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ANALYSIS OF CHARACTERISTICS OF SUSPENSION INSULATOR UNDER POLLUTED ENVIRONMENT

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ABSTRACT
Transmission and distribution power network use string of suspension insulators between line conductor and support structure. Most of the insulators are mounted in open air applications and so gradually contamination is deposited on the surface of insulator. Severe environmental conditions and pollution degree have a strong influence on insulator performance and reduce the voltage withstand capacity of insulator. The presence of pollution on the insulators surfaces considerably modifies the voltage distribution across an insulator string. This paper presents the results of calculation of the voltage distribution and string efficiency on string insulator of 132kV made up of porcelain due to the effect of dust and rainy condition with the help of MATLAB/Simulink.

***Keywords**: High voltage, Overhead line, Porcelain insulators, Pollution, String efficency, Voltage distribution, MATLAB.*

I. INTRODUCTION
In recent years, the demand of electrical power has been increased to a large extent. To satisfy this demand, electrical companies have had to improve the efficiency of their transmission lines. The efficiency of the system is based mainly on the continuity of the service, avoiding faults that suppose economical losses for companies and users. To maintain this continuity, one of the main problems that have been found is the failure of insulators of electric lines due to polluted environment. This pollution is one of the main causes of flashover in the insulators. The insulator begins to fail when the pollutants that exist in the air settle in the surface of the insulator and combine with the humidity of the fog, rain, or dew. The mixture of pollutants and the humidity form a layer that can become conductive and allow passing currents that will facilitate the conditions of short circuit. This is due to the decrease of resistance of the insulator surface. Insulators for overhead lines are considered to be of basic importance to the transmission system, through their ability to insulate the power lines as well as their function in carrying the weight of the line conductor.[1] Outdoor insulation is polluted by natural or industrial pollution (sea salt, salt sands, industrial dust). Additional sources of pollution are rain (e.g. acid rains) and gases—especially sulphuric oxide and nitric oxide (SO, NO). With heavily polluted areas the surface conductivity on insulators can exceed which leads to arcing development and eventually to flashover at continuous operating voltage.

In suspension insulator numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulators. Each insulator of a suspension string is called disc insulator because of their disc like shape. The insulators constitute one of the most important parts of the transmission lines as the flashover of polluted insulator can cause breakdown of the transmission network. Climate is the most effective factor in pollution formation on insulators and the flashover mechanism. A polluted layer on HV (High Voltage) insulators is very frequently in industrial and coastal regions. It has been considered that the flashover occurs more frequently in polluted insulators. Pollution flashover, observed on insulators used in high voltage transmission, is one of the most important problems for power transmission. Pollution flashover is a very complex problem due to several reasons such as modeling difficulties of insulator complex shape, different pollution density at different regions, non-homogenous pollution distribution on the surface of insulator and unknown effect of humidity on the pollution. [2] The performance of insulators under polluted environment is one of the guiding factors in the insulation coordination of high voltage transmission lines. On the other hand, the flashover of polluted insulators can cause transmission outage of long duration over a large area. Flashover of polluted insulators is still a serious threat to the safe operation of a power transmission system. It is generally considered that pollution flashover is becoming even more important in the design of high voltage lines. Contamination level and the design of the fittings, conductors and tower are eminent facts that influence the voltage distribution over an insulator string. [5-6] The line insulators are often covered with contaminations, especially in industrial and coastal regions due to the long time exposure in the air. In a condition of high humidity, the salt in the contamination will be dissolved by the moisture because of rain, fog or dew. Therefore, the conductivity of the surface pollution increases, leading to a possible flashover accident on the insulators. On porcelain insulators surfaces, wet atmospheric conditions easily lead to the formation of water films. If the contamination is very heavy, salts in the contaminations dissolve into the water films and result in uncontrolled leakage currents, which easily lead to flashover. [2-7] The voltage distribution across an insulator is not uniform, and the unit nearest to the line end is stressed to their maximum allowable value. Therefore, in this paper voltage distribution and string efficiency are calculated in polluted conditions such as rainy and dust condition, using MATLAB/ Simulink.

II. TYPES OF INSULATORS

The use of proper insulator is an important part of the mechanical design of the overhead lines. The various types of the insulators are:

A. Pin Type Insulators: This type is attached to a pin, which is secured to the cross- arm on the pole or tower. The porcelain should not be in direct contact with the hard-metal pin and a soft-metal thimble must separate the two surfaces. There is a groove on the upper end of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor, generally it is used up to 33kV [3].

B. Post Insulators: These are used for supporting the bus bars and disconnecting switches in the sub-station. A post insulator is similar to a pin-type insulator but has a metal base and, frequently, a metal cap so that more than one unit can be mounted in series. In this insulator, the porcelain elements are in the form of cones fitting one inside the other and bonded by special cement [3].

C. Suspension Type Insulators: As the voltage level increases, pin type insulators become very bulky and their cost also increases rapidly. Therefore, most popular insulators used for very high voltage transmission lines are suspension type insulators above 33kV. They are also known as disc insulators or string insulators. The suspension insulator consists of a disc-shaped piece of porcelain, and grooved under the surface to increase the surface leakage path, fitted with a metal cap at the top, and a metal pin underneath. Each unit is designed for low voltage 11kV but a string of such units gives the proper insulation against very high voltage levels. [3]

Table 1. Number of insulators in suspension string

Voltage(kV)	Number of units
33	3-4
66	5-7
132	9-11
230	14-20
400	18-21
750	30-35

Table1 shows number of insulators in suspension strings for different voltage levels. If it is proposed to increase the line voltage, adding the appropriate number of discs can increase the line insulation. Each disc is designed for a low voltage and the required degree of insulation is achieved by using a suitable number of discs.

III. VOLTAGE DISTRIBUTION AND STRING EFFICIENCY

The main problem with suspension insulators having a string of identical insulator discs is the uniform distribution voltage over the string. Each insulator disc with cap and pin constitutes a capacitor. When several units are connected in a series we can conclude that [3- 4]:

The voltage on each insulator over the string is not the same.
The location of the unit within the insulator or string dictates the voltage distribution.
The maximum voltage gradient takes place at the insulator unit nearest to the line conductor.

The units nearest to the line are stressed to their maximum allowable under stress, resulting in a 'waste' of insulating material. The string efficiency is a measure of the utilization of material in the string. [4]

String efficiency = voltage across the string/n *(voltage across unit adjacent to the conductor).
The line unit is always under the maximum stress. To avoid possibility of puncture of line unit due to excessive stress, efforts are made to have uniform potential distribution. Hence some methods are used to get uniform distribution and higher string efficiency. These methods are,

[A] Reducing ratio of shunt capacitance to self capacitance: Reduction in the shunt capacitance relative to the capacitance of each unit. The voltage across the line unit depends on the value of (k = C2 /C1). Only increasing the length of cross- arm can do this. Due to the limitations of mechanical strength and cost of towers the value of (k) cannot be reduced to less than 0.l.

[B] Capacitance grading:By correct grading of the insulators, more uniform voltage distribution across the string can be achieved. In this the insulators are so selected that the self capacitance of the various units are different and the value of decreases from line unit towards top unit. So top unit has minimum mutual capacitance while line unit has maximum mutual capacitance, in that case more the capacitance lesser is the voltage across the capacitance. [4]

[C] Static shielding: This method uses a large metal ring surrounding the bottom unit and connected to the line. Such a ring is called “guard ring”. This is also known as a static shielding, introduces capacitances between different joints of line. Thus primary aim of the guard ring is to reduce the electrical stress on the tower units. [4].

IV. SIMULATION MODEL

Simulink is one of the designing tools of MATLAB software which is being used for simulation of electrical systems. The basic circuit and simulated circuit of string of suspension insulators are explained in detail as follows.

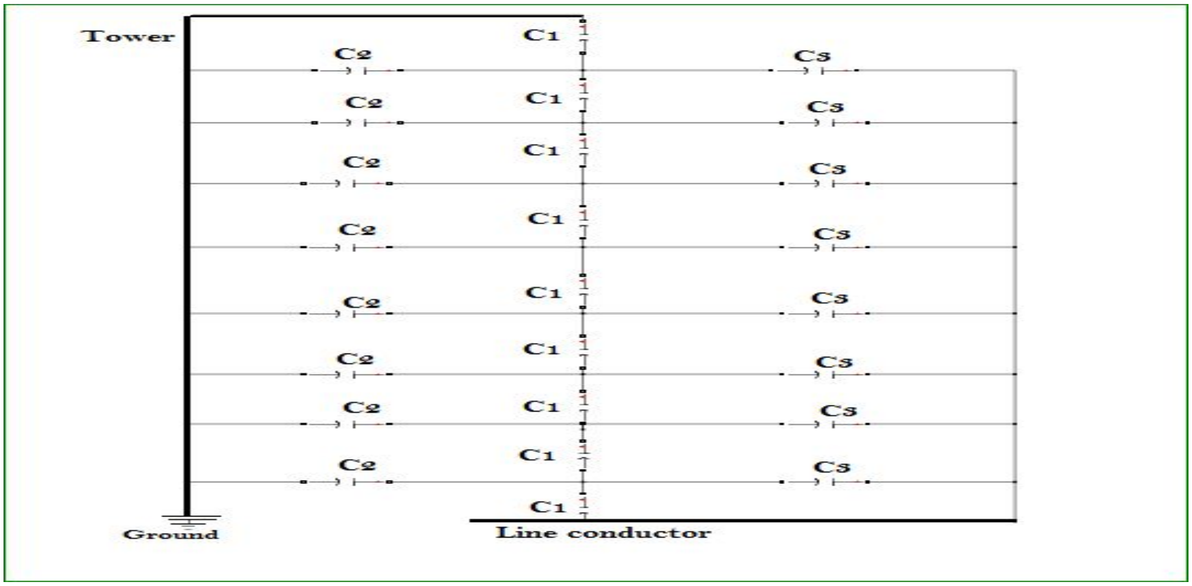

Fig.1 Basic circuit of a string of suspension insulators.

Fig.1 shows basic equivalent circuit of a string of suspension insulators for 132kV. The portion which is in between the two metal fittings forms a capacitor. This is called self capacitance and is denoted as C1. Hence whole the string shown in fig.1 will consist of nine self capacitors in series. If only such self capacitors exist alone in series, the voltage across them would have been equal and series charging current through them would have been same. But in addition to the self capacitance, there will be capacitance between each metal fitting and the earth i.e. tower. The air acts as a dielectric, such a capacitance is called “shunt capacitance” that is denoted as C2. Assuming the design of each section of the string same, the self capacitances are assumed equal. Similarly all shunt capacitors are also assumed equal. There will be capacitance between metal fittings and the line conductor i.e. guard ring capacitance. Fig. 1 also shows Guard ring capacitance of rating C3. A guard ring is a circular conductor located near the bottom of a high-voltage insulator string from where the line conductor or conductors are suspended. Its function is to evenly-distribute the potential gradient across the length of the insulator string, by preventing the concentration of electric field in the vicinity of the line conductor, which would otherwise act to break down the insulating properties of the insulator chain.

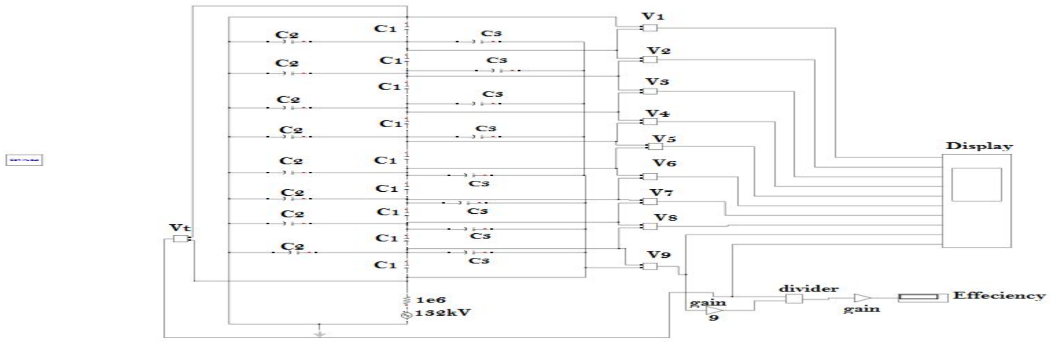

Fig.2 Simulink model for a string of suspension insulator under normal atmospheric conditions (132kV)

Fig.2 shows Simulink model for a string of nine unit's porcelain disc suspension insulators for 132kV.
There are nine discs of Self Capacitances C1=44.97pF are being used in designing of this model in MATLAB/SIMULINK, which are connected in series. Practically shunt capacitance C2 << C1 and its value is 2- 6pF,. In this paper its value is taken as 3pF. Hence eight No's of Shunt Capacitances of Rating C2=3pF are connected in Shunt. Guard Ring Capacitances are also connected in the simulation model whose values are as follows C3=0.375pF, C4=0.85pF, C5=1.5pF, C6=2.4pF, C7=3.75pF, C8=6pF, C9=10.5pF, C10=24pF. In this model different voltage V1, V2, V3……………V9 for nine units of insulator string, and Vt (total voltage) have been measured to find their voltage distribution and efficiency under normal atmospheric condition, that's shown in table 2.
In rainy season the self capacitance value increases. As a result of which series capacitance value has increased from 44.97pF to 49.46pF. The values of voltage distribution and efficiency are shown in table 3.

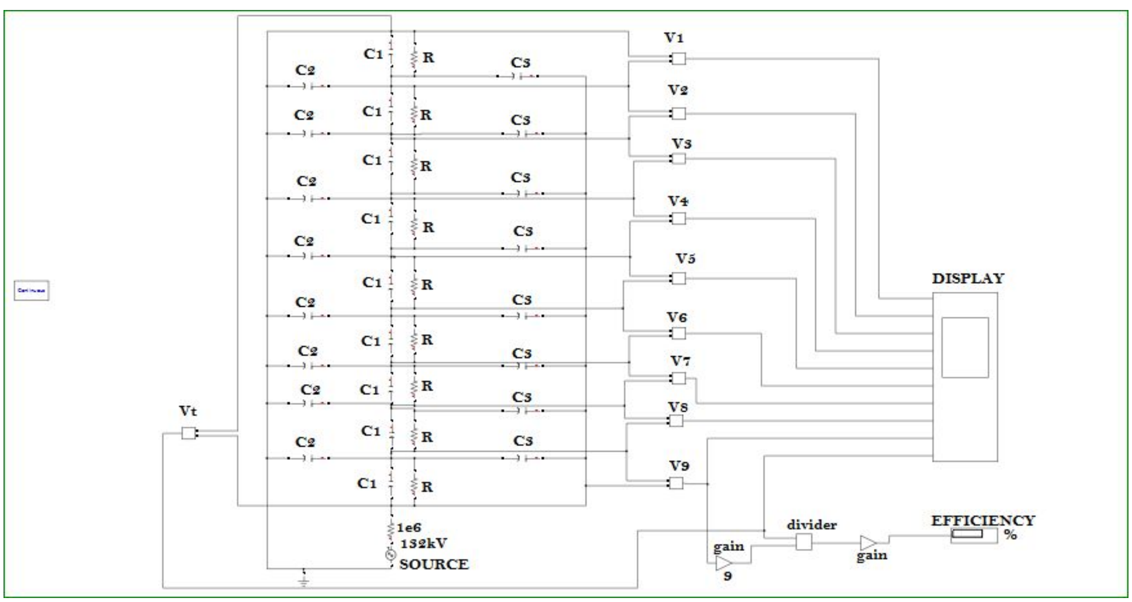

Fig.3 Simulation model for 132kV porcelain suspension insulator during dust(R) condition.

Fig.3 shows basic model of 132kV suspension insulator under dust condition. To calculate effect of dust on insulation, a parallel resistance is considered between pin of each insulator [8]. R represents values of resistances like 10e3, 10e4, 25e4, 5e5 for insulator under dust condition. Voltage distribution across different discs of string and efficiency are calculated for these resistances as shown in table 4.

V. RESULT AND DISCUSSION

Table 2: NORMAL ATMOSPHERIC CONDITION

Self capacitance C1= 44.97pF (for porcelain suspension insulators), Shunt capacitance C2=3pF, Guard ring capacitances are, C3=0.375pF, C4=0.85pF, C5=1.5pF, C6=2.4pF, C7=3.75pF, C8=6pF, C9=10.5pF, C10 =24pF

V_1(kV)	V_2(kV)	V_3(kV)	V_4(kV)	V_5(kV)	V_6(kV)	V_7(kV)	V_8(kV)	V_9(kV)	Efficiency (%)
13.04	13.25	13.65	14.28	15.12	15.24	15.40	15.80	16.25	96.86

The values of voltages as shown in table 2 are the values between each disc of 132kV string of suspension insulator under normal condition that is without considering effect of contamination obtained with help of simulation model.

Table 3: UNDER RAINY CONDITION

Self capacitance C1=49.46pF, Shunt capacitance C2=3pF, and guard ring capacitances are C3=0.375pF, C4=0.85pF, C5=1.5pF, C6=2.4pF, C7=3.75pF, C8=6pF, C9=10.5pF, C10 =24pF

V_1(kV)	V_2(kV)	V_3(kV)	V_4(kV)	V_5(kV)	V_6(kV)	V_7(kV)	V_8(kV)	V_9(kV)	Efficiency (%)
13.15	13.34	13.73	14.32	14.80	15.13	15.52	15.81	16.60	98.89

The values of voltage shown in table 3 are obtained with help of simulation model for 132kV suspension insulator observed under rainy condition.

Table 4: UNDER DUST CONDITION

Self capacitance C1=44.97pF, Shunt capacitance C2=3pF, guard ring capacitances are C3=0.375pF, C4=0.85pF, C5=1.5pF, C6=2.4pF, C7=3.75pF, C8=6pF, C9=10.5pF, C10 =24pF, and R1 =10e3, R2=10e4, R3 =25e4, R4=5e5

Voltage(kV)	R_1 =10000(ohm)	R_2=100000(ohm)	R_3=250000(ohm)	R_4=500000(ohm)
V_1	12.86	12.81	12.78	12.60
V_2	12.92	12.94	12.89	12.76
V_3	13.60	13.42	13.28	13.10
V_4	13.82	13.65	13.61	13.58
V_5	14.52	14.27	14.24	14.20
V_6	15.26	14.86	14.82	14.80
V_7	16.25	15.92	15.88	15.85
V_8	17.45	16.98	16.92	16.90
V_9	18.64	18.26	18.14	18.07
Efficiency (%)	94.67	92.84	85.67	83.24

The values of voltage shown in table 4 are obtained with help of simulation model for 132kV suspension insulator observed under dust condition shown in fig.3.The values of R1, R2, R3, and R4 shown in the above table represents different levels of dust contamination. It can be easily observed that as the value of resistance increases, the overall efficiency goes on decreasing 94.67%, 92.84%, 85.67%, 83.24% respectively as shown in above table. Fig. 4 shows graph between number of insulator units and voltage distribution across of string in normal, rainy and dust conditions.

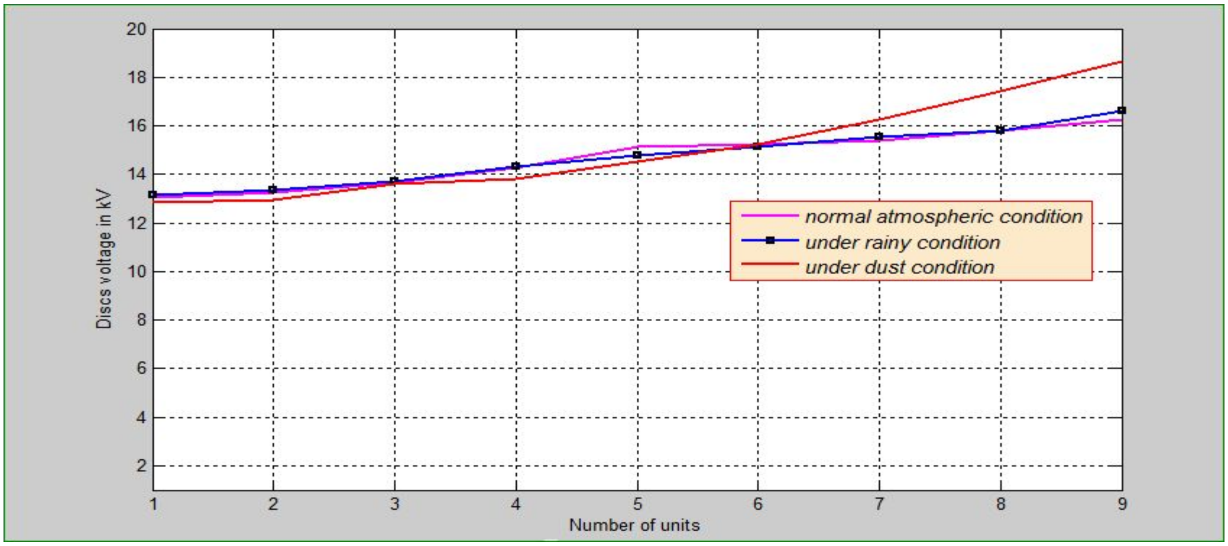

Fig.4 Graph between no. of suspension units of string & voltage distribution.

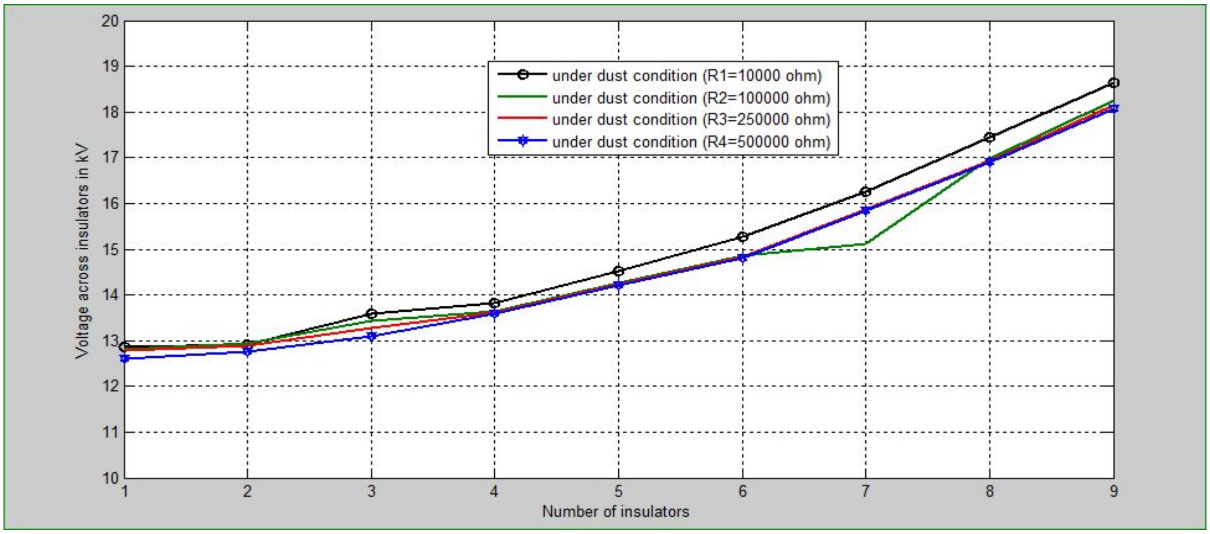

Fig.5 Graph between number of insulators and voltage across insulators for different values of resistances.

Fig.5 shows graph between number of insulators and voltage across insulators for different values of resistances. It shows that for lower value of resistance the voltage distribution is more uniform but the discs are more stressed and likely to fail.

VI. CONCLUSION

It has been observed that in the normal atmospheric condition the capacitance ratio values can adjust the voltage distribution on insulator string units up to the desired level as expected. In rainy condition of suspension insulators moisture or humidity increases at the insulators surfaces that increase the leakage path and self capacitance value will increase. Thus the ratio of shunt to self capacitance decreases. This increases uniformity of the voltage distribution. Hence in rainy season, string efficiency is higher than efficiency during clean condition.

The dust condition on insulator causes decrease in the magnitude of resistance. The dust on the insulator's surface creates a path for leakage current and this reduces the inequality of voltage distribution. Although for lower value of resistance the voltage distribution is more uniform but the discs are more stressed and likely to fail.

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