Application Note

“First trip” test

A circuit breaker spends most of its lifetime conducting current without any operation. Once the protective relay detects a problem, the breaker that was idle for maybe a year or longer has to operate as fast as possible. Many utilities have experienced situations in which a breaker is suspected to be slow during a fault clearing. Timing tests are then performed on the breaker, but it shows to be within specifications. At this point the delay was usually suspected on the relay system. As a result of this assumption, relays testing would have been performed, finding nothing wrong. Another example is a breaker that burns up a trip coil during a slow fault clearing, where a faulty trip coil would be suspected. Assumptions that trip coil was faulty would lead testers not to look any further.

Situations such as these may indicate a lubrication failure of the circuit breaker operating mechanism. Circuit breaker contains numerous mechanical components that rely on proper lubrication for their successful operation. However, bad lubrication, due to age, temperature, airborne contaminants, and improper or infrequent maintenance practices have left many circuit breaker mechanism parts prone to failure.

Traditional timing equipment relies upon the breaker being removed from service to perform the test. Once this occurs during the examination of a “slow breaker,” the breaker has been operated at least twice; once during the fault operation, and once again during the removal of the breaker from service to investigate the problem. Thus, once the breaker has been commissioned for service, typical problems encountered with age may go undetected utilizing traditional timing equipment. Since traditional (timing) diagnostic testing procedures fall short of providing thorough data regarding the breaker operating mechanism, another test method is necessary to provide this information. The idea of measuring breaker's control circuit electrical information during operation to provide insight into the condition of the operating mechanism has been around for many years.

Trip latch bearings are one of the leading causes for a slow operating circuit breaker. One reason is thinning of the lubrication layer in the trip latch bearings. Due to this and other issues (corrosion, lubrication drying), the very first time the breaker operates after long idling is much slower then when you test it afterwards. Based on coil current signature it can be determined the moment of breaker actually coming off latch, during the breaker opening operation. Comparing opening coil current signatures between the first and the second trip can provide breaker’s performance information that can’t be detected by traditional means.

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Coil current signature

The correlation between the breaker operation condition, and the coil current signature suggests the use of the actuating coil as a ready-made non-invasive condition monitoring sensor during the “First trip”. The resulting coil current signature provides a chronological record of the operating sequence and timing associated with the various breaker components during an operation. The coil plunger motion can be characterized evaluating the current flowing through the coil.

When the opening command is initiated the coil is energized (Figure 1, point 1) and the current rises causing a magnetic field to apply a force on the iron plunger. When the force on the plunger exceeds that of a retaining force the plunger begins to move (point 2). The motion of the iron plunger induces an *EMF (Electromotive Force)* in the coil, effectively reducing the current (part from point 2 to point 3).

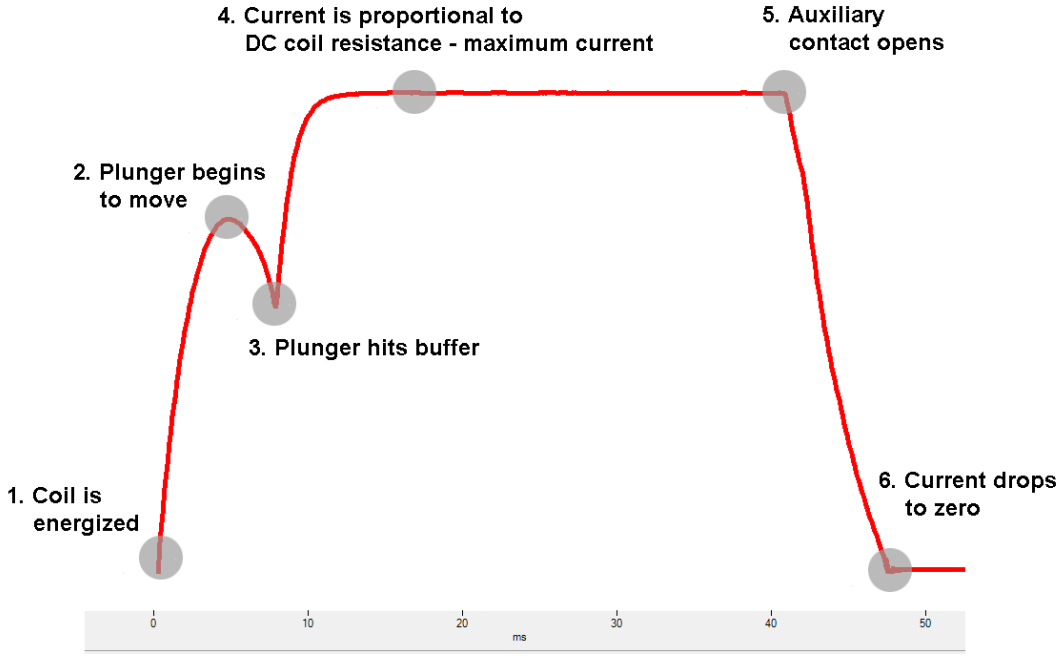

Figure 1. *Opening coil current signature with the zoomed part*

As the plunger continues to move through the coil, the current flowing through the opening coil may change (Figure 1, points 2 to 3) since the plunger strikes the latch mechanism. There, a sudden reduction in the velocity of the plunger may cause a “cusp” in the current waveform (in the part between points 2 and 3). The combined mass of the plunger and the latch continue to move at a reduced velocity until it hits a buffer bringing it to a rest (point 3). With the plunger at the rest position the current increases to the saturation level (DC current which is proportional to the coil resistance, point 4). Meanwhile, the latch unlocks operating mechanism, releasing the stored energy to open the main breaker

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contacts. Typically, after a short delay the auxiliary contacts open, disconnecting the coil from the substation DC battery supply, or any other supply (point 5). As the coil is de-energized the current drops quickly to zero in accordance with the coil inductance (point 6).

Coil current signatures comparison

The “First trip” will typically represent and reveal true CB’s operating characteristics, unlike subsequent operations where mechanism components are loosened or freed up. Comparisons between the “First trip” and second or third breaker operation can also reveal problems and should be used in determining breaker condition. If the time obtained from the “First trip” is slower than subsequent operations, a mechanism component sticking in some form is present. One such example is given in the Figure 2. Auxiliary contacts disconnect the coil circuit in “First trip” 10 ms later than in the second trip. As can also be seen from the Figure 2, “Off latch” time (point 3 in the Figure 1.) in the “First trip” is longer than in the second trip, indicating that the mechanism latch had increased friction and that is the main reason the circuit breaker operated slower by 10 ms during the “First trip”.

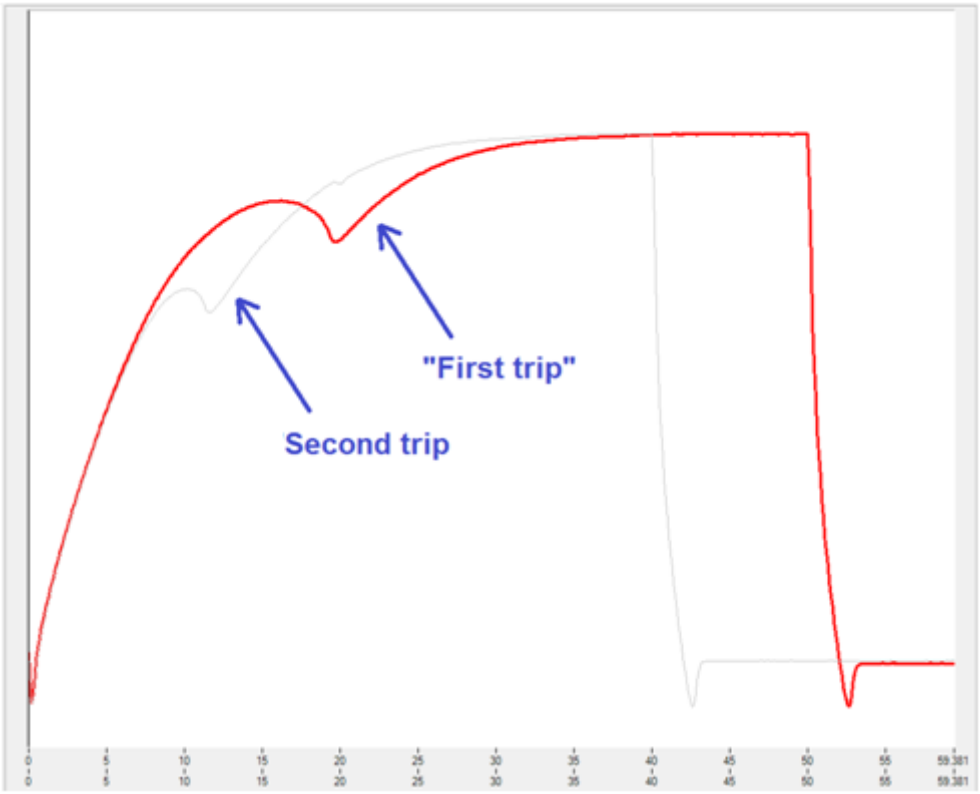

Figure 2. *Coil current signatures comparison between ”First trip” and second trip*

Using the previous analysis of coil current signatures, one can detect a failure of the lubrication in the coil latch or operating mechanism. It is possible the circuit breaker has not

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been operated for a long time, and the latch friction has increased. For many breakers the “Off latch” time of 20 milliseconds or less is normal. When capturing the “First trip” many breakers may produce the “off latch” time of 180 milliseconds, while the very next trip may produce an “Off latch” time of 18 milliseconds. That indicates an “Off latch” time of 9 cycles for the first trip. The main contacts at this point have not separated, but rather are just beginning to move in the separated position. In other words, this scenario assumes no main bearing issues but only trip latch bearing issues. While it may be difficult to believe that a breaker will speed up as much as 9 cycles or more during just 1 operation of a breaker, it can and does happen. This is the very reason that traditional diagnostics is unable to detect the problem.

Test connections

Due to the safety requirements for off-line testing, the first trip operation command is issued while the CB is on-line and at that time no recording can be done. That way, one has missed very important breaker condition data. Within just one breaker operation all of the relevant information has been lost unless captured by an instrument designed to gather this information. For that reason there are many companies that demand recording breaker performance during their "First trip". Also, some utilities have on their schedule once a year opening and closing breakers just to test them, and keep the lubrication working, while checking operational performance (testing the first trip).

Therefore, the “First trip” test is performed when the circuit breaker is on-line. Since the test is performed when the circuit breaker is in service and a special permission is required for this operation, the standard way of circuit breaker operation can’t be applied. This test is started from the control room or by a dispatch center. The instrument which is used to capture the “First trip” needs to be able to initiate measurement when the triggering signal is detected.

All CAT II series models have capability to the record “First trip” test. These CAT devices have six analog channels, each channel with four voltage ranges (1 V, 5 V, 60 V and 300 V AC/DC). This allows simultaneous measurement of the coil current, battery voltage and main circuit current on the CT's secondary side (as shown in the Figure 3). Also, this provides a current measurement of each single opening coil individually during the “First trip” test on independent-pole operated circuit breakers (Figure 3).

Six analog channels available in CAT II series devices are used to record currents and voltages as well as for initiation of the measurement by an external voltage or a current signal. Coil currents are measured on the first three analog channels (Analog 1, Analog 2 and Analog 3) when using the Hall-Effect DC current probes connected to the coil circuit wiring as shown in the Figure 3). For the assessment of the main contact operation times,

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currents of a current transformer (CT) secondary side are used. These currents are measured by AC current probes connected to the CT secondary wiring and other three analog channels (Analog 4, Analog 5 and Analog 6), as seen in the Figure 3. Substation battery voltage can be measured on any of the six analog channels (**Note**: This prevents a possibility of using that channel for the current signal measurement). By monitoring a battery voltage, the voltage drop can be assessed when a coil current flows. The battery voltage graph can indicate possible battery problems or wiring issues. Furthermore, a failure in rectifier can be observed, as well.

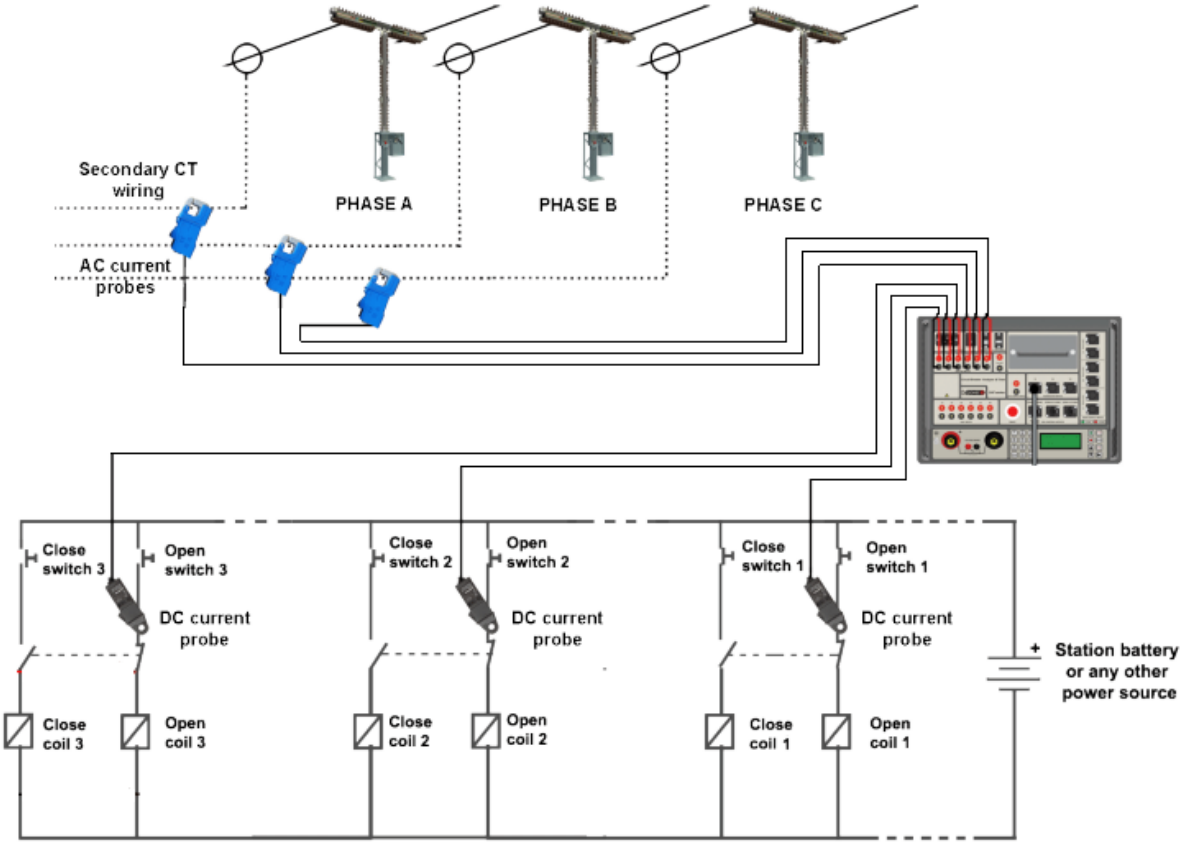

Figure 3. *Connecting AC and DC current probes for "First trip" test*

There are two modes of measurement triggering: on the opening (trip) coil current or on the coil voltage. For triggering on the trip coil current, it is needed to have DC current probes (which are used for coil current measurement) connected as shown in the Figure 3. For triggering on the coil voltage, it is needed to connect the voltage sense cable on any of the first three analog channels and to the opening coil, as shown in the Figure 4. The red wire of the voltage sense cable should be connected to the positive pole of the circuit breaker

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opening (trip) coil, while the black wire should be connected to the negative pole of any of the circuit breaker coils (if the minus polarity is common for all coils).

Beside analog channels, auxiliary channels are also enabled during the “First trip” test providing the measurement of the auxiliary contacts (52a and 52b) operating times. Time measurement of the auxiliary contact operation is an indicator of interrelation between mechanism and auxiliary switch performance and it is performed on auxiliary timing channels.

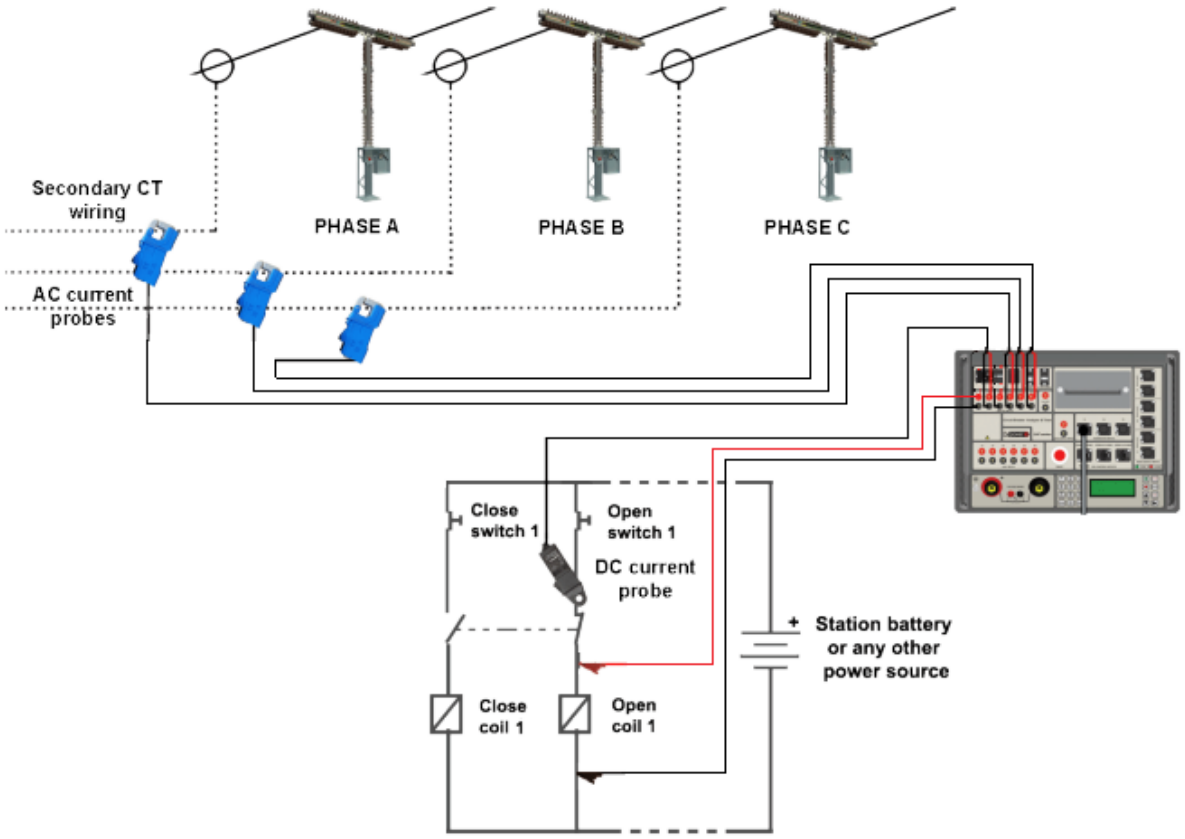

Figure 4. *Connecting AC, DC current probes and coil voltage for triggering*

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Settings in DV-Win software

Main setting adjustments for the First trip test are performed on the analog channels. After selecting a “First trip” test from the list of available tests (Figure 5), it is needed to select ***Aux and analog channels*** tab. Window as shown in the Figure 6. will appear.

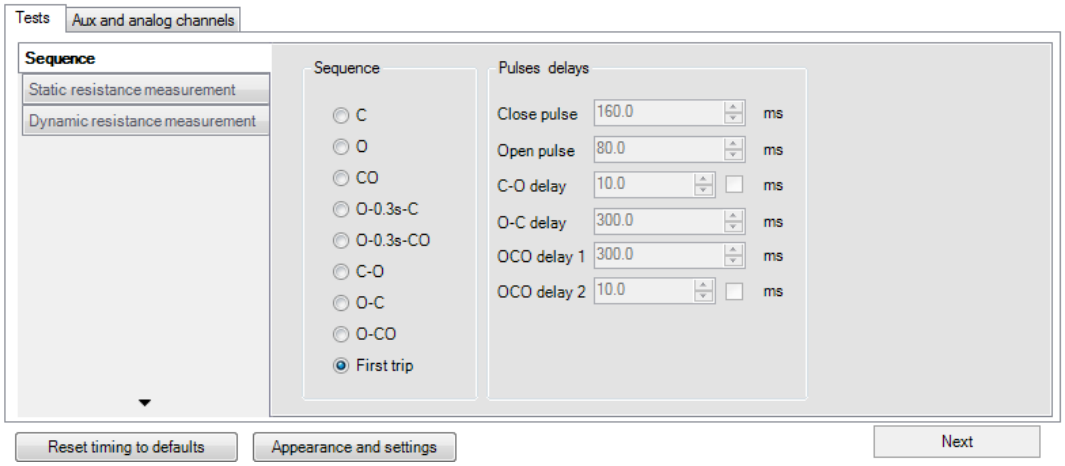

Figure 5. *List of tests available in tab Sequence*

As illustrated in the Figure 6, ***Transfer functions*** are enabled by a default setup on all analog channels. The transfer function ratio has to match the ratio adjustment on the current probes used and connected to analog channels. For DC current probes used for coil current measurement, the transfer ratio of 10 mV/A should be set. This value of the transfer ratio has to be set on one or on all the first three analog channels (Analog 1, Analog 2, Analog 3), depending on how many currents are being measured. The AC current probes used for CT secondary current measurement have the fixed transfer ratio of 1000 mV/A and this ratio should be set for the other three analog channels (Analog 4, Analog 5 and Analog 6).

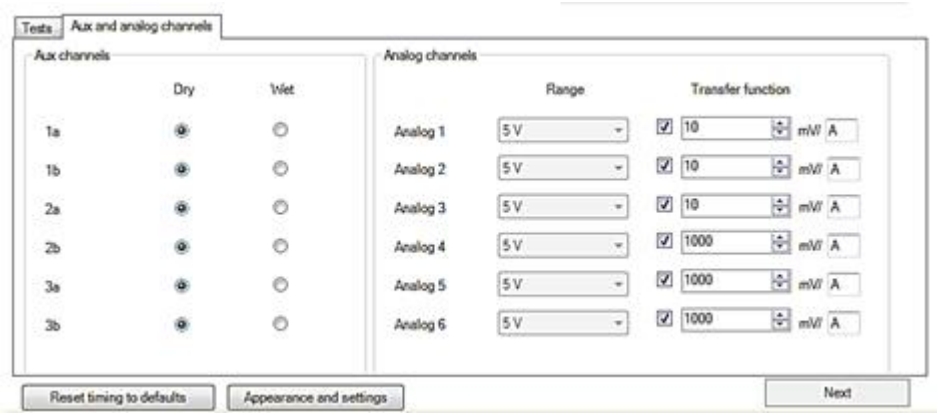

Figure 6. *Setting transfer functions on analog channels*

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If a substation voltage needs to be measured or a coil voltage used as a signal for measurement triggering, the ***Transfer function*** should be disabled on the channel selected to be used for this purpose (e.g. Analog 2 or Analog 3, as shown in the Figure 7). Then select the voltage range 60 V or 300 V, depending on the measured voltage value.

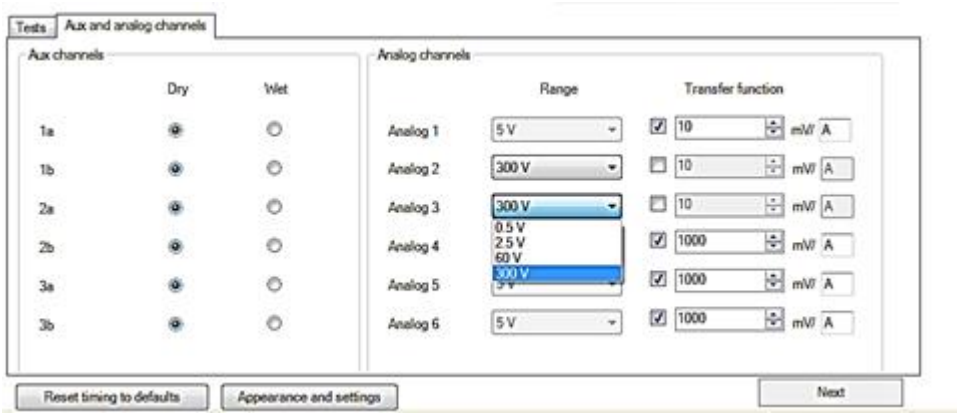
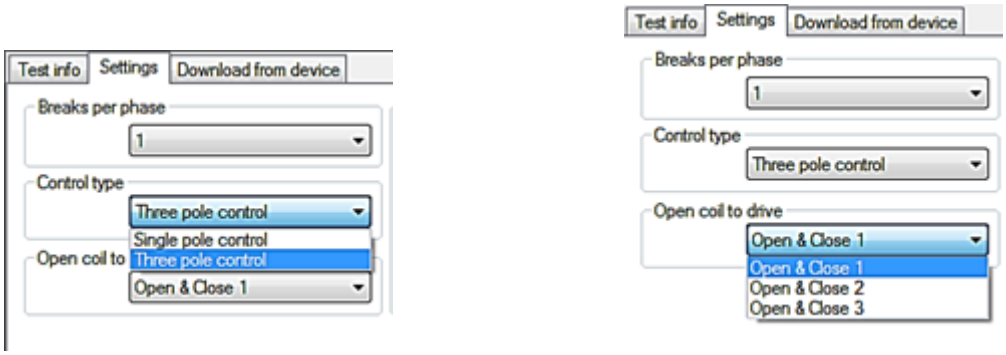


Figure 7. *Setting analog channel for voltage measurement*

In case the circuit breaker is three-pole controlled, one coil current is measured, in the ***Control type*** field, the ***Three-pole*** option should be selected (Figure 8a). Next, a selection of options in the field ***Coil to drive*** is related to the automatic selection of analog channels that will be used for a coil current measurement. If option ***Open & Close 1*** is selected (Figure 8b) in the field ***Coil to drive***, the analog channel Analog 1 will be enabled for the coil current measurement, when selecting options ***Open & Close 2*** or ***Open & Close 3***, then analog channels Analog 2 or Analog 3 will be enabled, respectively. The other free channels are available for voltage measurement.



a) b)

Figure 8. *Selection of CB control type and channels for coil current measurement*

If the circuit breaker is independent-pole controlled, the three trip coil currents are measured, and in ***Control type*** field the ***Single-pole*** option should be selected. In this way all three analog channels (Analog 1, Analog 2 and Analog 3) will be enabled for a coil current measurement.

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The ***External trigger source*** field provides options for measurement trigger. The analog channels Analog 1, Analog 2 or Analog 3 are available as the channels for measurement triggering (Figure 9). If a selected triggering analog channel is set for a coil current measurement (in the tab ***Aux and analog channels***), then the coil current is used as a trigger signal. A recommended current threshold for triggering in this case is 0.5 A (Figure 10). If a selected triggering analog channel is set for a voltage measurement (in the tab ***Aux and analog channels***, e.g. Analog 2), then the coil voltage is used as a trigger signal (Figure 11). The voltage threshold for triggering in this case is expressed in percent of the selected voltage range (in the tab ***Aux and analog channels***) with the recommended value of 5% in case of selecting the 300 V voltage range.

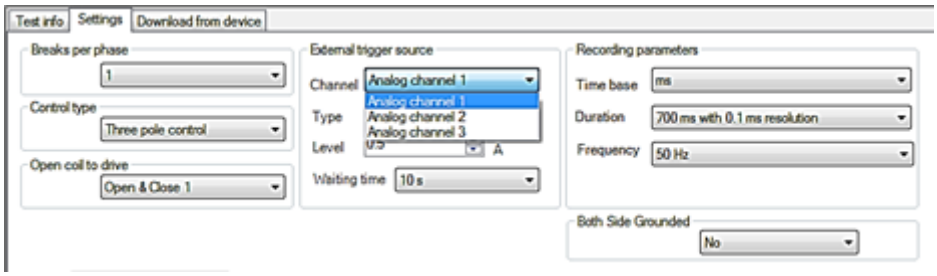

Figure 9. *Setting analog channel for measurement triggering*

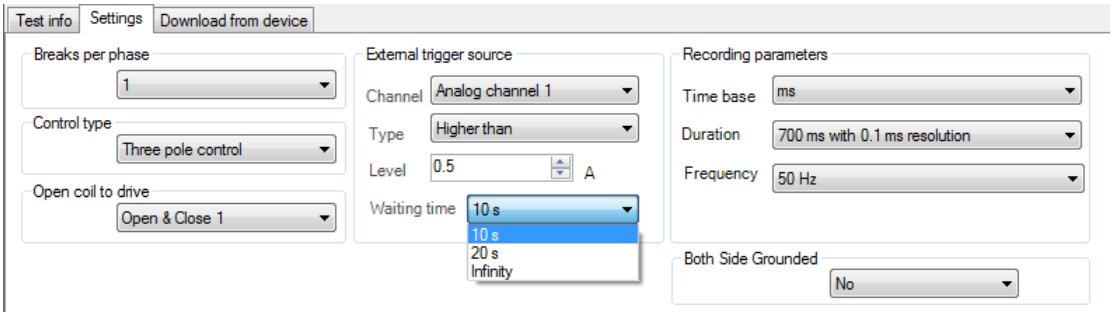

Figure 10. Setting current threshold for measurement triggering

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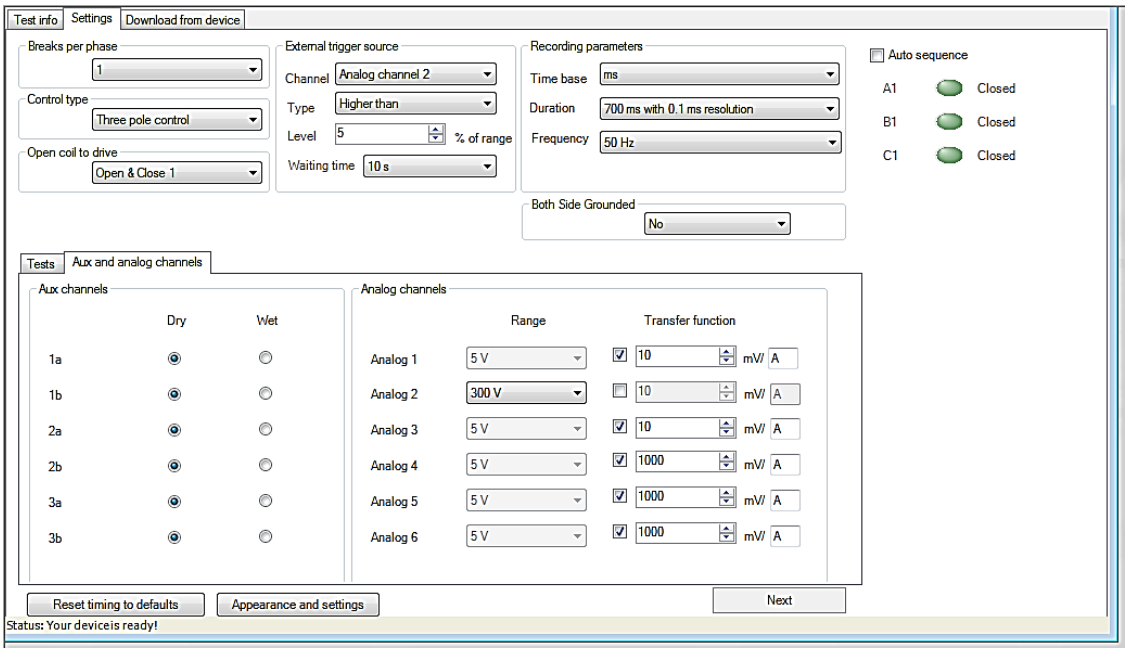

Figure 11. *Setting voltage threshold for measurement triggering*

The waiting time represents time a device will wait for a trigger signal from the moment a test is initiated by DV-Win software. If a trigger signal appears within this time interval, a measurement will be started and if not, DV-Win software will revert back to the ***Settings*** menu after expiration of the adjusted time. As presented in the Figure 10, the available options for the waiting time are 10 s, 20 s and infinity.

Before the “First trip” operation is started, a CAT instrument should be in the “standby” mode. This is achieved by pressing the ***Next button*** (Figure 11) and the ***Start button*** in the subsequent window (Figure 12). Following that, the window with the message “Waiting for trigger” will appear (Figure 13). This window will stay on for a defined waiting time (10 s, 20 s, or infinite) and the circuit breaker operation should be started within this time interval. At the moment the operation has started, a voltage is applied to the operating coil and a current will flow through the coil. The CAT will sense this voltage or current (depending what is used as a trigger signal) over the analog channel and start the measurement.

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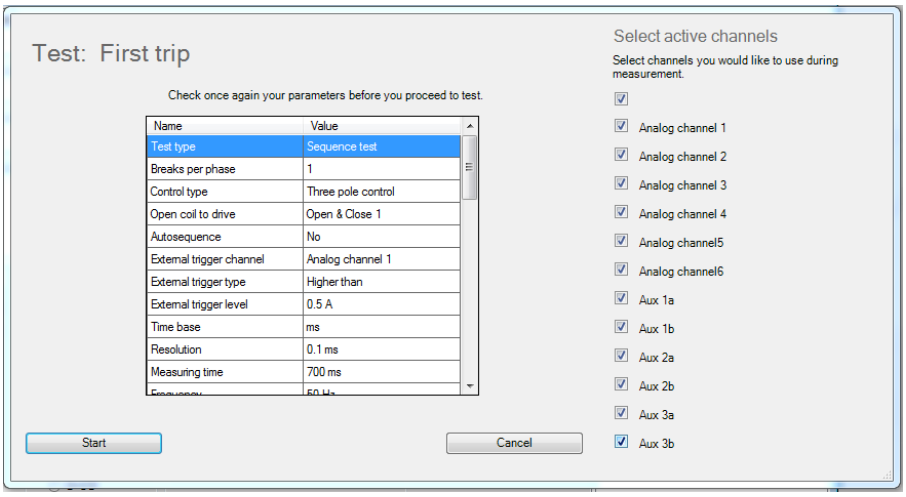

Figure 12. *Window for runing „standby“ mode*

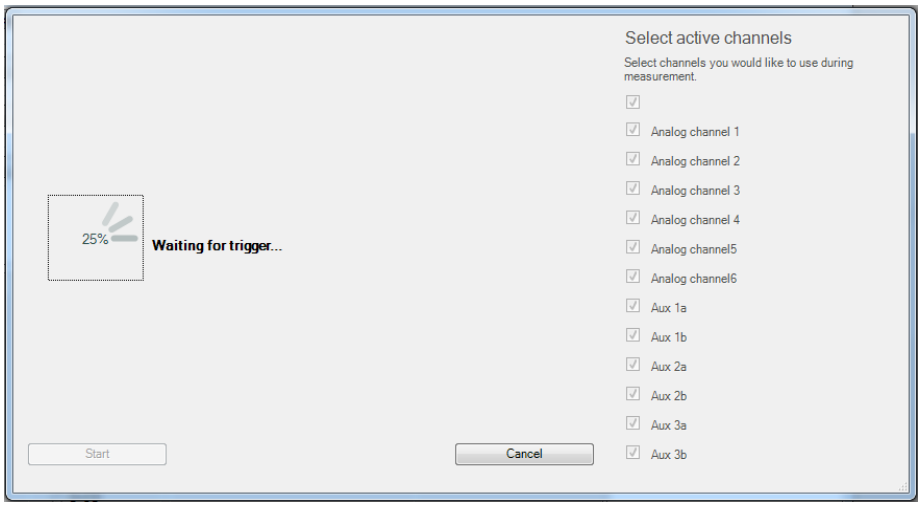

Figure 13. „Standby“ mode

Results

After performing a circuit breaker operation and applying the trigger signal across one of analog channels designated for triggering, graphical and numerical results should appear as shown in the Figure 14. It is possible to enable/disable each single graph in the left part of the window called ***Inventory***, where a legend for graphs is also presented. Coil currents waveforms and CT secondary currents waveforms are shown in the same window and have common scale of values. Numerical values are automatically extracted in the tab ***Numerical results***, available on the right part of the window. Coil parameters are calculated based on the recorded coil current waveform, while the main contact opening time is calculated based on the CT secondary current's measurement.

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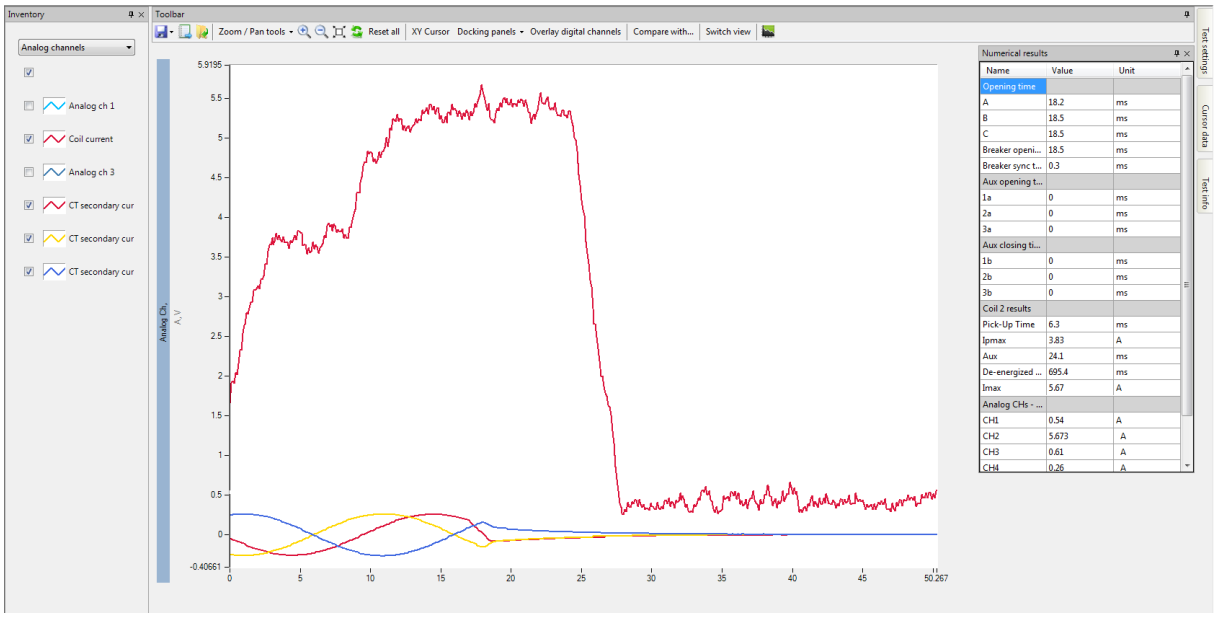

Figure 14. *Numerical and graphical results for First trip test*

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