DETERMINING INSULATION LEVELS FOR 220KV TRANSMISSION LINES IN NAMIBIA USING THE IST SOFTWARE

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Abstract: The correct dimensioning of insulators for power lines remains a critical issue for power utilities around the globe, both from a financial position and for ensuring the safe and reliable operation of such lines. Currently, computer programs exist which use statistical analysis methods to determine the correct insulation requirements for a given line servitude, based on pollution measurements and insulator performance tests. This paper describes the use of such software to generate insulation specifications for a 220 kV transmission line in the western region of Namibia. The intended line route was divided into six segments, and the pollution level for each segment was determined by use of Directional Dust Deposit Gauges. The analysis was based on a standard silicone rubber insulator model, whose performance curves are contained within the program database. The results show that a specific creepage distance of 21 mm/kV is sufficient for the entire line without over- or under-specifying the insulation.

1 INTRODUCTION

Determining the correct insulation levels, expressed in mm/kV, for a given service environment is an important step in creating specifications for new transmission lines in power utilities worldwide. Critical factors in this process include climate conditions along the servitude of the intended line as well as voltage levels. Insufficient insulation levels can cause insulator failure and costly line outages, while an overly conservative approach can result in unnecessary expenditures. A balance must thus be found between technical requirements and financial considerations.

In light of this, STRI has developed the Insulator Selection Tool (IST) software. This program utilizes statistical processes to calculate the pollution performance of overhead lines using relevant geometrical and electrical parameters of insulators. The information needed for the calculations is based on line data and pollution levels entered by the user. A customised program database contains insulator performance curves for a number of standard insulator types, as well as for insulator types for which required data has been supplied by the customer.

In 2009, NamPower (Namibia's sole power utility) acquired the IST software for creating insulator specifications based on Namibian service conditions. Previously, insulation specifications for new lines were generated based on conservative estimations of the prevalent pollution conditions along the line servitude, as well as past service experience. The increased accuracy gained from the use of the IST software is useful in obtaining the required balance between technical requirements and financial constraints.

This paper describes the procedure by which the IST software is used to create insulation specifications for a new 220 kV line for NamPower's transmission network. The environmental conditions along the intended servitude of the line are determined by pollution measurements and entered into the IST program, along with critical line parameters. The software is then used to generate the optimum insulation specification for this particular line.

2 ENVIRONMENTAL CONDITIONS

Situated in sub-Saharan Africa with the Atlantic Ocean alongside its entire western border, Namibia sports extensive desert & semi-desert regions. Consequently, a large part of NamPower's power network runs through such regions, as will the line used for this specific analysis.

The line in question will be situated in the Namib Desert, with the distance to the Atlantic Ocean varying from approximately 20 - 50 km. This region consists of highly arid land, with high daytime and low night-time temperatures. Close proximity to the ocean brings frequent fog occurrences (± 100 days of fog per year) and a humidity of 40 – 60 %, which however might drop to levels of < 20 % during east wind conditions. Annual rainfall lies below 50 mm. Altitude along the intended route varies from 100 – 600 m.

Combining these factors yields an environment in which insulators experience a large build-up of dust particles and contaminants on their surface, while the lack of rainfall results in little or no natural washing. Close proximity to the sea further means that salt deposits can produce a highly conductive pollution layer, and the large number of foggy days provides the moisture necessary to form such a layer. This results in a high risk of insulator flashover for the intended line.

Prior to the acquisition of the IST software, insulation specifications for transmission lines in such servitude would have been set at 25 mm/kV, which is the minimum specific creepage distance for a heavily polluted environment [1]. While this creepage distance might be required for some parts of the line, it could be excessive for regions farther removed from the ocean. However, in order to utilize the IST software to determine the correct creepage distance, more detailed pollution measurements are needed.

As part of NamPower's Insulator Pollution Program (IPP), a number of Directional Dust Deposit Gauges (DDDG's) were installed at various locations in the Namib Desert [6]. These devices are used to collect dust and other airborne particles into so-called dust jars from the four major compass directions. The dust jars are collected on a monthly basis and their contents mixed with distilled water, after which the conductivity of the resulting solution is measured. The four results for each site are then combined to yield the pollution index (PI) for the specific site. This value can then be used to classify the pollution level of the site according to guidelines set out in international standards [2]. Typical installations are shown in Figure 1.

Figure 1: Typical DDDG installations in the Namib Desert.

A total of six DDDG's are installed in locations along or close to the intended route of the line used for this analysis. Their relative distance to the ocean, their pollution levels and site classifications are given in Table 1. Two pollution values per site were considered in this analysis: the average value of all available monthly measurements and the maximum value recorded during the entire operation period.

As can be seen, only the station closest to the ocean shows a site classification in the medium pollution class, and that only as an overall maximum pollution value. This seems to be in contradiction to the initial assessment of the environment. However, it should be noted that the use of DDDG's does not permit the measurement of instantaneous pollution events, which can occur in areas where salt fog frequently occurs [1]. Moreover, the pollution level of a site can be increased by one level if the site shows a high level of non-soluble deposits [1]. Although this is very likely to be the case in a desert environment, since no exact measurements have been made regarding non-soluble depoits the site classifications are taken as is. An exception was made for stations 5 and 6, where the average pollution levels put them into the upper reaches of the "very light" class [2]. However, due to the large maximum pollution values, it was decided to rather classify them as light pollution, thus introducing an extra degree of safety to the analysis.

Table 1: Pollution classifications of DDDG stations along line route.

Station Name	Distance to Ocean [km]	Average Pollution Level:		Maximum Pollution Level:	
		Pollution Index [µS/cm]	Pollution Class	Pollution Index [µS/cm]	Pollution Class
Station 1	20.0	58.724	Light	273.345	Medium
Station 2	20.4	35.153	Light	118.588	Light
Station 3	21.3	29.846	Light	95.679	Light
Station 4	31.4	28.212	Light	122.843	Light
Station 5	43.2	23.161	Light	99.866	Light
Station 6	50.9	17.947	Light	109.399	Light

3 IST OPERATIONS

As described previously, the IST calculates insulation requirements based on information entered by the program user. The insulation requirements are determined for specific insulators available in the program's internal database, which can be customised for each user. Performance curves for the insulators contained within each database are either generated through laboratory or field tests.

Currently, the database of NamPower's IST software contains nine different insulator models, which have been tested on NamPower's 220 kV insulator test tower situated in the Namib Desert [5]. Insulator performance at this test site was determined by leakage current measurements, while site pollution severity was determined once again by DDDG measurements.

The user then has to enter information regarding the line to be analyzed into the IST program. This information includes:

- Maximum system/line voltage in kV
- Number of insulators on the line
- Permissible Mean Time Between Failures (MTBF) for the line, expressed in years
- Average altitude of line in meters

The user then selects the appropriate insulator model from the program database, depending on the insulator type and material intended for the line. Additionally, the user has to specify if the pollution layer encountered along the line servitude is uniform or non-uniform in nature, with respect to its distribution along the length of the insulators. Although insulators mostly develop non-uniformly distributed pollution layers across their surfaces in field conditions, a uniform pollution layer presents a more severe condition. This adds a safety margin to the results of the analysis. For this reason, the pollution layer was taken as uniform for this analysis.

Once the relevant information has been entered, the IST software generates the results in form of a graphical interface, displaying the required specific creepage distance for a range of pollution values. The user then uses a cursor to obtain the correct creepage distance for the required pollution severity, as determined by the site pollution measurements. Figure 2 shows a typical results window obtained for such an analysis. All critical results are also displayed in text form in the results window for the user's convenience.

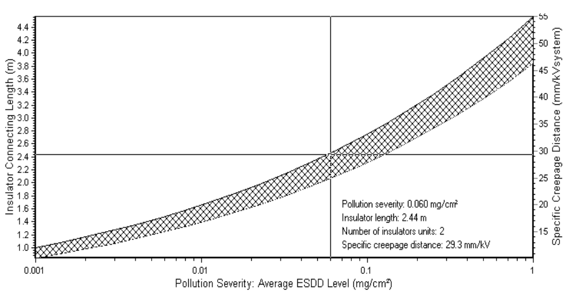

Figure 2: Typical result window of IST program.

After having described the general working of the IST program, the following chapter will describe the analysis of the chosen line.

4 LINE ANALYSIS & RESULTS

As the intended line passes close to six DDDG stations installed in the Namib Desert, the line was divided into six individual segments. The segments were determined by grouping the towers of the intended line under the DDDG station closest to each individual tower, based on the direct distance between tower and station as measured by Global Positioning System (GPS). Each line segment thus corresponds to a specific environmental area with its own pollution classification. A total of three insulators per suspension and six insulators per strain tower were assumed for each segment. The line segments with their corresponding DDDG stations, as well as the total number of insulators and the average altitude (based on GPS measurements) of each segment are displayed in Table 2.

Table 2: Details of line segments.

Line Segment	Corresponding DDDG Station	No. Of Insulators	Average Altitude [m]
LS1	Station 1	66	220
LS2	Station 2	96	180
LS3	Station 3	18	240
LS4	Station 4	84	340
LS5	Station 5	84	470
LS6	Station 6	66	540

As can be seen from Figure 2, the IST program gives a range of applicable specific creepage distances for each pollution level, due to the degree of uncertainty inherent in determining the accurate site pollution level. This is depicted as a cross-hatched area between the two curves in the results window. The program thus requires the user to specify the degree of certainty for the site pollution level. As a result, the analysis was perfomed twice for each segment: once with the average pollution value and once using the maximum pollution value of each respective site, as shown in Table 1. Using the maximum value results in a smaller spread in the results, as the program assumes that this value is based on a larger range of measurements. For the average value, the range of measurements is assumed to be smaller, resulting in a greater degree of uncertainty and thus a greater spread of results.

Before being entered into the software, the pollution levels have to be converted into the Equivalent Salt Deposit Density (ESDD) value, measured in mg/cm^2. A site classification of "light" was taken as 0.02 mg/cm^2, while "medium" was equivalated to 0.1 mg/cm^2 [2]. In both cases, the upper end value of each respective spectrum was chosen in order to introduce a degree of safety to the analysis.

Each analysis is based on the performance curves for a specific insulator model contained in the IST database and chosen by the user. In the case of NamPower's 220 kV database, it was established by prior research that a 20 mm/kV high temperature vulcanized (HTV) silicone rubber insulator installed in a vertical position is most representative for the environmental conditions experienced in the Namib Desert and a line voltage of 220 kV [3]. As a result, the analysis for this line was based on this particular insulator model.

Finally, this being a 220 kV line, the maximum system voltage was taken as 245 kV. Through consultation with specialists, it was determined that the MTBF was to be set at 20 years. Figure 3 shows the results for the average and maximum pollution levels for line segment LS 1. As the spread of results for the average pollution value is larger, both the mid-range and maximum value of the range of results were identified for the average pollution level of each segment. Table 3 shows the results obtained.

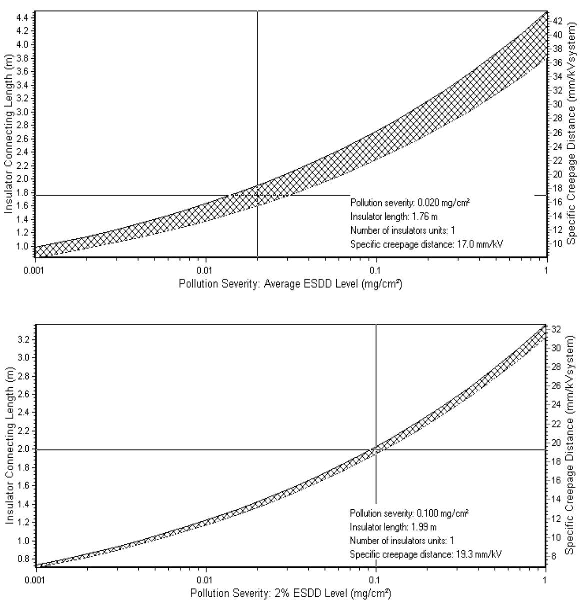

Figure 3: Result windows for analysis of segment LS 1: average (top) and maximum pollution level (bottom).

When combining the results obtained for the average and the maximum pollution levels, it can be concluded that a specific creepage distance of 21 mm/kV is more than sufficient for line segments LS 1 – 2 and LS 4 - 6. Although a value of 19 mm/kV would also be adequate, it can be argued that since determining the site pollution via DDDG measurements does not take instantaneous pollution into account, a higher value of 21 mm/kV will provide additional protection against such pollution events.

For line segment LS 3, the obtained creepage distances were lower than for all other line segments (see Table 3), indicating that a specific creepage distance of 19 mm/kV would be sufficient for this segment. The reduced insulation levels can be explained by the fact that this segment has the lowest number of insulators of all segments, as well as the third lowest average altitude. Especially the altitude has an effect on the insulation levels, as the IST software corrects the insulator flash-over voltage with respect to altitude according to IEC 60071-2 [4]:

$$FO_A = FO \cdot e^{-m(A/8150)} \tag{1}$$

where: FO_A = corrected flashover voltage (kV)
FO = flashover voltage at standard atmospheric conditions (kV)
A = Altitude (m)
m = Chosen as 0.5

Accordingly, a higher altitude reduces the flash-over voltage of the insulator, resulting in a decrease in insulator performance. However, since LS 3 represents only a small part of the line, the specific creepage distance can be kept at 21 mm/kV for the entire line, with only minimal extra costs incurred for the extra insulation length for this segment. Logistically, this has the added advantage that only one type of insulator has to be ordered for the entire line.

Table 3: Resulting specific creepage distances for all line segments.

Line Segment	Specific Creepage Distance [mm/kV] obtained for:		
	Average Pollution Level: Maximum Value	Average Pollution Level: Mid-range Value	Maximum Pollution Level
LS 1	18.4	16.9	19.3
LS 2	18.4	16.9	17.4
LS 3	17.8	16.5	16.8
LS 4	18.6	17.1	17.5
LS 5	18.7	17.2	17.7
LS 6	18.8	17.2	17.7

Equation (1) also explains why the analysis yielded similar creepage lengths for segment LS 2 and segments LS 4 to LS 6. Although LS 2 has a higher number of insulators, it has the lowest average altitude of all segments, which reduces the flashover voltage and, as a result, insulator performance.

5 CONCLUSION

The analysis of the insulation requirements for an intended transmission line using the Insulator Selection Tool computer software has shown that a specific creepage distance of 21 mm/kV is sufficient for silicone rubber insulators placed into service in environmental conditions encountered along the intended line servitude. Prior to the use of such software, insulation specifications were set at 25 mm/kV. The resulting reduction in insulation requirements shows that the use of such software can result in cost savings for power utilities, while still ensuring that insulation specifications are kept at a level that ensures safe and reliable operation of power lines.

6 ACKNOWLEDGMENTS

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