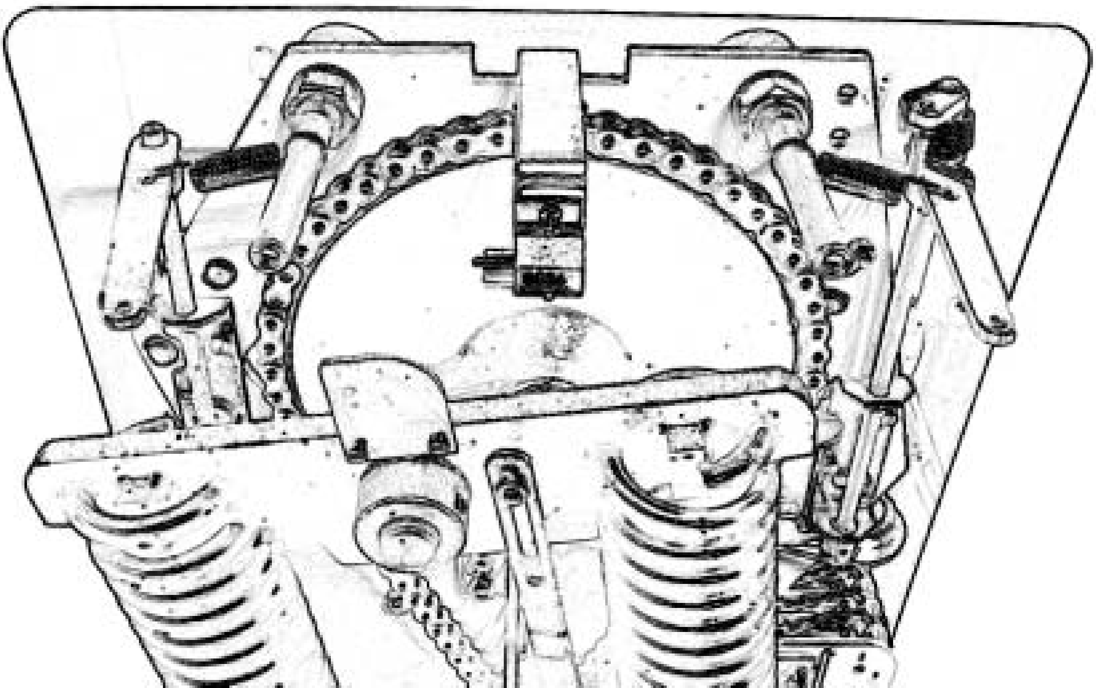
CIRCUIT BREAKERS
test & analysis

An EuroSMC® training paper



INTRODUCTION

Circuit breakers form part of the primary *switchgear,* a class of devices responsible of effectively interrupting and further re-establishing the electrical current on a power line. As opposite to *isolation switches*, circuit breakers are able to operate under service load conditions. To accomplish this, these devices are built to special engineering standards that allow them to withstand considerable static and dynamic workloads during their lifecycle, which is supposed to span to several decades.

IMPORTANT WARNING

The circuit breaker under test must be clear from the energized environment and every safety measure and procedures must be doublechecked with the maintenance staff before taking the following into practice.

Circuit breakers are to be operated by hand or, more often, from protective elements like relays on the secondary zone of a power system when a service fault arises.

Periodically analysing their physical and electrical parameters and comparing to those from previous tests will help *predict* an abnormal operation before it happens, resulting in a much more cost- and service-effective pratice than a corrective or even preventive maintenance plan.

Close and trip times, contact resistance and synchronism, trip & close coils condition and mechanical tolerances are the most commonly checked parameters, as well as the status of the auxiliary power –usually DC batteries- needed by the breaker to operate.

This paper illustrates a hands-on example of testing an Isodel Series BNRM circuit breaker with an EuroSMC PME-500-TR. The tested unit is a three-phase, medium- to high voltage breaker with oil-isolated, single-chamber poles. The PME-500-TR will simulate the commands typically issued by a relay to the circuit breaker and will record its movements and the evolution of is electric parameters at the same time.

OUR CIRCUIT BREAKER

The circuit beaker's mission is to effectively disrupt *(trip)* the line when a faulty condition arises. Though some breakers are able to trip as a result to an *internal fault* (e.g. an auxiliary power failure), in this practice we are testing the characteristics that are relevant to the breaker's ability to withstand the service demand and to respond to an *external fault,* such as a short circuit or an overload. These faults are always detected by other elements in the protection scheme like relays, which in turn trigger the fault-clearing *(trip)* and service-resuming *(close)* processes by driving the breakers' actuators accordingly.

The Isodel BNRM is a *Metalclad*[1]-type construction with three oil-filled phase chambers for medium- to high-voltage applications. The trip and close mechanism is energized by a 112 VDC motor that loads a couple of main and secondary springs providing sufficient energy to deliver three changes of state (TRIP-CLOSE-TRIP) in a quick sequence before a further, slower motor-assisted reload cycle is required.

The trip and close coils, also operated at 100 VDC, release the spring retention latches to interrupt or re-establish the service correspondingly. A pair of auxiliary contacts and an end-of-cycle contact allow for the correct coordination of the whole mechanism, and a secondary set of contacts, mechanically coupled to them, are provided for control and monitoring.

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[1] A 1940's Westinghouse self-contained breaker design that allows easy sliding of the whole mechanism on- and off-line for maintenance or replacement purposes.

We shall analyze the movement of these secondary contacts in this example.
Some designs feature additional contacts at the negative side of the trip and close coils to allow for the implementation of complementary control and locking functions required by the particular protection scheme.

When auxiliary DC is applied, the motor will start turning, if needed, until its end-of-cycle contact is reached, thus loading the actuator's main springs. The assembly is now ready for a rapid change of state. If the main contacts were now in *closed* position, a *close* command would cause no effect, because the *close* coil's supply circuit is now open by the auxiliary contacts. The same occurs to the *trip* coil when the breaker is in *opened* position.

The breaker can always respond immediately to an *open* command even before the motor has re-energized the power springs. This is a required feature to quickly break the line's current if a fault is still present after reclosing.

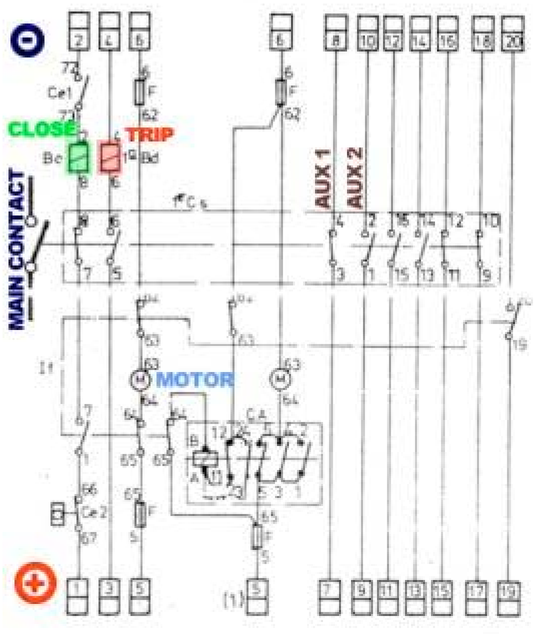
THE PME-500-TR

This small unit provides all the required functions –time measurement and recording of automatic O-C, C-O, O-C-O and C-O-C sequences, coil current sampling, contact resistance measurement, relative pole displacement, pre-programming of test parameters and environmental data, results preview and storage, PC communications and 10-hour battery operation.

Everything is controlled from the menus on the tactile LCD display. The user navigates through four menu tabs and set the test data, operation parameters and testing options. After the test is conducted, the user can view the results on-screen and even store them on the PME-500-TR's memory to download and organize the reports on a PC later on.

TEST PREPARATION

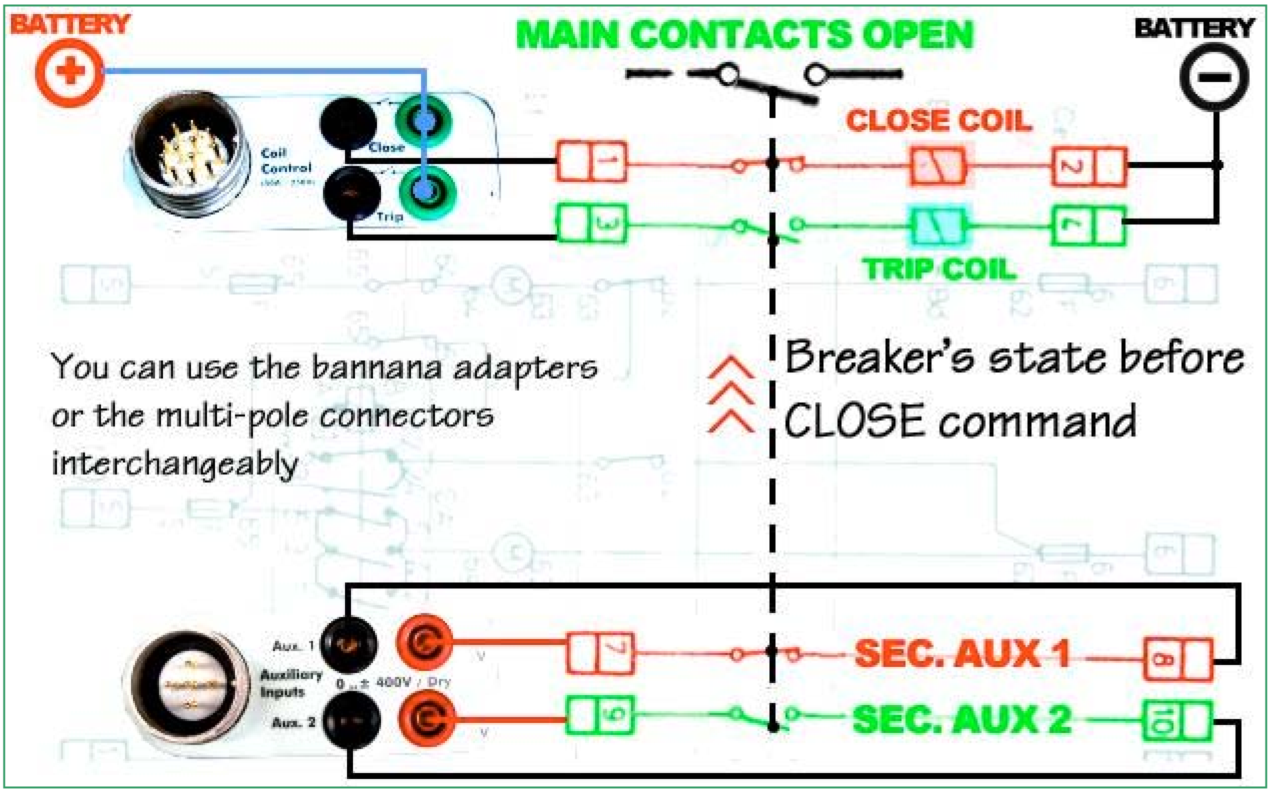
Before putting your hands to work on a circuit breaker you *must* learn about its operational state, its basic design and its working principle. Ask to the personnel in charge of the breaker's maintenance for specifications and cabling diagrams. It is important to know if that particular unit is showing a healthy or defective behavior and, above all, **to be sure and doublecheck that it is fully disconnected, isolated and clear of any energized line.** Also, adequate auxiliary power must be available to fully conduct the tests.



Beware that you cannot fully analyze a multi-chamber breaker with the PME-500-TR, nor can you perform *travel* speed measurements with this unit. Also, you'll be forced to conduct an externally-triggered breaker test if the breaker uses AC-operated coils.

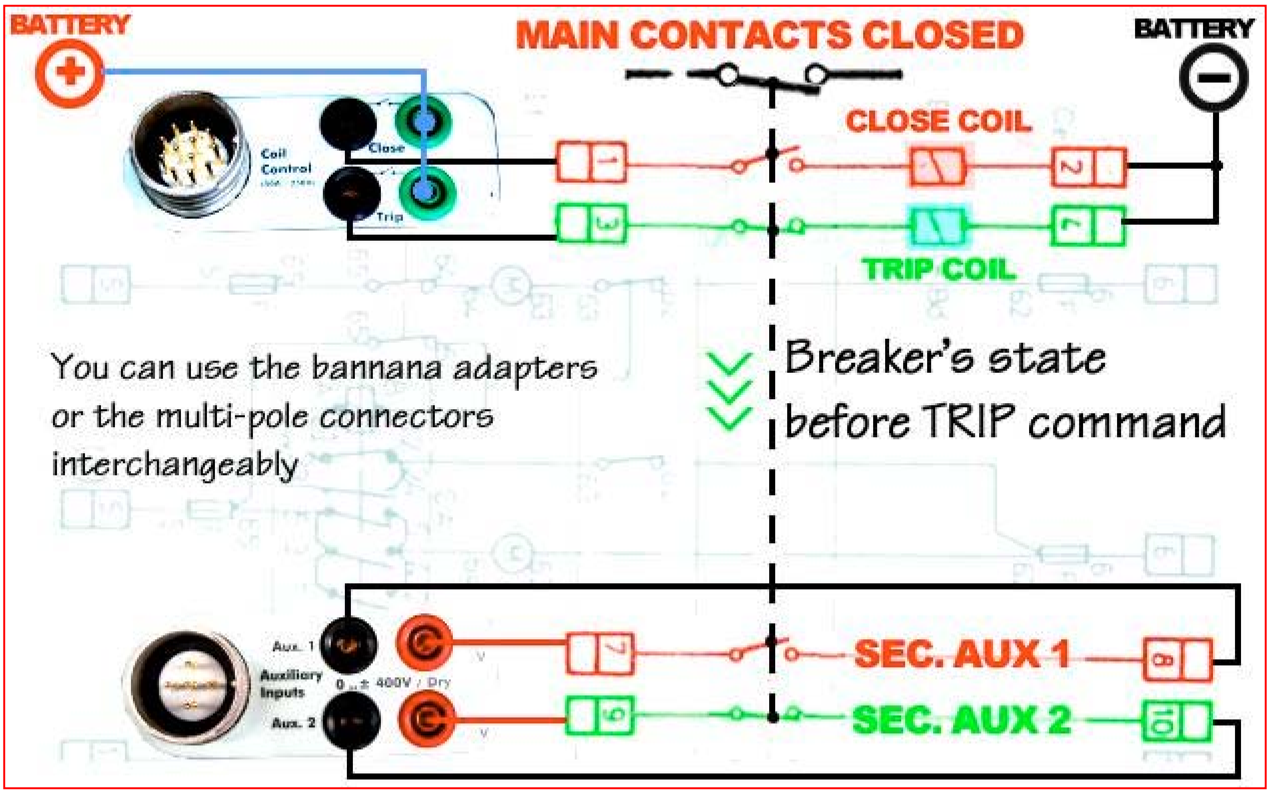
CABLING

Concentrate in this task. Get the breaker's cabling diagrams and locate the following connection points: **trip and close coil DC supply (positive and negative sides); auxiliary control connectors; external main contact endings; auxiliary DC supply taps and polarity references.** Remember that your test



instrument will command the breaker's trip and close actions exactly like a relay would. Communicate this to the maintenance staff.

Four multipolar, foolproof connectors are available, so The PME-500-TR is typically wired to the tested breaker in four easy steps for a fully-automated, one-touch operation:



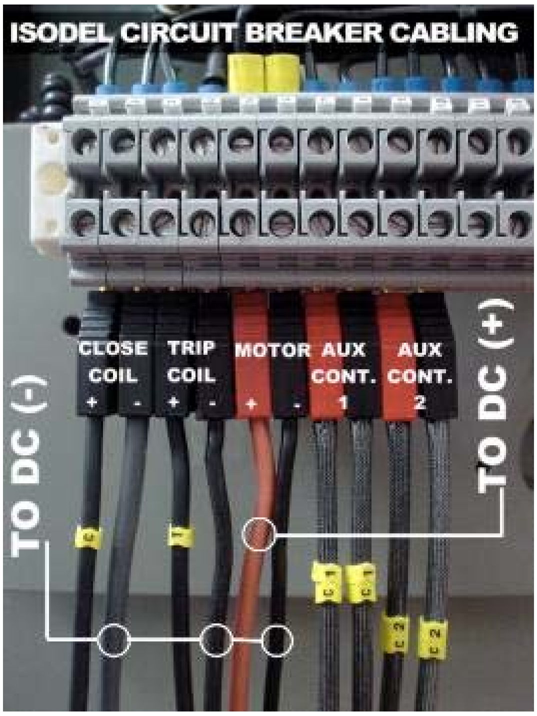
WARNING

Once you are done with the cabling, power the PME-500-TR on before applying auxiliary DC voltage to the circuit breaker, so that the buit-in overlad protections can work as expected.

1) COIL CONTROL: This is the **command** connection. Plug the matching multipolar connector into this tap and insert both leads of the “close” and “trip” pairs **in series** to their corresponding coil. You are actually inserting a small solid-state breaker in each coil’s supply circuit, so you **must watch the polarity (negative to the positive side of the coil, positive to the batttery’s positive side)**

2) COIL OVERVOLTAGE SUPPRESORS: If the PME-500-TR was set to open the coil supply circuit before an auxiliary contact would, or if there was simply no auxiliary contact in charge of this, or it was malfunctioning, the protective electronics in the instrument would prevent the circuit from being opened, since this would impose an excessive, harmful voltage on its c-mos control circuitry. Some breakers feature protective electronics for the coils in case an auxiliary contact failed to operate in time, but others don’t. In these cases, preventively connect the provided voltage suppresor diodes in parallel to the operated coils, watching the polarity. Any cut-off overcurrent will then re-circulate through the coil, thus releasing the voltage and allowing the PME-500-TR to open the coil supply circuit at the proper time. Refer to the diagram in the instrument’s lid for a diode connection drawing.

3) AUXILIARY INPUTS: This breaker’s aux contacts are *dry contacts* (no voltage present). You simply connect each lead to one side of each contact. The PME-500-TR will monitor their *open* or *closed* state through this connector during the test.



4) (Main) CONTACTS: These wires monitor the main contact closure and opening events and also inject a 10-Amp current for resistance measurement. Polarity is not a factor, but we assign a number to each pole and use the same color (red or black) for the same side of the three poles.

5) RES. MEASURE: These wires capture the voltage drop under a 10-amp current on the closed poles when we finally press the Resistance Measurement “TEST” button. Ensure a good, solid and direct contact to the breaker’s poles. Reusing the contact provided by the injection leads will produce incorrect resistance readings.

Study carefully the diagram shown in the instrument’s lid. You will also find a quick guide to the menus there.

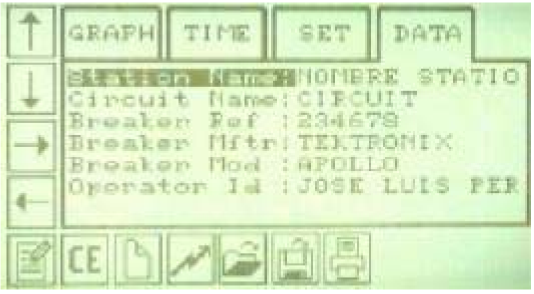
Now that we have completed and checked the cabling, we power-on the PME-500-TR, clear the breaker’s surroundings and apply auxiliary power to it. Since the breaker’s springs were unloaded, the actuator’s motor immediately starts to spin and stops when full spring load is attained. This time the breaker’s contacts are in OPEN (trip) state.

THE TEST

In this practice we are stressing the full capabilities of our testing tool, the PME-500-TR, so we’ll end up with a report containing time measurements of the main and auxiliary contacts, trip and close coils current analysis and main contact resistance for a CLOSE-OPEN-CLOSE test sequence.

<u>Test data entry</u>

In the display’s DATA tab, you first enter the name of the circuit and station to where the breaker belongs, the breaker’s model, serial number and manufacturer’s name, and the tester’s (yours, in this case) name. This data will identify the printed test reports for future reference. The system’s date and time will also be recorded.



Under the SET tab, you specify the test type and characteristics such as the *sequence* (in this example, “C-O-C” which means CLOSE-OPEN-CLOSE), *duration* (we shall set an 80-millisecond length for the OPEN and CLOSE commands), *interval* (we set a 60-millisecond pause between commands), *debounce time* (here we set the system to discard any event shorter than 2 milliseconds *from the timed listings*, though not from the graphic representation), and *trigger* (here we select OPERATION, because the sequence will be initiated by the PME-500-TR at the touch of the START/STOP button).

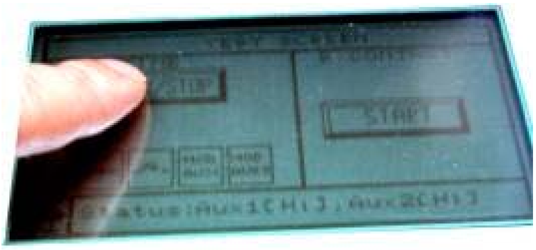
To conduct a C-O-C sequence, the breaker must obviously be initially in OPEN state. The PME-500-TR would otherwise display an error message prompting us to change the breaker’s state or to program a different sequence.

The C-O-C test sequence

WARNING

A breaker’s close or trip manoeuver is usually noisy, violent and potentially harmful to unwarned assistants. Clear the surroundings and advise of the inminent event to people nearby before proceeding.

Go to the TEST screen and press START/STOP. The test **will take a couple of seconds to start** (internal checks and memory initialization will take place, and you will also have a short chance to abort with a second press of the button). This is what happens next:



1) The PME-500-TR releases DC power to the *close* coil for the programmed 80-millisecond CLOSE command duration.
2) DC current through this coil is sampled and recorded into memory at a rate of 1 sample per millisecond.
3) The *close* coil reaches its trigger voltage and pushes the *close* retention latch well before the 80-millisecond command length has been completed. The breaker closes its main contacts and the AUX 1 contact at full speed. The AUX 2 contact reaches its *open* state shortly later.
4) The PME-500-TR cuts the power off the *close* coil.
5) 60 milliseconds later, the *trip* coil is fed with auxiliary DC for another 80 ms.
6) In 30 milliseconds roughly, this coil is charged enough to release the *trip* retention latch and the breaker *trips.* Auxiliary current keeps flowing through the coil to complete the programmed 80-milliseconds command length.
7) At *trip* time the AUX 2 contact is closed and AUX 1 reaches its *open* state shortly later.
8) After another 60-millisecond pause, the PME-500-TR repeats steps 1) thru 4) and completes the testing sequence leaving the breaker in CLOSED state.

Contact Resistance

Only after a CLOSE command can you conduct the contact resistance measurement. You press the START button under the “Res. Measure” section of the TEST tab and wait for a message indicating test completion.

Test Results

In order to correctly interpret a breaker’s test results, a good understanding of a few basic principles of operation is recommended:

1) The PME-500-TR always records two-seconds worth of data from the time start of the test. You can use the “Rec. Length” setting after the test is completed if you want a *zoomed graphics* view of only that fraction of the test that actually picks up the information that is relevant for your report. This will also consume less storage memory if you later decide to save a test’s results into the PME-500-TR for future

reference or download to a PC. The numerical data is independent of this setting and will always be shown and stored in its entirety.

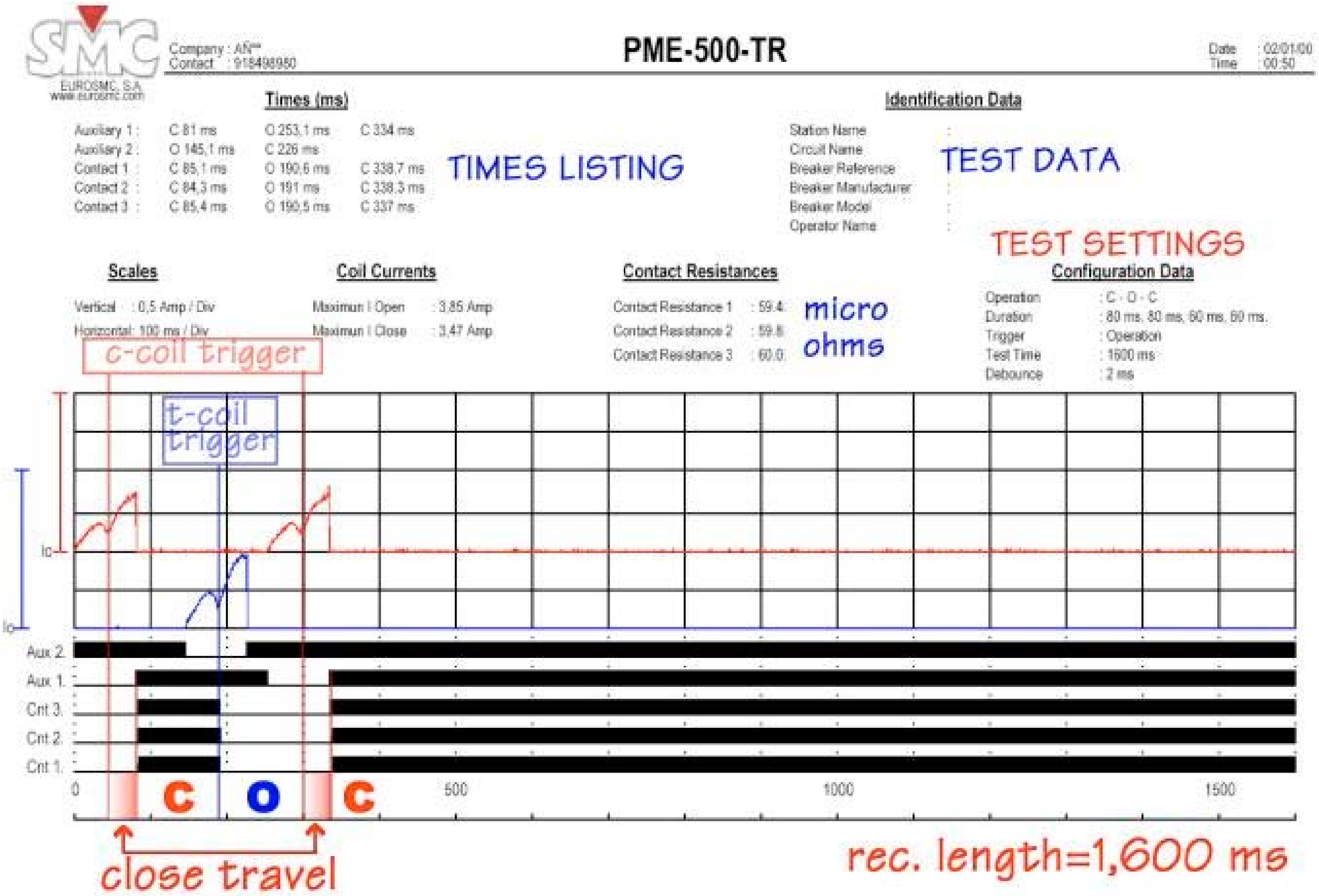
2) The two sides of a contact separate very quickly from each other, but it takes much longer for them to travel back to connection from an open position.

3) Coil current stops when any of the following two events happen, whichever takes place first: a) the PME-500-TR reaches the programmed command length or b) a breaker's logical circuit trips the coil when the corresponding control *(trip* or *close)* action is assumed to be completed.

4) A half-weight stripe in the main contacts graph indicates the action of a **pre-insertion resistor**.

5) A contact resistance measure bigger than 100 microhms positively indicates a faulty or loose measurement leads contact to the breaker poles, or a damaged breaker.

6) You should **repeat a test at least twice** before you can grant the results as valid.



The PME-500-TR lets you inspect your test's results inmediately on its display. You will find a low-resolution graph on the GRAPH tab and a numerical data report on the TIME tab. If you discover any mistake or inconsistent information, you can quickly check your settings and/or your cabling, make the required adjustments and press START/STOP again.

If it looks like a good test (though not necessarily *a good breaker),* you can go ahead and print it and/or save it into memory.

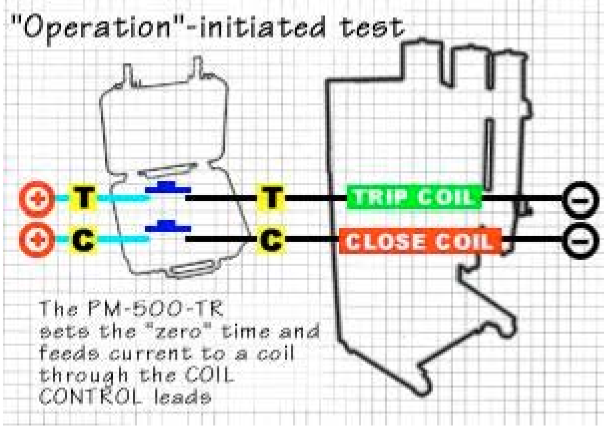
WARNING:

Thermal printouts will quickly vanish and should not be used as permanent reports.
Photocopy them as soon as possible or, better, download the test results and store them on a PC's disk.

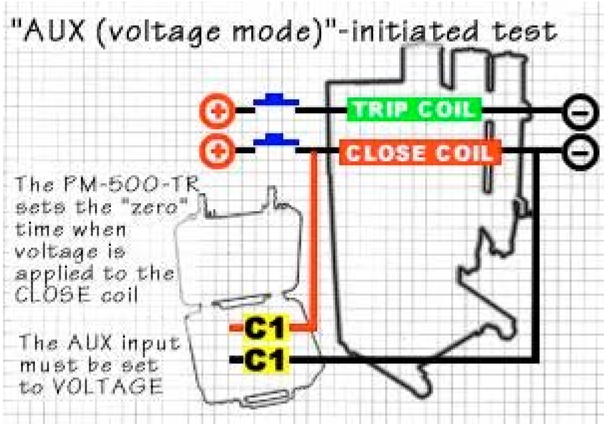
You can store 40 to 60 test recordings in the PME-500-TR non-volatile internal memory. They will stay there until you delete them manually, even if the unit runs out of battery.

External Trigger

The structure of a breaker's analisys is always the chronogram of a series of consecutive and/or simultaneous events that take place inside the breaker from a given time. We shall call it the *zero* time. In order to exercise the full set of features built into the PME-500-TR, the test described in this paper is fully driven by the instrument's ability to *command* the circuit breaker, as if it was a protective relay. The PME-500-TR actually *simulates* the action of a relay by opening and closing the auxiliary DC power line to the breaker's control coils, thus producing TRIP and CLOSE commands.



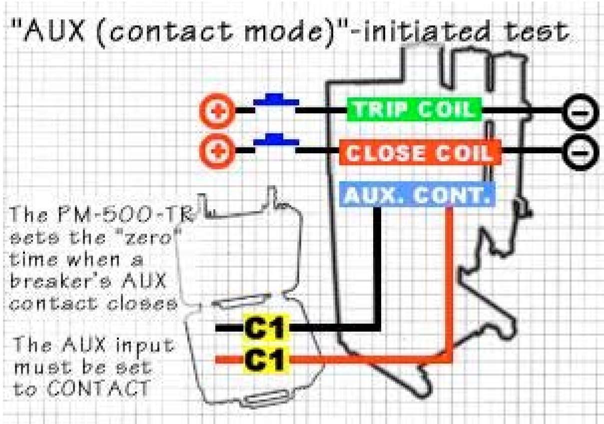
In our above example, the *zero* time is set when the PME-500-TR initiates the first CLOSE command, i.e. when auxiliary DC voltage is applied to the *close* coil.



We can face situations, however, where it is not possible or practical to physically *insert* the instrument's *close* and *trip* circuits in the coil circuits of a breaker. In these cases we shall be forced to relate the breaker's events to a different *zero* reference: the change of state in an auxiliary contact or the presence of voltage on a control coil.

The procedure is as follows:

1) We shall NOT set the TRIGGER parameter to OPERATION when configuring the test
2) AUX 1 or AUX 2 will be our trigger references instead
3) AUX 1 (or 2) ON will set the *zero* time when a positive event (contact closes or voltage appears) occurs on this PME-500-TR's monitor input.
4) Similarly, AUX 1 (or 2) OFF will set the *zero* time when a negative event (contact opens or voltage drops) on this monitor input.
5) With the MOD AUX button in the display's SET tab, we shall choose between *contact* or *voltage* for the type of signal that will be present on the selected AUX input.



6) The "START/STOP" button will produce no apparent effect this time. It will only initialize the PME-500-TR and set it waiting for the specified type of event to occur in the monitored AUX input.
7) We can now initiate the desired *trip* or *close* action on the circuit breaker by means of any of the available (relay or command key) methods.
8) The contact resistance measurement will only be possible once the breaker is resting in the CLOSED position.

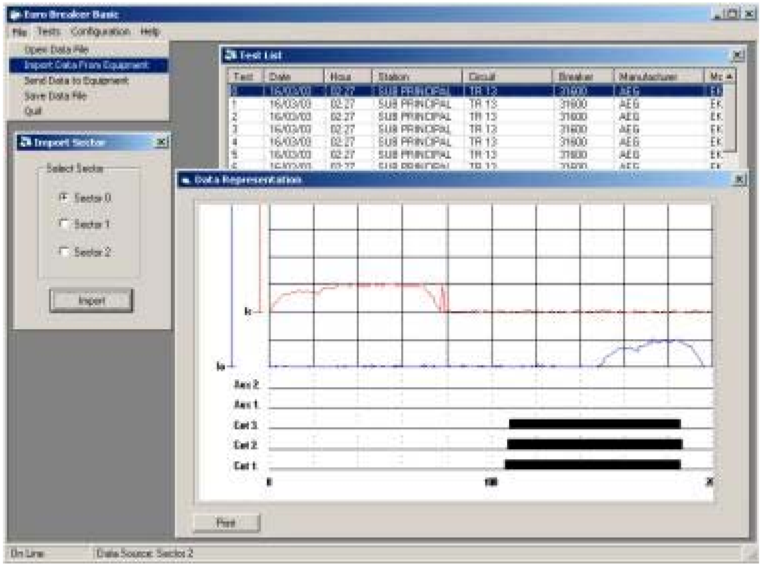
Test Report Management

You can view the results recorded by the PME-500-TR in all or any of the following ways:

1) Inmediately after each test, under the GRAPH and TIME tabs of the instrument's display
2) Printing them out with the built-in thermal printer. You can split the printed output in two halves, put them side by side on a photocopier and get a handy, permanent letter-size report.

3) Saving each test into the PME-500-TR non-volatile memory and later downloading them to Windows folders in your PC with the help of EuroBreaker, a very simple and convenient utility provided with the instrument. You can organize your test files by date, by site and/or by breaker type and model, at will. Eurobreaker can also output a nice report composition to your connected printer.

The regular use of EuroBreaker will let you organize all your tests in your PC's hard disk. This is a highly recommended practice because the condition of a particular breaker at a particular time must always be compared with the braker's condition at regular intervals in the past. And the PME-500-TR internal memory size is ok for a few days' worth comissioning job but falls short to archive the whole history of a substation's breakers team.



BRIEF CONCLUSION

Testing a circuit breaker can be a safe and simple task if you pay attention to a few important aspects:

1) Observe every safety rule and protect yourself and others while in high-voltage environment. Apply your common sense and be assisted by the site's maintenance personnel.
2) Study the breaker's characteristics, principle of operation and service condition in advance.
3) Fully understand the test's objectives and figure out what the results will look like beforehand.
4) Analyze the test results and find the relationship between them and the observed in-service behavior of the circuit breaker.
5) Save and organize the results so you can locate them easily in the future to depict each particular breaker's evolution.
6) Keep your test equipment in perfect working condition, and have it regularly calibrated and revised by the manufacturer.

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