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High voltage lines: energy losses in insulators

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ABSTRACT

In the case of high voltage lines, the role of insulators is twofold: to support the weight and tensile forces of the electrical cables and then to maintain the isolation distance between the live conductors and the metal pylons.
Overhead lines and substations in power transmission systems are exposed to various constraints including pollution of insulators which is a factor of energy loss especially during bad weather.
Dust, acids, salts and other pollutants found in the atmosphere are deposited on the insulators and thus reduce their insulating properties.Indeed, in times of rain or fog, the polluting deposits that attach to the insulating surfaces considerably reduce the surface resistivity of the insulators and the bypass by the electric arcs can then occur.This article explains the problem and lays down the calculation bases for an evaluation of these energy losses in insulators of high voltage lines.
***Keywords**: Pollution, insulators, energy losses, power lines.*

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I. INTRODUCTION

For more than a century now, insulation of high voltage lines has been generally provided by ceramic insulators (glass and porcelain).Desert pollution is mainly characterized by the sand deposits that form on the surface of insulators after the sand winds.In the vicinity of certain industrial zones, pollution is caused by smoke evacuation from factories (refineries, cement works, minerals, etc.).

The presence of conductive elements in the layers and / or the dissolution of the salts which they contain cause the circulation of the leakage currents which are more or less strong depending on the concentrations of the pollutants on the insulators.
The factories are not the only ones responsible for this kind of pollution; gas vehicle exhaust and fertilizers in agriculture also contribute to deposits observed on the surface of insulators.

Once moistened, these deposits become more or less conductive (depending on the concentrations of soluble salts they contain) and generate the flow of leakage currents which can appear suddenly and sometimes followed by partial electric arcs which lead to the bypass total of the insulator.

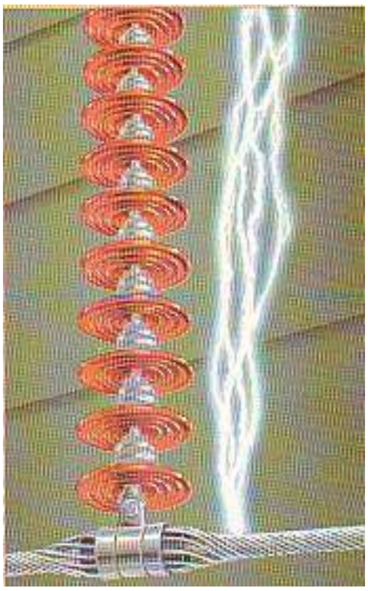


Fig1. High-voltage line insulator

A layer of pollutants formed on the insulator becomes conductive when wetted by mist, rainwater or simply condensation. A leakage current is then established through the superficial layer causing subsequent drying of the pollution layer and electrical arcs may arise.For example, saline deposits appear on power lines located close to the oceans.

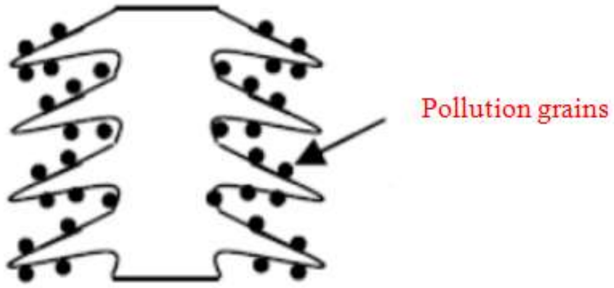


Fig 2. The pollution on an insulator

II. The bypass of the insulator

Bypassing the insulator occurs when an electrical discharge occurs between the ends of the insulator and bypasses its surface.The bypass can cause a circuit-breaker to open because a short circuit exists between the phase conductor of the high voltage line and the pylon (single-phase ground fault).

The bypass of the insulators usually causes the momentary interruption of the transport of electrical energy through the electrical network.The bypass line is the shortest distance on the insulator between two conductive parts.

The bypass voltage is the lowest voltage level from which all
Arcs connect the two electrodes of the insulator, this bypass voltage depends on :

- the average volume resistivity of the pollution;
- the distribution of the pollution layer;
- the length of the insulator;
- of the insulator profile

The holding voltage is the highest voltage level that can be insulated without causing disruptive discharge.

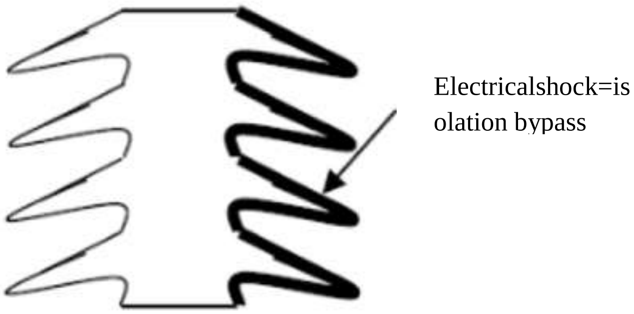


Fig3. Insulator bypass

III. Isolator override mechanisms

Phase 1: pollution deposition.
Pollution grains are deposited on the surface of the insulator (Fig.2).

Phase 2: Formation of a conductive electrolyte layer
Dry, the surface resistance of the insulator remains high despite the deposition of pollution. When the layer of pollution becomes wet (rain, fog, moisture, morning dew, etc.), it turns into a conductive electrolyte and gives rise to a surface leakage current If flowing over the surface of the insulator (Fig.4).

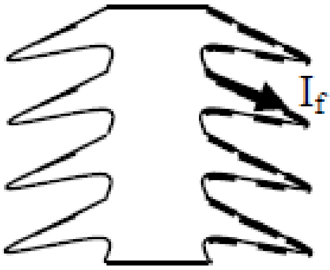


Fig 4. Leakage current on the insulator

Phase 3: Isolation of the insulator.
In parts of the insulator where the current density is high, some of the electrolyte evaporates and creates a dry band.Since the electrical resistance of the dry strip is much higher than the rest of the electrolyte, virtually all the voltage across the isolator is now applied to the ends of this dry zone. There is then a breakdown in the dry band:

- Either the discharge is switched off: therefore no bypass (Fig.5).
- Either the discharge progresses on the surface: therefore the insulator is bypassed (Fig. 4).

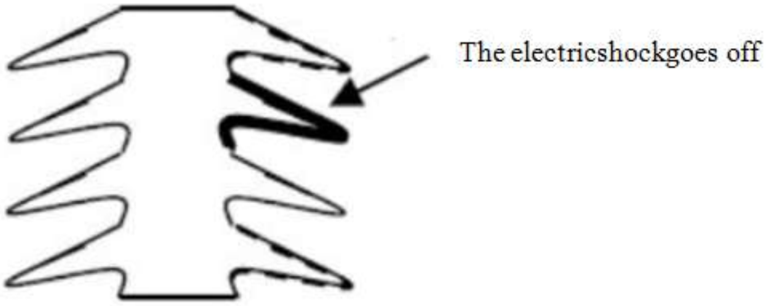
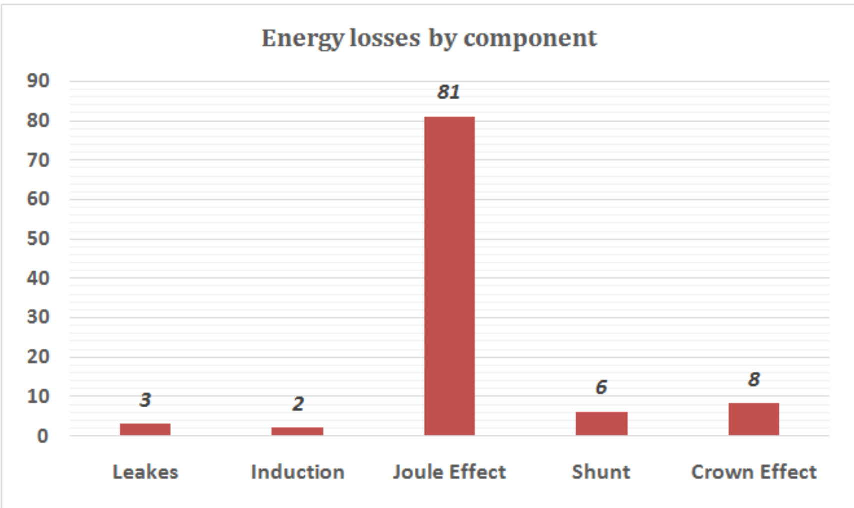


Fig 5: Electric shock off

IV. Energy losses in insulators

It is now assumed that insulation is not a source of infinite electrical resistance, and that there are sometimes weak leakage currents which cause joule losses.
Leakage currents in insulators are based on the number of isolator chains per pylon and the power line utilization factor, considering that leakage currents occur mostly in wet conditions (rain, snow, fog , Etc.).
Measurements on actual lines, in service, provide information on the value of these losses in Watt.
Here the percentages of electrical transmission losses as given by Hydro-Québec:



As an indication, the following table shows the results of measurements made by WEICKER ([B.190-0]) on a 6.5 kV power line equipped with rod insulators.

Table I. Losses due to insufficient isolation of insulators

State of the atmosphere	Losses for an insulator(W)
Light Fog	0,15
Snowfall, below 0 ° C	0,25
Heavy Rain	1
Long and continuousrain	1,10
Rain storm	1,50
Heavy snowfall mixed with rain	2,20

Energy losses in insulators are not a concern for power system operators in dry weather and especially when power lines are new. On the other hand, where pollution is important, special attention must be paid to the fact that the more insulation becomes imperfect, the more disturbing is the initiation of electrical arcs on the isolators.

IV.1. Losses in insulators in good weather

U: line voltage;
Riso: Isolation resistance for a chain of insulators in good weather;
Np: number of pylons per kilometer;
G: the conductivity of a phase by imperfect isolation of the insulator chains.
We have:$g = \frac{n_p}{R_{iso}}$ (1)
The following formula makes it possible to calculate these losses caused by the insulators:

$$P_{iso} = \left(\frac{U}{\sqrt{3}}\right)^2 g \qquad (2)$$

$$\mathbf{P_{iso}} = \left(\frac{\mathbf{U}}{\sqrt{3}}\right)^{\mathbf{2}} \frac{\mathbf{n_P}}{\mathbf{R_{iso}}} \text{on (W/km)} \qquad (3)$$

In good weather, tests have shown that a string of insulators for a 220 kV power line has an insulation resistance of approximately 2, 4.109 Ω.
The average distance between two pylons being about 350 m, ie three pylons per kilometer;
The losses due to the imperfect isolation of the insulators are:
$P_{iso} = \left(\frac{220.10^3}{\sqrt{3}}\right)^2 \frac{3}{2{,}4.10^9} = 20{,}1667$ W/kmby phase, either 60,50 W/km or the three phases.
Since these losses are proportional to the square of the voltage of the power line, it can be seen that the losses at 400 kV are 3.24 times more than the losses at 220 kV.

IV.2 Losses in insulators during rain

According to the experimental data given in Table I, active energy losses at insulator levels in times of heavy rain are k = 22 times greater than those measured in dry weather, ie in times of heavy rain, for a voltage of 220 kV, the energy losses due to imperfect insulation of the insulators will therefore be equal: Piso = kx 60,50 = 1331 W / km for all three phases.

V. Conclusion

The losses we have just calculated are strongly influenced by the pollution state of the insulators and the climatic conditions.During periods of inclement weather, such as rainfall or winters, losses in isolators become maximum as energy distributors should take them into account in order to better plan the production and transmission of electrical energy.This paper explains this phenomenon and sets out a method for determining the energy losses due to pollution on insulators, depending on the voltage of the power line.

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