Insulator pollution in transmission lines

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1. Introduction

In recent years, the demand of electric power has enlarged considerably. To satisfy this demand, electrical companies have had to improve the efficiency of their transmission lines. Also, with the liberalization of electrical markets, the individual clients will have the possibility to choose the supplier companies that provide them a better quality of service.

The efficiency of the system is based mainly on the continuity of the service, avoiding faults that suppose economical losses for companies and users. To maintain this continuity, one of the main problems that have been found is the effect produced by pollution in the insulators of electric lines. This pollution is one of the main causes of flashover in the insulators. The insulator begins to fail when the pollutants that exist in the air settle in the surface of the insulator and combine with the humidity of the fog, rain, or dew. The mixture of pollutants, plus the humidity form a layer that can become conductor and allow passing currents that will facilitate the conditions of short circuit. This is due to a decrease of the resistance of the insulator surface. Unless there is a natural cleaning or an adequate maintenance, the electrical activity will be affected by a possible flashover in the insulator.

In other words, the pollution degrades the insulators and affects severely to their electric characteristics, being one of the main causes of mis – operation of the insulators. Therefore, the electric companies should prevent the interruptions of the service, produced by insulators contaminated.
Most of the methods of pollution control are based mainly in:

- Analyzing the severity of the pollution, that is to say, to establish “zones of pollution”.
- Controlling the situation of the pollution on the insulators, to determine when a cleaning or maintenance of the insulators is needed for prevent the problems due to pollution.
- Comparing the behaviour of the different designs of insulators (form, length) and/or of the materials of the insulator that are going to work under contaminated environments.

The probability of appearance of fault situation depends on the type and material of the insulator, the weather of the zone, the type and level of pollution, as well as the working voltage of the insulator.

Other problems related to pollution are: corrosion and erosion of the insulator. Also in polymeric insulators, the phenomenon of dry bands, and the effect of pyrolysis, must be kept of analyzing the operation of the insulator.

2. Types of Pollution.

The level and the type of pollution of a region are associated with the sources of pollution, as well as with weather factors of the place. Table 1, shows the pollutants and the sources that produce them.

Independently of the existing pollution type, the normal phases in which a flashover can appear in the insulator by pollution are:

- The pollution is placed on the surface of the insulator and a contaminant layer appears. The pollution can be caused by a great variety of sources, (sea salt, industries, ashes…). The wind is the main bearer of the particles, having a secondary role the gravity and the electric field.
- By the action of rain, fog, etc. ... the layer on the surface is dampened and enlarges the conductivity.
- The contaminant layer dries. Thus, there is an increase of conductivity and leakage current.

- Dry bands are formed as a consequence of the warming-up of the layer on the insulator surface.
- Partial arches appear through the dry bands.
- Partial discharges are produced, these discharges produce audible noise.
- Finally, the total discharge is produced.

So that the flashover can be produced these phases have not to happen consecutively but that several phases can occur at the same time.

When the contaminated layer is dampened, the resistance diminishes and the current of filtration that passes through it is increased. With this increase, the temperature of the contaminant layer is elevated, and that diminish still more the resistance. The resistance will diminish until the temperature reaches the boiling point, beginning to lose humidity. From this point the layer resistance begins to enlarge little by little until its total drying. Then will reach the maximum value of resistance. This phenomenon is a lot more feasible in narrow parts of the insulator where the density of current is higher. The increase of the resistance makes the current diminish, but its formation implies that most tensions applied to the insulator appear through it, by being still humid the remainder of the layer.

An increase of pollution produces the increase in the leakage current and then the flashover of the insulator is more probable. But if we could distribute the pollution over all the insulator, the voltage would be forced to be more lineal, so we would avoid the electric concentration in any point of the insulator and the probability of flashover would diminish.

In some locations very close to large sources of pollution, the entire insulator is covered with the contaminant, but this situation is an exception more than a rule. Because of it, the most typical guideline is a not uniform distribution. The surfaces exposed or protected of the insulator are affected on different ways by the forces that are responsible for placing the contaminant and to clean the surface. Thus in many cases the most exposed areas are more contaminated than the areas protected, but there are cases where the contrary is also certain.

Contaminant	Source of pollution
Salt	• Coastal areas • Salt Industries • High ways with deposit of snow where salt is used to melt the snow
Cement	• Cement Plant • Construction sites • Rock quarries
Earth	• Plowed fields • Earth moving on construction projects
Fertilizers	• Fertiliser plants • Frequent use of fertilizers in cultivated fields
Metallic	• Mining handling processes • Mineral handling processes
Coal	• Coal mining • Coal handling plants/thermal plants • Coal burning/brick kilns areas
Volcanic ash	• Volcanic activity areas
Defecation	• Roosts of birds areas.
Chemical	• Wide variety of chemical/ process industries, oil refineries...
Smog	• Automobile emissions at highways crossing • Diesel engine emissions at railway crossing / yards
Smoke	• Wild fire • Industrial burning • Agriculture burning

Table I. Contaminants and their sources.

Although many factors can define the insulators pollution, three main types of pollution can be highlighted: the industrial, marine and desert.

A. Industrial Pollution.

People in their daily work generate smoke, dust or particles that are in suspension in the air. These particles mainly by the action of the wind spread over zones where electric lines exist.

The industrial pollution of the insulators appears with the industries development and by the contaminants generated and expelled to the atmosphere, being possible diverse types: metallurgical, chemical substances, dust, smoke, cement…

These substances will settle for the action of the wind, weight, electric fields…, on the insulators creating a contaminant layer. This layer settled on the insulators is formed slowly during a period that can last months or years. During this period will alternate dry epochs with humid epochs.

The most direct way to establish the behaviour of the insulator during this type of pollution is to control the behaviour of the amplitude of the leakage current with respect time, or the load of the leakage current accumulated during a certain period of time. Then it will be possible to see whether the activity of the pollution enlarges with the time and also the effect of the rain (natural wash) will be seen. In this way, we will be able to decide whether we have to do an artificial cleaning (maintenance) or whether with the natural wash is sufficient to avoid a dangerous layer to be formed.

If can't we use a method as the ESDD (Equivalent Salt Deposit Density) to control the behaviour, that is an indirect method, will be less sure. This happens because the risk of flashover in a specific insulator is directly related to the leak current amplitude (or to the value of the average current by second); while the ESDD does not

give us direct information of the behaviour of the insulator and this would stop functioning. For the same ESDD the risk of flashover depends a lot on the design and of the material on the insulator used.

Among the contaminants sources that characterize this type of pollution, we have to keep in mind the characteristics sources of industrial pollution as well as other sources that enlarge the problem:

- The typical contaminant sources are: the smoke of industries, the one produced by vehicles, buildings …
- Industries that consume fossil fuels, diesel, coal… the heavy particles of the fuel remain in suspension in the environment.
- Heavy industries such as fertilizing plants, oil refineries, businesses cement works … these can have severe emissions of contaminants particles.
- If the electric line is near the coast, we have to keep in mind the action of the waves, breezes or winds coming from the sea, the fogbanks and the particles of salt that are in suspension in the outskirts of the zone where the insulators are located.
- Agricultural areas, the farming of the lands, occasional fires, the harvest of fertilizers, etc….

B. Marine Pollution.

The insulators exposed to coastal or marine environments, can become to be conductors due to the formation of a conductive layer on its surface. This layer will be formed on account of the salted dew of the mornings in these zones close to the coasts. When dried with the heat produced in the same insulator or with the environment temperature, is going to deposit in the insulator the evaporated salt that had absorbed before. The particles placed in the insulators are not dangerous in dry weather but, the problem arises when the environmental weather is humid, rains, there is dew, fog… then the layer can be come conductor. The conductivity of this layer will depend on the kind of salt that form it. The weather conditions vary considerably from the coastal areas to the interior areas and they play a very important role in the contaminants deposition rate and in the operation of the insulator. The problem of the pollution depends mainly on the environment.

Also we must keep in mind the salt evaporated that is in the environment. By the action of the wind arrives at the insulators, being able to be placed in their surface. With the passage of time this layer will be thick enough to be dampened and to become conductor.

The danger of the pollution will depend on the type of material and on the form of the surface. Also the sources of pollution must be investigated and the way of deposition of the pollution. The wind is the main bearer of the pollution, being others, the gravity and the electric fields. The pollution will depend also on the direction of the wind for a greater or smaller pollution of the insulators.

The severity of the pollution in a location is quantified in terms of Equivalent Salt Deposit Density (ESDD) measure in units of NaCl mg/cm^2, in which are taking into account, the following five weather factors: Temperature, humidity, pressure, rain and velocity of the wind. This value of ESDD provides a base to do a classification of the severity of the pollution of the zone considered and will serve for knowing the value from which we have to do the maintenance of the insulator, that is to say to develop a politics of correct conservation. The marine pollution is located not only in the surrounding area of the coast, but also to considerable distances by the action of the wind.

C. Desert Pollution.

In some zones, the insulators of the electric lines are often subject to the deposition of contaminants substances of the deserts. This can cause a serious reduction in the efficacy of the insulator, having as a result the flashover and the electricity supply lack. Also the storms of sand must be kept in mind. The type of environmental conditions will affect considerably to the insulators. The predominant elements in this type of pollution are: the sand and the widespread, salty dust in a dry atmosphere. The desert climate is characterized for sand storms and hurricanes that contain particles that move to a high speed. These particles strike to the surface of the insulator causing the material erosion. The storms of sand are an important factor that causes a decrease of reliability in electrical lines.

In this type of pollution the following aspects are relevant:

- The early morning dew represents the greater source of wetting in the desert zones.
- Storms of sand enlarge the pollution problems. The worst conditions occur when the storms are accompanied by a high humidity or rainy weather.
- Pollution layers accumulated on the insulators during the storms are of larger grain and greater content in salt than the layers formed during the normal atmospheric weather of the desert. The pollution contributed by the storms of sand is normally carried by strong winds of distant regions.

The performance of ceramic insulators under desert conditions is satisfactory compared with the performance in other zones with industrial or coastal environments. Nevertheless the use of insulators of SiR is not so acceptable due to the hydrophobic characteristics change depending on the conditions of weather and humidity.

We can call also desert pollution to one that occurs in zones where there are semiarid climates, where the floor is not covered completely by lawn neither by trees. Therefore, the superficial layer of the land is very dry and the dust easily is scattered for the action of the wind. To

high speeds, these strike the surface of the insulator causing the erosion of the surface.

The dry insulators have normally low conductivity, but rain or dew are going to dampen the layer and they turn it into a conductor. The areas contaminated are heated, creating dry bands. This is owed heat generated by the leakeage current. Being a zone with little quantity of rain, these are not capable of washing naturally the insulator and to eliminate the contaminant layer.

D. Other types of pollution.

Inside the environments contaminated where the insulators work, also it is interesting to consider humid zones by the apparition of biological elements in the insulator, what is defined as biological pollution. The common contaminants are the bacteria, algae, mushrooms and lichens that can degrade the surface of the insulator or can create a conductive layer. The mushroom growth can be important because its roots can penetrate in the matter and create a porous structure on the surface of the material.

Lichens and algae are going to free organic acids, especially the oxalic acid, capable of damaging the surface of the insulator. At first, the humid layer formed by these elements has not reason to influence the work of the insulator. The problems appear when this layer dried and form a greasy layer during dry periods. The biological element dies, but an oily layer is formed on the surface of the insulator. If this greasy layer is dampened again, without having been cleaned, a layer of dry bands appears that let the flashover of the insulator.

In the case of algae and especially in some polymeric insulators, the growth rate is low and a lot of time is needed in order to extend over a large area, although humidity and temperature were high. Algae do not penetrate in the material, whether we have an adequate preventive maintenance, and the risk of flashover of the insulator by biological pollution in natural conditions, is lower.

Other source of pollution is salt, during the winter months, in zones of very cold climates. The aim is to prevent the formation of ice in sidewalks and the roads and to de-ice them as soon as possible. The utility of the salty substances is to descend the freezing point of the roads/sidewalks and thus to delay the formation of ice. The quantities of salt utilized can be immense.

Part of this salt will be placed on the surface of the insulator thanks to natural agents, like wind and movement of vehicles in these zones. An important pollution is the accumulation of a quantity of salt of around 0'1 mg/cm^2 on the surface of the insulator.

To de-ice, various types of salts are utilized. The most common one is the rock salt (sodium chloride) due to its low cost; it diminishes the freezing point of the surface to a few degrees. Other chemical substances that are also used are: the calcium chloride and magnesium chloride. They act better than the sodium chloride. For example, the calcium chloride works under (-8 ºC), and is effective for lower levels of relative humidity (42%) compared with the sodium chloride (72%). Also a mixture of salts is utilized, like rock salt with calcium chloride, calcium magnesium acetate (CMA). They are more effective, and they cause less corrosion. Environmentally, they are more pleasant than the rock salt; nevertheless they are more expensive than rock salt.

On the same way, the calcium chloride, magnesium chloride and CMA in liquid state are used. The experience has shown that the liquid resists more, adheres better to the surface and provides a greater reach, besides it applies easier. This way to de-ice is supported clearly by authorities and so the number of users enlarges.

3. Methods for reducing the effect of pollution.

To avoid the effect of pollution on the insulators there are three alternatives: correct election of the insulator type, maintenance of the insulators and elimination of the source of pollution.

The effect of pollution will depend on the region and on the efficacy of the maintenance plans and the correct election of the insulator type.

A. Types of insulators.

The standards and regulations indicate that the insulators utilized in the overhead electrical lines can be made of porcelain, glass or another material of adequate characteristics to their function. The most used insulators until some years ago were manufactured with porcelain, glass or soapstone. Due to their dielectric characteristics and their facility of casting, all the insulators have been manufactured for many years with these materials. However composed materials do a hard competence to the traditional one.

Porcelain is constituted essentially with kaolin and quartz of first quality. The insulators are cooked to 1400 ºC and later they are covered with a layer of enamel of silicate, boil subsequently to obtain a glazed in hot, doing them waterproofs and slippery, complicating in this way the adhesion of humidity and dust.

Glass is manufactured melting to temperatures among 1300 ºC and 1400 ºC, a mixture of salicylic acid with oxides of calcium, sodium, barium, aluminium, etc. The glass used in the insulators is a calcium glass alkaline, obtained by a special procedure by mean of abrupt cooling off through a cold air current during the process of fusion. In this way, a hard glass is obtained, of high mechanical resistance and with good stability for the changes of temperature. Although this material is cheaper than porcelain, it has the disadvantage of its coefficient of enlargement which is, very affected by changes of

temperature. Besides, it cannot be worked in complicated forms and the joining must be carried out by special procedures. However due to their smaller cost and their transparency, that facilitates the visual control, they substitute in many cases to those of porcelain.

Soapstone is used when the insulators should bear large mechanical efforts, because its mechanical resistance is approximately the double of the porcelain and its insulating properties are better. Another advantage is that the insulators of soapstone are mouldings to pressure in dry and their dimensions can be more exact than those of the porcelain insulators, which are prepared to pressure in humid. The main disadvantage of soapstone is their high cost. This is prepared from a paste with great content of talc, that, by cooking, becomes a mass of crystals of silicate of magnesium; the addition of small iron oxide quantities, gives it a characteristic colour grey or brown. Soapstone does not admit the enamel.

Related to compose materials, the families of polymeric material more usual are: rubber or rubber of silicone and propylene ethylene rubbers (generally EPDM). Several components are added to these materials to improve their properties. The insulators manufactured with these materials are known also as not ceramic insulators.

Although employing the same polymer base, the formulation can vary of a lot among the different types of insulators, since the compounds added can be up to the 80% in weight of the covering. Material of backfill is added, generally tri-hydrate of alumina or silica. It complies with the double function of reducing prices and enlarging the resistance to erosion and carbonization of the polymer, during the superficial electric discharges. Other compounds introduced are: plastics, catalysers, antioxidant, pigments, stabilizing UV (ultraviolet), delaying of flame, etc.

The advantages against the insulators of glass and porcelain are important:

- They are lighter, what supposes to reduce the prices of installation, management and replacement.
- Greater resistance to vandalism, due to the inherent elasticity of the material.
- Better behaviour against pollution, which supposes smaller need of cleaning in pollution conditions.
- Smaller maintenance costs.

The objections that can be quoted are:

- They are submitted to chemical changes on their surface, due to the action of environmental agents and electrical discharges, which finish degrading the properties of the insulator.
- Compared with those of glass and porcelain, there is a smaller experience in service, being difficult to compare these diverse types of insulators, since materials are different and not always known.
- Despite its apparent simplicity, its final behaviour depends on the design and the process of production. For example the union of the metalwork to the nucleus of fibreglass, the distribution of the electric field in the covering, the union of this to the nucleus, etc.
- Difficulty to detect defective insulators.

The employed materials have diverse formulations. The ones that have their base in rubber or rubber of silicone seem to have a greater acceptance, among others reasons by their capacity of recovery set against the loss of hydrophobicity. The term hydrophobicity refers to the interaction between the material of the insulator and water.

In a hydrophobic surface, the water is placed in shape of remote drops. If the contribute of water be continuous, water abandon the surface of the insulator by the edge of their flippers. The hydrophobicity is a very valued property because improves the behaviour of the insulators against the pollution. This property reduces the magnitude of the leakage current on the surface of the insulator and also the probability of dry bands appearance.

In a surface lacking of hydrophobicity, the water dampens the entire surface that, together to the contaminant elements, form a conductive layer. If the insulator is contaminated some dry bands appear. On the contrary, in a hydrophobic surface, the layer of pollution dampened is broken, what make to be more difficult the creation of these dry bands and the flashover of the insulator.

After some time in service, an insulator can see diminished their hydrophobicity, although in can be temporarily. There are several possible reasons:

- Pollutant layer: the appearance of a layer of pollution supposes a loss of hydrophobicity.
- Electric discharge, witch depends on the design of the insulator, material of covering and pollution of the surface.
- Electric fields in zones of union of the different materials that make up the insulator.
- Environmental effects: UV rays, wind, rain, particles of sand, ice and snow.
- Chemical effects: concentrations of acids, hydrocarbons and solvents combined with water.

In the case of insulators whose polymer base is silicone, the insulator could recover its hydrophobicity, elapsed a time without external aggressions. Some sections of polymer of low molecular weight can be diffused through the headquarters vulcanized of polymer and material of backfill. These sections resemble to the silicone oil and, due to their low molecular weight in relation to the other molecules of the headquarters, they move naturally to the

surface. When they get to the surface they form a fine layer that restores the hidrofobicidad, including the materials that are found in it, for example the pollution. The sections of polymer of low molecular weight are found in the mass of the insulator, but also they are produced due to superficial electric discharges, that degrade the molecules of polymer in other smaller. The loss of these chains on the surface of the insulator has as a result the ageing of the insulator.

To enlarge the hydrophobicity of insulators in contaminated environments, one of the most utilized measures is the use of hydrophobic greases, being the most common the grease of silicon. It prevents the formation of a continuous film of water, which is the main responsible of the flashover on the contaminated surface of the insulator. This grease has approximately 4 years of activity, although this time depends on the level of pollution. Another grease that is increasing popularity is the layer of silicon RTV with regard to the grease of silicon. The RTV has a longer life from 5 to 14 years, which also depends on the nature of pollution. The most important property of the RTV is the migration of small molecules to the surface that maintain the insulator hydrophobic for more time. A thickness of 0,25 mm. is the adequate one to obtain a satisfactory result. The RTV applies with a brush or spray.

This practice has been utilized satisfactorily to diminish the risk of flashover during long time. Nevertheless, this alternative is quite costly and requires a periodic maintenance to remove and reapply the layer. The frequency of this activity can vary from months to various years, depending on the type, the level of pollution and the environmental conditions.

B. Maintenance of the insulator.

In zones where there is pollution, besides a good election of the insulator, is advisable to have a maintenance plan. In other words, we need to wash or clean the insulator. This is more important in areas with severe environments of pollution or low rain probability, being necessary the elimination of the pollutant layer placed on the insulator. This maintenance can be carried out with the system energized, wash in hot, or de-energized. The later method is used when cannot be applied another method by technical reasons or when the adhesive characteristics of the pollutant, require the use of wash with chemical solutions to recover the insulation level. Many times, the wash is carried out by hand.

In general the most employed methods are: the wash by water to high, average or low pressure, with dry air compressed or with spurts of abrasive materials and more recently the use of ultrasonic. Any of the techniques used has to guarantee that the insulator will not suffer damage, neither that we are going to get worse the present situation.

The wash with spurts of water is the most effective and economic method, if the contaminant is dust, salt or land, or if these pollutants are not much adhered to the surface. If the contaminant element has a high adhesion, (for example the cement or pollutant originating from chemical businesses or by-products of the petroleum) we have to wash the insulator with abrasive elements. They can be smooth elements, as shattered shell of cobs of corn or shells of nut, fine dust of lime, or more abrasive elements as the fine sand. Always the opinion of the manufacturer will be kept in mind for not damaging the surface of the insulator.

To prevent the flashover during the wash, the following observations have to be considered:

- The wash of the insulator will begin from lowest phase conductive.
- When we wash, the water should not fall directly on a dirty insulator.
- We will begin to wash from the lower part of the insulator until finishing in the upper part.
- Is very important to keep in mind the direction of the wind.

C. Elimination of the pollutant sources.

Generally, research has been directed toward the pollution reduction methods. It is owed to the fact that the elimination of the source of contaminant is only possible when the type of contaminant is industrial, because of the difficulty to eliminate other contaminant sources, such as desert, sea…

4. Conclusions.

The decrease of pollution will depend on: the type of insulator, the maintenance, the increase of the number of elements in the chains of insulators, the increase of the leakage line, a better design of the insulators, the new materials…

They are subjected to conditions that depend on the place in which they are installed. These conditions can vary extensively from a place to another, depending on the characteristics of the region considered. These characteristics make possible that the level of insulation required can vary in a same line, due to the conditions of the pollution are different for all the line. The weather factors influence in a very important way on the growth of the pollution levels in a region.

Usually the insulators show a significant change in their natural operation when they are exposed to severe environmental conditions.

If, during the construction of an overhead electrical line, we do not keep in mind the pollution of the zone and we do not choose an adequate insulator, we will be obliged a greater maintenance work to prevent faults. This supposes an additional cost for the business.

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