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A Review of the Flashover Performance of High Voltage Insulators Constructed with Modern Insulating Materials

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Pollution flashover of outdoor insulators is a common risk, which affects the safe operation of overhead transmission networks. Early electrical power systems, which feature insulators made from ceramic materials have been used all over the world with good performance. At present, non-ceramic insulators are in common use, as a result of their good electrical as well as mechanical properties. The aim of this paper is to discuss and compare the flashover performance of insulators typically used in power lines, such as, porcelain, ethylene-propylene-diene-monomer (EPDM) rubber, room temperature vulcanized (RTV) and high temperature vulcanized (HTV) coated silicone rubber. The effect of various parameters, including the severity of pollution, ice accumulation, and shade profile, are considered.. From the studies reviewed it was concluded that there is a distinct difference in the flashover voltages of different types of insulators, and the silicone provides the best flashover performance of all insulating materials.

Keywords : Flashover voltage, Environmental pollution, ESDD, Ceramic material, Composite materials

1. INTRODUCTION

With the increase in the voltage transmitted by electric power lines, especially in developing countries, in the effort to the meet increasing energy needs of industrialization and urbanization, the contamination flashover of high voltage insulators has become a hindrance to the safe and reliable operation of transmission and distribution lines. A large number of pollutants, originating from different sources, such as salts from industrial emissions, roads, and marine water, dust from agricultural fields and industrial factories, cement, and bird drooping, may be deposited on the surface of an insulator. In dry conditions, these contaminants do not significantly affect the flashover performance of high voltage insulators. However, when a contaminated high voltage insulator gets wet, due to operation in fog, rain and mist, the contaminated layer conducts electricity causing a leakage current to flow through the surface of the insulator [1]. This leakage current produces dry regions on the surface of the insulator, due to the heating effect associated with the flow of electricity, which causes electrical discharges across the different regions. In certain favorable conditions these discharges elongate over the whole surface of insulator and ultimately may cause flashover [2]. Historically, insulators were only made with ceramics (porcelain and glass), which have been used for a long time, with acceptable performance. However, the accumulation of deposits on the surface of these materials during long term operation, reduces their dielectric strength, resulting in poor flashover performance of the insulator. To mitigate the prevalence of insulator flashover in polluted environments, composite materials have been tested.

The first polymers used in the fabrication of electrical equipment were epoxy resins, which have been employed since the mid - 1940s, because of their good mechanical and thermal properties, as well as their excellent electrical properties [3].

Many materials like bisphenol and cycloaliphatic epoxy (CE) resins have been developed for outdoor insulation, because aliphatic cyclic structure are superior to aromatic bisphenol structures with respect to resistance to ultraviolet radiation, carbon formation, and surface discharges. As such, these materials have been used for high

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voltage (HV) applications since the 1960s.

In spite of the advantages of these materials, they also failed when used as outdoor insulation, and were never put into real application. Since then, the emergence of new CE materials has resulted in improved electrical performance [4].

Since the mid-1970s a number of new insulating materials have been developed, and the concept of a composite, also known as a polymeric structure, was advanced, with insulator coatings made from materials such as, ethylene propylene rubber (EPR), ethylene-propylene-diene-monomer (EPDM) linkage, polytetraflouro-ethylene (PTFE), silicone rubber (SIR), and a core of fiber-reinforced plastic (FRP). Polymeric insulators have many advantages over traditional ceramic insulators [5], including excellent anti-pollution performance in wet conditions, light weight, a higher surface resistance, easy handling, minimal maintenance, a considerably low cost, and a high resistance to vandalism. Because of these favorable features, polymeric insulators are increasingly adopted by electric power utilities across the world. Many tests have been conducted by numerous researchers to determine the flashover characteristics of composite insulators [6-10]. In the present work, an attempt has been made to compare the flashover performance of different insulators in various conditions.

2. FLASHOVER MECHANISM

Insulation pollution is the greatest cause of flashovers and long-term service interruption. The term flashover describes an unintended electric discharge over or around the surface of an insulator. Six steps describe the process of high voltage insulator flashover. These are the following:

Step 1: The insulator is coated with a layer of pollutants. In dry conditions, this pollution is harmless, as the layer does not conduct electricity. Wetting is necessary to make the layer conductive.

Step 2: As the surface of the polluted insulator is wetted by dew, fog, or light rain, the pollutant layer acts as an electrolyte, which is conductive in this energized condition. The effect of wetting on the strength of the electrolyte depends on the amount of soluble salts in the contaminants, the nature of the un-dissolvable materials, the length of the wetting period, surface conditions of the insulator, and the difference in temperature between the insulator and ambient air. In general, wetting of an insulator occurs through moisture absorption, condensation, or precipitation. Moisture absorption occurs during periods of high relative humidity, when the temperature of the insulator and its surroundings are the same. Moisture condenses on an insulator when its surface temperature becomes lower than the dew point of the ambient air.

Step 3: Once an energized insulator is covered with a conductive layer of pollutants, a leakage current can flow through the surface of the layer. This leakage current increases the thermal conductivity of the layer. Some of the water is lost through evaporation and dry bands are formed in the insulator, due to sharp local increases in resistance, and subsequently, heating power. The dry bands will form first on those sections of the insulator that have the highest leakage current densities, which are around the pin of the insulator.

Step 4: As the pollutant layer never dries evenly at every point of the insulator, the conduction paths are interrupted by dry bands in some regions, which restrict the flow of leakage current. The dry bands modify the voltage distribution along the surface of the insulator. Since these dry bands have a greater resistance than the wetted portion of the surface, it is across these that most of the voltage appears.

Step 5: Figure 1 illustrates dry-band formation and the arcing phenomenon. The voltage produces local arcing, the occurrence of short arcs bridging the dry bands. The length of the arc depends on the layer resistance. A larger layer resistance extinguishes the formation of arcs. However, due to the lower resistance of the wetted region, the length of the arcs increase. Thus, arcs propagate intermittently in the insulator. After several arcing periods, the arcs extend across the length of the insulator, and eventually, flashover may occur.

In comparison to the above procedure, the wetting process of a hydrophobic insulator is quite complicated, as surface water tends to collect in isolated areas, and the development of a continuous leakage current path on the surface is restrained. In addition, if the material is silicone rubber, the polymer material comprises chains of low molecular weight, which are mobile enough to diffuse from the surface of the material into the contamination layer, and the surface of the insulator itself becomes hydrophobic. The layer impedance of the insulator depends on the moisture that migrates into the underlying polluted layer, and the solubility of salts, a characteristic that may not be observed in the low molecular weight polymer. The combined effects of resistive heating in the layer and the applied electric stress on the water drops produce high resistance filaments on the surface of the insulator. Spot discharges spreading from the filaments, causes a localized loss of hydrophobicity, an increased filament span and, if the resulting electric field strength across the filament exceeds that of the produced arcs, flashover, as illustrated in Fig. 2.

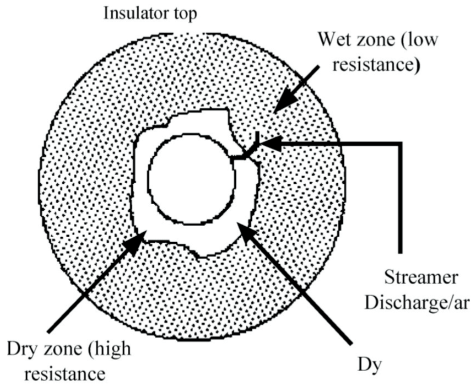

Fig. 1. Demonstration of dry-band formation and arcing on the surface of a porcelain insulator [11]. (© 2009 IEEE)

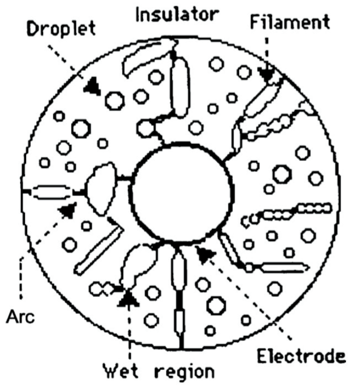

Fig. 2. Demonstration of filament formation and spot discharges on the surface of a silicone rubber insulator [11]. (© 2009 IEEE)

3. EFFECTS OF VARIOUS FACTORS ON FLASHOVER PERFORMANCE OF INSULATORS

3.1 Influence of equivalent salt deposit density and non-soluble deposit density on flashover voltage

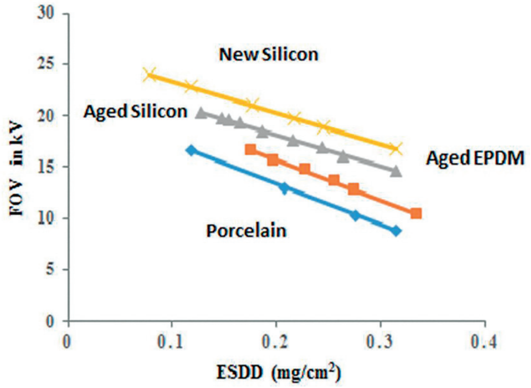

Fig. 3. Variation of flashover voltage with ESDD for different materials.

The amount of contamination can be determined using both equivalent salt deposit density (ESDD) and non-soluble deposit density (NSDD) measurements. ESDD measurement is performed by cleaning a known area of the surface and dissolving the contents in 1L of water. As composite insulators are hydrophobic [12], they can have a high level of ESDD, yet leakage current can be negligible, due to the fact that the water layer on the surface is in the form of scattered droplets, as opposed to a continuous film. This issue has been discussed in detail in the IEEE Working Group on Application and Inspection of Insulators. A number of expressions, relating to different parameters of the insulator are available in the literature to calculate ESDD and NSDD. From several studies, it can be established that the flashover voltage of a polluted insulator decreases with the increase of ESDD and NSDD [13-16], as shown in Fig. 3. Differences in the flashover voltage are indicative of inherent differences in the ability of a material to resist water filming. Reference [13] shows that of all the materials discussed, silicone rubber always has the highest resistance. Because of their hydrophobicity, the influence of ESDD on polymeric insulators is the least.

3.2 Influence of insulator profile

A. Effect of leakage distance

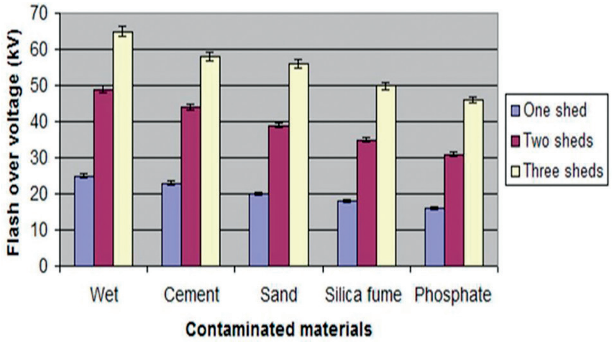

Fig. 4. Variation of flashover voltage (kV) with number of sheds, for a porcelain insulator exposed to various contaminants [17].

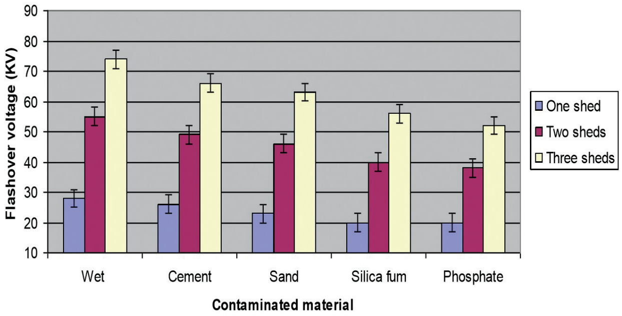

Fig. 5. Variation of flashover voltage (kV) with number of sheds for RTV silicone rubber coating insulator under various contaminated materials [17].

The number of sheds in an insulator also plays an important role in its flashover characteristics, the values of flashover voltages increase as the number of sheds increase. We can explain this as the insulators having a longer creepage path, which improves flashover performance. With equal creepage lengths and ESDD, an insulator coated with room temperature vulcanized (RTV) silicone rubber gives higher values of flashover voltage than an insulator without a coating in different environmental conditions [17], as shown in Fig. 4 and Fig. 5.

B. Effect of shed diameter and shed spacing to shed depth ratio

As the insulator used in overhead transmission lines have different shed diameters and shed spacing to shed depth ratios, the deposition of contaminants depends on these factors. Insulators with larger diameters are more vulnerable to flashover [16]. Increasing the diameter of the insulator tends to increase the pollution encountered, consequently degrading the flashover performance. The ratio of the shed spacing to shed depth delineates the limit of the maximum leakage distance, which is affected by unreasonably increasing the number of sheds, or by over sizing the shed depth. From the results of testing described in [16], it can be shown that the flashover voltage tends to increase when the shed spacing to shed depth ratio increases. We can thus say that an insulator with a high shed spacing to shed depth ratio makes better use of the leakage distance. There are two reasons that account for this assertion. Insulators with a smaller shed depth have better self-cleaning properties, and when a larger shed spacing is used needs a higher voltage is required to bypass the air gaps.

3.3 Influence of pre-contamination and ice accretion

Transmission and distribution insulators in cold climates are subjected to atmospheric icing in winter time. Ice on an insulator is a special type of contaminant, and may drastically reduce the electrical performance of insulators, leading to flashover, and subsequent power outages [18]. Icing flashover voltage depends on various factors such as, the type and thickness, or amount of ice accretion, the conductivity of frozen water, arcing distance, and severity of pollution on the surface of the insulator before ice accumulation, uniformity of ice and air pressure [19-23], and the shed profile of the insulators.

Results from [19-23] reveal the following:

i. The icing flashover voltage at first decreases with increasing ice thickness before a saturation occurs.
ii. The shed profile of polluted composite insulators can also affect the icing flashover performance. Composite insulators with different shed profiles have different values of flashover voltage in the same icing conditions. Since composite

insulators have more shed and a smaller gap between sheds, this gap can be bridged easily by the icicle, leading to a decrease in the flashover voltage.

iii. In freezing conditions the flashover voltage decreases with decreasing atmospheric pressure.

4. CONCLUSION

Contamination on an insulator is a severe problem, which affects the safe operation of electrical power systems, consequently degrading the electrical performance of the insulator, eventually causing the complete flashover in adverse conditions. This problem can be overcome in power systems by increasing the leakage path of the insulator string, primarily by adding units to the string, and secondarily, by applying a composite material coating to the surface of the insulator.

The overall conclusion made from the study is that the flashover performance of composite insulators in heavily contaminated areas can be significantly better than that of porcelain and glass insulators, because of their outstanding properties, discussed in Section I.

The contamination flashover voltages of different types of insulators decrease at various rates, with increasing pollution content. The deposition of contaminants depends on the profile, and material of the insulators. We also conclude that the flashover voltage of an insulator depends on the dimensions and material of the insulators, as well as the severity of pollution.

Various dielectric nano-filler materials can be used to enhance the electrical characteristics of composite insulators.

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