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On-site non-intrusive testing of AC circuit-breakers

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SUMMARY

With their capability to immediately interrupt electrical current flow, circuit breakers play a security and safety role within a power system. To ensure proper circuit breaker operation, it is important to test the performance of key components, including: kinematic chain (timing and motion of main contacts), control circuits (coil current analysis, minimum pick-up test, motor current analysis), and main contacts wear (static and dynamic contact resistances).

Recent developments in test equipment have improved usability and safety in performing these tests, in particularly: improved Dynamic Resistance Measurement (DRM) test, safer timing of Gas Insulated Switchgear (GIS), and demagnetization of Current Transformers (CT).

Dynamic Resistance Measurement, combined with a motion analysis, is an approach that is commonly used for determining length and condition of an arcing contact without disassembling the main contacts of the circuit breaker. Long been considered difficult to perform on-site, DRM measurements can now be easily carried out simultaneously on several interrupters, using modern test device. DRM measurement used as a basic test method, provides additional safety advantages, and capability of performing all tests without rewiring a live-tank breaker. As well, testing a Gas Insulated Switchgear without affecting its mechanical integrity and improved operator safety is achieved with innovative testing techniques.

Current Transformers, mounted on GIS and Dead-Tank CB, become magnetized after a DC contact resistance measurement. As a final step of maintenance tests, it is important to demagnetize the current transformers to avoid misbehaviour of protective relays during normal operation. A new demagnetization method has been invented, which can be performed without changing wiring configuration on secondary side of the current transformer, thus making maintenance tests more efficient.

Performing these tests with an appropriate multifunctional test system, provides a time-efficient and comprehensive assessment of the circuit breaker. These tests are performed non-intrusively. In addition, background knowledge of circuit breaker operation, new innovative testing procedures, and testing and analysis tools, will also be presented.

KEYWORDS

Circuit Breaker – Timing – Motion – Arcing - Contact – Coil - Pick-up voltage – Motor – Static – Resistance – Dynamic – GIS – Demagnetization – CT

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1. INTRODUCTION TO CIRCUIT BREAKER TESTING

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.
For reliable condition assessment of a circuit breaker it is of vital importance to have a correct interpretation of the results obtained during analysis. Non-intrusive test methods that are typically performed on-site are as follows:

- static resistance measurement
- timing analysis and coil current analysis,
- motion analysis,
- motor current
- dynamic resistance measurements.

1.1. Static Resistance Measurement

The micro ohm measurement or static contact resistance measurement on the closed main contacts is a measurement that should typically be undertaken. It injects larger DC current via the main contact and the voltage can be picked up with separate cables as close as possible to the main contact. International standard IEC 62271-1 requires a minimum test current of 50A. If deviations are observed, further tests at higher current must be performed to determine if a contact is defective [1].

1.2. Timing and Coil current analysis

The interpretation of a timing analysis is addressed by the standards, therefore this article only discusses how timing is influenced by operating mechanism designs.

1.2.1 Spring mechanisms

Spring mechanisms are used in many high voltage circuit breakers to store energy. The energy is released by the action of close and trip coils. By taking a closer look at the coil current, a lot of useful information can be seen. For instance:

- the electrical properties of the coils, such as the time constant
- the force, i.e. current which is proportional to that force, and must be applied in order to trigger the loaded spring
- the correct timing sequence of the auxiliary contacts

During coil current analysis, the current flow in the trip or close coil during the closing or opening sequence of the main contacts is measured and plotted over time. The deviations of measured curve from the expected electrical coil properties (time constant), the necessary driving force (proportional current), and the correct timing sequence of the auxiliary contacts can be used to identify electrical or mechanical problems within the trip and close mechanism of the circuit breaker. A typical current curve (see Figure 1) is shown below [2].

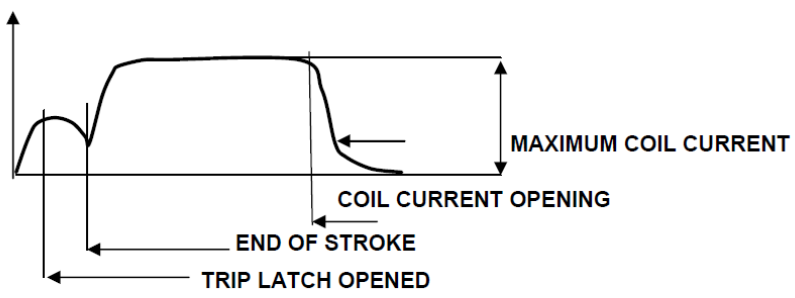

Figure 1: Typical coil current shape

Coil supply voltage has an influence on current shape. In spring mechanism, the operation speed is directly linked to the coil current and therefore also to the supply voltage. In order to make timing test repeatable, coil voltage must be controlled.

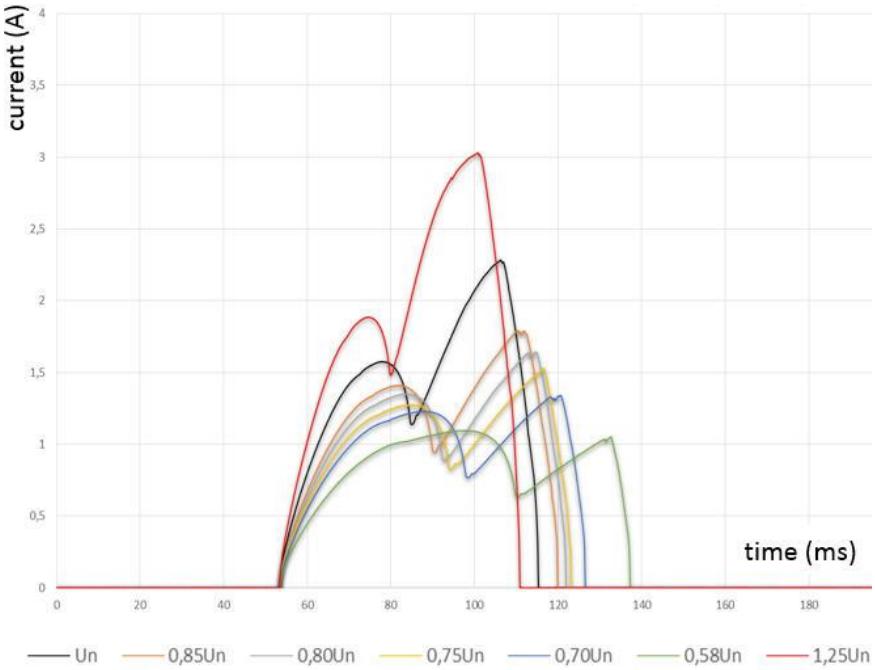

Figure 2: Coil current profile for different voltage from 0.25% to 1.25% of nominal voltage [3]

1.2.2 Magnetic operating mechanisms

Magnetic operating mechanisms are used more and more in medium voltage vacuum circuit breakers. A big actuator coil is directly linked to an interrupter. The energy is provided by one or two pre-charged capacitors which discharge several tenths of amps in coil. With less mechanical links, such breakers require less maintenance over time and are easier to manufacture. Moreover, the digitally controlled discharge of closing and opening capacitors allows for better handling of respective sequences.

Current measurement on breakers with actuator coil shows very similar current profile to that discussed previously. Similar principles apply for assessment. In order to monitor the breaker operation in sequence (e.g. CO sequence), it is essential to be able to measure coil current.

In most developed MV designs, the close position is maintained by the saturated coil which becomes a permanent magnet. The opening operation is supported by a spring after the coil demagnetization [4]. Such principles may require time controlled discharge sequence of currents from several capacitors for a single operation. Each state can be analyzed with a current measurement as shown below.

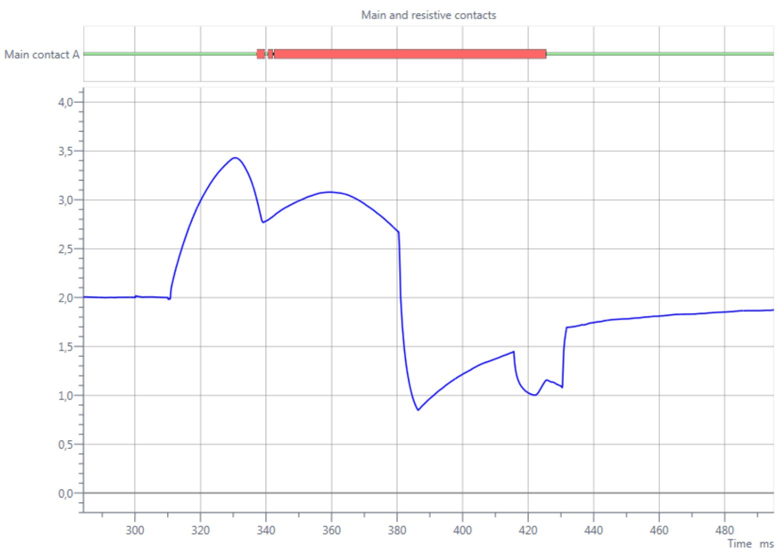

Figure 3: Actuating coil current over time in a CO sequence for a 2kV breaker

1.3. Motion analysis

Motion analysis can detect weak mechanical components in a circuit breaker, such as worn out damping units, problems with storing the energy for tripping or closing (a worn spring or leaking pressure system), and contacts which have reached the end of their life cycle. By detecting these problems at an early stage, preventive measures can be taken to ensure safe circuit breaker operation. A motion sensor attached to the mechanical linkage of a circuit breaker reveals a lot of useful information. Therefore, it is highly recommended to use this method for tracing the motion of the current interrupting mechanism. In order to classify the condition of the damping units and mechanical issues of the circuit breaker's operating mechanism, it is necessary to take note of important performance parameters such as overtravel (amplitude, duration), total travel, and speed behaviour of the contacts. Each motion analysis compares the reference data specified by the circuit breaker manufacturer with the measured values [5].

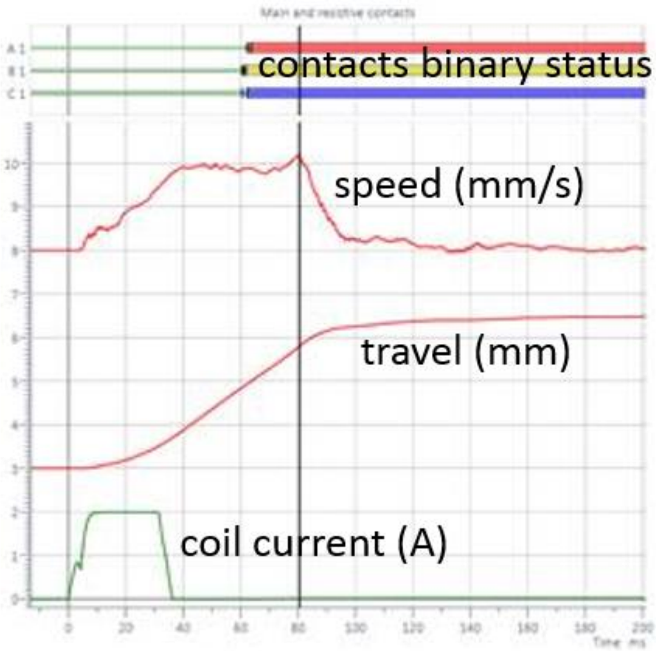

Figure 4: Damping analysis over time

1.4. Motor current

The motor current is recorded to determine any lubrication problems in the integrity including the motor and the drive. If the motor current has increased or if it takes longer to charge the drive, the operating mechanism must be investigated.

1.5. Dynamic resistance measurements (DRM)

Dynamic resistance measurement combined with motion analysis is a commonly used method, as it determines the contact length without having to disassemble the circuit breaker. When the arcing contact becomes shorter than the minimum requirement specified by the circuit breaker manufacturer, safe operation can no longer be guaranteed and the interrupter unit needs to be maintained properly.
The dynamic resistance method measures the contact resistance continuously during the opening operation of the circuit breaker's interrupter unit [6]. This is done by performing a four-wire DC resistance measurement during an open operation, with the breaker isolated from the high voltage:

- DC current is injected into the interrupter
- DC voltage drop across the interrupter is measured

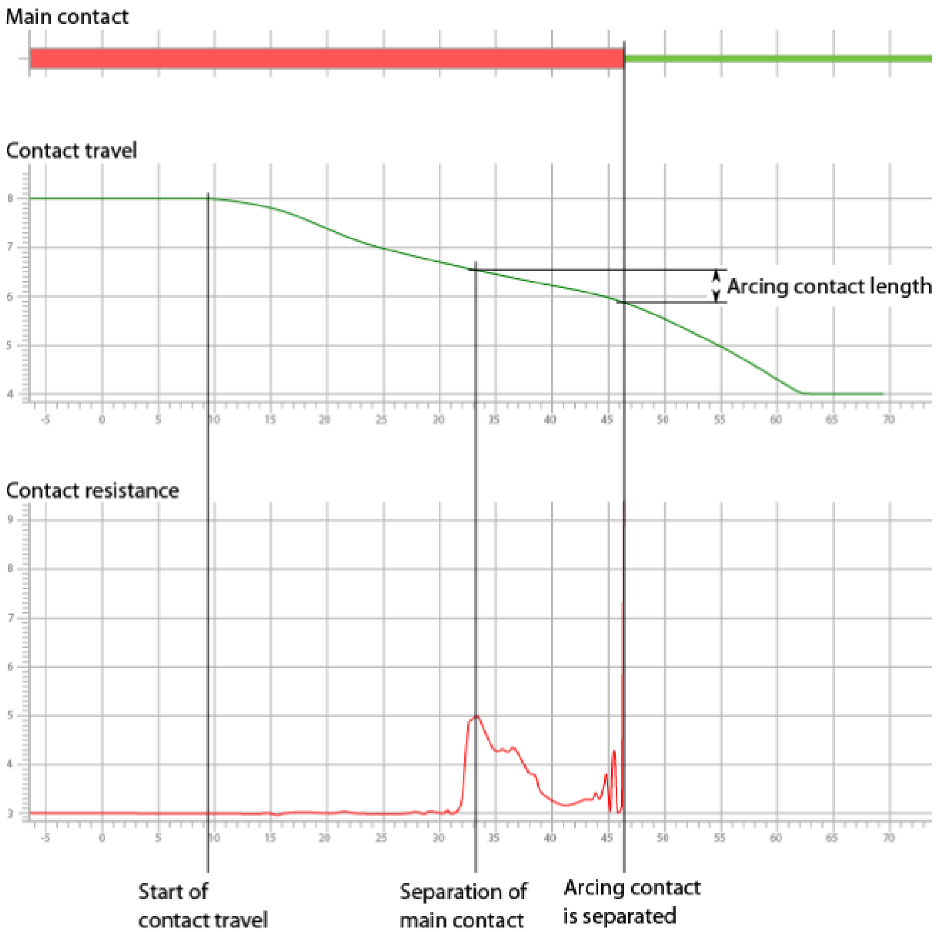

Figure 5: DRM curve interpretation for an SF6 circuit breaker

1.6. Current Sensor Measurement (CSM)

The current sensor measurement 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. The current variation in the ground conductor or the breaker path di/dt over time is directly measured by a Rogowski coil. As the rates of current change is used, the test current value is less important if the measuring coil is enough sensitive.

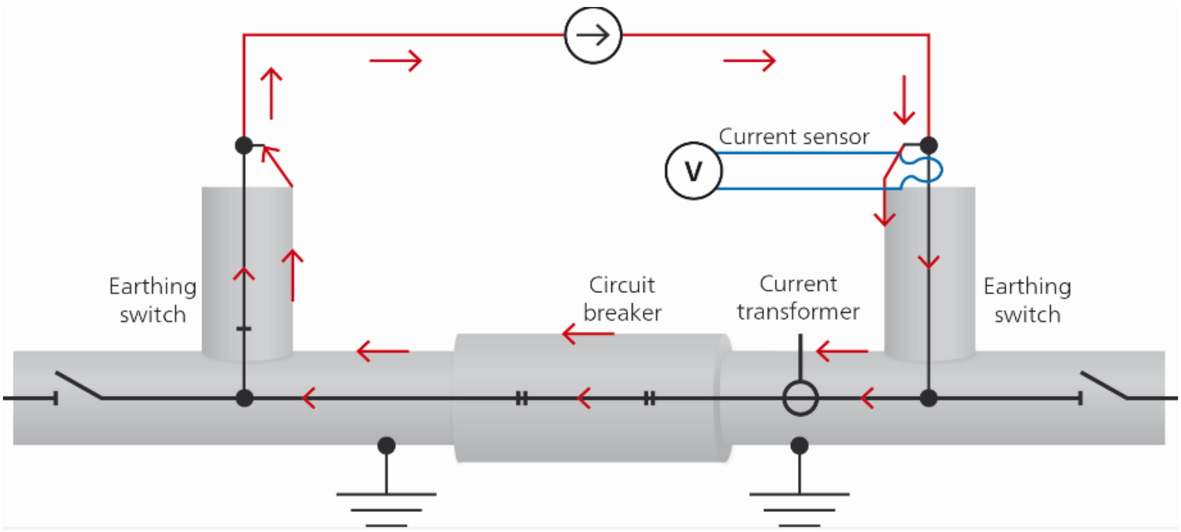

Figure 6: Rogowski coil (current sensor) through earthing switch shunt on a GIS grounded on both sides

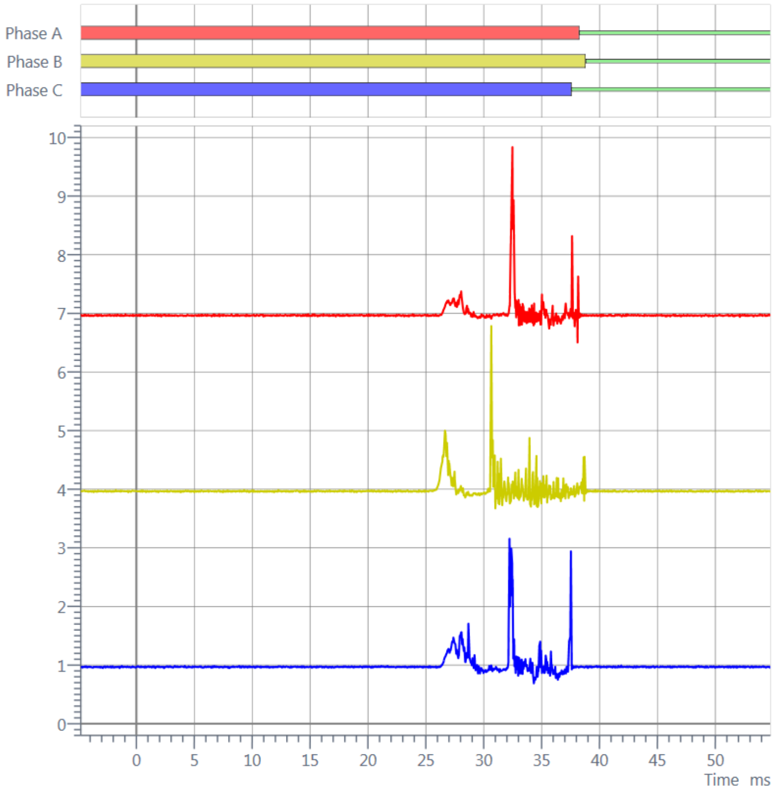

Figure 7: Current variations (A/s) ever time through each phase during open operation of a 145 kV GIS circuit breaker

Comparison of time measurement between DRM and CSM methods shew good matching during actual timing measurement [7]. The CSM pattern is unique for each contact system design. This allows comparison between sister circuit breakers. Because the method detect changes directly, it highlights discontinuity accurately for specific contact designs. Like the DRM, the combination with motion measurement provides information on arcing contact length.

2. DESIGN CONSIDERATIONS FOR AN ON-SITE CIRCUIT BREAKER TESTING DEVICE

2.1. Built-in coil and motor supply

One of the most challenging tasks is to make the tests repeatable. To test a circuit breaker, the voltage supply must not only be sufficient to operate the trip and close coils, but also to drive the motor which tightens the springs or compresses the gases or oil with which the circuit breaker operates. To supply the circuit breaker during the test, either a station battery or an external supply can be used. There are disadvantages to using a station battery like dangerous connections in a live system. Moreover the voltage of a station battery cannot be controlled. It can fluctuate within a certain range and thus the test undertaken is only conditionally repeatable. An external supply does not have these disadvantages if it is electronically stabilized, although unfortunately this is often not the case. It also creates the need for an additional device. One way to overcome these disadvantages is to have a coil and motor supply that is independent from station battery supply and provides stable voltage at different levels, built in to the testing equipment.

Undervoltage tests, through which the trip coils are triggered with, for example, a voltage of 20% within the nominal voltage, would also require a controllable power supply. Moreover, searching for minimum pickup voltage using pulse ramping sequence can be easily configured with a controlled embedded power supply. Furthermore, the embedded power supply makes it easier to test breakers with undervoltage coil. The opening time initiated by the undervoltage coil can be easily measured, as the time difference between when the supply is switched off and the instant when the breaker is open.

Separate tests on the motor and recording of the motor current over time would also be convenient with a built-in supply.

2.2. Safe and clear wiring

2.2.1. DRM modules based test

For high-voltage live tank circuit breakers, in particular, all interrupters on the same phase should be measured simultaneously. In addition to timing analysis, a dynamic resistance measurement must also be performed. In high-voltage applications, it may also be necessary to leave the circuit breaker grounded on both sides, throughout the entire test. The use of DRM modules (on the top of the breaker close the interruption units) fulfils such requirements. Each DRM module at the top of the circuit breaker is connected via a communication bus with the main device, and generates the test current. Measurement data is digitized in the DRM modules and sent to main unit on the ground level, which supplies power to the DRM modules via the same cable used for communication. As a default test method, measuring dynamic resistance is easy to set-up. With this setup, dynamic resistance measurement is performed simultaneously for all interrupters.
The high-current cables on top of the breaker are kept short. This also minimizes measurement interference from inductive coupling. Furthermore, this avoids the possibility of inducing dangerous voltages which could be sent back to the operator.
Grounding a circuit breaker on both sides may be necessary during maintenance operations. Because of capacitive coupling with energized line in parallel, any floating conductor may cause dangerous voltage. It is possible to test timing using a DRM module (see Figure 8), if this safety requirement is taken into account.

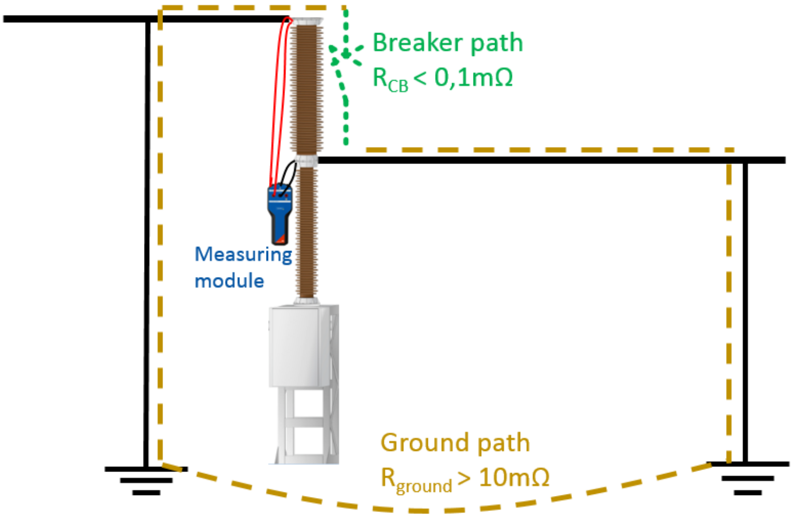

Figure 8: Testing DRM with both sides grounded

The transition between a closed and open position can be detected based on a resistance threshold. Test current must be high enough to get rid of 60 Hz of current which is induced in the ground path when the interrupter is closed. Experience on site shows that 100 A is the minimum value in order to get reliable results. Usually, the arcing contact behavior of SF6 breaker can also be measured.
Static contact resistance can be measured with both sides grounded, because the ground path resistance is much higher than the interrupter resistance. If the ground loop resistance is lower than expected, then the resistance in both closed and open positions will be measured, and circuit breaker resistance can be calculated.

2.2.2. GIS case

Test sets and the circuit breaker are usually connected by tapping the earthing switches on the switchbay. 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 [7]. 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 switchbay sections on the non-grounded conductor. Therefore, on-site testing using these methods is often impossible or prohibited in many cases.
The dynamic capacitance measurement (DCM) has been used to date to test GIS timing with both sides grounded. The DCM measures the resonant frequency of the test setup which changes when the circuit breaker is open or close. Installing additional ferrite cores on the earthing switch is required to increase the parallel ground impedance [7]. However, the assembly and setup is time-consuming. The feasibility of this process is also restrictive and a variety of ferrite core types are needed due to earthing switches designs.
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 and simpler alternative method for precisely measuring the operating times of a GIS that is grounded on both sides.

2.2.3. CT demagnetization

Current transformers (CT) mounted on a dead tank circuit breaker of build into a gas insulated switchgear are on the primary side 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 magnetism in the magnetic core of a CT.
Advanced testing devices have the capability to demagnetize the CT core by applying a certain signal pattern over the primary path of the CT. 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.

3. CONCLUSION

This paper discussed the most common and easy to use non-invasive circuit breaker diagnostic techniques available today. With these techniques the user will use certain condition indicators, as contact resistance or switching time, to detect contact wear, mechanical linkage status, performance of the drive mechanism and the control and auxiliary circuit performance. Also the newest methods are shown which enables the user to perform measurements in a very safe manner because the circuit breakers can stay both sides grounded.

BIBLIOGRAPHY

[1] P.G. Slade “Electrical Contacts: Principles and Applications” (Second Edition, p 943, CRC Press, 2013)

[2] T. Renaudin, A. Taneja, U. Klapper “Circuit Breaker Testing – A New Approach” (Electricity 2013 SEEEI conference, Jerusalem, Israel (2013))

[3] A. Herrera “Pruebas a Interruptores de Potencia” (Guatemala, 2013)

[4] Tavrida Electric, Vacuum circuit breaker product pages (South Africa)

[5] Andreas Nenning “Interpreting the results of circuit breaker analysis” (OMICRON Paper of the month, Klaus, Austria 2013)

[6] M. Landry, A. Mercier, G. Ouellet, C. Rajotte, J. Caron, M. Roy “A New Measurement Method of the Dynamic Contact Resistance of HV Circuit Breakers” (Cigré 2004)

[7] M. Weuffel, T. Krampert, C. Rausch, A. Schnettler “Measurement Procedure for Minimally Invasive Measurement of Switching Time in Gas-Insulated Switchgear (GIS) with Both Sides Grounded” (High-Voltage Switchgear Symposium, GIS User Forum, Darmstadt, Germany, October 11, 2016)