MANUAL/AUTOMATIC PARTIAL DISCHARGE MEASUREMENTS ON A PERIODIC /CONTINUOUS BASE, COMPARISON AND SOME RESULTS

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Abstract: GIS components can have different failure types. However, the failure mode, effects, and criticality analysis (FMECA) has shown that the risk associated with a failure of the primary components in GIS is dependent on the component's type and its location in the GIS [4]. Among others, busducts and interconnecting parts have high criticality level for the GIS reliability.

To prevent failures in these components, dielectric breakdown has to be prevented.

Therefore, a number of different diagnostics are introduced. Among the available diagnostics, partial discharge (PD) measurements are a useful method to assess the condition of the insulation medium. PD measurements can be performed on-line manually/automatically on a continuous/periodic base. PD measurements have been performed since 1996 manually on a periodic base in two of the 380kV GIS substations in the Dutch grid, owned and operated by the Dutch transmission system operator (TenneT TSO B.V.). Recently, two on-line PD monitoring systems have been installed at those substations to monitor the PD behaviour continuously under different operating conditions.

In this contribution, the differences between performing the PD measurements manually on a periodic base and automatically on a continuous base are illustrated and discussed, and some of the PD measurement results are presented.

1 INTRODUCTION

A gas-insulated substation (GIS) is a compact, multi-component assembly, enclosed in a grounded metallic housing in which the primary insulating medium is a compressed gas and that normally consists of buses, switchgear, and associated equipment (subassemblies) [1].

GIS substations have been in operation for more than 40 years, and are dealing with voltage classes of 52kV up to 1000kV [2]. GIS substations form important nodes in high voltage grids and are said to be very reliable. Due to GIS construction and its nature of operation GIS are exposed to different types stresses e.g. electrical, mechanical, thermal, and chemical stresses and therefore failures occur.

To ensure that GIS perform its functions correctly during its designed lifetime, it is important to prevent and to correct failures. Therefore maintenance has been introduced.

Maintenance actions are selected based on the results of diagnostic and monitoring systems.

Partial discharge (PD) measurement is one of the diagnostics in use. It is a generic diagnostic technique which can give information about the condition of the insulation medium.

In GIS, PD measurements are on-line measurements which can be performed manually/automatically on a periodic/continuous base.

In this contribution some results of the PD measurements which have been performed manually on a periodic base are presented. Subsequently, these results are compared to preliminary results obtained by two different PD on-line monitoring systems.

2 MAINTENANCE SELECTION

The maintenance is the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function [3]. In this paper it has been restricted only to technical actions.

Almost in all maintenance strategies, maintenance actions are selected and performed based on the diagnostics results. In addition, they have to be performed effectively to meet the owner interests or the owner business values like cost and risk minimization in one hand and to ensure a certain level of reliability and availability of the GIS in the other hand.

Figure 1 shows an approach to perform effective maintenance based on the GIS components criticality. Critical components in GIS have to be distinguished. Proper diagnostics have to be selected and oriented towards these components.

Based on the diagnostics outcome maintenance actions can be determined.

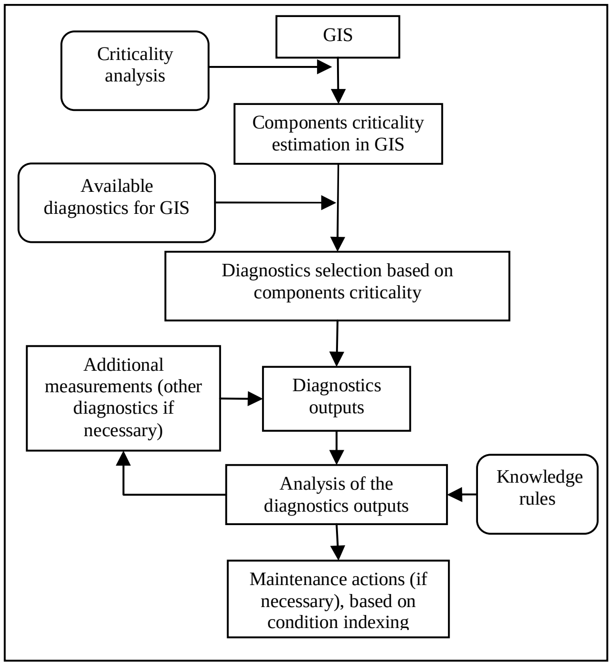

Figure 1: effective maintenance selection flowchart

3 CRITICALITY OF H.V. COMPONENTS IN GIS

The criticality levels for the GIS components have been analyzed and discussed in [4], the results are shown

1. the risk level depends on the type of the component
   - 1.1. Circuit breaker is the most critical component for reliability.
   - 1.2. Busbars and interconnecting parts, disconnectors, and SF_6 bushings have high criticality level.
   - 1.3. Surge arresters have medium criticality level.

2. The risk level depends on the components location in the GIS.

Failures in GIS components which have high and very high risk levels have to be prevented.

Among the GIS components, the busbars and the interconnecting parts have high risk level. They serve for interconnection between CB-bays and interconnection of individual apparatus. Failures in the busbars result in serious consequences to the H.V. station. For instance, a part of the GIS or even the complete GIS has to be taken out of service. In this paper focus will only be on the busbars and interconnecting parts.

The available diagnostic methods to prevent failures in busbars and interconnecting parts will be discussed in the next section.

4 AVAILABLE DIAGNOSTICS

The busbar and the interconnecting parts consist mainly of a H.V. conductor which is enclosed usually by a metal enclosure and insulated by SF_6 gas.

It has been shown that 66% from the failures occurring in GIS substations with operation voltage 300kV<U<500kV result from breakdown in the insulation system [5][6]. Thus to prevent major failures from occurring in GIS, the insulation medium is the most important to be monitored.

To prevent failures in the insulation medium, SF_6 gas quantity and quality has to be ensured. An overview of the available diagnostics to ensure the gas quantity and gas quality is listed in Table 1 [7], and discussed in the following sections.

4.1 Quantity of insulation

To ensure a proper insulation level in the busbars and interconnection parts the insulation has to be held above a specified minimum value.

Different methods are used to measure the gas density. SF6 density is usually measured by using a temperature compensated pressure gauge.

Table 1: Available diagnostics to prevent failures in the GIS insulation system [7]

Parameter	Diagnostic method
Quantity of insulation medium	SF_6 density by: • temperature compensated pressure gauge • temperature and pressure measurement • solid state density sensor
	SF_6 leak detection by: • soapy water “sniffers” • infrared imaging system
Quality of insulation medium	Purity of SF_6 by: • gas chromatography • chemical detection tube • SF_6 content • Infrared spectroscopy
	Moisture content by: • dew point • solid state sensor
	Partial discharges (PD)

An alternative way is to separately process the pressure and temperature transducer signals electronically. Recently, solid state sensors have become available. They can measure the gas density directly. The solid state sensor is based on a quartz oscillator in SF6 and a second reference oscillator in vacuum.

Low gas density in GIS can be occurred due to SF6 leakage. Gas leakage can be detected by different methods e.g. by using handhold gas detectors (sniffers) or SF_6-sensitive imaging systems.

SF_6 gas pressure in GIS is monitored continuously. An alarm is given if gas pressure changes significantly.

4.2 Quality of insulation

Different methods are used to estimate the insulation quality. Some of these methods reflect the overall condition of the insulation e.g. partial discharge measurements. Other methods measure specific physical quantities of the insulating medium, such as moisture content [7].

Chemical analysis methods such as gas and infrared chromatography, and chemical detection tubes can be used to detect SF_6 byproducts resulting from discharge activity in the GIS [7]. However, the volume of SF_6 gas in GIS compared to the volume of the by products is enormous, which makes it difficult to detect the discharges with chemical detections.

Moisture may condense in GIS Because of the temperature changes. Heaters and absorption materials are used to prevent moisture condense in GIS [7]. Therefore, the moisture content do not need to be monitored continuously in GIS, however samples are taken every 10 years for example.

Major insulation failures are usually preceded by partial discharges caused by the presence of small defects, such as conducting particles fixed, floating or freely moving in the gas. The presence of these defects influences the insulation strength by means of field concentrations. Thus, information about the partial discharge is very useful when assessing the quality of the insulation.

Many techniques have been developed to measure partial discharges [8], these are:

- Conventional PD measurements according to IEC60270: in this method a defect can be discovered by measuring its apparent charge.

- Ultra high frequency (UHF) technique: due to the presence of defects in GIS, electromagnetic waves with high frequencies (HF), very high frequencies (VHF), and ultra high frequencies (UHF) are emitted. The UHF method is based on the measurement of these electromagnetic waves.

- Acoustic and optical method: these methods are based on the measurement of the transmitted sound waves and the emitted light waves (photon emission) from the defects.

- Chemical method: SF_6 by-products are generated in the presence of defects.

Among these methods, the UHF method has proven to be a very suitable method for on-line PD detection in GIS due to its relatively simple measuring setup, its lower sensitivity to noise, and its high detection ability.

PD measurements by means of the UHF method have been performed since 1996 manually on a periodic base into two 380kV GIS substations in the Netherland, substation A and B. Recently, those two substations have been equipped with two on-line PD monitoring systems. On-line PD monitoring systems are usually able to perform PD measurements automatically on a continuous base. In the following sections these two systems are discussed, some of the measurement results are shown and compared with the measurement results obtained between 2005 to 2010 from the periodic PD measurements.

5 PERIODIC PD MEASUREMENTS

PD measurements have been performed manually once a year since 1996 in the 380kV substations A and B, by using the system shown in Figure 2. The system consists of:

1. UHF sensor: to pick up the UHF signals during the PD measurements.
2. Amplifier to amplify the signals.
3. Protection circuit: to protect the spectrum analyzer from overvoltages.
4. Spectrum analyzer to display and examine the measured spectrum.
5. Computer to control the spectrum analyzer and to process and save the measurements.

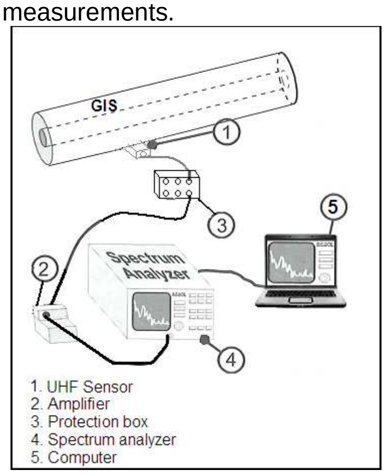

Figure 2: The UHF measuring system

5.1 Periodic PD measurements results in the 380kV GIS substation A

The substation A contains 80 sensors. PD activities have been observed at 14 sensors. An overview of the sensors at which PD has been observed is given in Table 2. In the table “yes” indicates that PD activity has been observed, “no” indicates that no PD activity has been observed, and the “×” sign in the table indicates that no PD measurements have been performed.

At some of the listed sensors PD activity yearly has been observed, see for instance sensor number 5. Based on the analysis of the measurements results it has been estimated that

- no immediate maintenance actions are required
- it is important to observe the trend of the partial discharge and therefore it is recommended to perform measurements each year.

The PD measurements in the 380kV GIS substations A and B have always been performed during the week during working hours, under normal operating conditions, and once a year. Therefore, information which can be important for the risk assessment is not included, such as, the PD behaviour during the night or the PD behaviour under up normal operating condition which may occur during a switching operation.

To observe the PD behaviour under different conditions and at various point of time a continuous on-line PD monitoring system is required.

Table 2: An overview of the UHF sensors at which PD activity is measured

Sensor	Date					
	2005	2006	2007	2008	2009	2010
1	yes	yes	yes	yes	×	yes
2	yes	yes	yes	×	yes	yes
3	yes	yes	yes	yes	yes	yes
4	yes	yes	yes	yes	yes	no
5	yes	yes	yes	yes	yes	yes
6	yes	yes	yes	yes	yes	yes
7	yes	yes	no	×	×	no
8	no	no	no	yes	yes	no
9	no	no	no	no	yes	no
10	no	yes	yes	no	yes	no
11	no	yes	yes	no	×	×
12	no	no	no	yes	×	no
13	no	no	no	yes	×	no
14	×	×	no	×	×	yes

5.2 Periodic PD measurements results in the 380kV GIS substation B

The 380kV GIS substation B contains 57 UHF sensors. No PD activity earlier has been observed on these sensors.

6 CONTINUOUS PD MEASUREMENTS

Two on-line PD monitoring systems A* and B* are recently installed in the 380kV GIS substations A and B respectively.

Despite some differences in their features, the on-line monitoring systems A* and B* use a similar measuring principle i.e. the UHF method. Basically each system consists of pre-amplifiers connected to the UHF couplers, a measuring unit, and a server for data acquisition. An example of the installation method of the systems on GIS is shown in Figure 3.

Some preliminary results of the PD on-line monitoring systems are presented and discussed in the next sections.

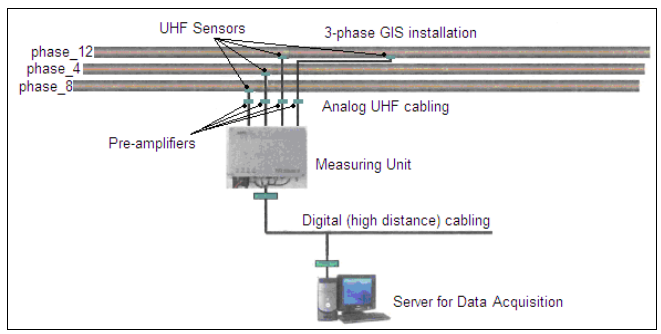

Figure 3: installation of the PD monitoring system on GIS

6.1 PD measurement results of the monitoring system in the 380kV GIS substation A

It is possible to connect and monitor up to 6 UHF sensors to the on-line monitoring system A*. The first 6 UHF sensors listed in Table 2 have been selected and being monitored by the system.

The monitoring results of 12 days are presented in this section. However, 12 days of observations is a short time to make any final conclusions.

Changes in the PD behaviour can be observed by viewing the trend of the measured PD signals i.e. the course of the measured amplitudes over the time. Changes in the load profile may influence the PD behaviour. Therefore, the load voltage and the PD trends are plotted in Figure 4. The left half of the figure shows the PD trend and the load voltage during the day hours (06:00-18:00), and the right half shows the PD trend and the load voltage during the night hours (18:00-06:00). In the figure indicators are used instead of the real values for the purpose of comparison.

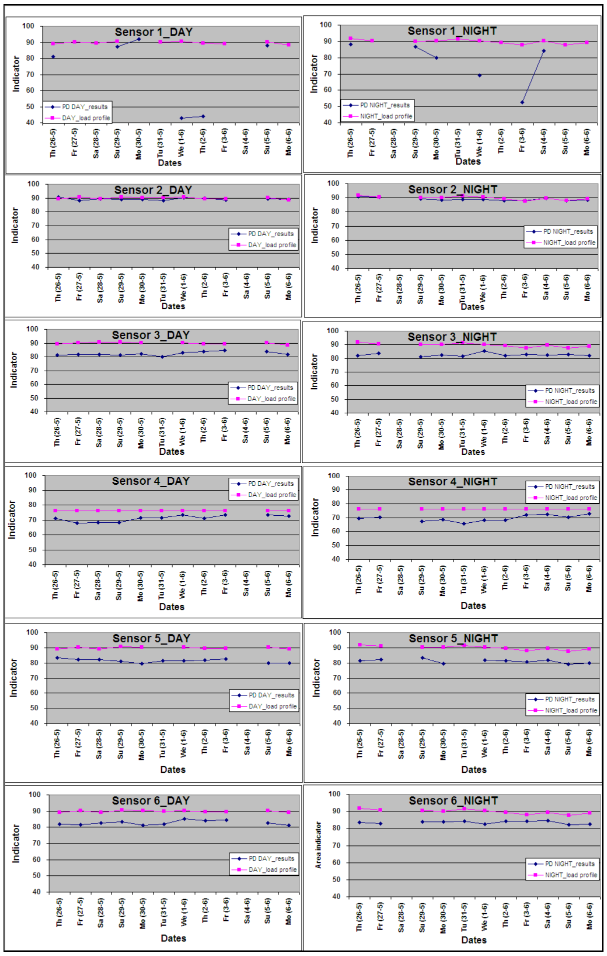

Figure 4: Sensors 1-6, the PD trend and the load profile

Based on Figure 4, the trend of the observed PD does not necessarily follow the changes in the load voltage.

In addition, the PD activity observed on sensor 1 does not show a continuous trend. Meanwhile, PD activity has been observed on sensor 1 during each session of the periodic PD measurements performed between 2005 and 2010.

In Figure 4, sensor 2 shows the highest PD trend which is not the case based on the periodic PD measurements

Sensor 4 shows the lowest PD which match with the Periodic PD measurements

6.2 PD measurement results of the monitoring system in the 380kV GIS substation B

With the on-line monitoring system B* it is possible to monitor up to 4 UHF sensors.

As mentioned in section 5.2, based on the periodic PD measurements no PD activity was observed in the 380 kV GIS substation B. Therefore, 4 UHF sensors have been arbitrary selected to be monitored by the system. Three sensors are located at the same position but have different phases. The fourth one is on a neighbouring position and has a similar phase to one of those sensors, see Figure 3.

The results for 8 days of monitoring are shown in Figure 5.

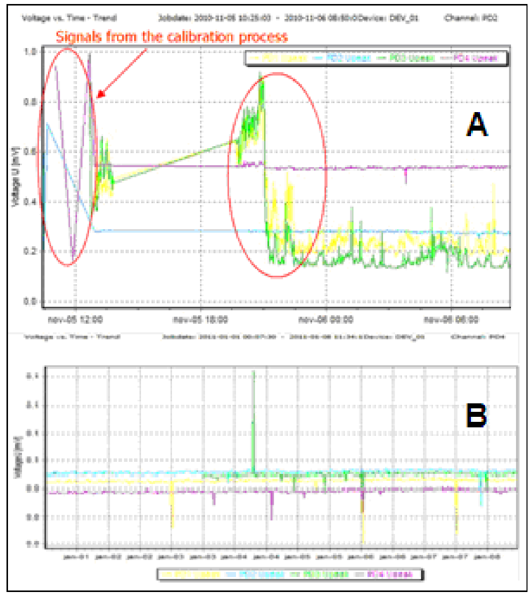

Figure 5: Sensors 1-4, voltage vs. time trend. The increase in the beginning of the figure is due to the calibration process

Some peaks in the trend can be observed on November the 5th at around 12 'o'clock, see Figure 5_A. Those peaks are due to the calibration process of the monitoring system.

Other peaks can be observed at sensor 1 and sensor 3 between November the 5th at 20:00 o'clock and November the 6th at 8:00 o'clock. Those peaks in the voltage trend can be further investigated by viewing the phase resolve PD pattern (PRPD) patterns. The measured PRPD patterns are shown in Figure 6.

The PRPD pattern shows some disturbances in the 1st half, see Figure 6_A. The pattern in the 2nd half might be originated from a PD activity. Afterwards no signals are observed in the PRPD pattern, see Figure 6_E.

In addition, no peaks are measured by the PD monitoring system B* during the next measurements session performed between 01-01-2011 and 08-01-2011, see Figure 5_B.

However, to confirm whether the peaks in the voltage trend originated from a PD or whether they can be classified as noise, the GIS operating conditions on 5&6-11-2010 between 18:00 and 07:00 O'clock have to be checked and these two sensors have to be kept monitored.

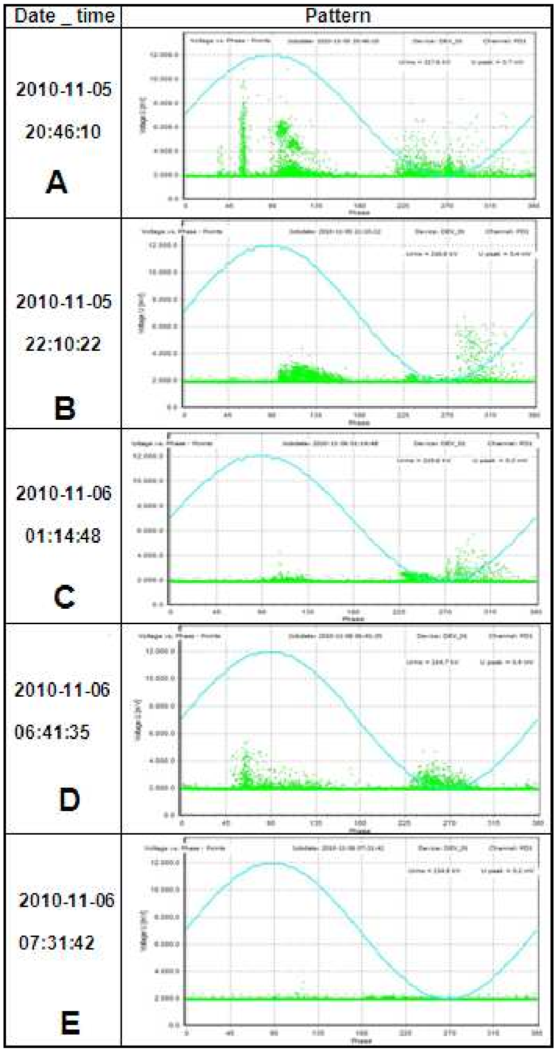

Figure 6: PRPD patterns measured at sensor 1

7 CONCLUSION

An efficient maintenance strategy in GIS can be determined based on the criticality of the GIS primary components. Busbar and interconnecting parts have shown a high level of criticality for the GIS reliability.

To ensure the reliability of the busbar and interconnecting parts, SF_6 quantity and quality has to be ensured. SF_6 quantity in GIS is monitored continuously. SF_6 quality is ensured by, among others, the PD measurements.

PD measurements are on-line measurements which can be performed on a periodic/continuous base.

Some results of the PD measurements performed manually on a periodic base, in the 380kV GIS substations A and B in the Netherlands, are presented. Recently, these two substations have been retrofit with two PD on-line monitoring systems. Some preliminary results are shown.

Periodic PD measurements help to assess the condition of the insulation medium only during the measurements time and usually under the normal operating conditions. To assess the insulation condition in time under various operating conditions and throughout the GIS lifetime, the PD measurements have to be performed on a continuous base.

8 REFERENCES

[1] IEEE Std C37.100-1992,"IEEE Standard Definitions for Power Switchgear"

[2] Cigré WG B3.17, "GIS State of the Art 2008", brochure 381, 2009

[3] Cigré Working Group 13.09. User guide for the application of monitoring and diagnostic techniques for switching equipment for rated voltages of 72.5kV and above. Cigré Brochure 167, August 2000

[4] Al-Suhaily, M. ; Meijer, S. ; Smit, J.J. ; Sibbald, P. ; Kanters, J. ; "Criticality assessment of GIS components ", IEEE, 2010, pp 626-629

[5] CIGREE Working Group 23.02, report on the 2nd international survey on HV GIS service experience. CIGREE Brochure 150, 2000.

[6] S. Meijer, j.j. Smit and A. Kanters. Experience with PD measurements in GIS maintenance concept. 2008 International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24, 2008, URL: http://ieeexplore.ieee.org /xpl/RecentCon.jsp?punu mber=4560066.

[7] Cigré brochure 167-2000_User guide for the application of monitoring and diagnostic techniques for switching equipment for rated voltages of 72.5 kV and above.

[8] CIGRE Study committee SC 23, Session 15/23-01-1992, diagnostics methods for GIS insulating system.