



SMART INSULATORS

Technical Update since the introduction in 2018

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During CIGRE 2018, SEDIVER introduced its proprietary so called “Smart insulator” which core target is to measure in real time the leakage current on a string of insulators on a line located in a polluted environment. The capacity to engage into this field is based on more than 30 years of experience in test stations (SEDIVER owned a test station in Dunkirk located on the shore of the channel north of France between a steel factory and an oil refinery and participated in numerous other stations around the world) and laboratory pollution testing. The needs to better understand and control leakage currents in polluted environments has led SEDIVER to continuously adapt and develop tools aimed at the monitoring of this critical component in the operation of overhead transmission lines or substations.

The understanding of pollution events, performance and constraints has been described in numerous publications and it is worth mentioning IEC 60815 series [1] where basic elements are described for the use of engineers seeking for guidance in this field.

For instance, it is critical to understand several key points which are needed when looking at critical leakage currents on overhead line insulator strings:

- a. Surface contamination on insulators becomes critical when the atmospheric conditions reach high humidity conditions, typically above 70%. The deposit of solid contaminants starts operating like a sponge making the NSDD become wet and generating currents which intensity increases with the dissolving of salt contained in the pollutants measured as ESDD.
- b. The ability of an insulator to sustain a certain level of leakage current is a function of its profile [3]. Especially for insulators exposed to salt fog conditions, the development of dry band arcing differs with the profile.
- c. In coastal environments, salt fog events are often rapid, and the increase of leakage current can be fast with little if any deposit or accumulation. Making a pollution level assessment for this type of pollution (classified as type B in IEC 60815 [1]) is not always optimum through the classical method of collecting ESDD/NSDD. Leakage current readings are therefore extremely interesting to have in such conditions.
- d. For dusty environments the accumulation of the pollutant layer on the surface of the insulator depends on the shape of the insulator which itself has an ability to sustain certain levels of leakage current before reaching

- a critical stage. In DC the dynamics of dry band arcing are different from AC, with different critical current levels which is a main contributor to the difference of insulator shape in DC [2].
- e. Silicone surfaces (so called HTM, Hydrophobic Transfer Material) have superior pollution performances thanks to the hydrophobic property of the material but line insulation with these materials require a careful approach since electric activity can rapidly damage the housing or the coating by erosion. During pollution events under humid conditions, it is not uncommon to see flashovers on silicone insulators taking place with little warning, and therefore the trigger for early-stage indication of a possible flashover needs to concentrate at relatively low leakage currents, sign of a progressive degradation of the hydrophobic property of the material. HTM insulators require a pollution management driven by the risk of degradation and not only the risk of having flashovers which usually is a consequence of earlier degradations or ageing.

1. Expected functions.

The SEDISMART can be used for several key objectives. The prime reason for having this device on a line is clearly to have access to the evolution of leakage current data to know ahead of time if there is a climatic scenario or pollution accumulation which could lead to a potential flashover or a reduction in the insulation level of a string. There is no need to install such a device everywhere along the line but only in locations known or expected to be spots where pollution is a potential risk. Most likely utilities and/or their maintenance teams know usually very well where the pain points are located, and one unit installed at one or more strategic locations along the line are enough to provide an effective monitoring. In this case the device will assist maintenance in their planning for washing sections of lines and have a better anticipation of the risks associated to polluted related events.

The second function can be an assistance in deploying a pollution map. Among other techniques, having the leakage current in a variety of locations can support the design of an ongoing real time pollution map where leakage current can be correlated with actual ESDD/NSDD levels to be calibrated locally or in conjunction with laboratory pollution test data.

Finally, the device can be useful in cases where a better understanding of local contamination is required for a future line design along a given route or the optimization of the performance of an existing line. Besides actual pollution sampling the leakage current values on specific profiles of insulators can have merits for the selection of the most appropriate USCD level, preferred shapes and/or the need to use silicone coating on the insulators surface.

2. Initial design of the Smart insulator.

From the very early stage of development, SEDIVER decided to design a device with a sensor built in the insulator itself (and not added separately afterwards), with a collector of leakage current at the base of the cap rather than using the technology of the Rogowski coil. The main reasons for this choice were the necessity for the Rogowski technique to amplify the signal substantially, and it is by nature not compatible with a DC application. With the built in leakage current collector, there is a stainless-steel ring directly applied at the base of the cap which forces any leakage current to be seen (figure 1 and 2) by the system.

The current is measured on the first insulator on the ground end of the string of insulators.

Originally the information was sent to an end point which itself was communicating through a LORA protocol to a gateway located in a radius of 3km to 5km. The Gateway was usually installed on the tower where the end point was located, but the concept was to be able to have several end points communicating through

one Gateway in a limited geographical region. The Gateway itself was communicating through GSM and the data transferred to our server. The data was then analyzed and presented for the end user with 2 levels of alarms one being a warning explaining that something is happening, the second being a warning of risk of flashover. These limits are based on the pollution performance of the given type of insulator in its given environment with respect to the knowledge, tests, and field data from the SEDIVER database. Figure 1 shows the initial set of equipment from the insulator string to the gateway as installed in the field in its early stage of development.

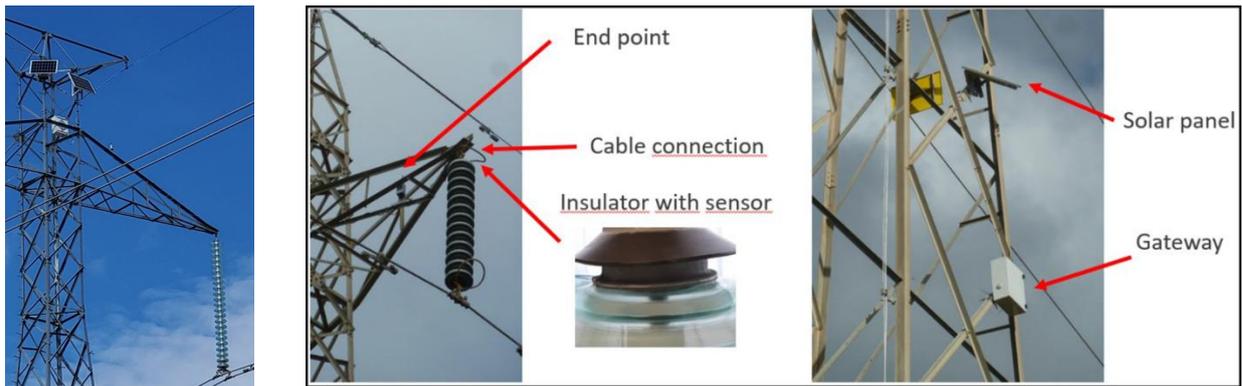


Figure 1: initial SEDIVER Smart system

One of the problems with an IOT embarked in the field on a tower that cannot easily be reached and with no power outlet to energize the system (which itself needs to be installed on the tower end of a string) is the question of energy management. This constraint has required in the early generations the use of relatively large solar panels as shown in figure 1. The supply of energy to the system has been one of the biggest challenges encountered in the early applications, linked somehow to the data acquisition and communication process consistency.

3. Lessons learned and current design.

The lessons learned from the early years can be summarized below and have led to the evolution of the system up to the current version generation V5.1 as shown in figure 2:

- a. The reality of pollution deposit and contamination conditions on a line do usually not require the need to have multiple sensors in the same geographical region. Therefore, the functionality of the Gateway to work as a data collector for several end points proved to be useless. While it removed the need for having the LORA communication protocol (which in the meantime has shown some limitations especially for the highest voltage classes) the idea to eliminate the Gateway completely and design the system with a direct GSM communication protocol was adopted. This was a major simplification, weight reduction and energy consumption reduction factor.
- b. Going to a GSM system, the antenna was modified to reduce the impact of wind. A mushroom antenna was then adopted as shown in figure 2.
- c. Taking advantage of the simplification, an energy management study was engaged resulting in the possibility to use a much smaller solar panel (one small unit versus 2 large panels before) and optimized electronic components. The buffer in energy available is better and the risk to see a solar panel damaged by strong winds is reduced. The current version takes approximately 2 mA to 3 mA compared to several 100mA previously.

- d. The sampling of leakage current values on an hourly bases was not considered as a satisfactory process and an automatic process based on a watch/sleep software was adopted. This program which is patented is constantly watching the leakage current values and dynamics and only wakes up for processing when needed, meaning when something interesting is happening. This can be either a specific magnitude and intensity of current or a sequence of peaks which could be of interest. The data is only collected and used accordingly if needed and reported at the regular timing scheme. This also contributes to a better management of the energy on board.
- e. In the early generation the system could only transmit from the tower to the receiver. This has been modified so that the device can be either updated or completely reprogrammed remotely. The bidirectional evolution of the system is especially interesting for maintenance and diagnostics.
- f. In the absence of leakage current one may wonder if the system really works and/or if something has changed the calibration of the system. In the latest version the system is self-calibrating periodically with an alert if something goes wrong or changed from the initial moment when the system was calibrated in the laboratory prior to installation.

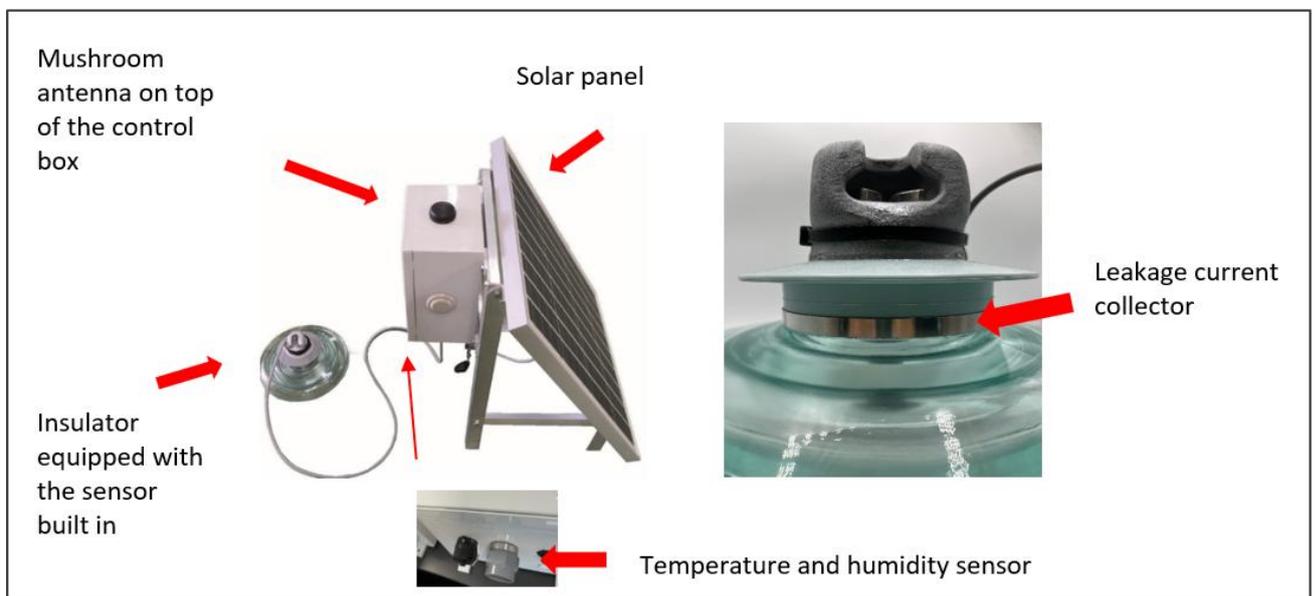


Figure 2: SEDISMART V5.1 system and detail of the leakage current collector

The insulator which contains the sensor is part of the tower and contributes normally to the insulation of the line. Therefore, there is no change in spacing of the string, and the leakage distance of the Smart unit is fully part of the insulation itself, with couplings, ratings, shape identical to the rest of the string. Also, the installation of the sensor is customized to each specific case with the same insulator than the model used on the line.

The installation of the control box and the solar panel is made thanks to a universal stainless-steel base which can adapt to any type of lattice tower (figure 3). If the system needs to be installed on a tubular pole a customized solution will be proposed.



Figure 3: example of base mounting system (brackets for solar panel and base for control box)

The quality of the signal which dictates the performance and continuity of the communication is defined prior to installation with the selection of the most appropriate frequencies. This is established through the validation ahead of time during the customization of the device of the following parameters from the LTE capabilities of different providers existing locally:

- RSRP: Reference Signal Receiving Power
- RSRQ: Reference Signal Receiving Quality
- SINR : Signal Interference + Noise Ratio

These can vary among providers and the optimum choice will be made for the specific location after a diagnostic is being made along the route of the line as shown in an example in figure 4.



Tower #	2	3	4	5	6	7	8	9	10	11	12
Provider 1	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow	Green	Green	Green
Provider 2	Red	Red	Red	Red							
Provider 3	Red	Red	Red	Red	Yellow	Green	Green	Green	Green	Green	Green
Provider 4	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow	Green	Green	Red
Provider 5	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Green	Green	Yellow

Figure 4: Diagnostic enabling the selection of the optimum communication provider and set of frequencies.

4. Leakage current and critical conditions of insulators in service

The SEDISMART device is intended to provide a diagnostic when the pollution is reaching a level where severe dry band arcing can take place and initiate a flashover. This critical stage is not the same for all insulators and depends on the shape and profile of the insulator. As an example, salt fog tests performed on 3 different shapes of insulators have shown that the value of the critical leakage current can vary in large ranges [3]. Figure 5 below shows that in salt fog conditions an outerib profile (middle) will flashover at 66% of the capacity of a string of fog types (left) while the maximum current is 45% less than the maximum leakage current which a string of fog type can take. This clearly demonstrate that making a diagnostic of pollution severity based on leakage current values requires the knowledge of the expected limits of each profile being used for each insulator string design. SEDISMART provides warning levels which differ as a function of the type of insulator being monitored.



Figure 5: relative limits under 80g/l salt fog test conditions of 3 different profiles [3]

As mentioned earlier the leakage currents are generated under critical conditions such as salt fog or clean fog and/or high humidity local conditions. To monitor these parameters all together and in real time, the SEDISMART is equipped with a temperature and humidity sensor fitted underneath the control box as shown in figure 2. As a result, the control screens available remotely will display all three parameters simultaneously (besides several additional parameters such as battery voltage level and solar panel voltage, number of events....). As can be seen from figure 6, the leakage current follows nicely the evolution of humidity in the surrounding environment of the tower equipped with the SEDISMART.

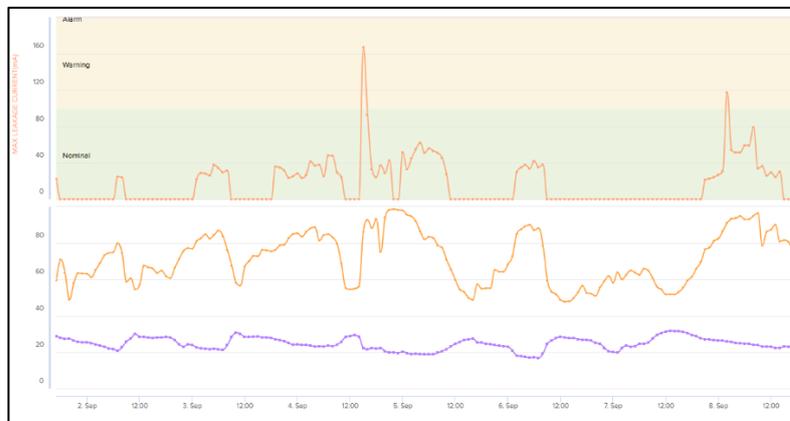


Figure 6: screenshot of the remote monitoring view of a SEDISMART near a coast over a 3-day period. Leakage current (top) follows the evolution of humidity (middle) at a relatively stable temperature (bottom).

The criticality of the activity on the insulator needs to be considered in its dynamics and not only through the prism of leakage current intensity. This can be seen for example with figure 7 where a sustained level of activity gave some suspicious signs of warning. This finally led to a flashover 2 weeks after the initial warning was sent from the system. For more than 10 days consistent currents including some relatively intense partial arcing were monitored. The maximum current prior to flashover was approximately at 268mA. This can be compared to figure 8 where even higher currents (approximately 320mA) did not lead to the same scenario mostly because it was an isolated event while in figure 7 we see clearly steady activity with repeated peaks of current.

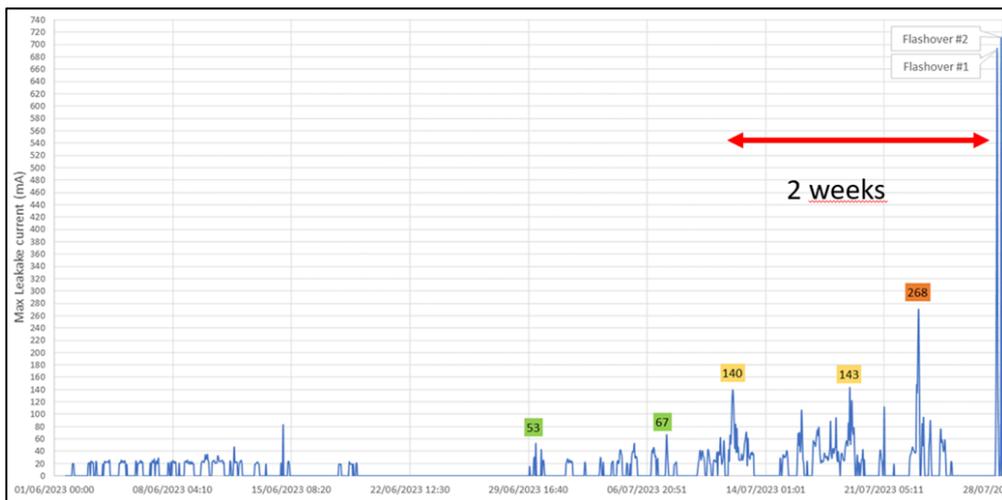


Figure 7: records of sustained activity leading to a flashover

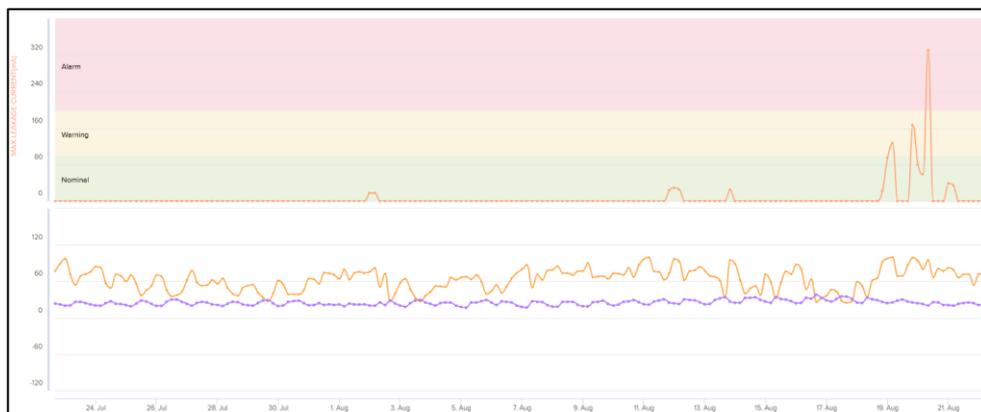


Figure 8: sequence of events over a month of monitoring with an isolated harmless high current event

5. The case of HTM surfaces

HTM surfaces (Hydrophobic Transfer Material) such as silicone housing or silicone coating over ceramic (glass or porcelain) insulators require a slightly different approach. An HTM surface by nature will enhance the ability of an insulator to avoid flashing until the hydrophobic property is severely compromised. Reaching a flashover without sustained dry band arcing is relatively common with silicone insulators and warning time

can be too short for a good diagnostic based only on critical currents. However, a silicone surface can be degraded and eroded largely before a flashover takes place and the SEDISMART considers that the monitoring of a silicone coated insulator needs to integrate the level of currents corresponding to sustained conditions leading to a change in the condition of the surface. SEDISMART does exist for silicone coated glass insulators as shown in figure 9.



Figure 9: SEDISMART on a coated glass insulator (left) and installed on a string (right with white circles locating the control box and solar panel)

Many polymer insulators or silicone coated insulators have been found with severe erosion but no flashover. The definition of a warning level for HTM should therefore take into consideration the beginning of surface degradation rather than current levels reaching a near flashover level. To provide this level SEDIVER took as a reference the leakage current levels found in laboratory tests such as a 2000h multi-stress test which is considered today as a reference for testing the aging of silicone coated insulators. Figure 10 shows how leakage currents are escalating once the hydrophobicity is decreasing and erosion starts for a given type of silicone coating. Based on such data we would consider a value of 100mA to be the trigger for a warning.

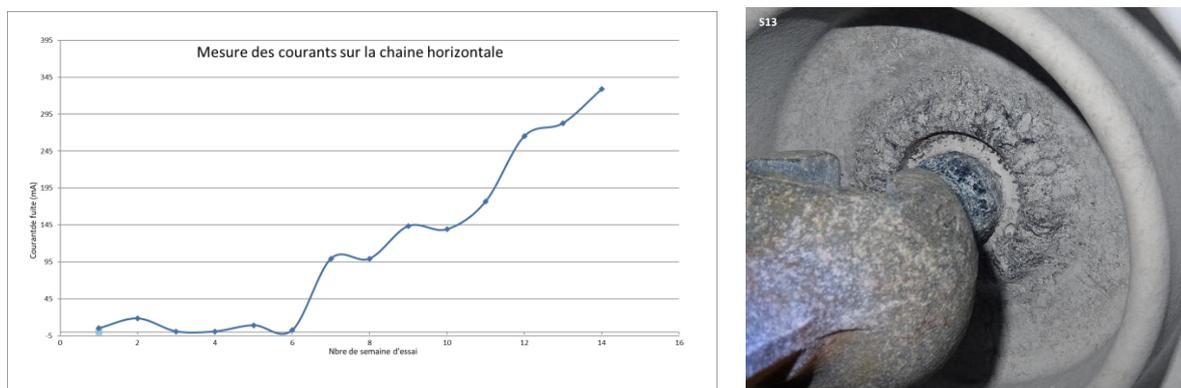


Figure 10: Escalation of leakage current on a HTM surface losing progressively its hydrophobicity and starting subsequently localized erosion on a coating during the 2000h multi stress test.

Figure 11 shows an example of leakage currents recorded with the SEDISMART in a coastal environment classified as heavy according to IEC 60815 [1]. It is also interesting to compare the level of activity monitored simultaneously on a naked glass surface insulator which was positioned in the same environment during a specific pollution event.



Figure 11: Comparative leakage currents between a silicone coated glass insulator (right side graph with approx. 30mA) and a non-coated insulator (480mA at the left side graph) as measured with SEDISMART on strings in a heavy pollution coastal environment. Relative Humidity above 80% during these events.

6. Take aways

- IOT applications on overhead power lines are challenging for a variety of reasons, all linked to the difficulty of access once installed and the necessity to optimize energy management. Since 2018 SEDIVER has successfully developed a system capable to monitor leakage currents with the associated climatic conditions delivering a much needed diagnostic of certain sections of lines subjected to harsh contamination conditions.
- Energy management has been dramatically improved over the years with important optimisations in signal management and quality of transmission.
- The SEDISMART device offers equal quality of service in AC and DC thanks to the design of the leakage current collector fully integrated to the construction of the insulator.
- Remote access to the data is possible either on a computer or cellphone providing real time information to the end user.
- Diagnostics are made possible thanks to the knowledge of SEDIVER in pollution performance of insulators in AC, DC and with silicone coating. The threshold values considered for the warning and alerts are differentiated per insulator design and also for silicone surfaces.

References

- [1] IEC 60815 series "Selection and dimensioning of high-voltage insulators for polluted conditions"
- [2] INMR Bangkok 2023. Insulators and pollution. JM George, D. Lepley, F. Virlogeux
- [3] INMR Creta 2009. Performance evaluation method and optimum selection of overhead line insulators for contaminated environments. JM George, JP Lopez, S. Prat