Impact of Wind on Pollution Accumulation Rate on Outdoor Insulators Near Shoreline

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***Abstract*— The present paper is an experimental investigation of the impact of wind speed on the pollution accumulation rate on outdoor insulators near coastal areas. Outdoor insulators near shoreline suffer from rapid saline accumulation due to heavy wind coming from the seashore, which is more dangerous in foggy weather conditions. A method was developed in laboratory to evaluate the impact of wind velocity and direction on the pollution accumulation rate on outdoor insulators and subsequently to determine a suitable mitigation method. In order to replicate seashore conditions on outdoor insulators an experimental setup was designed and installed inside an environmental chamber and was equipped with a wind generator and shoreline specification salts (NaCl, $CaSO_4$), as well as a kaolin powder injection system. ESDD and NSDD were measured on the top and bottom of insulator surfaces at different wind speeds. Useful observations were made, measuring wind speed and salt deposit density on energized and non-energized insulators. It was found that pollution accumulation rate increases as speed increases up to 8 m/s but that it decreases when the wind speed is higher than 8 m/s. Moreover, the pollution accumulation rate was different in energized and non-energized states.**

Keywords—wind speed, pollution accumulation, outdoor insulators, shoreline, ESDD, NSDD

I. INTRODUCTION

Climate conditions play an important role in the pollution accumulation process on outdoor insulators and can result in premature failures of power network systems. In addition to the level of contamination, its distribution and its nature, there are other parameters playing a major role in insulator contamination flashover. Near coastal regions, wind velocity and humidity are the most effective factors on the contamination accumulation rate while the effect of other environmental parameters like temperature, UV radiations and lighting strike is less on the severity and intensity of contamination accumulation.

A major problem with outdoor insulators near shoreline is the accumulation of saline contamination during dry weather conditions and its subsequent wetting, mainly by fog or snow, dew and drizzle. Pollution accumulation determination is an important factor in choosing proper insulation and maintenance techniques in polluted conditions. Lack of pollution accumulation records can cause lower reliability of power networks and excessive maintenance costs. Some researchers have studied [1-2], how strong wind speed causes saline contamination of high voltage outdoor insulators in the presence of rain, fog or snow. However they did not investigate the impact of wind velocity on saline accumulation rate. Despite past research, saline accumulation and surface flashover problems continue to rise significantly [3] with the effect of strong wind near shoreline. The speed and direction of wind is a major factor possibly influencing salt accumulation rate on insulators, while other factors, like gravity and electric field are secondary [4]. Saline pollution accumulates gradually on the insulator surface and forms a contamination layer that is characterized by an equivalent salt deposit density (ESDD) of hundreds of $\mu g/cm^2$. The highly soluble saline layer becomes a conductive path which allows a flow of leakage current on the insulator surface causing a drastic decrease in electrical insulation strength of outdoor insulators. After a broad literature review [1-7] it was found that the influence of wind on the rate of contamination build-up on the insulator surface near shoreline is not yet well understood. Therefore, there is a need to further our knowledge in this area.

The aim of this paper is to describe the experimental study that was carried out in an environmental chamber in order to simulate the natural phenomenon of sea salt accumulation on energized and non-energized high voltage outdoor insulators near shoreline. An experimental set up was developed to simulate the natural climate condition based on a modified solid layer method [8]. A series of experiment was carried out to investigate the impact of wind speed and direction on sea salt accumulation rate, equivalent salt deposit density (ESDD) and nonsoluble deposit density (NSDD) on outdoor insulator top and bottom surfaces.

II. EXPERIMENTAL ARRANGEMENT

The experimental setup shown in Fig. 1 was designed to investigate the impact of wind speed on sea salt accumulation on outdoor insulators near shoreline. The wind was generated by an air compressor with a speed adjustable controller. The sea salt and kaolin clay powder delivery system was fitted with sand blasting nozzles. A mixture consisting of marine specification salts (NaCl, $CaSO_4$) and kaolin clay powder were stored in two separate containers, attached in front of air flow nozzle. The nozzle diameter was reasonably larger to avoid blockage by sea salt and kaolin clay powder mixtures. The position of all nozzles can be adjusted freely and accurately. Wind speed was adjusted with a variable-speed controller that was attached on the air compressor with a range of 4 m/s to 12 m/s. The insulator was hung vertically in an environmental chamber and the outlet nozzle was positioned 75 cm away from the tested composite insulator to direct the deposition of sea salt and kaolin clay powder. Moreover, the direction of the main outlet nozzle was set at 90^0 to the tested insulator. Cold fog was generated five minutes before the contamination deposition, as described in a previous research work [9]. Moisture was absorbed on the insulator surface and increased adhesion between the insulator surface and the contamination particles. This resulted in a rather homogeneous contamination layer on the insulator surface. This setup provided a saline flow rate of 5 g/min and a kaolin clay powder flow rate of 20 g/min. The detail of experimental setup parameters of the contamination accumulation phase are summarized in the Table I.

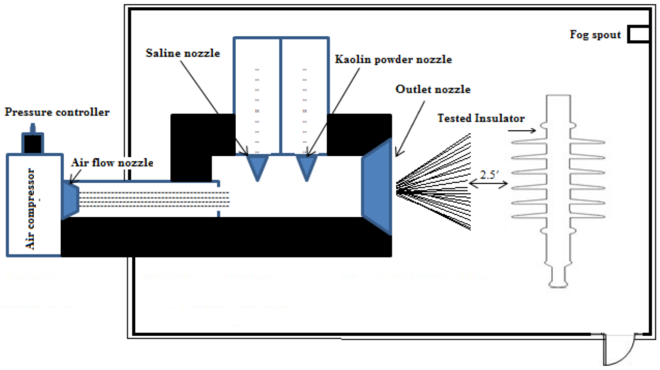

Fig. 1. Experimental setup.

TABLE I. PARAMETERS OF EXPERIMENT SETUP

Parameters	**Values**
Saline nozzle	2 mm
Kaolin clay powder nozzle	2 mm
Air flow nozzle	6 mm
Outlet nozzle	12 mm
Air Compressor	60-120 psi
Insulator distance	75 cm
Temperature	$2\,^0$C
Wind speed	4-12 m/s ± 2%
Accumulation duration	10 minutes

The test voltage was produced by a 10 kVA, 100 kV, and 50 Hz transformer. The supplied voltage can be increased manually or automatically at a rate of 1 kV/s. The following experimental procedures were adopted:

- To simulate the natural climate condition near coastal areas before each experiment, the temperature of the environmental chamber was set at $2\,^0$C and relative humidity of 100%.
- After the insulators were tested for ten minutes, they were removed for evaluation of ESDD and NSDD.
- ESDD and NSDD were evaluated under energized and non-energized condition.
- ESDD and NSDD levels were determined after each contamination test by swabbing and washing the surface of the contaminated insulator.
- After each test, both containers and all nozzles were cleaned with air pressure to remove all remained mixture particles inside.

III. MEASUREMENT METHODS

The insulator surface consists of soluble and nonsoluble contamination materials. The content of soluble contamination is denoted by equivalent salt deposit density (ESDD) and that of nonsoluble content by nonsoluble deposit density (NSDD). ESDD is used to evaluate pollution degree with IEC-60507 [10]. The contamination is collected with a piece of cotton from the top and button surfaces of the insulator separately, and washed in specific volume of distilled water with specific conductivity. The conductivity of the solvent is measured with RS Pro conductivity meter and ESDD achieved in mg/cm^2 with an atmosphere correction factor of 20 ^{0}C according to IEC 60507, using formula [11]. The NSDD is also an important factor of insulator surface degradation and pollution surface flashover. Therefore, detailed NSDD measurements were effected on insulator top and bottom surfaces with regards to the impact of wind speed. The NSDD contamination particles were separated from the water mixture using a pre-dried funnel and weighed filter paper (grade-A). The collected residual was dried before NSDD measurement. The NSDD calculation was carried out using the procedure defined in IEC 60815-1. It is known that NSDD does not depend on salt concentration. Thus, the setup arranged to satisfy the artificial pollution tests for longer treatment times and values provide a range of contamination levels that covers the evaluations of insulator contamination defined by [12]. The mean values of ESDD and NSDD given by Equations (1) and (2) as follows:

$$ESDD = \frac{ESDD_t \times A_t + ESDD_b \times A_b}{A} \tag{1}$$

$$NSDD = \frac{NSDD_t \times A_t + NSDD_b \times A_b}{A} \tag{2}$$

In Equations 1 and 2, the subscripts **t** and **b** represent the top and bottom of the insulator surface respectively and **A** is the overall insulator surface.

IV. RESULTS AND ANALYSIS OF POLLUTION ACCUMULATION RATE

In order to find the contamination accumulation rate on the insulator surface using the adopted modified solid layer contamination method described above, a series of experiments have been carried out with wind speeds of 4 m/s, 8 m/s and 12 m/s simulating natural environmental conditions observed near shoreline. Five readings corresponding to the each wind speed were taken on the insulator surface for ESDD and NSDD measurements. Initially light pollution was build-up on both energized and non-energized insulator surfaces. The energized and non-energized test insulators are shown in Fig. 2. Figure 2 shows that the contamination accumulation on the non-energized insulator surface was higher than for the energized one. This difference is probably due to leakage current and partial discharge activities in the case of energized insulators affecting the distribution of contamination on the surface of insulators.

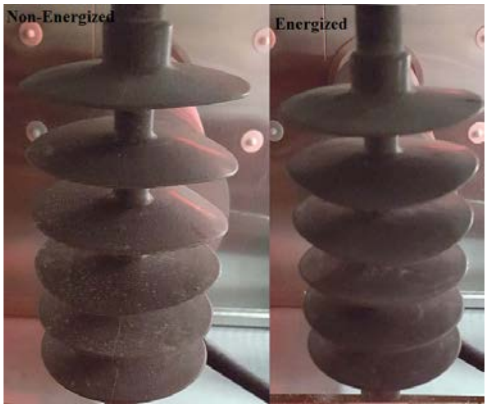

Fig. 2. Energized and non-energized insulators.

The measured values of ESDD and NSDD (energized insulator) for wind speeds of 4 m/s, 8 m/s and 12 m/s are summarised in Table II, III and IV.

TABLE II. ESDD AND NSDD VALUES AT WIND SPEED 4 m/s FOR ENERGIZED INSULATOR

Test	ESDD Top (mg/cm^2)	NSDD Top (mg/cm^2)	ESDD Bottom (mg/cm^2)	NSDD Bottom (mg/cm^2)
1	0.046	0.17	0.197	0.43
2	0.049	0.21	0.175	0.47
3	0.041	0.23	0.192	0.39
4	0.037	0.19	0.199	0.31
5	0.039	0.21	0.162	0.35

TABLE III. ESDD AND NSDD VALUES AT WIND SPEED 8 m/s FOR ENERGIZED INSULATOR

Test	ESDD Top (mg/cm^2)	NSDD Top (mg/cm^2)	ESDD Bottom (mg/cm^2)	NSDD Bottom (mg/cm^2)
1	0.073	0.51	0.210	1.10
2	0.084	0.44	0.271	0.93
3	0.038	0.49	0.240	0.99
4	0.081	0.48	0.226	0.82
5	0.049	0.53	0.217	0.89

TABLE IV. ESDD AND NSDD VALUES AT WIND SPEED 12 M/S FOR ENERGIZED INSULATOR

Test	ESDD Top (mg/cm^2)	NSDD Top (mg/cm^2)	ESDD Bottom (mg/cm^2)	NSDD Bottom (mg/cm^2)
1	0.057	0.40	0.193	0.73
2	0.043	0.33	0.214	0.67
3	0.047	0.37	0.209	0.63
4	0.041	0.38	0.183	0.69
5	0.051	0.41	0.217	0.71

The ESDD and NSDD variability were statistically measured by average values and standard deviation. The ESDD and NSDD of the top and bottom surfaces are different for each wind speed. The ESDD and NSDD values for the top surface are very similar and the average values range from 0.043 mg/cm^2 to 0.085 mg/cm^2 and from 0.196 mg/cm^2 to 0.49 mg/cm^2 respectively. However, the ESDD and NSDD of bottom surface are higher than those of the top surface, the average values of bottom surface being almost twice as those of the top. It is observed in the Tables II, III and IV that the percentage standard deviation error is constant, but less than 20% for the top surface. For the bottom surface, however, the standard deviation error percentage is very high at low wind speed and then decreases gradually as the wind speed increases. It can be seen from Fig. 3 that the relationship between ESDD, NSDD and wind speed for energized insulator is nonlinear near shoreline.

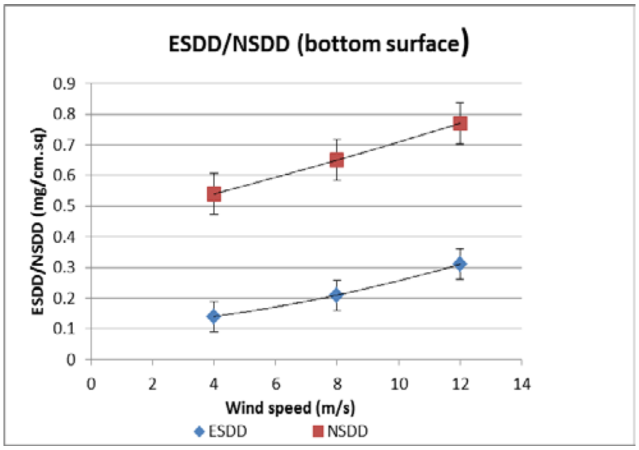

Fig. 3. Relationship between wind speed and ESDD and NSDD of energized insulator bottom surface.

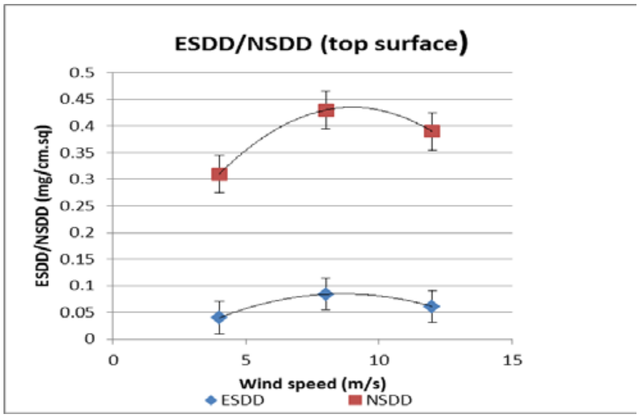

Fig. 4. Relationship between wind speed and ESDD and NSDD of energized insulator top surface.

The ratio of ESDD and NSDD at top and bottom of the insulator surfaces was almost constant between 4 m/s to 8 m/s. Figs. 3. and 4. show that the contamination accumulation rate on both top and bottom insulator surfaces increases with the increase of wind speed (from wind speed 4 m/s to 8 m/s). However, when the wind speed is 12 m/s the contamination accumulation rate was slightly lower both on the top and bottom of the insulator. The effect of contamination concentration severity leads to a much higher contamination accumulation rate on insulator bottom surfaces as compared to the top surfaces. The observation can be explained on the basis on fluid mechanics, as accumulation of contamination particles is very effective between 4 m/s to 8 m/s but not so for higher wind speeds because very high winds remove most of the contamination particles from insulator top surfaces as compared to bottom surfaces. The ESDD and NSDD values of the insulator bottom surfaces were more severe than those of the insulator top surfaces due to contamination accumulation level [13-15]. The ESDD and NSDD values of the bottom surfaces of insulator were more uniform as compared to those of the top surfaces as shown in Table II, III and IV. The contamination deposition was not only related to the type of insulator, but also to contamination level, various climate conditions, field distribution and other environmental stresses. Near shoreline, the contamination accumulation and the cleaning process are different between the insulator top and bottom surfaces. In fact, the rain can clean the top surfaces more thoroughly as compared to the bottom surfaces. Since the electric field at the bottom of insulator surface is stronger when the contamination layer is wet, thus the bottom is more affected by surface leakage current.

V. ANALYSIS OF THE NON-UNIFORM CONTAMINATION ACCUMULATION RATE

In energized conditions, the ESDD and NSDD ratios of the top value to that of the bottom value clearly affects the contamination accumulation rate, as they express the non-uniformity of the pollution accumulation rate. The ratio of ESDD and NSDD of the top to the bottom insulator surfaces are shown in Fig. 5. It clearly shows that the ESDD and NSDD ratios much vary at different wind speeds with average values of 0.154 mg/cm^2 and 0.584 mg/cm^2 respectively. The difference is due to the different effect of wind speed on the upper and lower surfaces on the insulator.

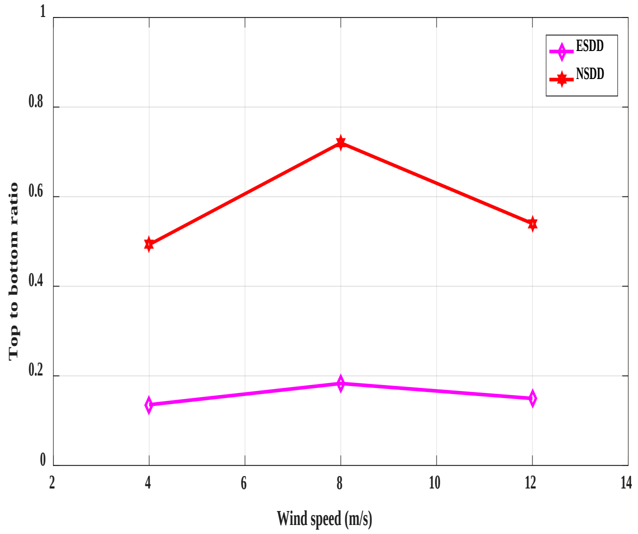

Fig. 5. Top to bottom ratio of ESDD and NSDD.

CONCLUSIONS

The experimental setup facilities used allowed simulating the natural climate conditions necessary to investigate the impact of wind on the contamination accumulation rate near shoreline. In this paper, the impact of wind speed and direction on contamination accumulation near shoreline was investigated based on ESDD and NSDD measurements. From the obtained results, it can be seen that wind speed affected the contamination accumulation rate on the test insulators, but that contamination accumulation rate was different for the energized and non-energized test insulators. The directional contamination deposition on insulator surface near coastal area was always less important on the energised insulators as compared to non-energized insulators. The results of ESDD and NSDD tests show that there was a significant difference between top and bottom energized insulator surfaces in terms of surface contamination accumulation rate. Thus it can be concluded that wind speed may be the main factor of the saline accumulation on insulator surface near shoreline.

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