. It uses variation methods (the calculus of variations) to minimize an error function and produce a stable solution.

Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses all the methods for connecting many simple element equations over many small subdomains, named finite elements, to approximate a more complex equation over a larger domain.

The potential and electric field surrounding the insulator and the conductor is modelled using the Finite Element Analysis (FEA) program. This program is a computerized method for analysis to draw the potential and electric field contours superimposed upon the drawing. The suspension insulator type 52-3 and the cutting plane of the suspension insulator model as shown in Fig. 4.

6. SIMULATION AND RESULTS

The paper discusses the application of two and three dimensional by using the FEA for the modeling of the insulators, that a comparison between normal and abnormal condition results from two dimensional analysis of the insulator strings is presented. Disk insulators of the string structure, which are used for the suspension of 115 kV overhead transmission lines, are simulated. The normal condition results of the potential and electric field distribution simulations are given in Figs. 5 and 6.

Table 3 expresses the comparison of the voltage across each unit between normal and abnormal condition. An abnormal condition was based on percentage of damage and surface pollution levels. The surface pollution levels can divide into three levels which consist of light, moderate and heavy pollution. The comparison of electric potential distribution each unit was shown in Fig. 7.

Fig.4. The suspension insulator type 52-3 and the cutting plane of the suspension insulator model.

Table 3. Voltage across each unit with and without pollution level (kV)

Unit	Normal condition without pollution	Abnormal condition with pollution level		
		Light	Moderate	Heavy
1	2.72	0.50	1.00	0.94
2	3.26	1.60	1.22	1.19
3	4.46	2.90	1.54	1.52
4	6.55	4.80	2.35	2.25
5	9.95	8.06	4.59	4.30
6	15.34	15.50	16.10	14.00
7	23.80	33.80	39.60	42.20

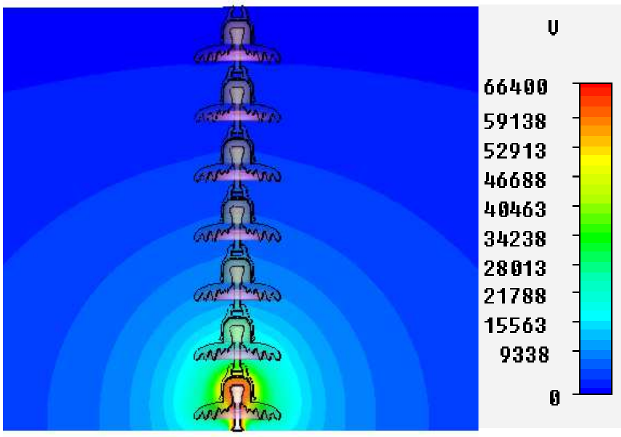


Fig.5. Potential field of normal condition.

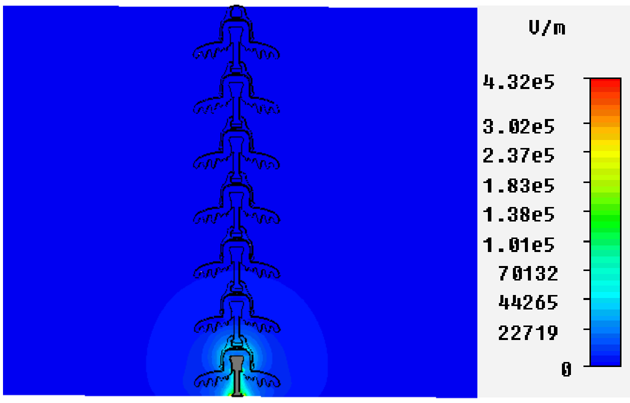


Fig.6. Electric field of normal condition.

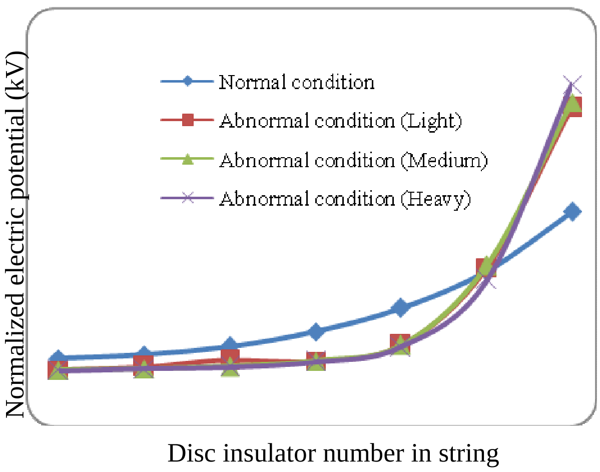
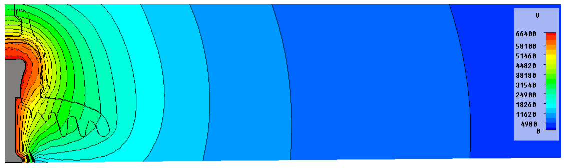
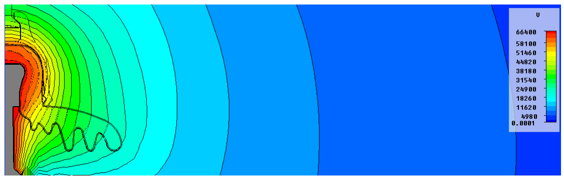


Fig.7. Comparison of electric potential distribution

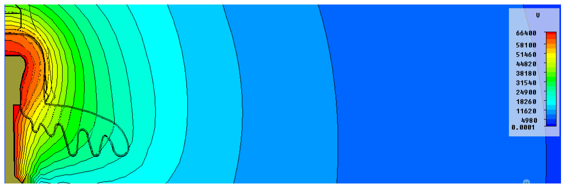
Fig. 8 and Fig. 9 indicated that the electrical potential contour and electric field distribution with pollution and without pollution respectively.



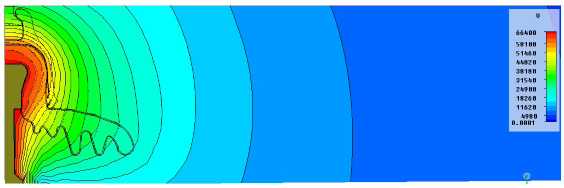
(a) Non-pollution



(b) Light pollution



(c) Moderate pollution



(d) Heavy pollution

Fig.8. Electrical potential contour with and without pollution.

(a) Non-pollution

(b) Light pollution

(c) Moderate pollution

(d) Heavy pollution

Fig.9. Electric field distribution with and without pollution

The computations results concerning the critical voltage of a cap-and-pin suspension insulator upon the equivalent salt deposit density (ESDD) .The computation of critical voltage (V_C) can divide into 3 levels consist of light, moderate and heavy level as shown in table 4. The critical voltage for insulator against ESDD without and with surface pollution level is shown in table 5 and 6 respectively.

Table 4. The critical voltage for insulator against ESDD

ESDD (mg/cm^2)	V_C (kV)	Pollution level
0.01	37.65	Light
0.10	23.348	Moderate
0.30	19.24	Heavy

Table 5. The critical voltage for insulator without surface pollution (kV)

Percentage of damages	Critical voltage
0	57.86
10	55.84
20	53.74
30	51.51
40	49.12
50	46.51

Table 6. The critical voltage for insulator with surface pollution (kV)

Percentage of damages	Critical voltage		
	Light	Moderate	Heavy
0	37.66	23.35	19.25
10	36.58	22.76	18.81
20	35.44	22.13	18.35
30	34.25	21.48	17.86
40	32.96	20.77	17.33
50	31.56	20.00	16.76

From table 3 and 5, the comparison of the critical voltage of insulator near the conductor without surface pollution based on percentage of damage was in the range of acceptable values.

From table 6, the critical voltage of insulator can use acceptably with percentage of damage and surface pollution levels within 30% and light pollution level.

7. CONCLUSION

The studied approach is applicable to an insulator type 52-3. The potential and electric field along polluted suspension insulators have been analyzed in this paper. This simulation analysis showed that the effect of the surface pollution levels on a suspension insulator is to line arise the potential distribution along the length of the insulator. The defective insulator which was based on both the percentage of damage and surface pollution levels (ESDD), it may be influenced on the dielectric behavior of the insulators has been examined in order to reduce the effect of system. The result have been shown that it can use acceptably with percentage of damage and surface pollution levels within 30% and light pollution level respectively.

However, the work needs to be focused on obtaining accurate technical data for the materials constituting the insulator in order to simulate and calculate the acceptable result.

REFERENCES

[1] Kreuger, F.H. 1991. Industrial High Voltage, Delft University Press, Delft, pp 38-40.

[2] Power Systems Research Center. 2004. Evaluation of Critical Components of Non-Ceramic Insulators (NCI) In-Service: Role of Defective Interfaces, Final Project Report, PSERC Publications 04-32, Arizona, August.

[3] Suat Ilhan and Aydogan Ozdemir. 2007. Voltage Distribution Effects of Non-Uniform Unit in Suspension String, Power Tech.

[4] IEC 60815. 1991. Guide for the selection and dimensioning of high-voltage insulators for polluted conditions, Part 1: Definitions, information and general principles.

[5] IEC Standard 60507. Artificial pollution tests on HV insulators to be used on AC systems.

[6] Shakir Mahmood Faisal. 2011. Simulation of Electric Field Distrubition on Ceramic Insulator Using Finite Element Method, European Journal of Scientific Research, ISSN 1450-216X Vol.52 No.1 , pp.52-60

[7] Vosloo W.L. and Holtzhausen J.P. 2002. The Electric Field of Polluted Insulators, IEEE Africon, pp. 599-602.

[8] Kontargyri V.T., Ilia NC, and Stathopulos I.A. 2004. Electric Field and Voltage Distribution along Insulators under Pollution Conditions, MedPower.

[9] Topalis F.V., Gonos I.F. and Stathopulos I.A. 2001. Dielectric behaviour of polluted porcelain insulators, IEE. Proc.-Gener. Trunsm. Distrib. Vol. 148, No. 4, pp. 269-274.