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Insulator Contamination Assessment and Mitigation for AC and DC Overhead Lines

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SUMMARY

Airborne dust or coastal salt contamination of overhead line insulators can seriously compromise the performance of a transmission line, either AC or DC, generating potential heavy financial losses and additional maintenance costs. Understanding basic concepts of the contamination process as well as the tools available for their evaluation can help finding the most appropriate sustainable mitigation methods. Among the diverse options offered in the relatively large spectrum of possibilities, utilities are often selecting designs which long term performance especially in harsh conditions is known today to be questionable, imposing additional inspection costs as well as service interruptions. CIGRE and IEC have established guidelines which can be considered as a good starting point in a rational approach for pollution mitigation. Specific creepage distance, profiles and shapes of insulators as well as surface properties of dielectric materials are taken into consideration on a theoretical level which still must be challenged by reality and actual laboratory testing.

While these parameters will be introduced in this paper, a specific mention for DC is necessary since the polarized effect around the conductors will act like a magnet amplifying the level of pollution compared to an AC line on the same route. Examples will be shown to better demonstrate the specificities of a unidirectional field on the performance of a DC overhead line.

Classical evaluation and mitigation methods require an outage during which either samples are periodically taken down to measure the pollution level or preventive line washing at predefined intervals is performed. Ideally information on the condition of the string of insulators should be more useful if provided on a real time bases. This would allow maintenance action at the proper time without any risk or unnecessary premature spending.

Innovative techniques for real time evaluation of the condition of a string of insulators are now possible thanks to smart insulators capable to communicate in real time their pollution condition. This paper will describe the fundamental aspects of this IoT technology where the insulator itself produces a diagnostic. Instead of measuring the level of contaminants through physical sampling on a string, this development will concentrate directly on the consequence of the environment on the performance of the string by measuring the actual leakage current. Using wireless communication technologies, the data is transferred to a dedicated server where the information will be analysed and presented to the end user with a diagnostic of risk of pollution related flashover. Such processes imply a detailed knowledge of the signature of each type of insulator in terms of leakage current since threshold values depend upon shape and profile. Actual examples will demonstrate this aspect.

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A similar approach is currently being implemented for other parameters impacting service conditions of a transmission line such as vibrations, actual load on a span, ice accumulation…this data will be systematically analysed and displayed on a universal platform where end users can check the condition of a line, including automatic alerts for maintenance crews.

KEYWORDS

Smart grid, insulator, contamination, leakage current, monitoring, AC, DC, overhead transmission lines, pollution.

CONTAMINATION OF INSULATORS

Insulator pollution problems have been a central point of discussion among engineers and maintenance crews for as long as overhead lines have existed. Today the accumulated knowledge and field experience provide tools, methods and solutions which can vary from one case to another based on the type of environment and the amount of contamination. The strings of insulators should then be designed with the most appropriate materials and specific leakage distance. Defining the type of contamination (coastal or dusty environment) is the easy first step in the evaluation. Airborne dust however needs to be qualified given the diversity of types of pollutants and the speed at which they might come on the insulator surface, building a solid crust. More critical is the determination of the amount of deposits. IEC 60815 [1] and CIGRE brochures [2] and [7] offer a comprehensive set of definitions. For coastal areas, the site severity needs to be established through leakage current monitoring on a sample string to define the Site Equivalent Salinity (SES) which later can translate in salt fog tests for the performance evaluation of a string of insulators designed for such conditions. It is more complex when solid airborne particles either salts or non-soluble elements combined end up on the surface of the insulators. In such case the measure of the pollution on site (typically before the dominant rain season and at the peak of the accumulation time) will provide two important numbers called ESDD and NSDD defined here after:

ESDD: Equivalent Salt Deposit Density (in mg/cm²) corresponding to the amount of soluble salts contained in the deposit and responsible for an increase of the surface conductivity.

NSDD: Non-Soluble Deposit Density (in mg/cm²) which is made of sand, soil and non-soluble dust acting like a sponge during foggy or muggy periods of time.

The graph in Figure 1 shows how the surface deposits measured through ESDD and NSDD will define the severity and the pollution level of the location under consideration.

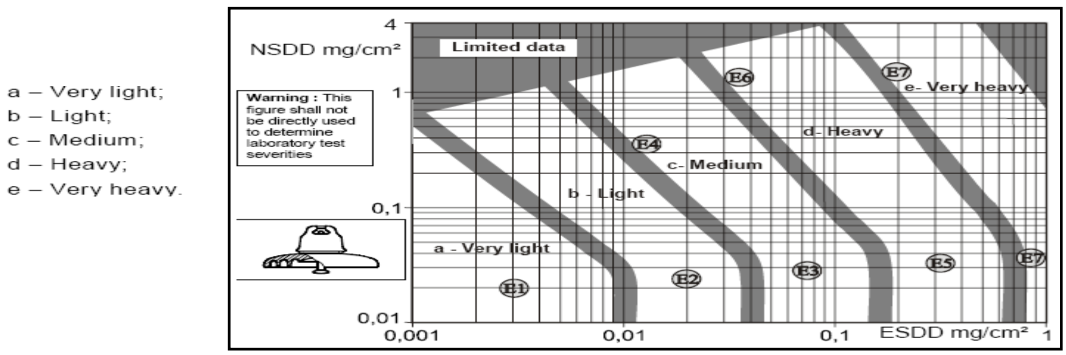

Figure 1: ESDD and NSDD chart for pollution class definition by severity of the deposits measured on the surface of the insulator [1], [2].

OPTIMUM SELECTION OF INSULATORS

The type of insulators to be used for any specific application needs to take into consideration the concept of Unified Specific Creepage Distance (USCD), as defined in IEC and CIGRE [1], [2], [7]. AC and DC must be considered separately.

1. **AC lines:** a first approach to specific creepage distance is given by [1] and [7] and summarized in Figure 2 below. At this stage, the designer is making sure that the selected polymer unit or the number of glass or porcelain insulators in a string will match this number (the new revisions of IEC are giving USCD phase ground). However, there is no indication so far of the optimum shape of insulator to be used. A more detailed approach would require selecting the shape and profile which would be the most effective for a given environment. Figure 3 provides such guidelines for glass insulators [3]. It is interesting to mention that ANSI C29 2B [4] does not describe any other shape than the old standard profile; in many cases this is the reason US utilities to have insulator strings either too long or ineffective, pushing engineers to use polymer insulators, in which life expectancy and ageing can compromise the resilience of the grid. Fog types or other shapes should be introduced in ANSI.

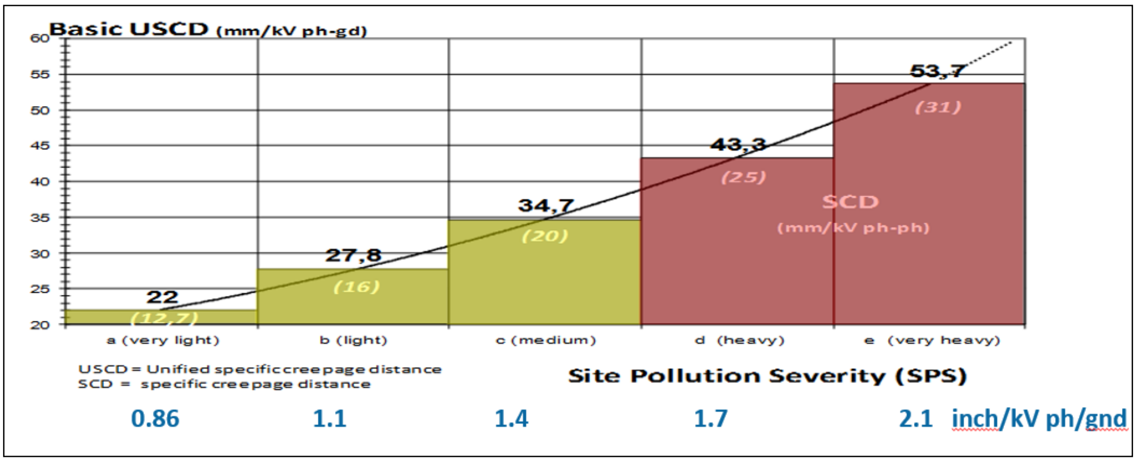

Figure 2: USCD as a function of pollution class [1], [3].

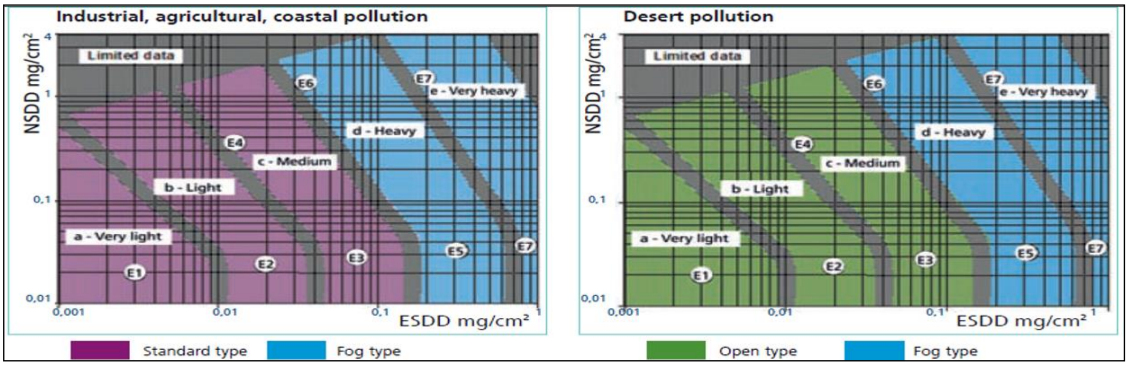

Figure 3: Shape recommendation for different pollution conditions [3].

2. **DC lines**: the unidirectional field of DC generates a higher concentration of airborne dust on the insulator strings than AC. Likewise, as shown in Figure 4, both polarities do not produce the same effect. More important, the pollution level is usually not uniformly distributed along

the string of insulators as shown in Figure 5. The increased level of contaminants collected by a DC line compared to an AC line can sometimes be complex to establish. IEC 60815 [1] and CIGRE TB518 [2] have approached this question through a set of equations but more work is needed [5].

Figure 4: Difference of pollution between polarities on a 350kV DC line (left +, right –).

The graph in Figure 6 shows the estimated increased severity in DC compared to an AC line. For these reasons DC lines will systematically need more leakage distance than an AC line. Therefore, DC lines are not designed around the classical insulation coordination methods where arcing distance and string length are defined by lightning impulse or switching but strictly by the pollution levels which are more critical in terms of string length.

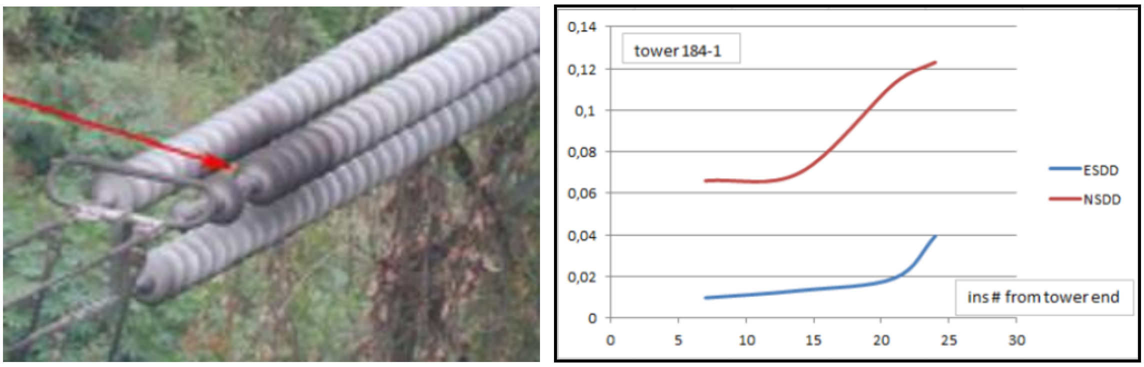

Figure 5: Left: non-uniformity of the deposit along the string (Congo 500kVDC). Right: non-uniformity of ESDD and NSDD measured on the PDCI 500kV (USA) with higher pollution measured on the conductor side (Insulator 1 on tower side, 25 on conductor side).

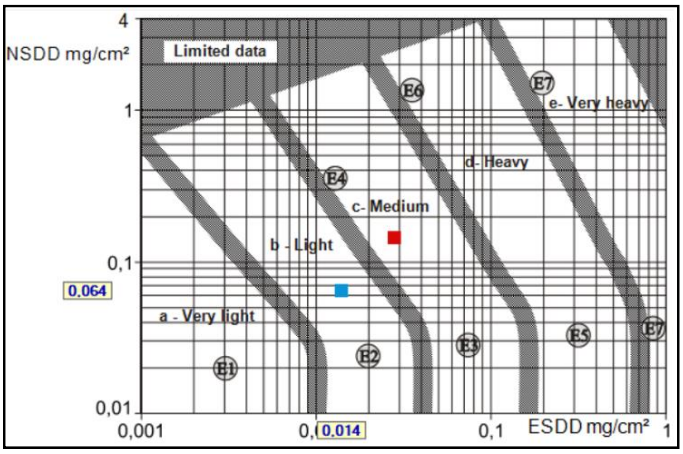

Figure 6: Blue dot shows the pollution measured on an AC line. The red dot shows the estimated pollution level if the line would be a DC line.

HYDROPHOBIC SURFACES

Polymer insulators using silicone rubber housings have made a major difference in contamination management. The reason for this success is mostly related to the hydrophobic nature of silicone. Silicone is water repellent but also can transfer this property to the contaminants on the surface of the insulator themselves (Figure 7). The main attribute is not the fact that there is less pollution on these insulators, but the leakage current developing under moist conditions on polluted surfaces will remain low enough to prevent flashovers.

Unfortunately, polymers have shown their limits especially in harsh environments where erosion will damage the housing leading to failure and possible string separations. An alternative which is developing very fast is the coating of silicone mostly over glass insulators for extreme cases where regular insulators with high creepage distances are not sufficient. An example of a comparative test is shown in Figure 8; the polymer is destroyed (but still hydrophobic, therefore still preventing pollution related flashovers from happening) presenting a major risk of failure (core exposed) while the coated glass is only eroded on the surface on the first bell with no risk of failure.

Figure 7: Water repellent hydrophobic property of silicone even over a polluted surface (silicone coated glass insulator after more than 10 years in a very heavy polluted environment).

Figure 8: Left and centre: comparison of ageing of a silicone polymer and silicone coated glass in Koeberg test station, South Africa, with strings having the same leakage distance tested in parallel. Right: compromised integrity of a polymer insulator that is still hydrophobic but has deep cracks after 10 years in coastal pollution.

LEAKAGE CURRENTS

One of the first consequences of pollution deposits on a string of insulators is the increase of leakage current which goes up during wetting processes, such as morning dew or moist evenings, as shown in Figure 9. This graph shows the relative evolution of leakage current during a 24h cycle of identical insulators (one coated, one not coated) installed in the same area in a coastal salty and dusty environment.

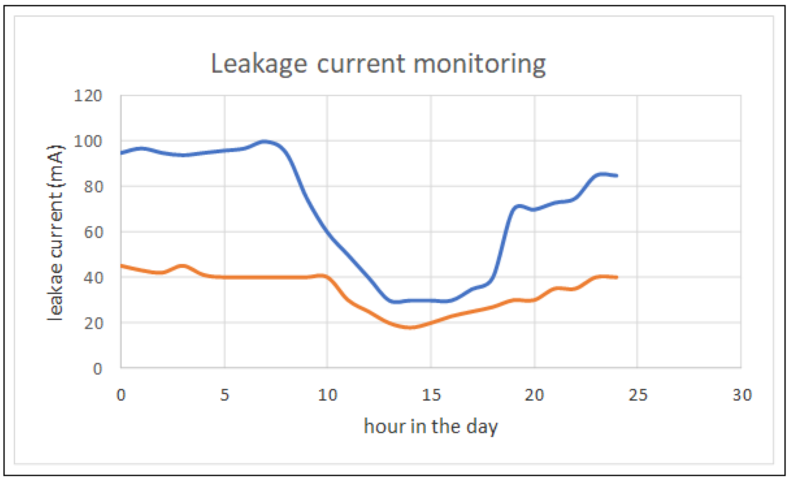

Figure 9: Relative evolution of leakage current in a 24h cycle of identical insulators. Blue curve is a regular glass insulator. Red curve is the same insulator coated with silicone RTV. Both are installed in the same area on a coastal salty and dusty environment.

Leakage currents provide a very good signature of the actual pollution condition of a string of insulators. There are many examples of leakage current measuring devices mostly used for laboratory investigations or test station monitoring. Some software applications have even been developed for assisting string designs based on theoretical equations using some reference leakage current patterns. However, the leakage current pattern and the electrical withstand characteristics of an insulator are directly linked to the shape of the insulator [6]. To run a diagnostic on the actual pollution of any given site where such sensors are installed, the knowledge of the performance under similar conditions is mandatory. Figure 10 explains how the nature of the shape of an insulator dictates its performance.

Type 1	Salt fog test 80g/l	Type 2
2725	Leakage distance (mm)	2750
80,6	Max withstand voltage (kV)	53,2
283	Leakage current (mA)	127

Figure 10: Different shapes, same string length and same leakage distance. Different leakage currents and flashover voltage values. Shape matters.

SMART INSULATORS

Taking into consideration all the previous elements, leakage current appears to be an ideal parameter for monitoring actual line pollution provided is it done in real time. It also requires the knowledge of the exact performance of the various insulator types installed on the specific lines under consideration. The recent evolution in IoT and communication systems has enabled new transmission protocols, such as LoRa (Long Range) wireless data communication. Figure 11 shows an example of an insulator which is built with a leakage current monitoring sensor in the metal cap of the insulator itself.

Figure 11: Overall smart insulator device arrangement.

Temperature and humidity are measured as well and transferred to an end-point which produces the first calculations and transfers the information directly through GSM (Global System for Mobile Communications) or LoRa to a server. The actual measures are analysed and compared to the database of similar insulators, either tested or evaluated in the field, under similar pollution conditions to provide a diagnostic. This diagnostic is immediately sent to an end, typically people responsible for servicing the lines, as shown in Figure 12. If needed this data can be examined in more detail as shown in Figure 13.

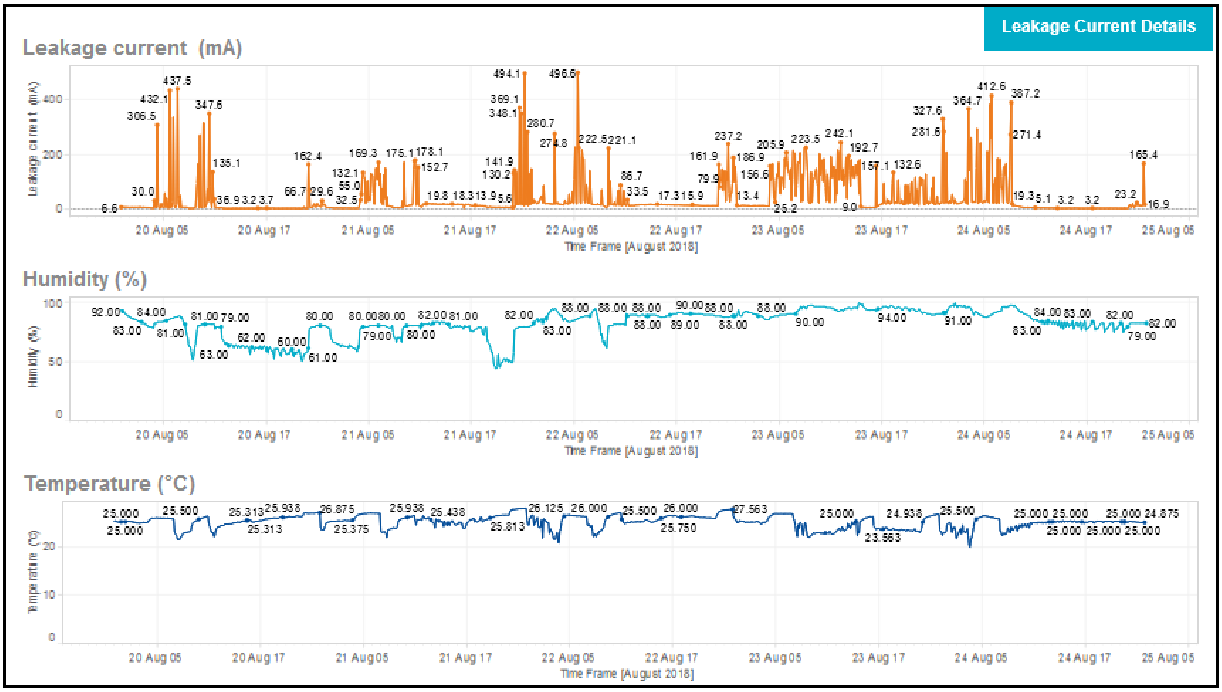

Figure 12: Information displayed.

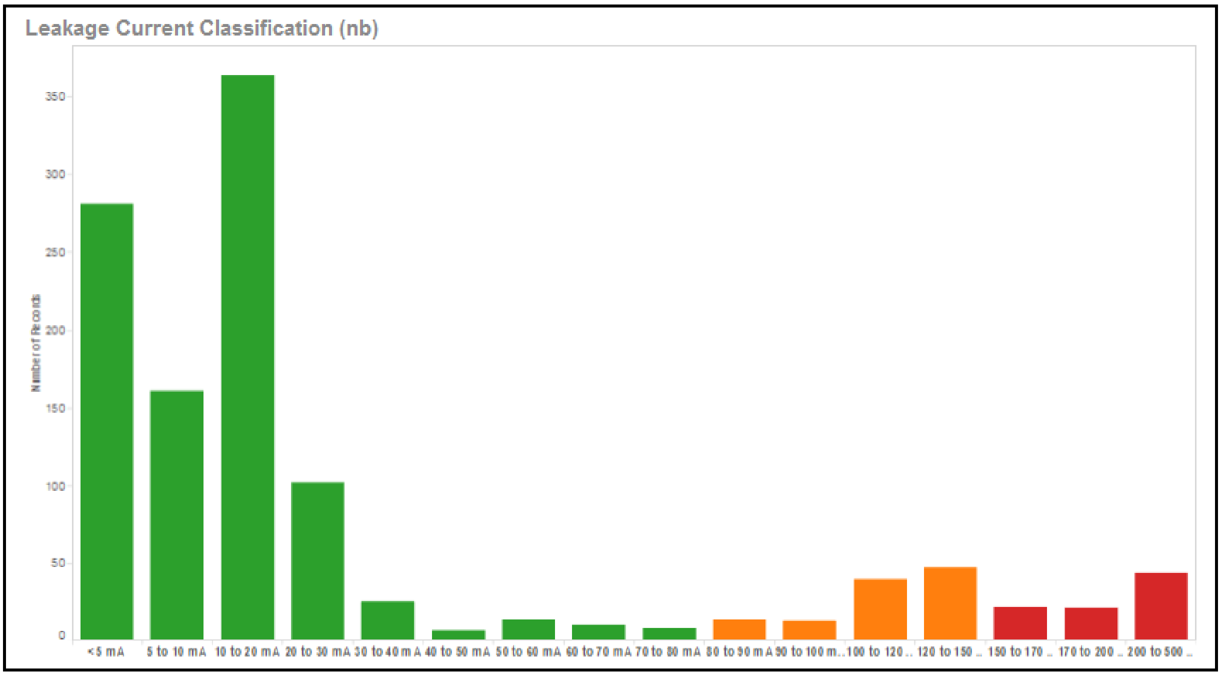

Figure 13: Detailed current bins display.

By year end more than 10 such systems will be in operation worldwide (AC or DC) in coastal heavily contaminated environments as well as sandy and mixed pollution locations. Simultaneously, other types of sensors are being added to the initial functionality, such as ice accretion and vibrations.

CONCLUSION

Technology is offering means and ways to improve the reliability of the grid. Insulators themselves are a central piece in the performance of a power line. The diversity of environment a line crosses requires a detailed approach in the selection of the most appropriate insulator, including AC vs DC considerations, and performance under extreme contamination without compromising reliability or expected service lifetime. Exact pollution type and quantified severity assessment is critical to select the most appropriate shape and design of insulators, including whenever necessary for extreme cases the addition of hydrophobic properties on the dielectric surface. Field experience is showing today that ageing of polymeric materials need to be addressed with specific consideration to accelerated ageing under harsh conditions. Usage of silicone coatings on traditional ceramic insulators is strongly worldwide to overcome this weakness. Additionally, insulators have joined the IoT world with built in sensors capable of providing an educated diagnostic wirelessly. These diagnostics, to be meaningful, need to be based on large databases where expert analytical systems and algorithms can predict future performance from actual pollution tests and field data.

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