International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Analysis of Leakage Current of 220kV Long Rod Insulators at Different Severity Level of Salt Contamination

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Abstract: ***Insulator is one of the most vital elements of Power transmission system at high voltage. The performance of high voltage insulator is strongly affected by environmental pollution in coastal regions. Long Rod insulator is widely used for good performance in pollution regions. In this paper Long Rod insulator is examined in different Salt contamination level. With long term use of insulators in salt areas like near coastal areas salt particles is accumulated on high voltage insulator with help of wind, humidity, fog and moisture. These particles form a conductive layer on insulator surface and provide an ideal path to flow leakage current from line conductor to ground through insulator. The performance of polluted insulator mainly depends on the conductivity of the polluted surface layer or on the equivalent salt deposition density (ESDD). In this paper Leakage current is evaluated at different ESDD level of salt pollution on 220kV Long Rod insulator. The performance of COMPOSITE and PORCELAIN Long Rod insulator is examined at different pollution level.***

Keywords: Long Rod Insulator, Salt contamination, ESDD, leakage current, pollution severity, MATLAB/Simulink

1. Introduction

In the recent years power transmission demand is abruptly increased. For satisfying the demand of power, transmission companies have had to improve the overall efficiency of transmission lines. The main problem comes arise due to environmental pollution in transmission of power. There are many types of pollution that affects the insulation property of transmission line. These are classified on basis of contaminant substance like- Salt, Cement, Fertilizers, Coal, Dust, volcanic ash, Chemical, Smoke etc. The main types of pollution can be represented as Industrial, Marine, and Desert pollution [1].

Marine pollution is commonly produced by salt particle deposition on insulation surface of insulator situated near coastal region. Near coastal areas most of insulator pollution is occurred due to airborne salt particles of ocean. Small water bubbles are raised up from sea level by ocean waves and storm. Wind is main transporter for these tiny bubbles [2]. These bubbles of sea water distributed uniformly in the air of coastal area. If the humidity is low and temperature is high then these salt carrying bubbles dry up on the surface of insulator and leave crystals of salt particles. Insulators exposed near coastal area are sprayed extremely by the strong ocean winds. The deposition density of salt is mainly depends on the wind velocity and distance from sea coast.

Formation of salt particle layer on insulator provides an ideal path for leakage current from line conductor to tower through insulator surface. The presence of Fog, humidity and temperature can cause in increase of leakage current and dry band formation. Partial arcs can occurs across dry bands and further flashover of insulator may occur in bad conditions. The danger of pollution mainly depends on the conductivity of salt deposition layer. The severity of salt pollution is defined in terms of equivalent salt deposited density (ESSD) [3]. The higher ESDD value denotes higher severity as conductivity of surface increases.

Long Rod Insulator

In the coastal region Long Rod insulator is preferable than disc type insulator because of their superior antipollution quality. The term 'Long Rod' is actually used for specific design of porcelain insulator which was first introduced in Germany in the 1920s as an alternative to cap-and-pin insulator. At that time various disc (cap and pin) type insulator were dominating in electrical over head transmission line insulation [4]. They were replaced by porcelain Long Rod insulator. Insulators of Long Rod-design have been in use in central Europe for more than 60 years. More recently, the advantages of Long Rod insulators have found new places of installation as special interest of long rod design as composite Long Rod insulator [5].

Long Rod insulator is classified as –

1) Porcelain Long Rod insulator

Porcelain Long Rod insulator is made up of single alumina porcelain structure, to be fired in automatically controlled kilns using oxidizing and reducing atmosphere. Porcelain insulator is heavier and larger in dimensions than composite Long Rod insulator. A porcelain Long Rod insulator is illustrating in fig. 1.

2) Composite Long Rod insulator

All composite Long Rod insulators consist of a fiber – glass rod as the mechanically bearing element. Composite or Polymer or Silicon rubber insulator has at least two insulating parts, such as a fiber glass core and a housing equipped with metal end fitting. To compare with the porcelain or glass insulator, it has many advantages and has a development trend. Construction of composite Long Rod is shown in fig.2. The fiber reinforced core, metal fitting and silicone housing can be seen.

Figure 1: Porcelain Long Rod insulator

Figure 2: Construction of a composite long rod insulator

There are basic advantages of composite insulator over porcelain Long Rod insulator that is as given below-

- Resistance to flashover in polluted atmosphere is higher.
- High performance in contamination and polluted environment.
- Unique hydrophobicity character & self cleaning property.
- 10% to 35% weight of ceramic insulator.
- High tensile strength and unbreakable in vandalism prone area.
- Easy transport and installation.

2. Salt Pollution Measurement

2.1 Determination of ESDD

Equivalent salt deposit density is determined by artificial pollution in laboratory. In order to artificially contaminate the surface of insulator, solid layer method is adopted according (IEC 60507). ESDD is measured by periodically washing down the pollution from selected insulators with Distilled water. The conductivity of the washed water is measured and the equivalent amount of salt is determined. The composition of contaminating suspension consist of 30gm of kaolin in one liter of de-mineralized water with 0.25gm, 0.5gm, 0.75gm, 1.0gm of salts, the salinity is adopted of 10kg/m^3, 20kg/m^3, 30kg/m^3 and 40kg/m^3. The ESDD value is calculated using the formulation derived by IEC 60507.

$$\sigma_{s20} = \sigma_{V\theta}\left[1 - b(\theta - 20)\right] \quad \text{eq. (1)}$$

Where σ_{s20} = is the layer conductivity at temperature of 20°C (in S) $\sigma_{v\Theta}$ = is the measured volume conductivity at a solution temperature of Θ°C (in S/m)
b = is a correction factor depending on the temperature Θ.

The salinity, S_a of the solution at 20°C is calculated by the equation (2)

$$S_a = (5.7\ \sigma_{s20})^{1.03}\ \text{kg/m}^3 \quad \text{eq. (2)}$$

The ESDD value is obtained by dividing the measured mg value of salt, by washed area at the insulator surface.
ESDD = $(S_a V)/A$ (mg/cm^2)

It is observed that ESDD of the insulator increases with pollution accumulation period [3].

2.2 Relation between ESDD and conduction

Fig.2 shows that for salt pollution from 0.03 to 0.12, the variation of conductivity and ESDD is almost linear [6]. Relation between various ESDD level and surface conductivity is shown in table 1.

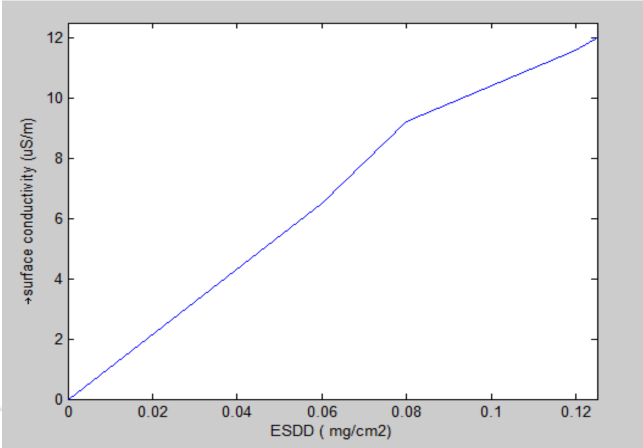

Figure 2: Graph between ESDD & surface conductivity

Table 1: Conductivity and ESDD of Insulator

NaCl (gm)	ESDD (mg/cm^2)	S_a (Kg/m^3)	σ_{s20} (μS/m)
5	0.03	3.4	3.2
10	0.06	13.5	6.5
30	0.08	59.05	9.2
50	0.12	74.84	11.6
100	0.25	146.67	22.3

It can easily understand that the value of surface conductivity is directly proportion to the salt contamination level. With the help of this table, surface conductivity is known at different ESDD level. So Pollution leakage resistance value for insulator can be calculated for Long Rod insulators at different contamination level.

3. Pollution Leakage Resistance for Long Rod Insulator

Specifications of parameters of composite long rod insulator are taken from Gem production site catalogue:

Model name	Rated voltage (kv)	Insulation height H (mm)	Creepage distance (mm)	Tensile strength (kN)
FXBW 220/160	220	1900	5180	160

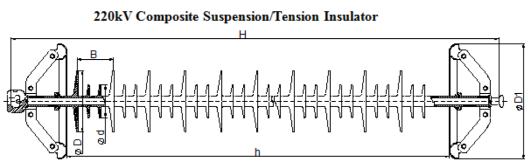

Figure 3: FXBW 220/160 Long rod suspension insulator

Leakage resistance due to salt pollution can be calculated with the help of conductivity given in table 1. Formula used for pollution leakage resistance is given as-

$$R_p = \frac{1}{\sigma s20} * L/A$$

Where L is the leakage distance of insulator in meter, A is cross sectional area of insulator in m^2. In this paper creepage distance 5180mm is taken of insulator FXBW 220/160, while diameter of shed is 256mm. By taking surface conductivity from Table.1 and values of L and A of given insulator model, leakage resistance value is calculated for all ESDD level given in Table.1. With different surface conductivity at different contamination level the pollution leakage resistance is tabulated as below in table 2.

It is observed that leakage resistance value is decreasing as salt pollution level is increased from low severity to high severity.

Table 2: Pollution leakage resistance of insulator

ESDD (mg/cm^2)	σ_{s20} (μS/m)	Pollution resistance R_P (MΩ)	Severity (IEC 60815)
0.03	3.2	14.782	Very light
0.06	6.5	7.968	Light
0.08	9.2	4.948	Moderate
0.12	11.6	3.740	High
0.25	22.3	1.957	Very high

4. Simulation Model

Long Rod insulator is a single unit insulator; it has no disc connected structure like string insulator. So there is one capacitance representing the whole unit rather than several disc capacitances in a string. In healthy condition there is no pollution and hence no leakage resistance. But in polluted condition a leakage resistance exists across insulator. An equivalent circuit of polluted Long Rod insulator is shown in fig.4

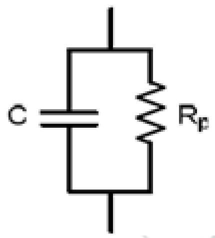

Figure 4: Simplified equivalent circuit of polluted Long Rod insulator

The capacitance exist between two end metal fittings of Long Rod insulator is known as self capacitance and denoted as C_1 in model. Beside the self capacitance, air behaves as dielectric between conductor end side of insulator and the tower. This forms earth capacitance or shunt capacitance and denoted by C_2 .

Usually shunt capacitance value is taken as 2 pF to 3 pF. In this model value of C_2 is taken as 3 pF , while shunt capacitance value is calculated for composite and porcelain Long Rod insulator separately by taking relative permittivity of composite and porcelain material ε_r =3.5 and ε_r = 6.5 respectively. C_1 = 3.11 pF is taken for porcelain Long Rod insulator and C_1 = 1.67 pF is taken for composite Long Rod insulator.

MATLAB / SIMULINK software is being used for modeling of that model. SIMULINK is one of the powerful modeling tools for modeling and simulation of electrical system. The complete model for measuring the leakage current of polluted long rod insulator is shown in fig.3

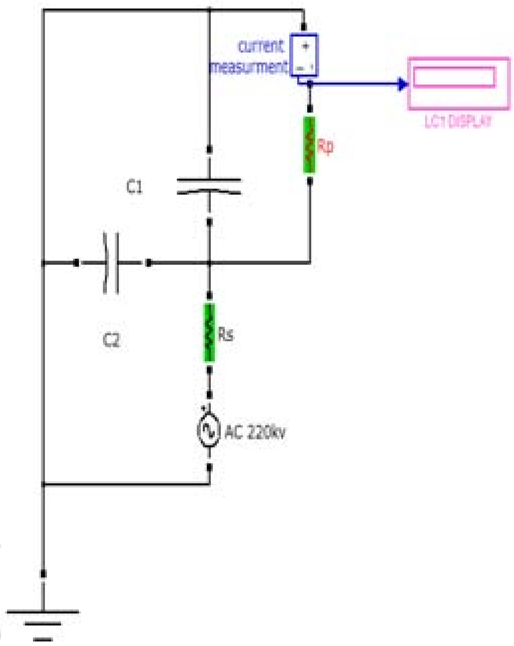

Figure 5: Simulation model of polluted long rod insulator

In that model 220kv supply is given with a source resistance R_s = 400 Ω. Leakage current is the current that flows over the surface of insulator that is intended for making rest part of tower non-conducting comparing from the line conductor. So the leakage pollution resistance is connected across the long rod insulator in series of a current measuring element. A display is connected from that current measuring element for taking the readings of leakage current.

5. Results and Discussion

From the model leakage current values during salt contamination are obtained for different severity level for porcelain and composite Long Rod insulator separately. Results are tabulated in Table.3 The values of leakage current shown in table.3 are obtained from simulation model of 220kv porcelain and composite Long Rod insulator at different level of salt contamination.

Table 3: Leakage current value at different severity level

ESDD (mg/cm^2)	Severity	Leakage current (mA)	
		Porcelain	Composite
0.03	Very low	12.19	8.64
0.06	Low	22.66	17.17
0.08	Moderate	38.98	28.57
0.12	High	57.50	43.09
0.25	Very high	84.99	51.10

A graph is plotted to compare the results of leakage current of porcelain and composite insulator.

As shown in Fig.6, it is clear from the graph that all values of leakage current during low to high salt contamination are in range of 1-100 mA for both porcelain and ceramic Long Rod insulator. In other investigations it is found that for disc type insulator the leakage current varies from 100 mA to 1.2A for all contamination level from low to high [7][8].

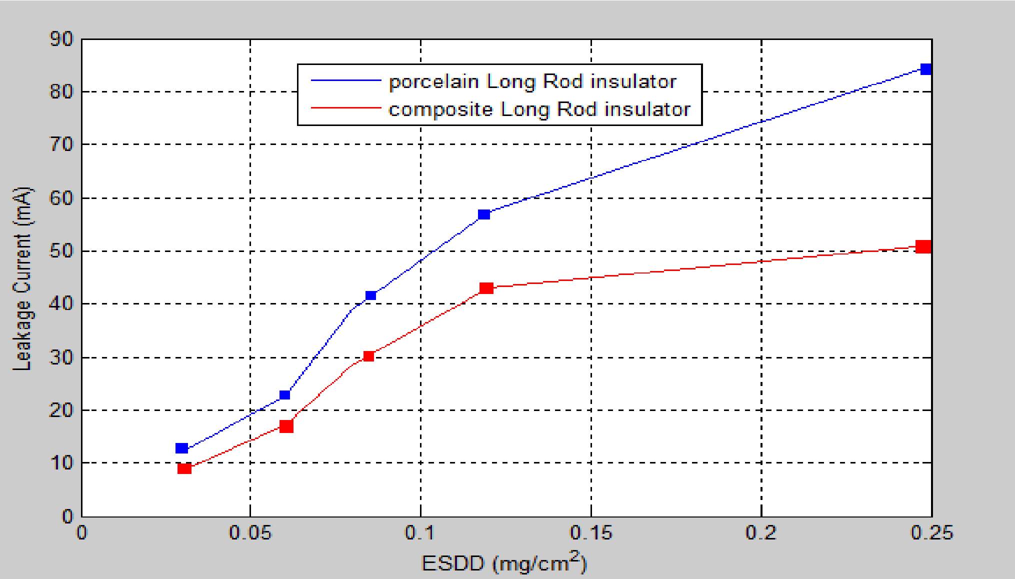

Figure 6: Graph between leakage current of porcelain and composite Long Rod insulator at different ESDD

From the above graph it is clearly observed that leakage current of composite insulator is lower than the porcelain insulator at ESDD level. This is also should be noticed that the percent of decreasment in leakage current of composite insulator at higher severity is excellent compare to porcelain insulator.

6. Conclusion

It has been observed that at different salt contamination level the performance of composite Long Rod insulator is excellent comparing to porcelain Long Rod insulator as the values of leakage current is very low. Further by comparison in Long Rod, composite Long Rod insulator has excellent antipollution performance with minimum leakage current compare to porcelain insulator at very high severity. At higher severity of pollution from 0.12 mg/cm^2 to 0.25 mg/cm^2, the increment in leakage current of composite long rod insulator is comparatively low than the porcelain insulator.

It can generally be concluded that at same pollution severity composite Long Rod insulator has minimal leakage current and very low pollution loss due to surface conductance.

Further work is required to investigate the effect of variation in specific creepage distance and effect of different type of shed shapes in long rod insulator.

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