

Predicting Contamination Flashover of Insulators: Successes and Shortcomings of Tests and Simulations

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Perhaps no single area of insulator behavior has fascinated researchers more so than predicting flashover under contaminated conditions. For traditional porcelain and glass insulators, there is a large body of literature published that includes both theoretical models and experimental tests to simulate this interesting and practically important aspect of insulator performance. Yet there still some critical gaps in the understanding of this complex problem. This article summarizes the state of the art for porcelain and glass insulators, which are still the workhorses of industry. In such insulators, the dielectric being inorganic, there is no interaction of the surface with the contamination layer on the surface. We know that with nonceramic (composite) insulators, there is an interaction (for example, hydrophobic recovery), which further complicates the flashover process. Needless to say, we understand even less about the flashover process on nonceramic insulators. It is therefore important that this subject be researched further from the point of view of obtaining reliable performance from both ceramic and nonceramic insulators.

The earliest scientific explanations for contamination flashover was the theory proposed by Obenaus in the 1930s [1]. He explained flashover in very simple terms with the schematic shown in Fig. 1. A partial arc generated by dry band activity is in series with the contaminated section of the insulator and this is represented as a series resistance. Various factors are responsible for the partial arc to elongate and bridge enough of the insulator (roughly 50%) which will then provide the necessary impetus to result in a flashover. An increase in contamination severity on the insulator is one factor that contributes to flashover.

An increase in contamination causes the leakage current to increase creating more intensive discharges. Due to the increased thermal ionization that is caused by high temperature arcs, it is natural to think that this would promote flashover. But it is also true that the increased contamination, if it is distributed along the entire insulator, will force the voltage distribution to become more linear, thereby alleviating the problem of electric stress concentration. This would discourage the flashover process to a certain extent. These conflicting factors are described by semi-empirical equations which form the basis of theoretical modeling. By their very nature, the models contain parameters whose values are not constant but vary, sometimes over a very wide range. Researchers have used this inherent variability to develop models that provide the best fit to experimentally obtained data.

As an illustration, Table 1 shows the results of flashover prediction from five research organizations [1]. All the groups have been active in this area of research and have multiple papers in reputable journals (Group 5 is the ASU group). The test object considered is an IEEE standard ceramic insulator (146mm shed spacing, 254 mm diameter, leakage distance of 280 mm). Various levels of contamination severity have been considered. For a particular geometry of insulator the conductance measured in the laboratory can be correlated with the ESDD, equivalent salt deposit density, and this is also shown in Table 1.

It is clear from the Table that: (1) the values of the predicted flashover voltage vary significantly for the same insulator and level of contamination and (2) based on the nominal number of bells for a particular system voltage no flashover should occur for contamination severities that are in the light to moderate pollution range as defined by the IEC 60815 ($ESDD < 0.1 \text{ mg/cm}^2$). For example, assuming that a minimum of 14 bells are used at 230 kV, the flashover voltage predicted by the models (14X flashover voltage per bell) all exceed the operating line to ground voltage of $230/\sqrt{3} = 132 \text{ kV}$.

From service experience, we know that this is not entirely true. There have been numerous reports of flashover on relatively clean insulators, especially under early morning dew and fog. It is possible that utilities may not have performed a detailed investigation before declaring contamination as the root cause. But to assume that all outages that cannot be explained by accepted theories fall into this category is wishful thinking.

What is missing in these models? For one thing, it assumes that the contamination is uniform along the insulator surface so that the arc will follow the surface until the point of flashover. It also ignores the possibility of arcs jumping from one shed to another due to factors like rain, wind assisted sprays, fog, dew, etc.

Regarding the uniformity of contamination distribution along the insulator, in some locations very close to major sources of industrial pollution, the entire insulator is coated with the contaminant. But this is more an exception than the rule. By far the most typical pattern is one of nonuniform distribution. The protected and the exposed surfaces of the insulator are affected differently by the forces that are responsible for depositing the contaminant and cleaning the surface. So in many cases the exposed areas are more contaminated than the protected areas, and there are a number of cases where the reverse is true.

In my numerous investigations of outdoor insulators that had “supposedly” flashed over due to contamination, or were considered to be at significant risk of contamination flashover, my first reaction on examining the insulator is one of disbelief. Typically on porcelain insulators that have flashed over there is a lot of glaze damage. On insulators that have not flashed over measurements of the ESDD (equivalent salt deposition density) vary over such a wide range that the average value is a pretty low number. There are many utilities that have reported flashover of insulators during the early morning hours and these insulators for the most part are clean. Such problems are more frequent at higher system voltages (230 kV and above) than at subtransmission or distribution voltages.

Figs. 2-4 show pictures of insulators that had “allegedly” flashed over due to contamination. It is quite obvious that except for the top surface the rest of the insulator is actually clean. Does this mean that all the contamination was removed by the power arc? This is very unlikely as the power arc is in air and is in contact with the insulator surface closest to the high voltage and ground electrode. The only other explanation is that flashover happened in a manner that is not adequately explained by existing theories and testing.

As far as laboratory testing is concerned, requiring that the insulator be uniformly contaminated is simpler to control and reproduce and these are critical for the establishment of industry

standards. Incidentally such a surface is much easier to model for calculations and simulations. But it is quite obvious that is not realistic for a majority of field applications. So how do we control and specify the non-uniform aspects of contamination distribution and artificial wetting in the laboratory?

Summary: It is worthwhile to mention that the most widely used standards for contamination testing, namely the salt fog and clean fog methods (IEC 60507) were developed because of significant amount of voluntary participation and collaborative work among the leading research and testing institutions of the world. This kind of long term cooperation has become almost nonexistent today. When we consider the added complications introduced by the dynamic material properties of nonceramic insulators, one really wonders whether we will be able to develop meaningful standards for use by present and future generations. Of course new standards will be introduced because the organizations responsible for these will be under pressure to keep producing something. But it is not clear (at least to me) whether they will contribute to improving the reliability of power delivery? Individual research groups and laboratories will end up developing their own versions of experimental test and simulation models. Which ones will survive will probably depend not just on technical merits but also the marketing strength of these organizations.

Reference:

[1]. J. P. Holtzhausen, "A Critical Evaluation of AC Pollution Flashover Models for HV Insulators Having Hydrophilic Surfaces", Ph. D Dissertation, The University of Stellenbosch, South Africa, 1998.

Table 1: Predicted values of flashover voltage (kV) for one IEEE Standard ceramic unit.

ESDD (mg/cm ²)	Research Group 1	Research Group 2	Research Group 3	Research Group 4	Research Group 5
0.01	23.0	39.6	23.2	44.8	29.7
0.02	20.2	31.6	21.2	35.8	23.8
0.03	18.8	27.8	20.0	31.4	20.9
0.04	17.8	25.2	19.4	28.6	19.0
0.05	17.0	23.6	18.8	26.6	17.8
0.06	16.4	22.2	18.4	25.0	16.8
0.07	16.0	21.2	18.0	23.8	16.0
0.08	15.6	20.2	17.6	22.8	15.3
0.09	15.2	19.6	17.4	22.0	14.8
0.10	15.0	18.8	17.2	21.2	14.3
Voltage gradient of the Pollution layer- E _p	5.8*rpu^{0.4}	10.33*rpu ^{0.33}	2.85*rpu ^{0.43}	11.36*rpu ^{0.33}	15.83*R_p^{0.33}
Arc voltage gradient-E _{arc}	59*I^(-0.5)	80*I ^(-0.5)	37.2*I ^(-0.5)	94*I ^(-0.5)	63*I^(-0.5)
Arc propagation criteria	E _p > E _{arc}	E _p > E _{arc}	E _p > E _{arc}	E _p > E _{arc}	E _p > E _{arc}

Where,

rpu - Average resistance in Ω/mm

I – Current entering the pollution layer in Amperes

R_p – Uniform pollution resistance in per unit length- Ω/cm

Fig. 1: Schematic of a contaminated insulator with dry band discharge initiated.

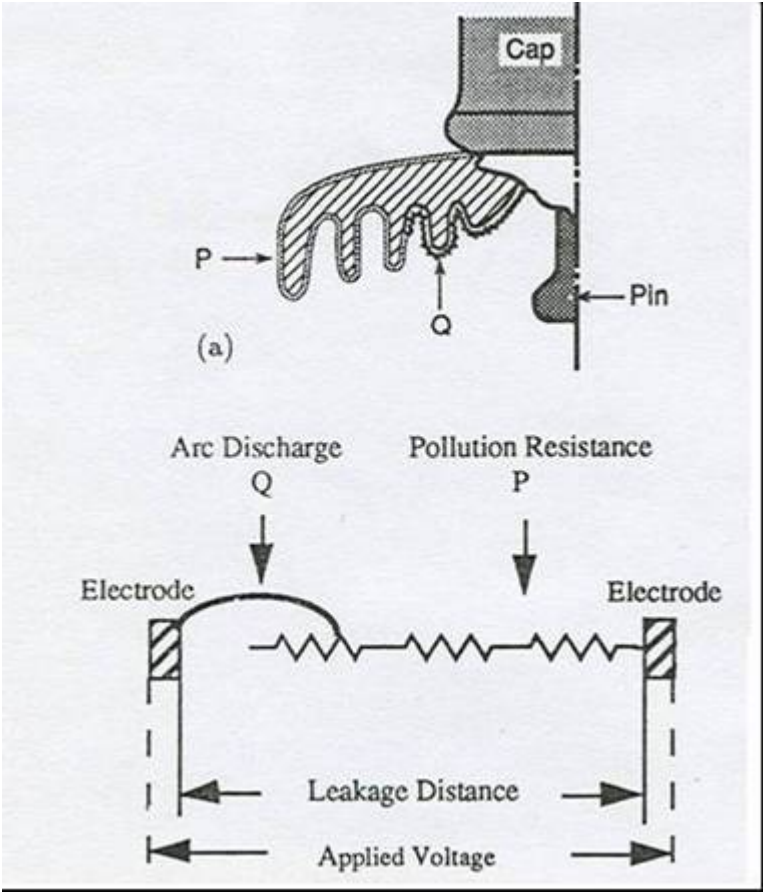


Fig. 2: Flashed 230 kV porcelain station post. Contamination was suspected as the root cause, but as is clear from the photograph, the insulator looks fairly clean.



Fig. 3: Flashed porcelain cap and pin suspension insulators from a mining location in the USA. Contamination was suspected as the root-cause, but except for hardware staining on the top bell, the rest of the bells look fairly clean (ESDD measured $<0.05 \text{ mg/cm}^2$).



Fig. 4: Flashed porcelain cap and pin suspension insulators from an urban location in the USA. Contamination was suspected as the root-cause, but except for glaze damage on the top bell, the rest of the bells look fairly clean (ESDD measured $<0.03 \text{ mg/cm}^2$).

