On-site non-intrusive and safe testing of circuit breakers

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Abstract

Résumé:
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 tests), control circuits (coil current analysis), and main contacts wear (static and dynamic contact resistances). Recent developments in test equipment have improved usability and safety when performing these tests, in particular: improved Dynamic Resistance Measurement (DRM) test, safer timing of Air Insulated Switchgear (AIS), Gas Insulated Switchgear (GIS), and demagnetization of Current Transformers (CT). Performing these tests with an appropriate multifunctional test system provides a time-efficient assessment of the circuit breaker.
Furthermore, newly designed medium voltage switchgears are totally encapsulated, and access directly to the primary side is not possible. These circuit breakers are instead equipped with capacitive or inductive couplers which can be used for timing tests. These tests are performed non-intrusively and in a safe way.
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On-site non-intrusive and safe testing of circuit breakers Thomas Renaudin OMICRON electronics Grenoble, France  thomas.renaudin@omicronenergy.com

Abstract—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 tests), control circuits (coil current analysis), and main contacts wear (static and dynamic contact resistances). Recent developments in test equipment have improved usability and safety when performing these tests, in particular: improved Dynamic Resistance Measurement (DRM) test, safer timing of Air Insulated Switchgear (AIS), Gas Insulated Switchgear (GIS), and demagnetization of Current Transformers (CT). Performing these tests with an appropriate multifunctional test system provides a time-efficient assessment of the circuit breaker. Furthermore, newly designed medium voltage switchgears are totally encapsulated, and access directly to the primary side is not possible. These circuit breakers are instead equipped with capacitive or inductive couplers which can be used for timing tests. These tests are performed non-intrusively and in a safe way. Keywords—Circuit breaker, timing, arcing contact, coil current analysis, static contact resistance, dynamic contact resistance, Gas Insulated Switchgear, demagnetization, current transformer, current sensor measurement, voltage based timing measurement, magnetic operating mechanisms I. INTRODUCTION TO CIRCUIT BREAKER TESTING For reliable condition assessment of a circuit breaker it is vitally important to have a correct interpretation of the results obtained during analysis. Non-intrusive electrical test methods that are typically performed on-site are at the minimum: • static resistance measurement • timing analysis and coil current analysis. A. 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]. B. 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) Spring mechanisms: Spring mechanisms are used in many high voltage and medium voltage circuit breakers to store energy. The energy is released by the action of close and trip coils. 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 [2]. Coil supply voltage has an influence on current shape and therefore also on operating times. In order to make timing tests repeatable, coil voltage must be controlled. 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 into the 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 measurements on breakers with actuator coils show very similar current profiles 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. II. CIRCUIT BREAKER TESTING DEVICE WITH BUILT-IN POWER 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, such as 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. III. TIMING TESTS WITH BOTH SIDES GROUNDED A. Dynamic resistance measurements (DRM) modules based test The DRM combined with motion analysis is a commonly used method, as it determines the contact length without having to disassemble the circuit breaker. The dynamic resistance method measures the contact resistance continuously during the opening operation of the circuit breaker’s interrupter unit [4]. 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 •
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, Fig. 1) fulfills 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 is 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. The transition between a closed and open position is detected based on a resistance threshold. Because the ground path resistance is much higher than the interrupter resistance, this transition is easily detectable. Test current must be high enough to get rid of 50 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 needed to get reliable results. Usually, the arcing contact behavior of an SF6 breaker can also be measured (Fig 2). Static contact resistance can be measured with both sides grounded. 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. Fig. 1. Testing DRM with both sides grounded Fig. 2. Use of DRM for a timing test with both sides grounded B. 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 being 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 (hosing of the GIS) can be removed for test purposes. 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] C. 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 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 (Fig 3). As the “rate of current change” is used, the test current value is less important if the measuring coil is sensitive enough. [6] 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 (Fig 4). Like the DRM, the CSM may provide information on arcing contact state. 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 coils 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. [7][8] Fig. 3. Rogowski coil (current sensor) measures current variations through earthing switch shunt on a GIS grounded on both sides Fig. 4. Current variations (A/s) over time through each phase during open operation of a 145 kV GIS circuit breaker [6] The CSM allows test timing on a live tank circuit breaker with the test system connected at the asset bottom, and with both sides grounded. The measuring module injects DC test current into the ground loop while the current sensor measures the current variation in the chamber during the circuit breaker operation. Thus, there is no need for the operator to use a crane or a specific long connection stick during wiring procedure. Fig. 5. Test setup principle to measure timing on a live tank circuit breaker by using CSM IV. CURRENT TRANSFORMER DEMAGNETIZATION FROM PRIMARY SIDE 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. [7] To ensure proper protective relay operations, CTs can be demagnetized from the 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, such as metering devices or protective relays. Human error can occur during the reconnection process upon completing demagnetization 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. [7] Fig. 6. Example of remanence result after primary demag.

process on 1200:5 C400 CTs of a 72.5kV dead tank circuit breaker V. VOLTAGE-BASED TIMING MEASUREMENT The voltage-based timing measurement (VTM) is another method which is used when timing measurements must be carried out while the circuit breaker stays in service. It is particularly beneficial on medium-voltage-SF6 installations where access to the main contacts is permanently sealed. Medium-voltage indoor-switchgear is often equipped with voltage detection systems which are used to detect the absence or presence of operating voltage, as defined in IEC 61243-5. These systems are capacitively-coupled to the primary circuit and provide a low-voltage signal to the secondary side. VTM uses the low-voltage signals and the trip or close coil signal to measure the breaking or making time. Moreover, the method allows the first-trip test, which simulates the first trip of a circuit breaker where the contacts and mechanism have not been actuated for some time and are suddenly required to trip. It may reveal that the breaker does not operate at all; only partially; or after a delay, as a result of ineffective or degraded lubricant, surface contamination, or corrosion of mechanical elements.