Implementation of Modern Methods of Insulation Coordination with Respect to Polluted Conditions in Design Practice of IECo

Evgeni Volpov¹, Senior Member, IEEE, Igor Gutman², Senior Member, IEEE

Abstract - The specific issues of IECo environmental conditions are generally characterized by long dry period followed by intensive wetting events, however local environmental conditions can be very different, from subtropical to desert, thus pollution conditions should vary a lot. Another issue is related with historical mixture of different types of outdoor insulators. This situation requires optimal insulator selection using modern statistical methods for insulator dimensioning. Presently, they accepted by both CIGRE and IEC. STRI have used these methods with success for practical applications in different countries (Scandinavia, South Africa, Namibia, and Canada). It has been revealed that STRI and IECo have very similar approaches for statistical dimensioning. The STRI method is more oriented towards laboratory testing, while the IECo method involves Insulator Profile and Pollution Flashover Model calculations. This paper presents the case study for one specially selected insulator-sample which is demonstrating applicability of both STRI and IECo approaches. In the future, there is a possibility to combine advantages of the both methods intending to improve the dimensioning procedure for outdoor insulators in Israel and world-wide.

Index terms - Insulation Coordination; Pollution Flashover; Insulator dimensioning; Polymeric Long-rod.

I. INTRODUCTION

The specific issues of IECo (Israel Electric Co) environmental conditions and present insulation selection approach can be summarized as follows:

- Existence of long dry period followed by wetting events due to a heavy fog, dew or rain.
- Influence of sand and wet sand storms.
- Historical mixture of different types of line- and apparatus insulators, which are ranged from rather outdated porcelain long rod insulators to different silicone rubber insulators.
- Despite a variety of the environmental conditions, a single insulation level (III (d), IEC 60815) is recommended for the whole IECo Network. This relatively high insulation level, however, is not enough through the whole country, because a number of outages due to pollution are still higher in the IECo than in the similar utilities of the Western Countries.

The IECo Network specificity remarked above requires application of an advanced dimensioning of outdoor insulation using statistical methods. The CIGRE/IEC experience clearly shows that the optimal insulation design can be achieved through application of the statistical methods. These methods were for decades used for insulation coordination, but at present are also well established for dimensioning in polluted conditions [1]. The principle of dimensioning of insulators with respect to polluted conditions is to select their dimensions allowing obtaining an acceptable level of flashover performance in the network. The basic principles involved in the insulation dimensioning process can be described with reference to [1] as “Stress-Strength” Concept, see Fig. 1 adopted from [1], Annex G.

As can be seen from Fig. 1, the spread in the environmental stress (i.e. pollution) is described by a statistical frequency distribution.
function, \( f(\gamma) \). The statistic nature of the dielectric strength (pollution flashover performance) of the insulation is also expressed in terms of a statistical function of the severity \( P(g) \). The risk for flashover that may occur is defined by the area underneath the curve which is obtained by multiplying the stress and strength probability functions. The final goal of the dimensioning process is to optimize the risk for insulator flashover against the additional cost. The Probability Density Function \( f(g) \) can be estimated from regular site severity measurements over a considerable period of time (minimum one year). The Cumulative Probability Function \( P(g) \) can normally be obtained through HV Testing, either under natural conditions in service or at the test station or in the laboratory (by performing pollution tests). This function can also be estimated by modeling of pollution flashover of the insulator of known geometry.

II. STRI APPROACH

To implement this Concept, STRI had developed and successfully used the Insulator Selection Tool (IST) Software, which is based on IEC recommendations and experimental customized databases [2-6]. The latest version of the IST program can provide the follows:

- Possibility of direct dimensioning (insulator creepage and insulation height) for AC and DC applications (see Fig 2). A user can choose between AC application and negative and positive DC applications. The latter are separated because electrical strength of a line insulator is lower for negative polarity and thus the program provides separate calculations per pole.

- Direct comparison of up to three different insulators per screen dump, see button “Add to comparison” in Fig 2.

- Additional input data in the form of DDDG measurements. If no standard ESDD data is available, Equivalent ESDD button and a special window for DDGI-S (Dust Deposit Gauge Index –Soluble) are activated, where a user can write in DDDG data, which the program will convert into standard ESDD data (see Fig 2).

- Two independent databases are also provided in the latest IST version. The first database called “STRI proprietary” is created by STRI and STRI is fully responsible for the data, which it contains. A customer has no right to enter this database and make own changes. The second database called “Customer” is completely open for a customer, which can create its own insulation data (both geometry and flashover performance). STRI has no responsibility for this type of the database.

- Finally the program allows making cost calculations for different insulators options (see Fig.3).

The IST program has been thoroughly verified by comparison of the calculation of outage rate for the overhead lines with known service experience and the results were pretty good from engineering point of view:

- By service experience in Russia [2], [3]
- By service experience at Koeberg Insulator Pollution Test Station in South Africa [2], [4]

The IST program has also been used in a number of practical projects, e.g.:

- Refurbishment of Western Cape OHL in South Africa [4]
• Refurbishment of OHL 220 kV in Namibia [4]
• Design of 500 kV OHL for the Nordic project (Sweden-Finland) [5], [6].

As stated in [1], “These data (i.e. flashover pollution performance to create P(g)) normally come from laboratory tests, service experience or field tests.” This is typical case for STRI experience, where majority of such input data originated from the artificial pollution tests on ceramic and composite insulators (mostly Solid Layer Test according to IEC 60507 and its modifications) at both AC and DC voltages. Some data was also originated via field test station (e.g. Koeberg Insulator Pollution Test Station in South Africa) or test towers (in Namibia).

III. IECo APPROACH

In contrast to STRI method which utilizes the laboratory test data (Performance Curves) [2-4, 7],

\[
\frac{U_{50}}{H} = A \cdot ESDD^{-\alpha}
\]  

(1)

Where, \(A\) is empiric insulator geometric factor. \(H\) is insulator axial length. \(\alpha\) is empiric static arc constant.

IECo approach involves a semi-empirical AC Flashover Model, which is based on dry-band arc propagation conditions formulation along the polluted surface [7]:

\[
U_{50} = B \cdot (K_f) \cdot L^{1-\alpha} \cdot \gamma
\]

(2)

Where, \(B = 0.67655\), \(\alpha = 0.35\), \(K_f\) is form factor, \(L\) is leakage distance, \(\gamma\) is specific surface conductivity.

The geometric characteristics \(K_f\) and \(L\) are determined with aid of the insulator profile models depicted in the Figure 4, as follows.

\[
K_f(R1, R2, r, c, b, \theta) = \frac{\theta}{b} \left( \frac{1}{R(R1, R2)} + \frac{2 \pi}{\cos(\theta)} \ln \left( \frac{R1 + R2}{R} \right) - 1 \right)
\]

(3)

\[
LA1(R1, R2, r, c, b, \theta) = \frac{\theta}{b} + c + 2 \frac{R1 + R2 - 2 \cdot r}{\cos(\theta)}
\]

(4)

Where, \(K_f, LA1\) are unit-related parameters expressed for alternating sheds profile. \(RE(R1, R2) = R1 \cdot R2 / (R1 + R2)\).

Similar parameters for uniform shed profile can be easily calculated by putting \(R2 = r\) (see Figure 4).

By Introducing (2)-(3)-(4) into the “Stress-Strength” design formulation illustrated in Figure 1, one can obtain the relationship between insulation performance indices (PFFR, MTBF, FO Risk) and insulator geometry characteristics.

\[
PFFR = \xi^\alpha \int_{(0)} \left[ \left( \frac{\gamma}{M, \beta} \right) \cdot \left( \frac{\theta}{(0)(\theta)(R1, R2, c, b, 0, N, \alpha, \sigma)} \right) \right] \text{d} \theta
\]

(5)

Where, \(\xi\) is the annual number of pollution events. \(m\) is number of parallel insulators exposed to the same pollution conditions. \(N\) is number of the insulator sheds. \(\sigma\) is standard deviation of the pollution flashover voltage \(U_{50}\). \(M, \beta\) are log-normal median and standard deviation of the pollution stress PDF. \(\gamma\) is truncation pollution stress. \(U_{50}\) is MCOV. PFFR is Pollution Flashover Failure Rate [outages/100 km/year].

**Figure 4: Piecewise linear models for basic Long-Rod Insulator Profiles.**

Thus, the advantage of the above method is that it enables the design engineer in assessing the candidate insulator performance at the early design steps through a sensitivity analysis related to its geometric pattern.
The proposed approach has been repeatedly proven by comparison to the test data. Figure 5 demonstrates design curves, which have been obtained for typical ceramic long-rod insulators at standard pollution conditions specified by IEC 60507 and IEC 60815. There is a good agreement between IEC 60815 Recommendations and the proposed model (5) when the design risk of 2% is specified (see Fig. 5). As has been shown in [8], 2%-design risk is adopted by default in the IEC 60815 Guidelines.

IV. CASE STUDY

4.1. Choice of insulator and case study parameters

Two major insulator options which are used at present at IECo are porcelain long rod insulators and composite long rod insulators. Thus, for comparison purposes, silicone rubber composite insulator with open profile was used in the case study. Its basic characteristics presented in Figure 6.

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>1</td>
<td>Min Creepage distance</td>
<td>4495 mm</td>
</tr>
<tr>
<td>2</td>
<td>Insulator Axial Length</td>
<td>1310 mm</td>
</tr>
<tr>
<td>3</td>
<td>Insulator Section Length</td>
<td>1500 mm</td>
</tr>
<tr>
<td>4</td>
<td>Inter-shed distance</td>
<td>25.5 mm</td>
</tr>
<tr>
<td>5</td>
<td>Shed Diameter</td>
<td>97 mm</td>
</tr>
<tr>
<td>6</td>
<td>Trunk Diameter</td>
<td>22 mm</td>
</tr>
<tr>
<td>7</td>
<td>Number of Sheds</td>
<td>49</td>
</tr>
<tr>
<td>8</td>
<td>Shed Type</td>
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</tr>
<tr>
<td>9</td>
<td>Shed/Envelope Material</td>
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</tr>
</tbody>
</table>

Figure 6. Specification of the Polymer Long-Rod Insulator 170-kV selected for Case Study.
This insulator was tested in artificial pollution test at STRI, while its flashover performance was calculated at IECo. The test method at STRI was as follows. Basically, the pollution performance of the insulators was assessed by Solid Layer tests and the flashover voltages were obtained by “up-and-down” method. It is virtually impossible to obtain uniform and stable pollution layer on silicone rubber insulators using standard requirements of IEC 60507. Thus, the conditioning was performed using dry kaolin powder, which was applied on the surface of silicone rubber insulator by brush. After such an application of kaolin, most of the kaolin was blown away by compressed air. However, a thin layer of kaolin still remains on the surface. This was controlled both visually and by Wettability Class measurements according to IEC TS 62073. The pollution suspension was based on kaolin and applied by spraying according to IEC 60507. The test procedure is illustrated in Fig 7 (procedure without recovery) and the test set-up is shown in Fig 8. At present this test procedure is under consideration of CIGRE and a round robin test is under way in 13 HV laboratories all over the world.

4.2. Comparison of the STRI vs. IECo Models

The flashover performance curves obtained in Section Choice of insulator and case study parameters were used to calculate the required insulator length for the hypothetical overhead line equipped with such insulators. The parameters for the calculation were chosen as follows:

- Standard Log-Normal deviation for the pollution stress, Ln (ESDD), $\beta = 0.6$
- Standard deviation for the discharge voltage $U_{dc}$, $\sigma = 10\%$
- Number of pollution events per year, $\xi = 100$
- Maximum system voltage for overhead lines, $U_n = 170$ kV.
- Number of insulators exposed to the same pollution event, $m = 1200$, which corresponds to about 100 km of the overhead line.
- Mean time between failures, MTBF = 1 year, which corresponds to 1 outage/100 km/year.

Calculations by IST Program are illustrated in Fig. 9. The final results in the form of required insulator length for ESDD levels: 0.1-0.2-0.3-0.4 mg/cm² are presented in the Table 1, which also contains the respective results obtained with IECo Model (5). From the Engineering standpoint, very good correlation between the compared data can be summarized.

V. CONCLUSIONS

This paper presents the case study which demonstrates applicability of both STRI and IECo approaches. In the future, there is a possibility to combine advantages of the both methods intending to improve the dimensioning procedure for outdoor insulators in Israel and world-wide.

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VII. BIOGRAPHIES

Evgeni Volpov (M’10), (SM’12) is Insulation Design Expert
in the Planning Development and Technology Division of
the Israel Electric Corporation Ltd. He graduated from St
Petersburg Technical University in 1982 with M. Sc. in Electrical
Networks and Systems, and received a Ph.D. in High Voltage
Technology and Physics from the Electrotechnical Institute of
Russia, Moscow, in 1990. Since 1986, he has been involved
in research projects regarding insulation design and diagnostic
testing of UHV AC-DC SF₆ GIS. His research interests
include E-Field modeling, Insulation Coordination, Statistical
Dimensioning of Outdoor Insulators, Shielding Protection and
Lightning Performance Assessment of Transmission Lines,
PD diagnostics, Failure Analysis, and Asset Management. Dr.
Volpov is a Senior Member of IEEE, DEIS; and CIGRE SC
B2, WG D1.44. He has authored 21 scientific publications
including 1 patent.

Igor Gutman (SM’05) was born in Leningrad, Russia, in
1958. He received the M. Sc. and Ph.D. degrees in high-
voltage engineering from the Technical University, Leningrad,
Russia, in 1981 and 1990, respectively. In 1981, he was with
the Leningrad HVDC Power Transmission Research Institute,
where his work has been connected with outdoor line and
station insulation, particularly with composite insulators.
In 1994, he joined STRI, Ludvika, Sweden. Currently, he
is a Senior Specialist, Technical Area Manager Insulation
with the Technology Services and Software Department.
His research interests are dimensioning and maintenance of
outdoor insulation intended to operate in clean and polluted
environments and aging characteristics and accelerated
aging tests of composite insulators. He has been published in
many magazine and conference papers on various aspects of
insulation performance. Dr. Gutman is a member of CIGRÉ
Working Group C4AG03-03 “Pollution and Environmental
Influence on the Electrical Performance of Power Systems,”
IEEE Task Force 15.09.09.03 “Icing performance of insulators,”
and is active in a number of IEC working groups.