New Methods for Non-intrusive On-site Testing of Gas-insulated Switchgear

Abstract

High voltage Gas-insulated Switchgear Systems (GIS) represent a space-saving alternative to classic outdoor installations. The GIS market is expending significantly and demand for non-invasive test methods for evaluating the condition of GIS installations is increasing.

Voltage withstand tests need to be performed during commissioning and after maintenance work on GIS systems, as per the IEC 62271-203 standard. These tests can be carried out with an integrated Power Voltage Transformer (Power VT) using a portable resonance test system. The Power VT has been designed to be integrated in the GIS and replaces the testing transformer that would otherwise be necessary. This also saves on transport costs and space when setting up the apparatus. In addition to this, the modification of the GIS structure to connect HV test leads, which normally involves the time-consuming process of venting and refilling the insulating gas, is not required anymore. In turn, this can also lead to a reduction in environmental risks.

Current Transformers mounted on GIS become magnetized after the injection of DC test current. As the final step in maintenance testing, it is important to demagnetize the Current Transformers to avoid the unintended consequences of Protective Relays during normal operation. A new demagnetization method can be performed without changing the wiring configuration on secondary side of the Current Transformer, thus making maintenance tests more efficient.

To ensure proper Circuit Breaker operation, it is important to test the performance of key components including kinematic chain and control circuits by measuring operating times. Today, it is commonly required that this test must be carried with earthing switch connection points grounded on both sides of the circuit-breaker under test. Presently, grounded test methods such as dynamic contact resistance and dynamic capacitance measurements do not give reliable results and are difficult to set up due to limited wiring space. This paper describes a new, simple solution to this problem which improves operator safety by allowing the operating times to be determined accurately with the GIS circuit breaker grounded on both sides, without affecting its mechanical integrity.

Keywords

Circuit Breaker – Timing — Arcing - Contact — Static – Resistance – Dynamic – GIS – Demagnetization – CT – Voltage withstand test

1 Introduction

The circuit breaker plays a significant role within the power system. It is an electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit, by immediately discontinuing electrical flow. It is also used to isolate part of a healthy circuit for regular maintenance.
Gas-insulated switchgear (GIS) systems are made up of many encapsulated elements. The internal high voltage conductor is insulated from the metallic wall of the capsule, which is at ground potential, using pressurized SF6 gas (or gas mixture).
During commissioning or maintenances jobs, opening a gas compartment is limited due to possible external contamination. Moreover, affecting the integrity of the mechanical assembly must be avoided when measuring timing which is a performance test of key components including kinematic chain and control circuits. Lastly, it is important to leave current transformers (CTs) demagnetized after maintenance work by using a method which does not lead to wiring error on the metring and protection side.

2 Voltage withstand testing

2.1 GIS high-voltage testing

GIS bays which are prefabricated as a unit, are already provisionally filled with SF6 gas and subjected to a dielectric withstand test in the factory. They are then sealed and transported to the construction site. However, impurities can also get into the system during on-site assembly. As such, an on-site insulation test needs to be performed. For this "stress test", a voltage higher than 1.5 times the nominal voltage is applied. During commissioning work, it is often recommended to perform a partial discharge measurement using an UHF unconventional method.
To date, a high-voltage generator and a special coupling mechanism (filled with SF6 gas and connected to the respective busbar) have typically been used for on-site testing. This heavy and bulky equipment needs to be transported from one construction site to the next in a large container, often via a cargo flight, frequently having to consider the often-strict customs regulations. This has always required precise logistics and often created considerable costs. Once on-site, the assembly of the system takes up a lot of valuable space, and is both difficult and time-consuming - requiring a crane and the careful precautions which are essential when working with SF6 gas.

2.2 Portable resonance test system

It is possible to perform GIS tests without the need of a bulky HV source when the system directly makes use of a specially designed “Power VT” for testing. This Power VT is an integral part of the GIS and generates the required test voltage. A voltage source injects power at the LV side of the VT, producing the necessary voltage on the HV side. A direct connection of the measuring system to the integrated VT of the GIS system eliminates the need for draining and refilling any SF6 gas. [1].
The busbars, the breakers, the disconnectors, the CTs and VTs inside a GIS represent capacitive load on the high-voltage side of the voltage transformer which is transformed to the low-voltage side by the square of the turns ratio.

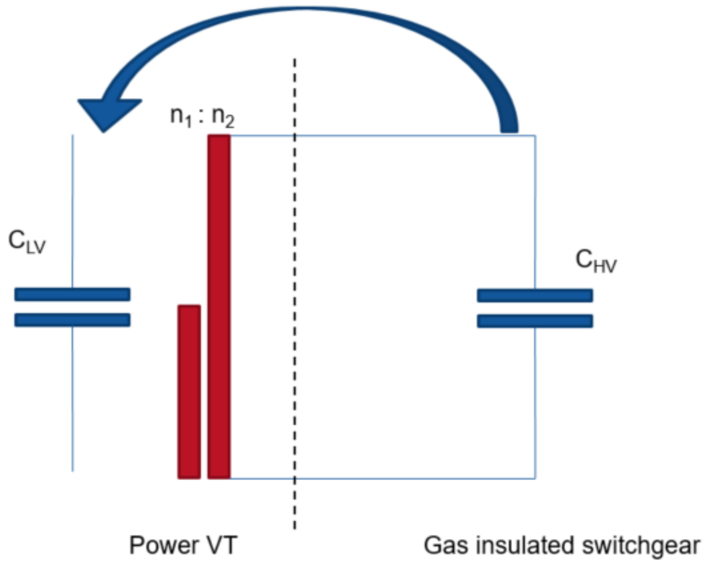

Figure 1: Primary capacitive load transformed to the secondary side

$$C_{LV} = C_{HV} * \left(\frac{n2}{n1}\right)^2 \qquad (1)$$

Without compensating this reactive power, a normal voltage source is not able to deliver the needed total power. The compensating coils L_{Comp} and the capacitive load C_{LV} build a parallel resonance circuit. To get the exact resonance point, the voltage source is capable to change output frequency to be tuned to resonance. Such resonance test system allows performing voltage withstand tests as per IEC 62271-203 with a maximum test voltage up 235 kV. [2]

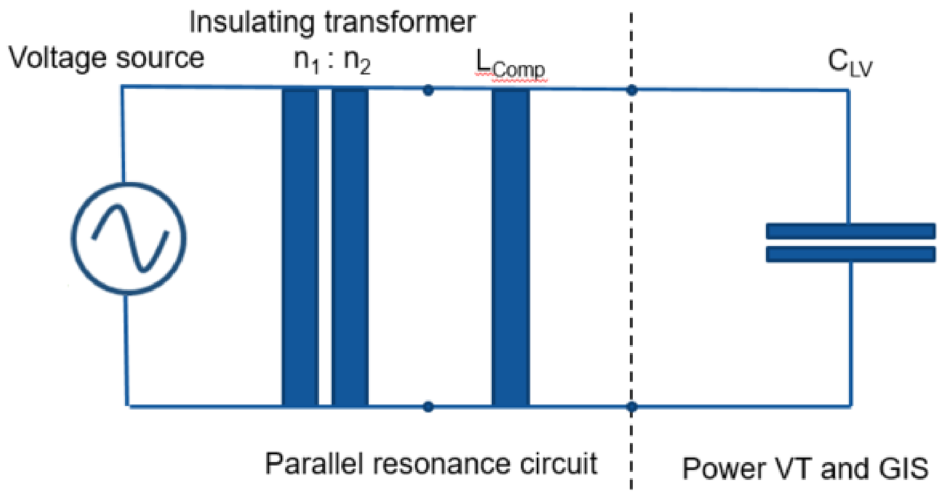

Figure 2: Resonance test setup

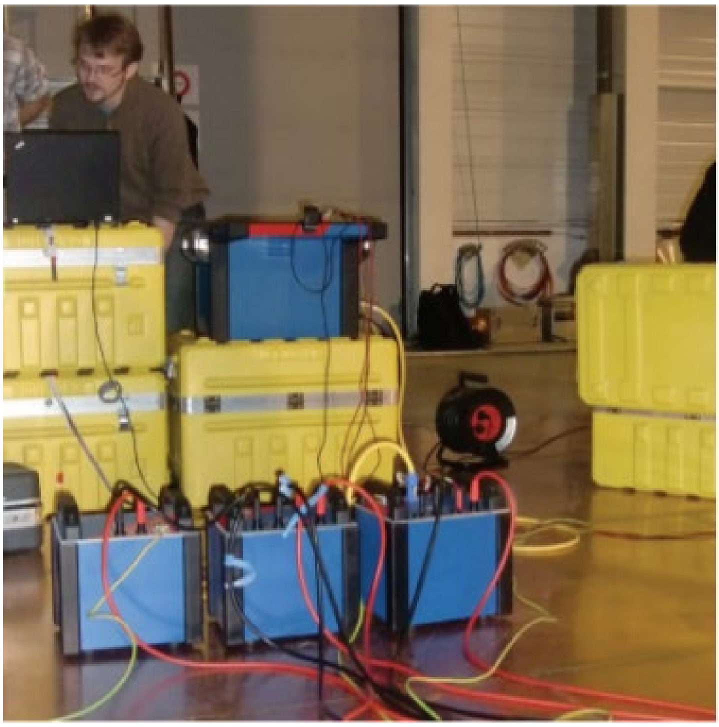

Figure 3: Parallel resonance circuit made of voltage source, insulating transformer and compensating coils

The power VT can be used as a regular VT, however it must be specifically designed, as the power required for the high-voltage test is supplied on the low voltage side. The slightly higher costs of the power VT are easily compensated by the many advantages it offers. The conventional high-voltage generator also required a great deal of space to be allocated during construction of the building, which also influences costs. The space saving allows the test procedure to be facilitated on offshore substation as well. The portable parallel resonance circuit can simply be positioned directly in front of the power VT which is often fixed on the busbar.

Figure 4: Power VT ready for assembling at factory

The portable resonance circuit makes the whole process significantly faster. The new method brings noticeable advantages in terms of safety and environmental friendliness. Modification work related with SF6 Gas filling and evacuation is no longer needed just to perform the tests. The most important benefit is that the system remains sealed, as the transformers are already preinstalled in the factory. This eliminates the risk of contamination getting into the system. [3]

3 Current transformer demagnetization from primary side

3.1 Motivation to demagnetize a current transformer

Current transformers (CT) used in gas insulated switchgear are mounted on the primary side, and, at times, are exposed to DC signals. These signals can be caused by contact resistance measurements, short circuit currents from the mains and switching events. DC signals can lead to residual flux in the magnetic core of a CT. Residual flux changes the saturation properties of the CT core, like the accuracy limiting factor. Moreover, the CT secondary reading can be strongly affected resulting in issues for protective logics computed by differential protection and distance protection. [4]

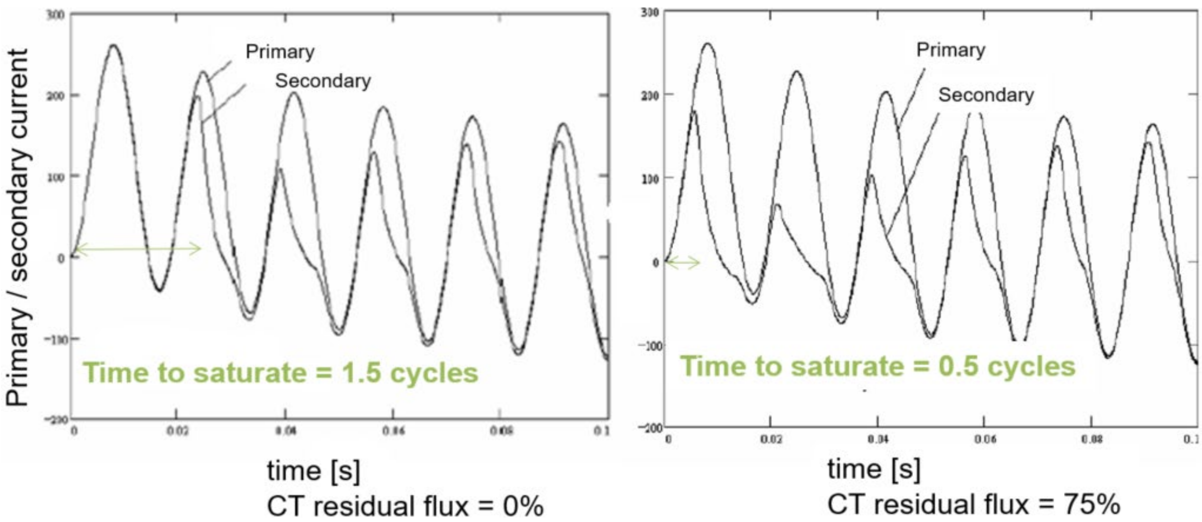

Figure 5: Effect of residual flux on CT secondary reading

3.2 Demagnetization from CT primary side

To ensure proper protective relay operations, CT can be demagnetized from secondary side (each core individually), or from the primary side (all cores at once). Demagnetizing from the secondary side requires isolation of the secondary assets like metring devices or protective relays. Human error can occur during the reconnection process upon completing demagnetisation procedure. Advanced testing devices have the capability to demagnetize the CT core by applying a certain signal pattern over the primary path of the CT. The same setup as for contact resistance measurement is used. This ensures that there is no additional wiring effort needed and it can simply be applied after all regular non-invasive diagnostic methods have been executed. Therefore, it is important to perform a demagnetization before a circuit breaker with mounted CTs is put back into operation. A residual flux below 5% is commonly accepted by protection engineers. [4]

CT (phase C)	C1	C2	C3	C4
Initial remanence	5%	55%	38%	9%
Remanence after contact res. test	76%	79%	81%	79%
Remanence after demag from primary side	2%	2%	3%	3%

Figure 6: Example of remanence result after primary demag. process on 1200:5 C400 CTs of a 72.5kV dead tank circuit breaker

4 Timing test with both sides grounded

4.1 Specific consideration when testing timing on a GIS circuit-breaker

To do safe maintenance work, grounding switches are commonly incorporated into GIS. They connect the conductor to ground and prevent any parts to be charged with high voltages as result of capacitive coupling. Because the grounding switch connects the line conductor to the ground connection, the line conductor can usually be accessed from outside of the GIS. If the grounding switch is closed, the line conductor within the GIS is connected via a grounding shunt on top of the grounding switch with the GIS housing which has ground potential. Grounding switches can be insulated or non-insulated. On insulated grounding switches the connection between the line conductor and the ground connection (housing of the GIS) can be removed for test purpose.
Due to the low-ohm ground connection resulting from the metallic GIS enclosure that runs parallel to the circuit breaker where both sides are grounded, there is no significant increase in the measured voltage or the resulting resistance at the time of the contact separation. Measuring the operating times is thus rendered impossible, as a suitable resistance threshold value cannot be chosen. Therefore, testing methods such as the dynamic resistance measurement (DRM) cannot be used for measuring the operating times of GIS. For this reason, timing measurements are often conducted with insulated grounding, or with grounding that is only on one side. Yet this carries the risk of capacitive coupling from adjacent components or switch bay sections on the non-grounded conductor. [5]

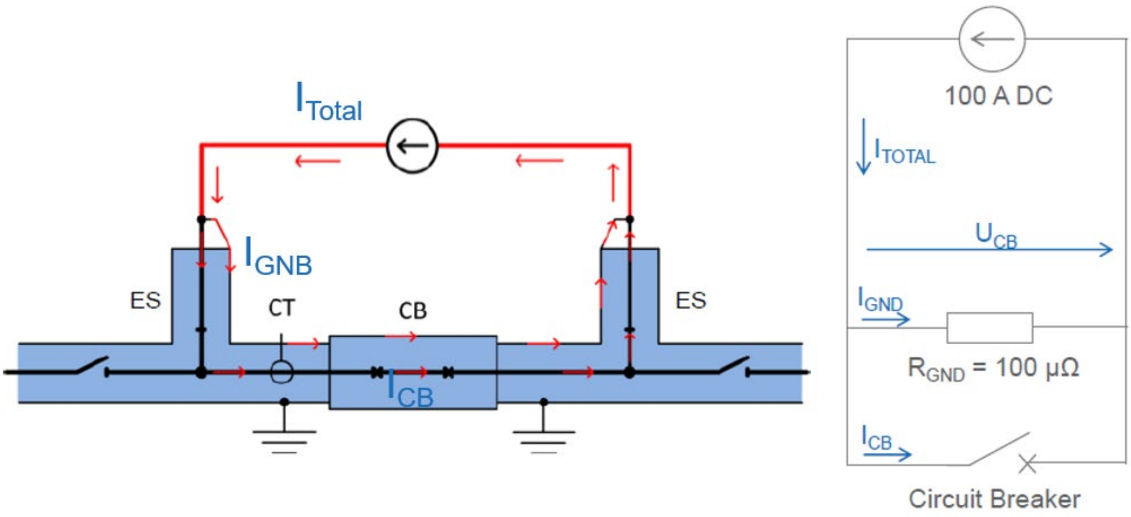

Figure 7: Test current flow in a GIS when testing contact resistance [6]

4.2 Current sensor measurement

The current sensor measurement (CSM) measures the operating time via an inductive current change measurement using the parallel ground connection or the circuit breaker path while the circuit-breaker remains grounded on both sides. Rogowski coils are laid around the earthing switch ground connections of each phase. The current variation over time in the ground conductor or the breaker path is directly measured by the current sensor as a DC test current is being injected between the circuit breaker both sides.

In case the breaker is closed the injected current is split into the both paths: the grounded GIS enclosure and the breaker main contact. The measured current over the ground links – which is the same potential as the GIS enclosure – is lower. Once the breaker contacts are open the entire current flows over the GIS enclosure. During the change from close to open state the change of current causes an induced voltage spike at the Rogowski coil output. The current change that is measured through the ground connection or the circuit breaker is then used to determine the switch response times. The circuit breaker remains grounded on both sides throughout the entire measurement. As the “rate of current change” is used, the test current value is less important if the measuring coil is sensitive enough. [5]

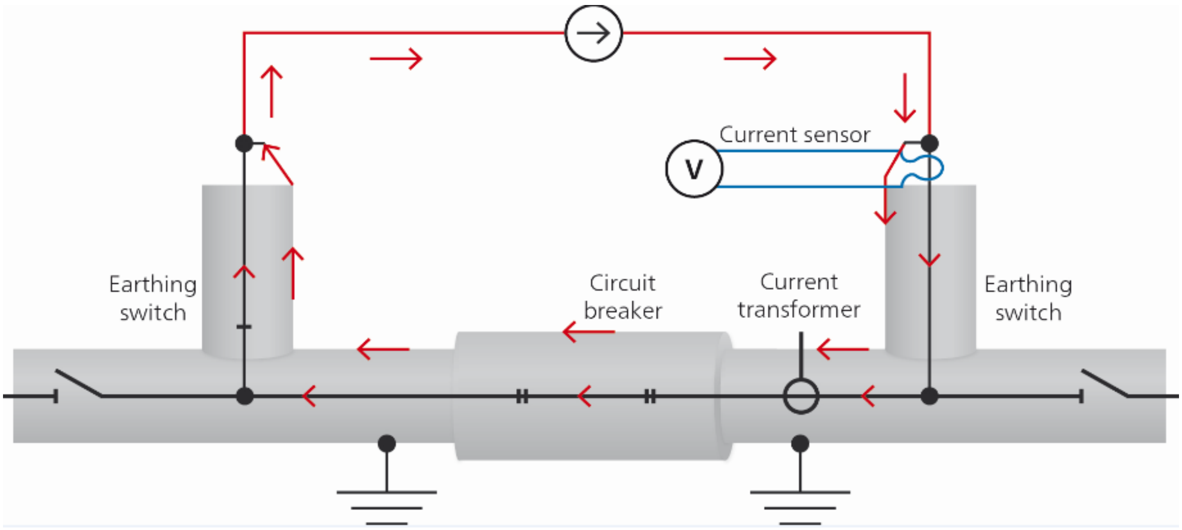

Figure 8: Rogowski coil (current sensor) through earthing switch shunt on a GIS grounded on both sides

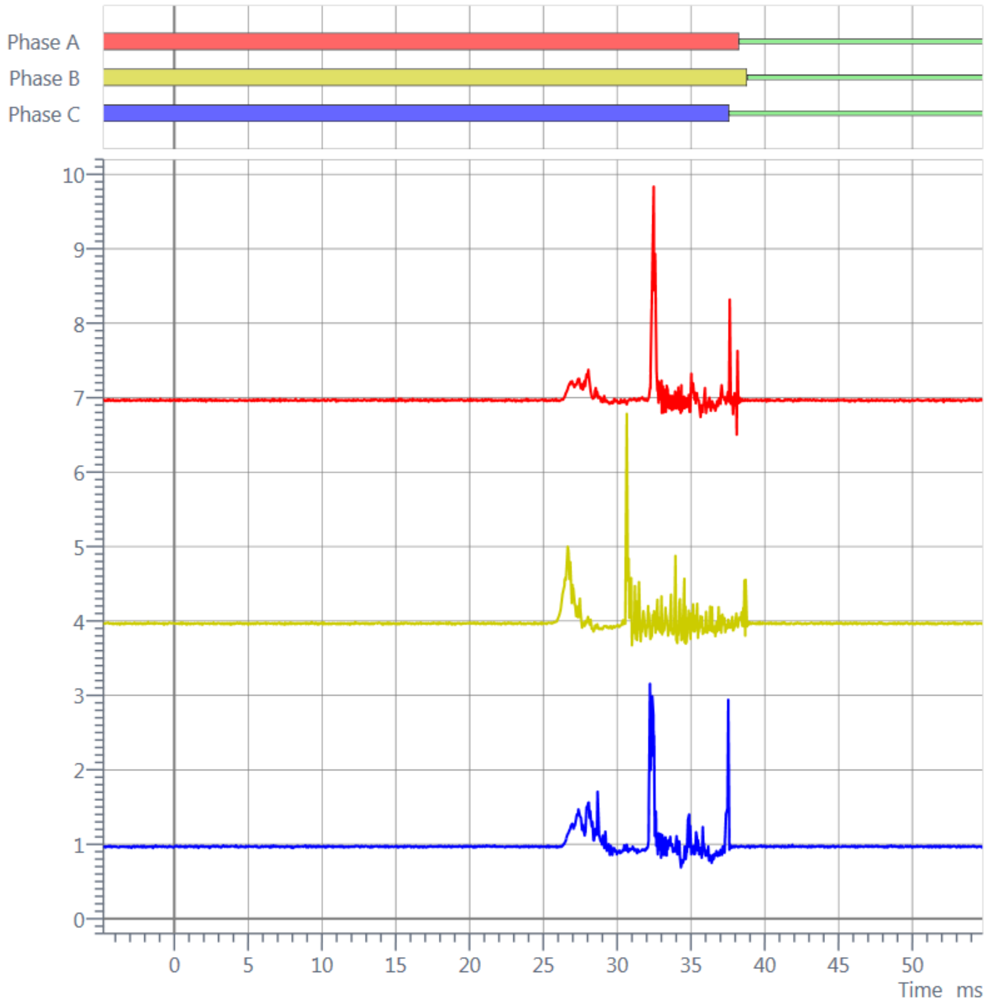

Figure 9: Current variations (A/s) over time through each phase during open operation of a 145 kV GIS circuit breaker [4]

The CSM pattern is unique for each contact system design. This allows comparison between similar circuit breakers. Because the method detects changes directly, it highlights discontinuity accurately for specific contact designs. Like the DRM, the combination with motion measurement provides information on arcing contact length. When using the CSM method, the ground connections on the earthing switch do not need to be removed and additional components do not need to be installed. A current sensor just needs to be connected to the switchbay earthing switch. Since Rogowski coil have a flexible design and can easily be installed on a multitude of different grounding switches, they are ideal for on-site applications in GIS installations. Therefore, the CSM method is a faster alternative method for precisely measuring the operating times of a GIS that is grounded on both sides. [4][7]

5 Conclusion

This paper discussed new non-invasive methods for testing circuit breaker. With these techniques, the GIS integrity is kept. During commissioning and maintenance tests, the opening of SF6 gas compartment is no longer necessary, and the risk of particles contamination is avoided. The SF6 gas work and associated risks are limited thanks to the integrated power VT. Demagnetization is also easier when the CT secondary side is not unwired for the procedure. Since only a coil is required on the switchbay grounding switch to perform timing test, the CSM method represents a quick, easy and safe way on a both sides grounded GIS.

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