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INVESTIGATION OF CERAMIC AND NON-CERAMIC 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. The insulator plays a vital role in electrical system. 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 (i.e. line conductors must be properly insulated from supports). Insulator is an electrical device, made of non- conducting material, used to give support to electrical conductors and shield them from ground or other conductors. String insulator is a two or more suspension insulators connected in series. 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– a 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. This problem can be controlled by a suitable design of the insulation level of the distribution line, applying different guides of outdoor insulation operating under different contaminated conditions. 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. The weather conditions vary considerably from the coastal areas to the interior areas and they play a very important role in the contaminants deposition rate and in the operation of the insulator. [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. Since silicone rubber does not readily wet-out, leakage current remains low and flashover are prevented. Contamination flashover performance of silicone is far superior to other insulation materials, and because the contamination layer is hydrophobic, power washing of silicone insulators is not required [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.

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II. INSULATING MATERIAL

Insulators used for high-voltage power transmission are made from glass, porcelain or composite polymer materials. Porcelain insulators are made from clay, quartz or alumina and feldspar, and are covered with a smooth glaze to shed water. Insulators made from porcelain is in alumina are used where high mechanical strength. Glass has a higher dielectric strength, but it attracts condensation and the thick irregular shapes needed for insulators are difficult to cast without internal strains. Some insulator manufacturers stopped making glass insulators in the late 1960s, switching to ceramic materials. Recently, some electric utilities have begun converting to polymer composite materials for some types of insulators. These are typically composed of a central rod made of fibre reinforced plastic and an outer weather shed made of silicone rubber or ethylene propylene dyne monomer rubber (EPDM). Composite insulators are less costly, lighter in weight, and have excellent hydrophobic capability. This combination makes them ideal for service in polluted areas.
The main cause of failure of overhead line insulator, is flash over, occurs in between line and earth during abnormal over voltage in the system. [3][7].

Properties of Insulating Material

The materials generally used for insulating purpose are called insulating material.For successful utilization, this material should have some specific properties as listed below:-

- It must be mechanically strong enough to carry tension and weight of conductors.
- It must have very high dielectric strength to withstand the voltage stresses in High Voltage (HV) system.
- It must possess high insulation resistance to prevent leakage current to the earth.
- It should not be porous.
- There must not be any entrance on the surface of electrical insulator so that the moisture or gases can ente r in it.

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]
Now days glass insulator has become popular in transmission and distribution system. Annealed glass is used for ins ulating purpose. Glass is manufactured melting to temperatures among 1300ºC and 1400ºC a mixture of salicylic acid with oxides of calcium, sodium, barium, 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 (Ethylene Propylene Dyne Monomer) made weather sheds. Rod shaped core is covered by weather sheds. Weather sheds protect the insulator core from outside environment. As it is made of two parts core and weather sheds, polymer insulator is also called composite insulator. 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. 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.

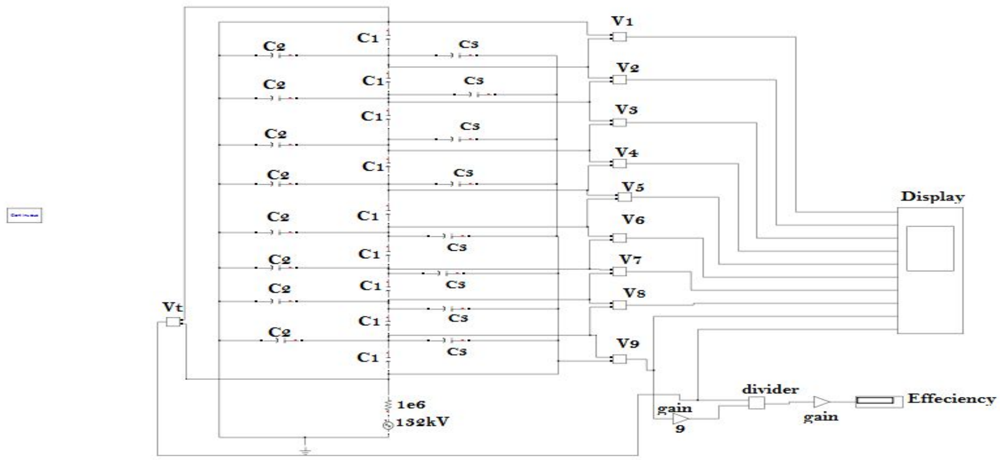

Fig.1 Simulink model for a string of suspension insulator under normal atmospheric conditions (132kV)

Fig.1 shows atmospheric model for ceramic and non-ceramic suspension insulators for 132kV. The porcelain portion which is an between the two metal fittings. Thus it forms a capacitor. This is called self capacitance that is denoted as C_1. Hence whole the string shown in fig.1 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. Assuming the design of each section of the string same, the mutual capacitors are assumed equal. Similarly all shunt capacitors are also assumed equal. There will be capacitance between metal fittings and the line conductor also, but its value is very small. Fig. shows Guard ring capacitance of rating C_3. 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. 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 44.97pF to 49.46pF. And shunt capacitance (C_2) values is 2- 6pF practically, $C_2 <<< C_1$. In this paper we have taken 3pF.In this model there are nine No's of Self Capacitances of Rating C_1= 49.46pF are being used in designing of this model in SIMULINK. In addition to this eight No's of Shunt Capacitances of Rating C_2 = 3pF are connected in Shunt. Guard Ring Capacitances are also connected in the simulation model whose values are as follows C_3=0.375pF, C_4=0.85pF, C_5=1.5pF, C_6=2.4pF, C_7=3.75pF, C_8=6pF, C_9=10.5pF, C_{10}=24pF. 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 33.28pF to 36.61pF. 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 28.78pF to 31.66pF. The values of voltage distribution of each discs and efficiency are shown in table 2.

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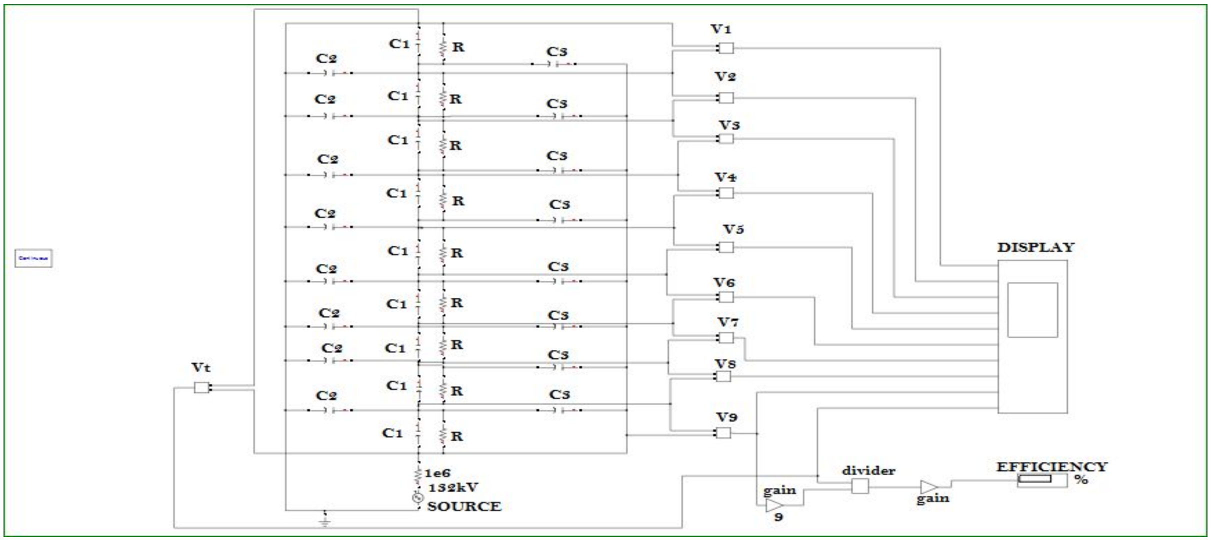

Fig.2 Simulation model for 132kV ceramic and non-ceramic suspension insulator during dust (R) condition.

Fig.2 shows basic 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).

IV. RESULTS AND DISCUSSION

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

Self capacitance C_1 = 44.97pF (for porcelain suspension insulators)
Self capacitance C_1 = 33.28pF (for glass suspension insulators)
Self capacitance C_1 = 28.78pF (for polymer suspension insulators)
Shunt capacitance C_2 = 3pF (for porcelain, glass and polymer suspension insulators)
And Guard ring capacitances are, C_3=0.375pF, C_4=0.85pF, C_5=1.5pF, C_6=2.4pF, C_7=3.75pF, C_8=6pF, C_9=10.5pF, C_{10}=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
12.60	12.80	13.29	14.02	14.90	15.03	16.20	16.40	16.88	89.26
12.50	12.81	13.34	14.02	14.60	15.20	15.68	16.70	17.07	85.90

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.1. In atmospheric condition the efficiency of porcelain, glass, and polymer (composite) insulators are 96.86%, 89.26% and 85.90% respectively.

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

Self capacitance C_1 = 49.46pF (for porcelain suspension insulators)
Self capacitance C_1 = 36.61pF (for glass suspension insulators)
Self capacitance C_1 = 31.66pF (for polymer suspension insulators)
Shunt capacitance C_2 = 3pF (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)	Efficiency (%)
13.15	13.34	13.73	14.32	14.80	15.12	15.52	15.81	16.20	98.89

13.34	13.45	13.88	14.73	14.88	15.05	15.25	15.45	15.92	98.57
12.71	12.96	13.48	14.25	15.08	15.34	15.48	16.01	16.73	97.13

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.2 and fig.3 respectively. In rainy condition, observed that the efficiency is increased from atmospheric condition it will be 98.89%, 98.57% and 97.13% of porcelain, glass and polymer suspension insulators respectively.

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

Self capacitance C_1 = 44.97pF (for porcelain suspension insulators)
Self capacitance C_1 = 33.28pF (for glass suspension insulators)
Self capacitance C_1 = 28.78pF (for polymer suspension insulators)
Shunt capacitance C_2 = 3pF (for porcelain, glass and polymer suspension insulators)

(a) FOR CERAMIC (PORCELAIN) INSULATORS

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

(b) FOR CERAMIC (GLASS) INSULATORS

Voltage(kV)	**R_1 =10000(ohm)**	**R_2=100000(ohm)**	**R_3=250000(ohm)**	**R_4=500000(ohm)**
V_1	12.35	12.33	12.28	12.10
V_2	12.58	12.54	12.48	12.32
V_3	12.99	12.95	12.88	12.73
V_4	13.58	13.52	13.44	13.30
V_5	14.36	14.27	14.15	14.10
V_6	15.40	15.38	15.26	15.14
V_7	16.54	16.24	16.04	15.85
V_8	16.86	16.30	16.18	16.07
V_9	18.72	18.52	18.23	18.17
Efficiency (%)	88.58	86.77	84.96	76.60

(c) FOR NON CERAMIC (POLYMER) INSULATORS

Voltage(kV)	**R_1 =10000(ohm)**	**R_2=100000(ohm)**	**R_3=250000(ohm)**	**R_4=500000(ohm)**
V_1	12.49	12.30	12.14	12.10
V_2	12.76	12.65	12.34	12.32
V_3	13.28	13.25	12.77	12.73
V_4	14.20	14.02	13.36	13.30
V_5	15.28	15.10	14.23	14.12
V_6	15.74	15.35	15.00	14.86
V_7	16.60	16.55	15.60	15.45

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V_8	16.96	16.67	16.35	16.20
V_9	18.98	18.80	18.63	18.24
Efficiency (%)	84.98	83.25	81.66	76.70

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.5. 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 efficency 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.

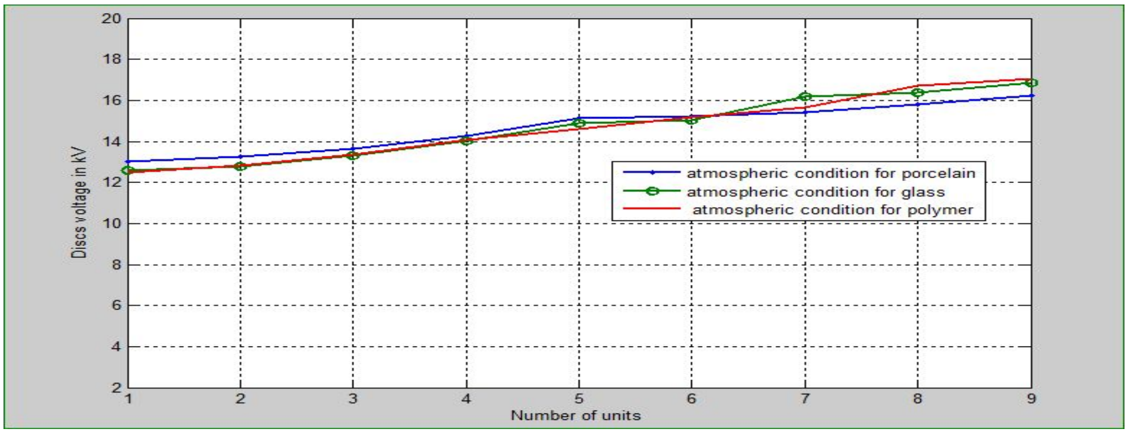

Fig.3 Graph between No of units of string & voltage distribution in porcelain, glass and polymer suspension insulators under atmospheric condition.

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 17.07kV, But in case of porcelain and glass the nearest voltage is 16.25kV and 16.88kV this is on minimum stressed.

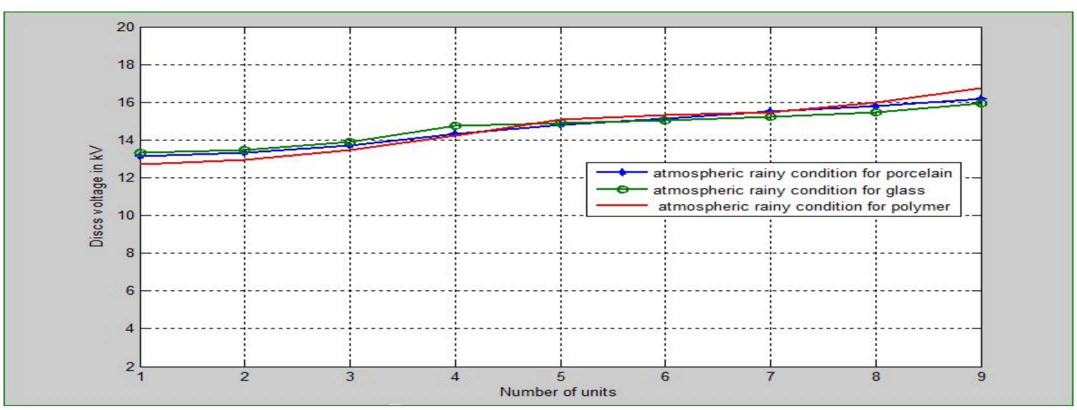

Fig.4 Graph between no. of units & voltage distribution in porcelain, glass and polymer suspension insulators under rainy condition.

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 16.73kV, But in case of glass under rainy condition the nearest voltage is 15.92kV this is on minimum stressed compared to porcelain and polymer rainy condition.

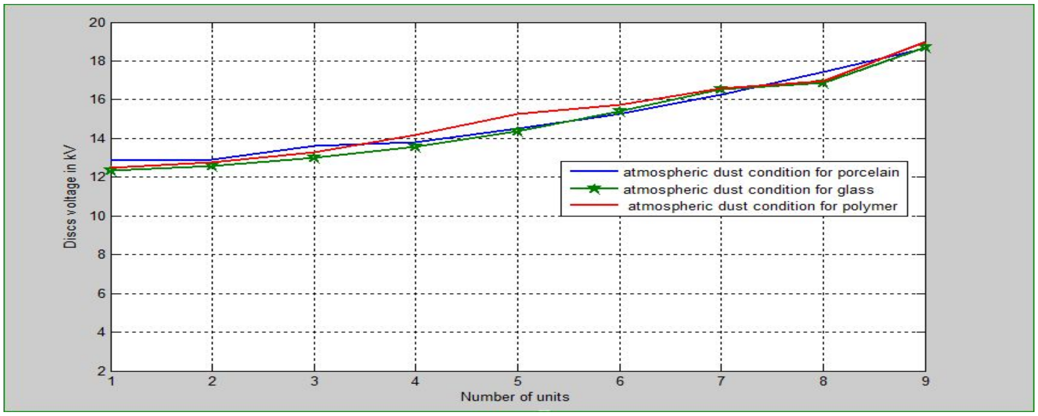

Fig.5 Graph between No of units of string & voltage distribution in porcelain, glass and polymer suspension insulators under dust condition.

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 18.98kV, 18.80kV, 18.63kV, and 18.24kV But in case of glass and porcelain under dust condition the nearest voltage is as 18.72kV, 18.52kV, 18.23kV, 18.17kV and 18.64kV, 18.26kV, 18.14kV, 18.07kV this is on minimum stressed due to the dust resistances $10e^3$, $10e^4$, $25e^4$, $5e^5$.

V. 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 are better performance compared that values of distribution and their efficiency's. We have concluded that the composite insulators performance better than glass and porcelain type suspension insulators. 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.

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