



RE-EVALUATION OF CREEPAGE DISTANCE REQUIREMENTS FOR OUTDOOR INSULATION IN SEC-ERB

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ABSTRACT

The design and selection of transmission line insulation for power frequency operation is governed by the pollution/contamination deposit on the insulator surface, which is a measure of equivalent amount of sodium chloride (NaCl) deposit and is commonly known as Equivalent Salt Deposit Density (ESDD). The pollution in the service area of Saudi Electricity Company-Eastern Region Branch (SEC-ERB) is characterized by sea pollution, desert pollution and industrial pollution.

The pollution conditions in the coastal area are so severe that flashovers have occurred inspite of regular hot line washing of transmission line insulators even at a specific creepage distance of 40 mm/kV. In order to establish a suitable ESDD level and a corresponding specific creepage distance for the coastal area with the prime objective of reducing maintenance costs on hot line washing, a task force was setup within SEC-ERB to study and evaluate these aspects in greater details.

This paper describes the methodology and approach adopted by the task force to establish the ESDD level, the specific creepage distance, upgrade insulation level and to determine optimum wash cycle. Further a suitable fog type insulator with extended leakage path was selected so that electrical conductor clearances on the existing family of steel tower designs are not impaired and new insulation level is accommodated without any modifications.

Keywords: *Outdoor Insulation, Specific Creepage Distance, ESDD Level, Pollution, Insulators Contamination, Wash Cycle, Overhead Transmission Line*

. (Equivalent Salt Deposit Density, ESDD)

(Flashovers)

(ESDD)

ESDD

ESDD

1. INTRODUCTION

SEC-ERB has specified insulator contamination level of 0.3 mg/cm^2 for inland area and 0.50 mg/cm^2 for coastal area based on a pollution build-up period of six (6) months. Corresponding to this ESDD level a minimum specific creepage distance of 40 mm/kV of line-to-line voltage has been specified for outdoor insulation of transmission lines and substations.

Types of insulators being used on the overhead transmission lines are Porcelain fog/aero form, Glass fog/aero form and Composite Silicone Rubber. The specific creepage distance for the tension strings has been kept in the range of 48-50 mm/kV, i.e. higher than that for suspension strings.

Inspite of operating the transmission lines at this specific creepage distance, the insulator performance has not been satisfactory under high-humidity conditions and thus intensive insulator washing practices have been adopted to maintain the performance at an acceptable level. The wash interval ranges from two months for coastal area to one year for inland locations. This intensive wash program puts a high cost burden in terms of maintenance costs and sometimes is not practicable under non-favorable environmental conditions.

2. BACKGROUND

Initially, when the first transmission lines were built in SEC-ERB system, these were designed with a low specific creepage distance of 25 mm/kV using standard insulators [Al-Gwaiz Engineering Associates, 1983]. This design resulted in an unacceptable insulator performance and had to be increased to a level of 40 mm/kV using standard fog type insulators with a leakage path of 432 mm (Figure 1). Later on it was found that even operating the transmission lines at this increased specific creepage distance, the performance had not been satisfactory

and flashovers had occurred under high humidity conditions. In efforts to reduce line wash costs, SEC-ERB had been experimenting with different specific creepage distances in the coastal areas by upgrading the insulation levels through field trials. Super Fog insulator was introduced in the system with the intention to increase the creepage distance of existing lines without changing/increasing the insulator string length. This insulator has a leakage distance of 612 mm as compared with the standard fog insulator, whereas the height/spacing is 146 mm. With the use of this insulator the existing insulation level can be increased from 40 mm/kV to about 58.5 mm/kV. This is approximately 46% increase with respect to the existing level. With this insulation level the washing interval had been extended up to 3 years on some of the lines.

Since it was a direct jump from 40 mm to 58.5 mm without knowing the performance of intermediate insulation levels, it was decided to re-evaluate the insulation level corresponding to the actual prevailing ESDD levels in the coastal areas.

In order to study these aspects in greater details, a Task Force was setup within SEC-ERB to review and discuss the existing insulation criteria, performance of various types of insulators, line wash practices and optimum wash cycle, and to establish new insulation level according to severity of pollution and study the need to develop a pollution map for SEC-ERB system area.

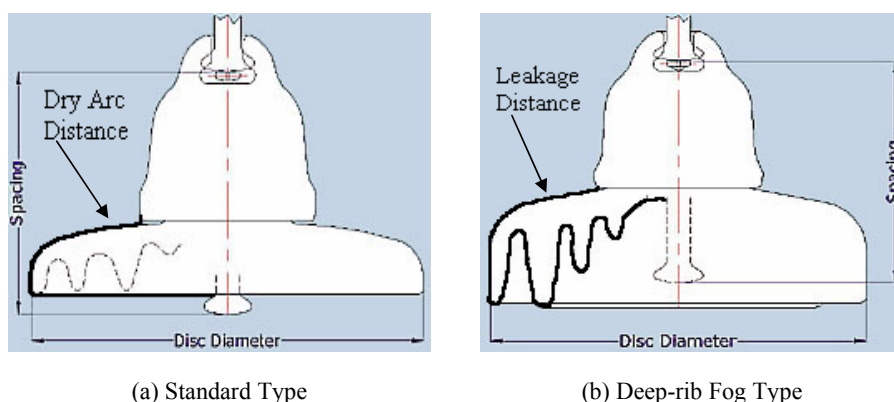


Figure 1: Shed profiles of standard and fog type insulators

3. DATA COLLECTION

Selection of outdoor insulation in a contaminated environment is governed primarily by the severity of prevailing pollution. It is, therefore, imperative to have a reasonable assessment of the site pollution severity for a technical sound insulation design. The dominant factors influencing the flashover voltage of a polluted insulator are:

- The amount of soluble materials (soluble material deposit density)
- Kinds of soluble material and
- The amount of non-soluble materials (non-soluble material deposit density)

Of these, the amount of soluble materials is the most influential, whereas the amount of non-soluble materials has a milder effect on the insulator flashover voltage. Therefore, in order to have a realistic and somewhat conservative assessment of site pollution, the existing data and information available within SEC-ERB as well as from outside sources were reviewed thoroughly.

4. ESTABLISHMENT OF ESDD LEVELS

In designing transmission system insulation for contamination, it is essential to know the degree of contamination over the area where transmission system is to be built. The degree of natural contamination is assessed by determining a parameter called Equivalent Salt Deposit Density (ESDD). The degree of contamination is expressed as the amount of sodium chloride (NaCl) needed to produce the measured conductivity by removing the actual contamination on the insulator surface in a known quantity of pure water divided by the area of the surface washed. The value is given as mg/cm^2 and thus ESDD provides a common means of characterizing contamination severity.

SEC-ERB had previously performed comprehensive ESDD measurements on one of its 115 kV transmission lines located in the coastal area (Ras Abu Ali Bay) in the period from 1992 to 1996 [KFUPM Reports, 1992 to 1996]. These measurements were done for comparison purpose between standard fog type and super fog type insulator to determine the optimum wash cycle for super fog through field trial. Further, as part of the national research program on insulator pollution sponsored by The Electricity Corporation, King Fahd University of Petroleum and Minerals (KFUPM) conducted ESDD measurements on sample insulators installed at energized as well as at un-energized test stations established in 1985 [KFUPM Study Reports, 1990]. These measurements were performed on monthly basis for a period of about three years. One of the energized test stations was located near Ghazlan Power Plant.

The Task Force considered adopting these measurements as a basis to establish a suitable value of ESDD. Specific Creepage Distance can, therefore, be selected on the basis of these ESDD measurements, past experience of SEC-ERB system with the existing insulation level of 40 mm/kV, performance of various types of insulators in SEC-ERB system and flashover voltage tests conducted by KFUPM on naturally and artificially polluted insulators.

On the basis of these measurements and to provide some additional safety margin to cater for any possible increase in pollution/contamination level in future, the Task Force established a value of 0.55 mg/cm^2 . This pollution level may be built up in a period of 2 to 3 years and thus washing interval could be extended safely up to 2 years.

Maximum ESDD level of 0.55 mg/cm^2 is applicable in the coastal area within a distance of 3 km from the coastline. Although, the pollution/contamination tends to decrease at locations farther from the coastline, for practical purposes the insulation design based on this level was considered to be applicable for a distance up to 50 km from the coast.

5. CALCULATIONS TO ESTABLISH CREEPAGE DISTANCE

The pollution withstand voltage of insulators is proportional to their string length, therefore, it is possible to figure out the required number of insulators in a string for a target design withstand voltage from the per unit withstand voltage.

The per unit withstand voltage for fog type insulators was determined on the basis of a relationship between flashover voltage and ESDD level developed by KFUPM [KFUPM Study Reports, 1990] through laboratory simulation of naturally polluted insulators. This relationship was used to determine the new insulation level corresponding to the selected ESDD level of 0.55 mg/cm^2 .

$$\text{FOV}_{(50\%)} = 15.462 (\text{ESDD})^{-0.2879} \text{ kV per meter of leakage distance} \quad (1)$$

Where,

$$\text{FOV}_{(50\%)} = \text{Flashover voltage of insulators corresponding to 50\% probability of flashover (also called critical flashover voltage, CFO)}$$

Therefore,

$$\text{FOV}_{(50\%)} = 18.366 \text{ kV per meter of leakage distance}$$

The withstand voltage of insulators is defined as the voltage corresponding to 5% flashover probability ($\text{FOV}_{5\%}$), which was obtained by reducing $\text{FOV}_{(50\%)}$ by 20%.

The flashover voltage of insulators also decreases considerably when the amount of non-soluble deposit density (NSDD) is of the order of ESDD or higher. The value measured at Ghazlan site amounts to about 6 mg/cm^2 . To account for this higher level of NSDD, a further reduction factor of 10% was applied to obtain the withstand voltage.

$$\text{FOV}_{(5\%)} = 13.223 \text{ kV per meter of leakage distance}$$

The flashover voltage of contaminated insulator strings is a function of the number of strings connected in parallel. For multiple parallel strings the flashover voltage decreases with the increase in number of strings [Electric Power Research Institute, 1982]. This is because of the fact that the number of weak points increases on the line and thus the probability of flashover increases. Therefore a further reduction factor of 10% was considered to account for 100 parallel strings on the transmission line.

$$\begin{aligned} \text{FOV}_{(5\%)} &= 0.90 \times 13.223 \\ &= 11.9 \text{ kV per meter of leakage distance} \end{aligned}$$

This results in

$$\text{Specific Creepage Distance} = \frac{1000}{11.9(\sqrt{3})} = 48.52 \text{ mm/kV (line to line)} \quad (2)$$

The Task Force suggested to round it off to 50 mm/kV_{L-L} and recommended to adopt this value as a minimum insulation level or specific creepage distance for coastal areas when ceramic insulators are used. For inland area and polymer insulators (in the coastal as well as in the inland areas) the specific creepage distance shall remain as 40 mm/kV_{L-L}. Suspension as well as tension insulators shall have the same specific creepage distance.

Total insulation level and number of fog type insulators for various system voltages corresponding to a specific creepage distance of 50 mm/kV were worked out as indicated in Table 1.

6. IMPACT OF UPGRADING INSULATION LEVEL

Existing tower clearances (conductor to cross-arm and conductor to tower body) were reviewed to accommodate the creepage distance of 50 mm/kV. The new insulation level could affect the conductor to structure clearance due to increase in insulator string length. However, by selecting an insulator with suitable leakage distance, the affect can be reduced. Existing tower designs for 69 kV, 115 kV, 230 kV and 380 kV transmission lines were, therefore, reviewed by using standard fog type insulator (432 mm leakage and 146 mm spacing) and extended leakage distance fog type insulators (545 mm leakage and 159/170 mm spacing).

It was determined that existing tower designs have enough clearance margins to accommodate the new insulation level without any modifications in the towers.

Table 1: Number of Fog Type Units

System Voltage (kV)	Total Insulation Level (mm)	No. of Standard Leakage Fog Type Insulators (432mm leakage distance)	No. of Extended Leakage Fog Type Insulators (545 mm leakage distance)
69	3450	8	-
115	5750	14	-
230	11500	-	22
380	19000	-	35

7. SELECTION OF OPTIMUM INSULATOR TYPE

Following fog type insulator ratings and leakage distances have been adopted for the overhead transmission lines in SEC-ERB:

- 111 kN M&E Strength, 146 mm spacing and 432 mm leakage (for suspension strings on 69 kV, 115 kV and 230 kV transmission lines).
- 178 kN M&E Strength, 159 mm spacing and 432 mm leakage (mainly for tension strings on 69 kV, 115 kV and 230 kV transmission lines).
- 178 kN M&E Strength, 159 mm spacing and 470 mm leakage (for V-strings on 380 kV lines).
- 222 kN M&E strength, 172 mm spacing and 550 mm leakage for (for tension strings on 380 kV lines).

Insulator with leakage distance of 432 mm is normally considered as standard and conventional fog type insulator, whereas those with leakage distance more than 432 mm are named as extended leakage insulators. To accommodate higher insulation level, extended leakage insulators were considered to be used at 230 kV and above, otherwise string lengths would become excessively high, which were, neither economically nor technically justified. The Task Force considered insulators with only two leakage distances, i.e. 432 mm and 545 mm for the entire system from 69 kV to 380 kV. Fog type insulators with 432 mm leakage were recommended for use on 69 kV and 115 kV lines in the suspension and tension strings. Whereas for 230 kV and 380 kV lines the leakage distance per unit insulator was recommended as 545 mm for both the suspension and tension strings.

By selecting suitable leakage distance and mechanical & electrical (M&E) ratings of insulators, the following options, as indicated in Tables 2 and 3 were considered for utilizing fog type insulators in the coastal area.

For Option 1, M&E ratings already existing in SEC-ERB system were retained and extended leakage was introduced in 111 kN and 178 kN insulators for 230 kV applications. For 380 kV applications, the only change was to increase the leakage distance from 470 mm to 545 mm for 178 kN insulators.

Table 2: Option 1

Rating (kN)	Spacing (mm)	Leakage (mm)	Voltage (kV)	Application (Suspension/Tension)
111	146	432	69	Suspension
111	146	432	115	Suspension
111	149	545	230	Suspension
178	159	432	69	Tension
178	159	432	115	Tension
178	159	545	230	Tension
178	159	545	380	Suspension
222	170	545	380	Tension

For Option 2, 178 kN insulator was replaced with 160 kN insulator. This was done in accordance with the requirements of IEC 60383 and ANSI C29.2 and in view of availability in the manufacturing industry. The Task Force recommended adopting this option for SEC-ERB transmission system.

Table 3: Option 2

Rating (kN)	Spacing (mm)	Leakage (mm)	Voltage (kV)	Application (Suspension/Tension)
111	146	432	69	Suspension
111	146	432	115	Suspension
111	149	545	230	Suspension
160	159	432	69	Tension
160	159	432	115	Tension
160	159	545	230	Tension
160	159	545	380	Suspension
222	170	545	380	Tension

8. CONCLUSIONS

- Uniform specific creepage distance of 50 mm/kV_{L-L} was adopted for suspension as well as tension strings for transmission lines in the coastal area, which is defined as the area within a distance of 50km from the coastline.
- For inland area, which is defined as the area located at a distance beyond 50 km from the coastline, the specific creepage distance was kept unchanged, i.e. 40 mm/kV_{L-L}. It was recommended to use the same specific creepage distance, i.e. 40 mm/kV on tension strings instead of 50 mm/kV.
- For Silicone rubber insulators, the specific creepage distance was kept as 40 mm/kV_{L-L} on suspension as well as on tension strings in the coastal as well as inland area.
- Optimum washing cycle shall be established by implementing the recommended specific creepage distance of 50 mm/kV_{L-L} on one of the 115 kV lines through field trials, initially keeping the wash cycle as one to one and half year and gradually increasing it to two years. Ras Abu Ali 115 kV transmission line was preferred for this implementation.
- Insulator ratings were standardized as 111 kN with 432 mm and 545 mm leakage distances and 160 kN and 222 kN with 545 mm leakage distance.
- The Task Force emphasized the need to initiate an insulator contamination survey by installing sample insulators on existing transmission lines as well as on some energized/un-energized test stations to collect, measure and monitor ESDD/NSDD levels in the coastal and in inland areas. This program will be a long-term program covering a period of 3 to 5 years. This will help in establishing a pollution mapping of the SEC-ERB service area.

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