New Approaches to Study Environmental Pollution Effects on Insulation of West Azarbayjan Electric Power Distribution Co

M. R. Shariati, S. J. A. Vaseai, Student Member, IEEE, M. Rezaei, and S. Abyazi

Abstract—High voltage insulators are exposed to various climates. Pollution resources combined with moisture provide undesirable conductive paths on insulations that result in faults and economic losses. Types and degree specification of pollution seems to be vital for efficient operation and proper choice of insulation. Various climates, pollution resources like Oromieh Lake, cement and plaster factories, as well as industrial towns respect to localization necessity of international standards motivated authors to perform field and periodic pollution measurements in Azarbayjan province as a test place.

The periodic measurements of ESDD-NSDD and DDG lead to the establishment of a pollution map of North-west of Iran.

The different climatic parameters of Oromieh and Khoy are compared with pollution variation procedure of the test stations to assess climate influence on pollution accumulation. According to authors’ researches, we feel, proves that the ESDD measurement alone is not sufficient to establish the pollution severity level of a given site. Likewise, analysis of the site pollution severity and the weather data indicated a strong correlation of SPS with some of the climatic parameters. Thus, new approaches to study environmental pollution effects on insulation of West-Azarbayjan province are presented in this paper.

Index Terms—DDG, ESDD, Insulation, NSDD, Pollution Map.

I. INTRODUCTION

HIGH voltage insulation provides isolation paths in T&D networks. The first aerial transmission line was designed in 1880 with 50 and 66 kV maximum operation voltage. The population growth as well as industry and agriculture development increases pollution resources. In the other hand, strategic situation of power industry and necessity of reliable networks with minimum outage as vital demand of today’s societies, stimulate extended activities in design, develop and operation of H.V insulators. An under construction transmission line in 1912 is shown in Fig. 1[1]. Pollution determination is vital to choose proper insulation and maintenance techniques in polluted condition. Lack of Pollution records in special regions of Iran results in T&D network instability to power voltage frequency, sever environmental conditions and excessive maintenance cost.

Fig. 1. Under construction transmission line in 1912.

High concentration of salt in Oromieh Lake, Persian Gulf and Oman Sea and Caspian Sea in northwest, south and north, respectively; in addition to insulation dependence on environmental climate, motivate a national process to perform accurate field activities in West Azarbayjan, Khusestan, Mazandaran, Guilan, Hormozgan, Bushehr and Sistan & Baluchistan those supported by Tavanir Org. and regional power utilities. Considering special climates of Iran as well as related international standards deficiency, these field researches are expected to localize foreign standards as well as modifications in special cases.

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II. ENVIRONMENTAL POLLUTION MEASUREMENT METHODS

A. ESDD and NSDD Method

ESDD is an approach to determine pollution degree respect to IEC 60507 [2]. The pollution is wiped off with squeezed cotton from top and button surface of insulators, and then solved in specific amount of distilled water with specific conductivity. Solvent conductance measured and ESDD equations achieved in mg/cm² by environment correction factor in 20°C. Afterwards, the solution shall be filtered by a pre-dried funnel; filter paper will be weighted after and before dissolving to measure NSDD in mg/cm² [1], [2], [3].

B. DDG Method

For the first time in Iran, DDG method according to B.S.1747 [4] was applied by Niroo Research Institute to assess pollution effects on insulation. The characteristics of the DDG are shown in Fig. 2.

Fig. 2. Directional Dust Gauge.

This instrument consists of four dust gauge, each set to one of the four cardinal points of the compass, were used to collect atmospheric pollution particles.

The approximate installation height is three meters. The device should be located far from trees or anything that affect on natural weather convection. It is inexpensive, easy to use and the calculations are simple and reproducible.

III. TEST STATIONS [3], [5]

Each test station contains an insulator string of six Cap & Pin discs; those are numbered according to Fig. 3. Specifications of test insulators are as follows:

- Creepage distance: 292 mm
- Diameter: 254 mm
- Height: 146 mm

The string insulators are installed on concrete or wooden poles with the same height as distribution network installations to simulate operation condition accurately.

The DDG instruments are installed in chosen locations respect to guidelines.

A. Test stations dispersion in the studied regions

The test stations locations are determined based on utility records, expert team recommendations and location choice criteria.

Fault records, security factor, site accessibility, distance from temporary pollution resource and vicinity to industrial pollution resources, factories, Oromieh Lake as well as power development plans and utility records are the considered factors in stations location choice.

Geographical distributions of the test stations are shown in Fig. 4.

B. Test Procedures

-- ESDD-NSDD method

The periodical ESDD-NSDD measurements were done as show in Table I.
TABLE  I
POLLUTION COLLECTION GUIDELINE WITH ESDD METHOD

<table>
<thead>
<tr>
<th>Designation No</th>
<th>ESDD-NSDD Measurement Guide</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Measurement</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$\checkmark$S1</td>
<td>-</td>
</tr>
<tr>
<td>Second Measurement</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$\checkmark$S3</td>
<td>-</td>
<td>$\checkmark$S2</td>
<td>-</td>
</tr>
<tr>
<td>Third Measurement</td>
<td>-</td>
<td>-</td>
<td>$\checkmark$S5</td>
<td>-</td>
<td>$\checkmark$S4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fourth Measurement</td>
<td>-</td>
<td>$\checkmark$S8</td>
<td>-</td>
<td>-</td>
<td>$\checkmark$S7</td>
<td>$\checkmark$S6</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Si: Sampling No (i=1-8)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Period of Sampling: 3 month</td>
<td></td>
</tr>
</tbody>
</table>

$\checkmark$: ESDD-NSDD Measurement was done  
-: ESDD-NSDD Measurement was not done

According to IEC 60815, 1986 pollution site severity classification and the minimum nominal specific creepage distance are shown in Table II [6].

TABLE II
POLLUTION SITE SEVERITY CLASSIFICATION

<table>
<thead>
<tr>
<th>Site Severity</th>
<th>ESDD (mg/cm²)</th>
<th>Minimum nominal Specific Creepage Distance (mm/kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0.0075-0.015</td>
<td>-</td>
</tr>
<tr>
<td>Very Light</td>
<td>0.015-0.03</td>
<td>0.03-0.06</td>
</tr>
<tr>
<td>Light</td>
<td>0.03-0.06</td>
<td>0.06-0.10</td>
</tr>
<tr>
<td>Medium</td>
<td>0.06-0.12</td>
<td>0.10-0.20</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.12-0.24</td>
<td>&gt;0.1</td>
</tr>
<tr>
<td>Very Heavy</td>
<td>0.24-0.48</td>
<td>0.60-0.80</td>
</tr>
<tr>
<td>Exceptional</td>
<td>&gt;0.48</td>
<td>-</td>
</tr>
</tbody>
</table>

In this research, the effect of the energizing of the insulators on the deposition rate is assumed to be 20-30% [5], [7].

-- DDG Procedure

To collect all the pollution in the bottom cylindrical jars, the slots were sprayed with distilled water. The collecting jars were separated from the cylinders and the conductivity of the solution was measured. The sampling interval was 30 days (with up to 10 day’s variations). The normalized conductivity was calculated using (1) [8]:

$$C_{N.S.E.W.}^{\text{Norm}} = C_{N.S.E.W.}^{\text{Meas}} \times \frac{V}{500} \times \frac{30}{D}$$  
\[1\]

$C_{N.S.E.W.}^{\text{Norm}}$: Normalized conductivity (µS/cm)  
$C_{N.S.E.W.}^{\text{Meas}}$: Measured conductivity (µS/cm)  
$V$: Polluted solvent volume (ml)  
$D$: Interval (days)  
$PI$: Pollution index of each station was calculated by (2):

$$PI = (C_{N}^{\text{Norm}} + C_{S}^{\text{Norm}} + C_{E}^{\text{Norm}} + C_{W}^{\text{Norm}} - 4C_{0}) / 4$$  
\[2\]

IV. REGIONAL CONDITION

West-Azarbayjan province is located in northwest of Iran with 43660Km² area and Oromieh as the center. Khoy, Salmas, Macu, Sardasht, Mahabad, Mandoab, Naghade and Piranshahr can be named as the realm. The province includes Oromieh Lake. Oromieh Lake is the second most saline inland lake in the world, which geography lies between 37.4-38.17°N longitude and 38-45°E latitude. Absolute temperature of the lake and its Islands is -22°C minimum and 38°C maximum. Precipitation is between 300-400 mm annually. The lake locates 1267 meter higher than base point, with 130-140 km length, 15-50 km width and 50-60 meter average depth. The salt rate of it is very high (60% of the Dead Sea).

A. Regional climate

The climate can be classified in two main categories:

--Coastal region of Oromieh Lake

This climate can be seen round of Oromieh Lake. The weather is cool-cold in winter and humid-hot in summer.

--Zagros heights

This climate can be seen in most regions of Iran. In winter it is cold or freezing and mild, dry and warm in summer. It is necessary to consider perfectly to insulation coordination for substations in this region due to height of regions. The geographical situation of the climate is shown in Fig. 5 [9].

Fig. 5. Two Categories for studied regional climate.

B. Meteorical conditions

Climates play significant rule in pollution procedure and resulted electrical failures. The followings are affected by climate:

--Pollution deposition on insulation  
--Pollution distribution on insulator’s surface  
--Durability of Pollution condition  
--Pollution dispersion amount from resource

Humidity is the most effective factor on pollution, pollution layer formation, self-cleaning and natural cleaning of insulation. Humidity includes different variables like relative and absolute humidity, fog, breeze and fallings.

Fallings affect on insulators self-cleaning and result in insulation faults if less than 20 mm annually. Basically dry pollution layer is ineffective on insulation strength and only in moistening periods particles solvent provide conductive layer
on insulation surface. Other environmental parameters like temperature, wind speed and direction, numbers of dusty and stormy days are effective on degree and intensity of pollution accumulation.

In this research the environmental conditions of Oromieh and Khoy are shown in detail in Fig. 6, 7 respectively [9]. The other cities of this region are the same as above.

--- Rain period

As shown in Fig. 6, less than 20 mm rain periods begins in the end of June and continues to the end of September. As mentioned, the natural washing factor reduces in this period.

--- Temperature

It can be seen in Fig. 6 that monthly maximum average temperature of the region in low rain and hot season is less than 30 °C and decrease in the other seasons. This condition provides suitable temperature condition for the lines and substations.

--- Wind (speed and direction)

Assessment of wind influence on superficial electrical discharge and pollution deposit process is very complicated. Wind, depends on speed and direction, can be cleaner or polluter; it can transfer particles from near or far pollution resources to insulation or clean them on their surface. According to wind studies in Oromieh, the prevail winds is west wind. Also, northeast and north winds in the summer Oromieh blow more than usual.

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V. Fault Performance Records

The flashovers on the network’s ceramic insulators are due to salt deposits, which in turn caused by rainless periods and seasonal winds. Faults records in T&D network of West Azarbayjan province among 2001 to 2002 (two years) are shown in Fig. 8 [10]. It can be seen that the outages follow the climatic variations, thus intensification of atmospheric factors are the main reasons of these faults.

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VI. Measurement Results

A. NSDD-ESDD degree and pollution index variations

The measured NSDD and ESDD in ten test stations are shown in Fig. 9 and Fig. 10. Pollution index variations curve obtained by 12 DDG stations is shown in Fig. 11.

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B. Maximum ESDD and NSDD

Sorted maximum ESDD and correspondence NSDD of the test stations are shown in Fig. 12.

It can be seen that test stations No. 31, 35, 37 in Rashakan and Golmankhaneh in Bari because of its vicinity to Oromieh Lake have maximum ESDD. Also, stations No. 38, 39, 40 in Khoy and Piranshahr have the minimum ESDD because of its location in mountainous climate and long distance from pollution resources.

High NSDD degree in station No.31 is noticeable as well.

C. The Cumulative Pollution Procedure

The cumulative curve of pollution based on ESDD and DDG test stations are shown in Fig. 13, 14 respectively.

The cumulative pollution value of test station No.4 in Oromieh, No.8, 9, 10 in Khoy and Piranshahr are less than the others.

The ascendant-descendent pollution procedure in different times as well as noticed order in the curve slope verifies the accuracy and integrity of the tests and analyses.
D. Pollution deposition variations affected by environmental condition variations in test period

ESDD and NSDD variations of the studied regions are shown in Fig. 15, 16 in four three-month periods.

ESDD-NSDD procedure significantly corresponds to the rain period variations.

DDG pollution index variations in the studies stations are shown in Fig. 17.

E. A new approach in pollution studies

-- ESDD-NSDD criteria

Proper criteria choice to classify environment pollution is very important.

In recent years, international pollution societies have focused their studies on NSDD criteria. Formerly, only ESDD was considered in pollution investigations (see Table II). Recently, researchers offered criteria respect to ESDD and NSDD degrees [1], [6], [11], [12].

Considering operation records in south provinces like Hormozgan, Sistan & Baluchistan, Khuzestan and Bushehr, if insulation designs just consider ESDD, insulation instability problems respect to power frequency and severe environmental conditions are inevitable in some regions. Thus, as mentioned in [11], [12], [13] according to operations records, new criteria application overcomes the problems.

Insulation over-design in West-Azarbayjan based on ESDD-NSDD criteria, in spite of more changeable conditions than south provinces, is the new and noticeable approach of this paper. Studied regions ESDD-NSDD curves are shown in Fig. 18. Operation records do not confirm the new offered pollution degrees. Thus, a correction coefficient as a function of environment conditions seems to be necessary for these regions.

--DDG criteria

Recently, DDG devices applications to determine environment pollution degrees increased. Considering climate and field measurements with related analyses in West Azarbayjan, Khuzestan, Busheher, Guilan, Mazandaran, Hormozgan and Sistan & Baluchistan proper criteria that presented in Table III confirmed by operations records are provided [14].
TABLE III
DDG INSTRUMENTS POLLUTION DETERMINATION CRITERIA

<table>
<thead>
<tr>
<th>Pollution Severity</th>
<th>Index (µS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Light</td>
<td>&lt;125</td>
</tr>
<tr>
<td>Light</td>
<td>125-200</td>
</tr>
<tr>
<td>Medium</td>
<td>200-400</td>
</tr>
<tr>
<td>Heavy</td>
<td>400-750</td>
</tr>
<tr>
<td>Very Heavy</td>
<td>&gt;750</td>
</tr>
</tbody>
</table>

VII. POLLUTION MAP

Fig. 19. shows the pollution map of West Azarbayjan province based on field tests. In this research, the effect of the energizing of the insulators on the deposition rate is assumed to be 20-30% [5]. West Azarbayjan Electric Power Distribution can now use this map to select their insulators.

Fig. 19. Pollution Map.

Maximum operation voltage of insulators, insulation coordination, special operation conditions, allowed clearance and maintenance should be considered in plan application. If pollution parameters are not dominated in a region, insulation coordination criteria must be considered. Also, clearance of towers, special design should be satisfied. It is recommended to use special material or profile in insulation of instant pollution regions.

VIII. DISCUSSION, CONCLUSION AND PRACTICAL RECOMMENDATIONS

A. In this paper, pollution deposition variations procedure in four three-month periods is investigated based on ESDD-NSDD methods. Also, variations of important environmental parameters like rain, wind and maximum temperature are assessed and analyzed. It can be seen that pollution deposition variations in test insulators are the same as environmental parameters variations. Also, neural networks and statistical techniques can simulate the procedure.

B. According to the field measurements results, region topography and pollution resource distance are two important factors in pollution deposition rate. Nearness to coasts, factories and mines, natural dilemmas, heights, valleys, vegetables, trees, aerial and windy vestibules are the most effective factors in pollution deposit rate.

C. In spite of reasonable correspondence of ESDD-NSDD method with operation records in south regions insulation choice of Iran [11], it is necessary to consider significant environment parameters like moisture, fallings and drought periods to apply correction coefficients. These coefficients avoid over-design in regions that environment parameters decrement insulation stresses.

D. Environment effect determination on pollution degree as well as pollution map is provided by accurate field measurements in 43660 km² laboratory (i.e. West Azarbayjan province). Regional pollution is less than medium. This fact is very surprising that hardly imagine before research.

E. The results show that pollution resource vicinity (especially Oromieh Lake with high salt rate) is the effective factor in pollution deposition on insulation surface. Also, dominate environment parameters as well as insulation cleaning is very effective. Different distances from pollution resources result in various pollution bands (see Fig. 19).

F. Environmental pollution effects on insulation are determined based on the field studies in different cities of the province.

IX. ACKNOWLEDGMENT

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X. REFERENCES


[9] Meteorological Data


XI. BIOGRAPHIES

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