High Voltage Circuit Breaker testing

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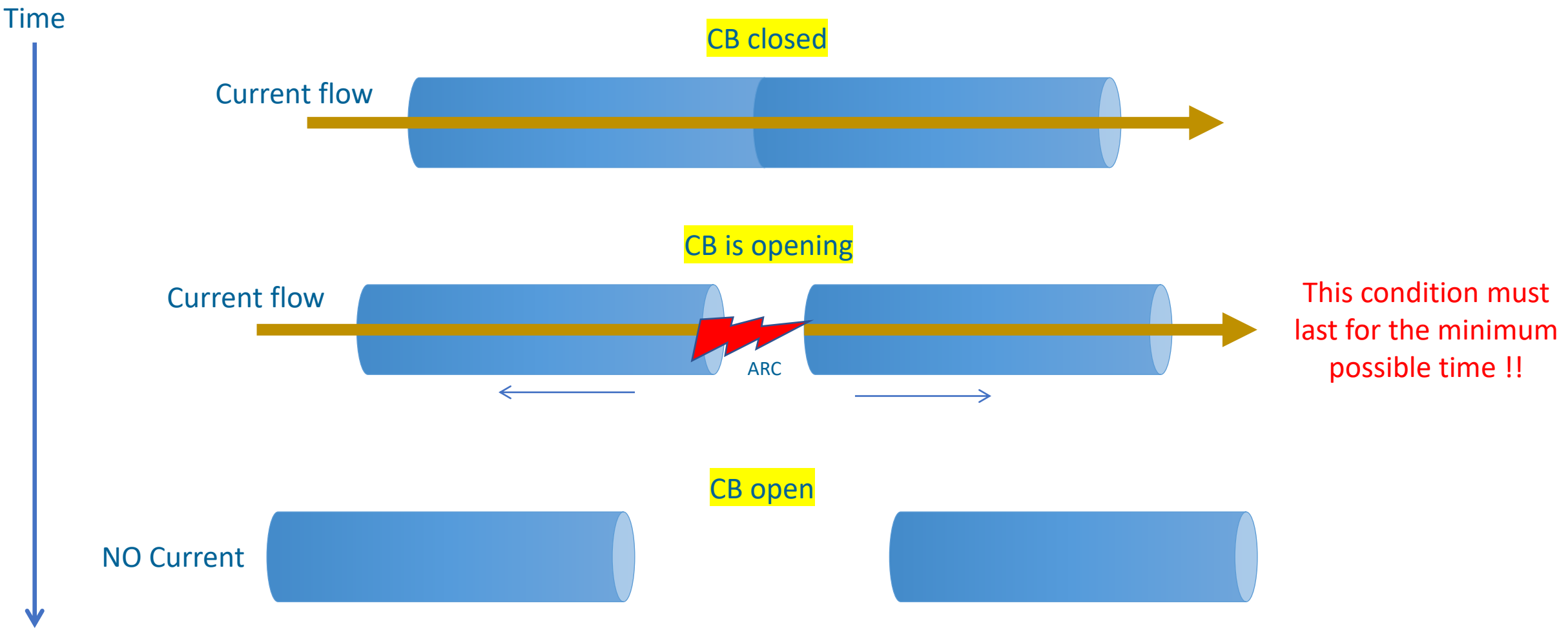
Circuit breaker is an automatically operated electrical device, design to close or open contacts inside the chambers, thus closing and opening an electrical circuit under load or fault conditions

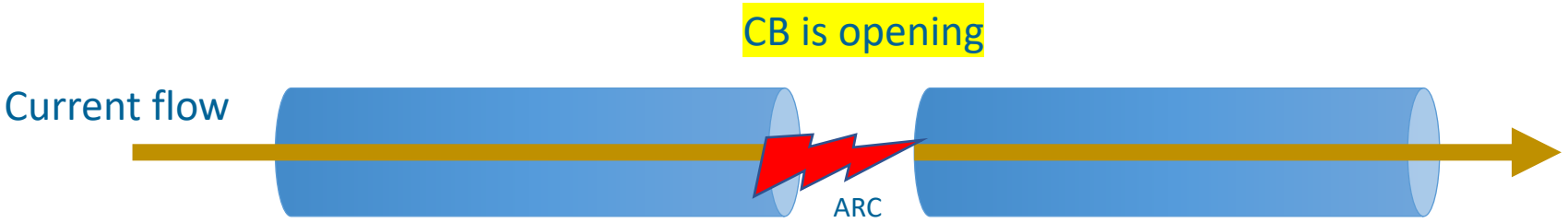
Its task is to sustain the load current, during its normal operation, and to interrupt the fault current in the

FASTEST POSSIBLE TIME

Once the fault occours



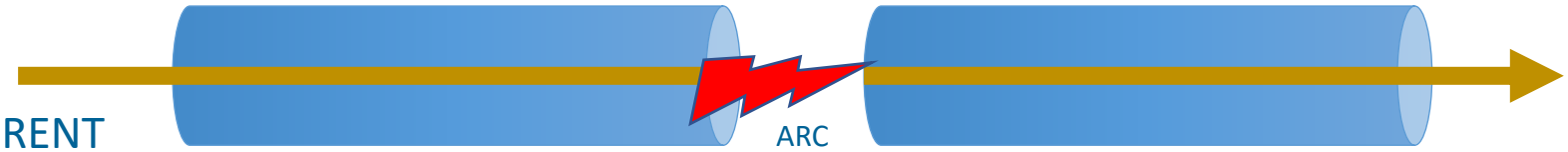
The opening time is the most important parameter



The electric arc can damage the conductors if it lasts too long!
The opening time must always last no more than a few tens of milliseconds

Risks due to the electrical arc

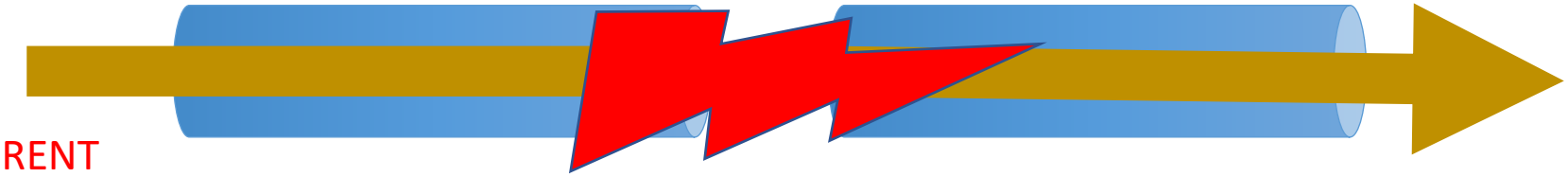
CB is opening



LOAD CURRENT
[100 A ÷ 300 A]

The main contact is designed to withstand hundreds of normal load current interruptions

CB is opening



FAULT CURRENT
[> 1000 A]

ARC

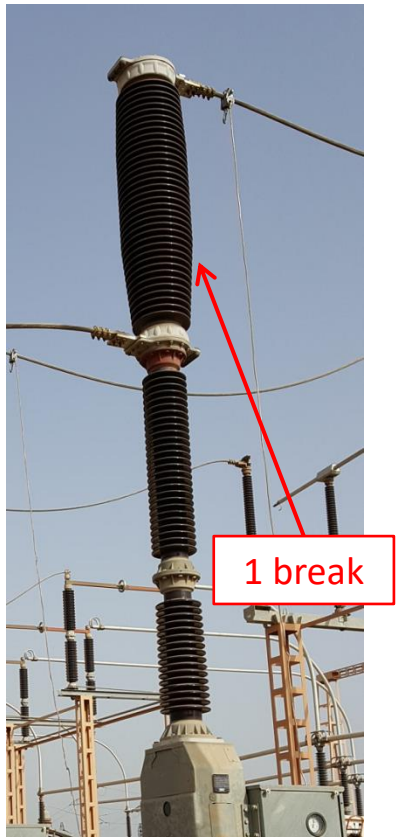
The main contact can withstand only a few interruptions of fault currents

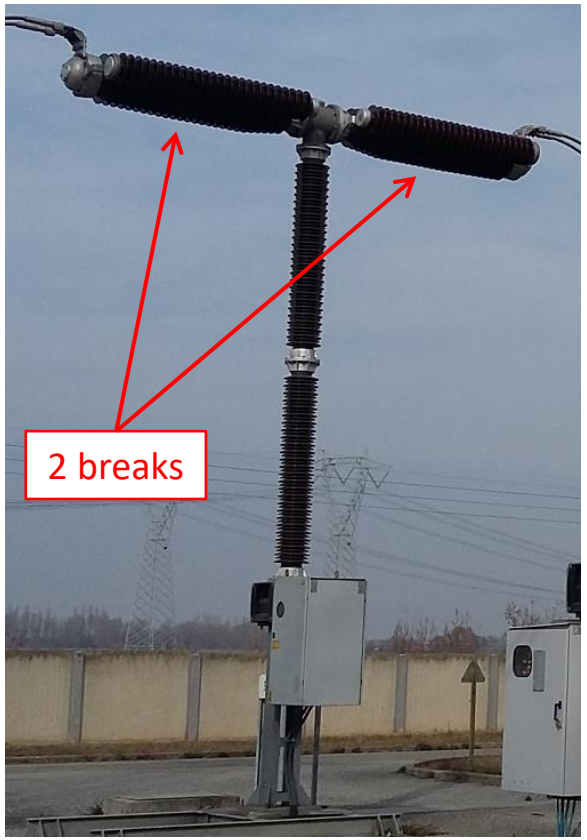
FAULT CURRENT INTERRUPTIONS REDUCE SIGNIFICANTLY THE REMAINING LIFE OF THE CIRCUIT BREAKER

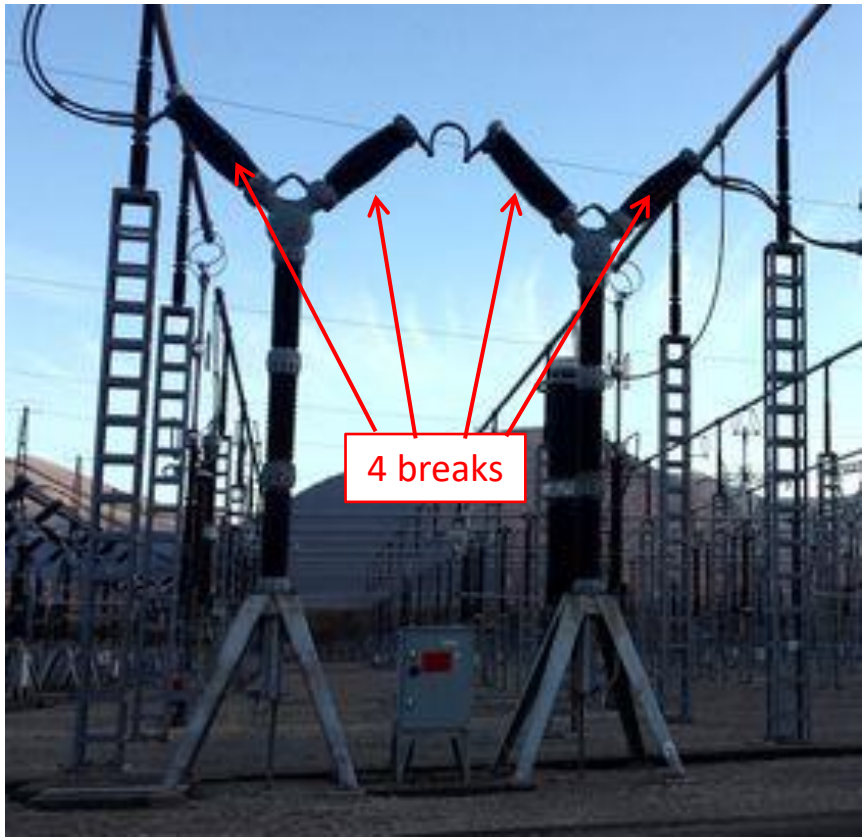
How an HV circuit breaker looks

Breaking chambers

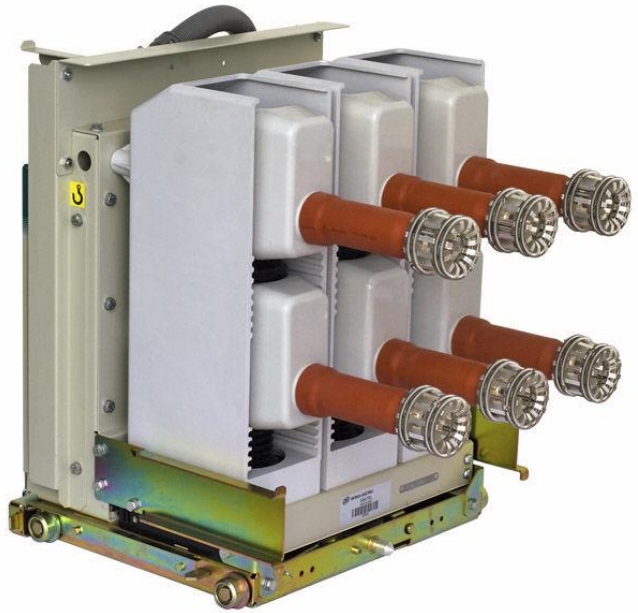
High voltage circuit breakers can have more than one moving contact (breaker) connected in series, used to interrupt the load or fault current. More than one single moving contact is required above 230 kV in order to properly quench the arc in the chamber.







Medium Voltage Switchgears



Most of the principles and concepts remain valid for medium voltage switchgears.

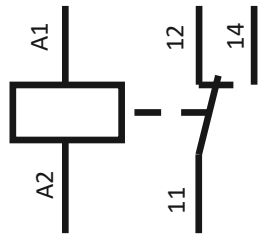
These devices are designed to operate at lower voltage, but basically do the same job as high voltage circuit breakers.

The operating chain

The leverages transfer the movement to the main contacts

When energized, the coil triggers the springs

COIL COMMANDS



MECHANISMS and LEVERAGES

MAIN BREAKER CONTACTS

The springs release the stored energy to the mechanisms

SPRINGS

AUXILIARY CONTACTS

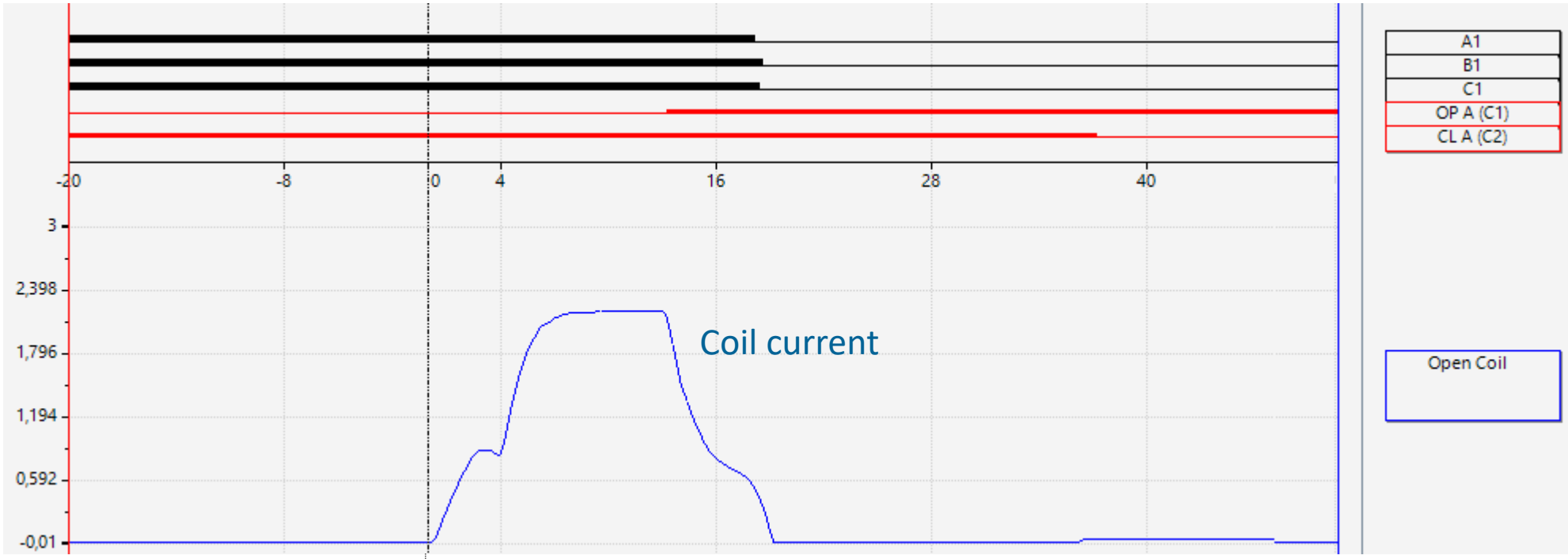
The motor charges the springs that store the energy

MOTOR

Aux contacts inform the substation devices, such as protective relays or SCADA, about the OPEN or CLOSED status of the main contacts

The operating chain

Example: one break per phase CB



Main contacts

Aux contacts

Open command
(Trigger)

THIN line: contact open

THICK line: contact closed

Which parameters should be kept under control?

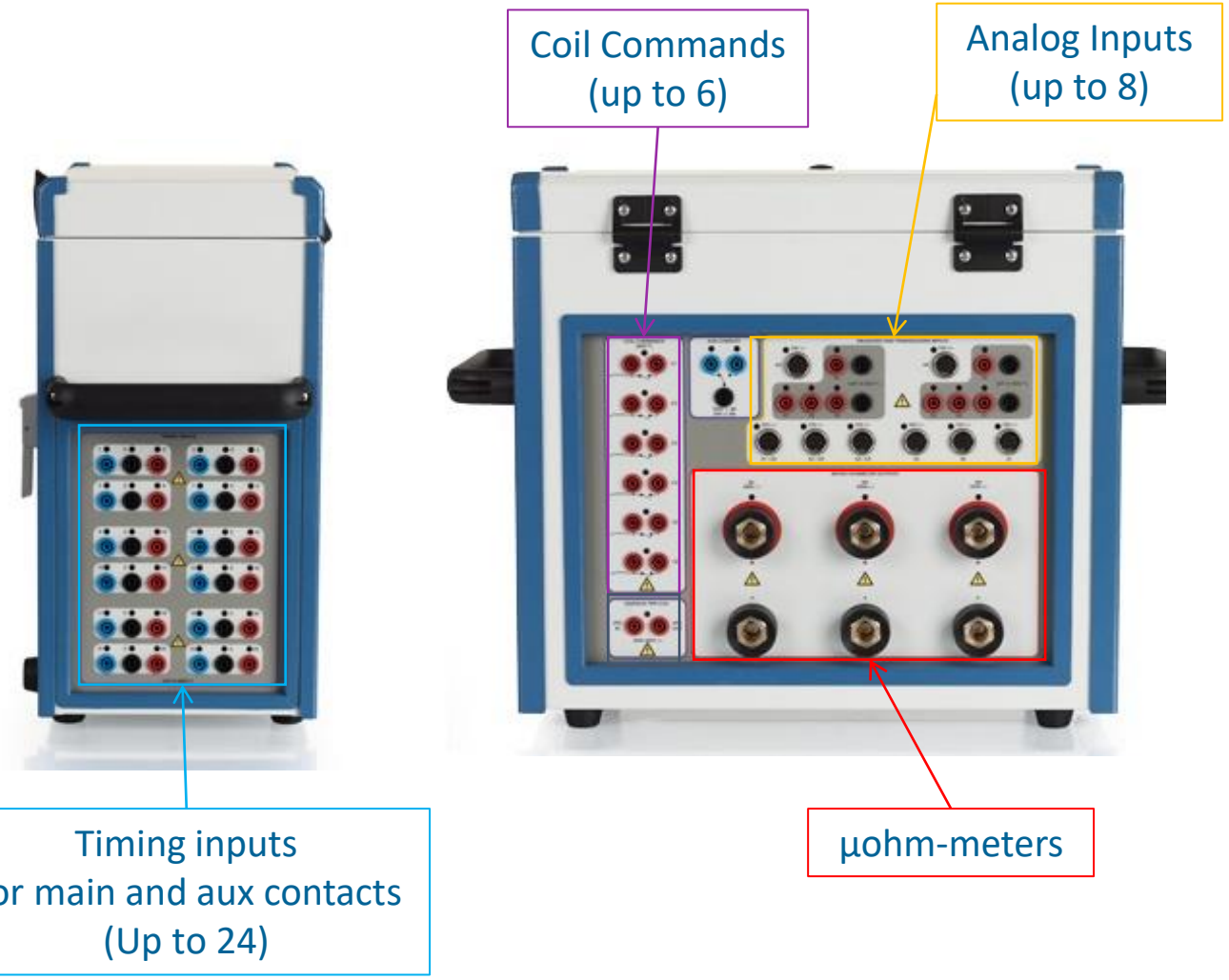
CIRCUIT BREAKER ELEMENTS	PARAMETERS
COIL COMMAND	• Peak of the energizing current • Flow time of the energizing current • Shape of the energizing current
MAIN BREAKER CONTACT	• Opening and Closing time • Static contact resistance • Dynamic contact resistance (arcing contact)
AUXILIARY CONTACT	• Switching time
PRE-INSERTION RESISTOR	• Resistance value • Insertion time
MECHANISMS and LEVERAGES	• Movement and speed
MOTOR	• Operating current

Circuit Breaker Analyzer

CBA 3000

Circuit Breaker Analyzer

CBA 3000



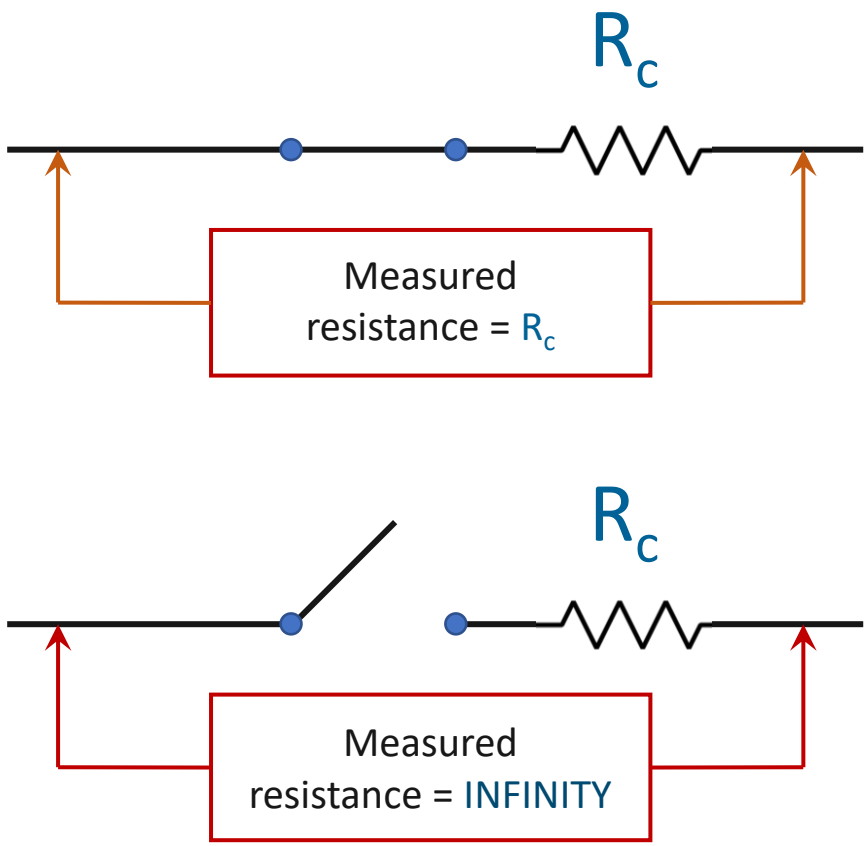
MAIN BREAKER CONTACTS

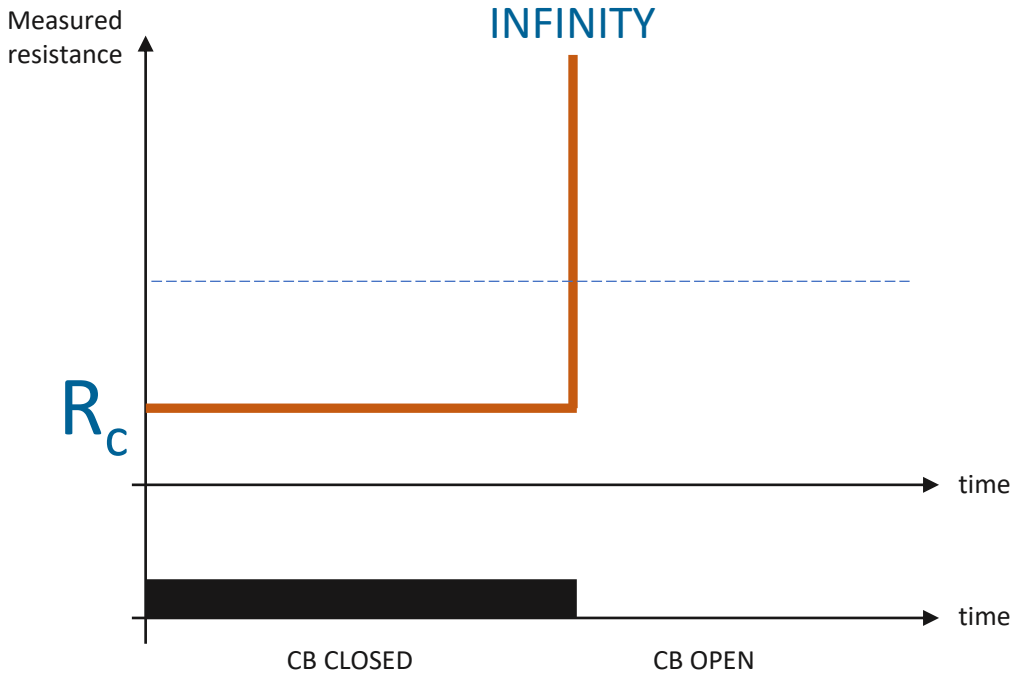
Opening and Closing time

Main breaker contacts

Opening and Closing time

The normal way to understand if the main contact is open or closed, is to measure a resistance value



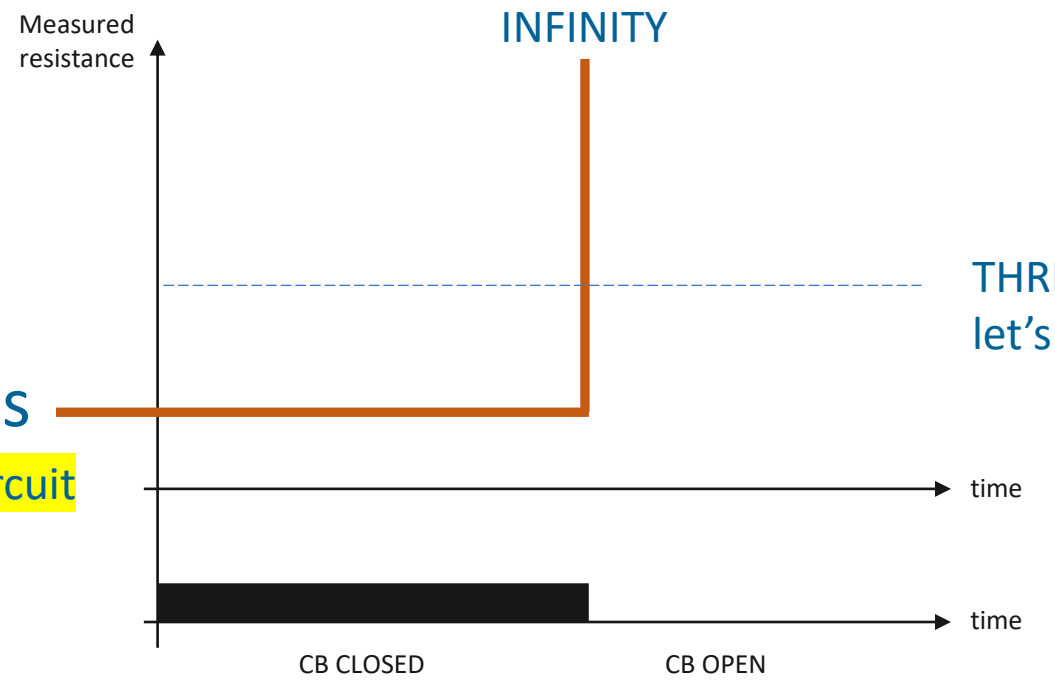


Main breaker contacts

Opening and Closing time

In other words, it is necessary to find a way to distinguish a short circuit from an open circuit.
To do so, it is necessary to decide a threshold:

- below the threshold, the contact is closed
- Above the threshold, the contact is open



THRESHOLD, can be any value, let's say 10 Ω

R_c= few micro-ohms

Can be considered as a short circuit

Main breaker contacts

Opening and Closing time - Test connections

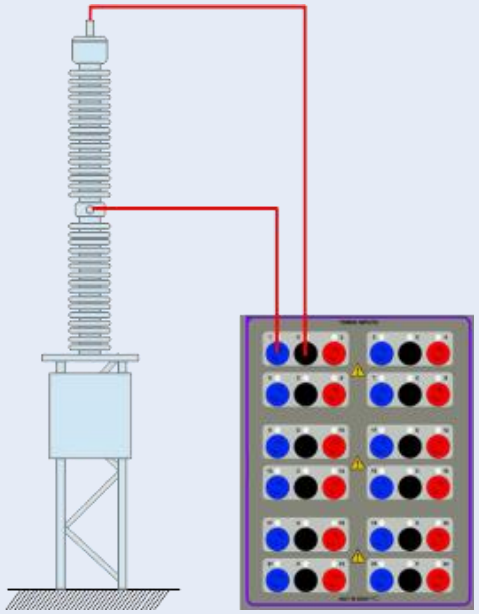
What do I need to perform a timing test for the main main contacts?

- Coil command

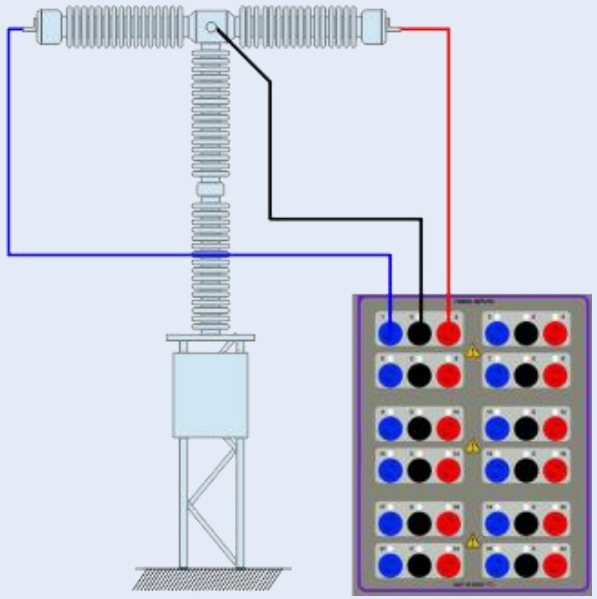
  The coil current is the reference to measure the time, when it starts to flow, the timer starts to count.

- Timing input

  used to monitor the CB contact status, and so to detect and measure its switch time.



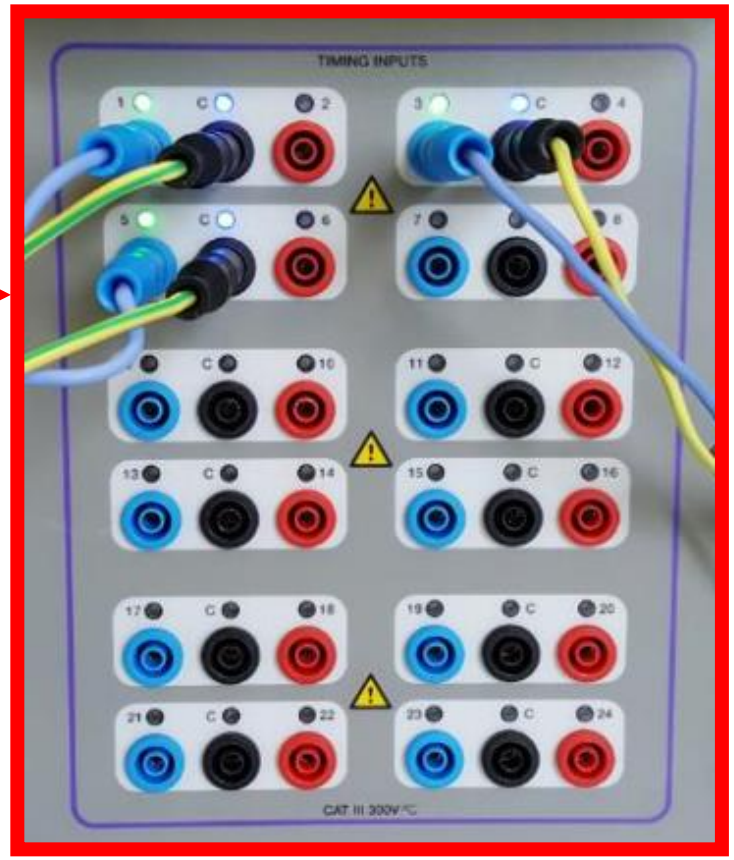
one break per phase CB



two breaks per phase CB

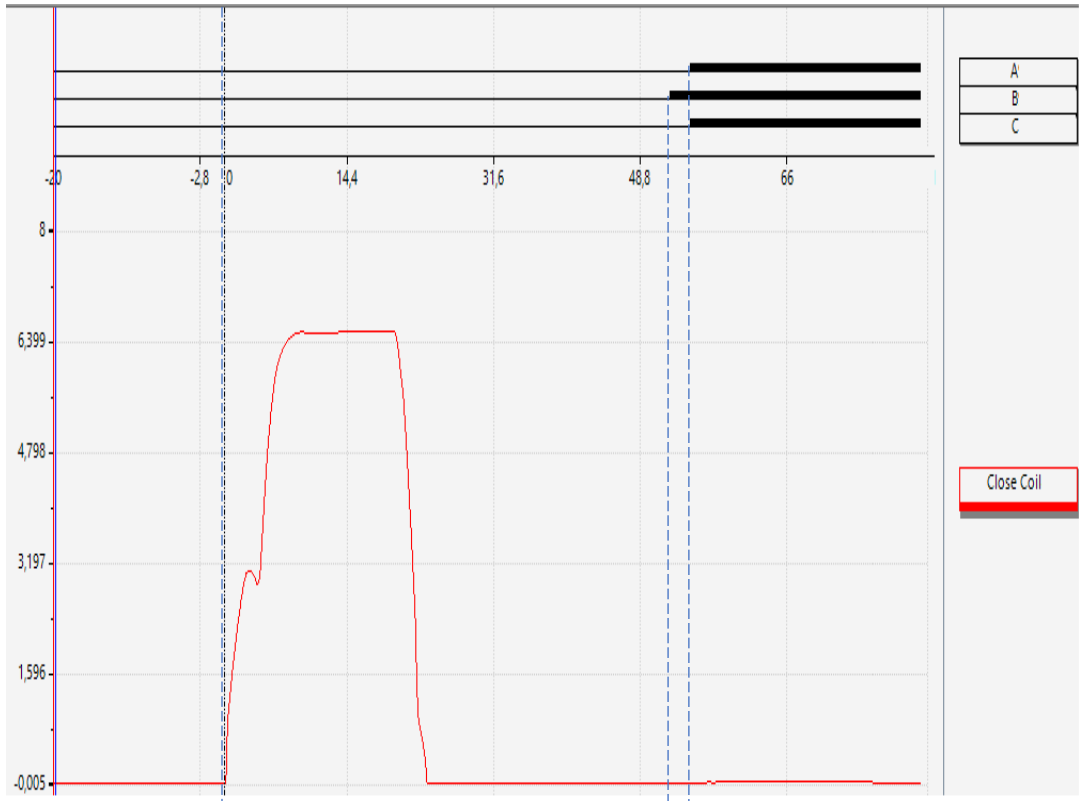
Circuit Breaker Analyzer

Opening and Closing time - Test connections



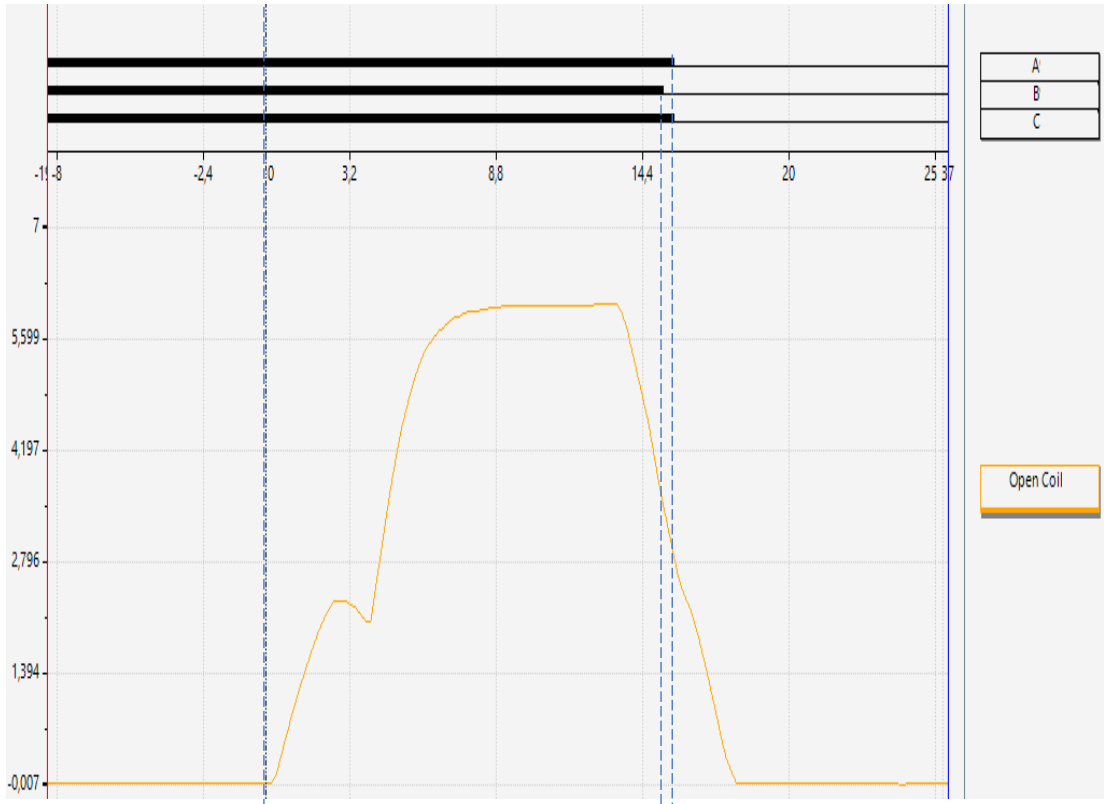
Main breaker contacts

Opening and Closing time – Results example



Closing time Ph. B

Closing time Ph. A & C



Opening time Ph. B

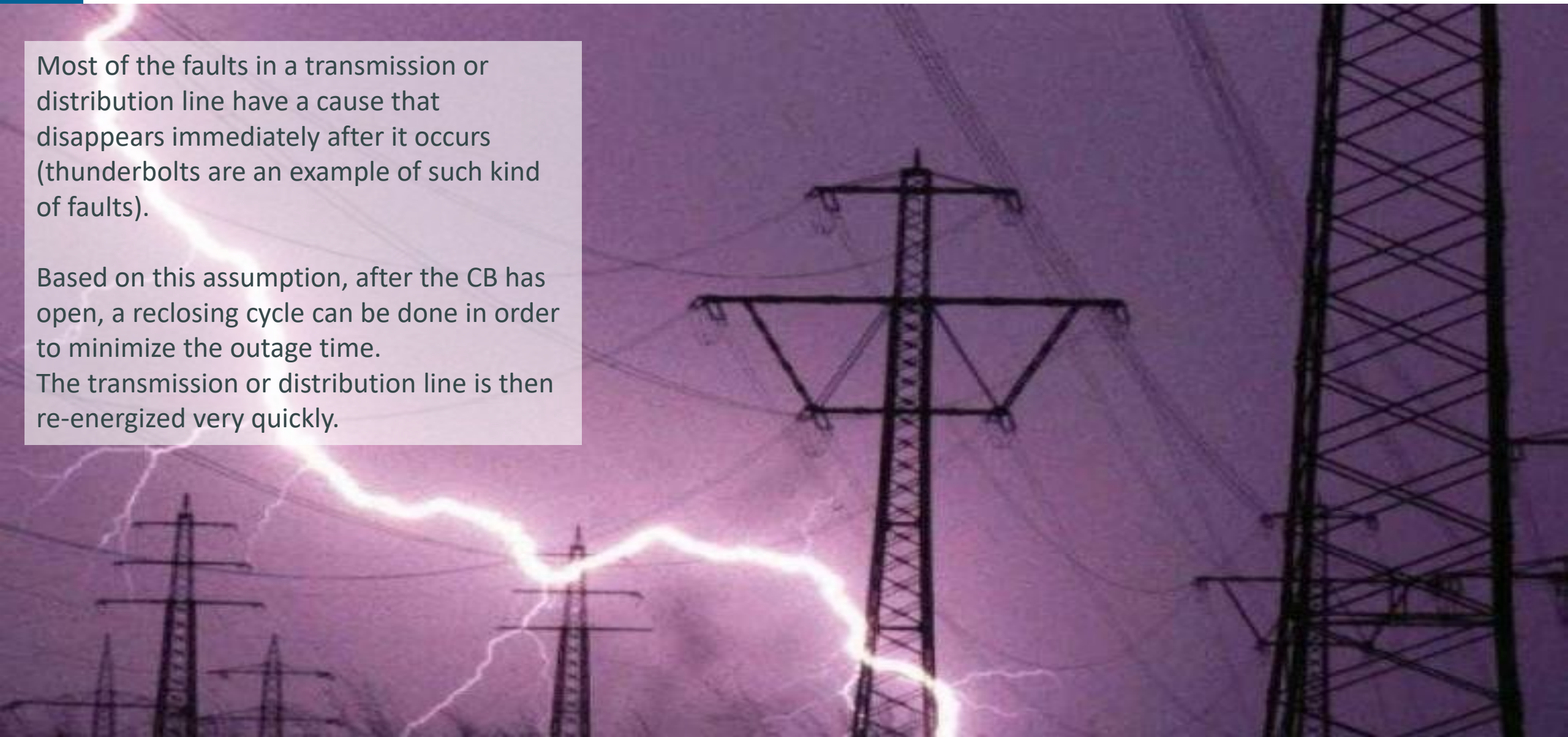
Opening time Ph. A & C

Main breaker contacts

Test of the reclosing cycle

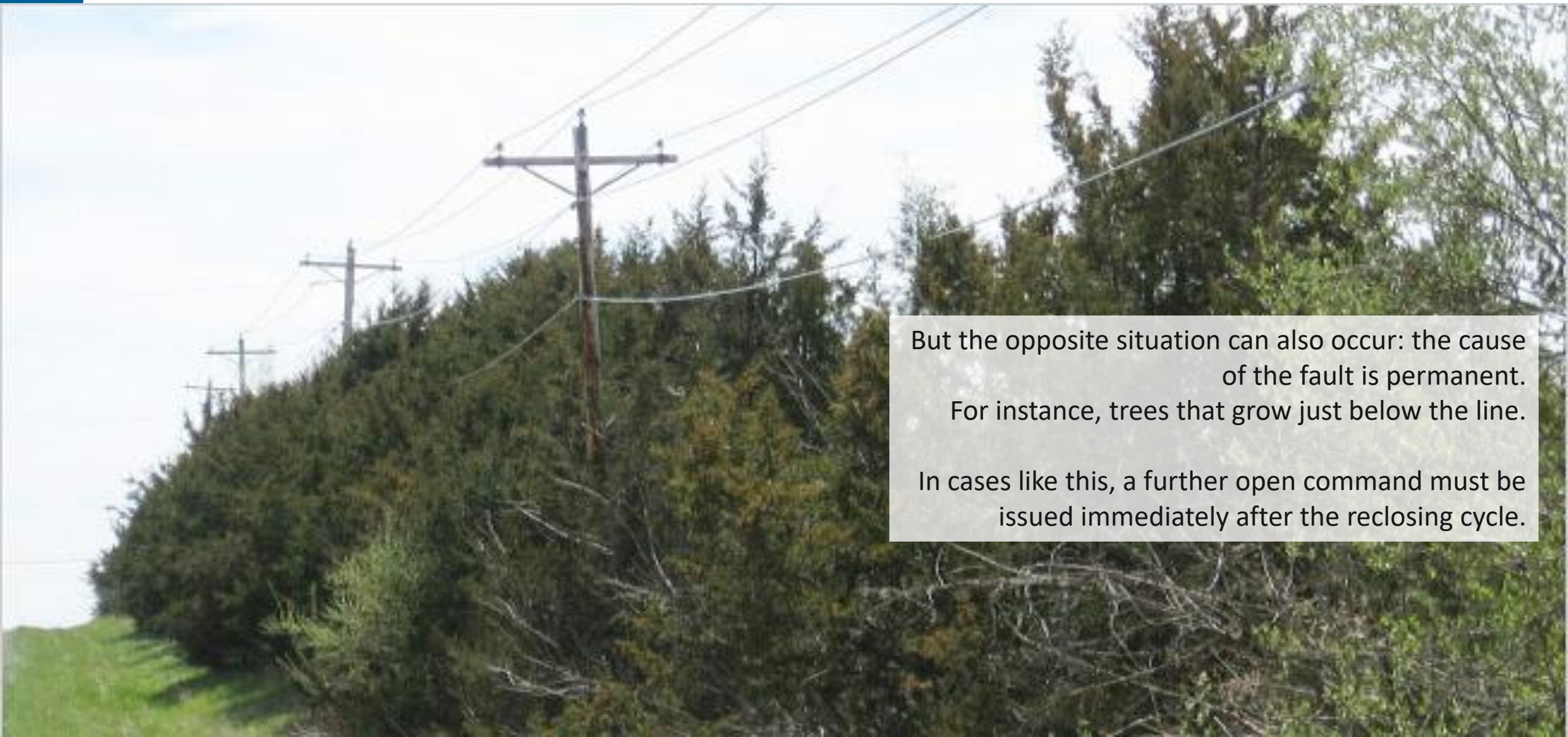
Most of the faults in a transmission or distribution line have a cause that disappears immediately after it occurs (thunderbolts are an example of such kind of faults).

Based on this assumption, after the CB has open, a reclosing cycle can be done in order to minimize the outage time.
The transmission or distribution line is then re-energized very quickly.



Main breaker contacts

Test of the reclosing cycle

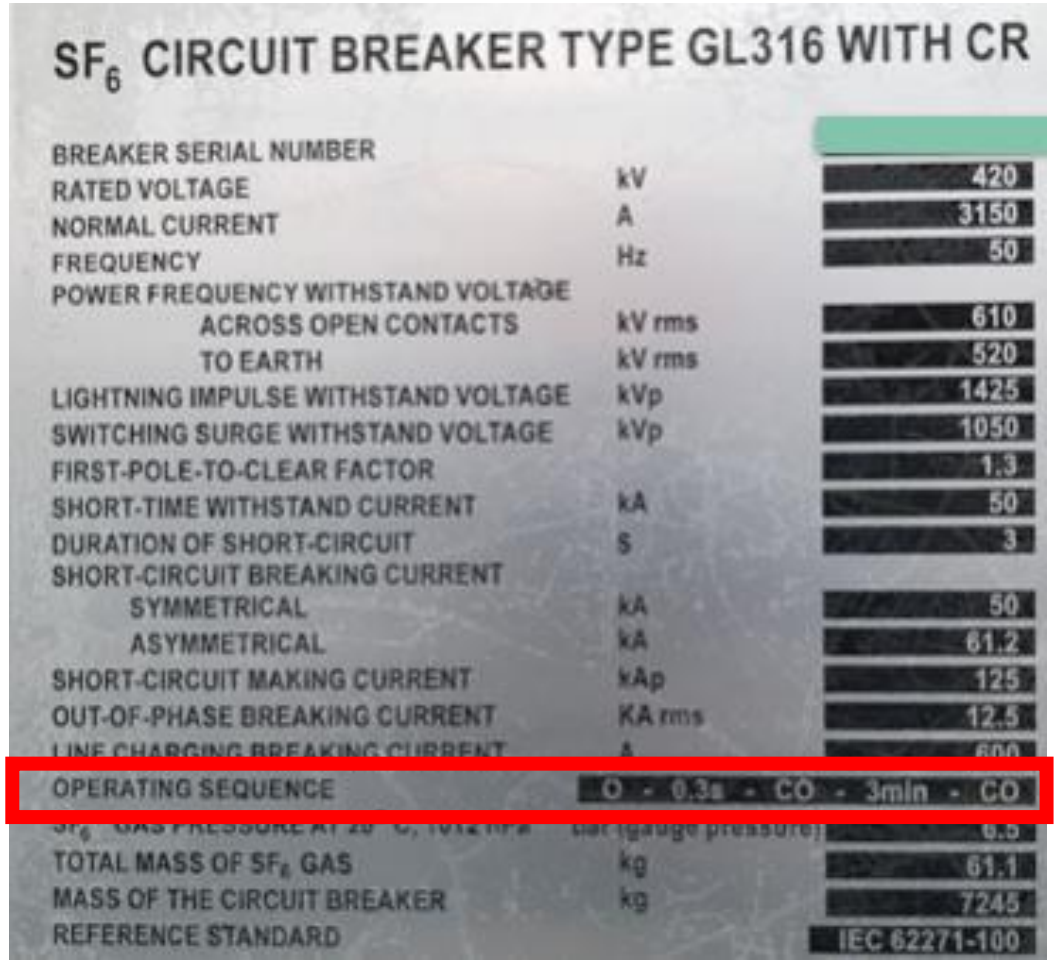


But the opposite situation can also occur: the cause of the fault is permanent.
For instance, trees that grow just below the line.

In cases like this, a further open command must be issued immediately after the reclosing cycle.

Main breaker contacts

Test of the reclosing cycle



SF_6 CIRCUIT BREAKER TYPE GL316 WITH CR

BREAKER SERIAL NUMBER		
RATED VOLTAGE	kV	420
NORMAL CURRENT	A	3150
FREQUENCY	Hz	50
POWER FREQUENCY WITHSTAND VOLTAGE		
ACROSS OPEN CONTACTS	kV rms	610
TO EARTH	kV rms	520
LIGHTNING IMPULSE WITHSTAND VOLTAGE	kVp	1425
SWITCHING SURGE WITHSTAND VOLTAGE	kVp	1050
FIRST-POLE-TO-CLEAR FACTOR		1.3
SHORT-TIME WITHSTAND CURRENT	kA	50
DURATION OF SHORT-CIRCUIT	S	3
SHORT-CIRCUIT BREAKING CURRENT		
SYMMETRICAL	kA	50
ASYMMETRICAL	kA	61.2
SHORT-CIRCUIT MAKING CURRENT	kAp	125
OUT-OF-PHASE BREAKING CURRENT	KA rms	12.5
OPERATING SEQUENCE	O - 0.3s - CO - 3min - CO	
TOTAL MASS OF SF_6 GAS	kg	61.1
MASS OF THE CIRCUIT BREAKER	kg	7245
REFERENCE STANDARD		IEC 62271-100

Reclosing cycle

Switch On To Fault (SOTF)

O - t - CO

OPEN cmd

Dead time between operations

FAST RECLOSURE : t = 0.3 s

SLOW RECLOSURE : t > 30 s

OPEN cmd

CLOSE cmd

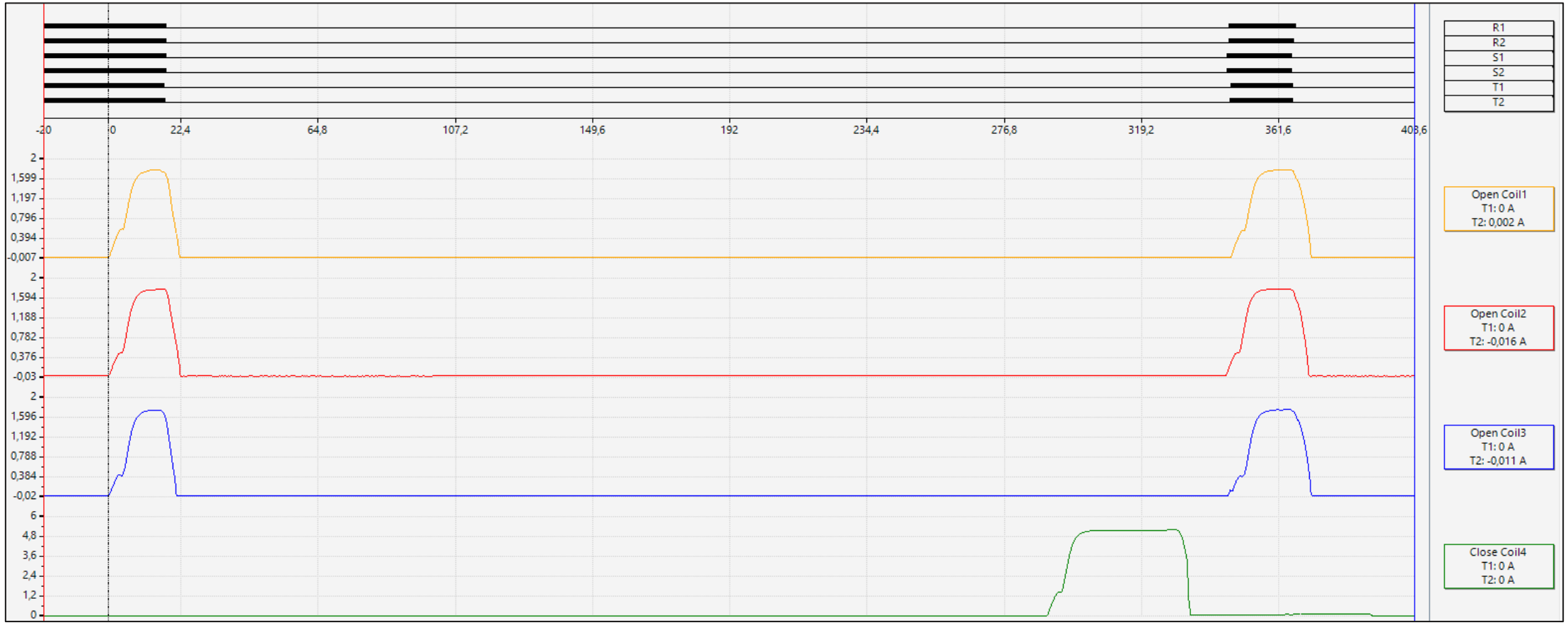
No intentional time delay between operations

« Fast Reclosure + SOTF » is the most critical sequence

The springs must release all their energy in a very short time

Main breaker contacts

Test of the reclosing cycle – Results example

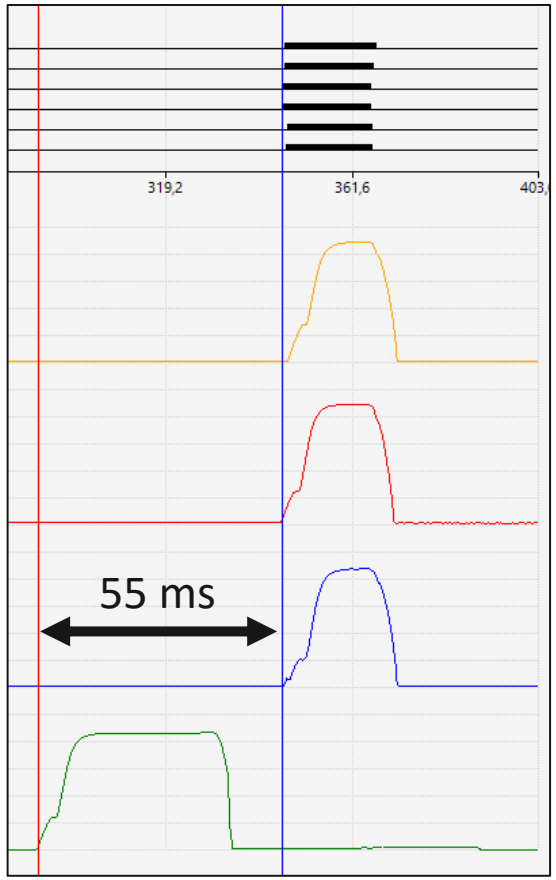


OPEN → CLOSE → OPEN

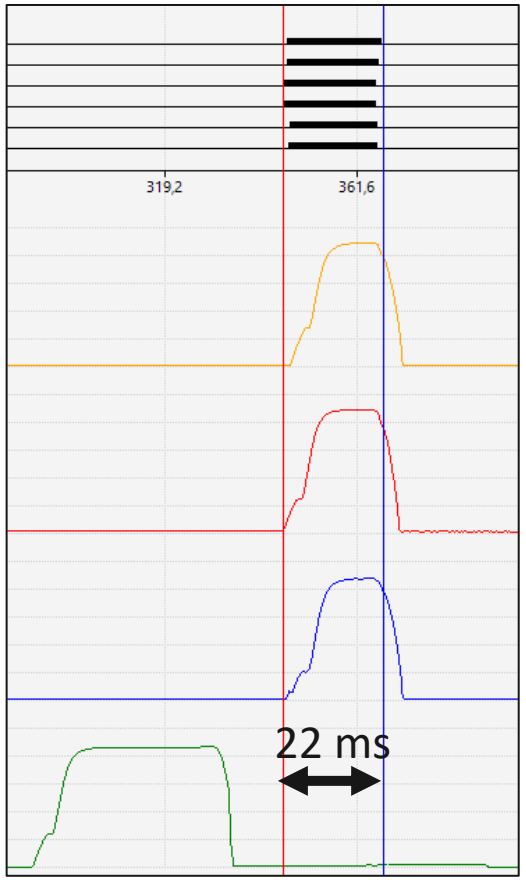
0.3 s

Main breaker contacts

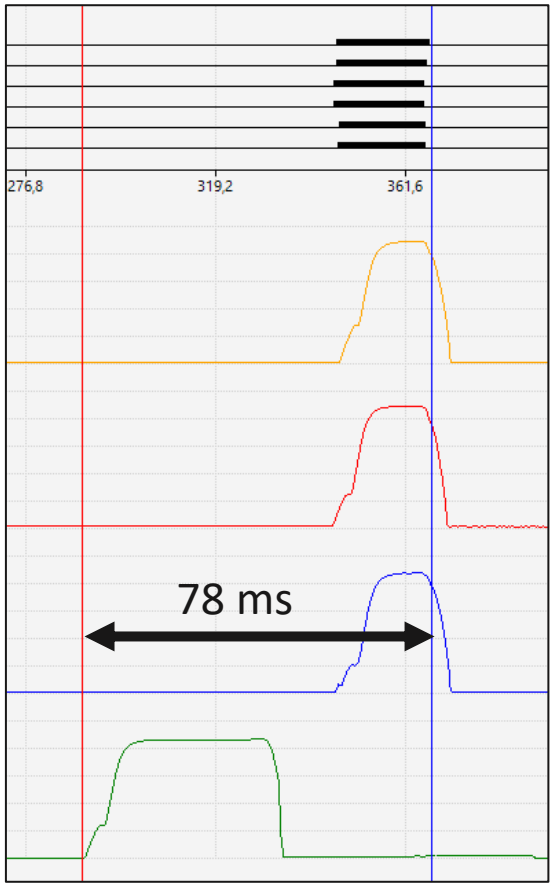
Test of the reclosing cycle – Results example



The 55 ms delay is due to a mechanism than avoid the overlap of a close and a open command



The time in which the main contacts remain closed is called DWELL TIME



Must be noted that the CB can perform a complete CO sequence in a very short time

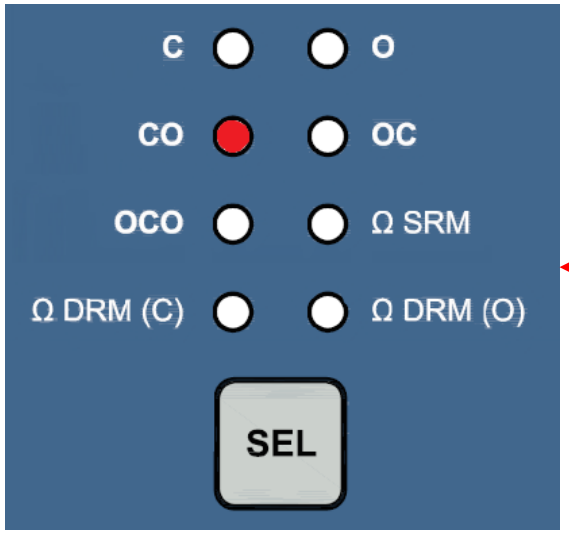
Main breaker contacts

Test of the reclosing cycle

CBA 3000 gives a very straightforward way to choose the sequence of operation to be executed

By means of the SEL button placed on the front panel, the operator can select the desired sequence and then press the START button.

All the results will be displayed on the built-in color screen



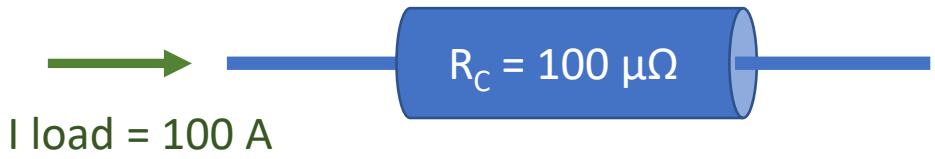
MAIN BREAKER CONTACTS

Static contact resistance

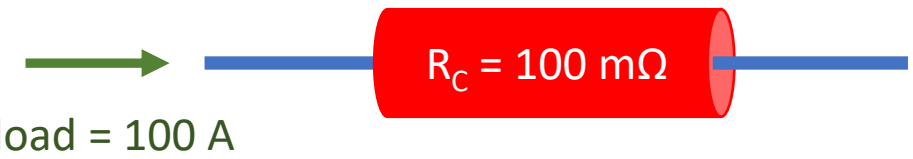
Main breaker contacts

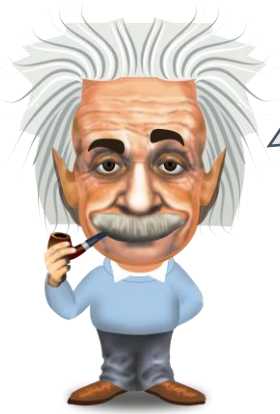
Why does the main contact resistance have such a low value?

$P = (100\ \mu\Omega) * (100\ A)^2 = 1\ W$



$P = (100\ m\Omega) * (100\ A)^2 = 1000\ W$

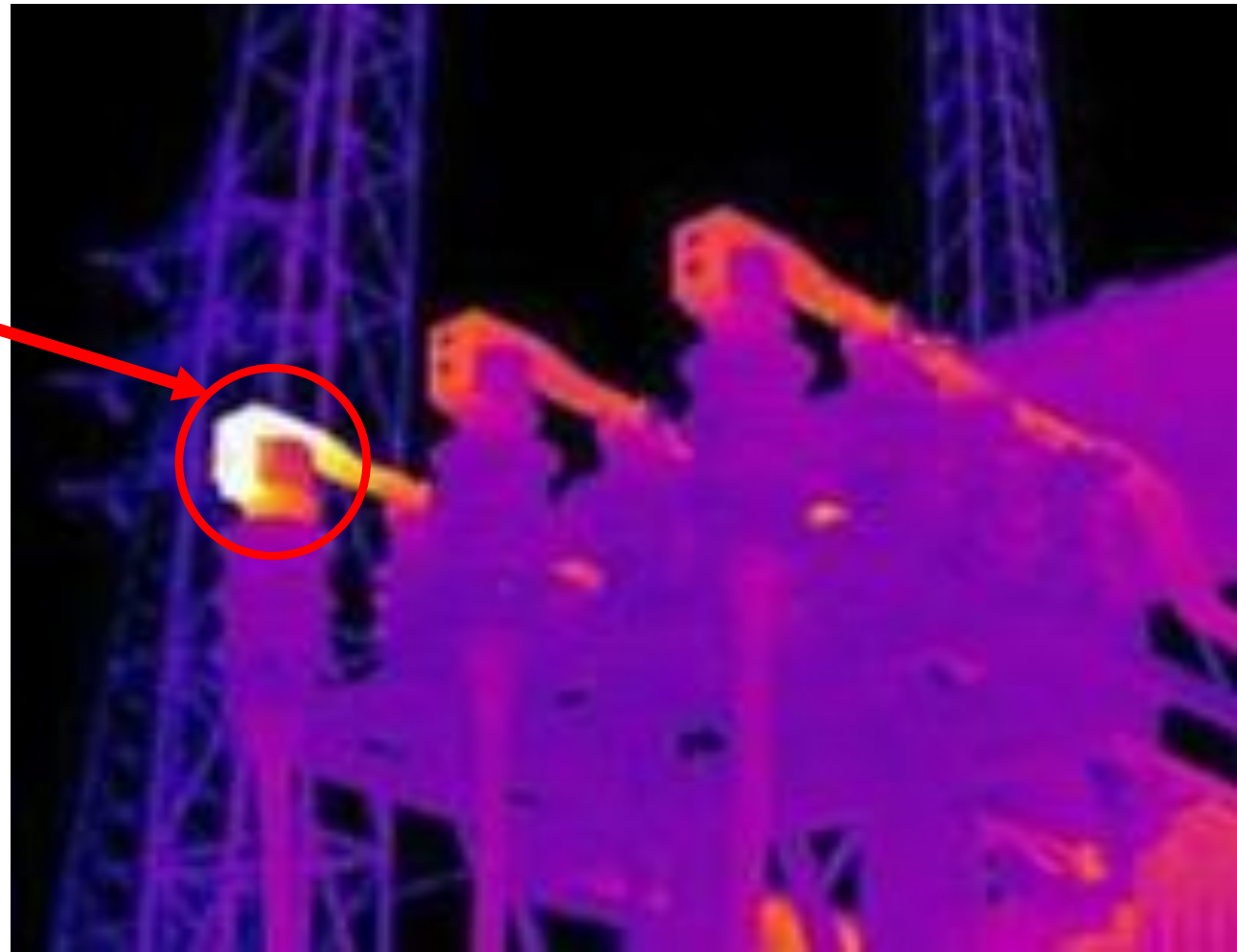




The heat is a function of the dissipated energy

ENERGY = P * t

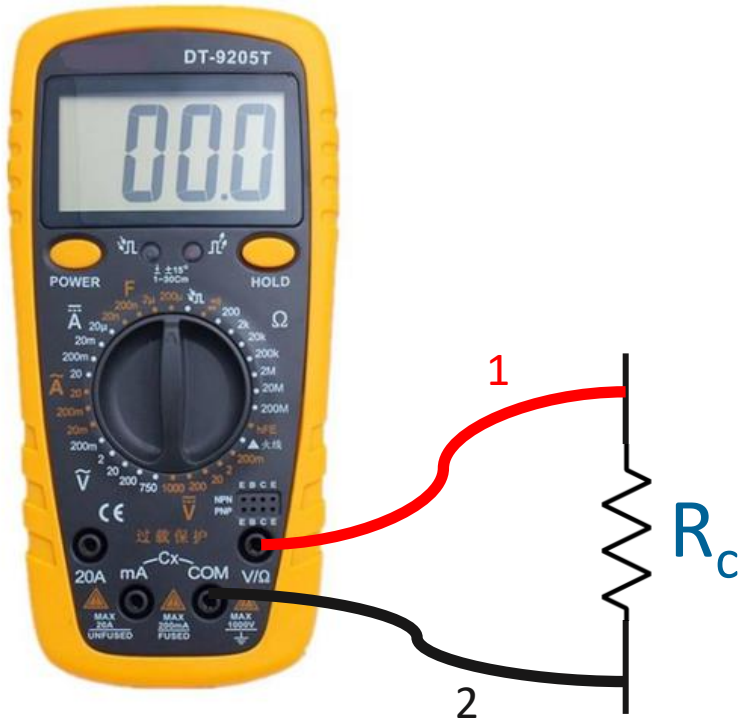
Higher is the resistance, smaller is the time to reach a high temperature

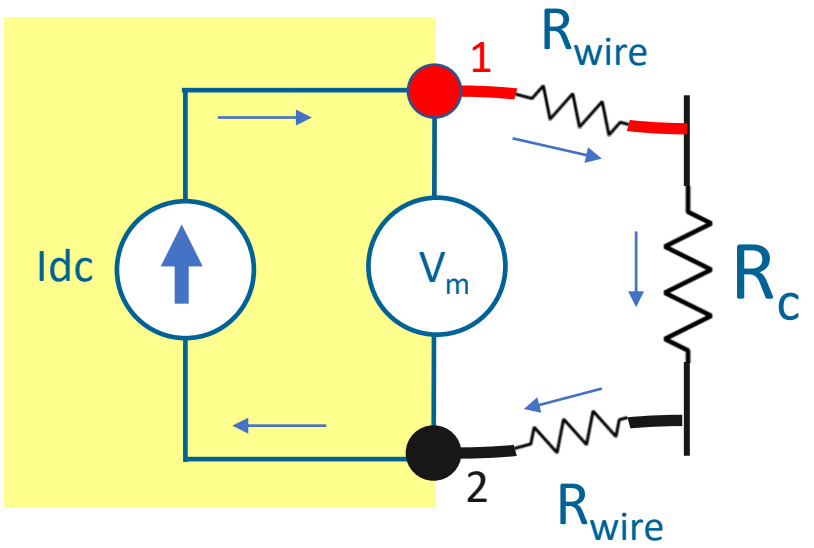


Main breaker contacts

Measure of resistance value – Two Wire method

The measure of a generic resistance value, at a first glance, seems a very simple operation.
Any good multimeter can do this job.





The actual resistance value is

$Vm = Idc * (R_C + 2R_{wire})$

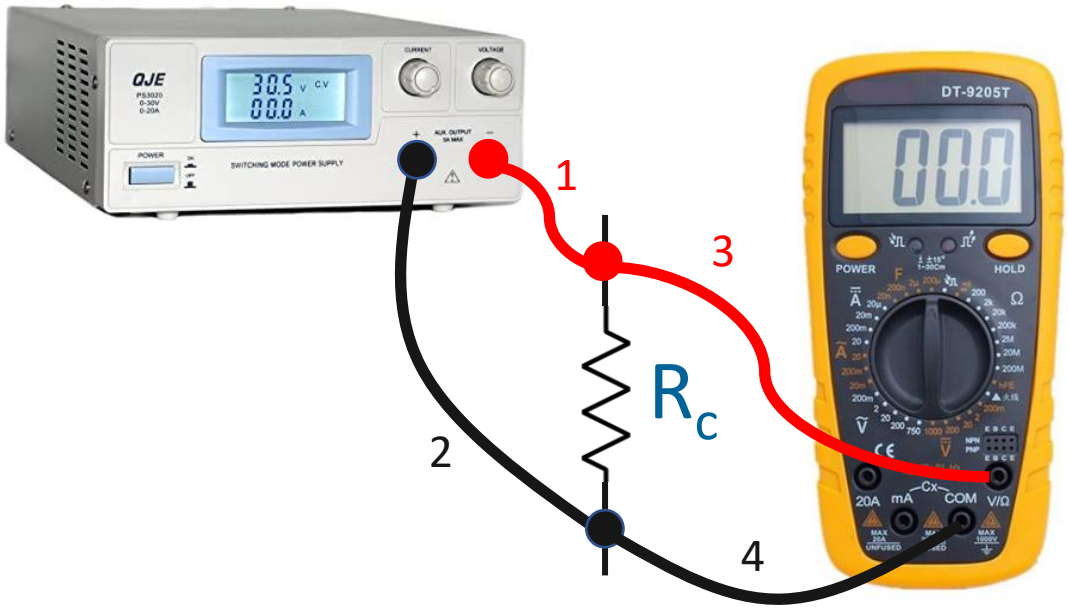
$R_{meas} = R_C + 2R_{wire}$

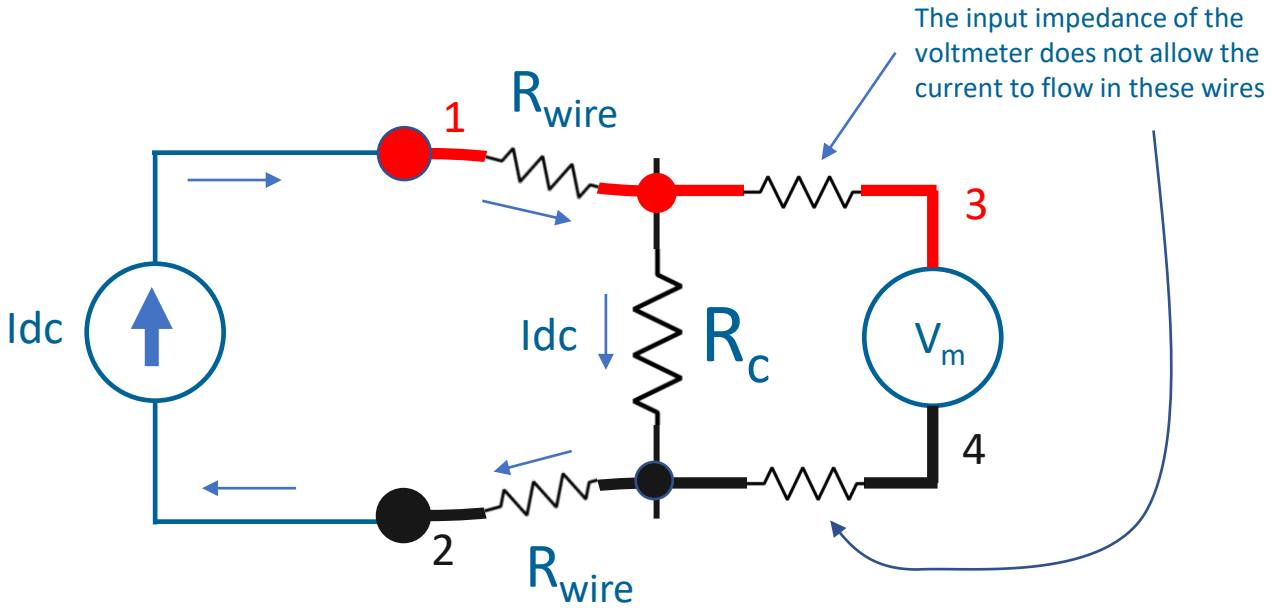
The two wire method is not suitable to measure resistance values in the range of few micro-ohms

Main breaker contacts

Measure of resistance value – Four Wire method

The multimeter can still be used, but as voltmeter rather than as ohm-meter.
The current must be generated from an external source.





The actual resistance value is

$Vm = Idc * R_C$

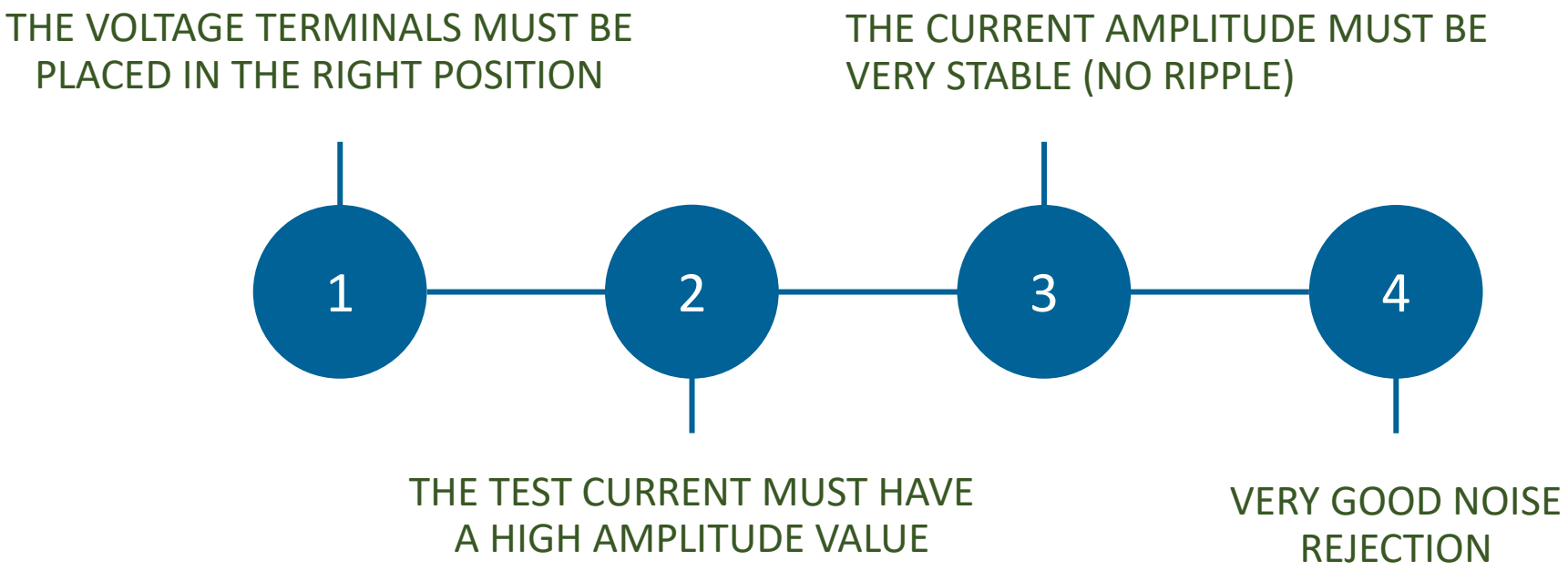
$R_{meas} = R_C$

The four wire method is the correct method to be used

Main breaker contacts

Static contact resistance

The four wire method does not always guarantee to get the most correct value.
The measure of micro-ohms needs precautions to be taken:



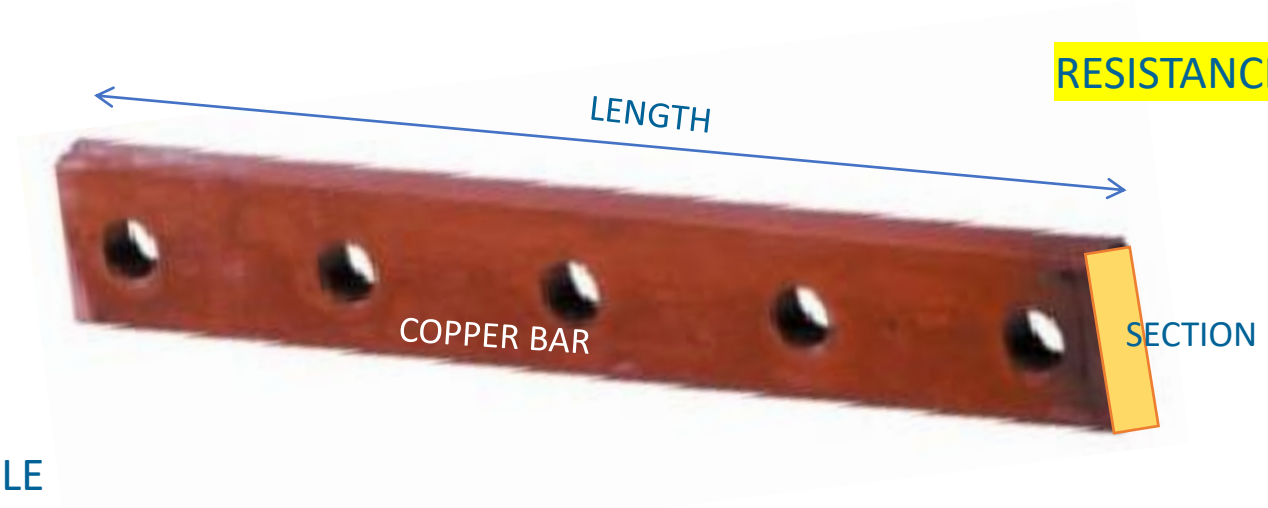
Main breaker contacts

Static contact resistance

1

THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION

RESISTANCE = Copper resistivity * (Length / Section)



EXAMPLE

Copper resistivity = 0.017 [Ω * mm² / m]

Length = 0.5 m

Section = 300 mm²

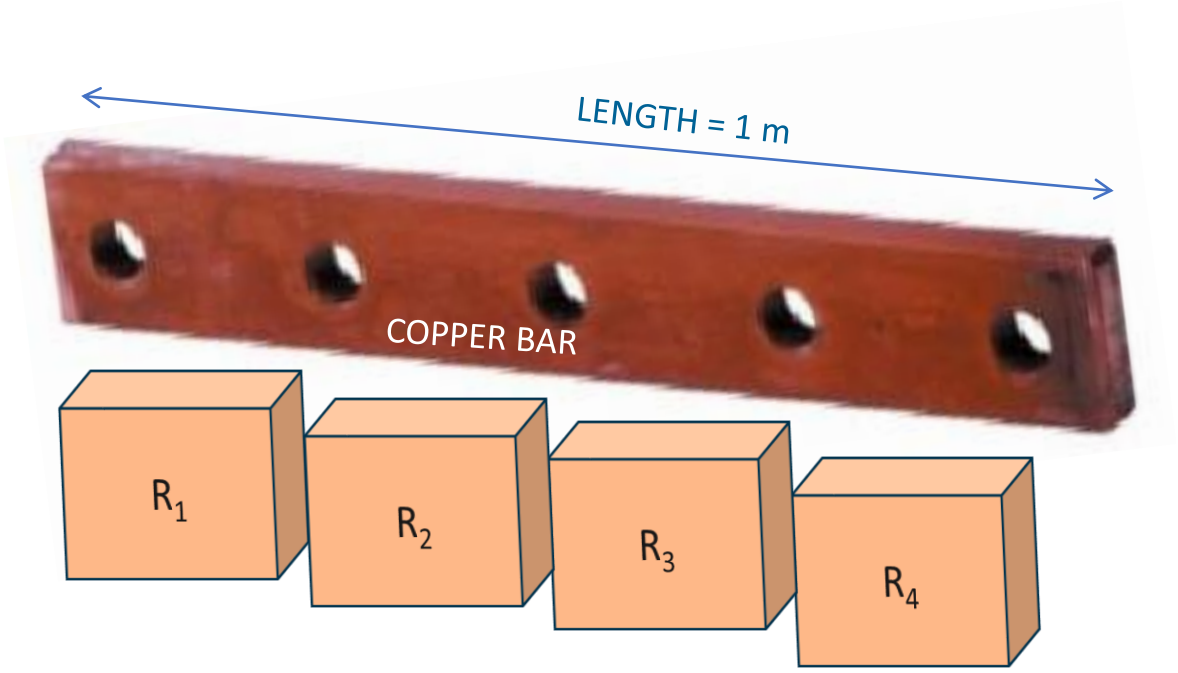
$$R = 0.017 \left[\frac{\Omega * mm^2}{m}\right] * \frac{0.5\ [m]}{300\ [mm^2]} \simeq 28\ \mu\Omega$$

Main breaker contacts

Static contact resistance

1

THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION



The copper bar can be seen as a sequence of shorter pieces, each one with its own resistance value.
In our example, we divide the bar in 4 pieces

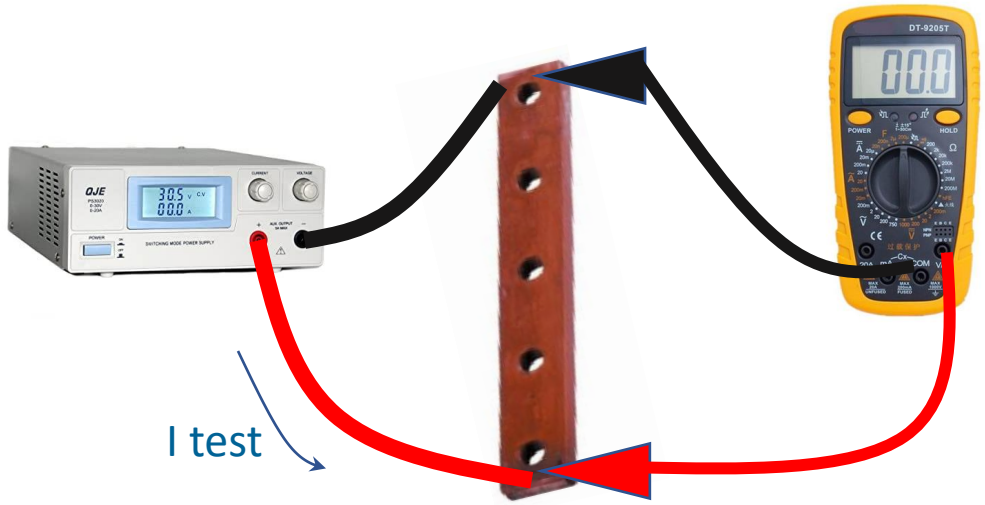
$$R = R_1 + R_2 + R_3 + R_4 = 28\ \mu\Omega$$

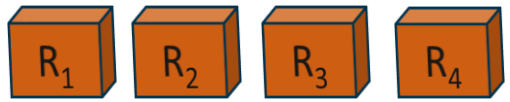
Main breaker contacts

Static contact resistance

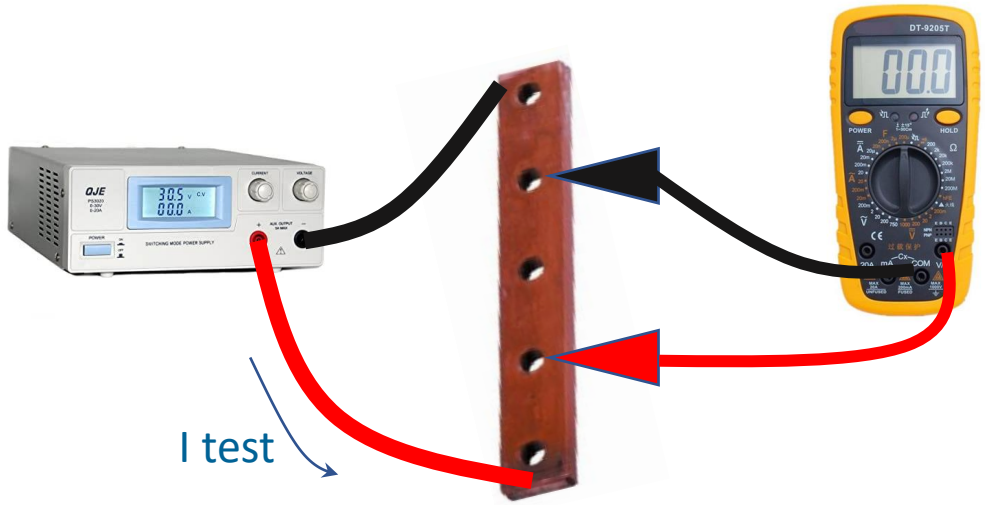
1

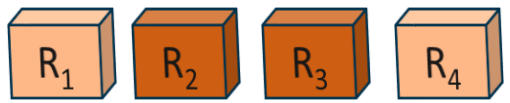
THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION





R measured = $R_1 + R_2 + R_3 + R_4 = 28\ \mu\Omega$





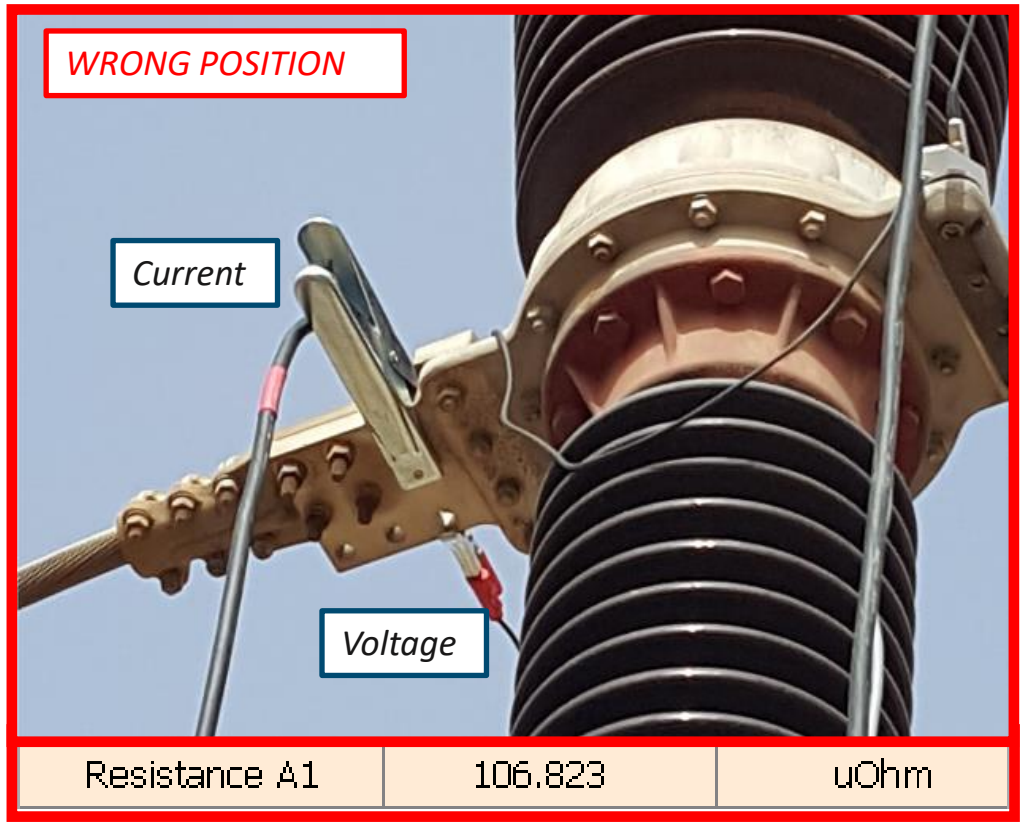
R measured = $R_2 + R_3 = 14\ \mu\Omega$

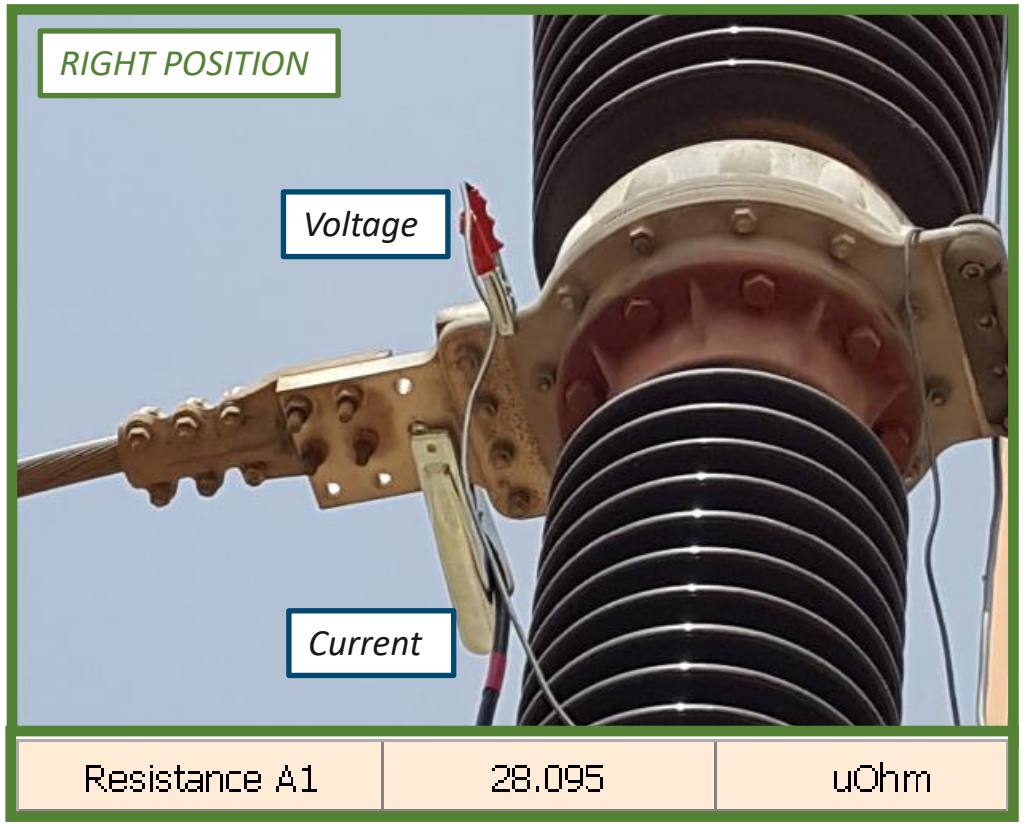
Main breaker contacts

Static contact resistance

1

THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION



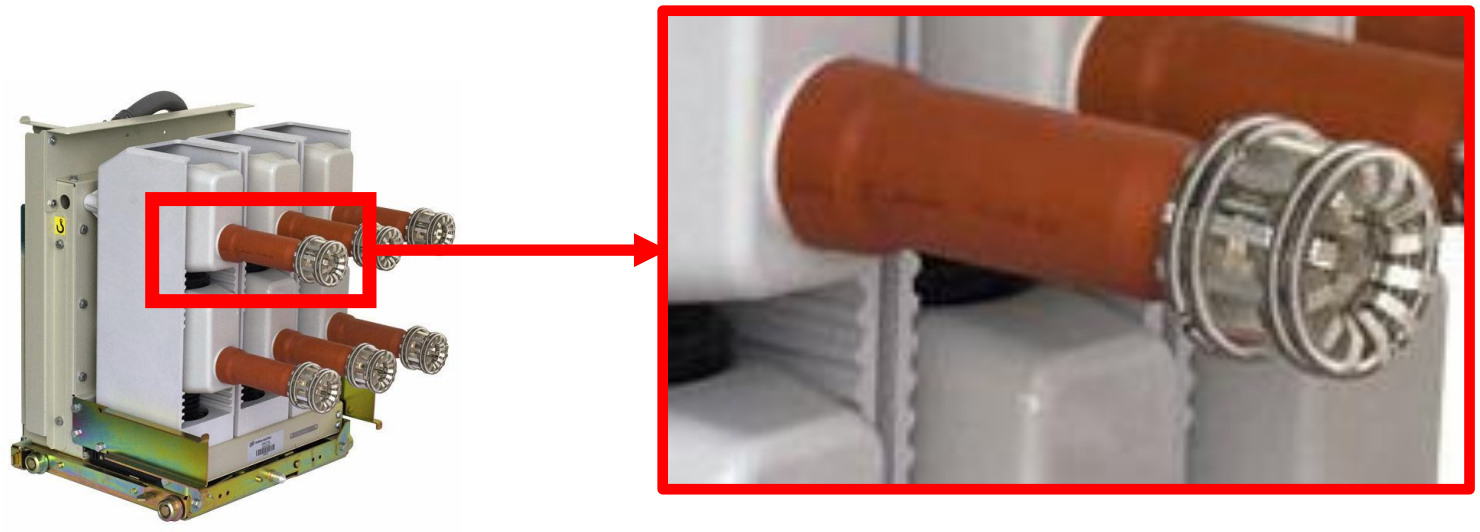


Main breaker contacts

Static contact resistance

1

THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION



Special adapters may be required for proper connection of voltage terminals

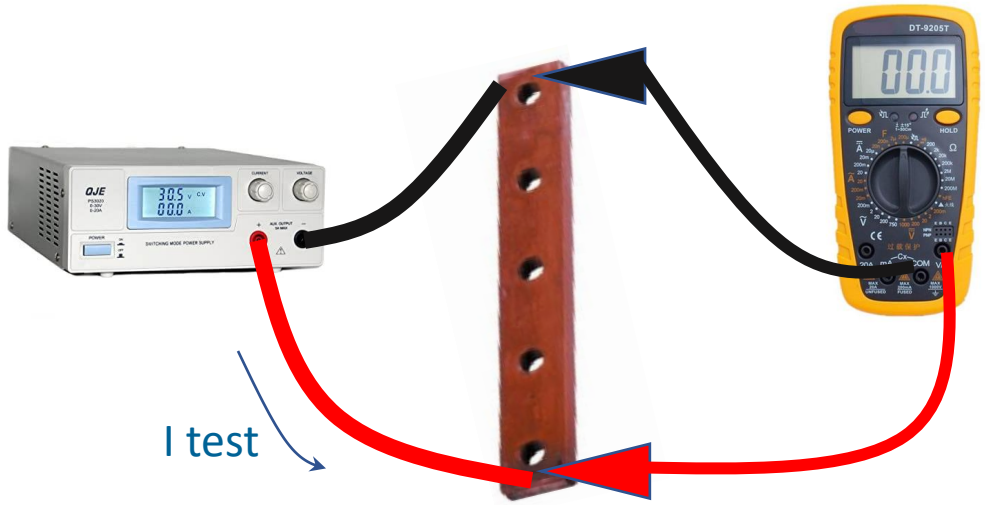
Withdrawable Circuit Breaker Switchgears (WCBS)

Main breaker contacts

Static contact resistance

2

THE TEST CURRENT MUST HAVE A HIGH AMPLITUDE VALUE

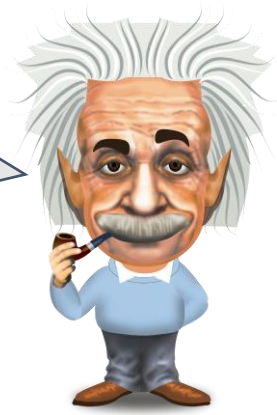


V measured = 28 µΩ * 10 A = 280 µV

It is very difficult to measure voltges whose amplitude is less than 1 mV.
For this reason, the recommended test current is 100 A

V measured = 28 µΩ * 100 A = 2.8 mV

The junction between two different conductor material, here represented by the copper bar and the voltage terminal, generates a voltage whose value falls the range of few microvolt (SEEBECK EFFECT).
This voltage acts as an offset, and must be compensated.

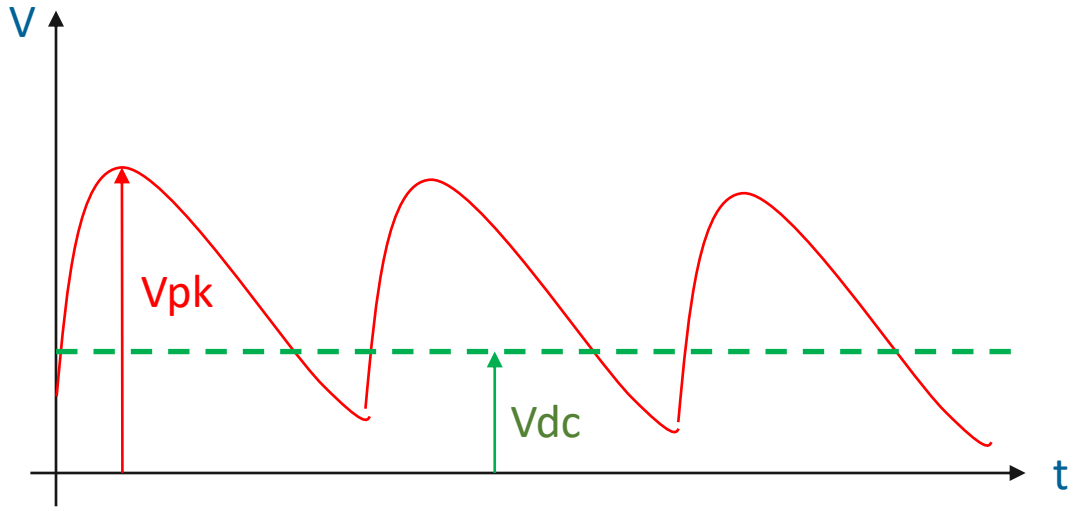


Main breaker contacts

Static contact resistance

3

THE CURRENT AMPLITUDE MUST BE VERY STABLE (NO RIPPLE)



The DC component must be calculated from the «non-DC» waveform

Possible causes of inaccuracy

- Mathematical approximations
- Vpk >> Vdc: the full scale range error can be higher than Vdc (e.g. range of 1V to measure 1 mV)

PURE DC SIGNALS GUARANTEE THE BEST ACCURACY

Main breaker contacts

Static contact resistance

4

VERY GOOD NOISE REJECTION

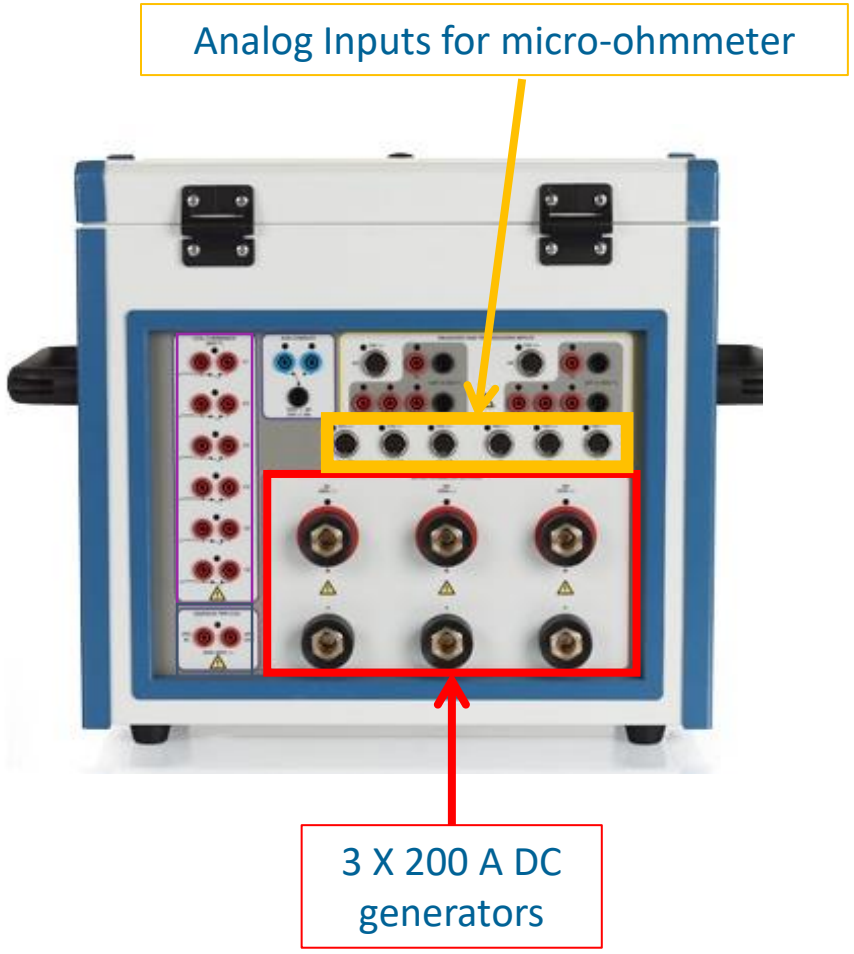
In substations the electrical noise can be very high, the busbar voltage can induce additional voltage in the measurement cables.

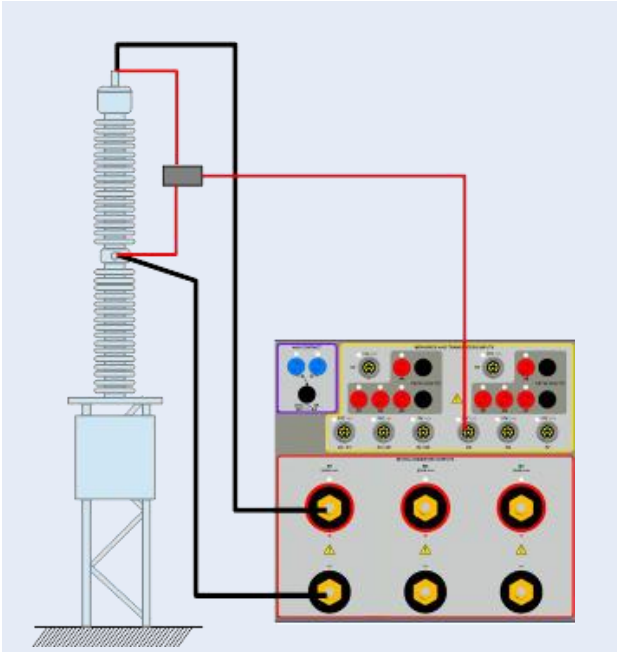
SOLUTIONS:

- Shielded cables
- Filters for signals at the line frequency

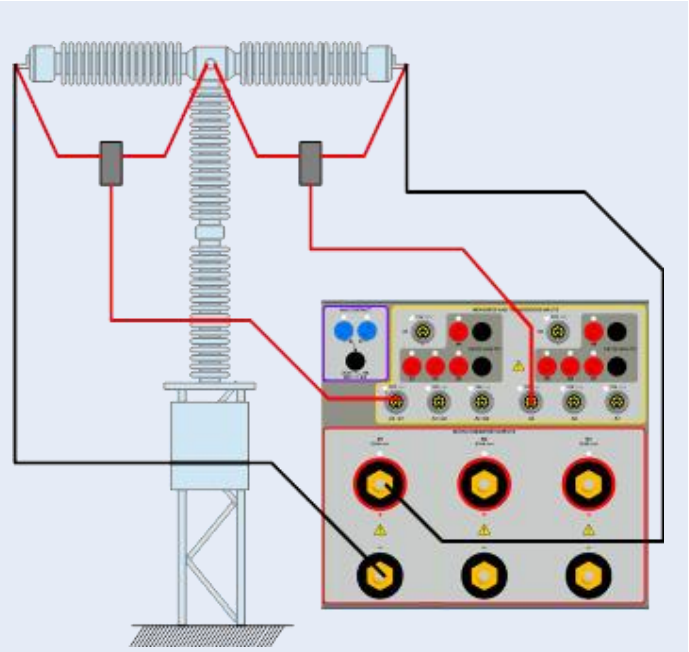
Main breaker contacts

Static contact resistance – measurement setup





one break per phase CB



two breaks per phase CB

POSSIBILITY TO MEASURE UP TO 6 RESISTANCES SIMULTANEOUSLY

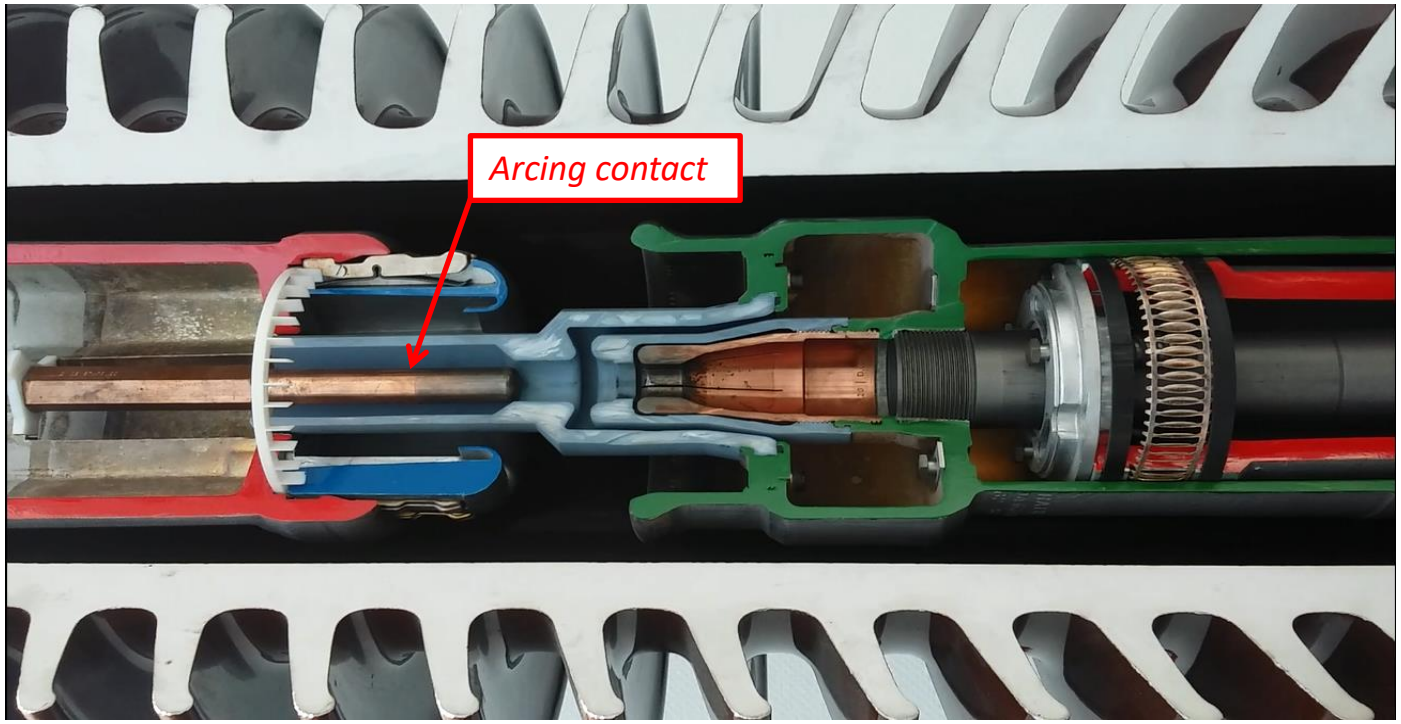
MAIN BREAKER CONTACTS

Dynamic contact resistance

Main breaker contacts

Dynamic contact resistance

Dynamic contact resistance measurement (DCRM) is the method to assess the conditions of the arcing contact



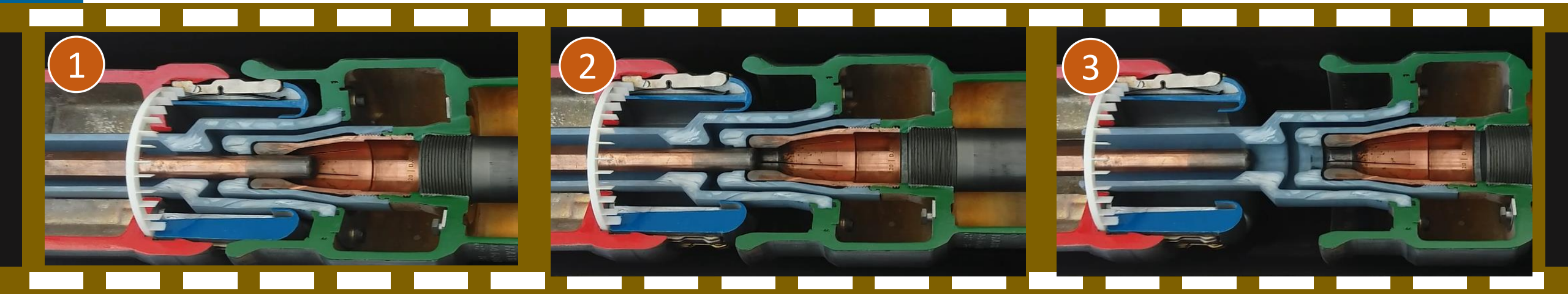
HOW TO PERFORM THE MEASURE

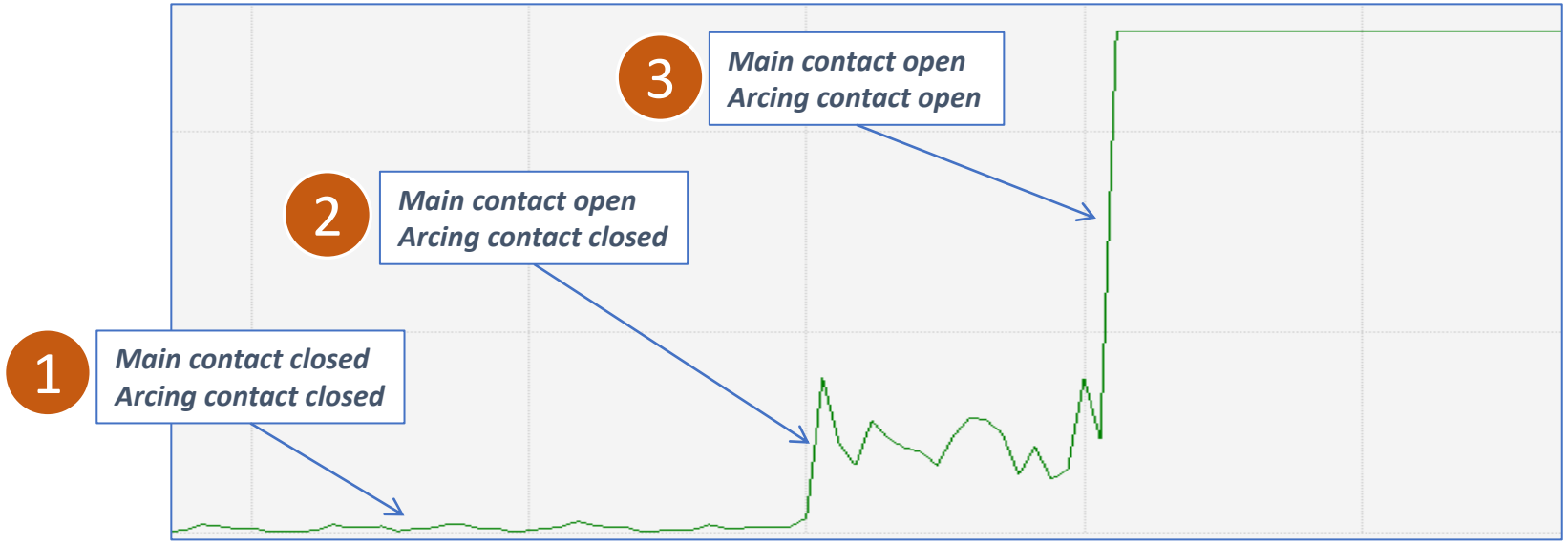
1. Start the current generation
2. Issue the OPEN command
3. Keep the current until the main contact is fully open
4. Record the current variations with at least 10 kHz as sample frequency (time resolution 100 µs)

The measurement setup is the same as the SCR

Main breaker contacts

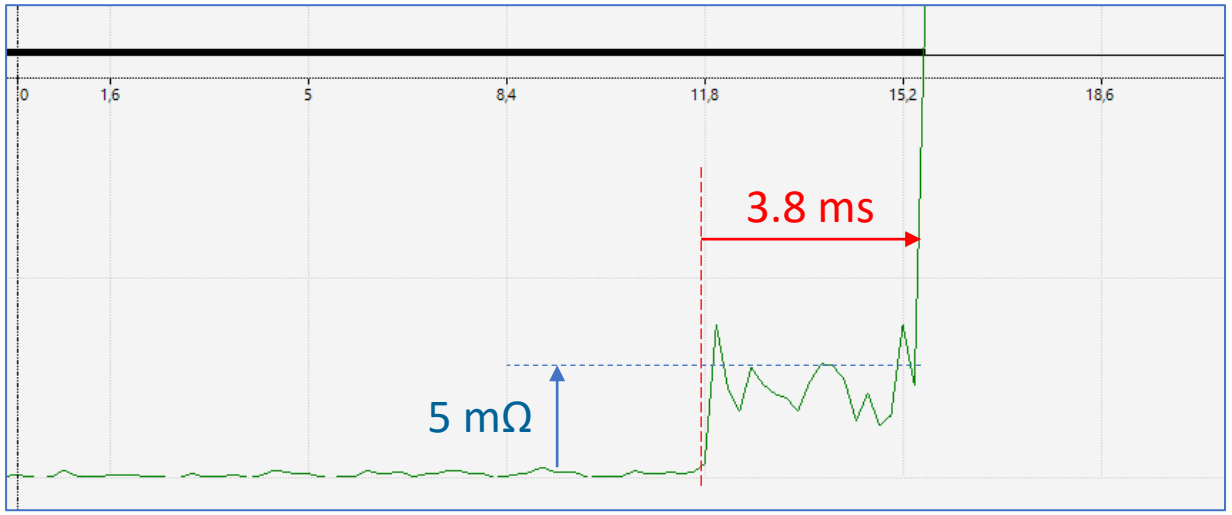
Dynamic contact resistance

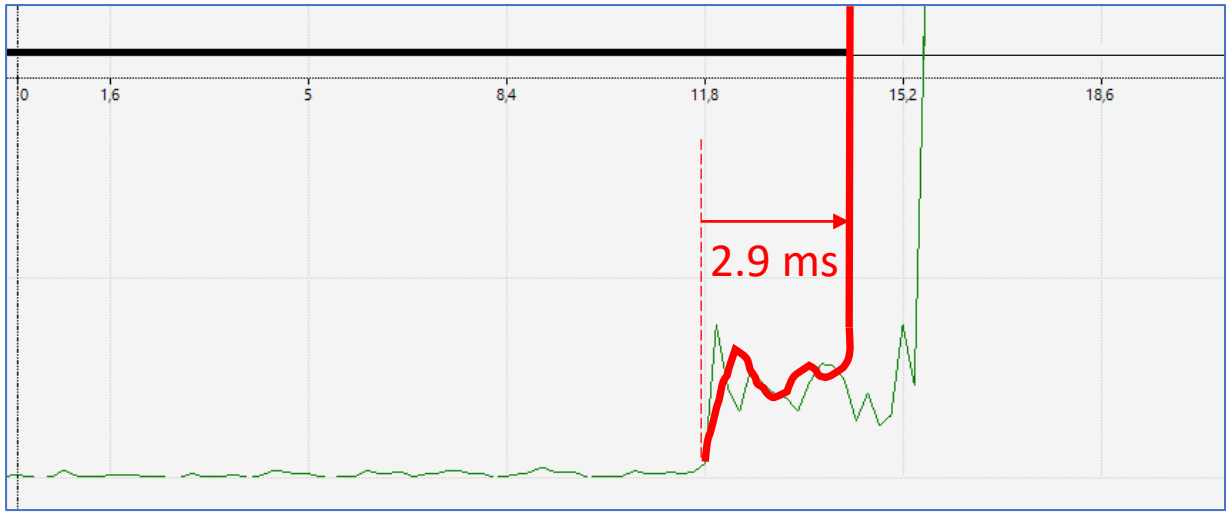




Main breaker contacts

Dynamic contact resistance



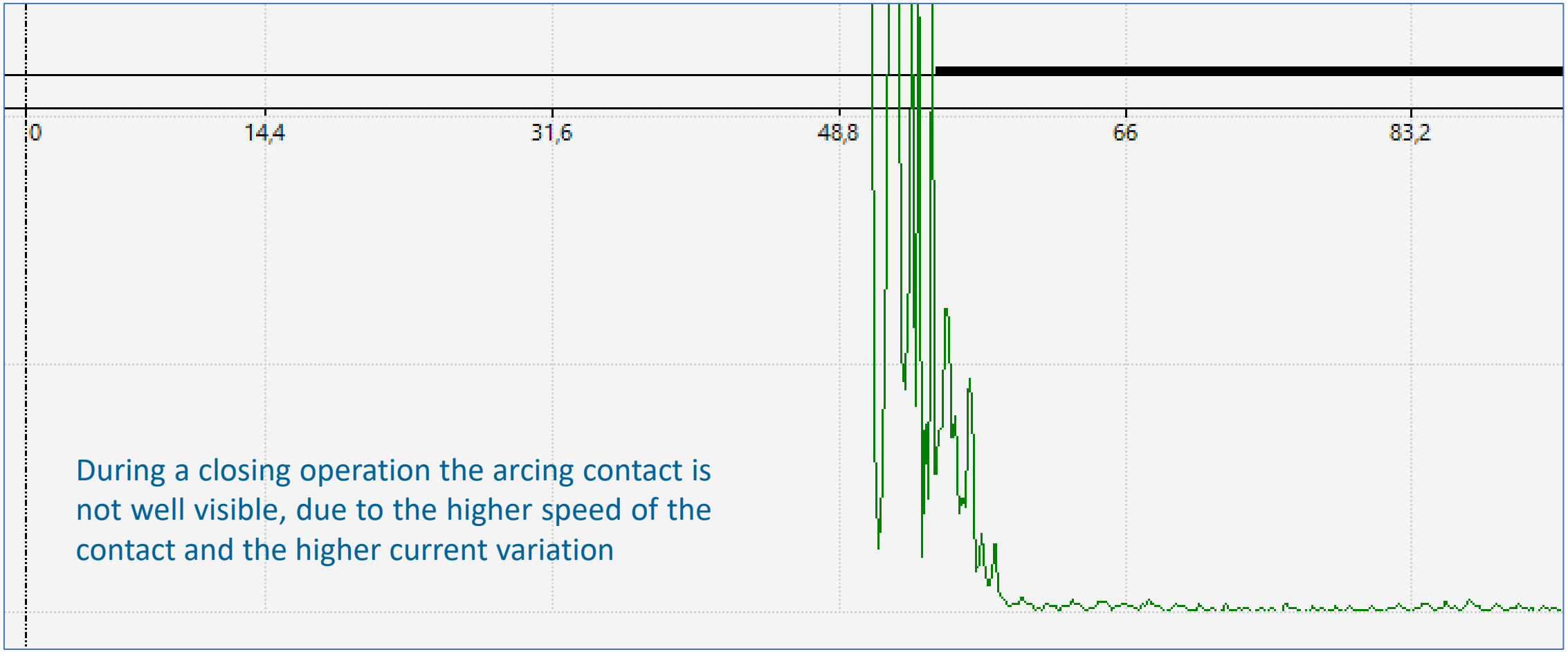


- Each time the CB interrupts the fault current, part of the arcing contact surface burns, then the equivalent length is reduced.
- The arcing contact length reduction can be seen as a reduction of the opening time.
- The length can be measured in millimeters, but the use of movement transducers is required (explained later on)

The minimum acceptable length is defined by the CB manufacturer.

Main breaker contacts

Dynamic contact resistance

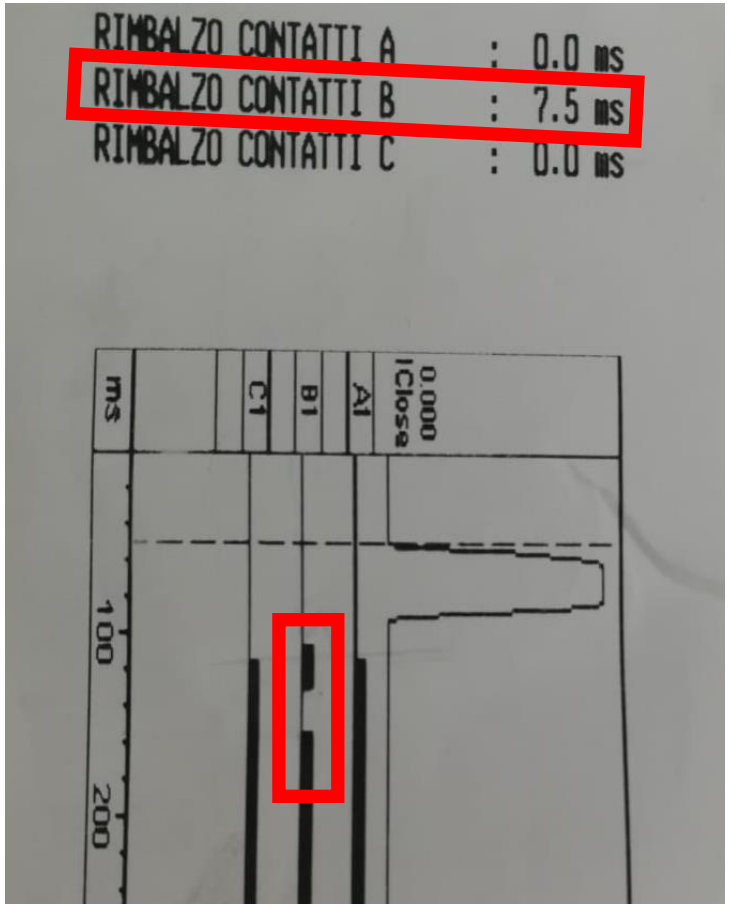


During a closing operation the arcing contact is not well visible, due to the higher speed of the contact and the higher current variation

Main breaker contacts

Dynamic contact resistance

DCRM can confirm the presence of bounces measures during the timing measurement (performed by ISA CBA 1000)



Bounce detected on phase B after a closing operation

MECHANISMS AND LEVERAGES

Motion Analysis

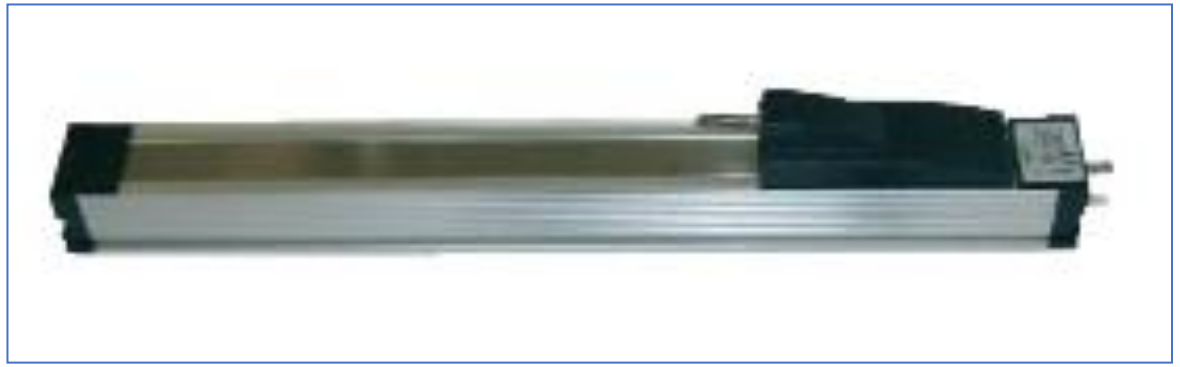
Mechanisms and Leverages

Motion analysis

Motion analysis purpose is to acquire the actual movements of the mechanisms and leverages of the CB during an opening or closing operation.

This is achieved by coupling a position transducers with the CB’s mechanism.

Rotary digital transducer

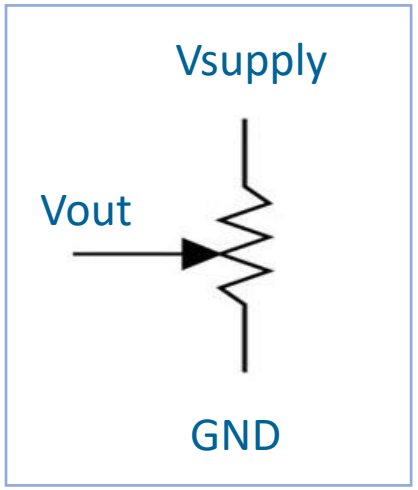


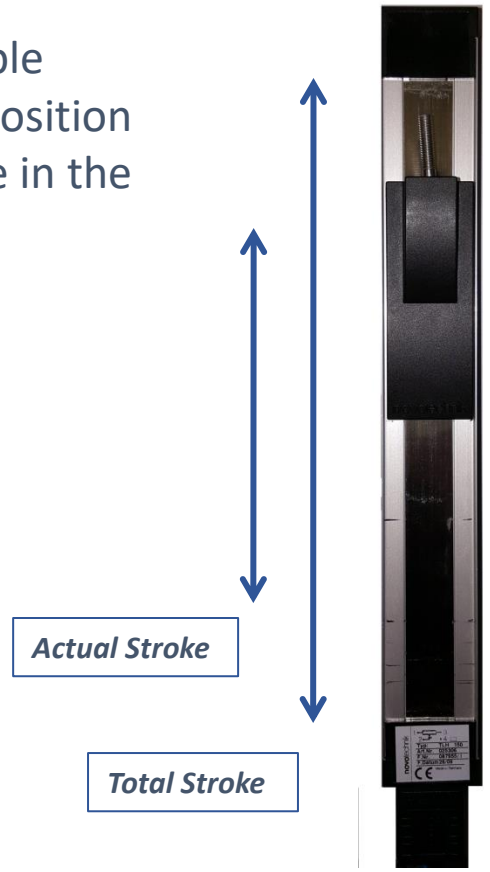
Linear analog transducer

Mechanisms and Leverages

Motion analysis

Analog transducers are variable resistors: depending on the position of the cursor *Vout* has a value in the range *0 V ÷ V supply*





In order to get the trend, expressed in mm, of the actual movements, must be found the following correlation :

$$K = \frac{\Delta V_{out}\ \text{(transducer)}}{\Delta\ mm\ \text{(Circuit Breaker)}}$$

Mechanisms and Leverages

Motion analysis

- ***Transducer voltage supply***
- ***Transducer total stroke***

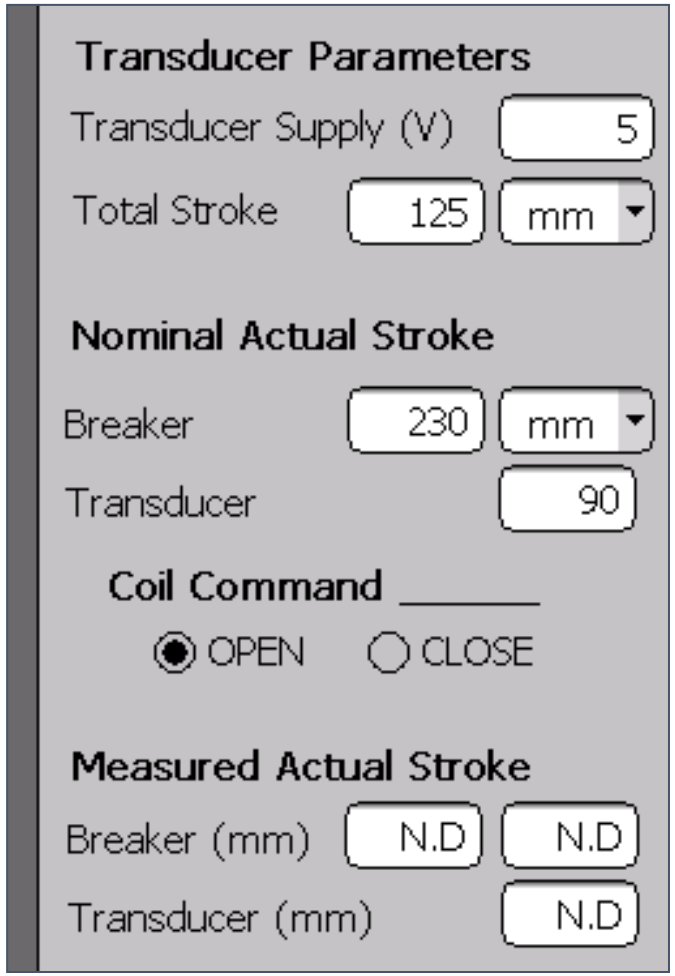
  maximum movement (mm or deg.) of transducer

With this two parameters is possible to obtain the transducers movement (mm) from its measured voltage, during tests.

- ***Nominal actual stroke (Transducer)***
- ***Nominal actual stroke (CB)***

  expected actual travelling values of transducer and CB.

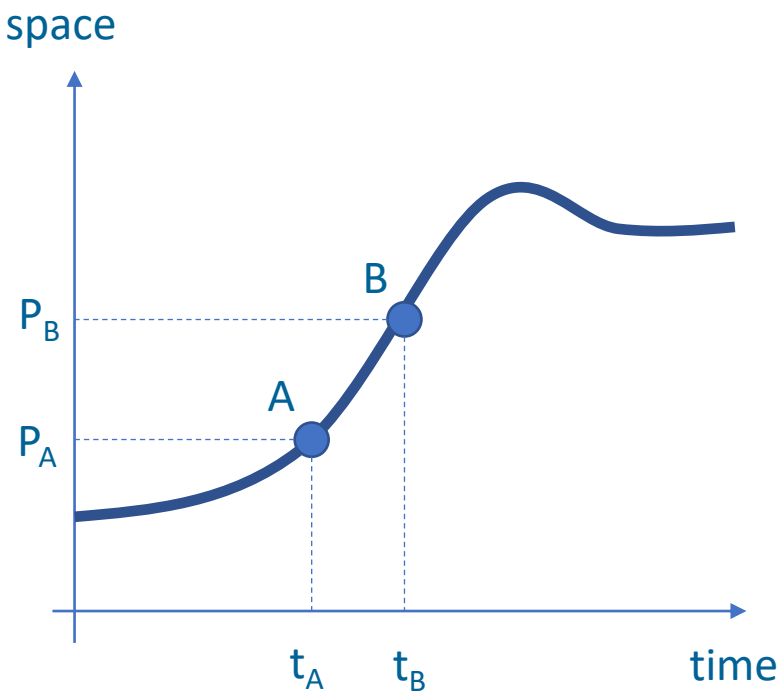
With this two parameters is possible to associate the transducer movement to the CB movement.
When calibrated they get measured and compared.



Mechanisms and Leverages

Motion analysis

SPEED MEASUREMENT: must be defined of two *Datum Points* in order to calculate the speed between them:



$$SPEED = (P_B - P_A) / (t_B - t_A)$$

Mechanisms and Leverages

Motion analysis – Datum Point definitions

INDEPENDENT DATUM POINTS

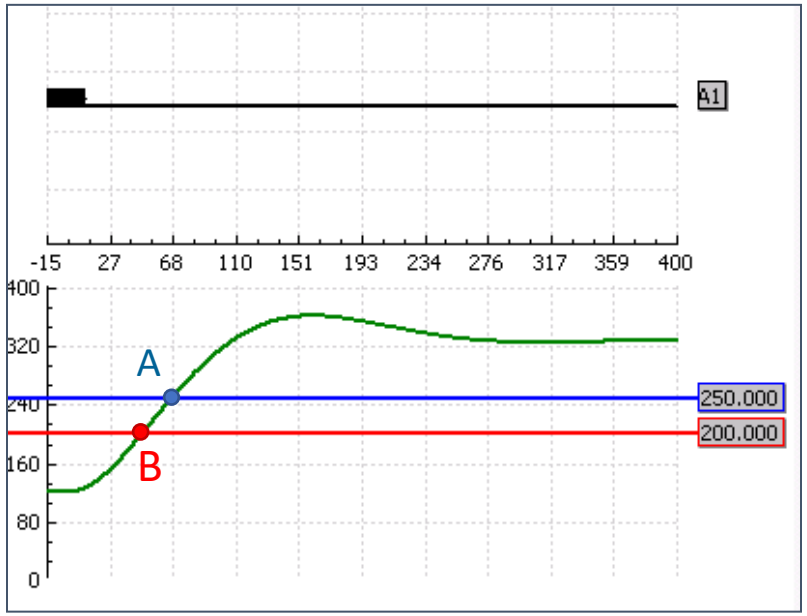
Datum A and Datum B can be placed where you like

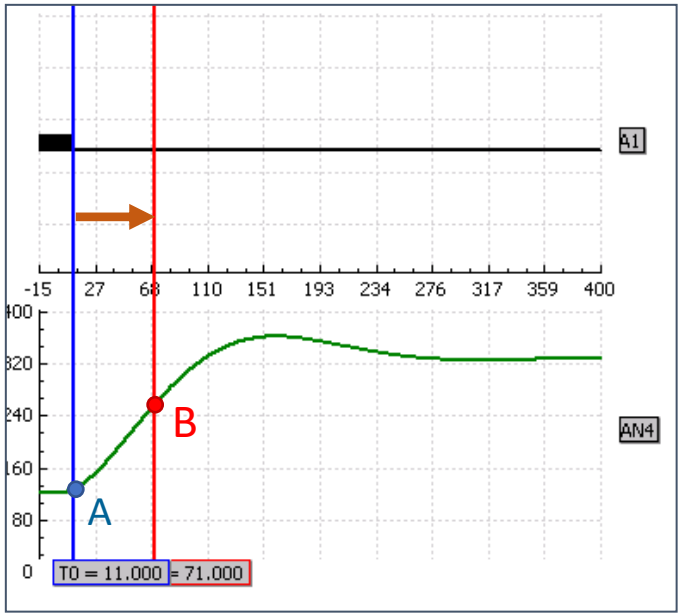
TIME OFFSET

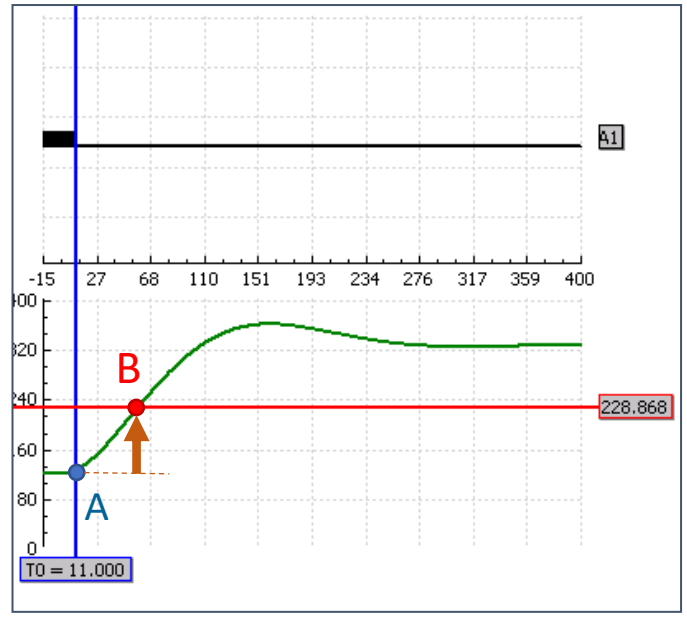
Datum A: automatically placed at the transition CO or OC
Datum B: placed at a predefined time offset from the transition

DISTANCE OFFSET

Datum A: automatically placed at the transition CO or OC
Datum B: placed at a predefined distance offset from the transition

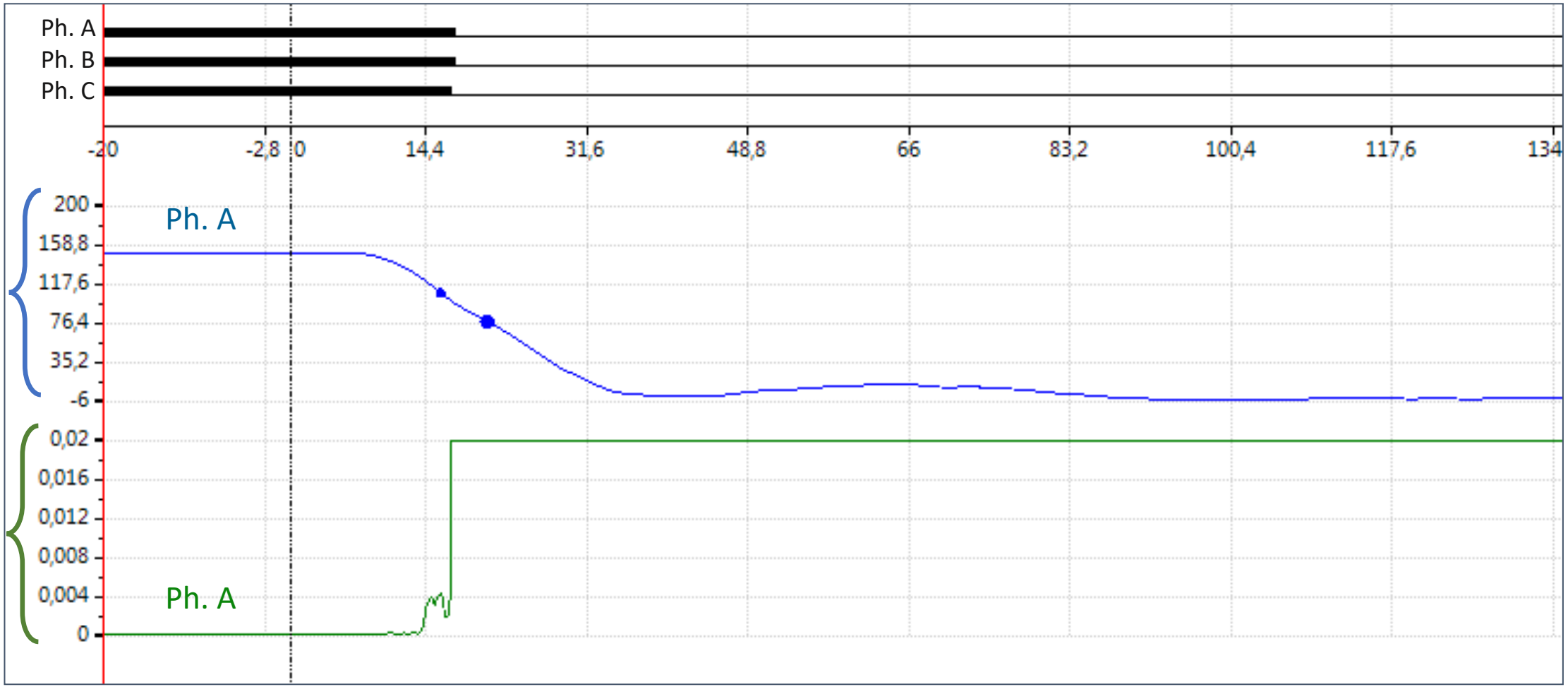






Mechanisms and Leverages

Motion analysis – Test example

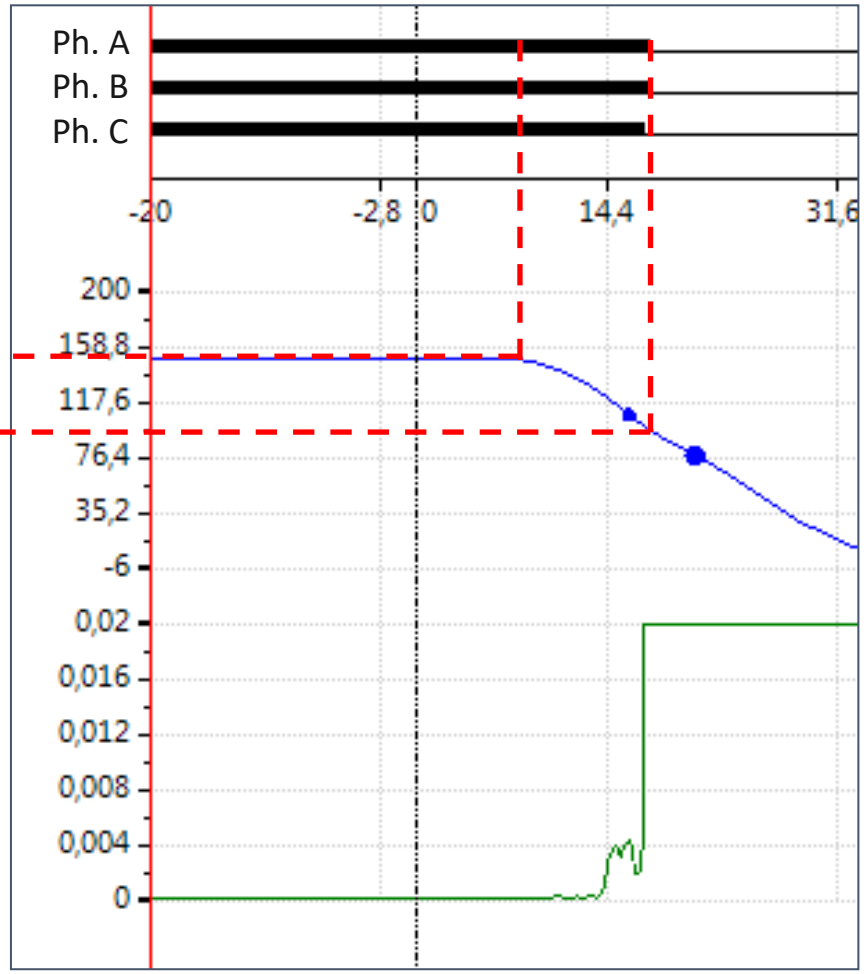


Dynamic resistance open test with motion analysis

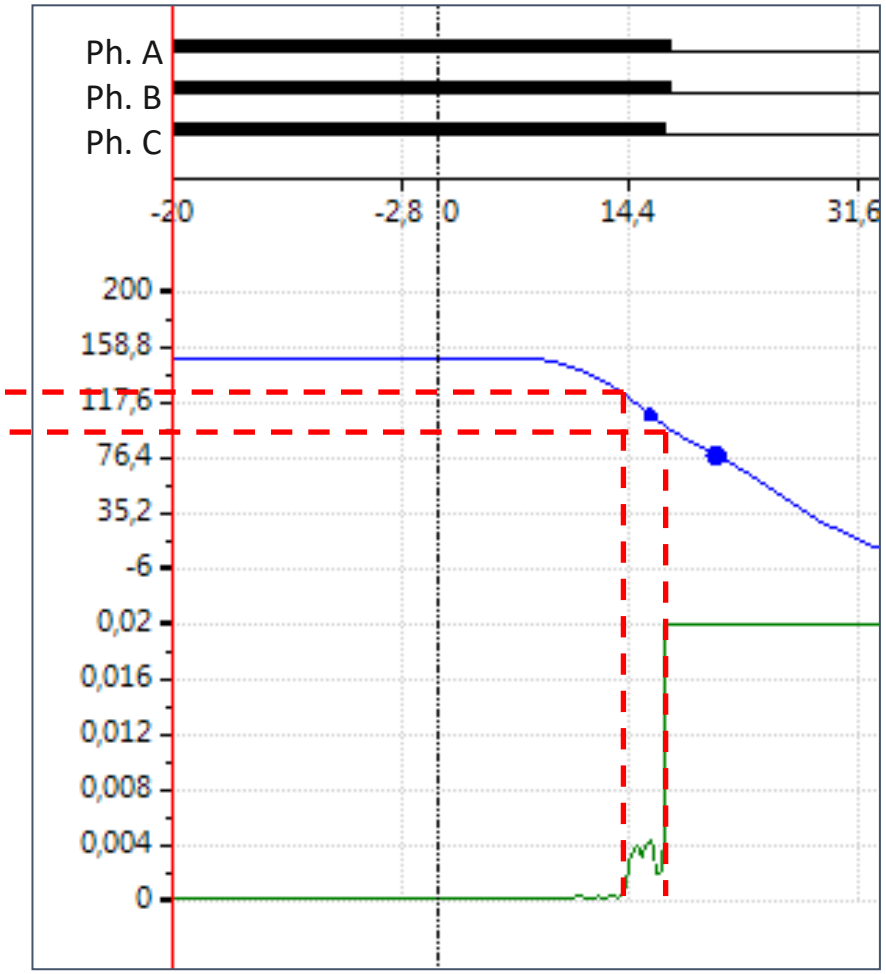
Mechanisms and Leverages

Motion analysis

Main contact wipe **58.7 mm**

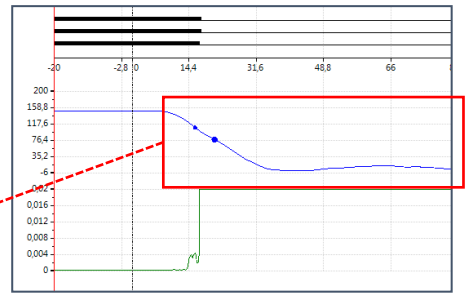


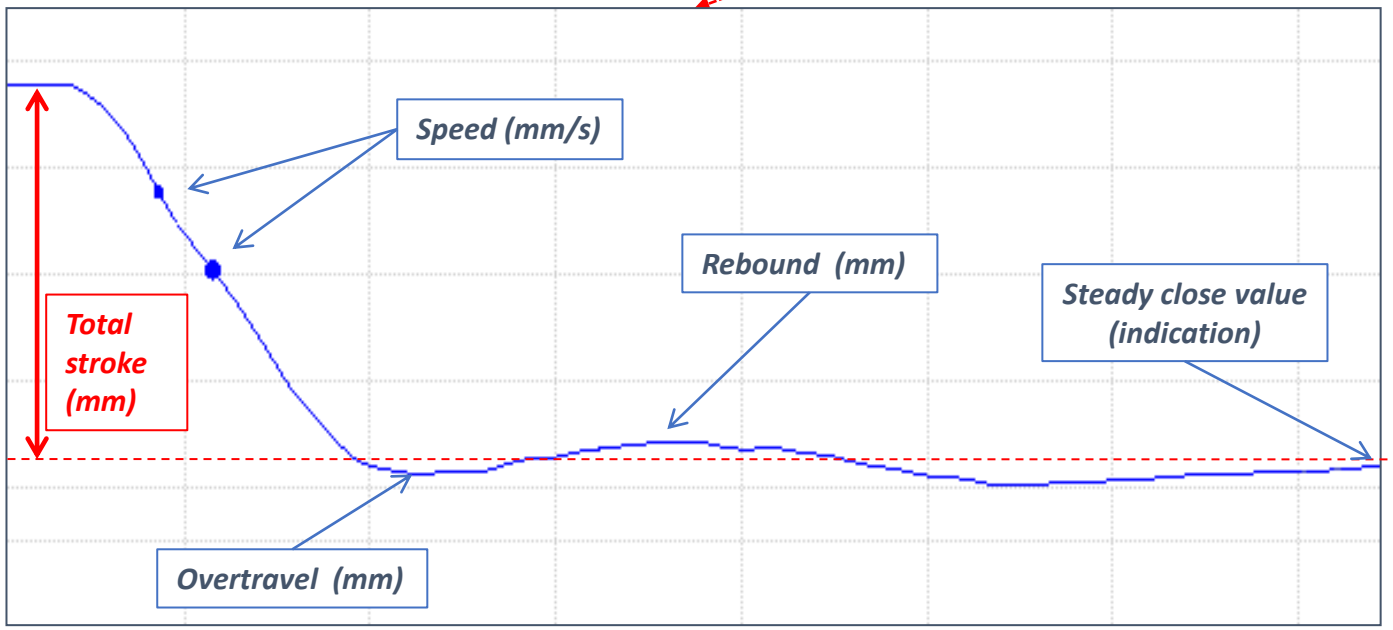
Arcing contact length **25 mm**



Mechanisms and Leverages

Motion analysis



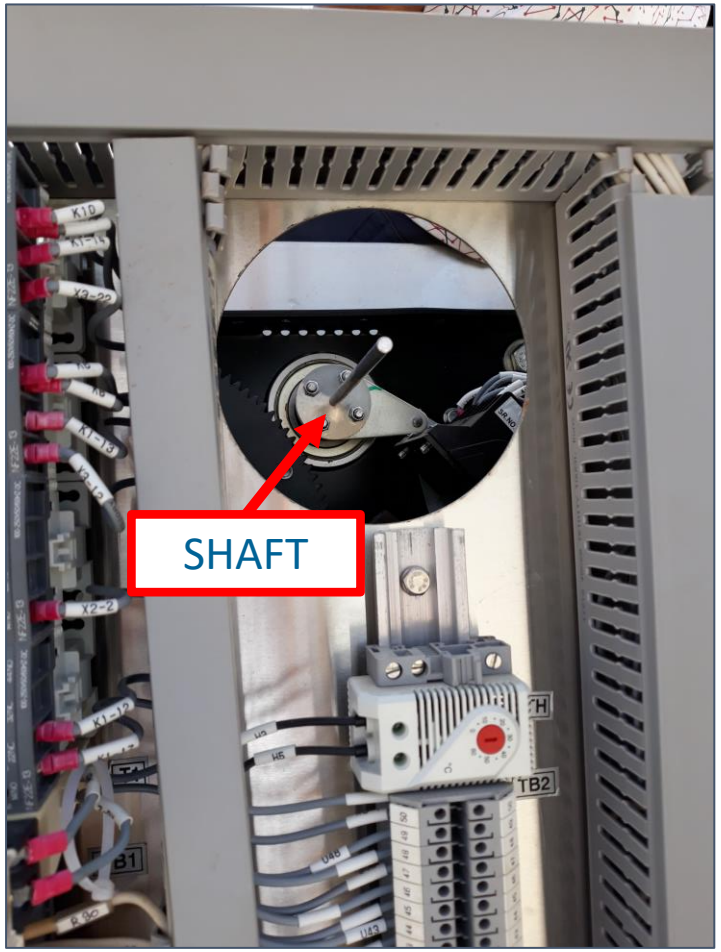


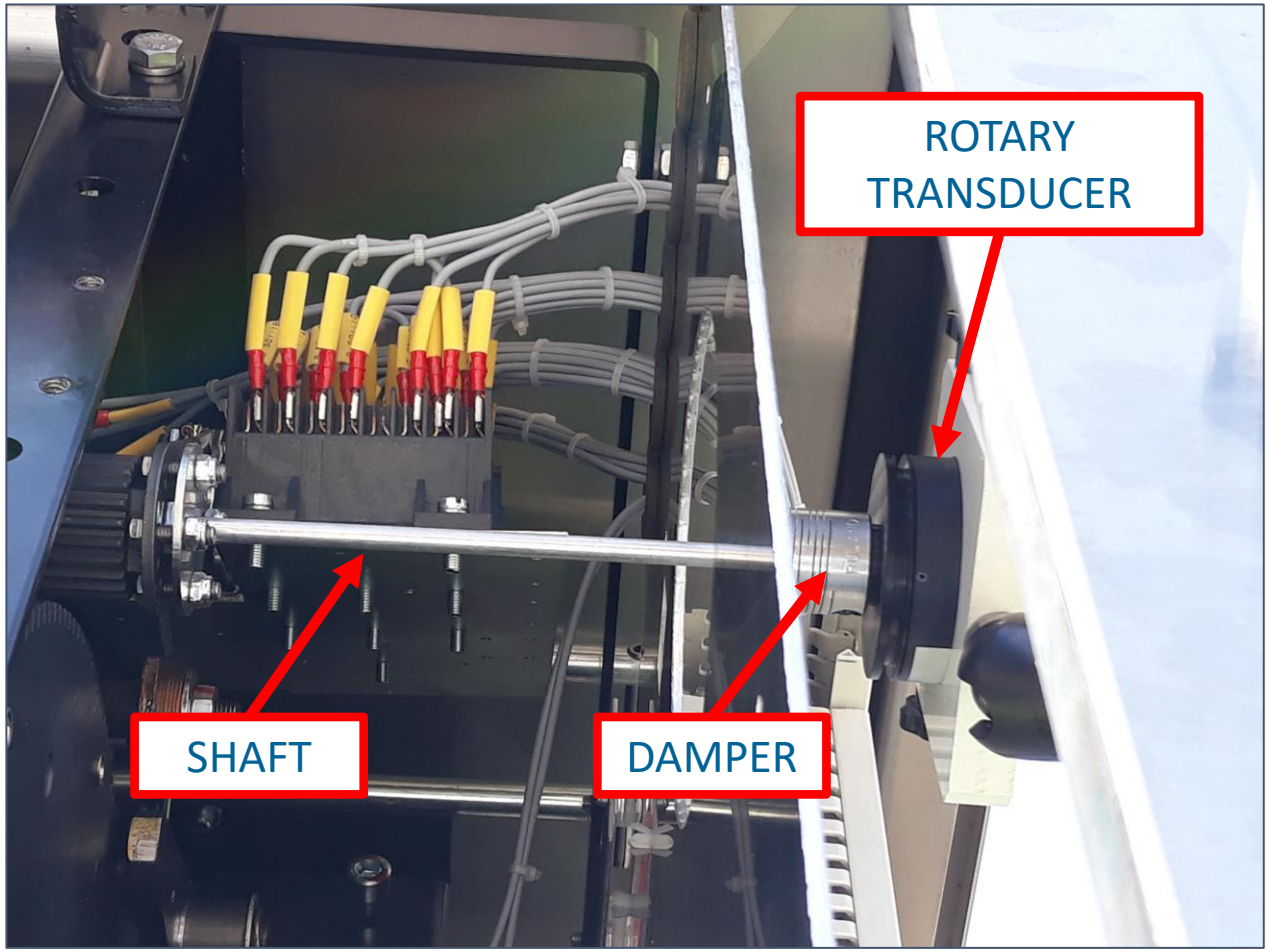
Description	Value	Unit
Session Date	18/01/2...	
O Coil Current A	2,024	A
Flow Time O Coil Curr. A	16,4	ms
Open Time A	17	ms
Wipe A	58,699	mm
CO Overtravel A	5,871	mm
CO Rebound A	11,22	mm
Breaker Speed (CO) A	5,555	m/s
Total Stroke Open A	149,345	mm

Measured values from motion analysis

Mechanisms and Leverages

Motion analysis – Mounting example





Mechanisms and Leverages

Motion analysis - Mounting example

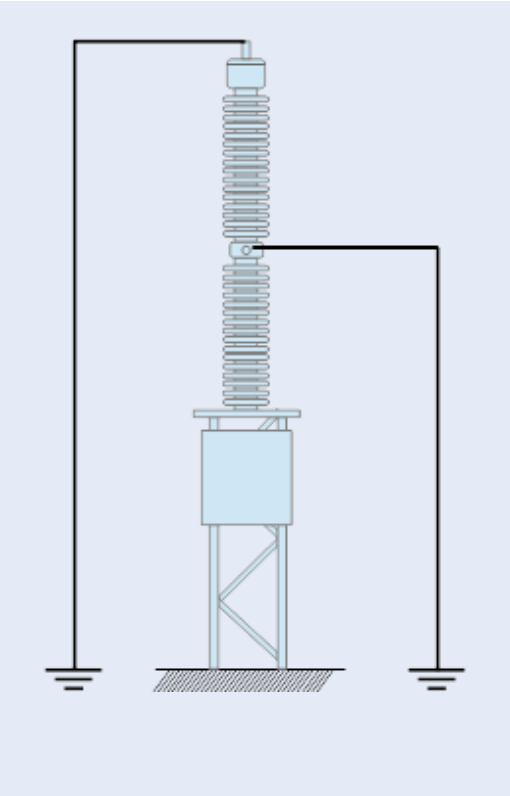
WORKING IN SAFE CONDITIONS

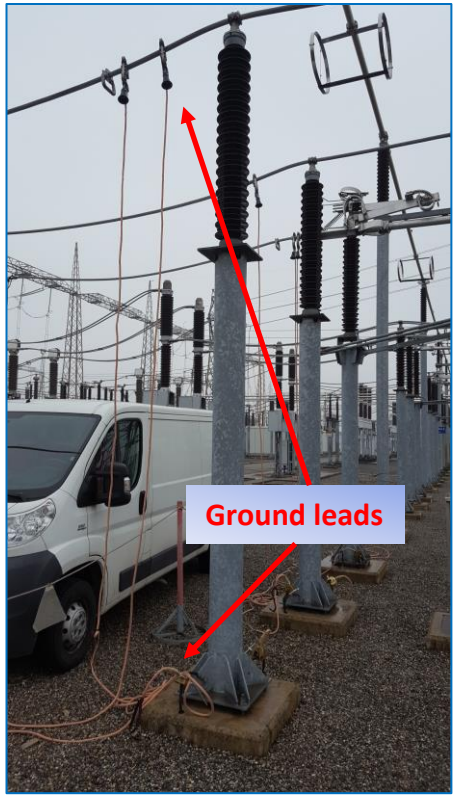
CB Both Sides Grounded

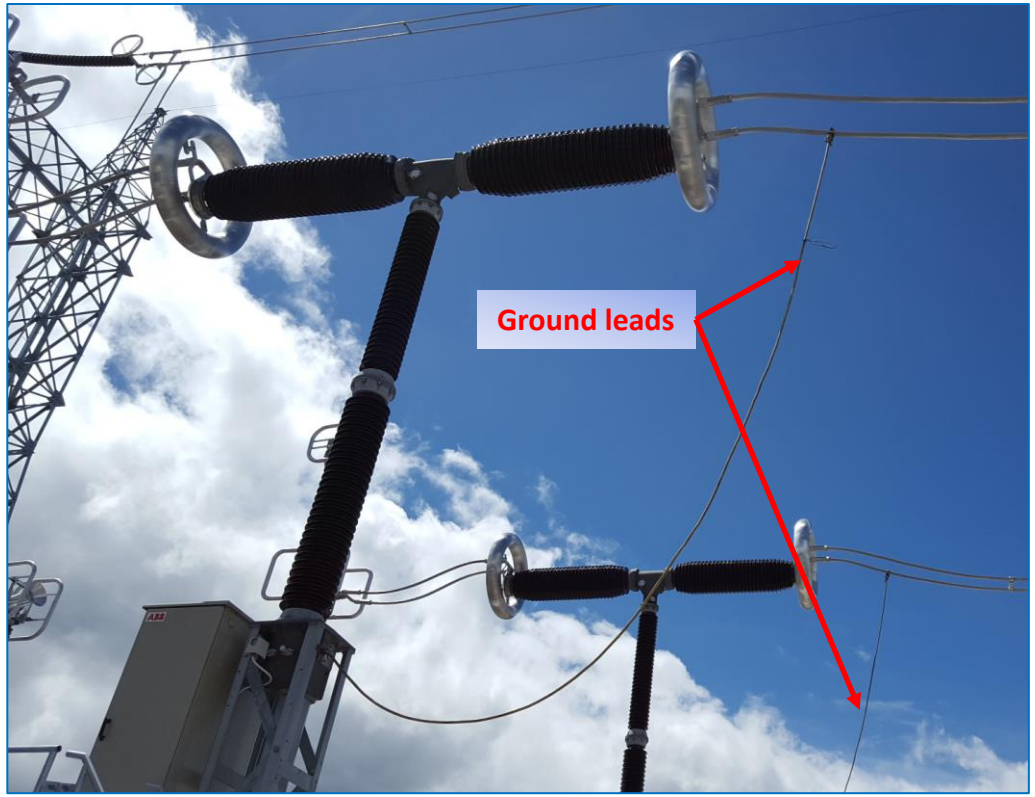
Working in safe conditions

CB Both Sides Grounded

When the CB is out of service, due to safety reasons, the two sides must be connected to the ground grid





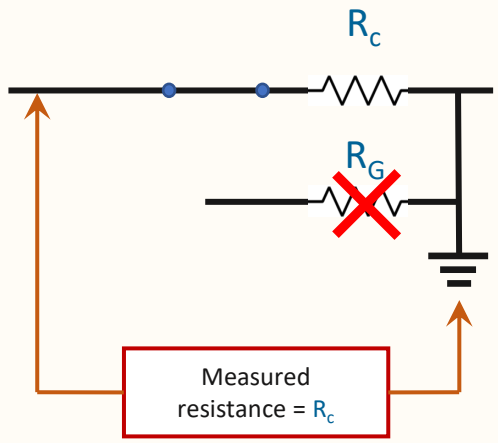


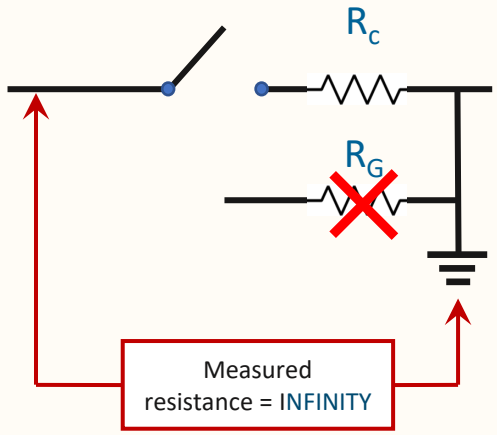
Working in safe conditions

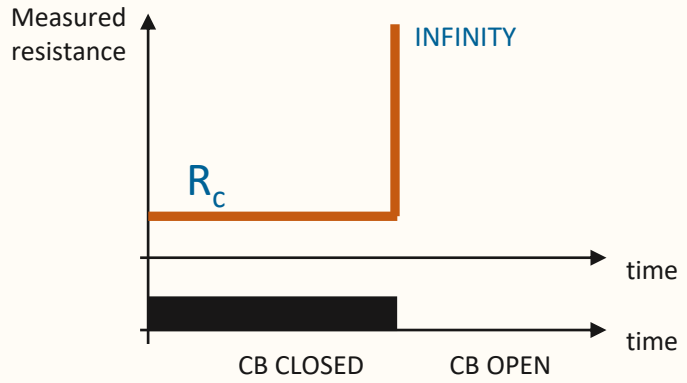
CB Both Sides Grounded

This means that the ground leads and the substation ground grid are connected in parallel to the main contacts

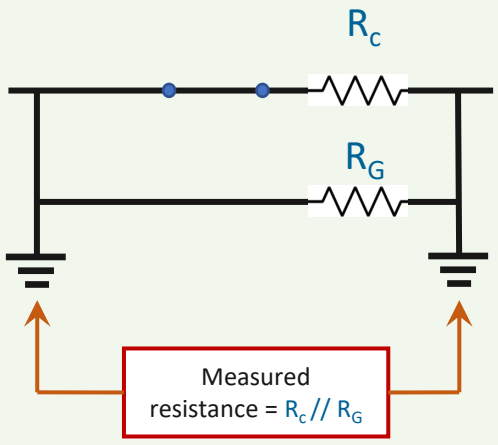
ONE SIDE GROUNDED

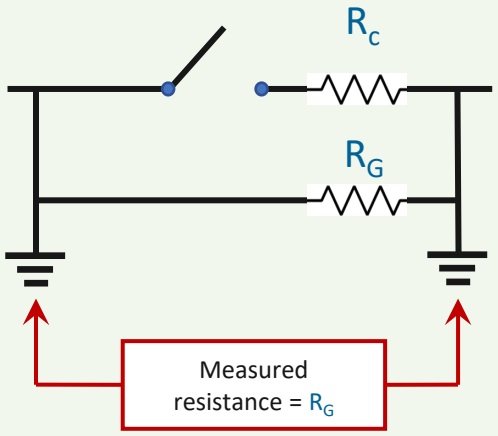


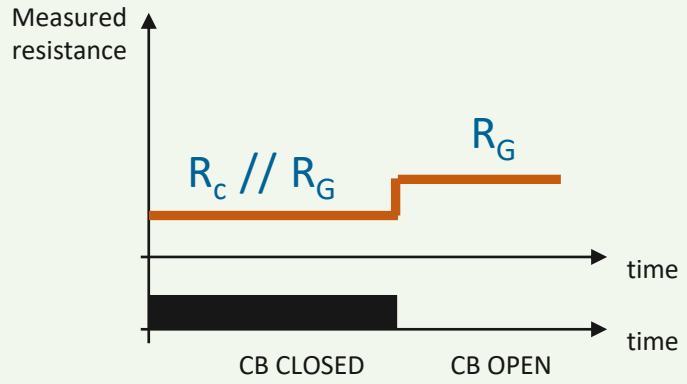




BOTH SIDES GROUNDED







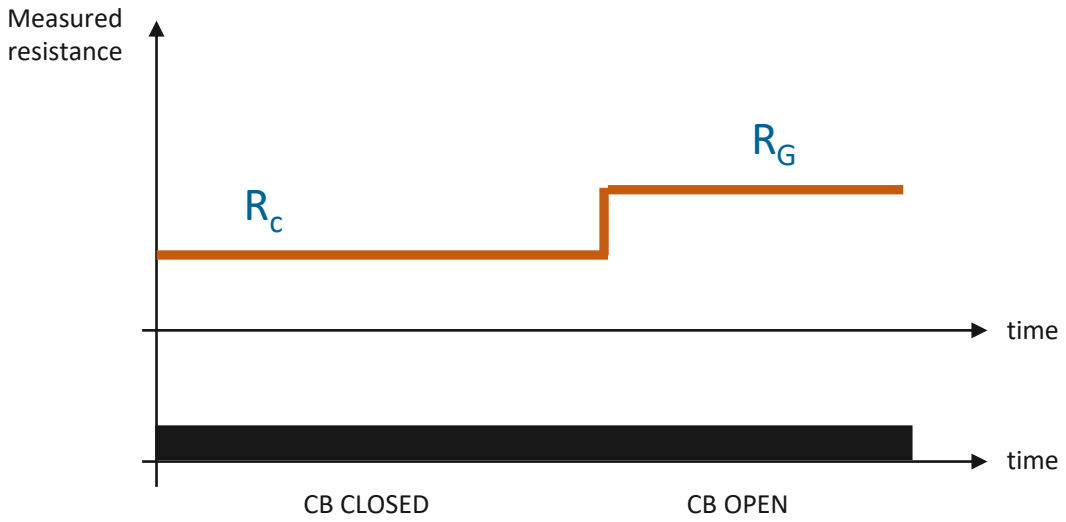
Working in safe conditions

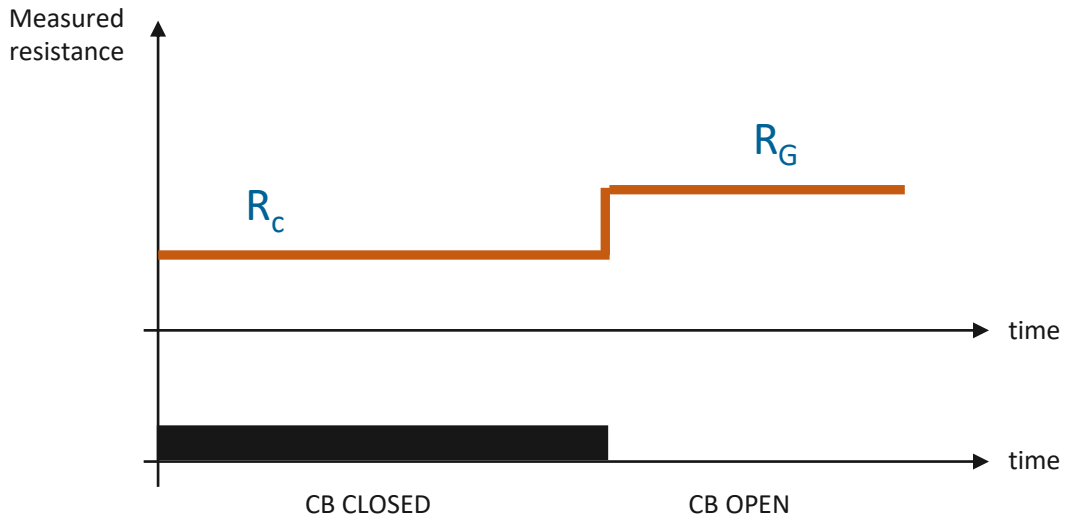
CB Both Sides Grounded

R_c : tens of μΩ

R_G : hundreds of mΩ

$R_c // R_G \approx R_c$: tens of μΩ





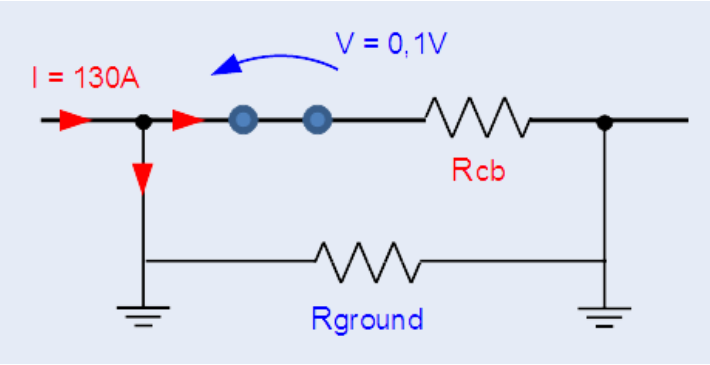
The traditional method for the timing measurement is not sensitive enough to detect such small resistance variation

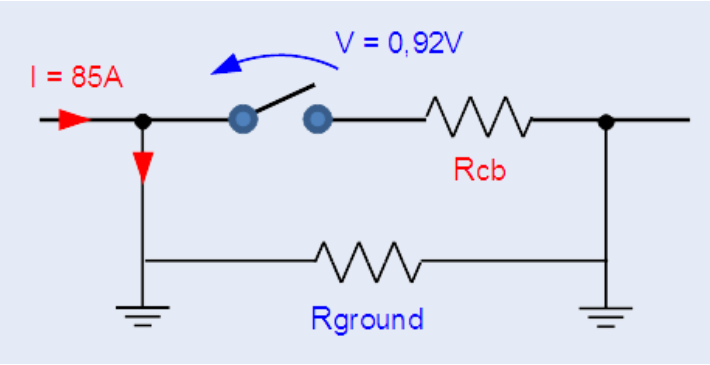
AN ADVANCED METHOD IS REQUIRED

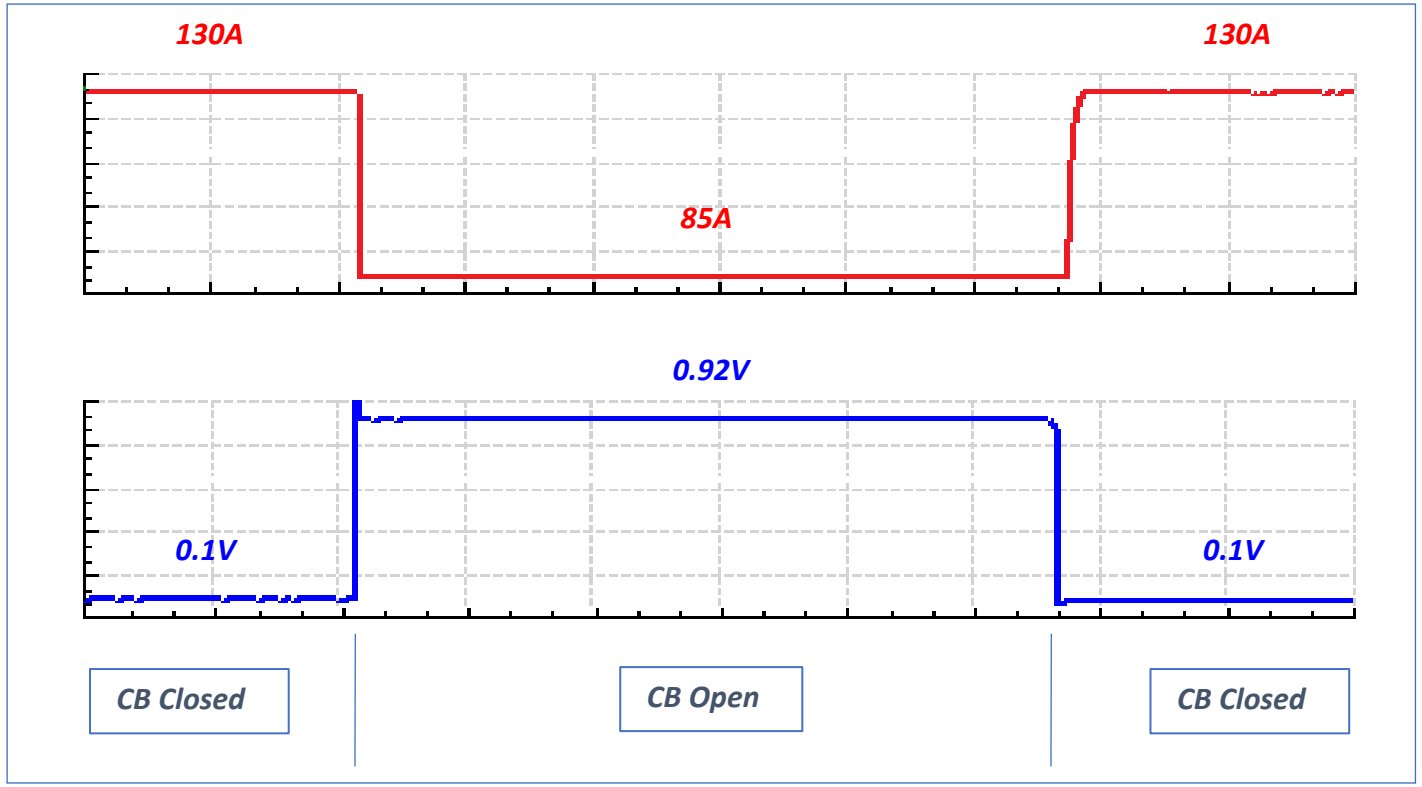
Working in safe conditions

CB Both Sides Grounded

The advanced method consists in the injection of high DC and therefore in the evaluation of the voltage / current variations during the opening and closing operations

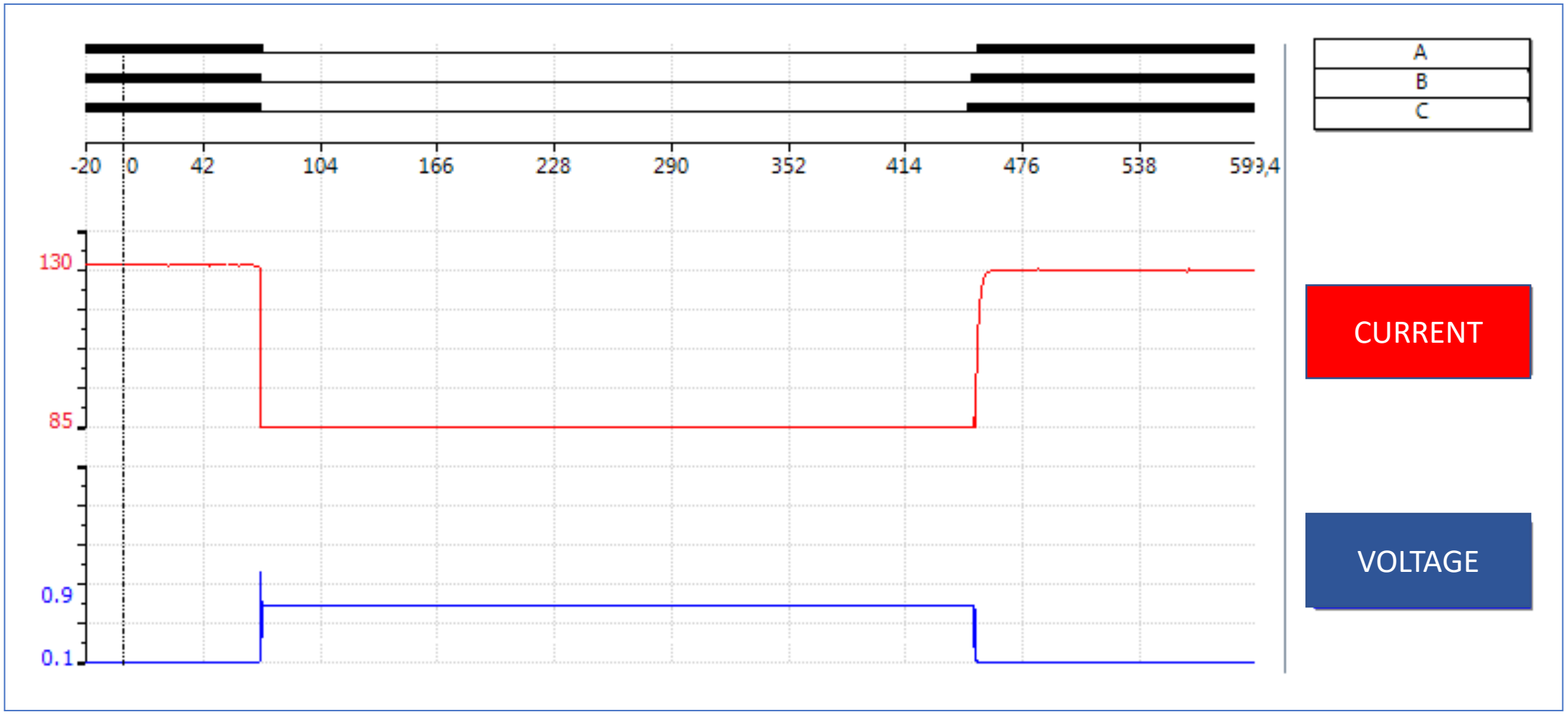






Working in safe conditions

CB Both Sides Grounded

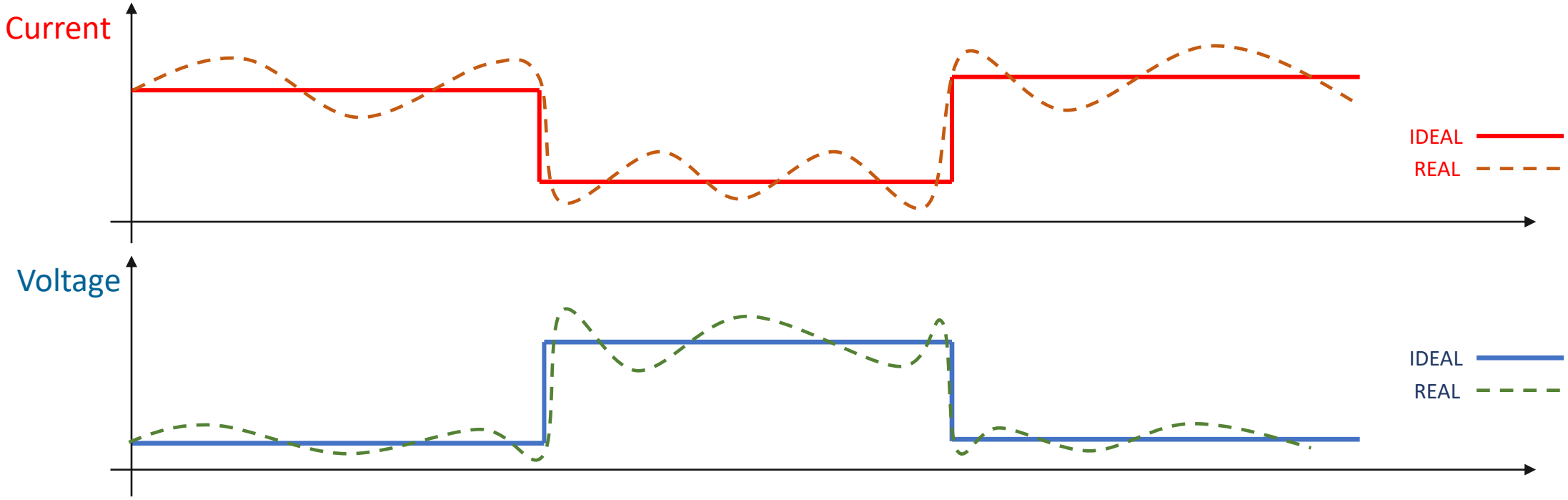


Working in safe conditions

CB Both Sides Grounded

ISSUE: The voltage of a near live busbar induces current in the testing cables and into the ground leads, the time and the resistances accuracy measure can be badly affected

SOLUTION: Inject high current values and filter out the noise signals.
The current amplitude must be very stable, the generators must not introduce false variations.

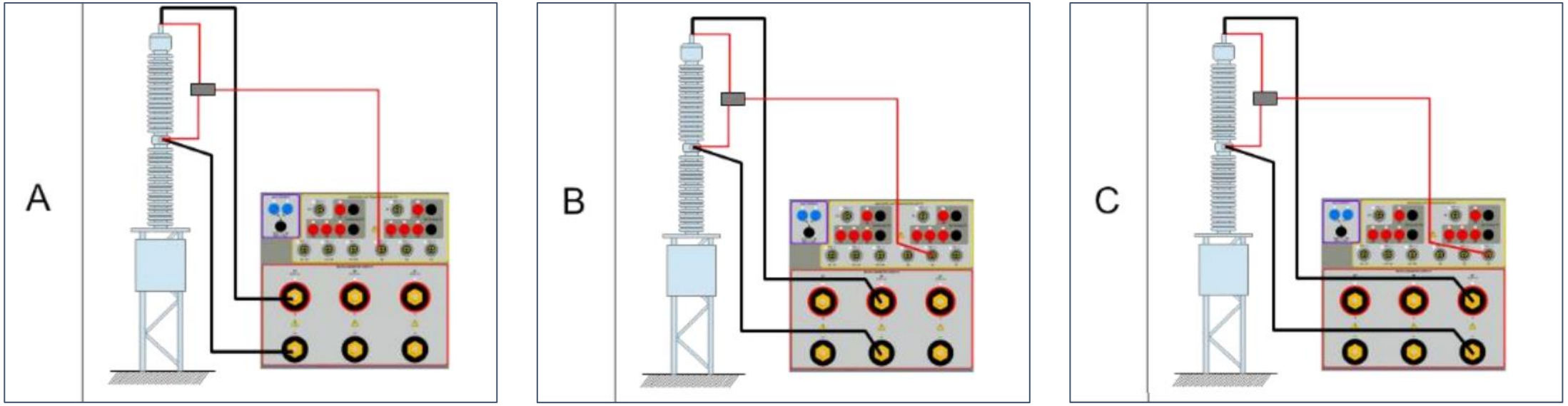


Working in safe conditions

CB Both Sides Grounded

A SINGLE SETUP FOR ALL THE MEASUREMENTS !

The measurment setup for the timing test in BSG mode is the same also of the static and dynamic contact resistance measurement.



Example: one break per phase CB in BSG mode

CBA 3000

Quick overview

CBA 3000

Quick overview – Timing inputs

Board 1

Board 2 *

Board 3 *

* optional

Each timing input board has 8 inputs.

The timing input board can be provided in two different models:

STANDARD board

Available settings:
- Main
- Auxiliary Dry
- Auxiliary Wet: 15V or 77V

Other features:
- P.I.R. detection

ADVANCED board

Available settings:
- Main
- Auxiliary Dry
- Auxiliary Wet: settable voltage

Other features:
- P.I.R. detection
- P.I.R. measurement
- Transducer testing

CBA 3000

Quick overview – Coil commands

Board 1

Board 2 *

Board 3 *

* optional

Each Coil Command board has 2 commands.

Possible settings:

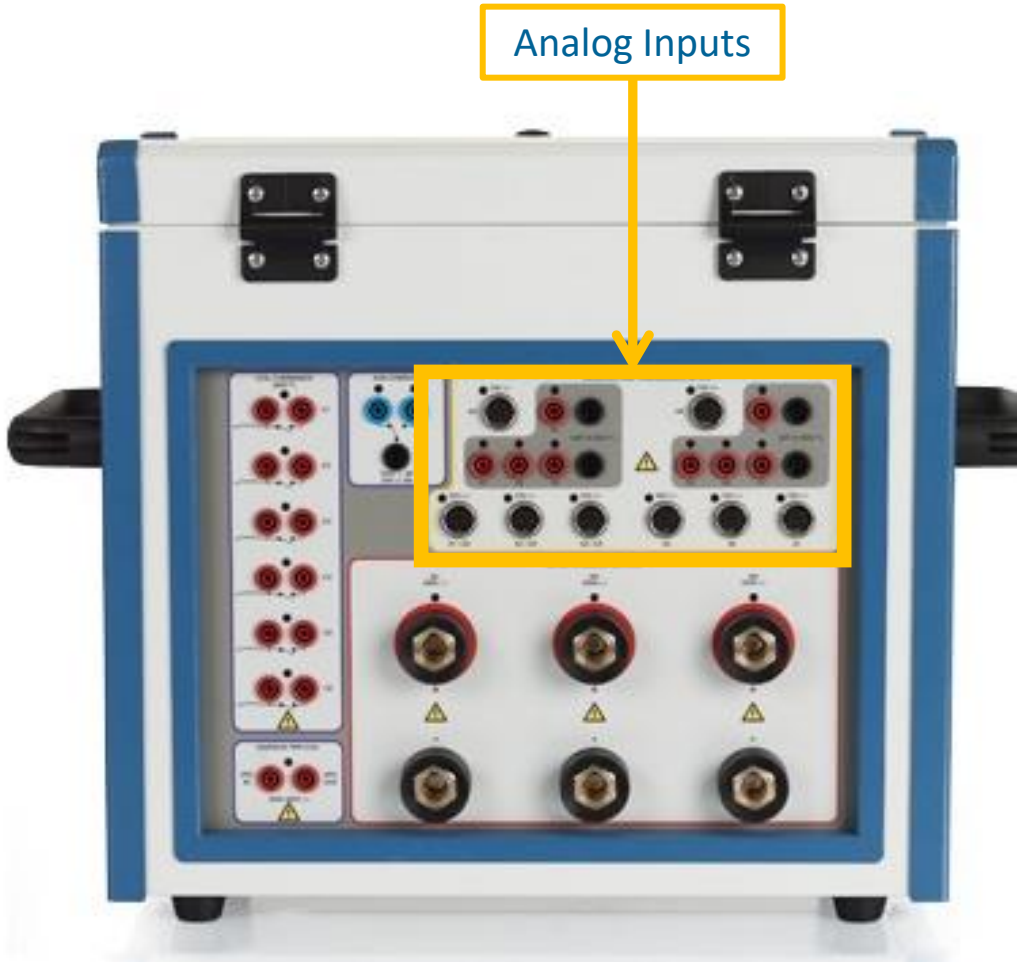
- Open coil
- Close coil

- Phase selection
  (A – B – C – ND)

- Range of measure:
  (3A – 10A – 60A)

CBA 3000

Quick overview – Analog Inputs



Each input is freely programmable as:

- **Analog IN**
  generic voltage input

- **Micro-ohmmeter**

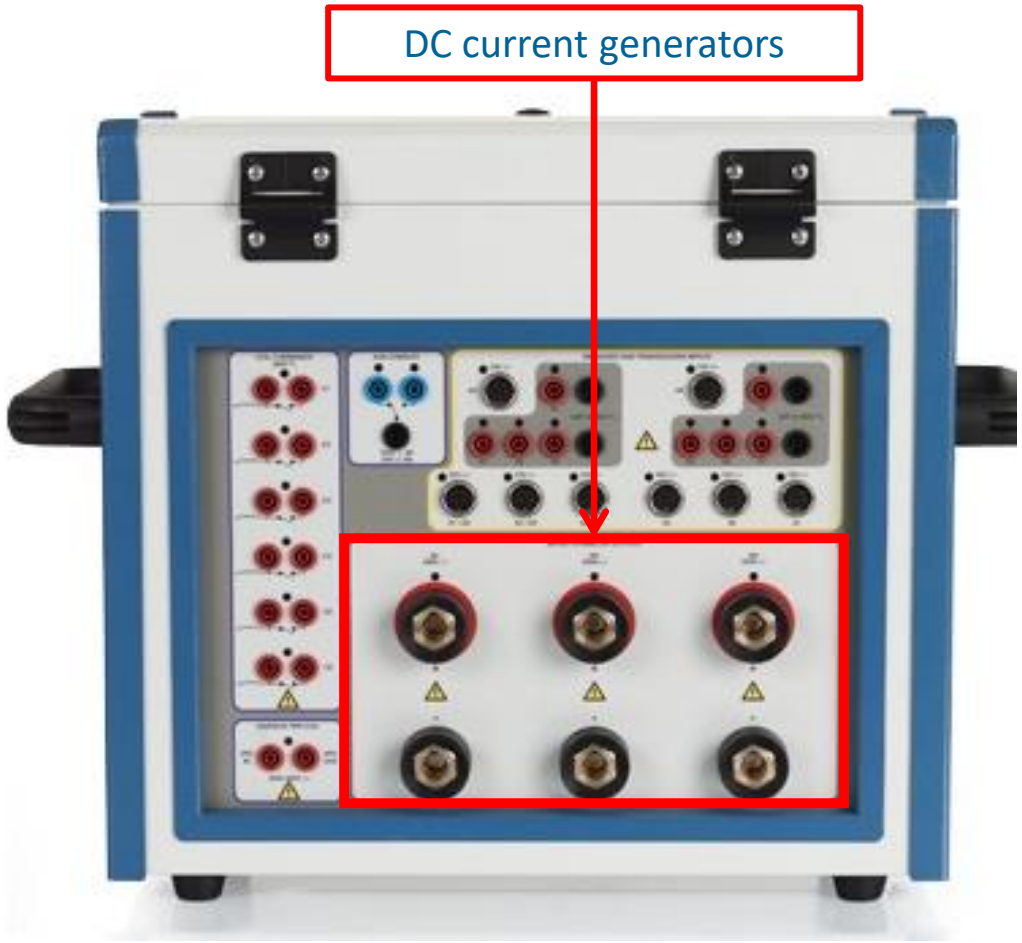
- **Analog/Digital Travel transducer**
  for Motion analysis of circuit breakers

- **Current clamp**
  allows to directly measure/visualize the current flowing through the primary side of a clamp

- **Pressure transducer**
  allows to directly measure/visualize the pressure of SF6 gas taken from a transducer

CBA 3000

Quick overview – DC current generators



DC current generators allow to perform static and dynamic resistance tests with a current value up to 200 Adc.

Generation of current can be sustained for seconds, allowing to perform every necessary test.

The generators installed can be 0, 1 or 3. The advantage of having 3 generator is the possibility to perform faster three phase tests, and the possibility to perform tests in BSG mode.

CBA 3000

Quick overview - Software

Instrument settings

Test Plan

Test and Result

Instrument settings
Choice of the right configuration for the tests to be executed

- **Test Plan**
definition of a list of tests to be executed in sequence

- **Test and Results**
test execution and results visualization

CBA 3000

Quick overview – Instrument settings

Predefined configurations are available for an easy and quick setting of the instrument

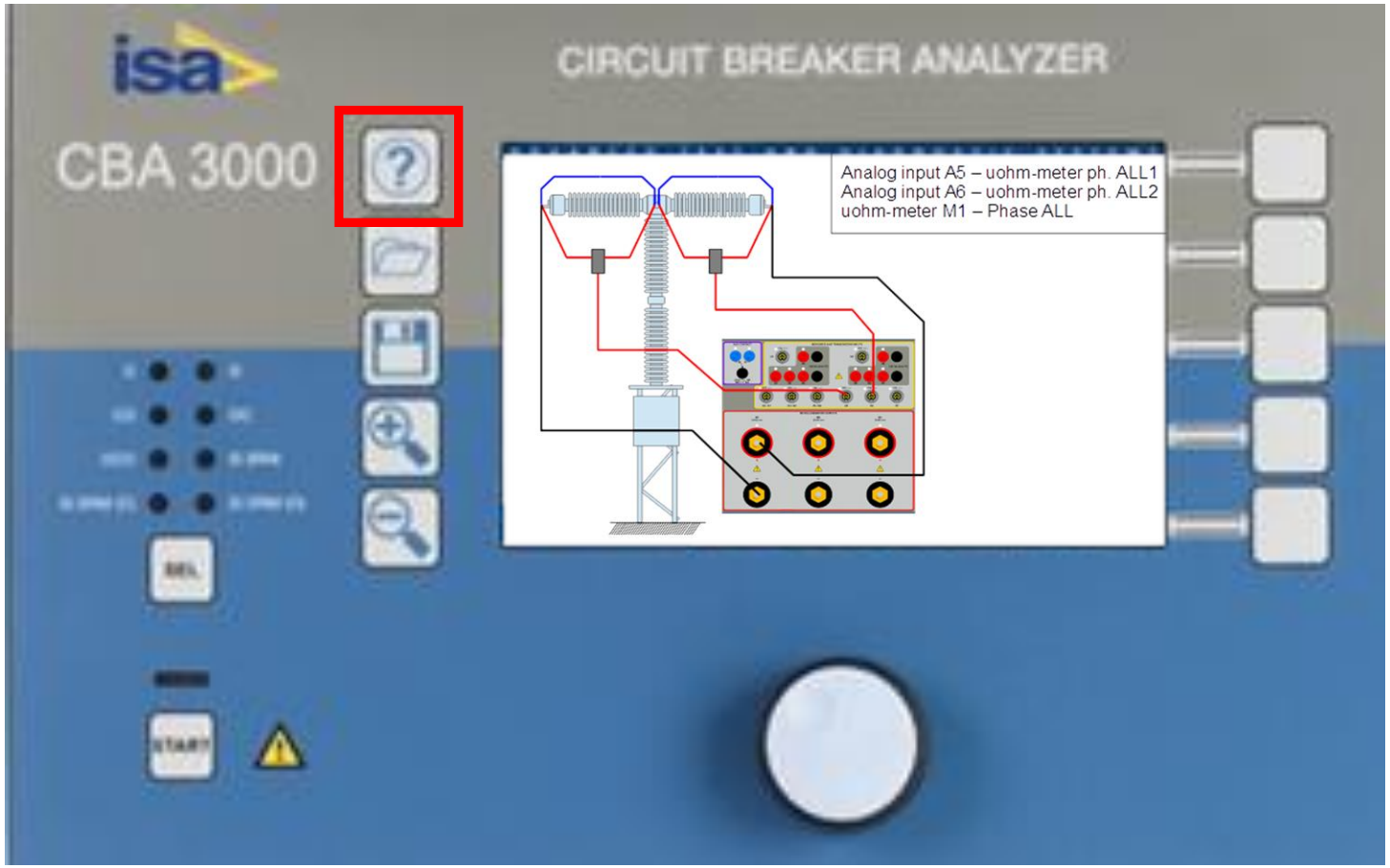
PREDEFINED CONFIGURATIONS

Circuit Breaker Type	Break Numbers	1
	Open Coils	1
	Close Coils	1
Hardware CBA	Micro-ohm-meters in use	0
Features	Both Side Grounded	No
	Pre Insertion Resistor	No
Accessories	Travel Transducers	None

CBA 3000

Quick overview – Instrument settings

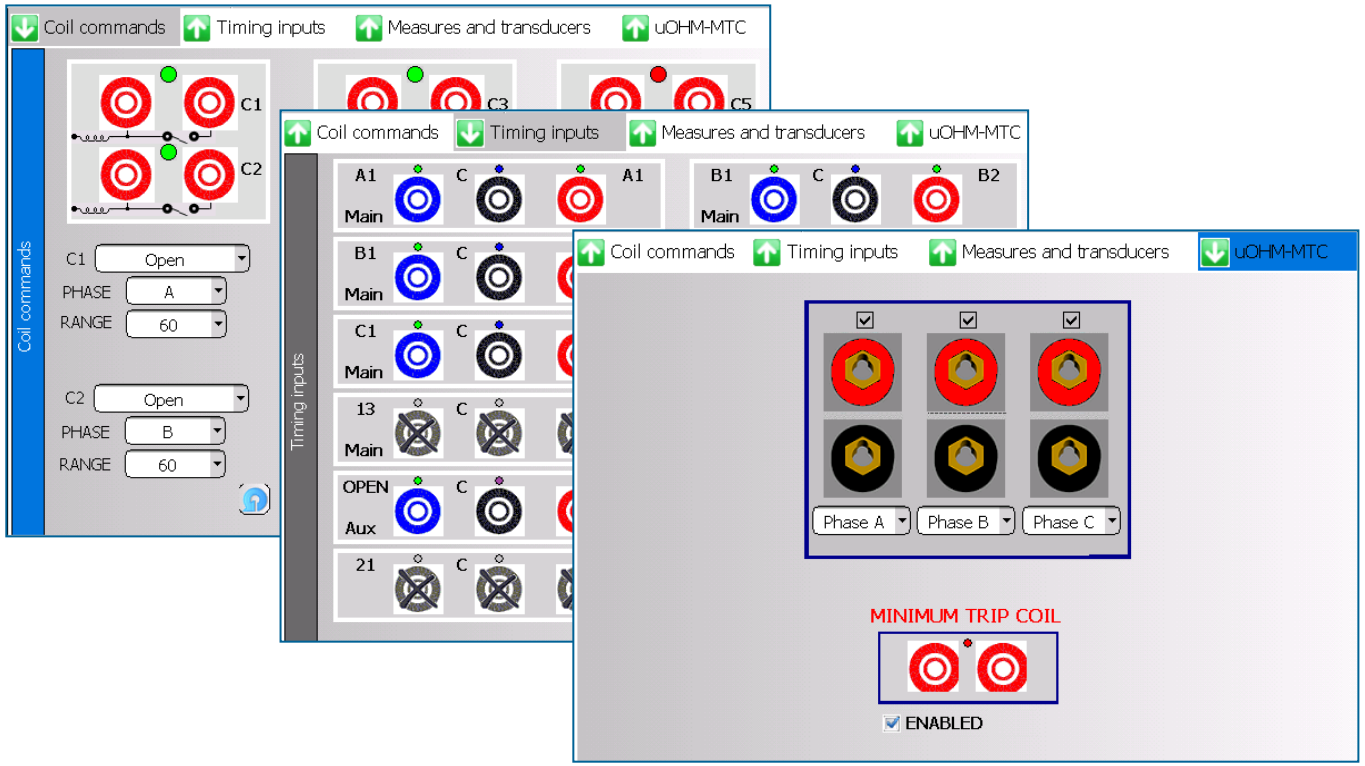
To use the predefined configurations allows the possibility to show setup connections, pressing the help button.



CBA 3000

Quick overview – Instrument settings

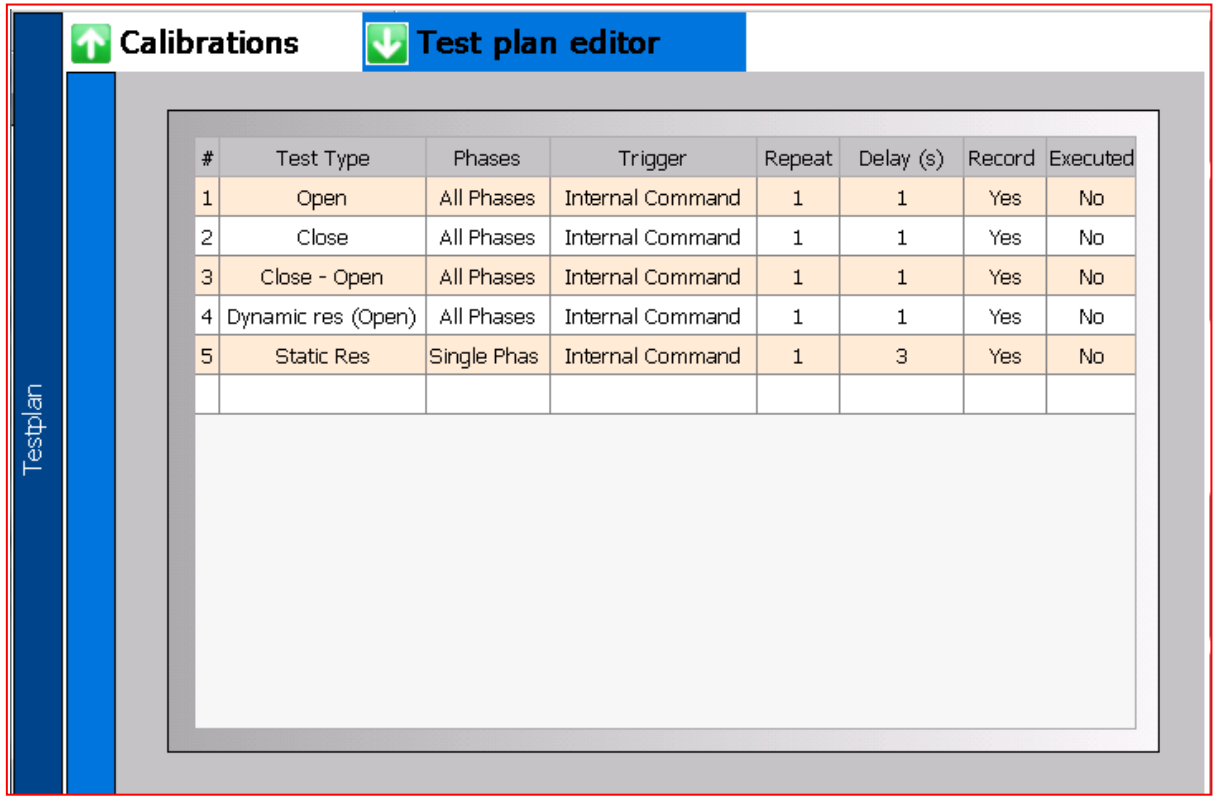
Custom configurations allow to manually set every input/output of CBA3000 as you like



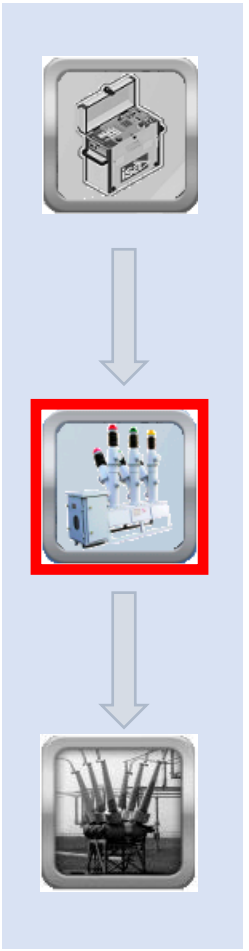
CBA 3000

Quick overview – Test Plan

In the Test Plan section it is possible to define a list of operations to be executed in sequence



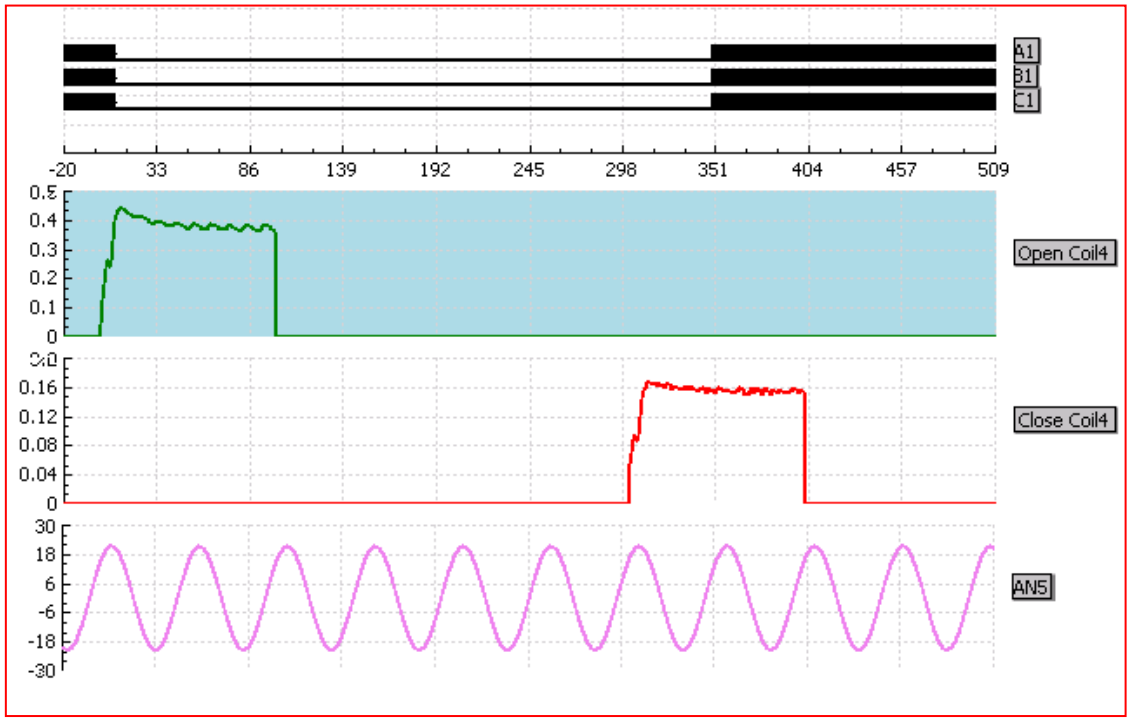
#	Test Type	Phases	Trigger	Repeat	Delay (s)	Record	Executed
1	Open	All Phases	Internal Command	1	1	Yes	No
2	Close	All Phases	Internal Command	1	1	Yes	No
3	Close - Open	All Phases	Internal Command	1	1	Yes	No
4	Dynamic res (Open)	All Phases	Internal Command	1	1	Yes	No
5	Static Res	Single Phas	Internal Command	1	3	Yes	No



CBA 3000

Quick overview – Test & Result

In the Test & Result section it is possible to perform the list of tests defined in the test plan.
The corresponding results are displayed accordingly:



GRAPHICAL RESULTS

Name	Value	Unit
C Coil Current	0.168	A
O Coil Current	0.442	A
Flow Time O Coil Curr.	100.000	ms
Flow Time C Coil Curr.	100.000	ms
Open Time First Release A1	6.400	ms
Open Time First Release B1	6.400	ms
Open Time First Release C1	6.400	ms
Close Time First Touch A1	44.800	ms
Close Time First Touch B1	44.800	ms
Close Time First Touch C1	44.800	ms
Open Time A1	6.400	ms
Open Time A DEF	6.400	ms
Open Time B1	6.400	ms
Open Time B DEF	6.400	ms
Open Time C1	6.400	ms
Open Time C DEF	6.400	ms

NUMERICAL RESULTS

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Thank you