

Technical guide

circuit breaker diagnosis

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Introduction to maintaining and testing circuit breakers

This is a short application briefing intended for anyone who wants to understand the basic principles of circuit breaker testing.

General

When a fault occurs, current must be interrupted quickly and reliably to avoid personal injuries and minimize damage. If a breaker fails to break the circuit, the resulting damage can be very serious indeed. Moreover, a needlessly large section of the power grid will have to be disconnected in order to interrupt the fault current.

A circuit breaker is the active link in the fault-clearance chain. Even though circuit breakers are comparatively reliable, faults can and do occur. Circuit breakers must thus be tested and maintained to ensure operation when a crucial need arises.

During its 40+ year service life, a circuit breaker must be constantly prepared to do its duty. Long periods of idleness often elapse during which the breaker's mechanical parts never move.

There are many reasons to maintain and test a circuit breaker. Friction and wear can affect the performance of movable parts. Leaks can occur in the valves and seals used in arc-extinguishing chambers, damping devices, pneumatic and hydraulic operating mechanisms. Faults can occur in electrical control circuits, and the contact surfaces in current-carrying circuits can deteriorate, thus increasing the risk of excessive heat generation.

Different maintenance strategies

If a maintenance strategy that is strictly *corrective* is adopted, no attempts are made to deal with a developing circuit breaker fault before it becomes fatal. This does not, however, ensure the reliable supply of electric power that consumers are entitled to expect. Short-term savings in maintenance costs will soon be eaten up by the cost of the damage and the cost of correcting faults. In *periodic maintenance*, a number of specific measures are taken at predetermined times, regardless of the conditions under which a circuit breaker operates. If this method is applied too strictly, however, it may lead to needless intervention. Disassembling a circuit breaker that has no faults entails needless expense, and it does not improve reliability.

Condition-based maintenance is being used more and more. Here, you ascertain the condition of a circuit breaker through testing and inspection. The results, supplemented with statistical data and cumulative experience, are then used to plan maintenance for the circuit breaker in question. The breaker's need for maintenance is based less on time than on the conditions to which it is exposed, how frequently it operates and its environment. Condition-based maintenance provides excellent opportunities to improve reliability and cut costs, but it requires effective diagnostic methods. Many circuit breakers provide longer service lives than expected. If you can ascertain that a breaker is in good condition, you can continue to use it rather than replace it. Here too, however, effective diagnostic methods are of prime importance.

Testing circuit breakers

Before a new circuit breaker is delivered, it is tested at the factory. After it has been installed, it is submitted to a commissioning test before being taken into service.

Thereafter, it is inspected and tested on different occasions. Usually, a circuit breaker has to be taken out of service in order to test it. Lately, however, more and more interest is generated around the concept of on-line testing, doing certain measurements on the breaker while it is in active service. More about this later.

The following parameters are often tested on a circuit breaker: closing time, opening time, and resistance of the main contacts and synchronization of contact operation. Contact travel and speed are also tested (as recommended in the IEC 1208 standard

and other literature). Some new methods for circuit breaker diagnostics are dynamic resistance and vibration testing. Moreover, checks are made to see that the solenoids and latches operate properly. This is done by measuring the lowest breaker operating voltage and checking the shape of the coil current curve.

Measured values are compared with limit values specified by the manufacturer or values that have been arrived at by the maintenance organization through experience. In many cases, a "fingerprint" consisting of different measurements taken when a breaker is new is compiled. This fingerprint can then be used as a reference for subsequent measurements. Any change that is found clearly indicates a change in the breaker's condition.

What needs to be tested on a circuit breaker?

Following are parameters that are recommended in ANSI and IEC standards for evaluating the condition of high voltage circuit breakers and that can easily be measured using TM1800.

Timing measurements

Simultaneity within a single phase is important in situations where a number of contacts are connected in series. Here, the breaker becomes a voltage divider when it opens a circuit. If the time differences are too great, the voltage becomes too high across one contact, and the tolerance for most types of breakers is less than 2 ms. The reason is that the multiple breaks together make a voltage divider (in open position). If the time spread is too big it will result in over-voltage on a single contact. Serious damages on the breaking chamber might occur.

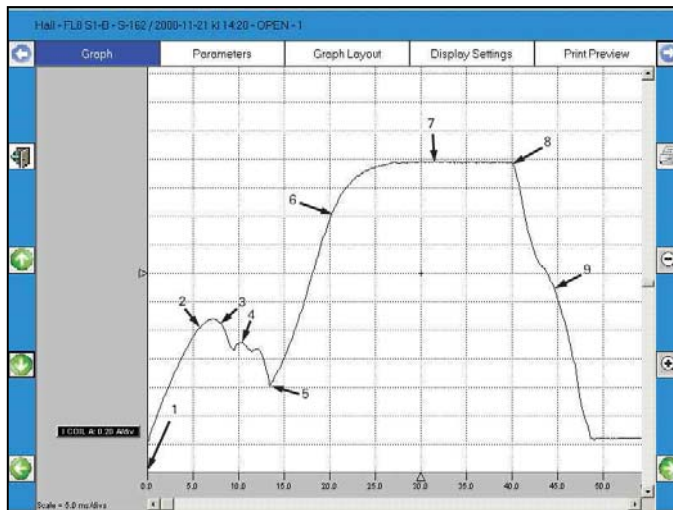
The time tolerance for simultaneity between phases is greater for a 3-phase power transmission system running at 50 Hz since there is always 6.67 ms between zero-crossovers. Still, the time tolerance is usually specified as less than 2 ms, even for such systems. It should also be noted that breakers that perform synchronized breaking must meet more stringent requirements in both of the aforesaid situations.

There are no generalized time limits for the time relationships between main and auxiliary contacts, but it is still important to understand and check their operation. The purpose of an auxiliary contact is to close and open a circuit. Such a circuit might enable a closing coil when a breaker is about to perform a closing operation and then open the circuit immediately after the operation starts, thereby preventing coil burnout. The a-contact shall close in due time before the main contact closes and the b-contact shall open at a time safely after the drive mechanism has released its.

The breaker manufacturer will be able to provide detailed information about this cycle.

Motion measurements

A high-voltage breaker is designed to interrupt a specific short-circuit current, and this requires operation at a given speed in order to build up an adequate cooling stream of air, oil or gas (depending on the type of breaker). This stream cools the electric arc sufficiently to interrupt the current at the next zero-crossover. It is important to interrupt the current in such a way that the arc will not re-strike before the breaker contact has entered the so-called damping zone.



Example of coil current trace measured with TM1800

Legend

- 1 Trip coil energized
- 2-3 Armature travel
- 3-4 Armature operates trip latch
- 4-5 Armature completes its travel
- 5 Armature hits stop
- 6 Change in coil inductance
- 7 Proportional to DC coil resistance
- 8 Auxiliary contact opens
- 9 Current decay

Speed is calculated between two points on the motion curve. The upper point lies at a definite distance from a) the breaker's closed-position or b) the contact-closure or contact-separation point. The time that elapses between these two points ranges from 10 to 20 ms, which corresponds to 1-2 zero-crossovers.

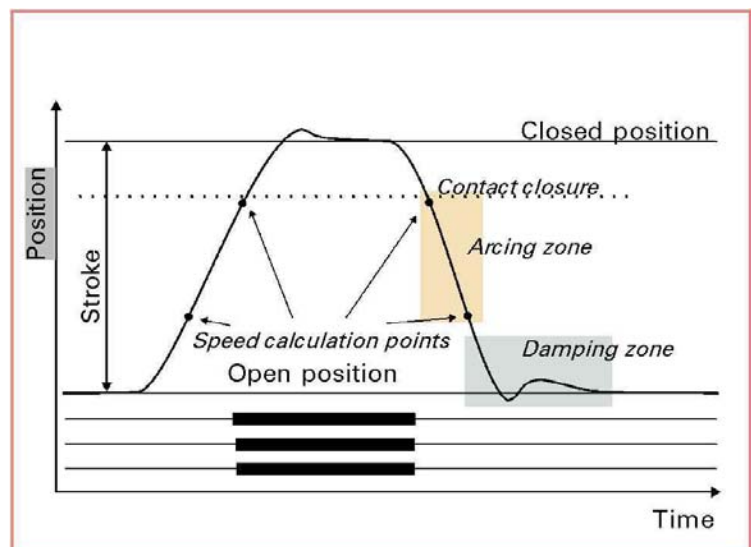
The distance throughout which the breaker's electric arc must be extinguished is usually called the arcing zone. From the motion curve, a velocity or acceleration curve can be calculated in order to reveal even marginal changes that may have taken place in the breaker mechanics.

Speed and acceleration

The mathematical derivative of motion is speed and the second derivative is acceleration. The analysis of instantaneous speed and acceleration curves will give a lot more of information about what happens along the way from open to close position than the travel curve itself.

Damping

Damping is an important parameter for the high-energy operating mechanisms used to open and close a circuit breaker. If the damping device does not function satisfactorily, the powerful mechanical strains that develop can shorten breaker service life and/or cause serious damage. The damping of opening operations is usually measured as a second speed, but it can also be based on the time that elapses between two points just above the breaker's open position.



Typical motion diagram for close-open operation

Coil currents

Coil currents can be measured on a routine basis to detect potential mechanical and/or electrical problems in actuating coils well in advance of their emergence as actual faults. The coil's maximum current (if current is permitted to reach its highest value) is a direct function of the coil's resistance and actuating voltage. This test indicates whether or not a winding has been short-circuited.

When you apply a voltage across a coil, the current curve first shows a straight transition whose rate of rise depends on the coil's electrical characteristic and the supply voltage. When the coil armature (which actuates the latch on the operating mechanism's energy package) starts to move the electrical relationship changes and the coil current drops.

The peak value of the first, lower current peak is related to the fully saturated coil current (max current), and this relationship gives an indication of the spread to the lowest tripping voltage. If the coil were to reach its maximum current before the armature and latch start to move, the breaker would not be tripped. It is important to note, however, that the relationship between the two current peaks varies, particularly with temperature. This also applies to the lowest tripping voltage.

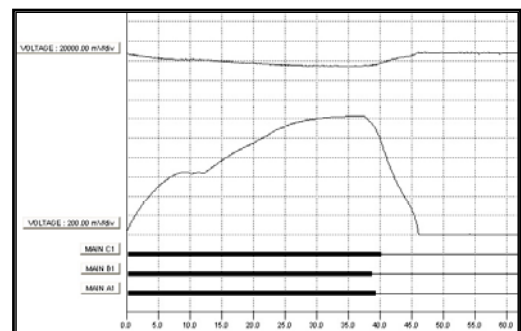
In some cases it is also of interest to measure DC voltage sagging during coil operation. The figure below shows trip coil current and DC voltage sagging in an open operation. The open circuit voltage is 128 V and the voltage sag is about 14 V at maximum trip current 11 A. These are normal values and do not indicate any malfunctions in the DC-operating voltage circuitry.

Trip voltage test

In some situations the supply voltage to the circuit breaker in the substation is only from the battery. If the battery is not in good condition the voltage supply for the circuit breaker can be lower than specified. It is important that the circuit breaker is operational for the full supply voltage interval. This is tested by supplying increasing voltage in steps and observing the lowest supply voltage that is enough to magnetize the actuating coil and trip the CB.

For a coil current test the supply voltage shall be stable and well known. If the station battery or any other unstable source is used any strange behavior in the supply voltage may be interpreted as a fault in the actuating coil or mechanics.

The Programma B10E is a power supply specialized for substation work.



DC voltage sagging during coil operation

Static contact resistance

Static contact resistance is measured by injecting a DC-current through the breaker and measure the voltage drop over the contact or joint that is of interest. The IEC standard requires a current of at least 50 A DC. The ANSI standard says minimum 100 A DC. Some manufacturers recommend 10% of the rated current for the breaker. There are several reasons for using a high test current. At low currents the measured values will be the same provided that the resistance is linear vs. the current. The risk is that low currents might give too high resistance values at some instances.

Such cases can be grease on the contact surface or a polluted contact from rest products from several breaks of rated current. The references values given by the manufacturers are static resistance values.

Vacuum bottle integrity test

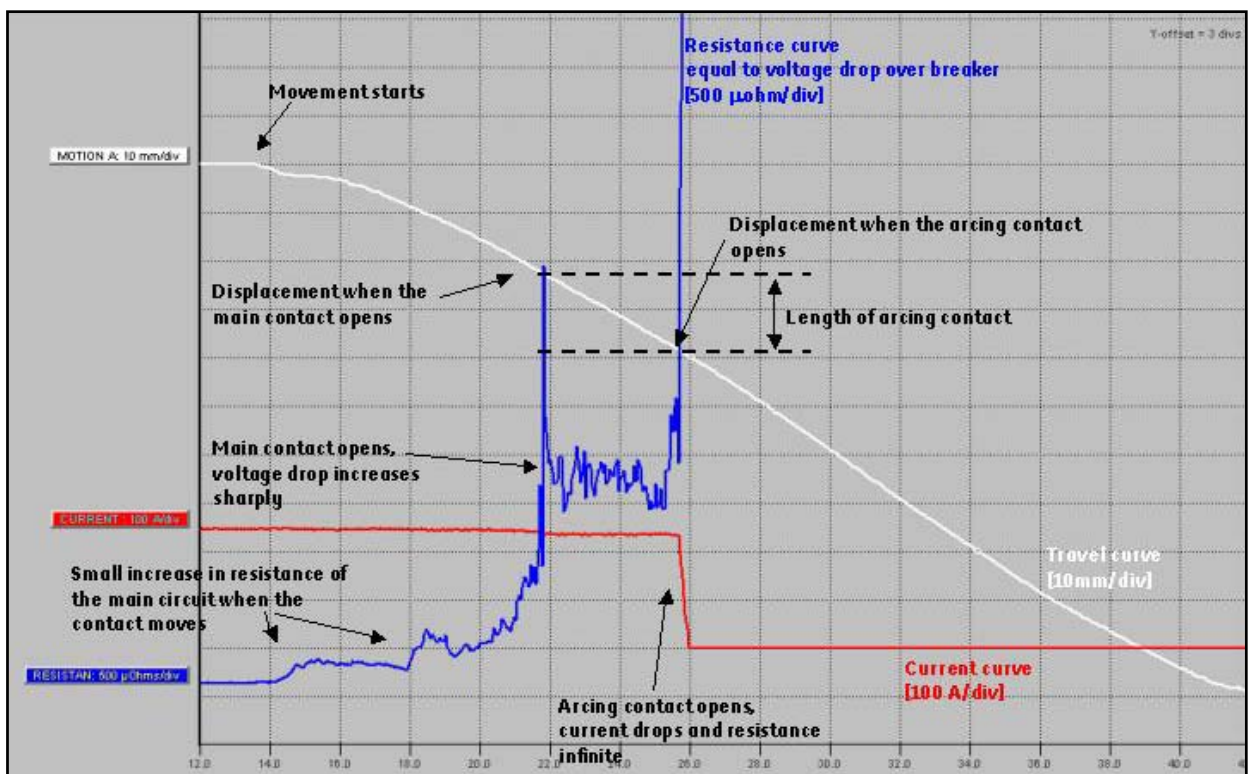
For circuit breakers with vacuum as insulation it is important to ensure the vacuum chamber has intact vacuum. If air has leaked into the chamber the circuit breaker may fail to interrupt a current as it is supposed to. To test the vacuum integrity a high voltage DC, 20-60 kV, is applied over the open contact. The leaking current is a measure of the vacuum integrity. VIDAR is the equipment for this test.

DRM — Dynamic resistance measurements

The DRM test method is very suitable for diagnostic testing. Tests are conducted by injecting DC current through the breaker and measuring the voltage drop and current while the breaker is operated. The breaker analyzer then calculates and plots resistance as a function of time. If contact movement is recorded simultaneously, you can read the resistance at each point of contact. This method is used for contact diagnosis, and in certain cases it is also used to measure times.

With DRM it is possible to reliably estimate the length of the arcing contact. In SF₆ and air-blast breakers the arcing contact is commonly made of Wolfram (tungsten). This contact is burned off and becomes shorter for each live operation of the circuit breaker. A DRM measurement will give you the length of the arcing contact. See the figure below.

TM1800 is particularly suitable for DRM since the timing channels also measure analog signals directly. Thus, a minimum number of channels and connections are needed.



Example of dynamic contact resistance measured with TM1800.

Vibration measurements

When a breaker operates, the mechanical motion generates strong vibrations. These signals can be used for diagnostics and maintenance, and Programma's Breaker Analysis Software CABA Win makes it possible to perform vibration measurement as a standard site test.

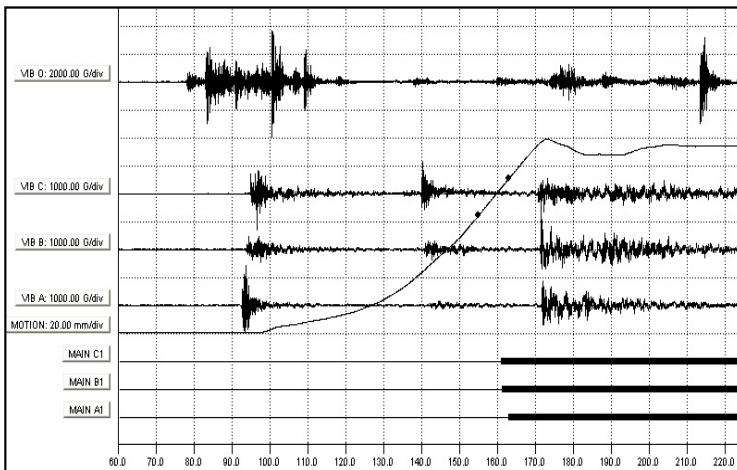
One or more accelerometers are attached to the breaker poles and operating mechanism. Vibration signals from the accelerometers proceed via a signal-conditioning unit that incorporates an amplifier and filter to the Breaker Analyzer System TM1800 where they are recorded during breaker operation. The directly recorded vibration signals can be analyzed in the CABA Win software, together with time, motion and coil current data. These data alone, however, do not suffice for determining breaker-condition trends.

A sophisticated procedure known as Dynamic Time Warping (DTW) is used for further analysis. DTW compares vibration signals with reference signals obtained (preferably) from a previous test conducted on the very same breaker. However, inter-phase

comparisons and comparisons with the results of tests conducted on other breakers of the same type can be used in the initial phase of a series of tests. Comparison results are presented on a time-time diagram that shows time deviations and also on a deviation diagram that reveals differences in vibration amplitudes.

All test data and analysis data can be reported along with other data such as motion and speed. The overall results provide a more detailed picture of breaker condition than has heretofore been available. In this picture you can easily discern deviations that are beginning to appear and trace their origins.

DTW vibration analysis is available in a separate program module that can be purchased as an optional add-on for CABA Win. This type of measurement requires a high sampling rate and a broad dynamic range. The Programma TM1800 uses 14-bit resolution and 40 kHz sampling rate. Together with Programma's specially designed Signal Conditioning Amplifier SCA 600, the TM1800 enables you to measure vibrations with frequencies ranging up to 15 kHz.



Example of vibration measurement. Close operation

Terminology

Cincinnati testing	Revolving drum with pen writing. When the circuit breaker operates the drum rotates and the graph is a travel curve.
Switch sync analysis	ABB controls the breaking time with Switchsync™ to occur at a phase angle so that no relighting and minimum of transients is created when the current is broken. There is a test kit and application note for analysis of Switchsync™ circuit breakers with TM1800 and TM1600. See also page C-1 in the ABB Product guide.
Doctor test	Micro ohm meter test. "American English"

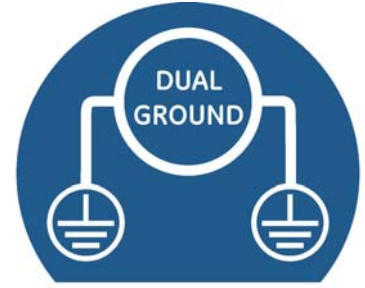
History of Programma circuit breaker test equipment

Programma has more than 25 years experience in the field of circuit breaker testing. Programma pioneered this field in 1977 with the MOM 600A, a micro-ohmmeter for measuring contact resistance on circuit breakers. The MOM 600A created the company more than opposite and here is the success story over the years.

- 1977** Micro ohm measurements with MOM 600A introduced.
- 1980** B10 Power Supply Unit.
- 1984** TM16 introduced. The first microprocessor-based breaker analyser.
- 1985** VIDAR Vacuum Tester. VIDAR test integrity of vacuum bottles.
- 1988** MA31 Motion Analyser. Module for TM16 that enables measuring analog entities such as contact travel/velocity and coil currents.
- 1989** TM1600 replaces TM16. TM1600 enables a larger number of timing channels.
- 1991** CABA software for DOS. used with TM1600 for facilitating circuit breaker analysis.
- 1993** First DRM method on the market method introduced for TM1600.
- 1994** MA61 replaces MA31. MA61 enables measurement of more analog parameters simultaneously.
- 1995** EGIL, an easy-to-use circuit breaker analyser specifically for capable of three phase, one interrupter per phase and motion.
- 1996** CABA Win Vibration. Vibration testing of circuit breakers with TM1600. MUNIN CBM (Circuit breaker monitoring), a stationary device to be mounted on the circuit breaker permanently. MUNIN is later discontinued.
- 1999** CABA Win for Windows.
- 2003** TM1800 introduced.
- 2006** Mjölner, enhanced micro-ohmmeter. DRM solution for TM1800.
- 2007** DualGround is introduced for Timing in TM1800. Also DRM, Micro Ohm resistance and Vibration methods are possible with both sides grounded.

DualGround

The DualGround trademark is used on equipment and methods that is adopted for safe, fast and easy operation with both sides grounded throughout the test.



All diagnostic test on CB with DualGround

Programma provides instrumentation that makes DualGround measurement possible for all diagnostic test on circuit breakers.

Measurement

Timing

Motion, aux contacts,
coil current...

Micro ohm

DRM

Vibration

DualGround

TM1800 with DCM

OK with conventional methods.

Mjölner with the 4 wire + CT

High current with DRM1800

The vibration solution from Programma works with both sides grounded.

Continued reading

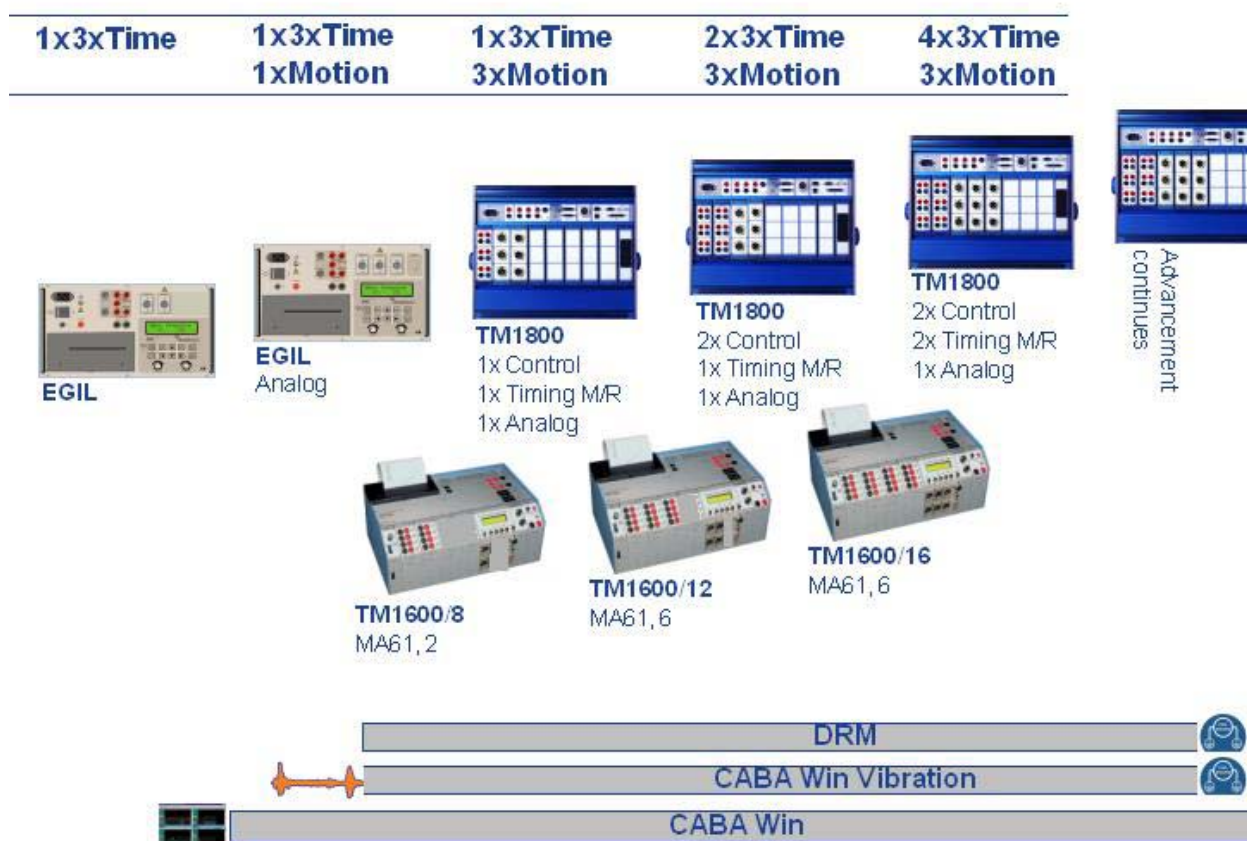
There are a number of internal and external publications available in the *Sales Binder Library*. Some examples:

- Employee Safety Concerns in the Electrical Supply Industry: How new technology can keep your managers out of court, support your corporation's stock price — and keep your HV test engineers alive. (White paper)
- PowerPoint presentation DualGround.
- The TM1800 pamphlet and the catalogue.

Programma product portfolio

Circuit breaker analyzers

Programma provides a complete portfolio of test equipment for circuit breaker testing. There are three circuit breaker analyzers, TM1800, EGIL and TM1600 within the Programma brand. EGIL for three phase circuit breakers with one interrupter per phase and one motion. TM1800 for all more demanding applications. Two versions of EGIL are available, with and without analog module and PC interface. For TM1800 the configuration can be adopted to very specific requirements. There are eight slots for modules. Available modules are Control, Timing M/R, Analog, Digital, Timing AUX and Printer. Typical configurations are shown in the figure below. CABA Win is available for TM1800, EGIL and TM1600. DRM1800 and CABA Win Vibration are available for TM1800 and TM1600.



For all levels of challenge there is a suitable configuration within the Programma Circuit Breaker analyzer portfolio.

TM1800

TM1800 is robust and reliable for field use. The flexibility of TM1800 makes it suitable for testing both in development, production, commissioning and maintenance of circuit breakers.

The Select-Connect-Inspect three step measurement method makes testing fast and fun.

TM1800, TM1600 and EGIL are all fully compatible with CABA Win. Many transducers can also be used on all the three breaker analyzers. A company can have a mixture of TM1800, EGIL and TM1600. Tests will be perfectly comparable in CABA Win independent of the instrument used for recording.

Circuit breaker manufacturers, electric utilities and service companies appreciate the flexibility of TM1800. The varying demands are fulfilled by configuration of TM1800 for their individual needs. Up to 48 + 48 timing channels can be configured. For OEM and other R&D activities there is special internal software available that makes it possible to operate the CB 5000 times and record every 20th operation.

TM1800 is fully compatible with CABA Win Vibration and DRM1800. Please note that there is not a calibration module available for TM1800, but an instruction on how to verify the calibration data with normal laboratory equipment.

Among the latest improvement is a weight reduction (by better material usage) bringing the TM1800 Basic Unit to 11,5 kg.



New!

Key benefits

- DualGround timing. (See several separate documents)
- Active Interference Suppression makes test result reliable even in rough field conditions with high interference levels. (See separate white paper.)
- Select-Connect-Inspect workflow and high-level user interface makes testing fast and easy. Reduced need for operator training.
- Stand-alone functionality. Be fully equipped with one unit.
- Modular concept. Adapt to user needs, pay as you grow, enjoy future development.
- Ethernet between TM1800 and PC with CABA Win ensures speed and reliability.
- USB interface enables easy backup and data exchange.

Suitable application domain	Development	Manufacturer	Commissioning	Service Maintenance	Routine Testing
OEM					
Generation					
Transmission					
Distribution					
Contractors					
Industry					

Language

TM1800 is available with internal software and User Manual on English, Swedish, French, German and Spanish.

EGIL

EGIL is intended for three phase circuit breakers with one interrupter per phase.

In addition to timing the coil current is captured automatically. The measurement results are printed in table and graph on the internal printer. With the analog module installed, motion or any other analog signal can be captured. Velocity is calculated.

Evolution of circuit breakers has made it possible to interrupt a 220 kV current with one single interrupter. With this the application area of EGIL grows. Especially for GIS the application area has increased.

EGIL uses a 100 mA current for measurement. This relatively strong signal current is required to withstand interference present in high voltage substations. 100 mA is well in line with requirements and competition. EGIL has been proven to work well in 220 kV outdoor switchyards and even 400 kV indoor GIS.

It is not recommended to do vibration testing with EGIL because the analog channel is not sensitive enough.



Key benefits

- Extremely easy-to-use.
- Stand-alone functionality reduces the number of items and boxes the tester needs to bring to the field.
- Portable, rugged design – suitable for field-testing.

Language

EGIL is available with internal software and User Manual on English, Swedish, French, German and Spanish.

Suitable application domain	Development Manufacturer	Commissioning	Service Maintenance	Routine Testing
OEM				
Generation				
Transmission				
Distribution				
Contractors				
Industry				

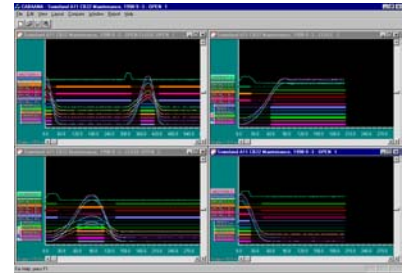
TM1600

Introduced in 1989 with over 3000 deliveries all over the world this is by far the most used circuit breaker analyzer. The proven reliability in harsh conditions and easy operation has been fundamental for the success.

TM1600 is a good choice when cost is critical and the high end user interface, superior measurement accuracy and advanced functionality of TM1800 is not necessary.

CABA Win

CABA Win is the advanced software for measurement assistance, advanced analysis, report generation and data storage. Connection with TM1800 over Ethernet is very fast and secure. Parameters and pass-fail limits can be modified on recordings. CABA Win is a superior interpretation tool where comparison and detailed studies are made. For backup purpose the database is perfect. TM1800 template for specific circuit breakers can be created. A test plan guides the user through the measurement and contains all specific thresholds and parameters.



CABA Win is the strongest software on the market for circuit breaker testing. CABA Win requires a PC computer and is compatible with TM1800, EGIL and TM1600.

CABA Win Vibration

The vibration software CABA Win Vibration is used for easy interpretation of vibration recordings.

TM1800 or TM1600 together with CABA Win and the vibration solution is required for vibration test.



DRM1800

With DRM the arcing contact condition and overlap length is evaluated without dismantling the breaker. Problems with contact fingers, lubrication and SF₆ exhaust contaminations is detected. DRM1800 is reduced in weight with 70% to the previous solution. Built in battery and short cables makes this perfect for commissioning work. DRM1800 is compatible with TM1800 and TM1600. DRM1800 give advantages together with TM1800 that is not present with TM1600.

TM1800 configuration guide

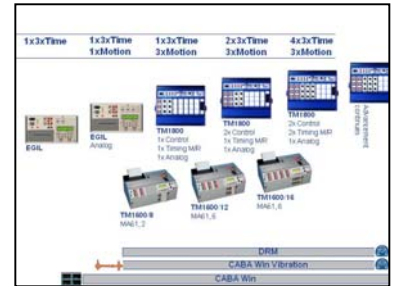
The TM1800 system is fully modular with high flexibility to configure TM1800 for specific duties. The choice of modules shall be based on the kind of circuit breaker that will be tested, parameters to be recorded and the templates to be used. The basic unit needs at least one module to become functional. It is very easy to find the correct configuration for any situation.

The basic unit has 8 slots for modules. Modules can be placed in any of the module slots 1 to 8. Slot number 9 in the module panel is specially designed for future development of a calibration module.

GE recommends using TM1800 together with CABA Win an all applications.

Standard configurations

The figure has typical cases in black on the top. It is number of contacts per phase and always times three phases for main contact timing. 2x3xTime shall be understood as Timing of 2 contacts per phase on 3 phases. Below is number of motions to measure. When there is one contact per phase EGIL is a good alternative for TM1800. The figure is available in larger format above.



Configuration Table

To be measured with TM1800	Required modules
Operate close and open with common mechanism Measure coil currents, supply voltage, resistance and auxiliary contact timing.	1 Control
Operate close and open with separate mechanism for 3 phases Measure coil currents, supply voltage, resistance and auxiliary contact timing.	2 Control
Main contact timing and parallel resistor contact timing including parallel resistor measurement for 3 phase with 1-2 breaks per phase	1 Timing M/R
Main contact timing and parallel resistor contact timing including parallel resistor measurement for 3 phase with 3-4 breaks per phase	2 Timing M/R
Main contact timing and parallel resistor contact timing including parallel resistor measurement for 3 phase with 5-6 breaks per phase	3 Timing M/R
1-3 motions or any other analog signals	1 Analog
4-6 motions or any other analog signals	2 Analog
1-6 motions or other incremental digital transducer (RS422)	1 Digital
6 auxiliary contact timing (in addition of what is measured with control modules)	1 Timing Aux