On-Site Testing of Gas Insulated Substation with AC Voltage

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ISH 99

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Abstract

Recent experience has proven that the reliability of a GIS/GIL can be ensured by an On-Site AC-Testing after assembly combined with a sensitive partial discharge measurement.
Either conventional 50/60 Hz transformer systems or resonant test systems with variable inductance as well as resonant test systems with variable frequency have been used to perform the GIS/GIL On-Site Testing.
The paper describes the different HV test systems with their advantages and limitations and the applicable partial discharge measuring methods. The UHF PD measuring method is emphasised.

1. Introduction

GIS/GIL testing has been performed either by AC-voltage, lightning impulse voltage or switching impulse voltage or a combination of them.
The experience showed that no single test method detects all fault causes with the same sensitivity.
A GIS/GIL AC-testing with an increased voltage level combined with a sensitive partial discharge measurement has met best the requirements for detecting the different fault causes [1].

Present AC test procedures of several GIS/GIL suppliers consists of a prestressing at a voltage level of about $(1.1\text{-}\sqrt{3})U_m/\sqrt{3}$ for some seconds up to some minutes followed by the 1 minute test voltage in the range of (1.1-1.5) U_m and finished by a PD measurement at a voltage level of $1.1 \cdot U_m/\sqrt{3}$.

The AC test voltage for On-Site Testing can either be generated by a SF6 insulated test transformer system, a conventional series resonant test system at 50/60 Hz or a series resonant test system with variable frequency (30 .. 300 Hz). The series resonant test systems are mainly applicable for a higher test capacitance and longer test duration.

2. On Site AC Test Systems

2.1 On Site Testing with SF6-insulated test transformer systems of the type TES

SF6 insulated test transformer systems are designed for a short time duty. The max. output voltage and 15 min output power is up to 1000 kV and 375 kVA at a weight to power ratio of approx. 10 kg/kVA. The TES-system can either be directly flanged to a GIS or used in combination with a SF6/Air-bushing.
If directly flanged to the GIS via a multiflange housing an encapsulated coupling capacitor can be integrated. With such an arrangement and the application of the conventional PD measuring method a PD level of less than 2 pC can be verified.

An optimised design of a SF6/Air bushing in combination with a low volume intermediate flange results in an easy and short time assembly procedure. To facilitate handling and transport all encapsulated components are mounted on a base frame.

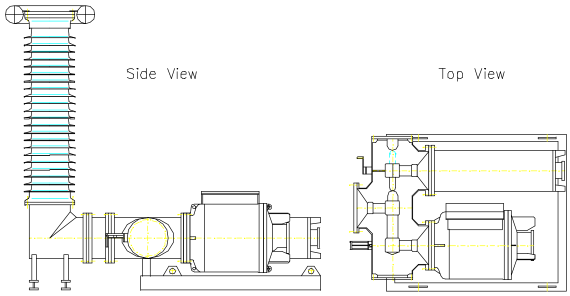

Figure 1: *230 kV, 45 kVA test system*

A TES-system which is possible to be tilted hydraulically up to vertical position is designed to meet the requirements for On-Site Testing of a GIS terminated by a SF6/Air bushing. In this case the AC-testing should be combined with an UHF PD measurement.

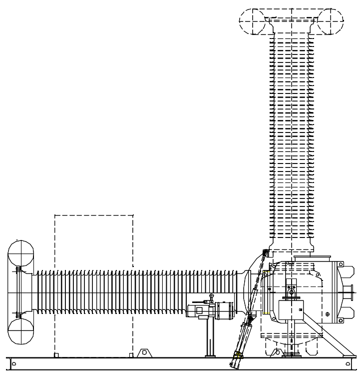

Figure 2: *510 kV, 105 kVA test system*

2.2 On-Site Testing with conventional series resonant test systems of the insulating cylinder type RZ

Conventional oil insulated series resonant reactors of the insulating cylinder type are designed for a longer test duty and higher power rating. Typical performance data of a two module tower is an output voltage up to 800 kV and a 1h output power of up to 3200 kVA at a weight to power ratio of approx. 5 kg/kVA. The test voltage is applied to the test object via an Air/SF6 bushing. Using this design several modules can be cascaded to increase the test voltage but a fully encapsulated On-Site Test arrangement is not possible to achieve. Therefore the UHF PD measuring method is preferred when using this test arrangement.

The auxiliary equipment such as exciter transformer, electrodes, base frames and the measuring capacitor is stored in a 20" container. Furthermore a control room is integrated in the container as well. The reactor itself is transported in a crate.

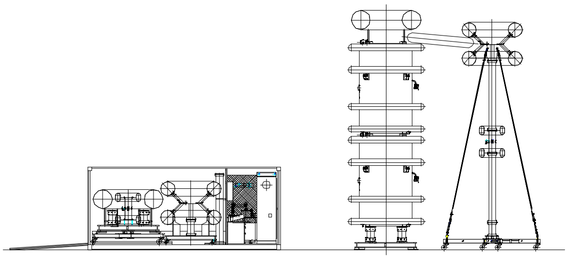

Figure 3: *800 kV, 4 A, 50/60 Hz series resonant test system*

2.3 On-Site Testing with SF_6-insulated resonant test systems with variable frequency of the type RSS

With a SF_6 insulated series resonant reactor with fixed inductance an encapsulated test set up with a higher output power rating compared to a SF_6 insulated test transformer can be achieved. The weight to power rating ratio can be optimised to approx. 0.6 kg/kVA.
The test circuit is tuned to the resonant condition by means of adjusting the frequency of a high clock rate frequency converter (1). The frequency range of the test system can be calculated by the following formula:

$$\frac{f_{\max}}{f_{\min}} = \sqrt{\frac{C_{\max}}{C_{\min}}}$$

Similar to SF6 test transformer systems the resonant reactor system (3) can either be connected directly to a GIS/GIL by using an intermediate flange or by means of a SF6/Air bushing.

Disturbances generated by the semiconductor switching in the range of some nC require a filtering and shielding (2) of the power supply in order to allow a sensitive PD measurement during the AC testing.
Using a fully encapsulated arrangement a PD level of less than 1 pC can be verified.
A signal windowing of the PD detector is not necessary the full phase angle range can be recorded.

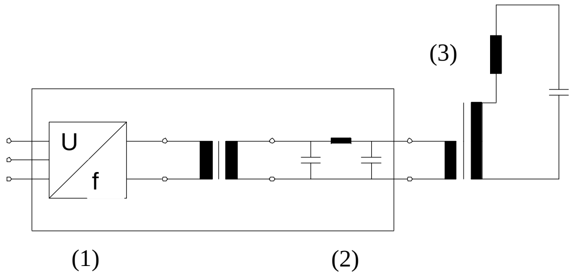

Figure 4: *Circuit diagram of a resonant test set with variable frequency*

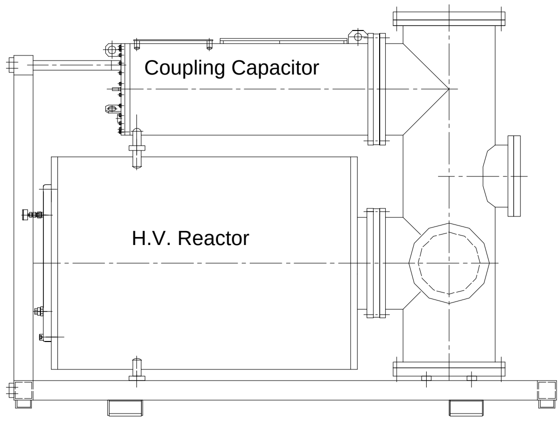

Figure 5: *400 kV, 3 A test system with 0.5 nF coupling capacitor*

If the resonant system is designed for resonant frequencies above 80 Hz/100 Hz the GIS can be tested with installed voltage transformers.
This allows testing of the fully assembled GIS without any temporary disassembly of voltage transformers which are designed for a 50/60 Hz system.

3. On-Site partial discharge measurements on GIS

3.1 Conventional PD measurements

For on-site PD measurements on GIS several different measuring techniques are applicable. The conventional PD measuring method according to IEC 60270 is the most known since it is in use already for many years in various fields of PD measurements. PD signals are measured using a coupling capacitor which can be fully enclosed or externally connected.

The PD signal is not significantly damped in the GIS so that this method can be calibrated. Since PD signals are measured in the kHz range excessive electromagnetic interference of much higher amplitude, such as corona discharges of incoming overhead lines, makes detection of PD in GIS difficult. To obtain an acceptable background noise level the use of costly filter and noise suppression methods is required. For this reason an on-site PD measurement with the conventional method is only suitable in fully enclosed test set-ups.

3.2 Acoustic PD measurements

The acoustic method is another sensitive PD measuring technique applicable on GIS. It is immune to electromagnetic noise in the substation and because it cannot be calibrated, a sensitivity verification was developed by the CIGRE working group WG15/33.03.05 [2]. Since the measuring range is limited to one gas compartment acoustic PD measurements on a complete GIS are very time-consuming. Therefore, this method is rather useful for the location of an eventually occurring defect than for an on-site PD test of a GIS arrangement.

3.3 UHF PD measurements

The measuring of PD in GIS using the UHF method has been discussed intensively in the literature and is meanwhile commonly accepted in the industry [3]. The PD signals are detected at UHF frequencies (300MHz- 3GHz) with built-in plate sensors. Since corona discharges do not create interfering signals in the UHF range on-site measurements on partially open test set-ups become possible. The sensitivity of the UHF method is comparable to the conventional method. Measurements can be performed either in the frequency-domain with a bandwidth of a few MHz, which is commonly referred to as the narrow-band method, or in the time-domain over a broad frequency range up to 2 GHz, which is usually called the broad-band method (fig. 6). The PD detection using the narrow-band method is done with a commercial spectrum analyzer and low noise / high gain UHF preamplifiers and results in the frequency spectrum of the PD signal. For the broad-band method the PD signals are detected from an UHF peak detector. Then, a suitable PD measuring device displays a PRPD pattern similar to those obtained with the conventional method. For noise suppression and protection of the measuring equipment the use of a high pass filter with a cut-off frequency of about 250-300MHz in series is necessary.

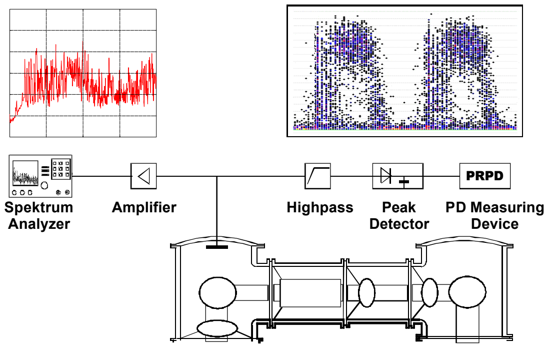

Figure 6: *Principle of the narrow-band (left) and broad-band (right) UHF detection method with typical obtained signals of a free moving particle*

Partial discharges in the GIS excite electromagnetic waves propagating along the coaxial waveguide constituted by the inner and outer conductor. Due to the very fast rise time of the discharge currents waves are not only excited in the TEM mode but also in several higher order TE and TM modes. Reflections at various discontinuities of the waveguide (spacers, T-junctions, etc.) cause standing waves and complex resonant patterns. The measurable UHF PD signal depends strongly on the set-up, type and position of the defect, and the sensors. Thus, a calibration of the UHF method is not possible. To overcome this shortcoming the CIGRE working group WG15/ 33.03.05 developed a two step procedure for a sensitivity verification of UHF measuring systems [2].

Investigations have proven that pulses of a certain characteristic injected via a sensor into a GIS excite a UHF spectrum similar to that of a free moving particle. The rise time of the pulse has to be less than one nanosecond, the pulse repetition rate less than 100 kHz, and the time to half-value needs to be more than a few ten nanoseconds, depending on the pulse shape. In the first step, the magnitude of the artificial pulse has to be determined by placing a particle close to a sensor in a compartment of the laboratory set-up (fig. 7). When the PD signal of the moving particle meets an apparent charge of 5 pC the UHF spectrum is measured at sensors located in other compartments of the set-up. Injecting artificial pulses with varying magnitudes to the sensor near to the defect the obtained UHF spectra are compared to the one of the particle until the spectra are equal with an accepted tolerance of 20% (fig. 8).

For the second step, the sensitivity verification on-site, the same type of test equipment has to be used as during the laboratory test. Artificial pulses of the same shape and magnitude are injected into a sensor of the GIS on-site. If the signal can be measured at a neighboring sensor, the sensitivity verification is successful for the GIS section between both sensors.

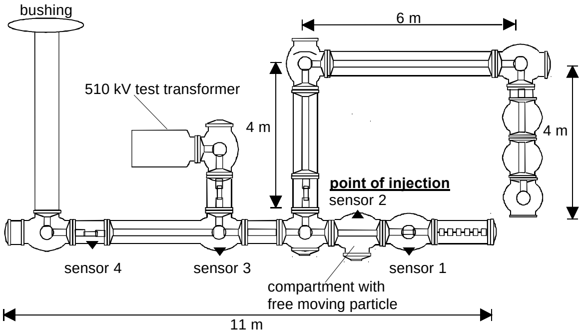

Figure 7: *Experimental set-up of the 420 kV GIS with location of sensors and free moving particle*

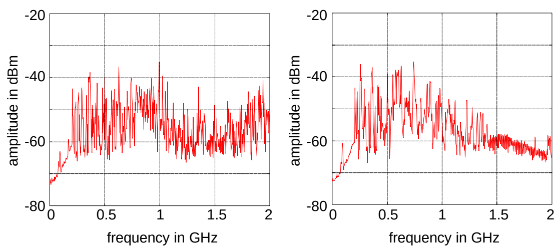

Figure 8: *UHF signals measured at sensor 3*
left: free moving particle, 5pC, l=4mm, Û=380kV
right: injected pulse at sensor 2, Û=7V

With the new sensitivity verification of UHF measuring systems developed by the CIGRE working group WG 15/33.03.05 its acceptance not only for monitoring of GIS but also for on-site testing will certainly grow further. In the near future a replacement of the lightning impulse test on GIS through a sensitive on-site UHF PD measurement seems to be possible. Generally, both UHF methods are suitable for on-site PD tests on GIS. The broadband method is certainly less cost intensive while the narrow-band method is slightly more sensitive and offers the possibility to suppress high frequency disturbances like TV transmitters or mobile phones.

4. Summary

AC testing with an increased voltage level combined with a sensitive partial discharge measurement is now a common test method used for GIS/GIL On-Site Testing after assembly [4-6].
Depending on the GIS/GIL design these tests can be performed by a fully encapsulated test arrangement or by means of an Air/SF6 bushing.

A fully enclosed On-Site Test arrangement can be achieved either by using a conventional SF6 insulated test transformer system of the type TES or by using a SF6 insulated series resonant system with variable frequency of the type RSS.

For „open“ arrangements with a SF6/Air bushing each of the introduced On-Site Test systems can be used depending on the output power and test duration.

Fully encapsulated test arrangements provide the lowest background noise level in order to perform a PD measurement either by conventional or with UHF method with the necessary sensitivity.

The UHF method is preferred for „open“ On-Site Test arrangement with interfering external signals.

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