Environmental Pollution Effects on Insulators of Northern Egypt HV Transmission Lines

M.A.Abouelsaad M.A. Abouelatta B.Arafa M.E.Ibrahim
Faculty of Engineering at Shoubra, Benha University PHVRC ECMI Company
108 Shoubra st., Cairo, Egypt Egyptian Electricity Holding Company
moh_an1@yahoo.com

Abstract- **Flashover of polluted high voltage insulators is a major problem for operation of power lines in Egypt. In 2010, insulators' pollution was the cause of several interruptions in the Egyptian electric network. Variations of climatic conditions and large industrial developments in the last few years call to update the pollution map of Egypt. To achieve this, six sites in northern Egypt with different types of pollution (industrial, desert, marine and their mixtures) have been investigated. To asses the pollution behavior of line insulators, IEC standard cap-pin suspension insulators were hanged for a time zone of 5 months. The study was conducted through measurements of: Equivalent salt deposition density (ESDD), Surface Conductivity, Maximum leakage current and Flashover voltage. The results are useful to assess the insulation performance in different environmental situations and as well to provide an updated pollution map in Egypt.**

I. Introduction

In recent years, the increased demand of electric power has led electrical utilities to build new power stations and to improve the efficiency of their transmission systems. The efficiency is, mainly, based on the continuity of the service while avoiding faults that result in economical losses for companies and users. High voltage outdoor insulators are, usually, subject to different pollution sources which may cause insulator's flashover and discontinuity of supply on a large scale [1, 2]. The possibility of flashover in contaminated environments depends on the type of pollution and the time that the insulator is subjected to such pollution [3]. A contamination layer is formed on the insulator's surface and may allow leaking currents that will facilitate the conditions of flashover. Larger pollution levels produce more leakage currents and the flashover of the insulator becomes more probable.

Three main types of pollution can be distinguished; namely, industrial, desert and marine pollution. The first appears with industrial development producing contaminants (metallurgical, chemical substances, dust, carbon and cement) into the atmosphere in both dry and gas forms which may lead to serious situations during wet conditions [4]. Desert pollution occurs due to a gradual accumulation of dust, sometimes salty, on the insulators which may result in reduced efficiency and possible supply interruption. Marine pollution exists in coastal environments where a conductive layer, due to the salted dew, can be formed on the insulators surface. The problem becomes more severe when the environmental weather is; highly humid, rains, dew, fog…etc.

Egypt is a country with a wide variety of different landscapes and climatic conditions. High voltage transmission lines run through various regions of the country and are exposed to different environmental pollution conditions which may require specific insulation level. In 2010, insulators' pollution was the cause of several interruptions in the Egyptian electric network. Several studies have been initiated by the Ministry of Electricity and Energy of Egypt in the last two decades to assess the severity of insulators' pollution and to compile a pollution map for Egypt. This map divides Egypt into four regions [5]; non- industrial areas in southern Egypt considered as light pollution level regions, desert areas and light industrial pollution in mid-south considered as medium level pollution regions, agricultural areas in northern Egypt considered as heavily polluted regions, and finally coastal pollution near the Mediterranean and the Red Sea and areas of heavy industrial pollution considered as very heavy pollution regions.

During the last few years, significant variations of the climatic condition as well as large industrial developments in various regions of Egypt have contributed to producing more contaminations that could, largely, affect the power lines' insulators performance. Modern heavy industry factories (cement, quarries, steel & iron, etc.) have been established in desert and coastal regions which lead to the interaction and mixtures of different pollution types. It is, thus, necessary to re-assess the pollution level in these regions and evaluate its impact on the outdoor insulators' performance.

In this paper, six regions in Northern Egypt (Cairo and Alexandria) of different types of pollutions have been identified. These sites cover marine pollution, industrial carbon pollution (Brick Kilns), mixture between marine pollution and industrial pollution (iron), mixture between quarries pollution, desert pollution and industrial pollution (cement), and finally light mixture between costal pollution, desert pollution and industrial pollution (cement). Results of pollution level and site pollution severity in these regions are presented. IEC standard cap-pin suspension insulators were hanged for a time zone of 5 months. The performance of insulators is assessed through measurements of; the Equivalent salt deposition density (ESDD), Surface Conductivity (μS), Maximum leakage current and Flashover voltage. Tests have been carried out in the Pyramids High Voltage Research Center (PHVRC), Cairo, Egypt. The results are useful to

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assess the insulation performance in different environmental situations and to improve the design if necessary and finally to propose an updated pollution map in northern Egypt.

II. Pollution Measurements and Testing Procedures

Several measurements and tests were applied to identify the content and type of pollutants. These tests are: Equivalent salt deposition density (ESDD), Surface Conductivity (μS), Maximum leakage current and Flashover voltage. These tests are illustrated in this section.

A. ESDD Measurement

The pollution degree is determined by measuring the equivalent salt deposit density (ESDD) on insulators; removed from operating transmission lines [6,7]. It is a standard method for determining the electrical conductivity of an arbitrary pollution deposit with unknown composition [7]. ESDD is the quantity of NaCl in water which would give the same volume conductivity as that of the actual deposit dissolved in the same quantity of water [7]. For site pollution severity measurements purposes, an un-energized insulator is hanged at a height as close as possible to that of the line. The dirt on the surface of the insulators is cleaned and well washed. ESDD value is determined based on the conductivity of water obtained referred to 20˚C, water temperature, and the volume as follows [7];

$$ESDD = (S_A\ V)/A. \quad (1)$$

$$S_A = (5.7\sigma_{20\ S/m})^{1.03}. \quad (2)$$

$$\sigma_{20} = \sigma_\theta[1\text{-}b(\theta - 20^\circ)]. \quad (3)$$

$$b = -3.2\times10^{-8}\theta^3 + 1.03\times10^{-5}\theta^2 - 8.27\times10^{-4}\theta + 3.544\times10^{-2} \quad (4)$$

where: S_a= Salinity in kg/m^3 or mg/cm^3
V= volume of distilled water (cm^3)
A= area of washed insulator surface (cm^2)
$\sigma_{20\ S/m}$= volume conductivity at 20˚C (S/m)
σ_{20}= corrected conductivity at 20˚C
σ_θ= measured conductivity at temp. θ
θ= temperature of the solution (˚C)
b= is a factor depending on θ

B. Leakage Current and Flashover Voltage Measurements

Measurement of maximum leakage current is an effective method for minimizing the pollution flashover of insulators on transmission lines. In case of flashover, the maximum leakage current value is defined as the peak current value in the half cycle before flashover [8]. The laboratory tests are performed in the multi-function artificial climate chamber (MACC) in which the relative humidity can be controlled between 40% and 100% [9].

C. Surface Conductivity Measurement

The insulator surface conductivity is defined as the measured conductance of the pollution layer multiplied by a form factor, determined from the insulator dimensions, and generally expressed in μS [7]. The layer conductance measurement is repeated on the insulator during its wetting until the maximum value is reached [7]. The layer conductivity is related to the reference temperature of 20˚C using the following formula [7];

$$k_{20} = k_\theta\,[1\text{-}b(\theta - 20^\circ)]. \quad (5)$$

where: k_{20}= layer conductivity at 20˚C in μS
k_θ = layer conductivity at temp. θ in μS

III. Results And Discussions

Six regions were chosen to simulate the different types of pollution along 66kV and 220kV lines located in Northern Egypt (Cairo and Alexandria). Description of the locations and the related pollution characteristics are given in table 1.

IEC standard cap-pin suspension insulators, shown in Figure (1), were hanged in the chosen locations and exposed to various types and intensities of pollution for three durations. Three groups of insulators; each consisting of an insulator string of three units were hanged, un-energized, at the same height of the line insulators.

The first group of insulator has been detached from the lines after one month of exposure duration (First Period) while the second group has been detached after three months (Second Period) and finally the last group has been detached after five months of exposure duration (Third Period).

The aforementioned types of measurements have been performed on each group to estimate the pollution level for each region. The results obtained during the three periods for the six regions, given in Figures (2-5), show general conformity and consistency between the four tests. As expected, increase in the pollution level upon any insulator means, in general, higher values of ESSD, Maximum leakage current, Surface conductivity and lower flashover voltage. An assessment for each region is presented next.

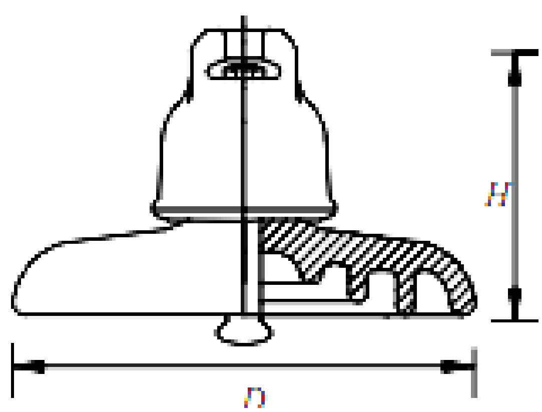

Fig. 1. Profile of the cap – pin insulator with leakage path 215mm, D = 280mm, and H = 146mm

TABLE I
DESCRIPTION OF THE LOCATIONS

Region-Hanged Date	Type of Pollution	Description of the Location
1. Burg Al Rab (Alex.)- 1/1/ 2012	Light mixture between Costal, Desert and Industrial (cement)	66kV TL inside a cement factory located 2km away from the Mediterranean.
2. Sidi Krir (Alex.)- 1/1/ 2012	coastal	220kV TL inside a steam power plant with fuel oil and natural gas effects. Heavy rain and salted dew effects.
3. Al Dekhila (Alex.)- 28/12/2011	Coastal and Industrial (iron)	220kV TL inside Al Dekhila steel factory (200m away from Salinas region).Both marine and industrial pollution effects.
4. South Tebeen (Helwan)- 8/1/ 2012	Desert and Industrial (cement)	66kV TL beside the national cement factory in Helwan desert (heavy sandstorms).
5. Wadi Hoof (Helwan) - 7/1/ 2012	Desert and Quarries	66kV TL beside Quarries and Helwan cement factory (desert / industrial /sandstorms)
6. Al Saf (Giza) - 15/1/ 2012	Industrial (Carbon)	66kV TL beside several Bricks Kiln with high chimneys which produce carbon leftovers

A. Region 1 (Light Mixture)

The measurements, Figures (2-5) show the pollution level over the three periods to be relatively light. This may be due existence of chimneys filters in the factory which may contribute to reduce the precipitating pollutants on the insulators; in addition to the relatively larger distance from the sea. The pollution severity of this region may be classified as 'Light-Medium'[10].

B. Region 2 (Coastal)

Being closer to sea, with increased salted dew and rain, the pollution level is higher than Region 1. It can be concluded that the pollution severity of this region is 'MEDIUM'[10].

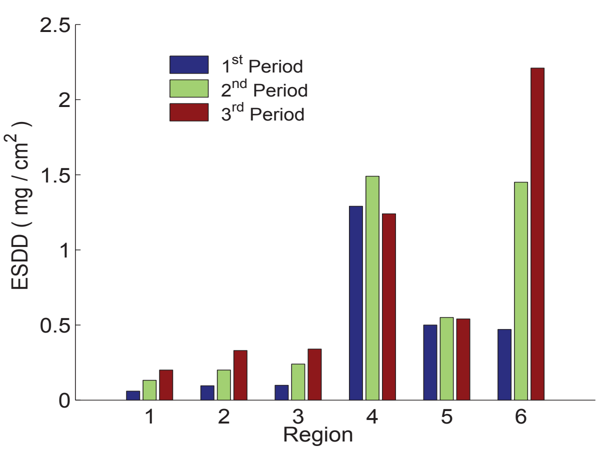

Fig. 2 ESSD levels for the different regions

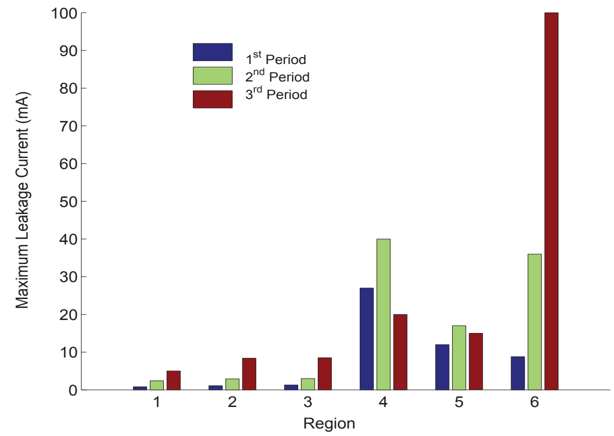

Fig. 3 Maximum leakage current results for the different regions

C. Region 3 (Coastal / Industrial)

Results of the pollution level are similar to those of Region 2; both are close to the sea. According to IEC 60815 [10], the pollution level of this region is considered 'MEDIUM'.

D. Region 4 (Desert / Industrial)

Due to high humidity, fog and dew the pollution level rises significantly especially during the second period in this region. This was accompanied by heavy sandstorms prevailing in the Helwan desert. The pollution level relatively decreased during the third period which may be due to frequently occurring strong winds in this region that may result in, slightly, cleaning the insulators' surfaces and decreasing the level of dew and fog. The pollution severity of this region may be classified as 'Very Heavy'[10].

E. Region 5 (Desert / Quarries)

In this region, sandstorms are less frequent than those of the fourth one, and the direction of the smokes coming from mines are not directed to insulators as in the fourth region, accordingly the pollution level of this region is 'Heavy' [10].

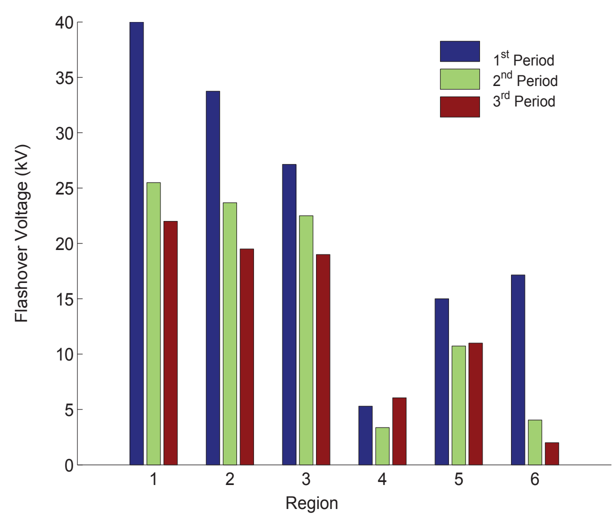

Fig. 4 Flashover voltage values for the different regions

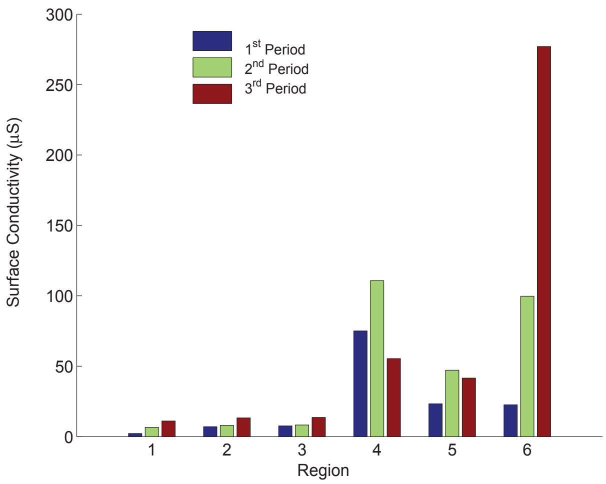

Fig. 5 Surface conductivity outcomes for the different regions

F. Region 6 (Industrial):

The pollution level in this region is rather high due to the larger levels of carbon fumes, resulting from the bricks kiln mines, which precipitate upon the insulators. According to IEC 60815 [10], the site pollution severity of this region may be classified as 'Heavy- Very Heavy'.

In general, it can be noticed that the pollution level of the coastal regions are clearly lower than those of the desert regions which is related to the heavy rains frequently occurring, in the coastal areas, during these time periods resulting in partial cleaning the insulators' surfaces from contaminants.

From the above results, accordingly, the effect of pollution on the insulators will depend upon the region and on the efficacy of the maintenance plan and finally the adequate selection of the insulator type and design. For the first three regions, adequate scheduled maintenance plan may achieve the required insulators' performance. Also, it may be advisable to require factories to use suitable filters to reduce emissions and contaminants emanating from them. For regions 4 to 6, it may be necessary to avoid flashover through appropriate design of the insulators (shape, length and number).

IV. CONCLUSION

Assessment of pollution level and site pollution severity has been carried out in six regions of Northern Egypt in order to evaluate the insulations' performance under different pollution and environmental patterns (industrial, desert, marine and their mixtures). Standard tests and procedures were applied to update Egypt's pollution map. Standard cap-pin suspension insulators were utilized in this study. The present results are helpful to utilities to take adequate measures towards improving the efficiency of their transmission systems, reducing pollution flashover of high voltage insulators, scheduling of their insulator maintenance strategy and finally updating their overall pollution map of the country.

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