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Analysis of Pollution Impact on Potential Distribution of Suspension Type Discs Insulators in Overhead Lines

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Abstract: The disk insulator strings are applied in the overhead transmission lines due to their flexibility against the mechanical forces and easy to replace characteristics. One of the problems encountered in using this type of insulators is the non-uniform potential distribution on each insulator unit exists on the string. In this paper, the effect of insulator string distance from the tower and the dirty impact on the potential distribution and the leakage current magnitude of each insulator unit exists in the insulator string of a 63 kV line is simulated in Matlab/Simulink and the results are analyzed then.

Key word: Overhead lines, Insulators, Potential distribution, Contamination (pollution)

INTRODUCTION

One of the important properties of electrical energy is the possibility of transmitting this energy to long distances. According to the economic considerations, this transmission is usually accomplished through the overhead lines by the assist of the power towers. The conductors of these lines are connected to the towers through the insulators because of their high voltage levels. The insulators have to transmit (damp) the mechanical forces caused by wind, ice and conductor tension etc, in addition to the isolation provision between the conductors and the tower. Nowadays, the disk insulators are applied in 20 kV and higher voltage level lines because of their flexibility (pendulum property) in mechanical oscillations attenuation, easy to replace property, and low manufacturing costs. Since this type of insulators have low electric stamina to be applied in high voltage levels, the series combination of insulators are used in string. The number of insulator units in these strings depends on the line nominal voltage, the pollution amount of region the line passes through, the number of lightning, and other parameters. In spite of the advantageous such arrangement raises, it brings non-uniform potential distribution on each insulator unit, which can be due to the existence of insulators metal lid and the capacitance exists between insulators and the metal tower. In result, some of insulator units are more under electrical tension and consequently their declination and destruction occur too fast and their isolation lifetime decreases. This increases the probability of their electric break down under critical conditions caused by lightning and switching over voltages. Such electric break down in a single insulator brings about the whole string break and consequently causes fault in the network. The importance of investigating such issue in the overhead transmission lines is recently increased according to the importance of reliability and efforts to improve the reliability of power system.

In [*H. EL-KiShky*,*1994*], the potential and the electric field distribution rate along the suspension insulators are calculated in 115 and 230 kV levels under wet and dry surface pollution conditions. In [*N.pattanadech, 2004*], the voltage variability on the porcelain insulators are measured in several conditions and different approaches, and an improved technique by the assist of spheres is presented for the voltage measurement. In [*S. M. Al Dhalaan*, *2003*] - [*A. S. A. Farang, 1993*], the effect of pollution rate on the potential distribution of dirty and clean suspended insulator strings is investigated under two metal rings existence and their absence conditions. In [*H. G. Cho, 2005*], the isolation and the mechanical characteristics of porcelain insulators in two brand new and old conditions are evaluated through the experimental techniques and fast aging tests.

In this paper, the potential distribution and the efficiency of the insulator string are initially simulated and the results are presented according to the impact of string distance to the tower body in 63 kV lines for clean insulators in order to investigate the effect of pollution on the potential distribution of string insulators. A model is then presented for the mentioned string insulator with surface pollution. The mathematical relations of such model are obtained and in continuous the simulations are carried on the obtained model. Finally, the effect uniform pollution rate on the string insulator of the mentioned line is then analyzed.

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Investigating the String Insulator Operational Modes under Different Pollution Conditions:

As mentioned above, selecting the number and the kind (material) of disk insulator in a string depends on the lightning and the pollution of the region line passes through. As the voltage level increases, the number of insulators should increase to create proper isolation. The lightning number and its power are considered as other important factors affect the number of selected insulators. Lightning occurrence would lead to electric arc creation between line conductors and tower body if the number of insulators were not properly selected. Another important factor is the region pollution rate according to the several standards can affect the insulator's leakage path. For example, in heavy polluted regions, the selected insulator should possess long leakage path to have higher surface resistance rate in addition to insulator leakage current reduction. Therefore, this factor can be considered as an important parameter in insulators kind and number selection, and insulator designing. The experimental insulator number selection for different voltage levels considering the mentioned factors are denoted in Table 1.

Table 1: The number of insulators in different voltage levels

Voltage level(kV)	400	230	132	63	20
Insulator number	18-21	14-20	9-11	5-7	2-3

In this paper, the 63 kV transmission line with five insulators is considered to investigate the impact of pollution and simulating its operation on the insulators exist in an insulator string.

Considering no or Light Pollution (Clean):

In this section, it is assumed that the considered line passes through a low polluted region. Here, the mentioned insulator string model is illustrated as Fig. 1.

According to Fig.1, c_1 is the capacitance of each insulator and c_2 is the capacitance exists between each insulator bar and the tower body. Value of c_1 depends on the kind and the insulator material and it is considered 3pF in this simulation according to the standards. The value of c_2 varies according to the shape of the tower and can vary from 2pF to 6pF [*S. M. Al Dhalaan, 2003*]. For simplicity, these two capacitances are considered to depend on one another and are denoted by parameter k. This parameter is defined as follows:

$$k = \frac{c_2}{c_1} \tag{1}$$

According to Fig.1, the Kirshoff's lows are expressed as follows for each node in order to investigate the potential of the insulators.

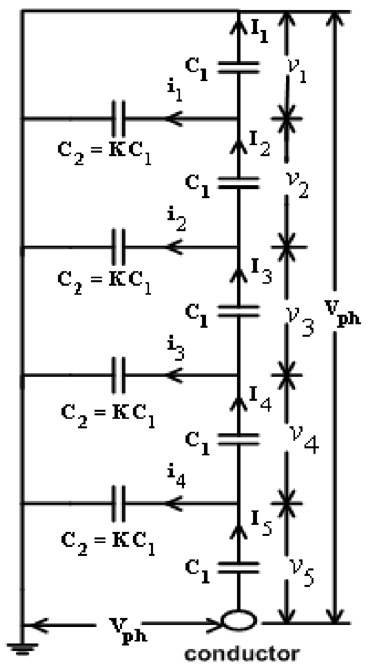

Fig. 1: The insulator string model in 63 kV line (in clean condition).

The following is valid for node 1:

$$v_1 + \mathrm{k}v_1 = v_2 \tag{2}$$

$$\mathrm{c}_1 \mathrm{j}\omega v_1 + \mathrm{kc}_1 \mathrm{j}\omega v_1 = \mathrm{c}_1 \mathrm{j}\omega v_2 \tag{3}$$

$$v_1 + \mathrm{k}v_1 = v_2 \tag{4}$$

Therefore, the following is obtained:

$$v_2 = (\mathrm{k}+1)v_1 \tag{5}$$

For the rest of the nodes the similar calculations would result in the followings:

$$v_3 = (\mathrm{k}^2 + 3\mathrm{k} + 1)v_1 \tag{6}$$

$$v_4 = (\mathrm{k}^3 + 5\mathrm{k}^2 + 6\mathrm{k} + 1)v_1 \tag{7}$$

$$v_5 = (\mathrm{k}^4 + 7\mathrm{k}^3 + 15\mathrm{k}^2 + 10\mathrm{k} + 1)v_1 \tag{8}$$

The following is also valid:

$$v_1 + v_2 + v_3 + v_4 + v_5 = \mathrm{v}_{\mathrm{ph}} \tag{9}$$

In result, the following can be easily obtained:

$$v_1 = \frac{\mathrm{v}_{\mathrm{ph}}}{\mathrm{M}} \tag{10}$$

$$v_2 = \frac{(\mathrm{k}+1)}{\mathrm{M}}\mathrm{v}_{\mathrm{ph}} \tag{11}$$

$$v_3 = \frac{(\mathrm{k}^2 + 3\mathrm{k} + 1)}{\mathrm{M}}\mathrm{v}_{\mathrm{ph}} \tag{12}$$

$$v_4 = \frac{\mathrm{k}^3 + 5\mathrm{k}^2 + 6\mathrm{k} + 1}{\mathrm{M}}\mathrm{v}_{\mathrm{ph}} \tag{13}$$

$$v_5 = \frac{(\mathrm{k}^4 + 7\mathrm{k}^3 + 15\mathrm{k}^2 + 10\mathrm{k} + 1)}{\mathrm{M}}\mathrm{v}_{\mathrm{ph}} \tag{14}$$

Where M is considered as follows:

$$\mathrm{M} = \mathrm{k}^4 + 8\mathrm{k}^3 + 21\mathrm{k}^2 + 20\mathrm{k} + 5 \tag{15}$$

The efficiency of insulator string would be obtained as follows:

$$\eta = \frac{\mathrm{v}_{\mathrm{ph}}}{\mathrm{n}v_5} \tag{16}$$

In this investigation, the following is valid assuming n=5 and V_{ph} = 63 kV:

$$\mathrm{v}_{\mathrm{ph}} = \frac{63\mathrm{kV}}{\sqrt{3}} = 36.37\mathrm{kV} \tag{17}$$

As it is obvious from the above relations, the voltage drop on each insulator just depends on the k parameter and varies as k varies. The simulation results of k variation consequences are illustrated in Fig.2 and Table 2.

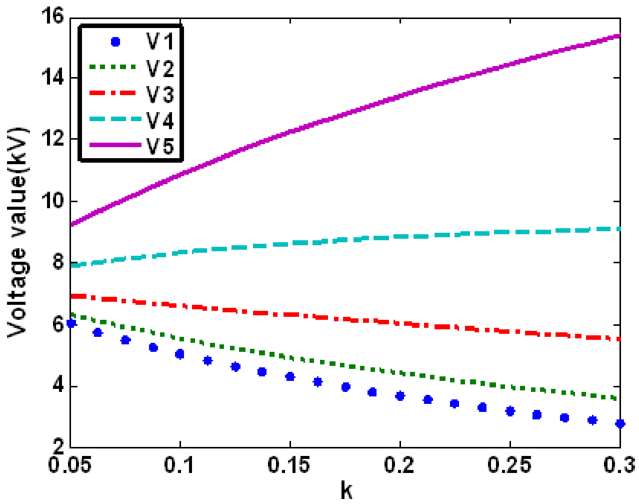

Fig. 2: The voltage drop variation of each insulator in terms of k variations.

Table 2: Potential distribution according to k variations.

K	v_1 (kV)	v_2(kV)	v_3 (kV)	v_4 (kV)	v_5 (kV)	η (%)
0.1	5.039	5.543	6.601	8.319	10.869	66.9
0.2	3.672	4.406	6.022	8.842	13.43	54.1
0.3	2.777	3.609	5.519	9.089	15.385	47.2

According to Fig.2 and table 2 it is obvious that the k increase, (the increase of capacitance exists between insulator and tower (ground)) leads to more variability of potential distribution on each insulator in a way that the k increase from 0.05 to 0.3 decreases the efficiency from 77.8% to 47.28%. The mentioned insulator's efficiency variations in terms of k variations are illustrated in Fig.3.

It is now obvious that the potential distribution on the insulator string can be maintained desirably non-uniform by controlling the k parameter value (selecting the insulator kind and adjusting its distance from the tower body).

Considering Pollution:

The environmental pollution is more considered in external solid isolators. According to the settlement of particles on the surface of insulators and surface conduction and leakage current creation, the heat and destruction increase and consequently the isolator breaks down faster.

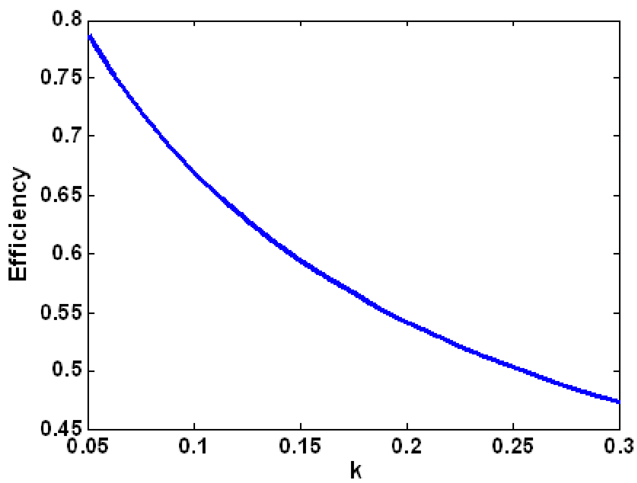

Fig. 3: The efficiency variations of investigated insulator in terms of k variations.

One of the solid isolators greatly applied in power systems is overhead lines insulator. Several pollutions such as sea salt, desert sand, the factories smoke and etc. can affect the performance of this device. The most important pollution is salt fog, which can unfavorably affect the whole devices particularly the overhead lines insulators. This pollution can significantly decrease the surface leakage path of the insulator and increase the electric break down probability. Therefore, the pollution is one of the most important parameters considered in selecting the kind and the number of insulators.

In modeling process of pollution stands on the overhead line insulators (which would decrease the isolation resistance), the pollution is modeled as resistance. Therefore, the impact of pollution is modeled as a resistance stands in parallel with the capacitance of each insulator. As the pollution amount is increased, the surface conduction is increased and consequently the surface resistance magnitude is decreased.

In Fig.4, the model of 63 kV polluted insulator string is illustrated. As it is obvious, the pollution caused isolation resistance change is modeled as resistances stand in parallel with each insulator, which is also modeled with a capacitor.

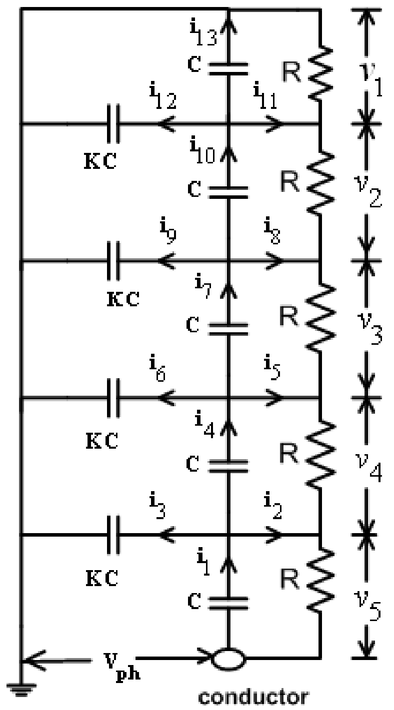

Fig. 4: The insulator string model in 63 kV line (with pollution).

The circuit relations of each node are calculated in order to investigate the insulators potential. The following is valid for each conductor-connected node:

$$i_1 = i_2 + i_3 + i_4 \tag{18}$$

Therefore, according to the voltage fall on each insulator unit, the following is obtained:
The following relations are also obtained for the rest of the nodes as above:

$$cj\omega v_5 = \frac{1}{R}[v_4 - v_5] + kcj\omega[v_4 + v_3 + v_2 + v_1] + cj\omega v_4 \tag{19}$$

Assuming $Y = cj\omega$ and $A = kY/(Y + 1/R)$, the following can be easily achieved:

$$v_2 = v_1[1 + A] \tag{20}$$

$$v_4 = v_3[1 + A] + A[v_2 + v_1] \tag{21}$$

$$v_3 = v_3[1+\mathrm{A}] + \mathrm{A}v_1 \quad (22)$$

$$v_2 = v_1[1+\mathrm{A}] \quad (23)$$

The followings are valid:

$$v_1 + v_2 + v_3 + v_4 + v_5 = \mathrm{v_{ph}} \quad (24)$$

$$v_1 = \frac{v_{ph}}{\mathrm{M}} \quad (25)$$

$$v_2 = [1+\mathrm{A}]\frac{\mathrm{V_{ph}}}{\mathrm{M}} \quad (26)$$

$$v_3 = [\mathrm{A}^2 + 3\mathrm{A} + 1]\frac{\mathrm{V_{ph}}}{\mathrm{M}} \quad (27)$$

$$v_4 = [\mathrm{A}^3 + 5\mathrm{A}^2 + 6\mathrm{A} + 1]\frac{\mathrm{V_{ph}}}{\mathrm{M}} \quad (28)$$

$$v_5 = [\mathrm{A}^4 + 7\mathrm{A}^3 + 15\mathrm{A}^2 + 10\mathrm{A} + 1]\frac{\mathrm{V_{ph}}}{\mathrm{M}} \quad (29)$$

Parameter M is calculated as follows:

$$\mathrm{M} = \mathrm{A}^4 + 8\mathrm{A}^3 + 21\mathrm{A}^2 + 20\mathrm{A} + 5 \quad (30)$$

The efficiency can be obtained as (16). The resistance value can be infinite if there is no pollution on the insulators surface. Therefore, parameter A, equals to k (A=k). Two non-uniform and uniform pollution conditions are investigated for more evaluation of the pollution impact on the insulators potential distribution. The relations mentioned above are analyzed in Matlab/Simulink in order to simulate the impact of pollution on the insulators performance.

Uniform Pollution:

In this section, it is assumed that the pollution exists on the insulators is uniform. In non-uniform pollution is considered as the similarity of the resistance value of each insulator and its variation is considered as an identical variation of insulator string resistances. According to the simulation, the potential distribution of the investigated insulator string for 50MΩ resistance and in terms of k variation is illustrated in Fig. 5. The efficiency variation in terms of k variation is well shown in Fig. 6.

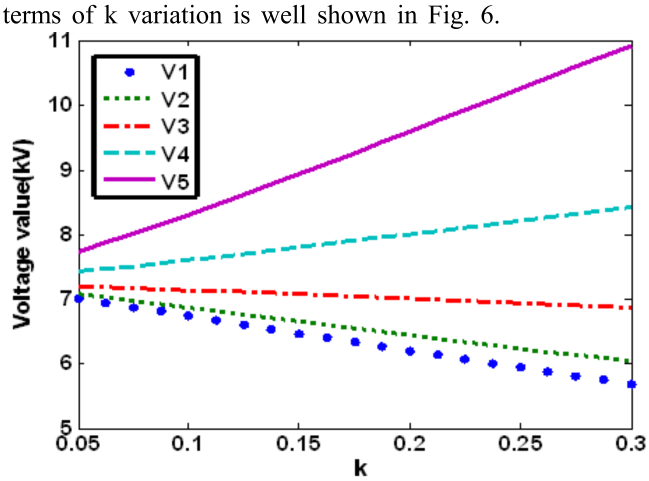

Fig. 5: The voltage drop variations of each insulator of considered line in terms of k variations.

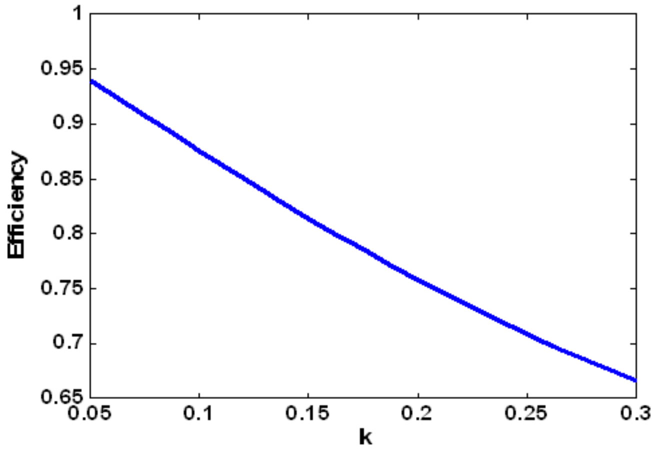

Fig. 6: The efficiency variations of the investigated insulator string in terms of k variations.

According to the simulation results and compared with the results of previous section (no polluted insulators), it is obvious that the potential distribution of the string is more uniform and the efficiency is increased. In addition, the efficiency and the voltage variations domain are decreased at the presence of pollution in a way that pollution presence decreases the k parameter's impact. In Fig. 7 and Fig. 8, the impact of uniform pollution on the potential distribution of each insulator and on the efficiency of insulator string is well shown.

Table 3, shows the numerical potential value of each insulator unit in terms of pollution rate (resistances).

Table 3: The potential drop of each insulator unit according to the pollution rate.

R(Ω)	v_1(kv)	v_2(kv)	v_3(kv)	v_4(kv)	v_5(kv)
10^6	7.274	7.274	7.274	7.274	7.274
10^8	5.666	6.033	6.831	8.311	10.22
10^{10}	4.513	5.115	6.398	8.535	11.81

Therefore, according to the simulation results, it I obvious that the potential distribution is almost uniform for the resistances less than $10^7\Omega$ where the leakage current is considerably high. In addition, the potential value for the resistances higher than $10^9\Omega$ is the same as the performance of insulators in no pollution condition (dry and clean) and consequently, the leakage current is considerably small. This is well depicted in Fig.7 and Fig.9.

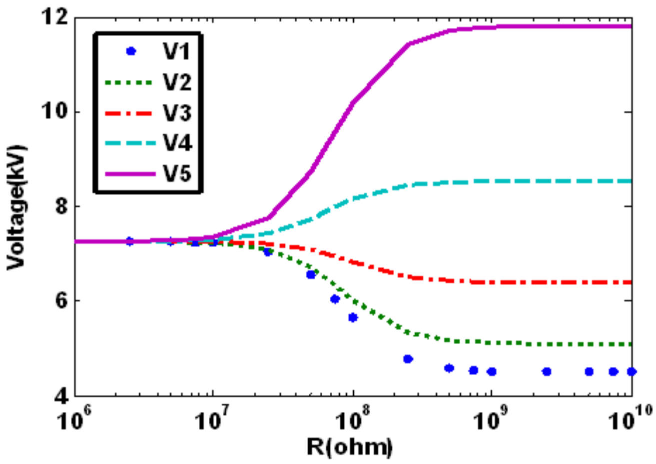

Fig. 7: The potential distribution on each insulator unit of investigated insulator string in term of pollution rate (equivalent resistance).

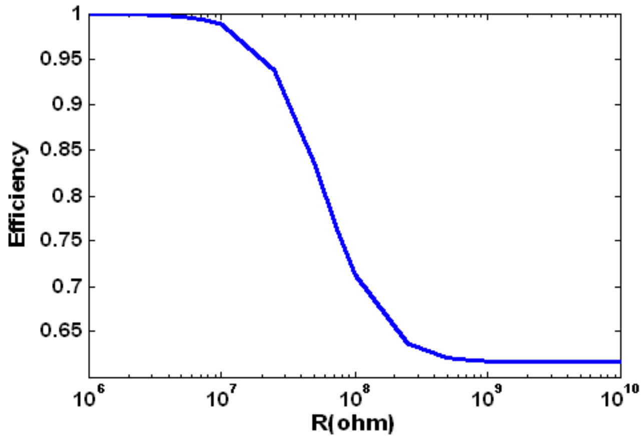

Fig. 8: The string's efficiency variations in terms of pollution rate.

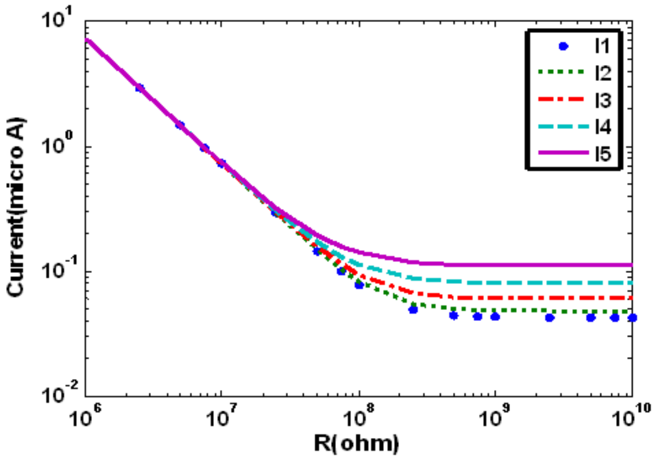

Fig. 9: The leakage current variations of each insulator unit in terms of pollution rate.

The reason of the mentioned fact is that for different resistance values, the surface resistance of the insulator is considerably high if compared with its capacitive reactance under no pollution condition and in result, operates in an open circuit mode in a way that the ground capacitor presence leads to voltage unbalance. On the other hand, in the presented model, the capacitors play open circuits roll as the pollution rate exceeds a specific level (less than 10 MΩ resistances) and consequently the voltage is divided in proportion with the resistance magnitudes of each insulator, which results in equal leakage current flow of all insulators. The voltage falls on insulators would be equal if the resistances of insulators are the same.

Conclusion:

In this paper, an insulator string consists of 5 units usually used in 63kV overhead transmission lines is considered in order to investigate the impact of pollution and its amount on the performance of the insulators of a insulator string. The pollution amount is modeled as the insulators paralleled resistances for pollution impact investigation. Therefore, according to the obtained relations and the simulation results, it was distinguished that the potential distribution on the insulator is non-uniform and insulator behaves as the no dirt condition for resistance values more than $10^9\Omega$. In addition, it was concluded that the potential distribution is uniform if the resistance value is less than $10^7\Omega$ in which the leakage current magnitude on insulator surface is several times more than that of the previous condition.

However, the simulation results showed that pollution could not be considered as an advantage despite it improves the potential distribution on insulator surface because it would bring about problems such as losses and leakage current of insulator string increase. This would lead to temperature increase of insulators, which can finally result in insulators weaken and electric break down.

REFERENCES

EL-KiShky, H., R.S. Gorur, 1994. Electric Potential and Field Computation along ac HV Insulators. IEEE, Trans. on Dielectrics and Electrical Insulation, 1(6): 982-990.

Pattanadech, N., 2004. The measurement Technique for Distributed Voltage of a Sting Insulator using a Standard Sphere Gap. IEEE, International Conference on power sys technology – Powercon – singapor.

Al-Dhalaan, S.M., M. Elhirbawy, 2003. Simulation of Voltage Distribution Calculation Method Over a String of Suspension Insulators, IEEE, Trans.

Al-Dhalaan, S.M., M. Elhirbawy, 2003. Investigation on the Characteristics of a String of Insulator due to the Effect of Dirty. IEEE Trans.

Farang, A.S.A., F.M. Zedan, T.C. Cheng, 1993. Analytical Studies of HV Insulators in Saudi Arabia. IEEE Trans. on Electrical Insulation, 28(3): 379-391.

Cho, H.G., S.W. Han, K.H. Park, D.H. Han, 2005. Ageing Characteristics of Porcelain Suspension Insulators for Transmission Line by Cool and Heat Accelerate Method, IEEE, 7th International Conference on Properties And Applications of Dielectric Materials.