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INVESTIGATION OF CERAMIC AND NON-CERAMIC SUSPENSION INSULATOR UNDER DIFFERENT POLLUTED CONDITION

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ABSTRACT
There is basic importance of insulators in a transmission line system through their ability to insulate the power lines as well as their function in carrying the weight of the line conductor. For higher voltages, a string of suspension insulators is used, in which a number of insulator units are used. The number of insulator units depends on the voltages of the lines. The voltage is not equally shared between the units of suspension insulator string. The capacitance between each cap/pin junction & tower and between the cap and pin of each unit determine the voltage distribution. In this paper, analysis of voltage distribution and string efficiency of ceramic and non-ceramic suspension insulator string for 132kV is done for different condition such as clean condition, polluted condition and rainy condition. For these, equivalent circuit models are developed considering their capacitances and resistances. Models are developed in a software package named as MATLAB/Simulink.

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

I. INTRODUCTION
Electrical Insulator must be used in electrical system to prevent unwanted flow of current to the earth from its supporting points. Overhead line conductors are not themselves insulated; they should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports. The higher the operating voltage of a transmission line, the longer the insulators string [1-2]. In the early days, insulators were made of ceramic and glass materials. But in 1963, polymeric insulators were developed and its improvements in design and manufacturing in the recent years have made them attractive to utilities. It consists of a fibre glass core rod covered by weather sheds of skirts of polymer such as silicone rubber, polytetrafluoroethylene, EPDM (ethylene propylene dyne monomer) and equipped with metal end fittings. It is also called composite insulators, which means made of at least two insulating parts core and housing equipped with end fittings. [3-5]
One of the main problems under which the distribution network is exposed is the environmental pollution of its electrical insulation. The particles placed in the insulators are not dangerous in dry weather, but the problem arises when the environmental weather is humid, rains, there is dew, fog then the layer can become conductor. The conductivity of this layer will depend on the kind of salt that form on it.[4] The long term electrical performance of a polymer insulator is contingent upon the weather ability of the polymer material and the level of electrical stress subjected to the material. Hydrophobicity is the characteristic of silicone rubber that sets it apart from other commonly used insulator materials [6-10]. In this paper, the voltage distribution on the insulators (ceramic and non-ceramic) units of the suspension insulators string and the efficiency of the string of at 132kV is observed using software "MATLAB". For this a model is developed, which based on the capacitance and the resistance of the insulators units of the insulator string under rainy and dust conditions. The simulation shows of voltage distribution and efficiency over a string of suspension insulators in case of clean, dust, rainy conditions are presented.

II. INSULATING MATERIAL
The materials generally used for insulating purpose are called insulating material. Insulators used for high-voltage power transmission are made from glass, porcelain or composite polymer materials.
Porcelain in most commonly used material for over head line insulator .The porcelain is aluminum silicate. The aluminum silicate is mixed with plastic kaolin, feldspar and quartz to obtain final hard and glazed porcelain insulator material. The surface of the insulator should be glazed enough so that water should not be traced on it. The insulators are cooked to 1400ºC and later they are covered with a layer of silicate, boil subsequently to obtain a glazed in hot, doing them waterproofs and slippery, complicating in this way the adhesion of humidity and dust. [3-5]

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Glass insulator has become popular in transmission and distribution system. Annealed glass is used for insulating purpose. Glass is manufactured melting to temperatures among 1300ºC and 1400ºC a mixture of salicylic acid with oxides of calcium, sodium, aluminum, etc. However due to their smaller cost and their transparency, that facilitates the visual control, they substitute in many cases to those of porcelain. [3-5]
In polymer insulator has two parts one is glass fiber reinforced epoxy resin rod shaped core and other is silicon rubber or EPDM made weather sheds. Rod shaped core is covered by weather sheds. Weather sheds protect the insulator core from outside environment. The rod shaped core is fixed with hop dip galvanized cast steel made end fittings in both sides. It has higher tensile strength compared to porcelain insulator. Its performance is better particularly in polluted areas. [5-8]

III. SUSPENSION INSULATOR

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.

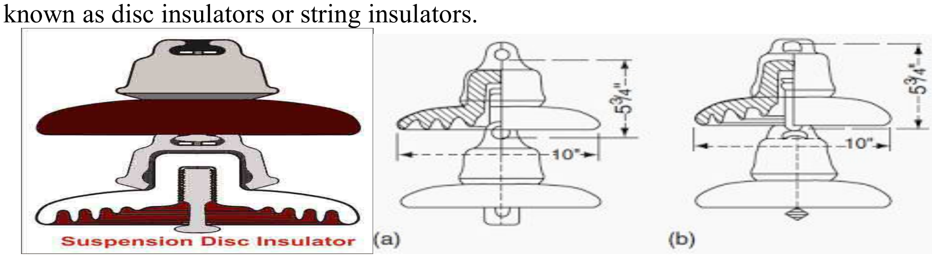

Fig.1 Standard diameter of suspension disc insulator

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. Fig. shows suspension disc insulator, the standard diameter is 254 mm, and for large unit considered diameter of suspension insulator is 314mm. The self capacitance value of suspension insulator is calculated by disc capacitance = 8εA, where A is radius, ε_o =8.854*10^{-12} f/m, ε_r is relative permittivity. The relative permittivity values are different for glass, porcelain, and polymer materials are (3.7-10), (5.0-7.0), (3.2-9.8) respectively.

IV. 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 ($k = C_2 /C_1$). 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. The primary aim of the guard ring is to reduce the electrical stress on the tower units. [4]

V. SIMULATION MODEL

MATLAB / SIMULINK software is being used for the modelling of this model. Simulink is one of its designing tools which is being used for modelling and simulation of electrical systems in MATLAB software. The complete precise modelling of the circuit along with their mechanism is explained in detail as follows below.

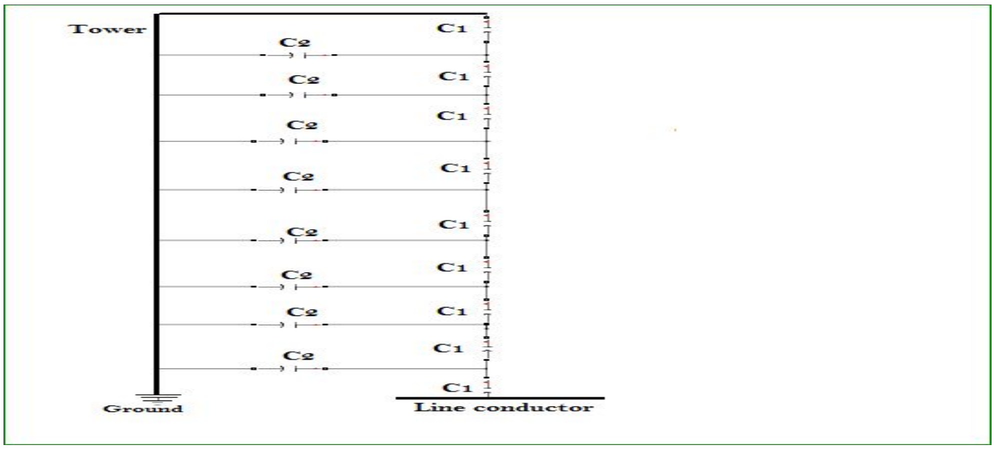

Fig.2 Basic equivalent circuit of a string of suspension insulators

Fig.2 shows basic equivalent circuit for string of ceramic and non-ceramic suspension insulators. The portion which is a between the two metal fittings. Thus it forms a capacitor. This is called self capacitance that is denoted as C_1. Fig.2 will consists 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 C_2, as shown in circuit.

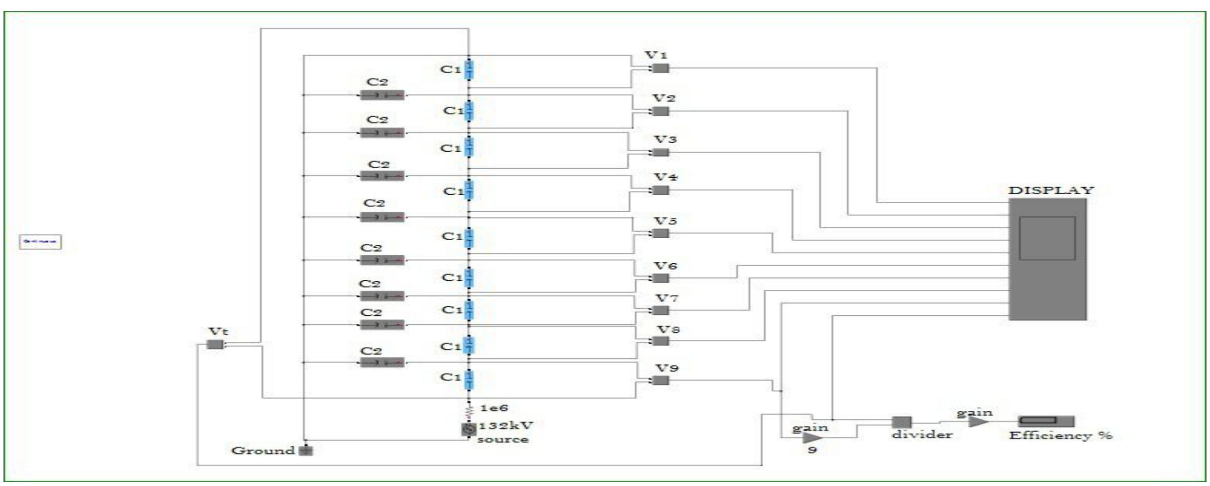

Fig.3 Simulink model for a string of suspension insulator under normal atmospheric conditions (132kV)

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Fig.3 shows atmospheric model for ceramic and non-ceramic suspension insulators for 132kV. The porcelain portion which is a between the two metal fittings, forms a capacitor, i.e. called self capacitance denoted as C_1. 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 C_2. Assuming the design of each section of the string same, the mutual capacitors are assumed equal. Similarly all shunt capacitors are also assumed equal. The capacitance ratio is $C_2/C_1= k$, thus the shunt capacitance is k times of the mutual capacitance. In this model different voltage V_1, V_2, V_3..............V_9 for nine units of insulator string, and Vt (total voltage) have been measured to find their voltage distribution and efficiency as shown in table1.
In rainy season the self capacitance value increases. As a result of which series capacitance value has increased from 50pF to 60pF. And shunt capacitance (C_2) values is 2-6pF practically, $C_2 <<< C_1$. In this paper we have taken 2pF.In this model there are nine No's of Self Capacitances of Rating C_1= 60pF are being used in designing of this model in SIMULINK. In addition to this eight No's of Shunt Capacitances of Rating C_2 = 2pF are connected in Shunt. The values of voltage distribution and efficiency are shown in table 2.
In case of glass suspension insulators during rainy season the self capacitance value increases. As a result of which series capacitance value has increased from 40pF to 48pF. The values of voltage distribution and efficiency are shown in table 2.
In rainy condition of polymer suspension insulators, the insulators are wet and the self capacitance value increases. As a result of which series capacitance value has increased from 30pF to 36pF. The values of voltage distribution of each discs and efficiency are shown in table 2.

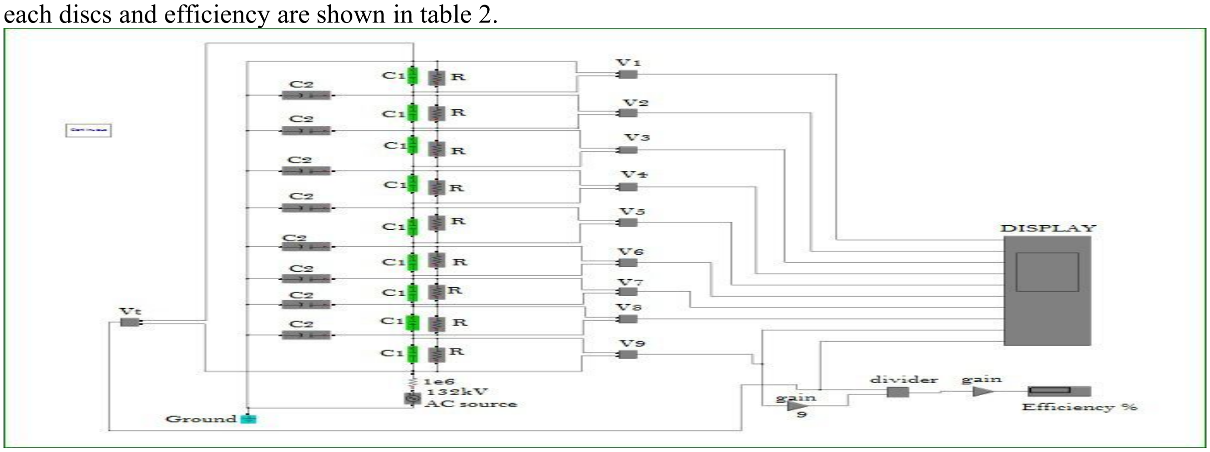

Fig.4 Simulation model for 132kV ceramic and non-ceramic suspension insulator during dust (R) condition.

Fig.4 shows simulation model of 132kV ceramic and non ceramic suspension insulator under dust condition (R). To calculate pollution effect on insulation considering resistance reduction by pollution, a parallel resistance is considered between each insulator [7]. R represents values of resistance $10e^3$, $10e^4$, $25e^4$, $5e^5$ for insulator under dust condition. The values of voltage distribution and efficiency for different values of R (showing amount of dust on ceramic and non-ceramic suspension insulators) is shown in table 3(a), 3(b) and 3(c).

VI. RESULTS AND DISCUSSION

TABLE 1: NORMAL ATMOSPHERIC CONDITION FOR PORCELAIN, GLASS AND POLYMER SUSPENSION INSULATORS

Self capacitance C_1 = 50pF (for porcelain suspension insulators), k = 0.04
Self capacitance C_1 = 40pF (for glass suspension insulators), k = 0.05
Self capacitance C_1 = 30pF (for polymer suspension insulators), k = 0.06
Shunt capacitance C_2 = 2pF (for porcelain, glass and polymer suspension insulators)

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)	η (%)
7.39	7.68	8.29	9.22	10.52	12.25	14.46	17.26	20.73	57.76
6.63	6.96	7.64	8.80	10.20	12.21	14.82	18.17	22.45	53.35
5.58	5.96	6.72	7.95	9.70	12.08	15.28	19.51	25.03	47.87

The values of voltages as shown in table 1 are the values between each disc of 132kV string of porcelain, glass and polymer suspension insulator under normal atmospheric condition that is without considering effect of contamination obtained with help of simulation model as shown in fig.2. The efficiency of porcelain, glass, and polymer suspension insulators are 57.76%, 53.35% and 47.87% respectively. In porcelain suspension insulators, (a). When upper disc is large as 80pF and lower disc is 50pF, the line nearest of the conductor voltage is 15.30kV and efficiency will be increased up to 78.22%. (b). When lower unit is 80pF and remaining units are 50pF, the last unit voltage is 13.97kV and efficiency is 85.75%. In glass type, lower disc large as 70pF and remaining units are 40pF the line voltage nearest of the conductor is 14.08kV and efficiency increased from 53.75% to 85.04%. In polymer suspension insulator, (a) When lowest unit is 55pF and remaining 30pF the line voltage is 15.26kV and efficiency 78.50%. (b) In last unit of polymer suspension we connected a disc of glass insulator one unit 40pF, the line voltage is minimum stressed 19.92kV and efficiency 60.12%. (c) Now in last unit we connected porcelain disc 50pF in series the line voltage is 16.56kV and efficiency increased up to 72.37%.

TABLE 2: UNDER RAINY CONDITION FOR PORCELAIN, GLASS AND POLYMER SUSPENSION INSULATORS

Self capacitance C_1 = 60pF (for porcelain suspension insulators)
Self capacitance C_1 =48 pF (for glass suspension insulators)
Self capacitance C_1 = 36pF (for polymer suspension insulators)
Shunt capacitance C_2 = 2pF (for porcelain, glass and polymer suspension insulators)

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)	η (%)
7.96	8.22	8.76	9.60	10.75	12.26	14.17	16.55	19.51	61.40
7.25	7.55	8.18	9.13	10.45	12.25	14.49	17.40	20.99	56.95
6.25	6.60	7.32	8.44	10.05	12.18	14.98	18.66	23.35	51.31

The values of voltage shown in table 2 are obtained with help of simulation model for 132kV porcelain, glass and polymer suspension insulator observed under rainy condition which is shown in fig.1, fig.3 and fig.4 respectively. In rainy condition, observed that the efficiency is increased from atmospheric condition it will be 61.40%, 56.95% and 51.31% of porcelain, glass and polymer suspension insulators respectively.

TABLE 3: UNDER DUST CONDITION FOR PORCELAIN, GLASS AND POLYMER SUSPENSION INSULATORS

(a) FOR CERAMIC (PORCELAIN) INSULATORS

Voltage(kV)	R_1 =10000	R_2=100000	R_3=250000	R_4=500000
V_1	7.16	7.24	7.30	7.37
V_2	7.43	7.52	7.60	7.67
V_3	8.01	8.11	8.18	8.28
V_4	8.90	9.00	9.10	9.15
V_5	10.17	10.28	10.39	10.50
V_6	11.76	11.92	12.06	12.22
V_7	13.20	13.84	14.31	14.35
V_8	16.32	16.85	16.94	17.22
V_9	19.84	20.18	20.48	20.69
Efficiency (%)	73.05	66.41	62.38	58.62

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(b) FOR CERAMIC (GLASS) INSULATORS

Voltage(kV)	R_1 =10000	R_2=100000	R_3=250000	R_4=500000
V_1	6.46	6.53	6.57	6.62
V_2	6.78	6.86	6.90	6.95
V_3	7.44	7.50	7.55	7.63
V_4	8.42	8.55	8.61	8.68
V_5	9.89	10.02	10.09	10.18
V_6	11.84	11.96	12.08	12.18
V_7	14.40	14.55	14.65	14.79
V_8	17.62	17.80	17.96	18.15
V_9	21.74	21.98	22.19	22.41
Efficiency η (%)	75.95	68.28	60.19	54.57

(c) FOR NON CERAMIC (POLYMER) INSULATORS

Voltage(kV)	R_1 =10000	R_2=100000	R_3=250000	R_4=500000
V_1	5.54	5.46	5.32	5.20
V_2	5.88	5.80	5.72	5.64
V_3	6.90	6.75	6.60	6.47
V_4	7.92	7.64	7.46	7.25
V_5	9.26	8.66	8.42	8.20
V_6	11.98	11.85	11.64	10.98
V_7	14.56	14.89	14.44	13.78
V_8	19.78	19.44	19.21	19.08
V_9	22.56	23.95	24.48	26.34
Efficiency (%)	78.67	64.30	52.71	46.90

The values of voltage shown in table 3(a, b, c) are obtained with help of simulation model for 132kV porcelain, glass, polymer suspension insulator observed under dust condition shown in Fig.4. The values of R_1, R_2 and R_3 shown in the above table represents different levels of dust contamination and also the table represents different values of voltage and the effecency so obtained under different dust condition. In table shows different voltages in the string where in that case the nearest unit of conductor is more stressed in case of ceramic and non-ceramic suspension insulators. The different values of voltage distribution and efficiency of these insulators are observed under different dust condition. A graph is plotted between no. of units and voltage distribution under clean, rainy, and dust condition which is shown in fig 3, 4, 5 respectively.

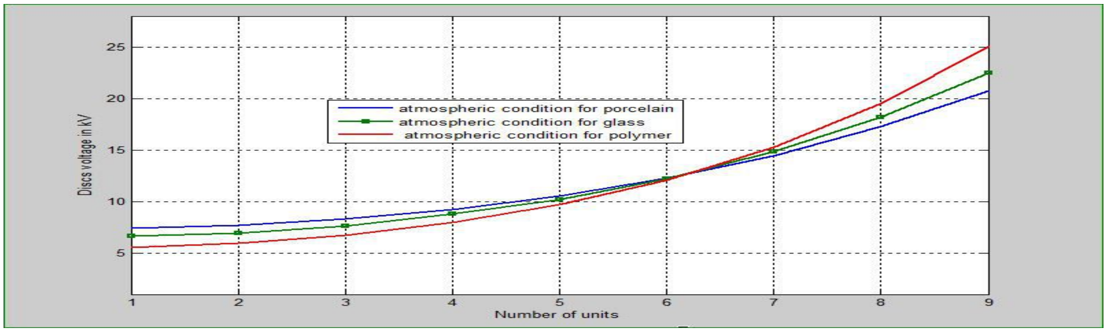

Fig.3 Graph between No of units of string & voltage distribution in porcelain, glass and polymer suspension insulators under atmospheric condition

From the above graph it is clearly observed that the voltage across the lower unit of polymer suspension insulators is maximum during atmospheric condition is more as compared to porcelain and glass suspension insulators. In last unit of polymer suspension insulator have maximum stressed in atmospheric condition because where have more voltage as 25.03kV, But in case of porcelain and glass the nearest voltage is 20.73kV and 22.45kV this is on minimum stressed.

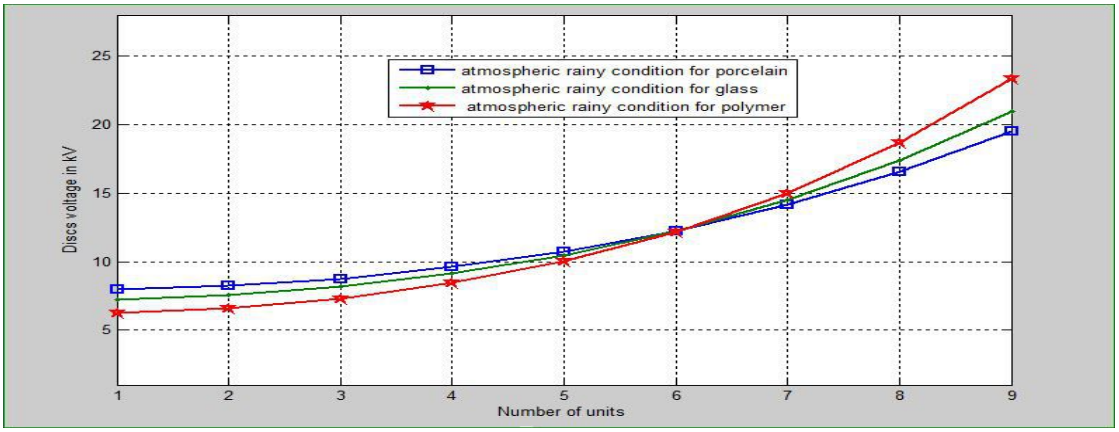

Fig.4 Graph between no. of units & voltage distribution in porcelain, glass and polymer suspension insulators under rainy condition

From the graph it is clearly observed that the voltage across the lower unit is maximum, under polymer rainy condition of more as compared to rainy condition of porcelain and glass. In last unit of suspension insulator have maximum stressed in case of polymer rainy condition because where have more voltage as 23.35kV, But in case of glass and porcelain under rainy condition the nearest voltage is 20.99kV and 19.51kV.

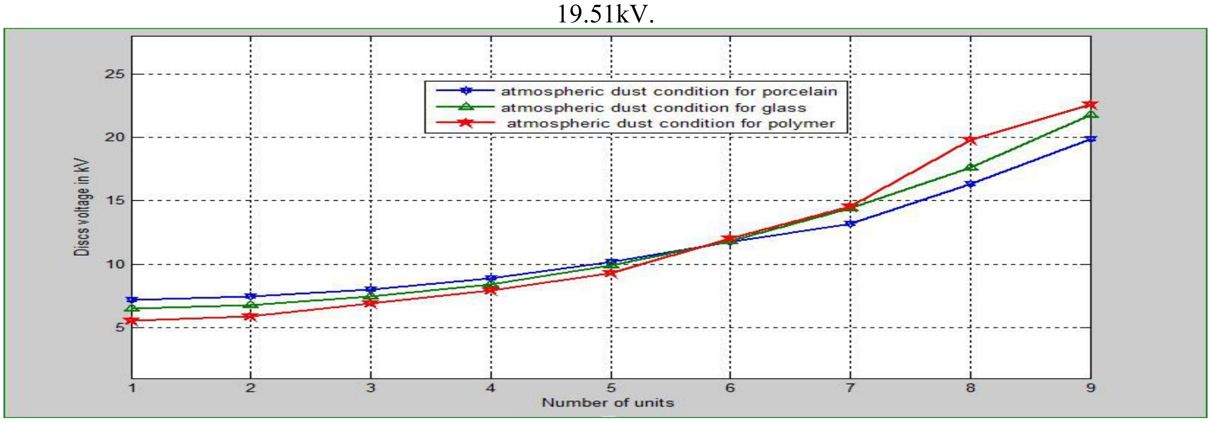

Fig.5 Graph between No of units of string & voltage distribution in porcelain, glass and polymer suspension insulators under dust condition

From the graph 5 it is observed that the voltage across the lower unit is maximum, under polymer dust condition of more as compared to dust condition of porcelain and glass. In last unit of suspension insulator have maximum stressed in case of polymer dust condition because where have more voltage like as 22.56kV, 23.95kV, 24.48kV, and 26.34kV But in case of glass and porcelain under dust condition the nearest voltage is as 21.74kV, 21.98kV, 22.19kV, 22.41kV and 19.84kV, 20.18kV, 20.48kV, 20.69kV this is on minimum stressed due to the dust resistances $10e^3$, $10e^4$, $25e^4$, $5e^5$.

VII. CONCLUSION

It has been observed that the capacitance ratio (k) values can adjust the voltage distribution on insulator string units up to the desired level as expected. If there is a self-capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same. The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance. The disc nearest to the conductor has maximum voltage across it. During rainy condition of ceramic and non-ceramic suspension insulators the last unit has minimum stressed compared to normal atmospheric condition. 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.

REFERENCE

[1]. IEC 383, 1993, "Tests on Insulators of Ceramic Material or Glass for Overhead Lines with a nominal voltage greater than 1000V''.
[2]. S. M. AI Dhalaan, M. A. Elhirbawy, "Simulation of Voltage Distribution Calculation Methods Over a String of Suspension Insulators", paper has been submitted to IEEE/F'ES 2004 Transmission and Distribution Conference and Exposition theme "Blaring Trails In Energy Delivery and Services". USA.
[3]. S. Kumagai, and N. Yoshimura, "Leakage current characterization of estimating the condition of ceramic and polymeric insulating surfaces", IEEE Trans. Dielectric Electr. Insul, Vol. 11, pp. 681-690, 2002.
[4]. S. Chandrasekhar, K. Krishnamurthy, M. Paneinerselvam and C. Kalaivanan, "Investigations on Flashover Performance of Porcelain Insulators under Contaminated Conditions", National Conf. Electrical Engineering and Embedded Systems, (NCEEE), pp.112-116, 2008.
[5]. Matsuoka, 1996, "Assessment of basic contamination withstand voltage characteristics of polymer insulators," IEEE Trans. on power delivery, vo1.11, no4, pp.1895-1900.
[6]. Gutman, X. Liang, B. Leo, Z. Su, E. Solomonik, and W. Vosloo, "Evaluation of OHL performance based on environmental stresses and pollution laboratory testing of composite insulators", Cage Session, Paris, C4-112, 2008.
[7]. D.A. Swift, C. Spellman and A. Haddad, "Hydrophobicity Transfer from Silicone Rubber to Adhering Pollutants and its Effect on Insulator Performance", IEEE Trans. Dielectric. Electr. Insul. Vol. 13, pp. 820-829, 2006.
[8]. H.Mackey, "lithe krformance of High Voltage, Outdoor Insulation in Contaminated Environment", transactions of the South African Institute of Electrical Engineers, pp. 80-92, April 2007.