

Online Partial Discharge Detection Technique for GIS based on UHF Sensors

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Abstract:

Gas-Insulated Switchgear (GIS) have been in operation for more than 45 years and show a high level of reliability. However, experience indicates that some of the in-service failures are related to defects in their insulation system. Many of these defects can be detected by Partial Discharge (PD) diagnostics. PDs generate electromagnetic and acoustic waves, emit light and produce chemical decomposition of insulation materials; these physical and chemical effects can be detected by various diagnostic methods and appropriate sensing elements (sensors). Besides the so-called 'conventional' electrical method described in IEC 60270, it is possible to detect and measure PDs with various 'non-conventional' methods. The Ultra-High Frequency (UHF) measurement method, which was introduced in the late 1980's for PD detection, is used worldwide by GIS manufacturers during routine testing in factory, during commissioning on-site and by utilities for continuous monitoring in service. The UHF method is less sensitive to noise, so easier to handle in comparison with the conventional method according to IEC 60270. To avoid technical misinterpretation, there was a special need to give recommendations for this non-conventional method. This paper is based on the experience and describes its practical applications for GIS. A detailed description of the procedure is given and supported by examples. Guidelines will help the users for the effective application of the UHF method for Online PD detection on GIS.

Keywords: *GIS, Partial Discharge, Online Diagnostics, UHF Sensor.*

1. Introduction

In the ever growing electrical power network, SF₆ gas filled GIS (Gas Insulated substation) have been replacing existing AIS (Air Insulated Substation) systems due to its compact size and less maintenance requirements. The reliability of GIS is very high but there would be outages of several days if there is any internal breakdown inside the GIS causing all the consequential losses. In addition to it, if the GIS is connected to a critical network; it could lead to heavy penalties and financial losses to the utilities. Hence, early detection with all the condition based monitoring techniques is considered very vital.

Offline PD detection techniques proves very helpful in factory acceptance but such measurements during operation of such panels on site, it becomes very difficult due to external uncontrolled conditions. Hence online detection of a PD activity would be very crucial information for effective diagnostic assessment of insulation in GIS installed on-site. Hence, there is a need for developing an online PD monitoring diagnostics at site for GIS.

Online PD testing can be performed while the GIS apparatus is still in service. It is considered as non-invasive and it is very safe to operate in live conditions also. While considering the efficiency of these kind of tests, one must look at the value of information obtained in such less cost and time. This paper further familiarises the readers with important aspects of online PD detection and its level of practicability at site with UHF sensors.

2. GIS Specific Aspects

2.1. General:

In gas-insulated switchgear, the defects which can occur and affect the dielectric performance of the equipment fall into several main categories:

- a) Assembly errors;
- b) Introduction of conductive contaminants, e.g. metallic particles;
- c) Poor or loose electrical and mechanical contact between conducting parts, e.g. field electrodes and shields, resulting in components at floating potentials;
- d) Fixed defects such as metallic protrusions on the high voltage conductor and particles attached to solid insulator (spacer) surfaces;
- e) Insulator defects including manufacturing defects;
- f) Surface tracking caused e.g. by flashovers during HV testing;
- g) Contamination which affect the quality of the SF₆ gas (by-products, moisture content, erroneous gas filling etc.).

The short rise times of PD pulse current (<1 ns) excite electromagnetic waves ranging from HF up to the UHF range (3 MHz up to 3 GHz) and exceeding in several insulation materials. The propagation velocity of the resulting UHF waves is dependent on the resulting relative permittivity (ϵ_r), e.g. in oil estimated to about $2/3 \times C_0$ or 2×10^8 m/s (C_0 denoting the speed of light in a vacuum) [1]. The measurement frequency range depends on the specific apparatus. Metal parts of GIS enclosures act as waveguides or resonators. Effects such as dispersion, attenuation, cavity resonances, standing waves, reflection and diffraction all influence the propagation of the PD pulse signals and the pulse characteristics respectively. Transmission path characteristics typically depend on:

- Material characteristics and dimensions,
- Electromagnetic impedance and dielectric behaviour of the surrounding dielectric medium,
- Distance between source and sensor.

2.2. Advantages of UHF Measurement method:

Compared to the conventional PD measurement techniques as described by IEC 60270, the main advantages of UHF PD measurement methods include:

- Greater immunity to disturbances and noise, which implies that sensitive measurement of PD can be made with AC supplies that are noisy themselves or when the test object is connected to the HV source. This can greatly reduce the costs of performing PD tests and increases the probability of achieving reliable results.
- Since the associated frequencies are preserved with wideband UHF detectors it is sometimes possible to determine the nature of the PD source with the UHF method.

- Higher signal-to-noise-ratio when measuring PD in the UHF range as most of the energy from electromagnetic noise in the power system tends to occur at frequencies that are below several MHz.

2.3. UHF Measuring system:

For detecting and measuring the electromagnetic waves emitted by partial discharges, different aspects of the method are shown in Figure 1.

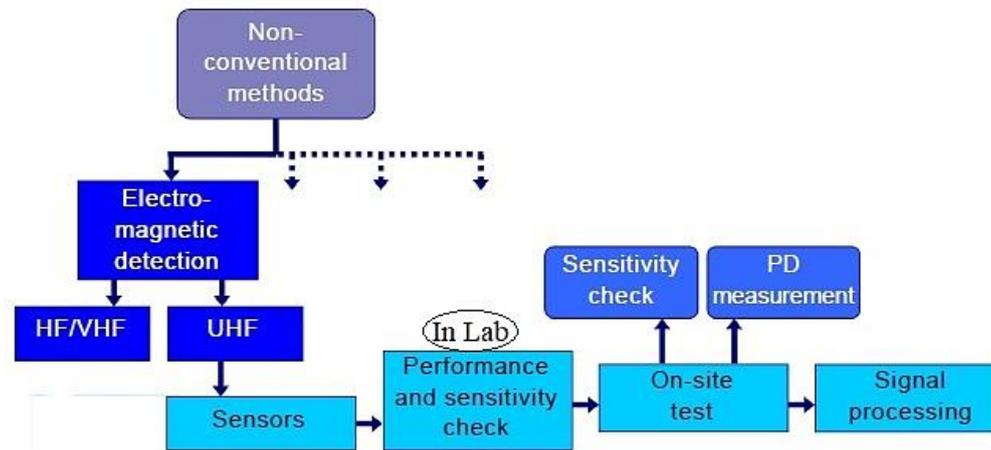


Fig. 1 Overview of UHF PD Detection

Some examples of sensors mainly used in the UHF range:

- Disc and cone-shaped sensors;
- External window couplers;
- hatch couplers;
- Barrier sensors;
- Field grading electrodes;
- Wave guide sensors;
- UHF antennas;
- Directional electromagnetic couplers.



Fig 2. External UHF sensor for GIS application [3]

The output of UHF sensor is typically a voltage signal. These values measured by the instruments are in linear correlation to the measured electromagnetic field and the sensor transfer characteristic. Derived quantities however should be in correlation to the PD

parameters. This can be linear, when using the direct output voltage of the UHF sensor, or quadratic by processing the power quantity (W) of the sensor signal, or the signal energy (J) as related to the defined measuring resistance of the PD measurement system. The UHF sensor is described with its characteristic in terms of its effective height (m), effective aperture (mm²) and antenna gain (dBi) [1].

It should be emphasized that when employing the electromagnetic detection (radio frequency) method, the PD magnitude as apparent charge cannot be evaluated directly as a calibrated value. However, a verification of the detection sensitivity can be performed and has proven to be useful in practice. Achievable detection sensitivity is demonstrated in a worst-case configuration by direct comparison in a simultaneous IEC 60270 measurement of apparent charge (pC) from an actual, significant and meaningful PD source taken in laboratory setup as shown in figure 3.

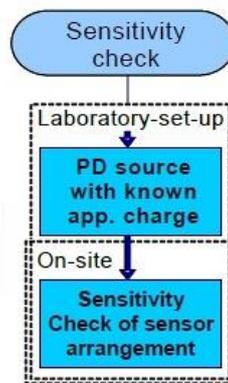


Fig 3. Sensitivity check for GIS apparatus

On-site; the UHF Sensors can be installed inside the high voltage component or externally mounted at dielectric apertures such as e.g. GIS Joints or inspection windows or valves. The sensors should be installed as close as possible to the particular PD detection area and inside the metallic enclosure or on the spacer joints of the GIS.

In larger high voltage GIS systems it is beneficial to install multiple sensors to improve measurement sensitivity and to help in PD source detection as shown in figure 4. Multiple sensors can also be used for the sensitivity check of the arrangement. The sensors should not have any negative impact to the dielectric design and functionality of the high voltage component.

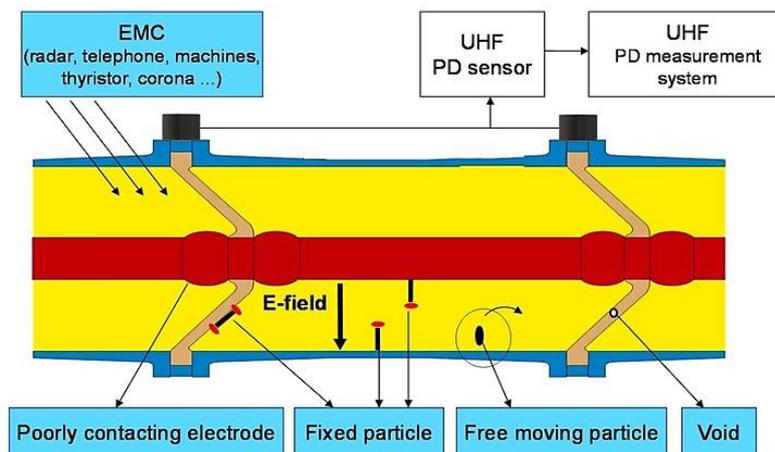


Figure 4. UHF measuring system for GIS PD defects [2]

The output signals of these sensors can be processed in the time or frequency domain. Narrow-band frequency domain signal processing may allow a better noise suppression capability where noise and external disturbances may be present and consequently features an improved sensitivity in noisy environments. The PD measurement system processes the output of a swept frequency or a so-called ‘real-time spectrum analyser’ processes a power spectrum versus a defined frequency band. This can also be displayed as a spectrum of the measured signals (PD and other signals).

3. Results and Discussion:

As described in the above section, UHF sensor output was compared with a simultaneous IEC 60270 measurement of apparent charge 100 pC from an actual, significant and meaningful PD source from a 10 KVA 11 kV/ 433 V transformer having internal PD for verification of detection sensitivity in the lab having faraday cage. Base trace is of 1 pC as shown in figure 5 which was first taken to verify presence of EM emissions from other object in the lab. Then the transformer was given high voltage till it gave a 100 pC apparent charge reading in an IEC 60270 measurement. The output signals for both the traces from UHF sensor was processed in frequency domain and displayed as a spectrum of actual PD amplitude in terms of power quantity (dBm) versus the frequency band of 50 to 500 MHz.

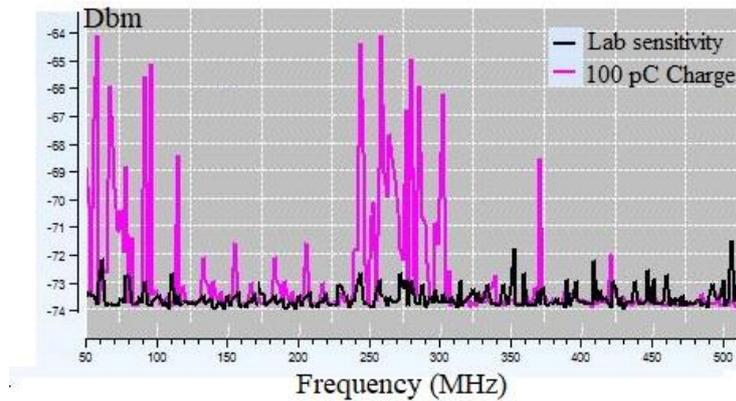


Figure 5. Detection sensitivity check in Lab

The lack of field application of using UHF sensors is due to difficulties faced in mounting the UHF sensor inside the GIS and its safe operation during shut downs. To overcome this issue an external integrated UHF sensor was placed on dielectric aperture spacer joints on the physical real GIS as UHF waves cannot travel through the thick metal apertures.

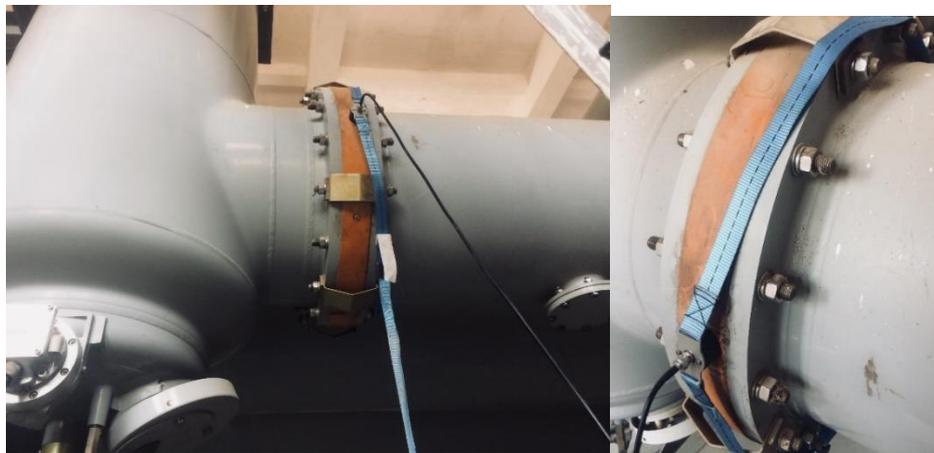


Figure 6. UHF Sensor arrangement on physical real GIS spacer joint

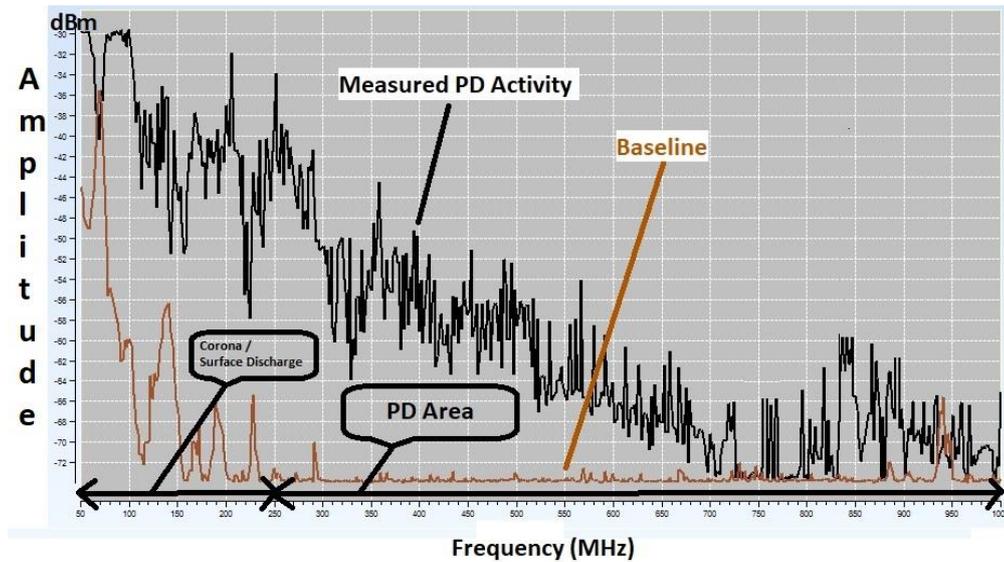


Fig 7. Online PD Measurement of GIS panel with UHF sensor

There are two waveforms shown in one spectrum where firstly the ambient background waveform pattern was taken to verify presence of EM emissions from other object in the vicinity. Baseline trace was taken 20 to 30 meters away from the GIS bay under test. The second waveform was taken when UHF sensor was mounted on the dielectric aperture of the GIS bay which is the closest possible distance for PD detection providing the highest sensitivity. Frequency response from 50 MHz to 250 MHz gives corona or surface discharge depending upon environmental factors and condition of GIS. Internal PD extends up to 1000 MHz where signal strength of any PD activity is determined by high amplitudes and continuous wide signal response when compared to baseline. The reference level is the maximum magnitude of the decibel scale on the Y axis of the above plot. Every level of power at a given frequency has a value less than 1 (0 dBm) relative to 1mW of radiated power. When the signal received by UHF sensor is converted from watts to dBm, all the values below 0 dBm become negative. The Y axis shows the signal strength in terms of power. Power quantity (mW) of the sensor signal is in correlation with the PD parameters with the help of below formula

$$[\text{dBm}] \text{ at a particular frequency} = 10 \cdot \log_{10} \left(\frac{P_{\text{Output at that frequency}}}{0.001 \text{ Watt}} \right) \quad [4]$$

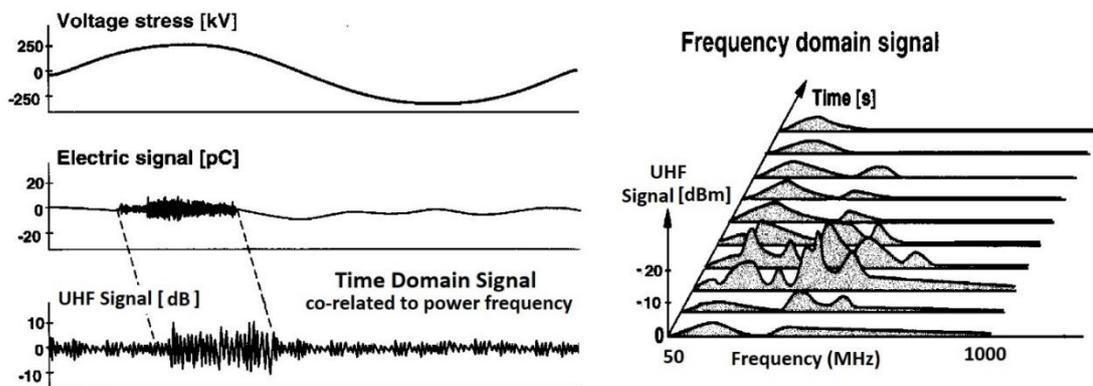


Fig. 8 Co-relation of derived quantities with PD Parameters [4]

The time resolved UHF signal from high frequency electrical PD signal graphically displays signal amplitude in dB with respect to time as shown in figure 8. The time window is 20 ms (50 Hz) and pulse train with different width appears within that time window. As discussed in the earlier section, output of the UHF sensor is dependent in terms of its effective height (m), effective aperture (mm^2) and antenna gain (dBi). We can clearly see in figure 7 that P_{Output} values at a particular frequency are more when the sensor is kept on the dielectric aperture of GIS (PD detection area) when compared to P_{Output} values taken in the baseline trace at the same frequency where sensor is kept around about 20 meters away from the HV equipment.

4. Conclusion

This paper provides helpful information to improve online PD detection and proposing a new on-field PD detection method for GIS. In near future, with improvisation in GIS designs, authors suggests that extensive online diagnostic monitoring should be supplemented with it. This will have mainly two advantages; first the utilities would adapt to online condition based maintenance and secondly it would reduce the unplanned outages of the GIS switchgear which in turn will reduce the revenue expenditure. The method presented in the paper is not a calibration. However, the aim is to find the best possible match for a real PD defect in order to verify the sensitivity of the UHF measurement in GIS. A comparison with the spectra of different output power pulses was done by visual comparison. However, our field trials for GIS show that there are still problems in UHF PD detection method due to its difficulties in sensor arrangement on metal enclosures and complex environments on-site.

5. References

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