POLLUTION MITIGATION SOLUTIONS FOR OVERHEAD LINE INSULATORS

J.M. GEORGE, D. LEPLEY, E. BROCARD, F. VIRLOGEUX*
S. ROUDE

SEDIVER RESEARCH CENTER
SEDIVER HIGH VOLTAGE LABORATORY

FRANCE

ABSTRACT

When overhead transmission lines cross regions where either natural or industrial contamination prevail, airborne dust or conductive contaminants can impact the electrical performance of insulator strings. The global term « pollution » describing this phenomenon is very often assimilated to anything that comes on the surface of an insulator, but such « pollution » should be defined precisely to allow for the most appropriate counter measure selection.

First approach usually implemented by maintenance crew is to go for washing activities. But those actions which can be performed offline or live-line are costly, manpower and equipment intensive and with a limited effect in time.

Among the solutions adopted by utilities at design level the increase of leakage distance is the most common method. When dealing with pollution problems, the first set of actions is to know what type of pollution the line is facing. Sampling techniques are described as well as ranking and classification charts established to determine the severity of the environment.
Another step is to select the most appropriate insulator type and design. The mechanism of dry band arcing and dynamics of arcing will be examined showing that leakage distance is not the only parameter to take into consideration. Shape matters greatly and we will show how different shapes with the same leakage distance can generate different behaviours and withstand properties.

Likewise, the use of a hydrophobic material such as silicone rubber has proven to be an effective tool. Silicone rubber materials have proven to work well preventing flashovers from occurring in a variety of contaminated environments (composite insulator or silicone coating). We will describe the physico-chemical processes at work to better understand how hydrophobicity can help mitigating pollution problems but also understand how such material can suffer and age prematurely in harsh environments.
Many research projects around the globe look for innovative methods to mitigate pollution like for example by measuring the critical leakage current in service. A concept will be introduced as well as the way to use such "live" data in preventive maintenance.

This paper will cover the general aspect of pollution for overhead line, present the various solutions available to help maintenance teams in their daily activities.

KEYWORDS

Glass insulators, String, UHV, Overhead transmission lines, Pollution, Maintenance, Silicone coating, Leakage current, Monitoring, Harsh environments

1. Introduction

High voltage outdoor insulators play an important role in the safe and reliable transmission of power. Although the cost of insulators in an overhead transmission line project may be as low as 5 to 8 % of the total cost of the line, their performance is of vital importance in power system as they can be responsible for as much as 70% of the line failures and up to 50% of the line maintenance cost. During service conditions, outdoor insulators are exposed to various types of stresses (electrical, mechanical, etc.). Mechanical design specifications for outdoor insulators are well developed and provide

* fabien.virlogeux@sediver.com

promising results in different climates. However, the electrical performance of outdoor insulators in harsh environments is more challenging. The reliability of electrical transmission system is dependent on the performance of outdoor insulators in adverse weather conditions. When overhead transmission lines cross regions where either natural or industrial contamination prevail, airborne dust or conductive contaminants can impact the electrical performance of insulator strings. The global term « pollution » describing this phenomenon is very often assimilated to anything that comes on the surface of an insulator. But such « pollution » should be defined precisely to allow for the most appropriate counter measure selection.

In contaminated conditions, soluble and non-soluble contaminants deposit on the insulator surface. Under moisture, cold fog and mist, the pollution layer becomes wet, and soluble contaminants dissolve in water leading to the formation of a conductive layer, resulting in a flow of leakage current, dry band formation and, under certain conditions, flashovers.

2. Definitions

The challenge for line design engineers and maintenance crews is to know how such electric flashovers can be avoided by either using insulators catching less contaminants, more resistant to arcing or designed and made with materials which will reduce the ability of an external arc to take place.

When dealing with pollution problems experts use several definitions which are listed hereafter:

Creepage distance: (sometimes the word "leakage distance" is being used). It is the distance an arc needs to cover from one metal end fitting to the next one following the surface of an insulator (figure 1).

Arcing distance: the shortest distance between ground and energized side of an insulator (figure 1)

ESDD is the acronym for Equivalent Salt Deposit Density. It represents the quantified value of the contaminants which dissolve in water like salt. When salts dissolve in water the conductivity of the humid/wet film on the surface of the insulator increases, and subsequently the risk of having a flashover increases as well. The unit of measure is mg/cm².

NSDD is the acronym for Non-Soluble Deposit Density. It corresponds to the amount of deposit on the surface of the insulator which does not dissolve in water and remains inert on the surface. Sand for example is a typical component of NSDD. The non-soluble component of the pollution layer will work like a sponge catching more humidity which in turn will facilitate the conductivity on the surface of the insulator.

Leakage current: is the electric current flowing along the surface of an insulator along the leakage distance. Each insulator type has a limit above which the leakage current will lead to arcing and possibly a complete bypass of the insulator (this final stage of arcing is then called flashover).

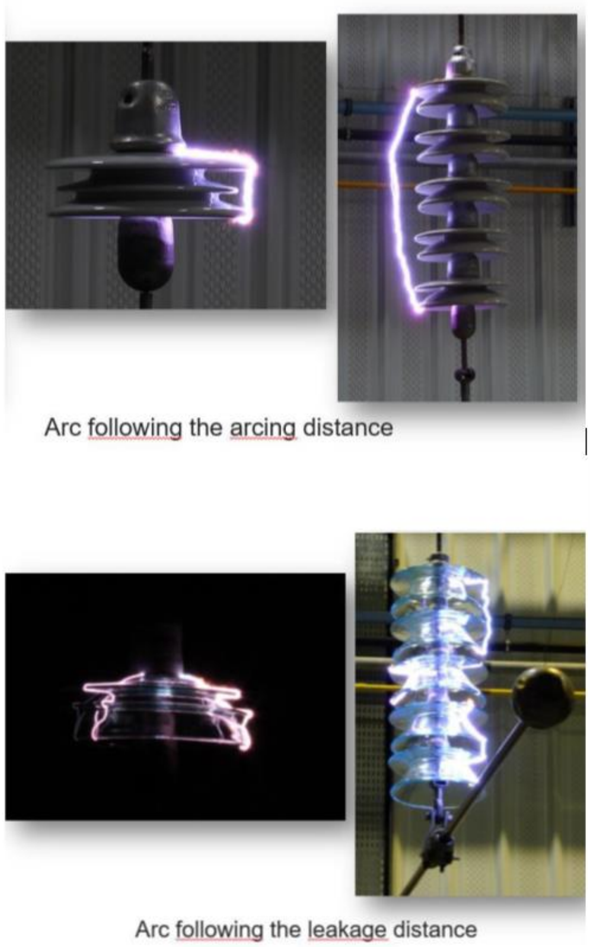


Figure 1: arcing distance (top) versus creepage distance (bottom)

Specific leakage distance: the ratio between the leakage distance of an insulator (or string of insulators) and the phase to ground voltage. The unit is mm/ kV and referred to as USCD (Unified Specific Creepage Distance)

Dry band arcing: is a dynamic process by which an arc once initiated will dry the area where it takes place. By drying a segment of the insulator, the arc will progressively have more and more difficulties to be sustained, will self-extinguish until the surface is wet again, leading to currents which will generate new arcs, new dry spots….

The evaluation of the pollution level in any given area on an insulator can be made by measuring both ESDD and NSDD. The procedure consists in washing the surface of the insulator with deionized water which conductivity is measured prior to washing. After washing, the conductivity is measured again, and tabulated for conversion in equivalent salt weight. This number is then divided by the surface which was washed. Once this is done, the washing water is filtered on a paper filter which needs to be dried in an oven. The weight of solid deposit is divided by the surface of the insulator to give the final NSDD in mg/cm². (figure 2)

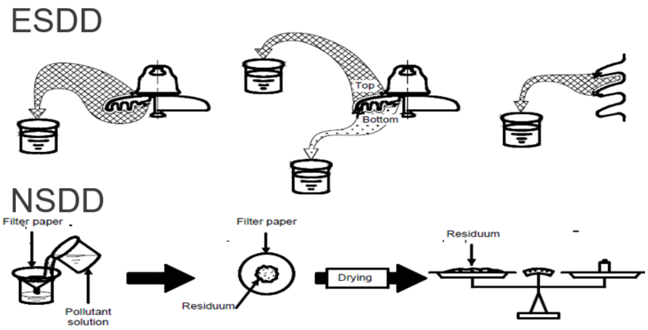


Figure 2: ESDD/NSDD evaluation method (source IEC 60507)

Once ESDD and NSDD are defined, it is possible to establish the pollution class as per IEC 60815 (figure 3).

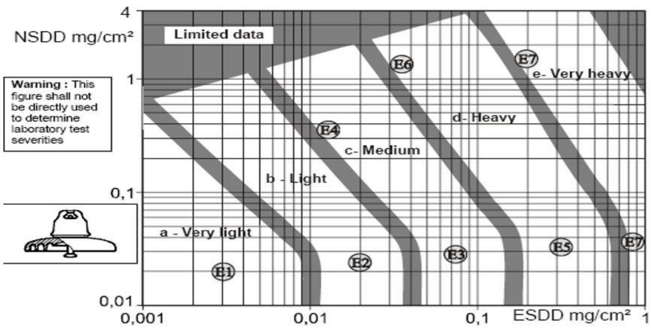


Figure 3: IEC 60815 pollution classification

For each class of pollution IEC gives an average USCD as a reference base value for selecting a leakage distance in the environment under consideration (figure 4).

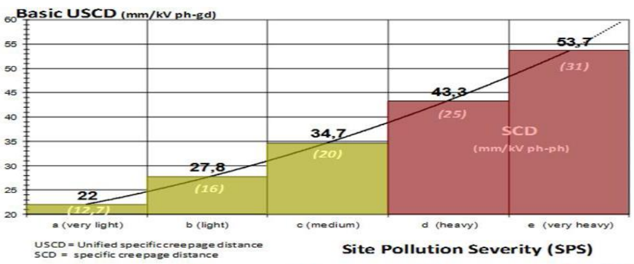


Figure 4: Typical USCD values per pollution class as per IEC 60815

3. First approach with insulators selection and string dimensioning

It is not unusual to meet lines in service for many years that are suddenly suffering from outages related to insulation faults. Main reason is that the environment of the lines changes over the time and the insulation design at the time of the line erection is no longer matching the requirement of the current environment. Those changes can be due to various causes such as climate change, new human activities such as agriculture development, new industry development, etc... In such cases the first approach usually implemented by maintenance crew is to go for washing activities. But those actions which can be performed offline or live-line are costly, manpower and equipment intensive and with a limited effect in time.

Figure 5: Overhead line cleaning operations

The other option is to modify the design of the insulator string within the dimension tolerances allowed by the current design (respect of clearance rules, etc). The design option to look after includes the shape of the insulator and the creepage distance of the string.
Cap and pin insulators offer several dielectric shell geometries to cope with various environments as explained in IEC 60815-1 [1]:

- Standard geometry is designed for inland, relatively clean environment
- Pollution type (so called also anti fog profile) with deep under-ribs are suited for heavy pollution, some coastal applications
- Aerodynamic profile (or Open Profile) offer benefit for areas where pollution mainly deposited by wind such as desert
- Alternating shed disc profile is another option for polluted environment with high solid pollutant deposit

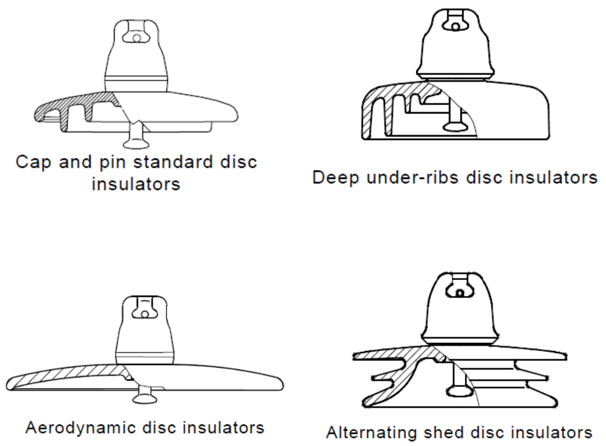


Figure 6: Insulator profile description according to IEC 60815-1 table 6

Some shapes will catch and retain more dust while others are more adapted to fight arcing activity in moist, humid or foggy conditions. Figure 7 shows a selection method based on shapes.

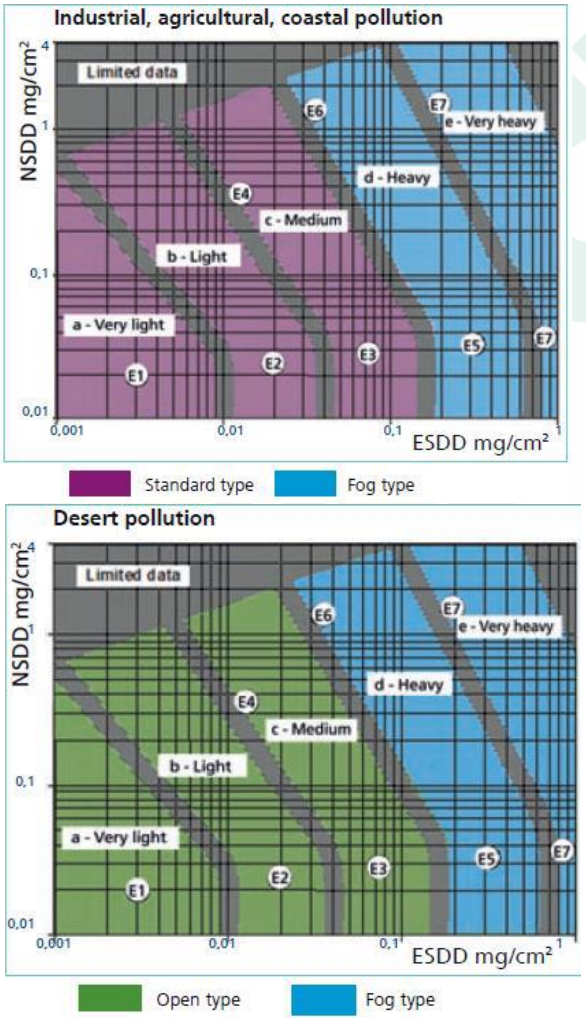
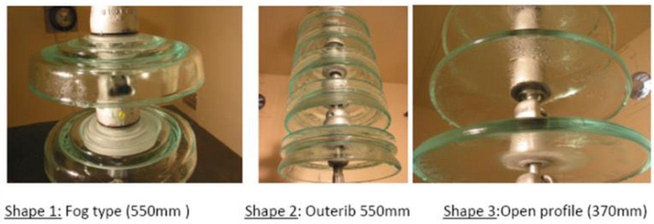


Figure 7: Recommended shapes for various pollution environments (shapes as per SEDIVER catalog)

Another important aspect in pollution mitigation is the fact that shape will dictate the dynamics by which the leakage current and the dry band arcing will behave. Figure 8 shows an example where insulators with the same leakage distance have very different flashover values and very different ultimate leakage currents threshold values. It is easy to understand that it is not possible to set a maximum reference leakage current value without defining the type and shape of insulator under consideration.

If the case of a salt fog environment is simulated in laboratory, using a very high salt density of 80 g/l, the performances of the 3 short strings composed of different profiles offer following set of results:



	5 x F160P/170	5 x F160PH/170	6 x F160D/146
Leakage distance (mm)	2725	2750	2220
MAX WITHSTAND (kV)	80,6	53.2	49
Max withstand kV/m leakage	29,6	19.3	21.7
Mean leakage current during withstand steps (rms) mA	283	127	212

Figure 8: Influence of the insulator shape in performance under salt fog conditions

Those results clearly illustrate the importance of the insulator shape to get full benefit of the creepage distance offered by the insulating units. The performances of the various profiles are highly dependent on the environment. The shape of the insulator is of key importance to ensure that the selected creepage distance is effective.

4. Second approach with hydrophobic surface materials

When dimensional and clearances constraint don't allow the changes proposed in the first section, then the alternative is to use a material offering an "hydrophobic" or "water-repellent" surface property. A material is considered as hydrophobic if the contact angle on the surface of the material exceeds 90° (figure 9). For outdoor high voltage insulation, the preferred material is a silicone rubber compound.

A material with this property will remain dry, water droplets and therefore will keep the leakage current at low values, preventing flashovers from happening. Silicone compounds have also the ability to transfer this property to any contamination on its surface. This mechanism called "hydrophobicity transfer" is the result of low weight molecules (LMW) inherently part of the silicone compound migrating to the surface and embedding the pollutants on the surface. The surface can remain water repellent even with surface contamination. Under extreme pollution conditions silicone rubber surface can make a decisive difference in withstand capabilities.

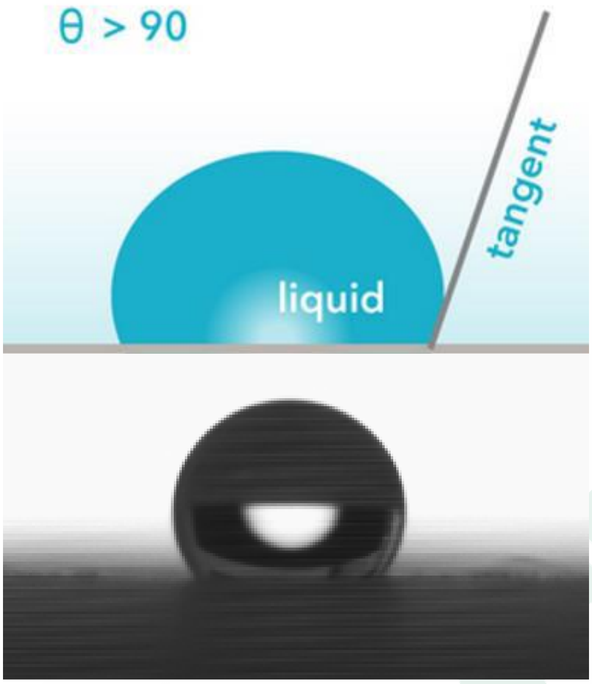


Figure 9: Hydrophobic surface property illustrations

While these properties seem extremely attractive, silicone shows also some weaknesses. Among those is the fact that silicone is relatively sensitive to dry band arcing, leading to erosion and possible cracking of the material (figure 10). Electric arcing under the form of dry band arcing or corona (result of the breakdown of air under intense electric field) generates ozone which in turn reacts with nitrogen in air to form nitric acid.

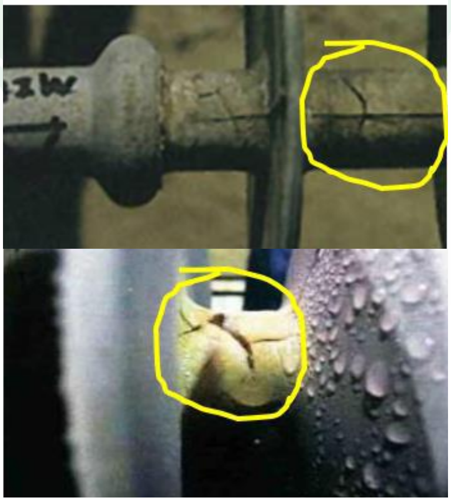


Figure 10: Erosion of silicone rubber under the effect of electric activity

To reduce such effects silicone can be designed with additives such as fillers (like Alumina Tri Hydrate, ATH)
slowing down the degradation process. However, failures of silicone polymer insulators are occurring mostly once the rubber housing is deteriorated leaving moisture to penetrate inside the core. These degradation mechanisms are not easy to spot during line inspection and failure modes such as brittle fractures, cannot be anticipated. This poses problems for maintenance but more so for live line work.

Like for silicone rubber used in composite insulators, coatings can be made with silicone containing various fillers to increase the resistance to erosion or none at all (quartz or ATH fillers are commonly used among manufacturers). As an example (among a large diversity of test protocols established for accelerated ageing tests) interesting results can be found from a 2000h multi-stress test combining UV, rain, salt fog, humidity, voltage on a weekly cycle performed according to a specification from TERNA (Italy). A clear discrimination appears between various silicone materials including coatings made with different types of ATH (figure 11).

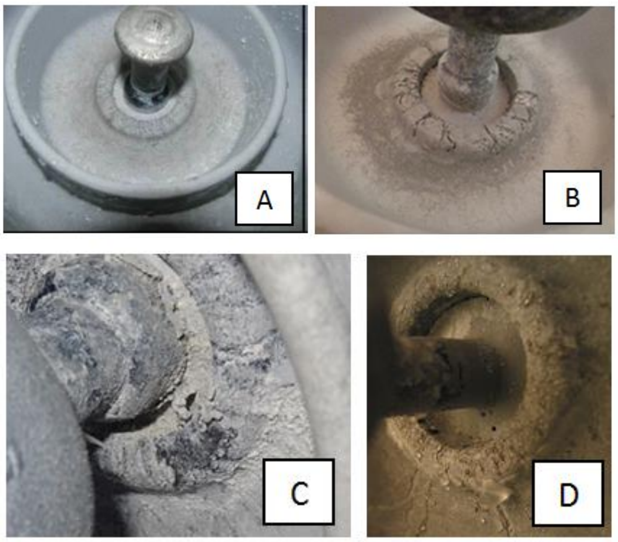


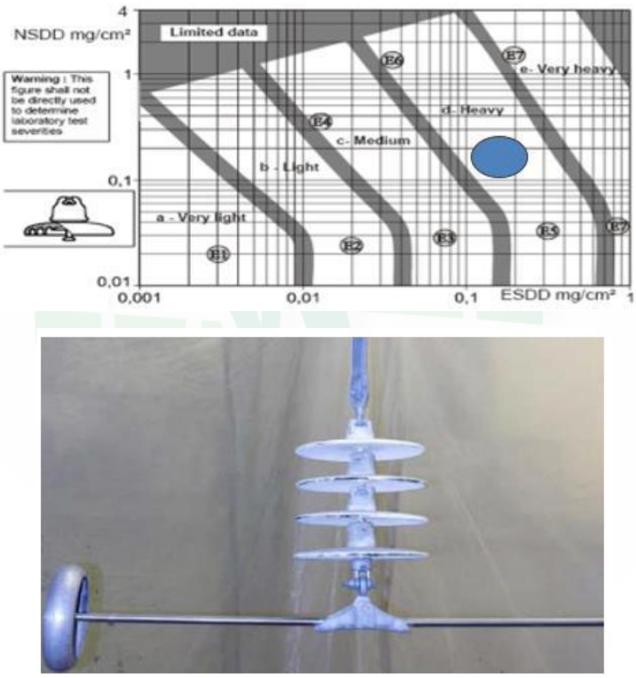
Figure 11: Samples after 2000h ageing test.
A: polymer 1 ATH type a – B: polymer 2 ATH type b – C: polymer 2 ATH type c – D: polymer 2 quartz filler

Field experience has shown that extreme pollution can be handled with silicone, but at the same time it has been established that more the contamination is severe the faster the degradation and risk of failure of polymers. On the other hand, the resilience of toughened glass is known to be a major asset for overhead lines stability. Combining both has been a concept introduced more than 20 years ago, with great success. Silicone coatings work better when applied in an industrial controlled environment. In some cases, the application is made in the field but thickness of the coating as well as adherence remain out of control. In a factory environment both parameters are carefully controlled.

The performance under pollution has been established in laboratory tests either with salt fog conditions or with solid deposits having an ESDD/NSDD under clean fog conditions (figure 12). Field performance confirms these results with more than a million units used only in Italy along the coasts removing the need for washing for more than 12 years. Likewise, in the Middle East, silicone coated glass insulators have been successfully in service for about 20 years [2] ; [3]. Samples have been removed from the line for a performance check and the results show that these units outperform after 20 years new non-coated insulators tested with artificial pollution deposits equivalent to those measured on the line (figure 13). In the USA the same trend exists, and large utilities are now using silicone coated units in replacement of polymer insulators.

	Test 1	Test 2	Average
RTV-coated, SDD 0.3 mg/cm^2	88 kV	80 kV	84 kV
RTV-coated, SDD 0.1 mg/cm^2	128 kV	136 kV	132 kV
Non coated glass, SDD 0.1 mg/cm^2	76 kV	76 kV	76 kV

Figure 12: Clean fog pollution test with solid layer ESDD: 0,1mg/cm², NSDD: 0.19 mg/cm² CUR: 0.7 on short string of 5 insulators



Non coated string : U50 = 73 kV
19 year old coated string: U50 = 240 kV (*)

Figure 13: Pollution performance of coated glass insulators after 20 years in service

5. New option : live leakage current measurement

Sediver recently introduced the concept of “equipped” insulator which offers ability to collect service data from the insulator string in real time.
The patented device developed by Sediver engineering group offers the ability to measure data on the insulator string (including but not limited to environmental data such as temperature, humidity, time, insulator pollution status by the mean of the leakage current, etc...). this data pack is then transferred to the utility maintenance crew to define and organize relevant action plan accordingly.
As explained earlier in this paper, the leakage current is a critical indicator in both the evaluation of the pollution and in the development of the electrical activities potentially leading to flashover. The concept is to follow the development of those surface currents and be in position to anticipate any critical situation.

This device is installed as a replacement (or in addition) to the first insulator on the tower end of the string.

Figure 14 : Description of the device

The system measures the relevant parameters and transfers the data through the internet platform. This information will then be treated and displayed to be easily accessible to the maintenance team.

<u>Figure 15 :</u> typical dash board of collected data.

While many different types of parameters could be introduced through this system, the decision was made to monitor the leakage current since many utilities are looking for any piece of information which can be related to environmental contamination and insulation properties of transmission line insulator strings. Having a clear understanding of the impact of pollution levels on site can help maintenance crews to be more precise on washing cycles but also provide valuable information if the utility is implementing silicone coated insulators in questionable areas of the grid.

Conclusion

Pollution mitigation for overhead line insulator is a complex subject where multiple parameters will influence the final performance.

A precise knowledge of the environment where the overhead transmission will pass by together with measured values of pollution deposits are the first required step in approaching the subject.

The selection of the best suited insulator (shape) and the design of the insulator string (length, creepage distance) is of critical importance to avoid the costly and time consuming process of insulator washing.

The use of hydrophobic surface (silicone rubber) will help improving the performance under pollution and should be combined with a long term and proven technology such as toughened glass insulator. The technology of silicone coating applied in factory on the surface on the toughened glass insulator is mature with more than 20 years of service experience nowadays.

Recent development in live measurement of leakage current will offer a new tool to maintenance crews to identify critical area subject to pollution issue and to plan at the right time inspection and potential corrective actions. This will allow an optimization of the activities planning and leverage the cost related to inspection and maintenance.

REFERENCES

[1] IEC 60815-1 : Selection and dimensioning of high-voltage insulators intended for use in polluted conditions - Part 1: Definitions, information and general principles – IEC standard

[2] Review of 20 Years of Silicone Coated Insulators in the Field ; VIRLOGEUX F., PRAT S., GEORGE JM ; INMR 2017 World Congress, nov 5 - 8 2017, Barcelona, Spain.

[3] Alternative Pollution Management Methods for Overhead Line Insulators, GEORGE JM. ; CEATI Transmission Conference 2016: Best Practices for EHV Line Design & Asset Management - November 1-2, 2016 - San Diego, CA, USA