Circuit Breaker testing: evolution of best practices

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Engineering expertise and advanced diagnostics to ensure that all people globally have ***reliable***, ***safe*** & ***secure*** energy in a sustainable world

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FOR THE NEXT CENTURY.

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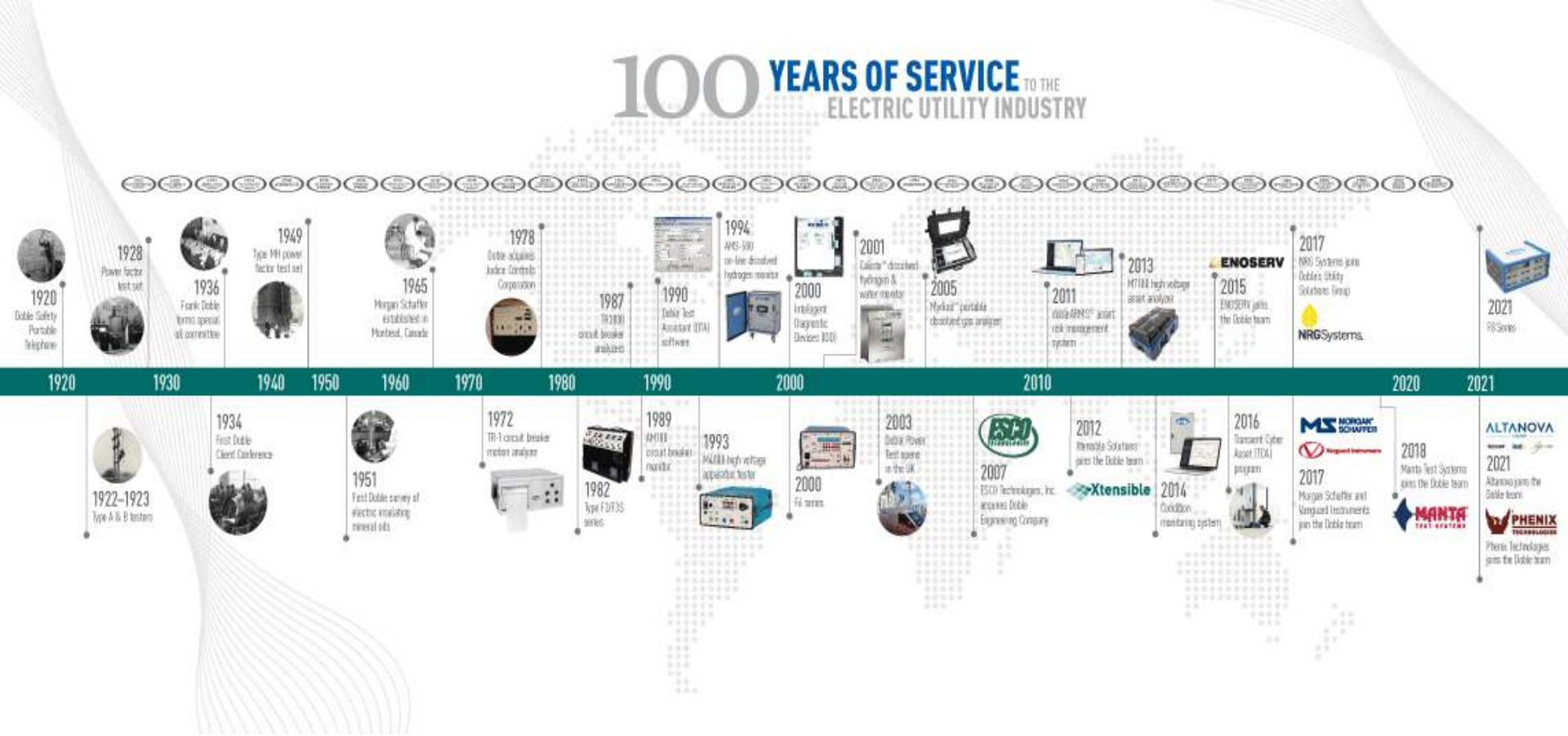

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12 GLOBAL OFFICE LOCATIONS

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- Growing demand for electricity
- Distributed energy & renewables
- Evolving cybersecurity & regulatory requirements
- Keeping up with the IoT
- Artificial intelligence & emerging technologies

With an eye toward the future, Doble will help utilities navigate change – just as we have for the past 100 years.

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- Consulting & testing services
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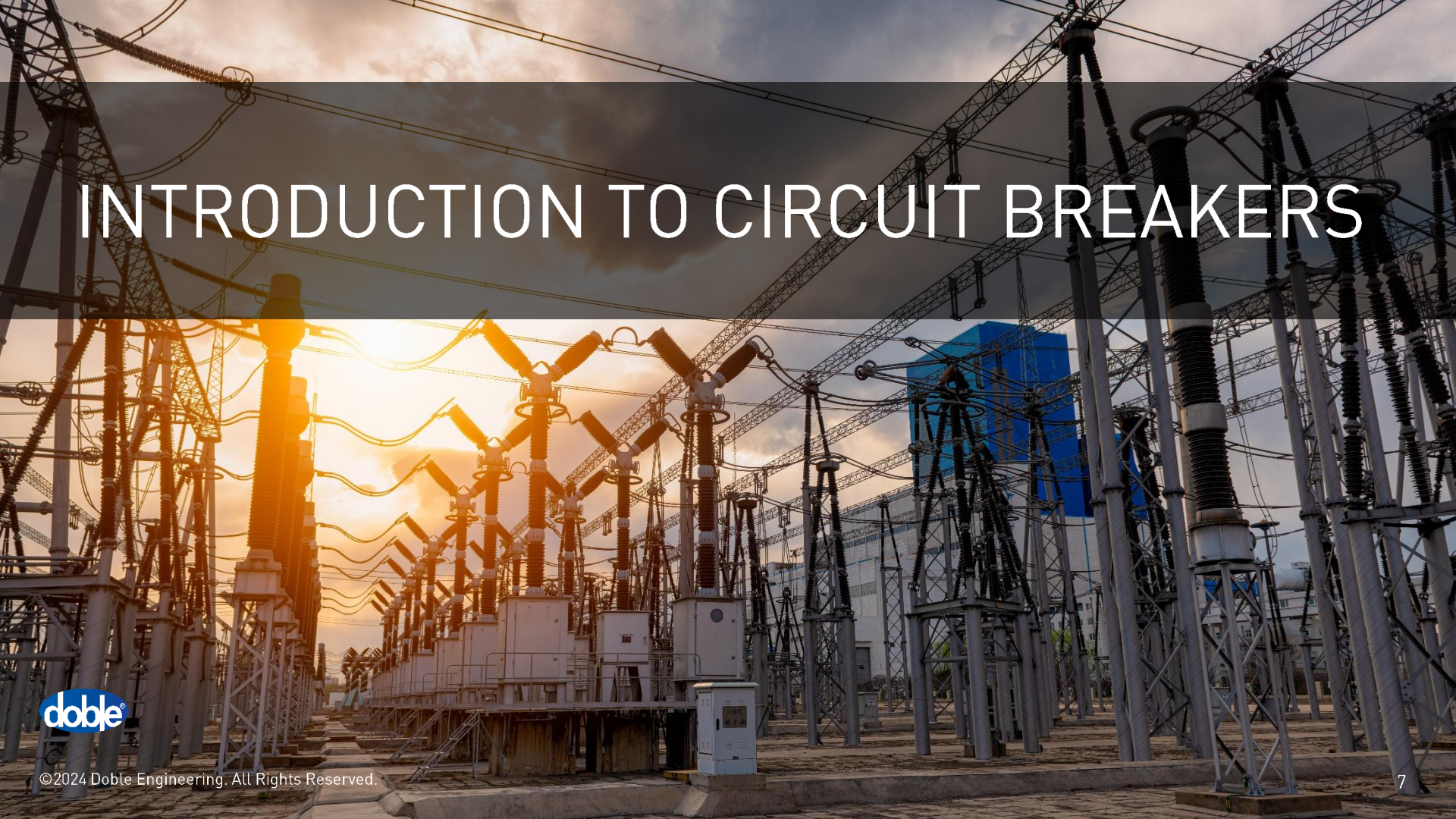
Transformers | Bushings | Circuit Breakers | Rotating Machines | Protective Relays | Cables

INTRODUCTION TO CIRCUIT BREAKERS



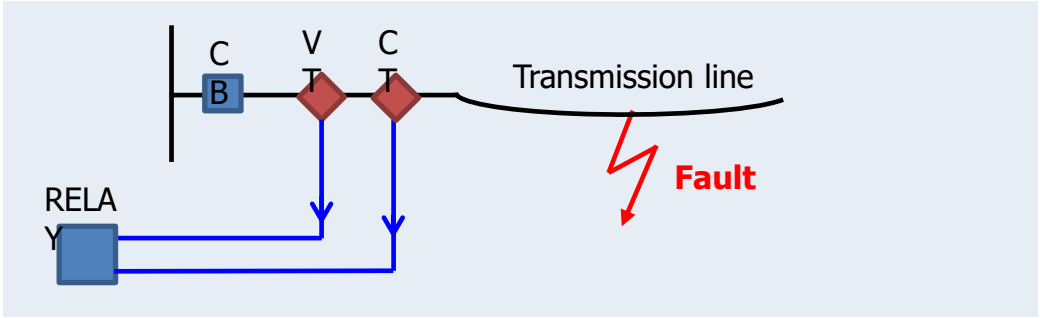
Circuit Breaker: What is it?

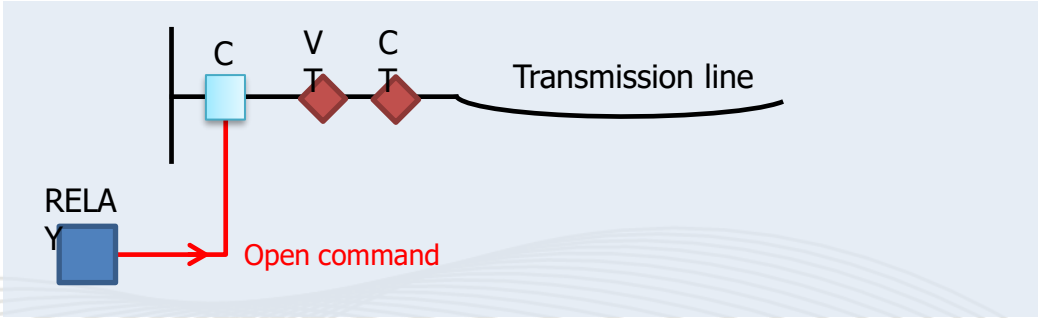
Circuit breaker is an automatically operated electrical device, design to close or open contacts inside the chambers, thus closing and opening an electrical circuit under load or fault conditions

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

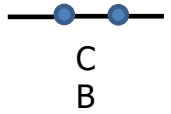
FASTEST POSSIBLE TIME

Circuit Breaker: What is it?

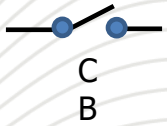




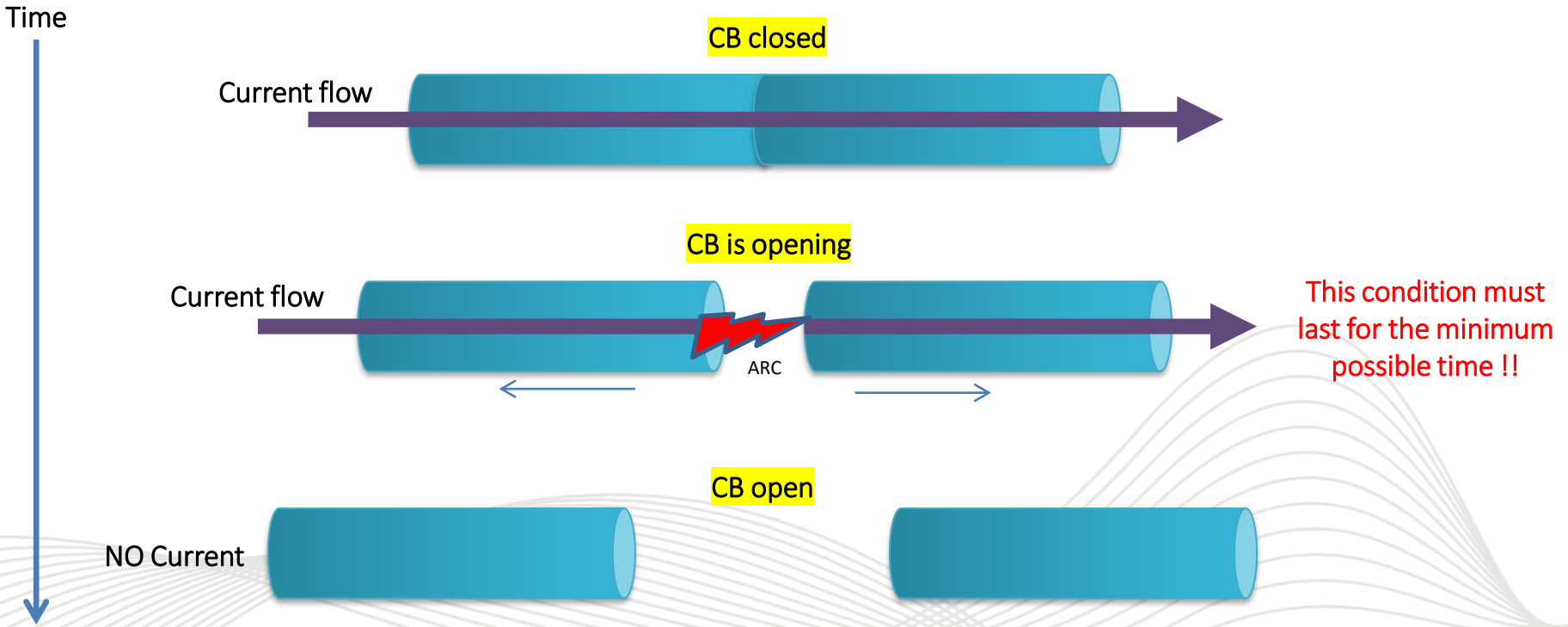
Relay detects a fault condition from the VTs and CTs



Relay commands the circuit breaker to open in order to interrupt the fault current



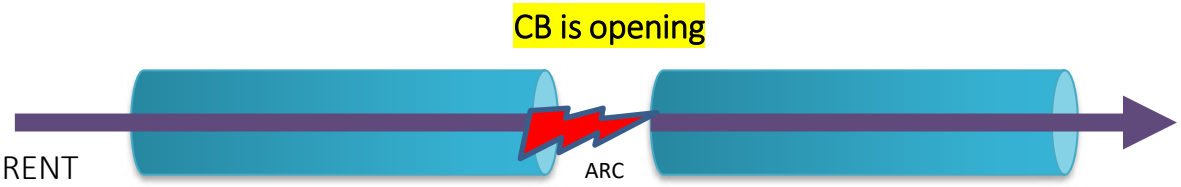
Once the fault occurs



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



LOAD CURRENT
[100 A ÷ 300 A]

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

FAULT CURRENT
[> 1000 A]

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

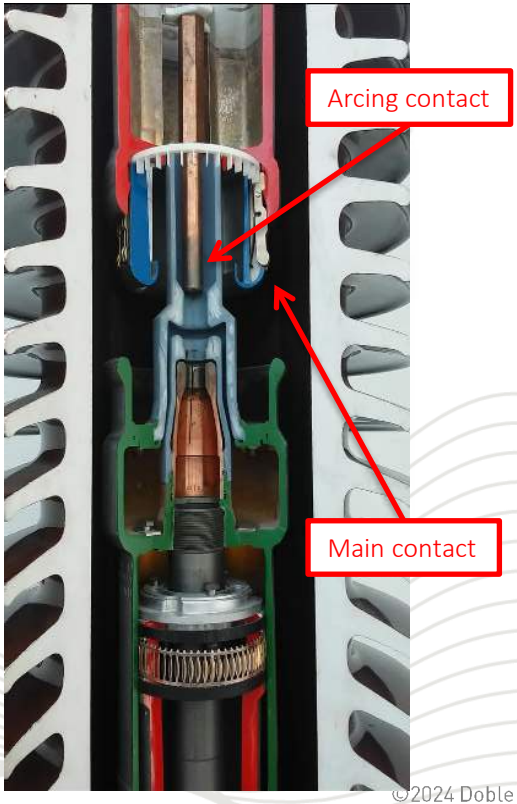
FAULT CURRENT INTERRUPTIONS REDUCE SIGNIFICANTLY THE REMAINING LIFE OF THE CIRCUIT BREAKER

Arcing contact

Arcing contact purpose is to extinguish the arc that is created in the first milliseconds of the opening operation.

It is composed by a contact with a higher resistance than main one (some mΩ compared to hundreds of μΩ) .
It remains connected to the second end of the CB pole for a little more time, during the opening.

Each time the CB interrupts the fault current, part of the arcing contact burns, so it is required to measure its length (will be explained later on)



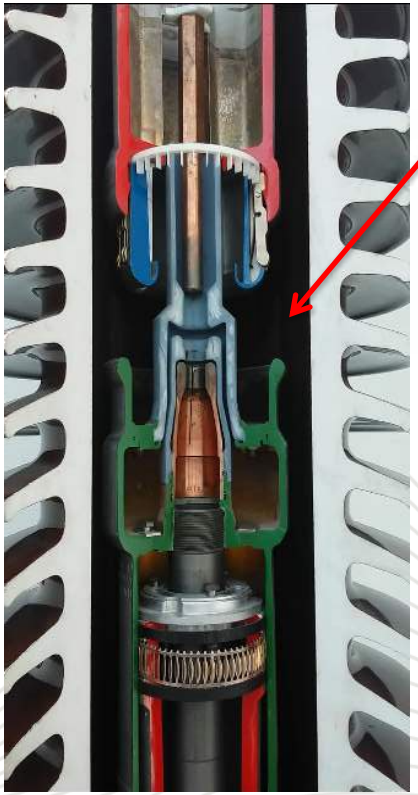
SF6 gas

SF-6 (sulfur hexafluoride) is a non-flammable, non-poisonous and odorless gas that acts as an interrupting medium and insulating medium.

SF-6 is compressed inside the breaking chamber: the higher is the pressure, the greater is higher is the interrupting power.

Any loss of SF-6 reduces the pressure and, if it becomes too low, the CB cannot operate

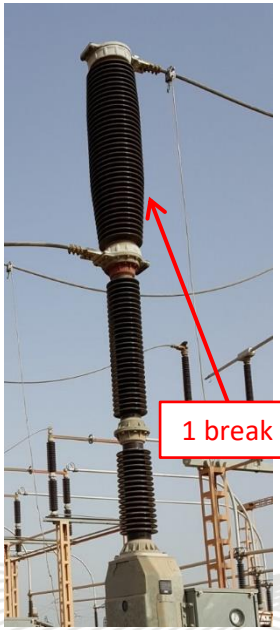
SF6 filling connection under circuit breaker

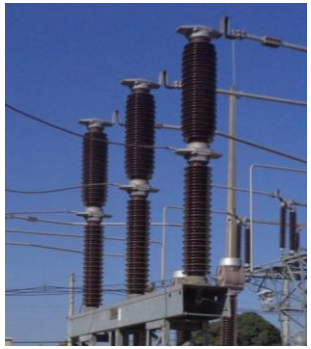


Compressed SF-6 gas

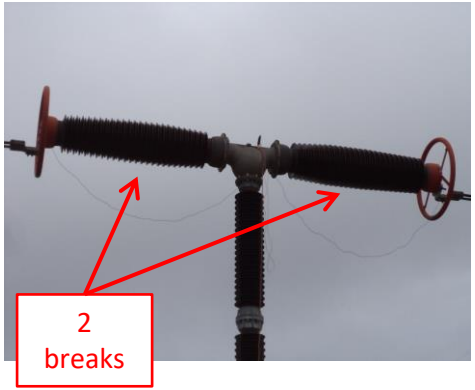
Circuit Breaker: Breaking Chambers

HV circuit breakers can have more than one moving contact (breaker) connected in series, used to interrupt the load or fault current.

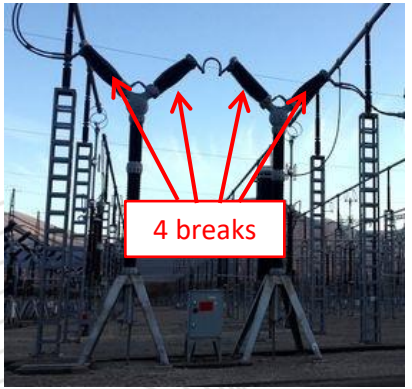




1 break per phase
(up to 300 kV - CB in SF6)



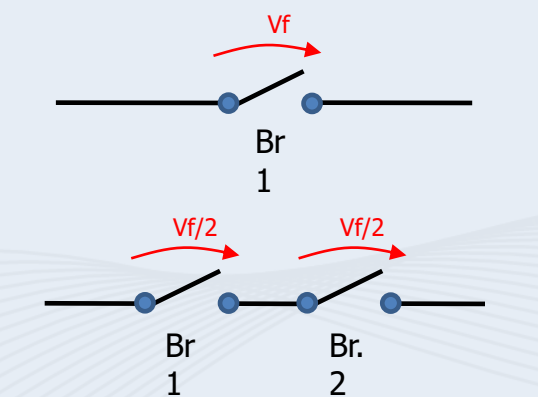
2 breaks per phase
(up to 550 kV – CB in SF6)

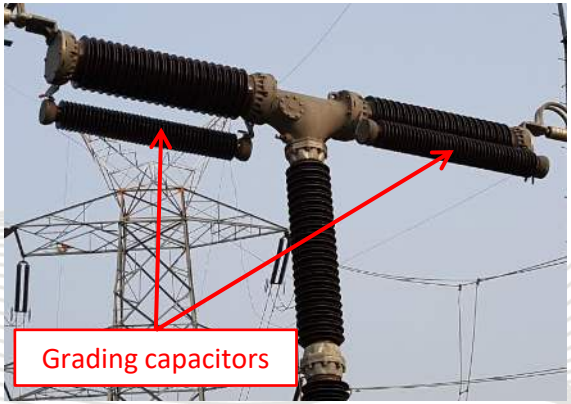


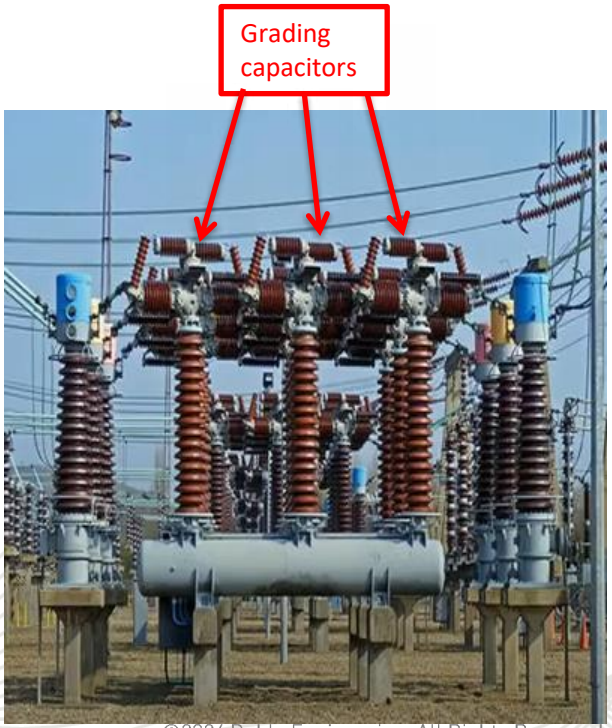
Circuit Breaker: grading capacitors

Grading capacitors ensure uniform voltage distribution across all contact points during normal and switching operation.

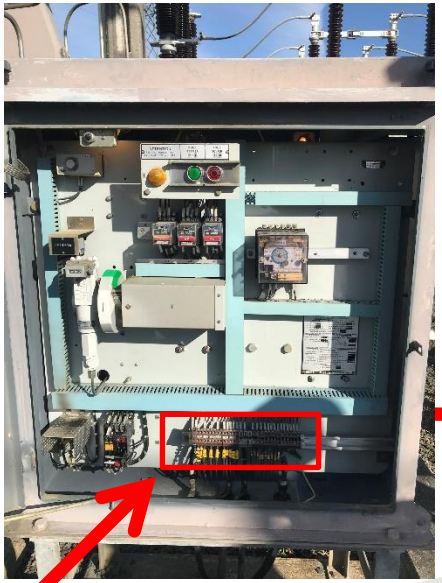
They can also increase the switching capacity of the circuit breaker under certain conditions





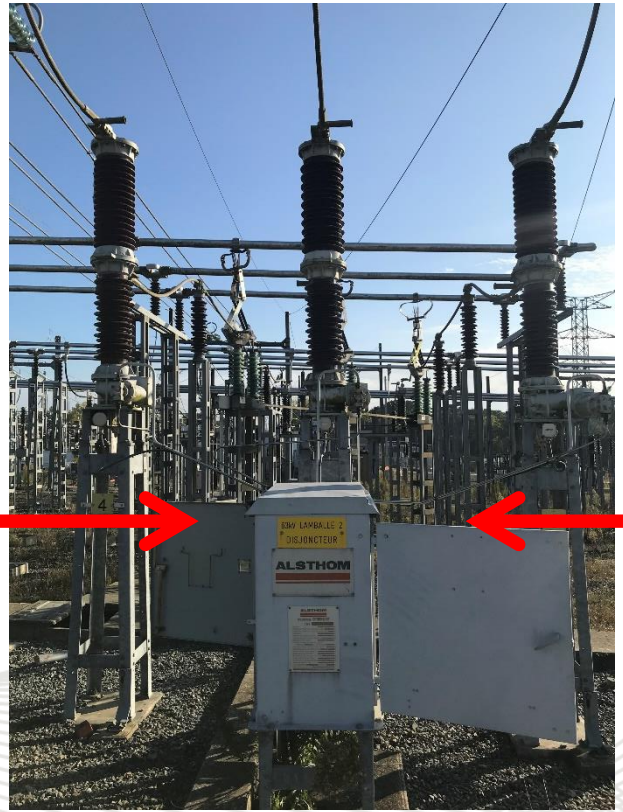


Circuit Breaker Commands



Command Cabinet

Terminal block including O/C coils and auxiliary contacts



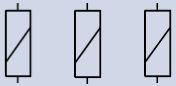
Auxiliary Cabinet
Circuit Breaker 63kV

Hydraulic Command Cabinet

Coil commands

The movement of the circuit breaker is generated by a command:

- Opening by Open Coil
- Closure by Closing Coil

Circuit Breaker	LV 600 V	MV & HV Till 50 kV	EHV 225 /410 kV
Opening			
Closure			

Possible commands:

- Locally (CB's auxiliary)
- Remotely(control room)
- Relay (protection system)

REMARK : A circuit breaker is tested locally with CB's auxiliary

Terminal block with coil commands

Circuit Breaker: PIR

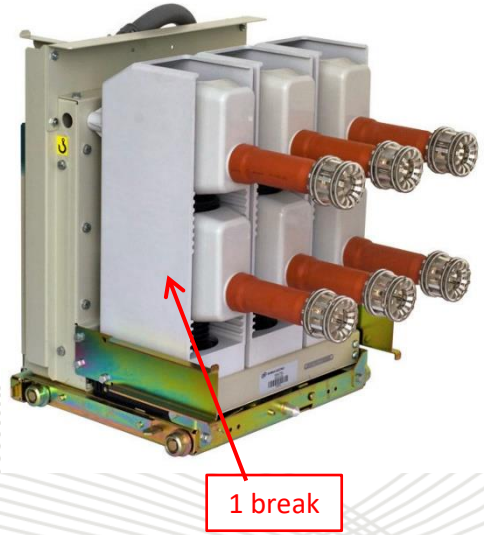
Preinsertion resistors reduce the voltage transients generated when a no-load transmission line is energized or re-energized after a line fault.

Grading capacitors and pre-insertion resistor can be both present in the same time.

The voltage transients have voltage peaks whose value can go beyond the rated voltage

Circuit Breaker: Breaking Chambers

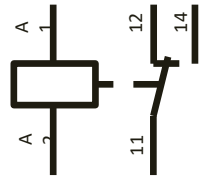
MV circuit breakers (Switchgears) usually has one moving contact (breaker).
These devices are designed to operate at lower voltage, but basically do the same job as high voltage circuit breakers.

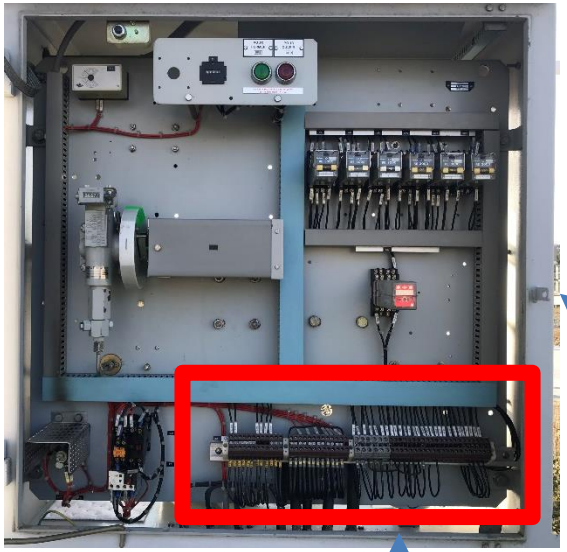


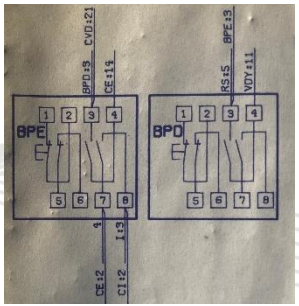
The operating chain

When energized, the coil triggers the springs

COIL COMMANDS





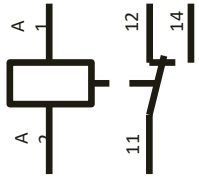


Coils commands
Auxiliary Contacts

The operating chain

When energized, the coil triggers the springs

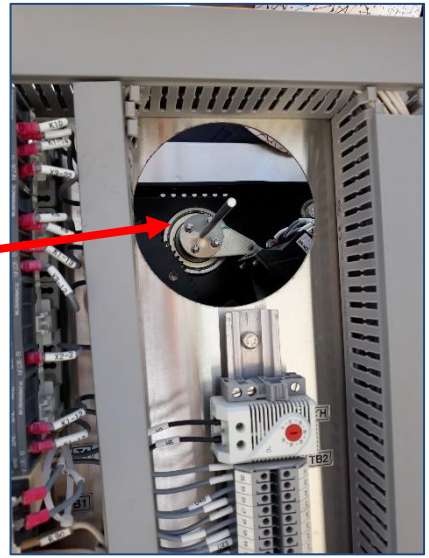
COIL COMMANDS



SPRINGS

The springs release the stored energy to the mechanisms

MECHANISMS and LEVERAGES



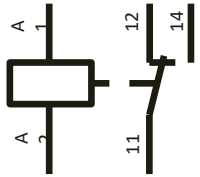
The motor charges the springs that store the energy

MOTOR

The operating chain

When energized, the coil triggers the springs

COIL COMMANDS



The springs release the stored energy to the mechanisms

SPRINGS

The motor charges the springs that store the energy

MOTOR

The leverages transfer the movement to the main contacts

MECHANISMS and LEVERAGES

MAIN BREAKER CONTACTS

AUXILIARY CONTACTS

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

CIRCUIT BREAKER MAINTENANCE:

Reference of good practices (*)

(*) Source: EXCELEC Datasheet – Edition 2007

Levels based on the Afnor FDX 60000 booklet - Industrial maintenance - Maintenance function (contains maintenance levels - May 2002 publication)

HV circuit breakers with oil or SF6 breakers

OPERATION DESIGNATION	PERIODICITY	LEVEL
Visual inspection of general condition, cleanliness, chipping, cracking, absence of corrosion on supports, etc.	Annual, On-line	1
Maneuver counter reading	Annual	
Tightening check: - Framing screws - HV connections	Annual : - On-line - Off-line	2
Check general condition and absence of traces of heating of earthing connections	Annual, On-line	
Checking oil levels (oil type CB) Checking the seals	Annual, On-line	
SF6 filling pressure control of the poles (SF6 type CB)	Every 3 years, On-line	
Cleaning porcelain (particular risk: porcelain under pressure)	Every 3 years, On/Off-line	

1 Routine maintenance.
Interventions relating to the equipment are generally described in the manufacturer's maintenance manual

2 Interventions requiring simple procedures and/or support equipment for simple use and implementation (generally described in the manufacturer's maintenance manual).

HTB circuit breakers with breaking in oil

OPERATION DESIGNATION	PERIODICITY	LEVEL
Checking operating times and synchronism	Every 3 years, Off-line	3
Measurement of dielectric losses (poles, insulating oil, insulating transmission oil if applicable)	Every 3 years, Off-line	4
Main contact Static Resistance Measurement	Every 3 years, Off-line	4
Replacement of insulation oil	Every 5 years, Off-line	2
Checking arcing contacts for wear (Dynamic Resistance Measurement)	Every 5 years, Off-line	4
Renovation and upgrading	Every 20 years	2

3 Operations that require complex procedures and/or complex use or implementation support equipment

4 Operations whose procedures involve the mastery of a particular technique or technology and/or the implementation of specialized support equipment.

HV circuit breakers with breaking in SF6

OPERATION DESIGNATION	PERIODICITY	LEVEL
Checking operating times and synchronism	Every 3 years, Off-line	3
Control of densimeter operation and gas quality control	Every 5 years, Off-line	4
Main contact Static Resistance Measurement	Every 5 years, Off-line	5
Replacement of capacitors	Every 5 years, up to use	3
Renovation and upgrading	Every 20 years	5

4 Operations whose procedures involve the mastery of a particular technique or technology and/or the implementation of specialized support equipment.

5 Operations whose procedures involve know-how, using particular techniques or technologies, processes or industrial support equipment.

Circuit breakers in GIS

OPERATION DESIGNATION	PERIODICITY	LEVEL
Measurement of operating times (main and auxiliary contacts)	Every 5 years, Off-line	3
Checking contact wear	Every 5000 operations off-line	4
Replacement of capacitors	Every 5000 operations or 25 years – Off-line	5
Checking the setting of the circuit breaker linkages (if applicable)	Every 15 years, Off-line	3
Renovation and upgrading	Every 20 years, Off-line	5

3 Operations that require complex procedures and/or complex use or implementation support equipment

4 Operations whose procedures involve the mastery of a particular technique or technology and/or the implementation of specialized support equipment.

Circuit Breaker Analyzer

Among these operations, some require **complex or specialized support equipment**:

- Checking operating times and synchronism (MAIN BREAKER CONTACT)
- Static Resistance Measurement (SRM)
- Dynamic Resistance Measurement (DRM)

These tests can be carried out using **Circuit Breaker Analyzers**, whose technologies are evolving to guarantee precise, reliable measurements while improving the speed of implementation, safety and ease of use.

Circuit Breaker Analyzer

Circuit Breaker Analyzer

CBA 1000

CBA 2000

CBA 3000

Up to 2 Breaks per phase	YES	YES	YES
Up to 6 Breaks per phase	NO	YES	YES
Static & Dynamic contact resistance	YES, single phase	YES, single phase	YES, three-phase
Travel transducers	1 analog	3 analog or 3 digital	4 analog or 4 digital
Both Sides Grounded AIS	NEW! **YES (1 Break per phase)**	NEW! **YES (1 Break per phase)**	YES (up to 2 Breaks per phase)
Both Sides Grounded GIS	NO	NO	YES

Circuit Breaker Analyzer

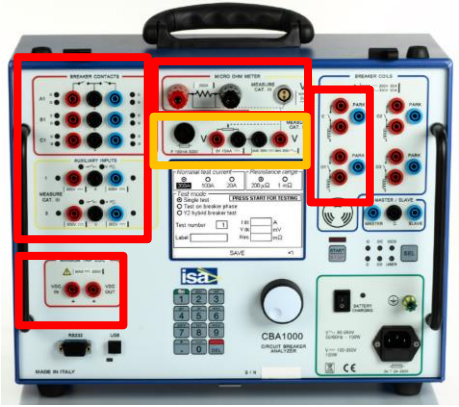
Main tests and measurements with CBA1000/2000

Basic features

- Times O, C, OC, CO, OCO
- Peak of energy current
- Duration of the energizing current
- Form of energizing current
- Time of auxiliary contacts

Up to 2 breaks per phase (CBA1000)

Up to 6 breaks par phase (CBA2000)



CBA1000

Options

- Static Resistance Measurement (SRM)
- Dynamic Resistance Measurement (DRM)

Embedded Microohmmeter 200A

- Min. Trip Coil (MTC) or thermal printer)

Embedded module

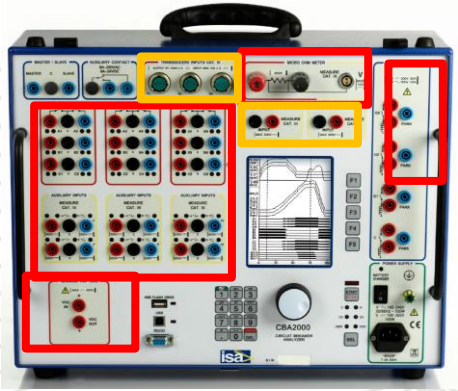
- Movement and speed
- Pressure
- Motor current
- First trip test

Possible with external accessories (clamps, current, transducers, accessories)

NEW!

- Times O, C, OC, CO, OCO with Both Sides Grounded

external clamps



CBA2000

Circuit Breaker Analyzer

Basic features

- Time O, C, OC, CO, OCO
- Peak of energy current
- Duration of the energizing current
- Form of energizing current
- Time of auxiliary contacts

Up to 2 breaks per phase
Up to 4/6/8 breaks par phase (option)

Options

- Static Resistance Measurement (SRM)
- Dynamic Resistance Measurement (DRM)

Up to 3 embedded Microohmmeters 200A

- Min. Trip Coil (MTC)
- Thermal printer)

Embedded module

- Movement and speed
- Pressure
- Motor current
- First trip test
- Both Sides Grounded for AIS & GIS

Possible with external accessories (clamps, current, transducers, accessories)

CBA1000 – main features

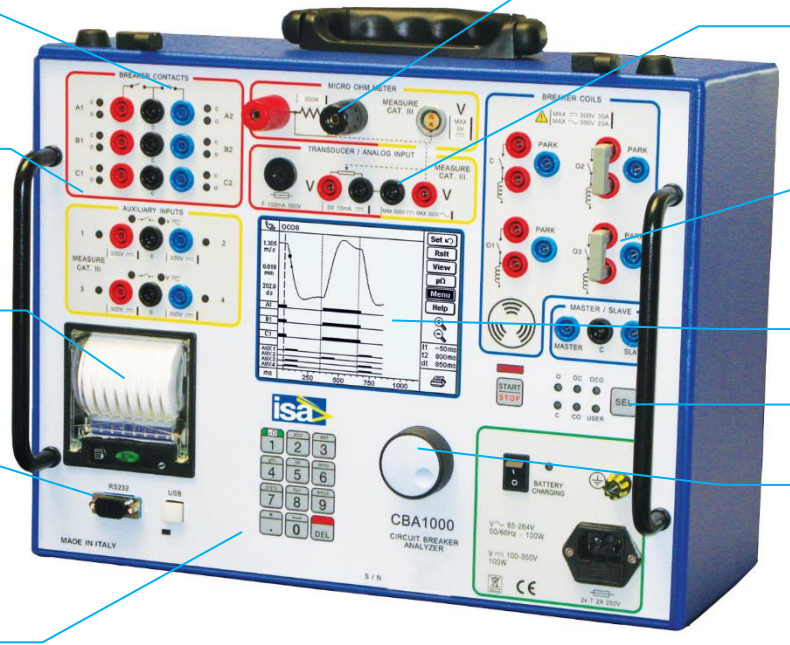
2 breakers per phase:
main digital inputs

4 auxiliary digital inputs (dry and/or wet till300V)

Option : Minimum Trip Coil or Thermal printer

USB and RS232 Comm port

Keypad



Option : 200 A µΩmeter

1 transducer channel/ analog.input (transducers & clamps in option)

Commands :
1 Open (+ 2 in option)
1 Close

Large Graphical display

Test selection

Control knob

CBA2000 – main features

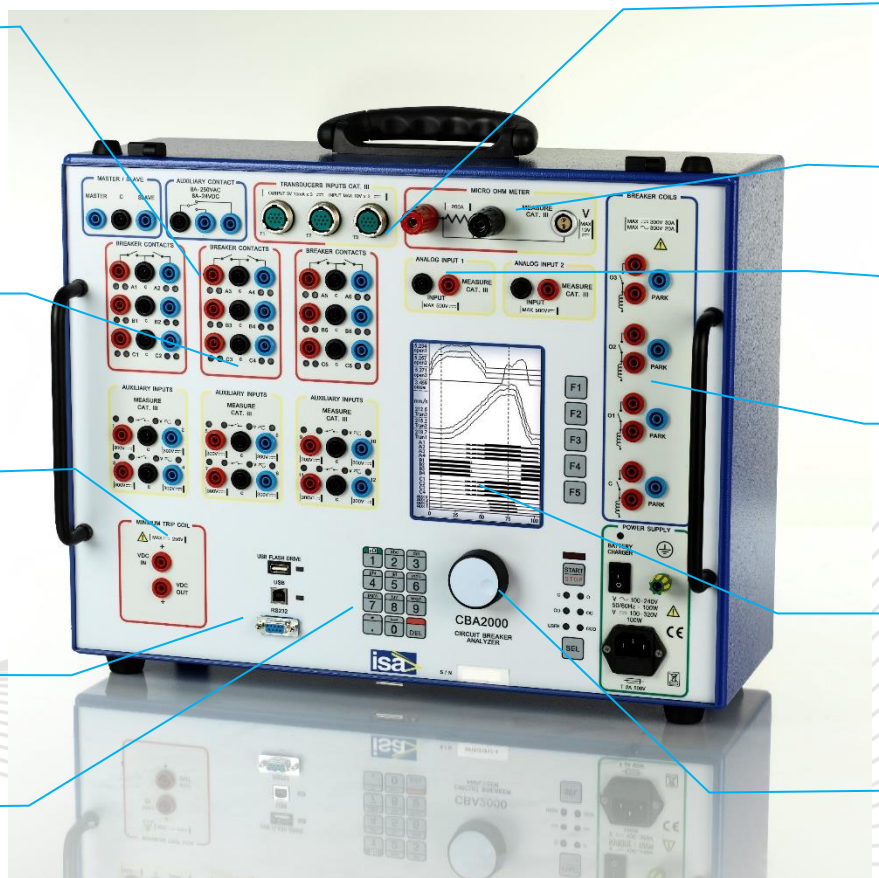
2/**4/6** breakers per phase: main digital inputs

4/**8/12** auxiliary digital inputs

Option : Minimum Trip Coil or Thermal printer

USB and RS232 Comm port & **Flash Memory**

Keypad



3 transducer channel/ **digital** inputs (transducers & clamps in option)

Option : 200 A µΩmeter

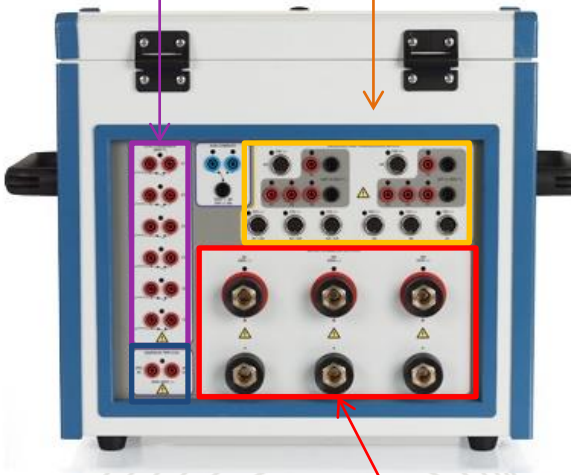
Analog. inputs (transducers & clamps in option)

Commands :
1 Open (+ 2 in option)
1 Close

Large graphical screen

Control knob

CBA3000 – main features



2/4/6 Coil Commands

8 analog. inputs

Large graphical screen

Test selection

8 / 16 / 24 time inputs
For main and auxiliaries contacts

Option : 1 or 3 µohmmeters 200A

Circuit Breaker Analyzer

ADVANTAGES of CBA1000 and CBA2000

- ❑ Simple, convenient and intuitive
- ❑ All-in-one without add-ons
- ❑ Modular, with basic time & synchronization measurements
- ❑ Editable and fast reports (printer, software)
- ❑ Internal memory for 250 results and 64 test plans
- ❑ Test management with CBA or remotely (TDMS software)
- ❑ Battery operation
- ❑ BSG testing (both sides grounded) of circuit breakers installed in Air Insulated Substations (AIS)

Circuit Breaker Analyzer

ADVANTAGES of CBA3000

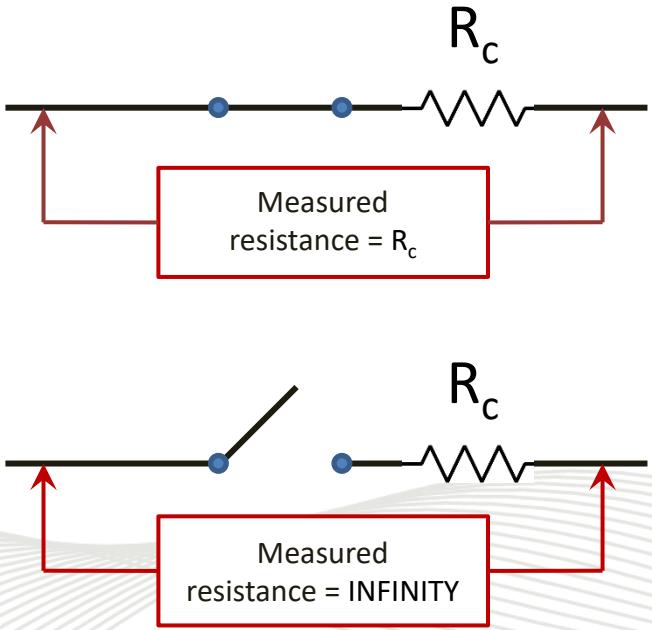
- ❑ Simple, convenient and intuitive + **Test wizard**
- ❑ All-in-one without add-ons
- ❑ Modular, with basic time & synchronization measurements
- ❑ Editable and fast reports (printer, software)
- ❑ Internal memory for 250 results and 64 test plans
- ❑ Test management with CBA or remotely (TDMS software)
- ❑ **BSG testing (both sides grounded) of circuit breakers installed in Air Insulated Substations (AIS) and Gas Insulated Substations (GIS)**
- ❑ **Combined measurements in a single cabling**

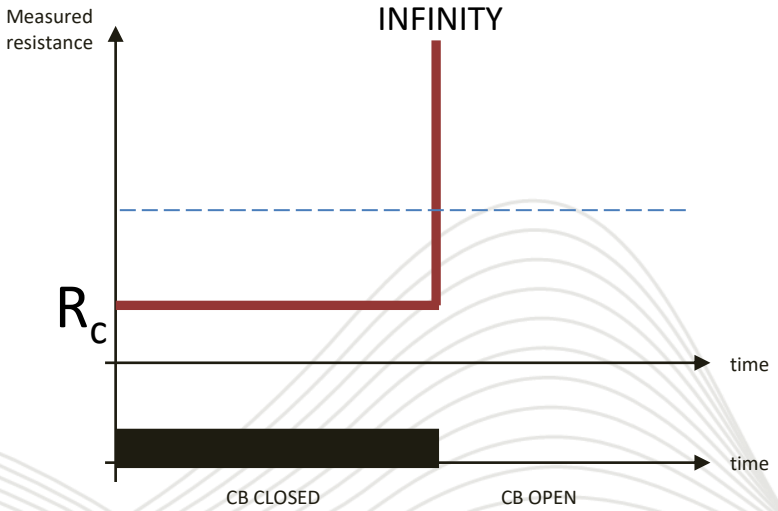
TESTS with CIRCUIT BREAKER ANALYZERS

MAIN BREAKER CONTACTS (AIS)

Main breaker contacts

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

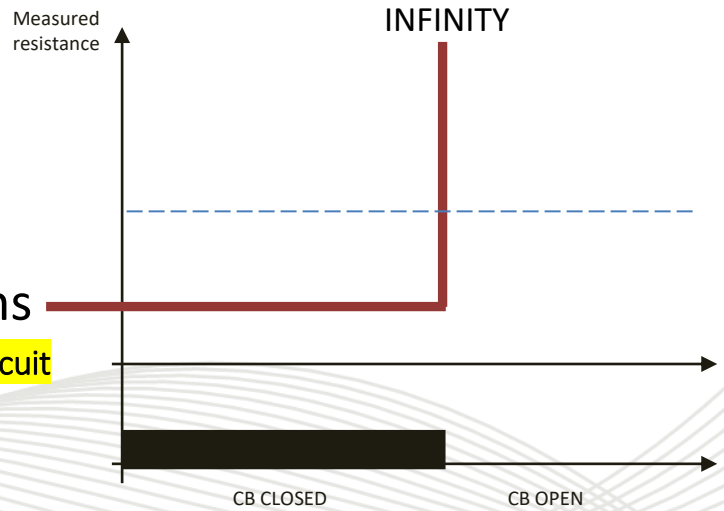




Main breaker contacts

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

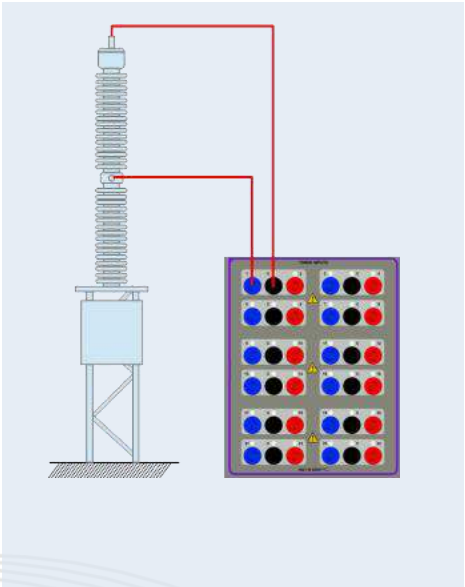
What do I need to perform a timing test for the main main contacts?

- Coil command

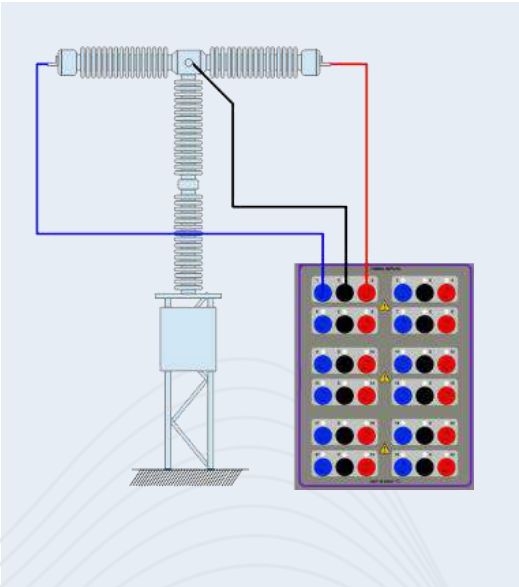
  The coil current is the reference to measure the time, when it starts to flow, the timer starts to count.

- Timing input

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

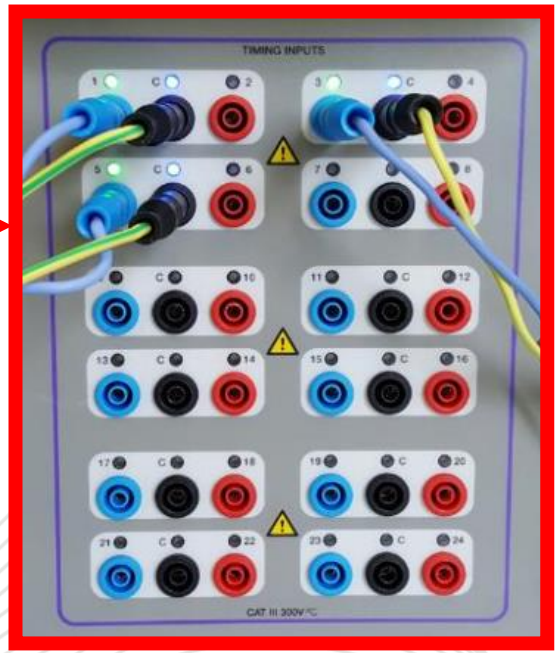


One break per phase CB

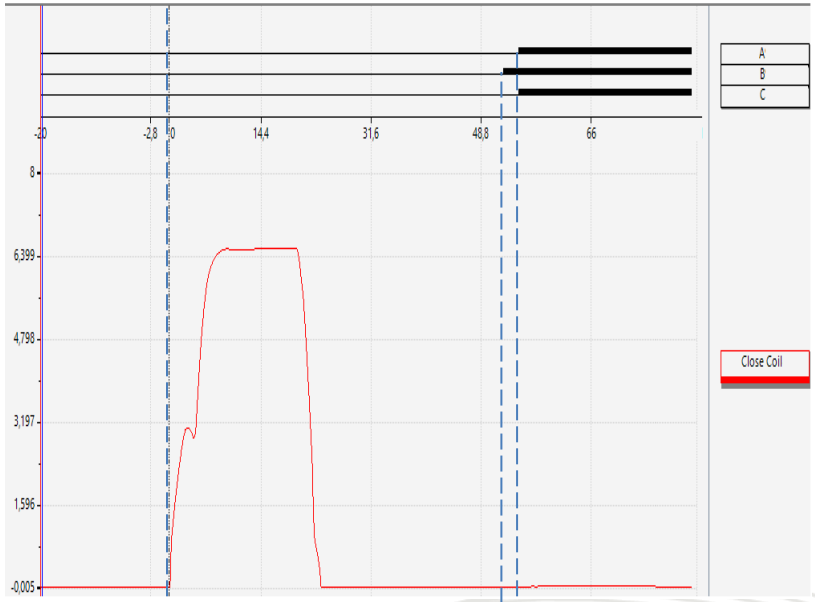


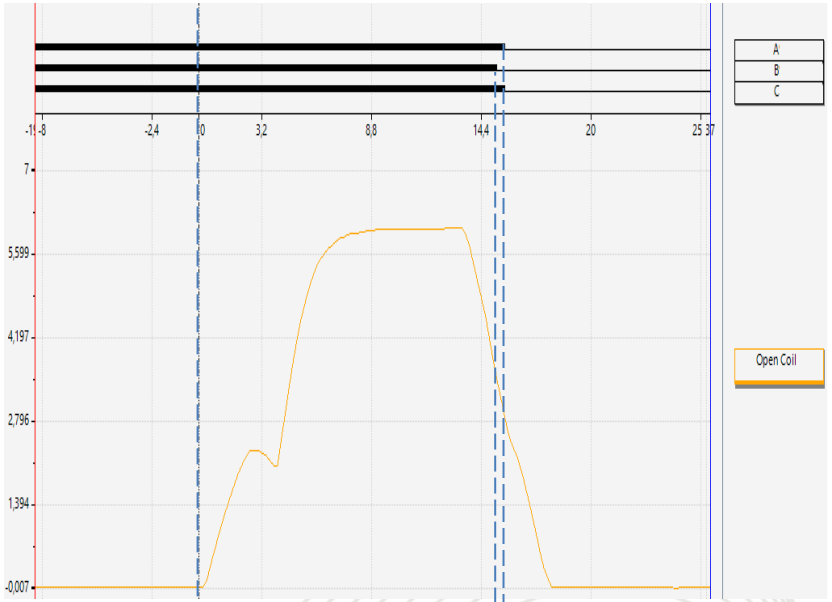
Two breaks per phase CB

Main breaker contacts



Main breaker contacts





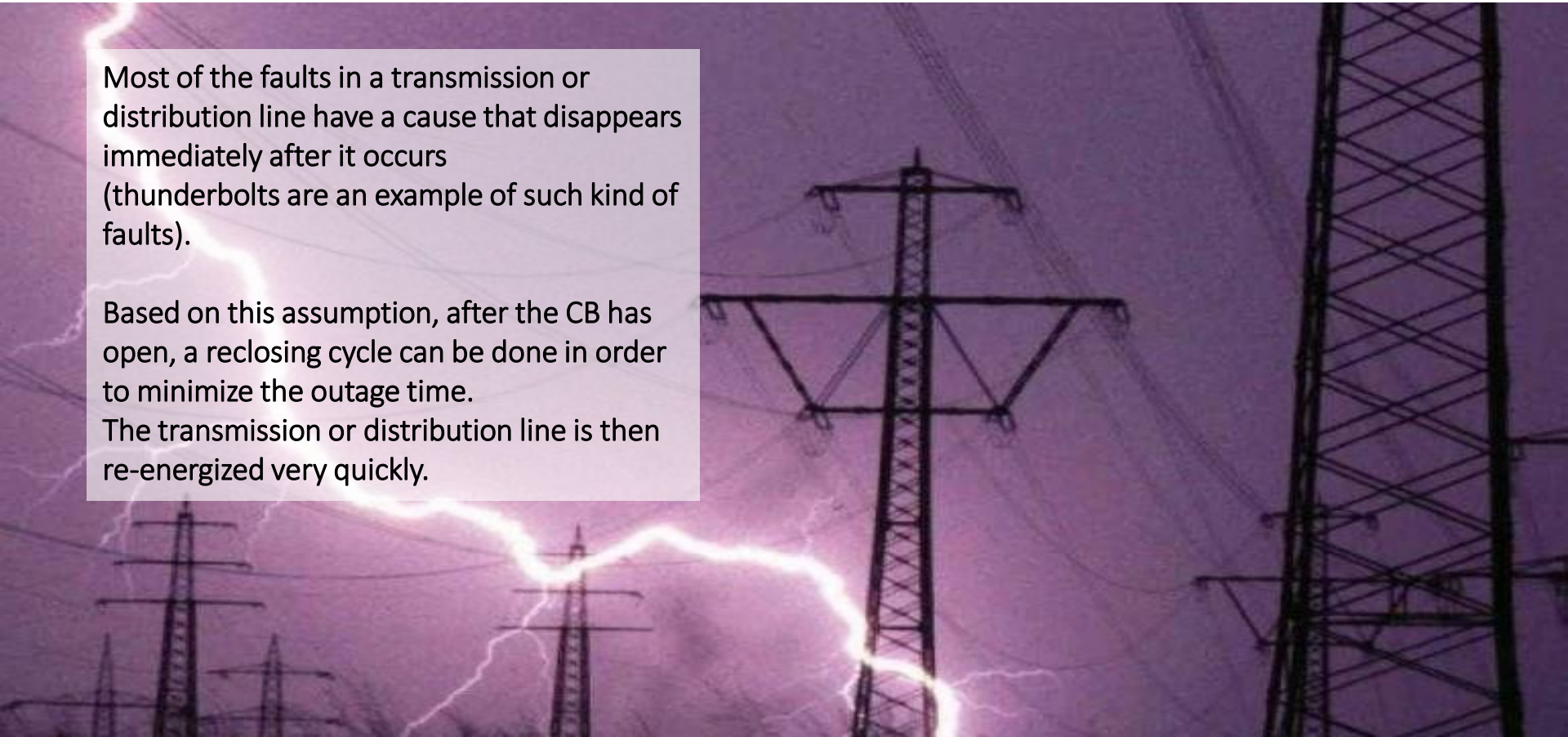
Closing time Ph. B

Closing time Ph. A & C

Opening time Ph. B

Opening time Ph. A & C

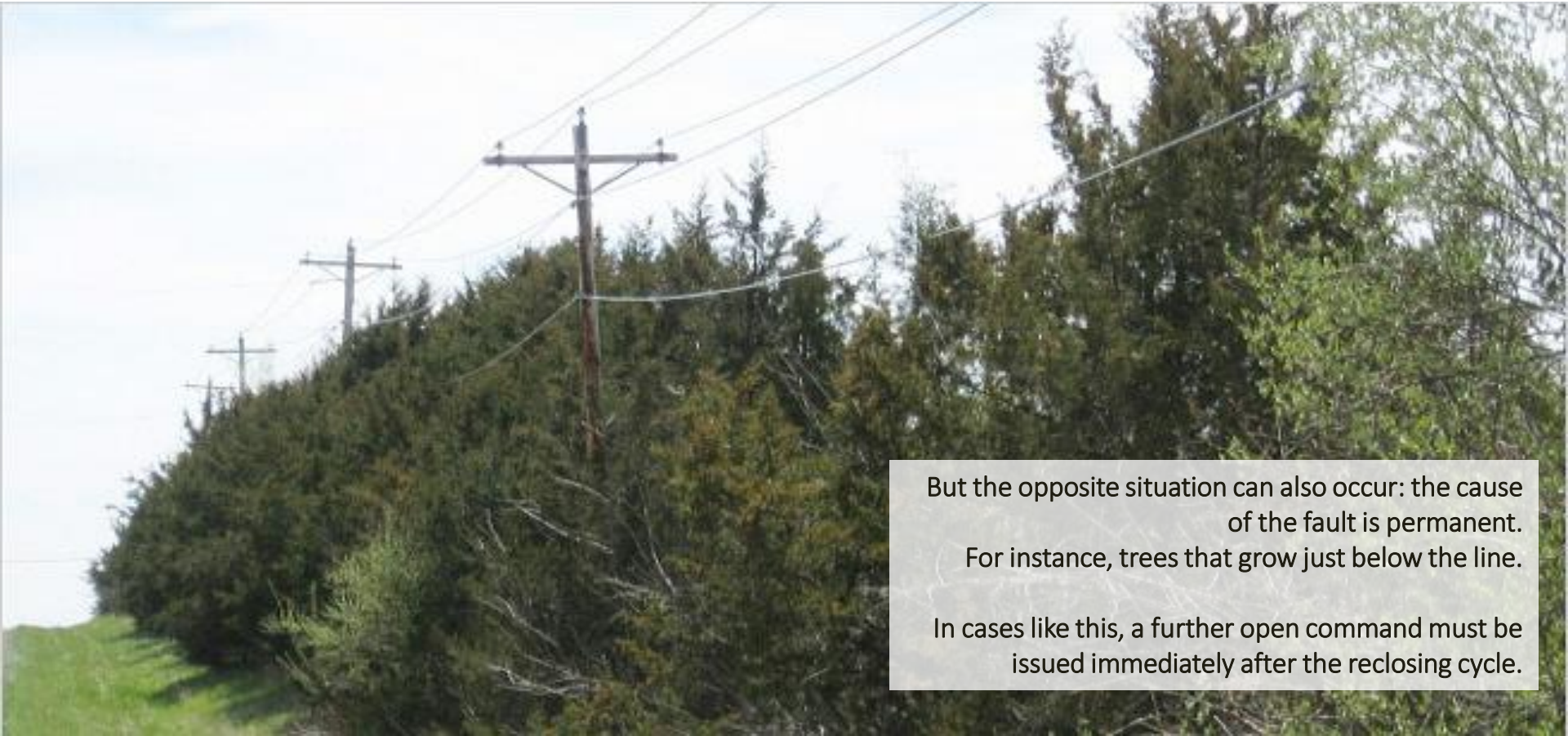
Main breaker contacts



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.

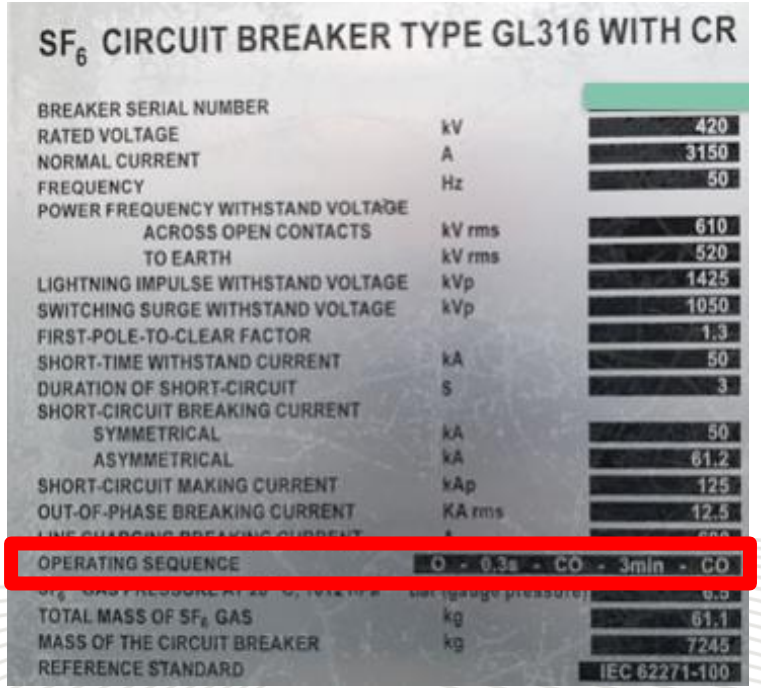
Main breaker contacts

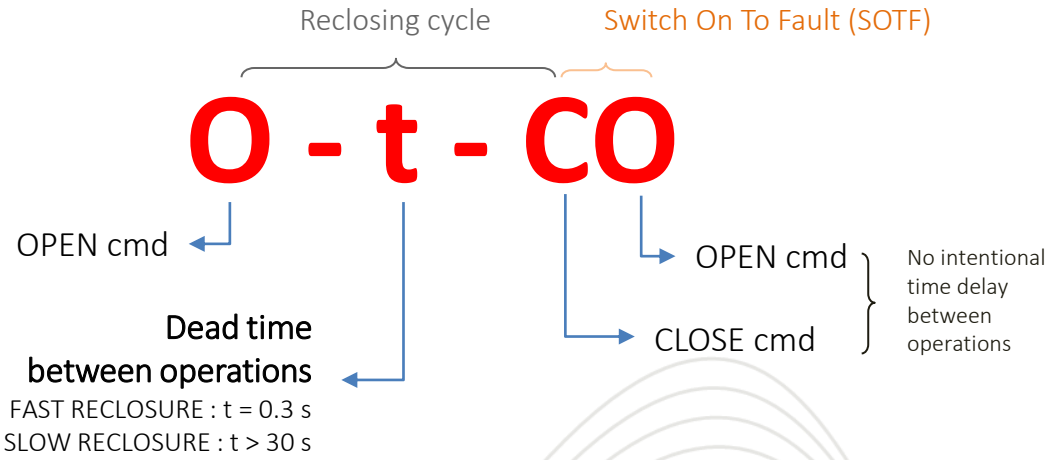


But the opposite situation can also occur: the cause of the fault is permanent.
For instance, trees that grow just below the line.

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

Main breaker contacts: reclosing cycle

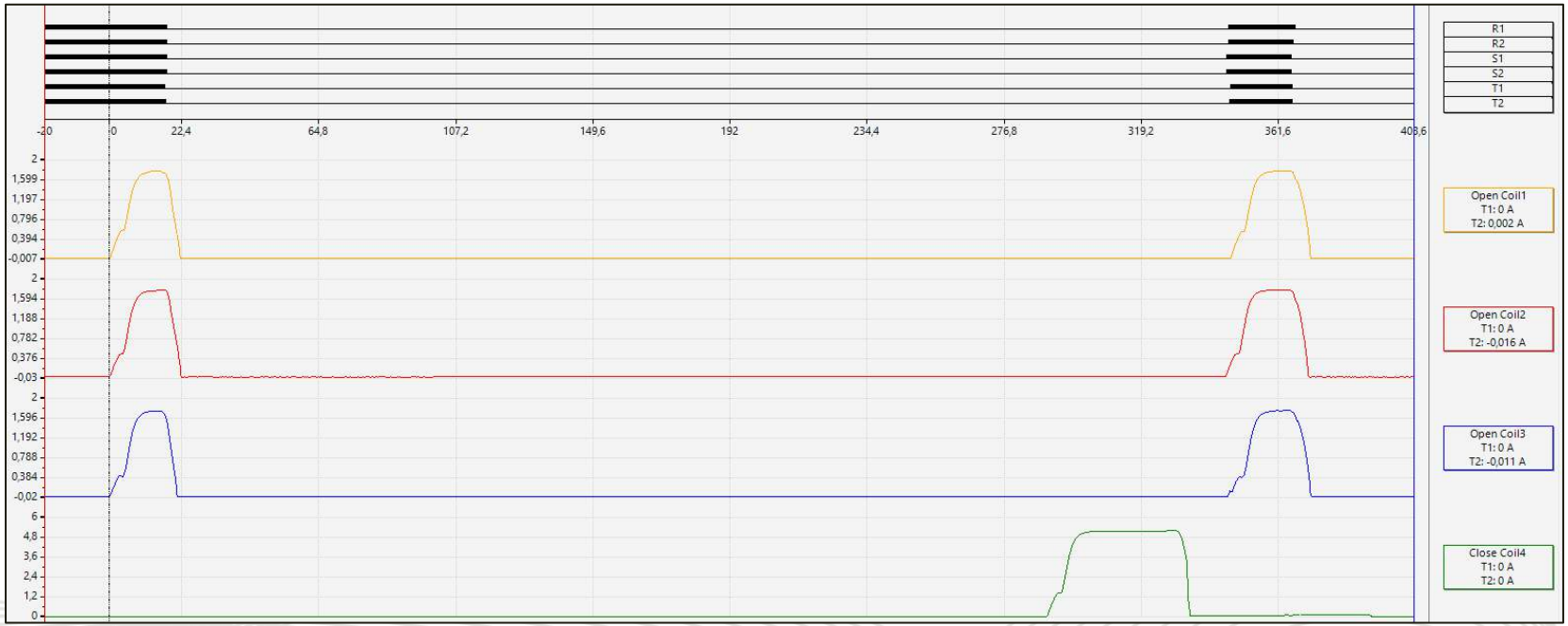




« Fast Reclosure + SOTF » is the most critical sequence

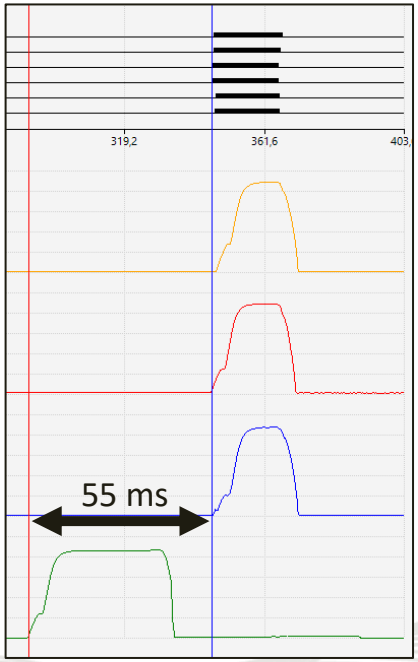
The springs must release all their energy in a very short time

Main breaker contacts: results examples

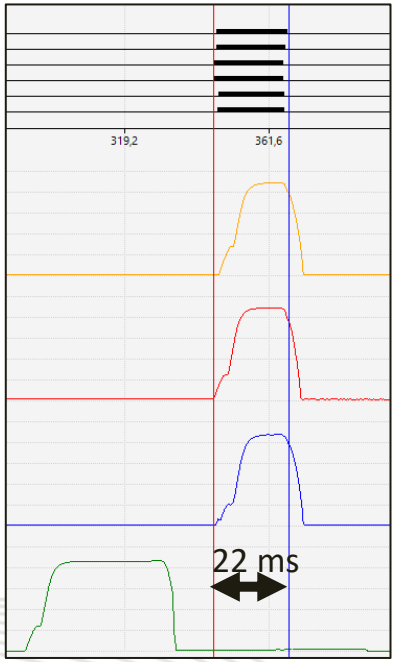


OPEN → 0.3 s → CLOSE → OPEN

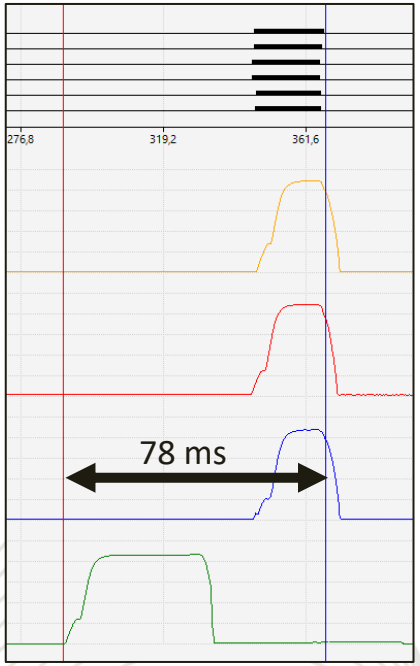
Main breaker contacts: Results examples



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

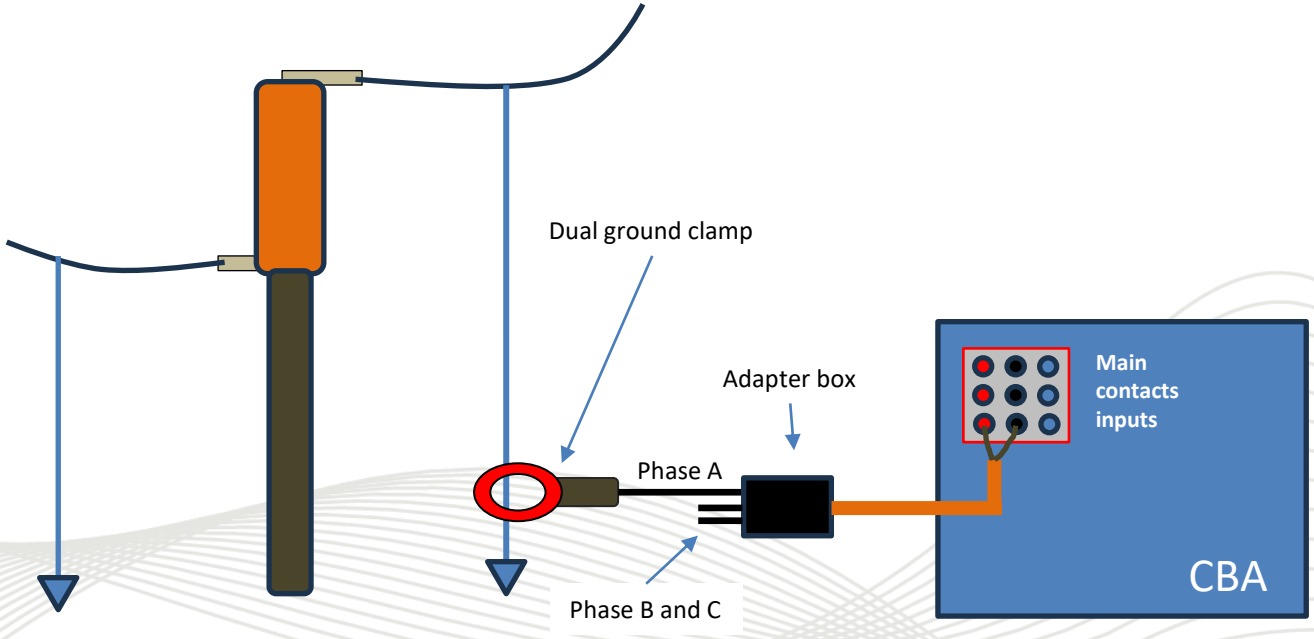
Main breaker contacts : Dual ground option

NEW!

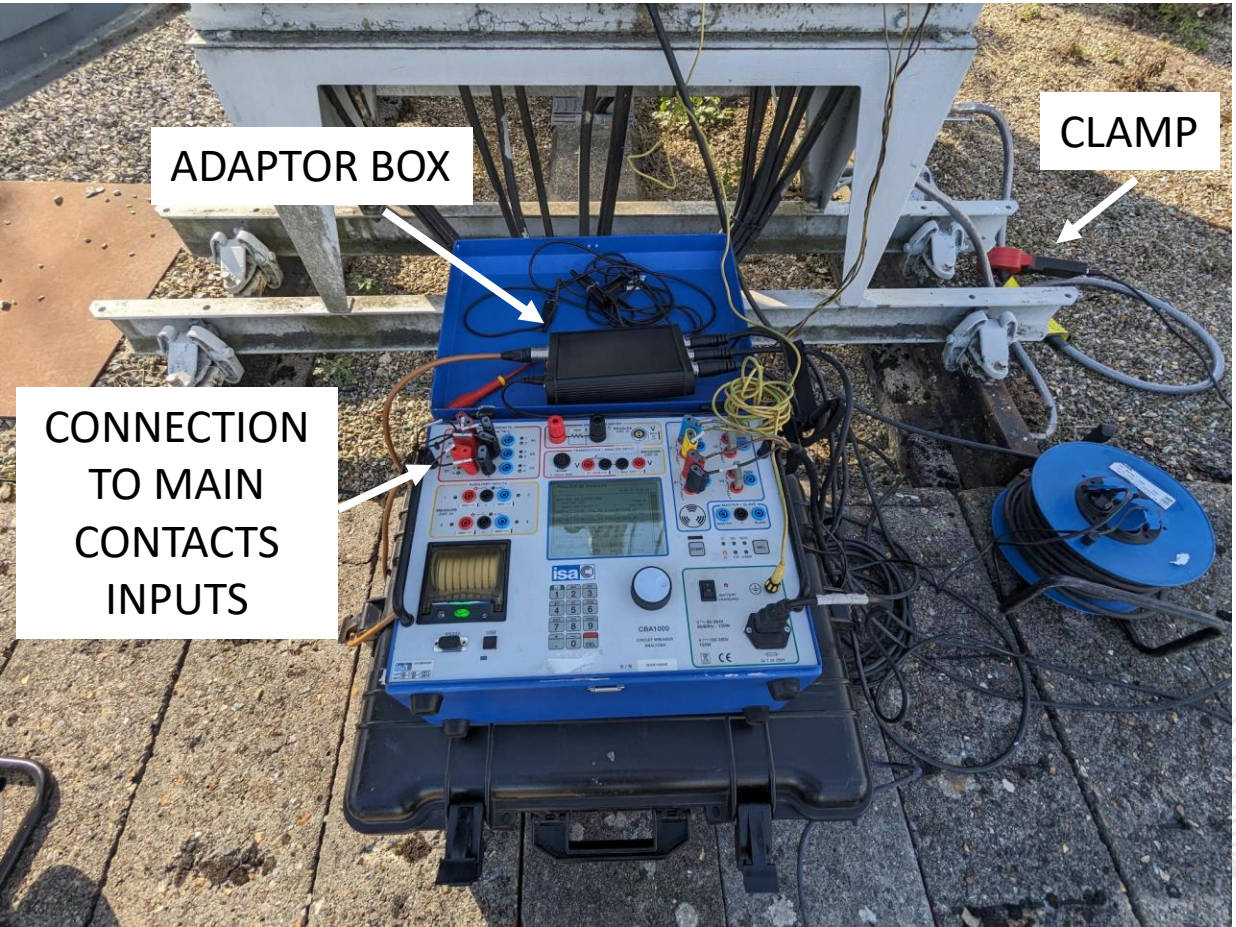
FAST, EASY AND MORE SECURE !

Main breaker contacts : Dual ground option

The kit consists of 3 special clamps that are connected directly to the grounding cable. The clamps interface with CBA via an adapter box which allows a connection to the inputs for main contacts. This solution is used without having to perform software or firmware updates to the CBA, simply connect and power it.



Main breaker contacts : Dual ground



- The setup is extremely compact and lightweight
- No lifting baskets are needed
- The connection is made at ground level
- Immediately compatible with your CBA
- Cables length up to 18 meters

MAIN BREAKER CONTACTS (GIS)

GIS Circuit Breakers

In gas insulated substation (GIS) the high voltage conductors are kept inside grounded metal enclosures, filled with SF6 gas. This includes circuit breakers, CTs, VTs, disconnectors, etc.

SF6 gas has a dielectric strength 2,5 times greater than air, and it is 100 times better for arc interruption. This allows to reduce the insulation space by 10 times compared to an air insulated substation (AIS).

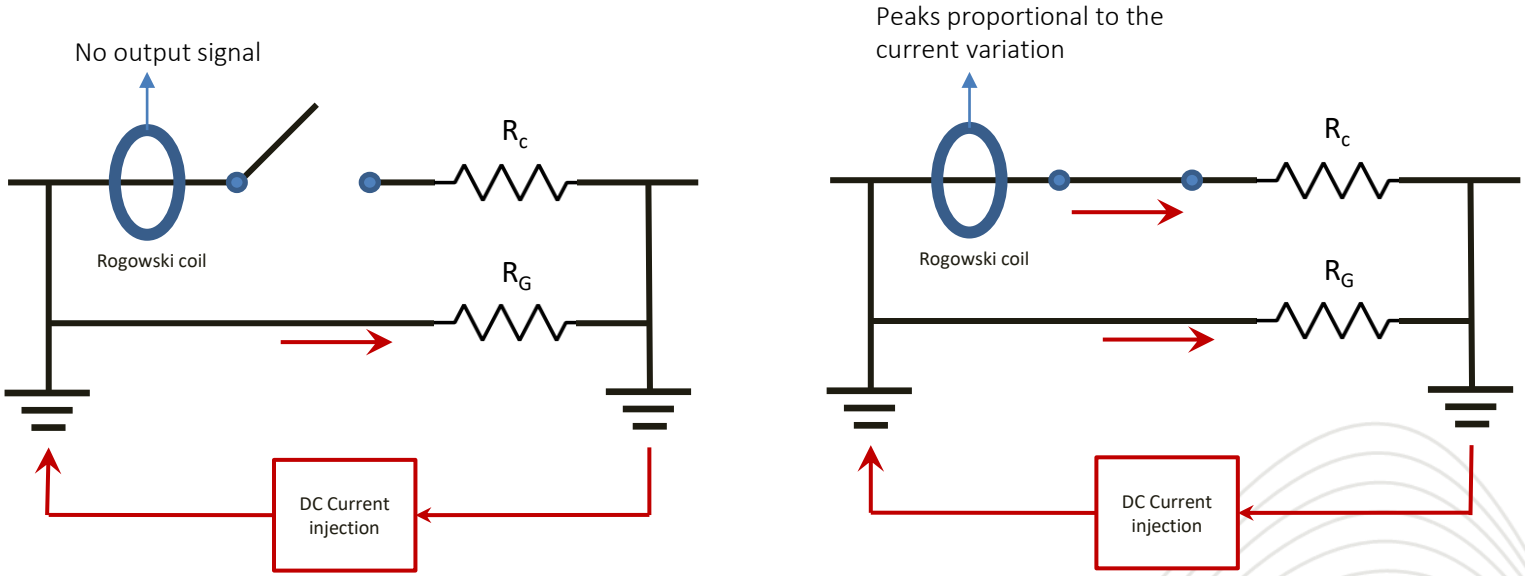
GIS Circuit Breakers

The enclosure is always strictly grounded through two earth disconnectors, at both sides of the CB.

This results in a resistance in parallel to the CB main contacts. The difference with AIS is that this resistance has an extremely low value (hundreds of μΩ).

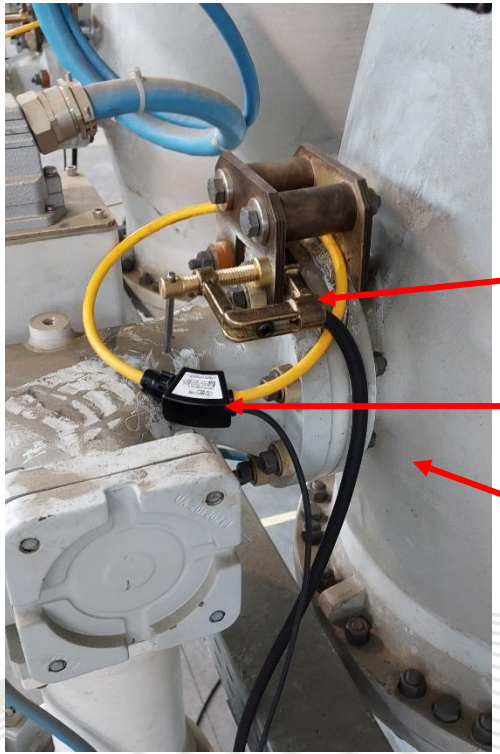
The measurement setup and the measurement principle CANNOT be the same as BSG mode for AIS breakers

GIS Circuit Breakers



By means of Rogowski coils it is possible to detect signals that are generated only when the direct current changes amplitude, in correspondence with the opening and closing of the main contacts

GIS Circuit Breakers



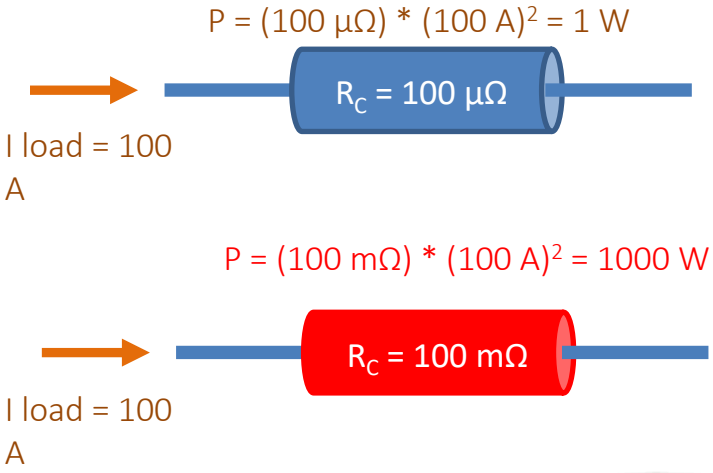
Current injection clamp

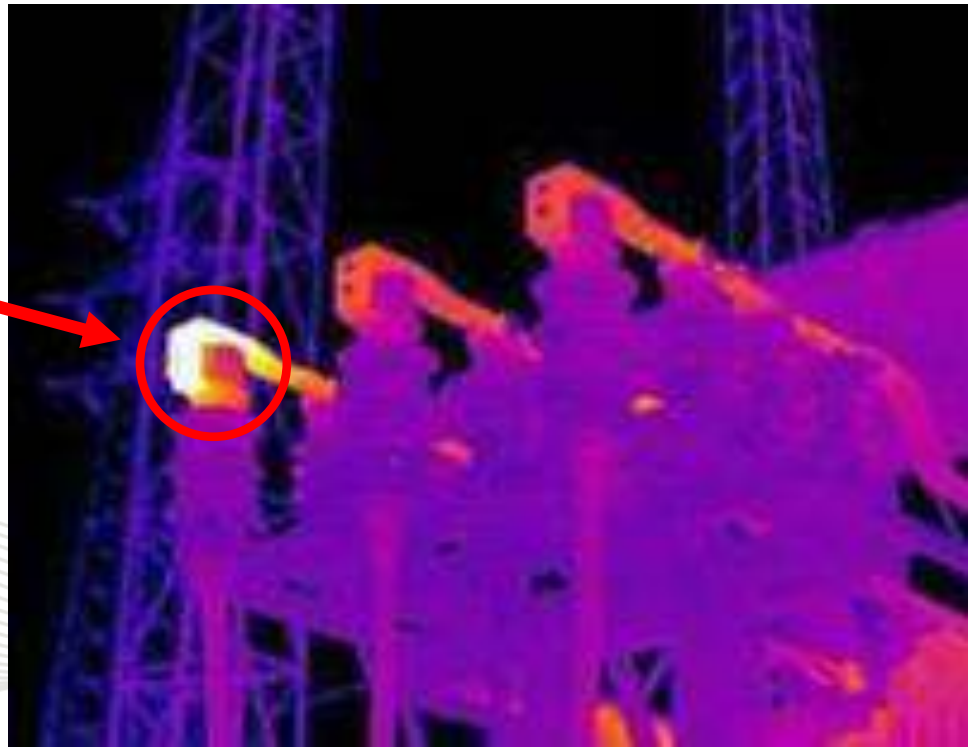
Rogowski coil

Earth disconnector

Static Resistance Measurement (SRM)

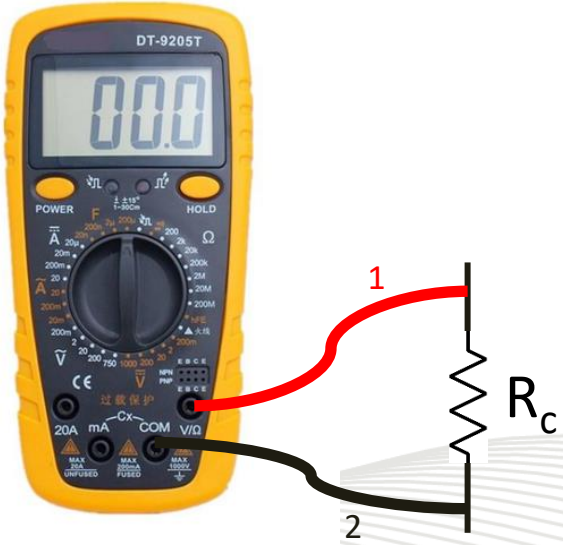
SRM: Why does the main contact resistance have such a low value?

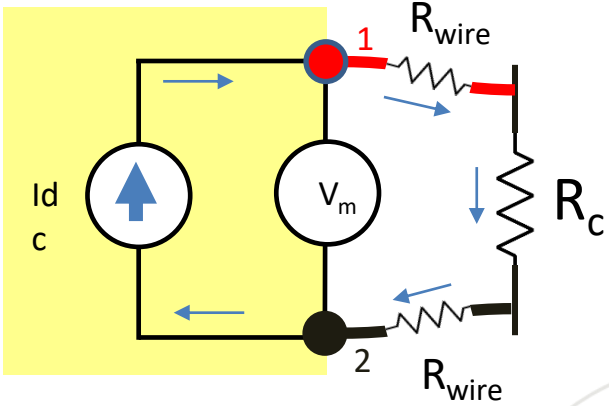




SRM: Measure of resistance value – Two Wire method

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

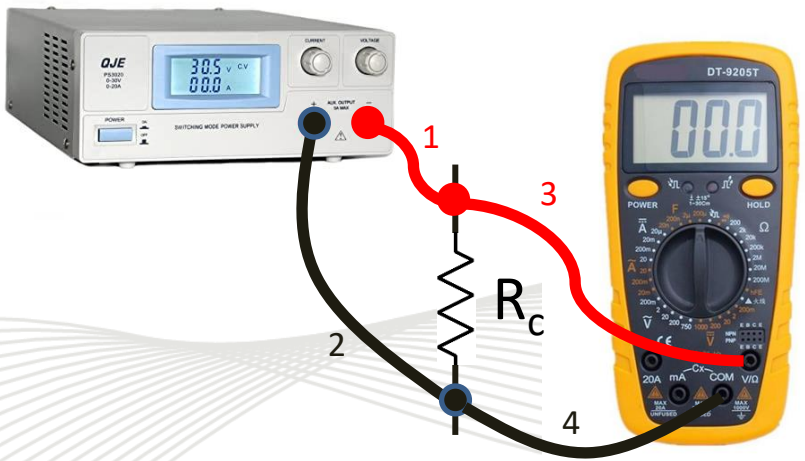
$Vm = Idc * (R_C + 2R_{wire})$

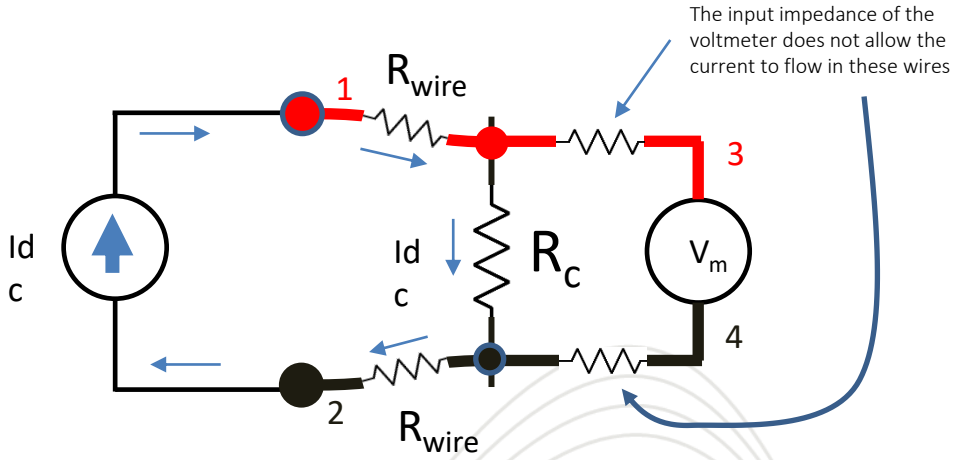
$R_{meas} = R_C + 2R_{wire}$

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

SRM: 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

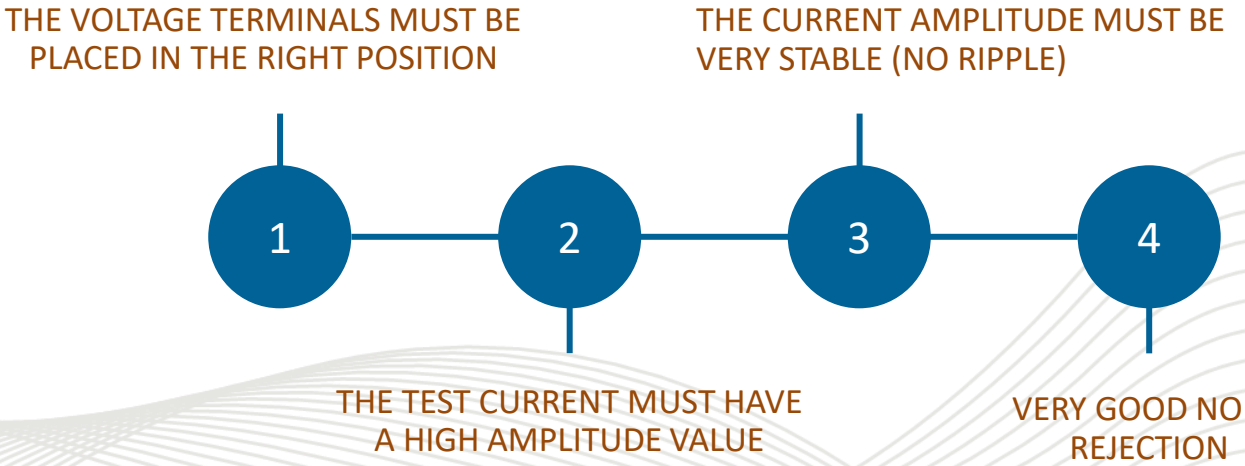
$Vm = Idc * R_C$

$R_{meas} = R_C$

The four wire method is the correct method to be used

SRM

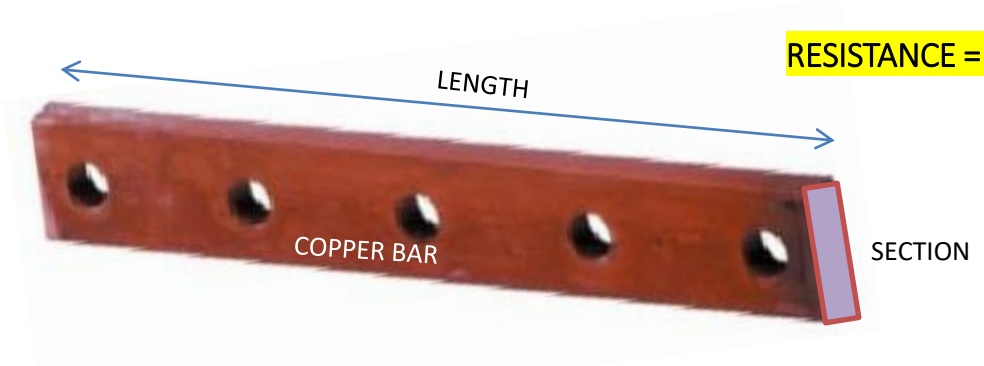
The four wire method does not always guarantee to get the most correct value.
The measure of micro-ohms needs precautions to be taken:



SRM

1

THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION



RESISTANCE = Copper resistivity * (Length / Section)

EXAMPLE

Copper resistivity = 0.017 [Ω * mm^2 / m]

Length = 0.5 m

Section = 300 mm^2

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

SRM

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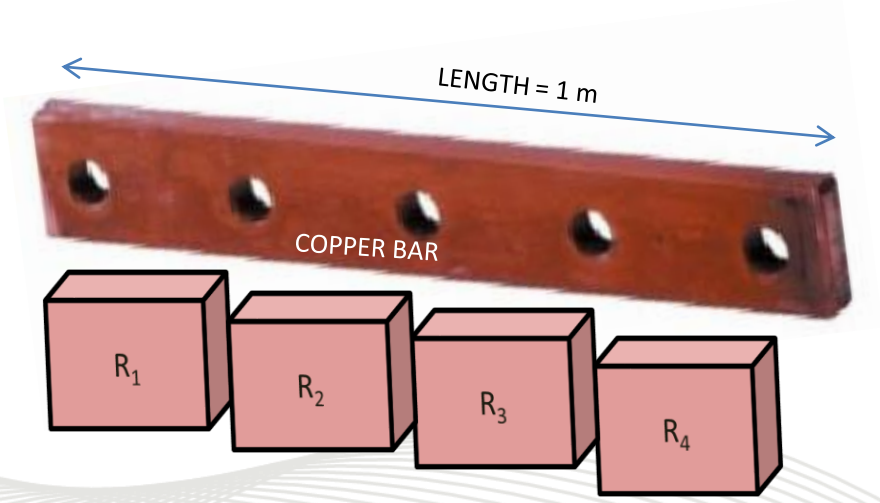
THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION



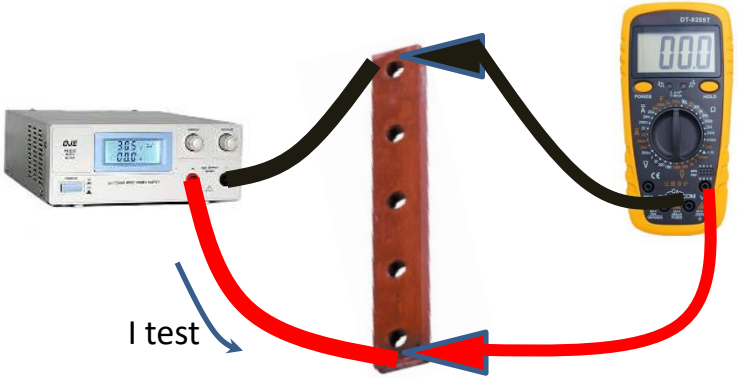
The copper bar can be seen as a sequence of shorter pieces, each one with its own resistance value. In our example, we divide the bar in 4 pieces

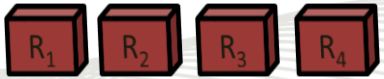
$$R = R_1 + R_2 + R_3 + R_4 = 28\ \mu\Omega$$

SRM

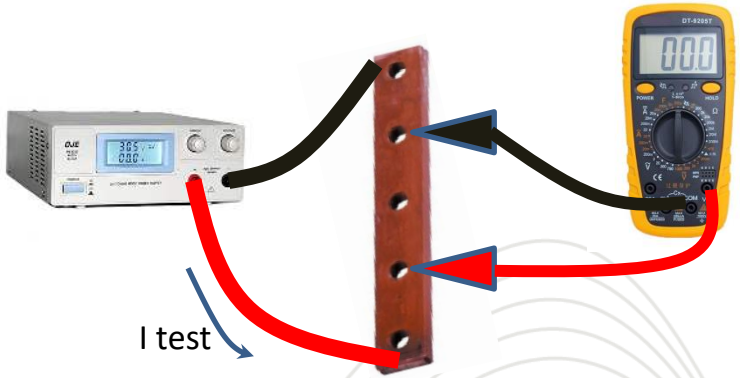
1

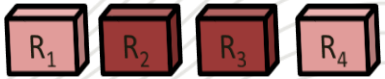
THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION





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



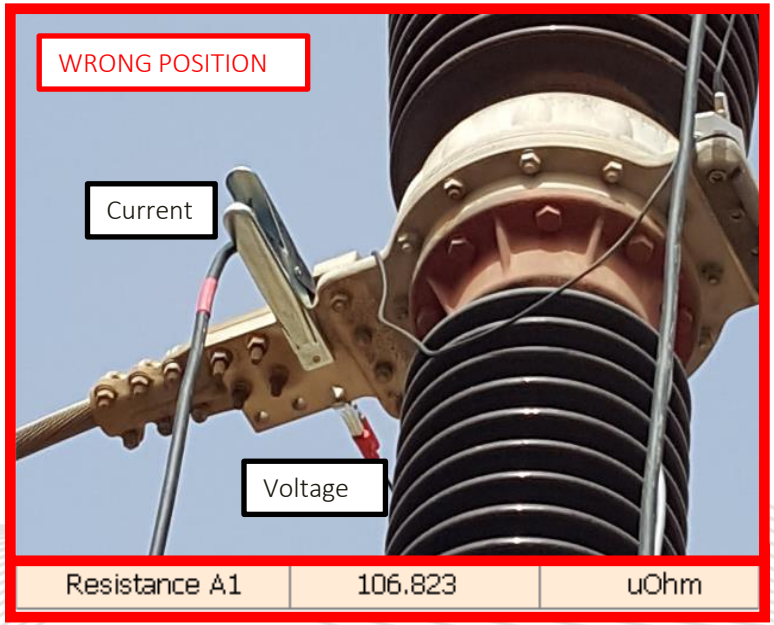


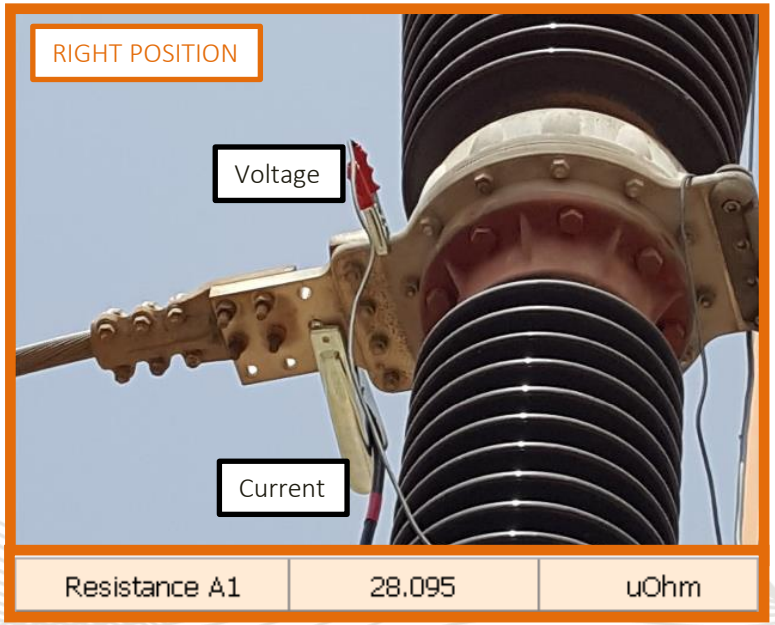
R measured = $R_2 + R_3 = 14\ \mu\Omega$

SRM

1

THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION

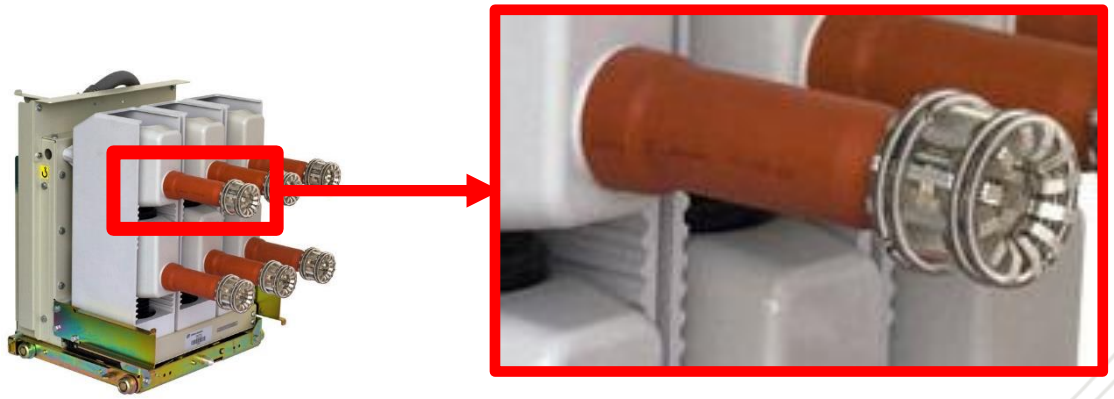




SRM

1

THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION



Special adapters may be required for proper connection of voltage terminals

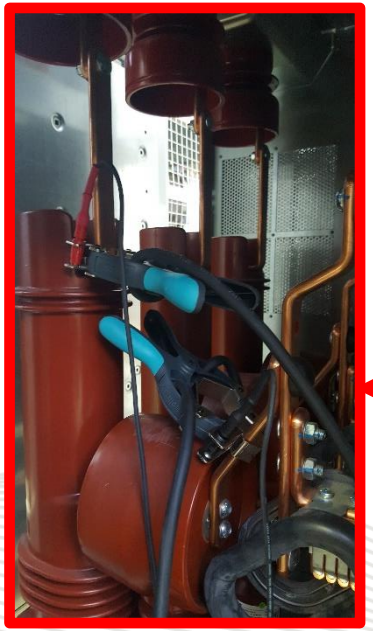
Withdrawable Circuit Breaker Switchgears (WCBS)

SRM

1

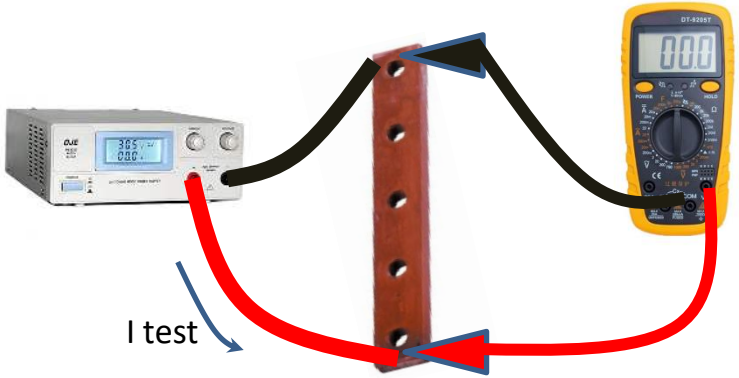
THE VOLTAGE TERMINALS MUST BE PLACED IN THE RIGHT POSITION

Fixed
Circuit
Breaker
Switchgears
(FCBS)



SRM

2 THE TEST CURRENT MUST HAVE A HIGH AMPLITUDE VALUE

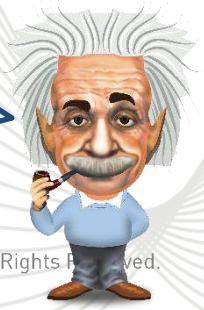


V measured = 28 µΩ * 10 A = 280 µV

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

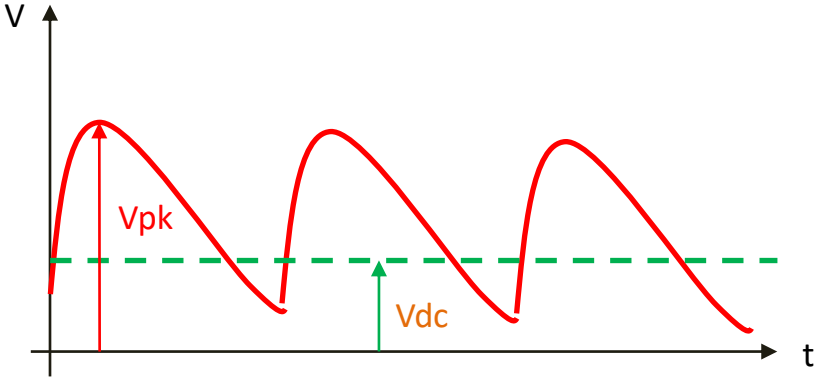
The junction between two different conductor material, here represented by the copper bar and the voltage terminal, generates a voltage whose value falls the range of few microvolt (SEEBECK EFFECT).
This voltage acts as an offset, and must be compensated.



SRM

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

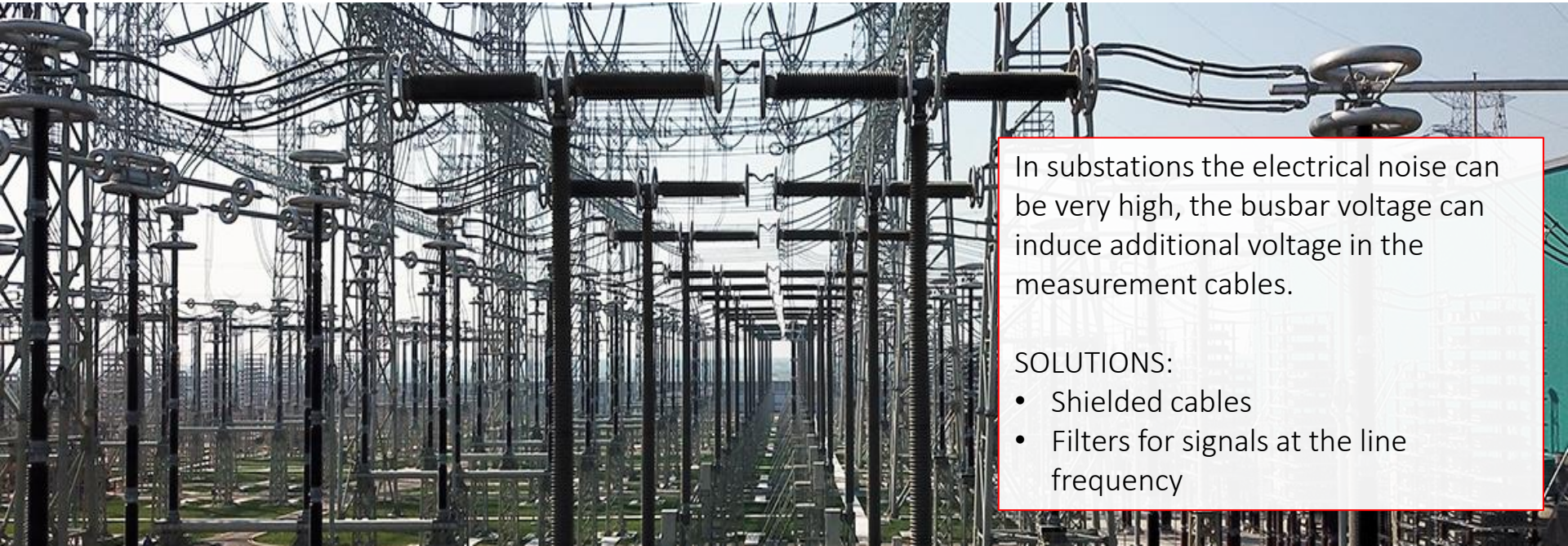
- Mathematical approximations
- Vpk >> Vdc: the full scale range error can be higher than Vdc (e.g. range of 1V to measure 1 mV)

PURE DC SIGNALS GUARANTEE THE BEST ACCURACY

SRM

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.

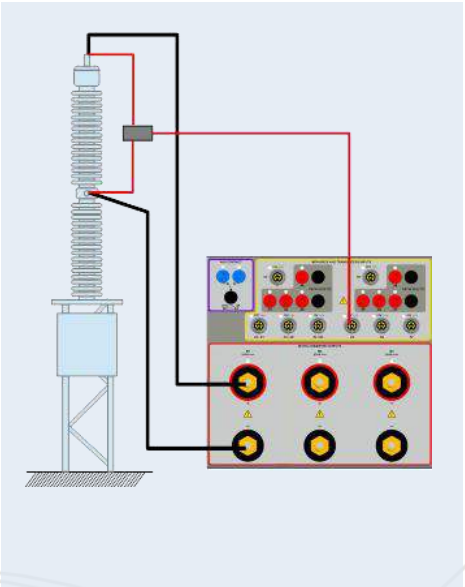
SOLUTIONS:

- Shielded cables
- Filters for signals at the line frequency

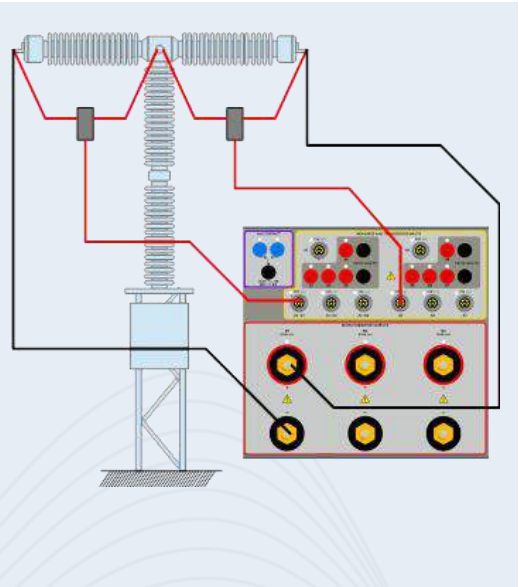
SRM

Analog Inputs for micro-ohmmeter

3 X 200 A DC generators



one break per phase CB



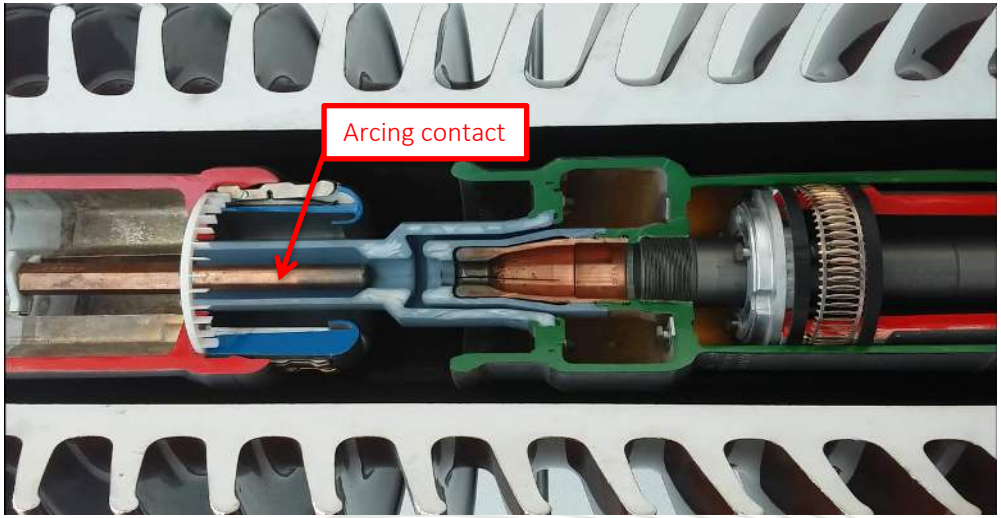
two breaks per phase CB

POSSIBILITY TO MEASURE UP TO 6 RESISTANCES SIMULTANEOUSLY

Dynamic Resistance Measurement (DRM)

DRM

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

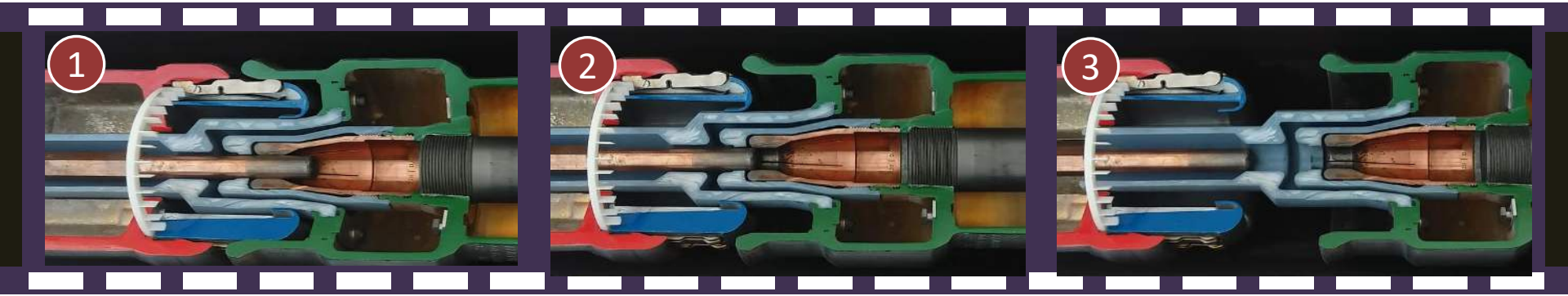


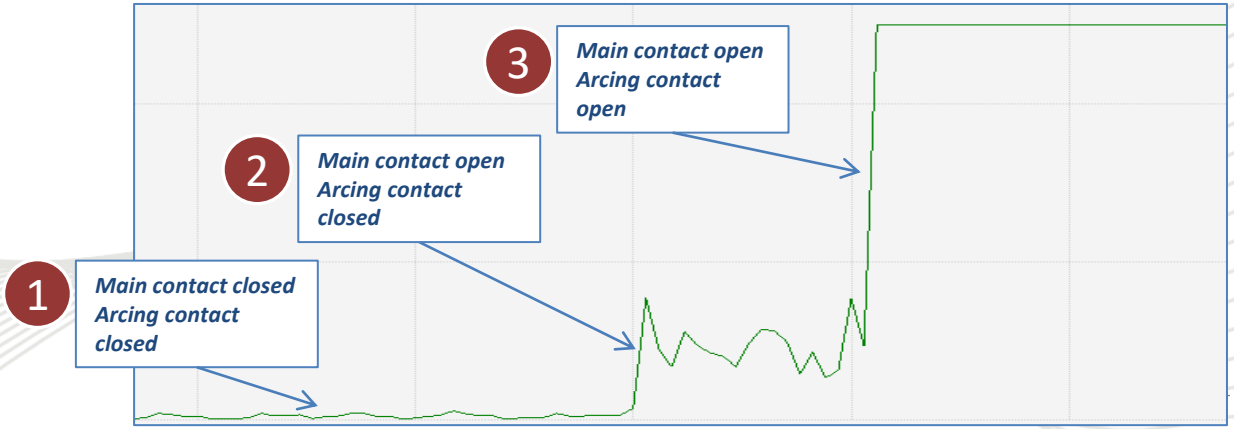
HOW TO PERFORM THE MEASURE

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)

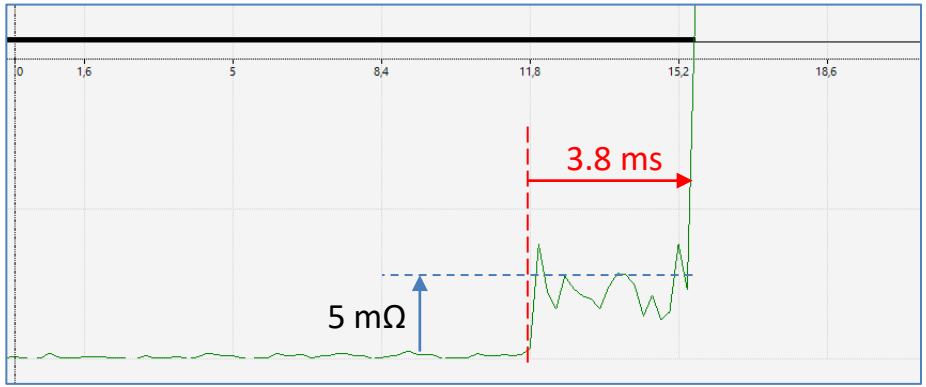
The measurement setup is the same as the SCR

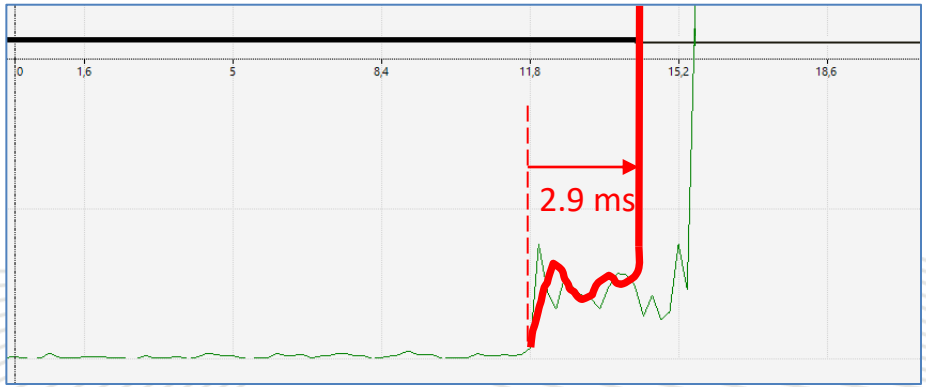
DRM





DRM

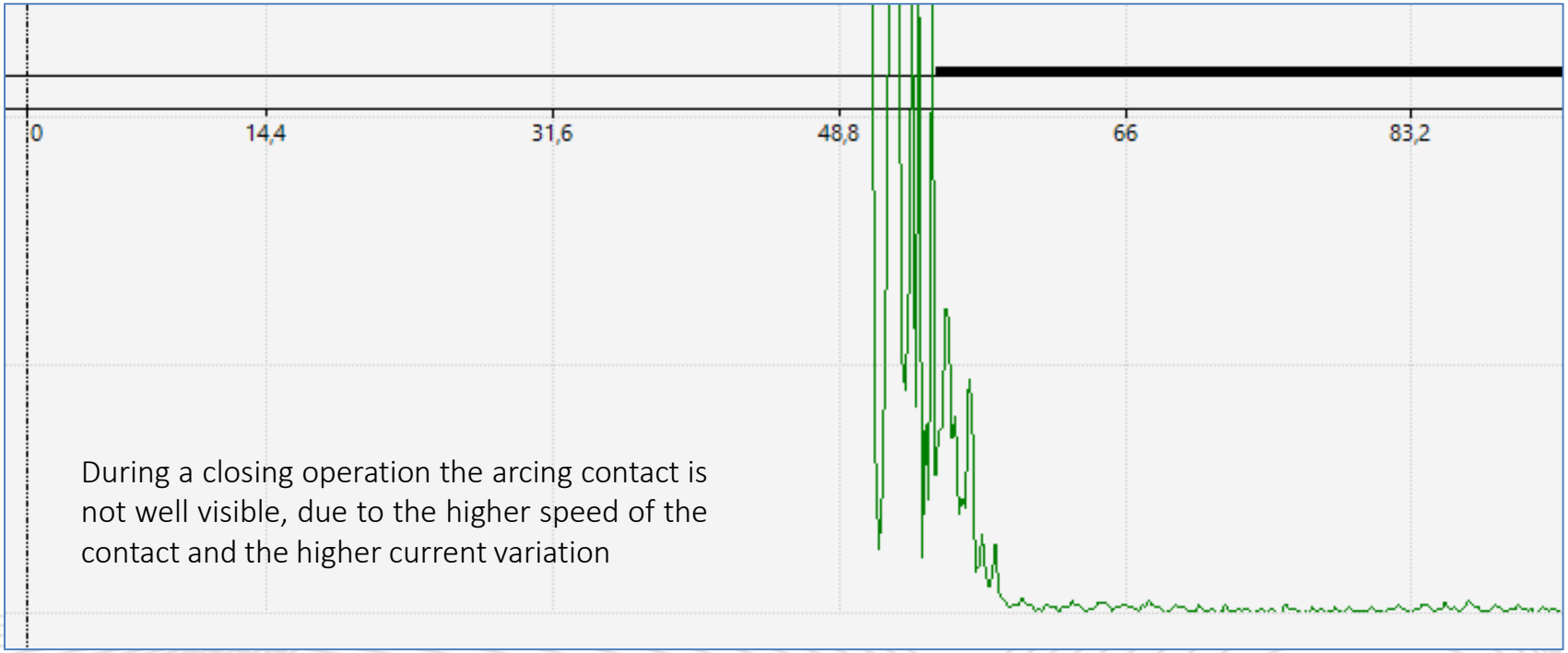




- Each time the CB interrupts the fault current, part of the arcing contact surface burns, then the equivalent length is reduced.
- The arcing contact length reduction can be seen as a reduction of the opening time.
- The length can be measured in millimeters, but the use of movement transducers is required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

The minimum acceptable length is defined by the CB manufacturer.

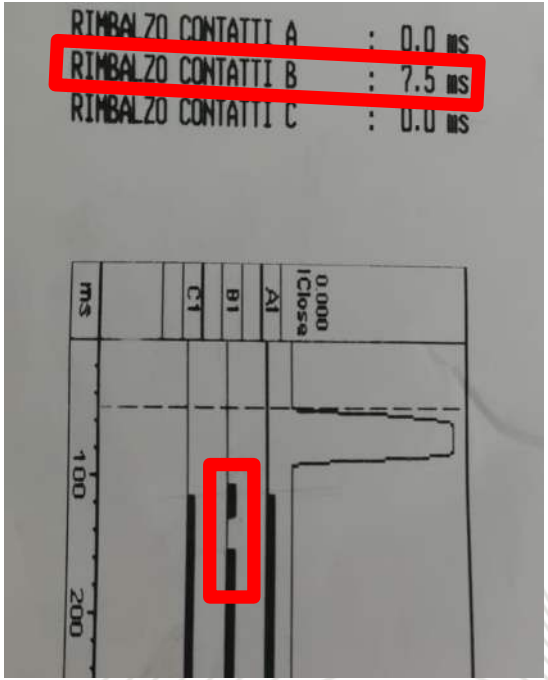
DRM



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

DRM

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

THANK YOU!

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